EFI FOUNDATION

Transforming the Energy Innovation Enterprise

Enhancing the Pace, Agility, Effectiveness, and Efficiency of the U.S. Department of Energy Management Structures and Processes

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Report Sponsors

The EFI Foundation would like to thank Breakthrough Energy for sponsoring this work. Breakthrough Energy provided helpful advice and suggestions during the course of the study. The EFI Foundation is solely responsible for the final content of this report.

Acknowledgments

The EFI Foundation would like to thank multiple reviewers for their insight and input on this study from multiple organizations including the U.S. Department of Energy, the National Laboratory Directors' Council, Third Way, the Information Technology and Innovation Foundation, the Bipartisan Policy Center, ClearPath Foundation, Boundary Stone Partners, and the Oppenheimer Fellowship program. We also wish to thank the participants of the 2022 Aspen Institute roundtable on Reimagining American Clean Energy Innovation, who provided early feedback on the scope of this study. Review participation does not imply endorsement of the analysis, approach, findings, or conclusions.

White Paper Authors

In support of the study, the EFI Foundation commissioned a set of white papers on specific topics for more detailed analysis. The EFI Foundation would like to thank the experts who authored these foundational white papers as part of the *"Transforming the Energy Innovation Enterprise: Enhancing the Pace, Agility, Effectiveness, and Efficiency of the U.S. Department of Energy Management Structures and Processes"* study. The white paper authors conducted their analysis independently, and their participation in the study does not imply that they or their institutions endorse the conclusions of this report.

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Report Summary

This report presents the results of an analysis of opportunities to enhance the U.S. Department of Energy's (DOE) organizational structure and its internal processes in ways that can accelerate the energy innovation process. These opportunities build upon the current initiatives already underway in the Department and can help provide a pathway to an even more effective future energy innovation enterprise.

The decade of the 2020s has the potential to be the most transformative period in the history of innovation in energy technologies, business models, and policies. Such transformative innovation is needed to enhance energy security, address the climate crisis, strengthen the global competitiveness of the U.S. industry, and support consumer needs for reliable and affordable energy. Innovation is the glue that binds together these objectives in a single conversation.

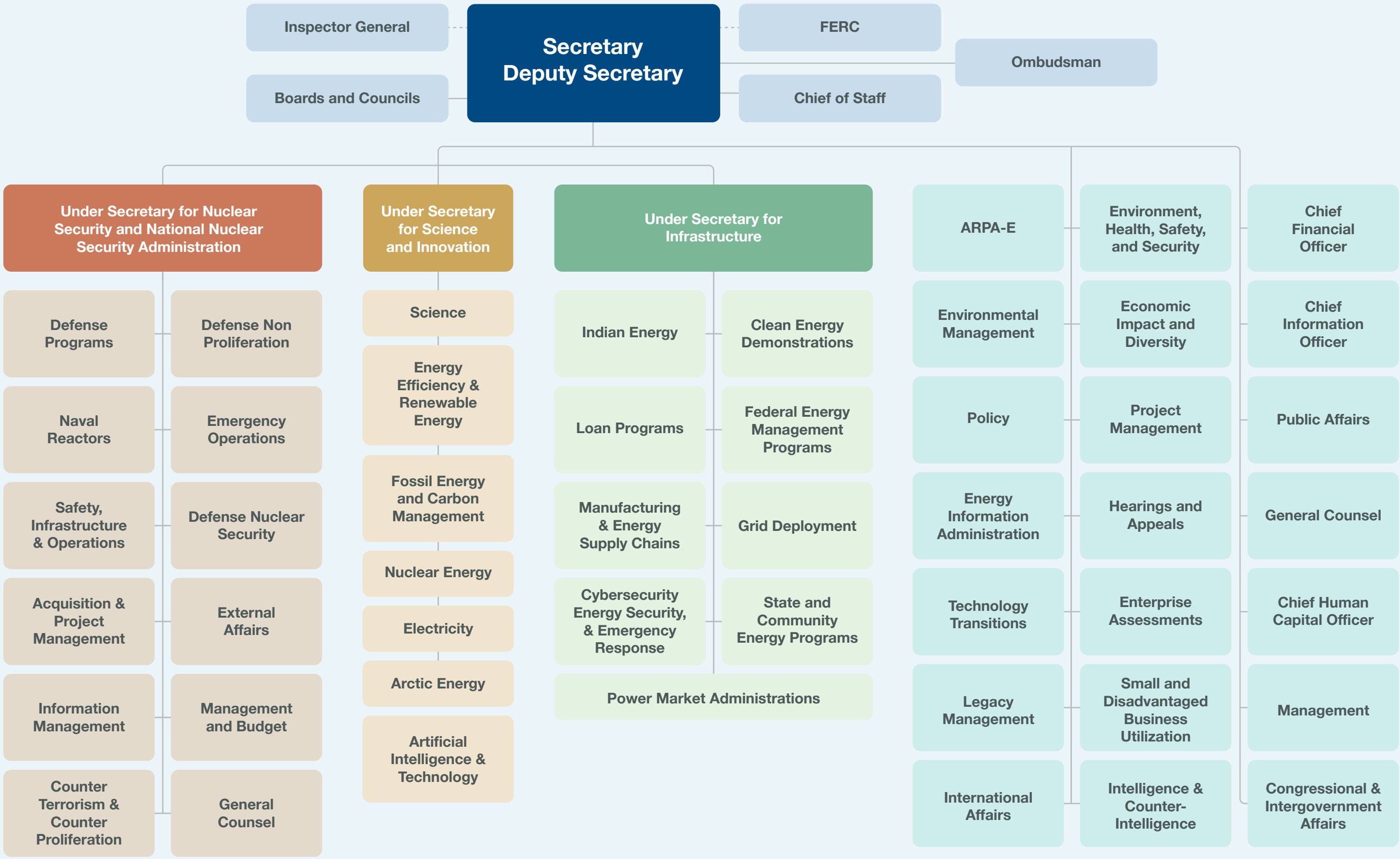
Achieving this transformation will require enhancing the pace, agility, effectiveness, and efficiency of the DOE organization and management. Over the past three years, Congress has passed legislation to provide significant new authorities, programs, and funding to, in part, accelerate the U.S. clean energy transition. These include the Energy Act of 2020, the Infrastructure Investment and Jobs Act, more commonly known as the Bipartisan Infrastructure Law (BIL), the CHIPS and Science Act, the Inflation Reduction Act (IRA), and the Fiscal 2023 Consolidated Appropriations Act.

> While it has given DOE significant new authorities and resources, Congress did not organize these new authorities and resources into specific structures and programs, providing, in part, the motivation for this analysis and its recommendations.

DOE has already taken major steps and made significant progress in integrating these authorities into its organizational structure and management processes in a manner that can accelerate the energy innovation process. In 2021, DOE reorganized its programs to bring together fundamental research and applied energy research, development, and demonstration (RD&D) programs under a new Under Secretary for Science and Innovation. It has also established a new position of Under Secretary for Infrastructure. In 2022, DOE enhanced the functions of the Under Secretary for Infrastructure's organization to take on an expanded role in the demonstration and deployment of new technologies, including the associated infrastructure and supply chain requirements. The current DOE organizational chart is displayed in Figure ES1.[1]

FIG. ES1

Current U.S. Department of Energy Organizational Structure



Energy innovation takes place in the Under Secretary for Science and Innovation and Under Secretary for Infrastructure organizations, as well as in Department-level offices such as the Advanced Research Projects Agency–Energy (ARPA-E) or the Office of Technology Transitions (OTT).

Source: See first figure mention in text for sources.

DOE is also implementing improvements in internal management and operations, such as increasing coordination of crosscutting issues through the formation of Intradepartmental Joint Strategy Teams; expanding crosscutting RD&D program planning and budgeting; developing and implementing targeted Energy "Earthshots"™—initiatives with stretch goals in areas critical to the clean energy transition; and expanded stakeholder collaboration through the increased use of formal Requests for Information (RFIs) and other input-gathering processes.

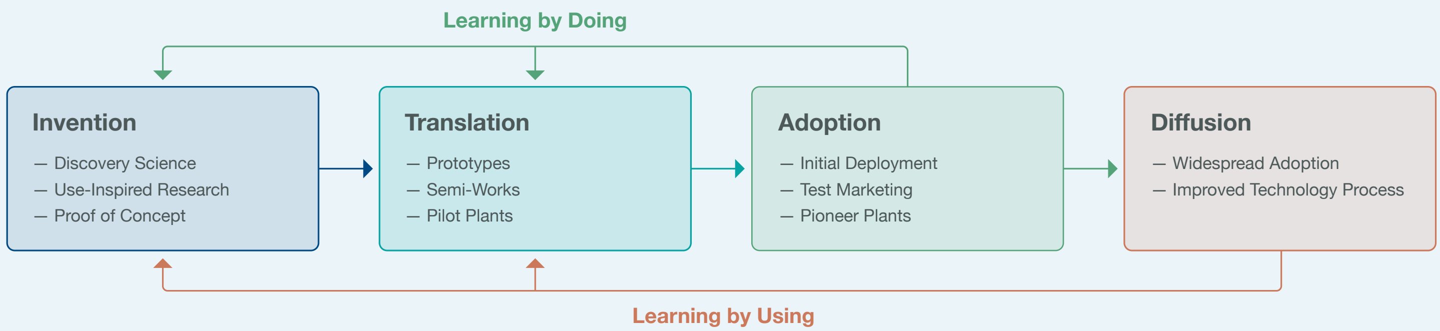
In view of the opportunities found in the new legislation, this study builds on recent DOE actions and addresses two overarching organizational and management challenges: how best to integrate DOE program planning and implementation seamlessly across the entire innovation spectrum for maximum impact; and what additional measures would enable implementation of expanded mission responsibilities in the most effective, efficient, and timely manner.

“In view of the opportunities found in the new legislation, this study builds on recent DOE actions and addresses two overarching organizational and management challenges: how best to integrate DOE program planning and implementation seamlessly across the entire innovation spectrum for maximum impact; and what additional measures would enable implementation of expanded mission responsibilities in the most effective, efficient, and timely manner.”

The process of innovation has grown increasingly complex with the increasing ability to move through stages of RD&D more quickly as well as incorporate numerous feedback loops, as illustrated below in Figure ES2.[2]

FIG. ES2

A Stylized Model of the Interactive Innovation Process



Innovation is a complex process, with transitions between stages and feedback loops, requiring distinctive support mechanisms and involving the interaction of multiple actors.

Adapted from: See first figure mention in text for sources.

Successful energy innovation strategies and programs will require closer integration across the entire innovation process, i.e., end-to-end integration. This will require not only management processes but also a comprehensive and balanced investment portfolio. The new legislation, combined with annual discretionary appropriations, could provide total federal resources on the order of $900 billion to support transformative energy innovation this decade. These new resources are heavily weighted toward demonstration and

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deployment. Increased annual appropriations funding for fundamental research and early-stage applied energy R&D will also be needed to establish a balanced portfolio that effectively supports end-to-end innovation into the next generation of technologies.

This report highlights key DOE program management initiatives already underway, which collectively form the launch-point for this study. In each area it then identifies opportunities for additional organizational and management enhancements that can accelerate innovation in the near-term. It closes by envisioning a future DOE that is positioned for long-term and successful outcomes, with initial steps toward this end.

The analysis and recommendations are organized around five major themes:

1. Establishing a comprehensive framework for end-to-end innovation;
2. Enhancing the role of the DOE National Laboratories as strategic partners;
3. Strengthening Department-wide support functions;
4. Clarifying protocols for international energy RD&D engagement; and
5. Envisioning a future DOE for long-term success.

1. Establishing a Comprehensive Framework for End-To-End Energy Innovation

The new statutes enacted by Congress create a clear need for DOE to establish a comprehensive framework to accelerate the energy innovation process from end to end. The report identifies four strategic pathways to this end: accelerating demonstration and deployment at scale, while capturing the value of "learning by doing"; expanding the innovation pipeline for the next generation of demonstrations; applying new tools to enhance public-private partnerships in the innovation process; and developing comprehensive strategies for sector-specific, regional, and place-based innovation.

Applying New Tools to Accelerate Demonstration and Deployment at Scale: Within the newly formed DOE Office of the Under Secretary for Infrastructure, the recently established Office of Clean Energy Demonstrations (OCED), together with the Loan Programs Office (LPO), plays a central role in DOE's demonstration and deployment programs. DOE has taken significant steps in standing up OCED as an effective and augmenting organization. Both OCED and LPO are currently intensively engaged in building robust project portfolios. A key element to the success of these programs will be establishing effective public-private partnerships with individual companies, as well as encouraging the formation of government-industry-university consortia. This, in turn, will require agile and effective business models. Recommendations for moving toward such models include:

- Pilot efforts involving the use of more flexible Other Transaction Authority Agreements (OTAs) in place of the traditional DOE cooperative agreements, adoption of milestone-based funding agreements, and encouragement of the use of Integrated Project Agreements (IPAs) to share benefits and risks among all project participants;
- Flexibility to tailor project-specific funding arrangements, including guidelines for cost-sharing formulas that allow greater flexibility among the stages of project execution, and modification of the current Federal Support Restriction to enable LPO mixed financing combining federal grant funding and loan guarantees to better leverage federal investment; and
- Pilot efforts to combine traditional supply-side project funding with demand-side policies and programs to support market development and expanded market-uptake, building upon the initial effort currently underway to encourage hydrogen market formation.

Capturing the Benefits of "Learning by Doing": Demonstration-scale programs and projects, even if not fully successful in meeting their initial objectives, can nonetheless provide a wealth of information that advances learning by doing. The report recommends that DOE establish a formal process for the National Laboratories to support the new Under Secretary for Infrastructure organization to capture the benefits of "learning by doing" from demonstration and deployment. The process would also identify new directions that require fundamental research and additional applied energy RD&D, providing important feedback to the front-end of the cycle. This process represents a critical link in the end-to-end innovation process.

Expanding the Energy Innovation Pipeline: While much of the enhanced effort is currently focused on bringing relatively mature technologies to commercialization, accelerating the innovation process will also require intensified discovery and moving the next generation of energy technologies more quickly through the innovation pipeline. Recommendations for doing so include:

- Establish a new technology-neutral fast track program to accelerate the mid-stage of the energy innovation process by funding the scale-up of promising technologies. Achieving end-to-end innovation will require closer integration of the ongoing DOE fundamental science and applied energy RD&D programs and ARPA-E with the new demonstration and deployment activities. In doing so, a fast track program can help to fill the pipeline for the next round of demonstration projects. It would also alleviate the "Valley of Death" experience of many new energy innovators and entrepreneurs seeking to move beyond the initial round of venture capital investment in early-stage proof of concept. Such a program could be initiated as a pilot effort, depending upon the level of funding, and expanded as experience is gained.

- Reform the DOE Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, which help small businesses move nascent technologies toward commercial viability and provide additional "seed grants" to small businesses for idea conceptualization and gestation. This can be achieved by incorporating greater flexibility and speed in the funding process and by establishing open technology solicitation processes to allow and encourage more early-stage technologies with high commercial potential to participate.
- Seek increased annual appropriations for fundamental research and early-stage applied energy R&D programs at levels authorized in the Energy Act of 2020 and the CHIPS and Science Act to maintain a robust and balanced end-to-end energy innovation portfolio.

Sector-Specific and Place-Based Innovation: There are two other crosscutting areas of innovation that require greater strategic focus and coordinated action.

- Establish a comprehensive industrial innovation strategy that addresses multiple industrial objectives, including product and process modernization, decarbonization, secure supply chains, global competitiveness, and workforce development. There are currently seven separate DOE program offices that support some form of industrial energy technology innovation, several of which have single-purpose objectives. Building from the current work of the DOE Industrial Joint Strategy Team, there is a clear need for a more comprehensive industrial energy technology innovation strategy that provides a clearer roadmap to support multiple industry sector objectives across the entire innovation chain, including effective integration of the emerging platform technologies supported by the DOE Office of Science with practical industrial applications. This effort needs to be closely coupled with and leverage the advanced manufacturing RD&D programs of the Department of Defense, the Department of Commerce, the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF).
- Establish an organizational focal point for enabling the formation of regional energy innovation ecosystems, with a focus on regions where such ecosystems are less developed. Significant regional differences in energy resources, capabilities, and interests exist that can best be addressed and leveraged to greater effect by regionally focused innovation efforts. This effort should address both Department-wide initiatives and work with the new regional innovation initiatives in the Department of Commerce and the NSF authorized in the CHIPS and Science Act. The National Laboratories represent a significant asset that can assist in these efforts.

2. Enhancing the Role of the DOE National Laboratories as Strategic Partners

The 17 DOE National Laboratories represent the largest single concentration of science and technology capability in the U.S. under one management umbrella, with a forward-looking perspective and cross-cutting capabilities aimed at developing solutions to address major challenges of national significance. The National Laboratories have contributed to major accomplishments in understanding the fundamental nature of matter and energy; applying nuclear energy to peaceful purposes; mapping the human genome; developing new science-based methodologies to maintain the safety and efficacy of the nation's nuclear weapons stockpile without the need for testing; advancing supercomputing technology; developing complex, large-scale models of scientific and technological phenomena; and pioneering new technological pathways such as quantum computing, biotechnology for energy and security applications, and machine learning.

The core capabilities of the National Laboratories in fundamental research and early-stage technology development should be preserved and strengthened. Building from this foundation, further actions will be needed to align the role of the National Laboratories with the Department's end-to-end innovation mission in a manner that can accelerate the pace of innovation outcomes. The actions are organized around two overarching objectives.

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Enhancing the strategic relationships between the National Laboratories and the Department in end-to-end innovation: Specific recommendations include establishing a formal strategic collaboration process with the Office of the Secretary, combined with further efforts to utilize the capabilities of the National Laboratories to serve as integrators for large-scale crosscutting RD&D initiatives.

Strengthening the role of the National Laboratories in technology maturation and transition to market: Specific recommendations include:

- Establish a major new, separately funded initiative—a *Laboratory-Directed Technology Maturation Program*—to enable National Laboratory leadership to identify and pursue opportunities to translate scientific advances in the Laboratories into commercial products and processes, modeled after the highly successful Laboratory-Directed Research and Development program.
- Expand National Laboratory test bed facilities to enable industry to test new technologies in a standardized setting, enabling industry to innovate faster and more efficiently. This concept would expand upon the current evolving Lab-embedded partnership programs.
- Incorporate incentives in National Laboratory management and operating (M&O) contracts to reward National Laboratories for successful commercialization efforts.

3. Strengthening Department-wide Support Programs

All DOE technology-focused program offices are supported by crosscutting Departmental support functions, including supply chain management, workforce development, energy information management, and financial management. Accelerating the innovation process in the various technology areas will require further enhancements to these support functions.

Energy supply chain management: DOE recently compiled its first-ever comprehensive assessment of energy supply chain issues, identifying a to-do list of 60 potential actions across a dozen technologies and industries. Many of these energy supply chain issues cut across all DOE programs. The DOE Office of Manufacturing and Energy Supply Chains (MESC) will need to broaden its purview to oversee successful implementation. This may also require additional upgrades to DOE's program organizational structure, as well as increased funding support. Expanding upon the recently announced DOE Critical Materials Collaborative, the report recommends the need for MESC to follow-up from the recent Critical Material Assessment to develop specific roadmaps for enhancing the security of key supply chain issues through a comprehensive suite of actions that include RD&D, increased domestic production and processing, recycling and materials substitution. Discipline will be needed to focus these efforts only on supply chains whose disruption would materially impede the clean energy transition or compromise energy and/or national security.

Workforce Development: A significant effort on workforce development within DOE, the National Laboratories, and the energy sector at large will be needed to accelerate the energy transition. Within DOE, a focus is needed both on a general expansion of the workforce and an expansion of the needed skill sets that are matched to new technologies and their demonstration and deployment. The report recommends near-term actions to enhance recruiting efforts, including utilization of specialized appointment authority, effective use of National Laboratory experts where justified, and new personnel models such as rotation assignments, term appointments, and executive exchanges.

Energy Information Collection and Management: Changing energy markets, combined with the implementation of new statutory initiatives, will require increased information and data needs in many areas such as energy jobs, energy use patterns, electricity grid operations, electrification of the economy, metals and minerals supply chains, hydrogen supply and demand and socio-economic impacts of the energy transition. Realignment of energy data collection priorities and information management and dissemination programs may be required. The report recommends a top-to-bottom review of all energy information collection and management, with resources reallocated from lower-priority legacy programs to those with emerging requirements.

Financial Management: The multi-year funding provided in the BIL and IRA will need to be integrated with annual discretionary appropriations to achieve a balanced whole. The report recommends more flexibility in setting administrative budget control points, combined with greater flexibility to reprogram funds to meet the changing needs of a fast-paced innovation program, with robust reporting to ensure financial accountability. The report also recommends the need to develop a comprehensive, prioritized multi-year budget planning process to support end-to-end innovation strategies and programs. These changes also will ease budget implementation within a dynamic (and often uncertain) federal fiscal environment.

Performance Measurement and Impact Assessment: The Department currently operates with a performance plan that delineates major objectives and milestones across all DOE programs. The new authorities and funding provided to DOE require a more extensive and rigorous program to track progress and assess the benefits of these programs and their impact on the pace and scale of the energy transition. The report recommends that DOE establish a comprehensive program to monitor implementation and assess performance.

4. Clarifying the Protocols for International Energy RD&D Engagement

The energy transition is a global challenge. Many country governments provide support for investments in energy innovation. Ongoing activities abroad are significant and influential. An effective energy innovation system in the U.S. must necessarily include considerations of international collaboration in its energy innovation strategy and programs. Current global energy challenges, however, including Russia's invasion of Ukraine, global supply chain shocks, intellectual property concerns, and domestic-oriented policy development, give rise to cautionary implications for international energy RD&D policy, posing potential impediments to mutually beneficial cooperation. The U.S. can and should avail itself of the significant benefits of international collaboration, provided it is keenly aware of and can mitigate risks to U.S. interests, facilitated by embracing the following principles:

- **Promote** mutual familiarity with international innovation processes, innovative U.S. technologies, and global markets;
- **Protect** national security and U.S. competitiveness when weighing risks and benefits;
- **Lead** in international standard-setting;
- **Assist** other countries with identifying and solving problems; and
- **Recognize** trade as a contributor to climate solutions.

There are two key recommendations regarding international energy RD&D collaboration.

- The White House Office of Science and Technology Policy should lead an interagency effort to establish new guidelines, or protocols, participation by DOE and other federal agencies in international clean energy innovation collaborations. The guidelines could help clarify the guardrails for future international energy RD&D collaborations.
- The federal government should continue its support of programs focused on international collaboration, such as Mission Innovation. The initial 5-year commitment to Mission Innovation was extended to Mission Innovation 2.0 in 2021. The U.S. should consider developing a third phase (Mission Innovation 3.0) with a greater emphasis on demonstration and deployment, reflecting the global need to accelerate the pace of decarbonization. DOE also should develop department-wide information-sharing policies for its novel demonstration projects with other countries that, reciprocally, do the same.

5. Ensuring a Future DOE for Long-term Success

The DOE organizational structure has evolved over time. At the time of its formation, DOE was organized by stages of innovation—fundamental research, technology development, and demonstration and deployment. It quickly evolved into a fuels-based organization, with separate program offices for fossil, nuclear, and renewable energy; energy efficiency across various end-use sectors was paired with renewables. Each

> "Over time, DOE has further evolved into a complex, hybrid organization that combines elements of fuel-based offices, innovation-stage offices, technology-specific offices, and end-use application offices."

had its own reporting relationship to the Secretary, its own constituencies, and its own Congressional supporters. Over time, DOE has further evolved into a complex, hybrid organization that combines elements of fuel-based offices, innovation-stage offices, technology-specific offices, and end-use application offices (Figure ES3).

FIG. ES3

Functional Taxonomy of U.S. Department of Energy Programs and Relationship to Organizational Structure

Fuels

- Nuclear
- Solar
- Wind
- Water
- Coal
- Petroleum and Natural Gas
- Geothermal
- Bioenergy

Technology & Crosscuts

- Electricity and Grid Technologies
- Cybersecurity, Energy Security, and Emergency Response
- Energy Storage
- Carbon Management
- Artificial Intelligence and Technology
- Arctic Energy
- State and Community Energy Programs
- Materials

Stage of Innovation

- Science
- OCED
- ARPA-E
- OTT
- LPO

End-Uses

- Building Technologies
- Vehicle Technologies
- Advanced Manufacturing
- Industrial Efficiency and Decarbonization
- Indian Energy
- Grid Deployment Office
- FEMP

Figure ES3 illustrates how the current DOE program offices can be classified according to their primary organizing concept – fuels, technologies and crosscuts, stage of innovation, and end-uses. The complex interplay between organizational structure and function underscores the need for effective crosscutting planning and coordination.

The report recommends additional near-term actions as well as steps leading to longer-term change. In the near term, the complexity of programmatic interaction within the current DOE organization can be addressed through more formalized internal coordination processes. These processes require clear definitions, transparency, and accountability. Looking to the longer term, a further step would be to develop a comprehensive energy innovation portfolio strategic plan, with the identification of potential changes in DOE organizational structure to facilitate efficient implementation.

Management of Crosscutting RD&D Initiatives: Energy innovation challenges and opportunities are increasingly multidisciplinary and have technology and market applications that cut across current program office boundaries. Moving toward end-to-end innovation strategies further compounds the challenges. DOE has developed several forms of intradepartmental coordination processes, including the formation of Joint Strategy Teams, Science and Energy Technology Teams, and other more informal working groups. These efforts have improved communication across the various program offices. The Energy EarthShots™ initiatives require effective crosscutting program planning and coordination to be successful. These kinds of crosscuts require intense planning at the technical and middle management levels across the Department with the cognizant DOE program office managers, the National Laboratories, the private sector, other stakeholders, the Administration, and Congress. The report recommends establishing a new Departmental Order to formalize the processes, roles, and responsibilities for crosscutting RD&D initiatives. The report identifies seven specific elements, including: (1) well-defined scope, (2) multi-year charter, (3) dedicated full-time senior leadership, (4) National Laboratory collaboration, (5) specific roadmap, (6) dedicated funding resources, and (7) flexible administrative implementation processes and performance measurement.

Development of a Comprehensive Strategic Energy Innovation Research, Development, Demonstration, and Deployment Portfolio: A strategic portfolio plan would provide a comprehensive, end-to-end innovation strategy integrating the full breadth of the innovation cycle from fundamental research through demonstration and deployment. Ideally, the innovation portfolio would derive from and support a broader national energy policy strategy, such as the Quadrennial Energy Review. A comprehensive portfolio plan linking end-to-end innovation could play to the strengths of the U.S. innovation enterprise, identify opportunities and gaps, guide resource allocations, and better define roles, responsibilities, and partnership opportunities among the various players in energy innovation. The report recommends that the Department take steps toward the development of a goal-driven energy innovation RD&D portfolio planning process.

Moving Toward a Future DOE Organizational Structure: Previous studies have pointed toward a future DOE organizational structure that is fuel- and technology-neutral, enables system-level integration, and both accommodates and reduces the complexity of crosscutting projects. Such an organization might be structured by focusing on end-use markets, combined with crosscutting organizational entities for clean electricity and clean fuels. The imperatives of implementing the new near-term initiatives, however, outweigh implementing any further major structural reorganization at this time. The recommendations in this report identify specific steps for enhancing the organization and management of the DOE structure that can be initiated with the longer-term vision in mind.

Conclusion

DOE has taken the initial steps to align its organizational structure and management processes to meet the challenges of advancing the clean energy transition across the entire innovation spectrum. Additional opportunities exist to build on these efforts in a manner that can facilitate and accelerate this transition.

> “DOE has taken the initial steps to align its organizational structure and management processes to meet the challenges of advancing the clean energy transition across the entire innovation spectrum. Additional opportunities exist to build on these efforts in a manner that can facilitate and accelerate this transition.”

The additional measures outlined in this report can be framed and implemented with a clear-eyed vision of a future that can best meet the longer-term objectives of energy security, net zero emissions, economic competitiveness, social equity, domestic economic growth, job creation, and consumer value. Many can be implemented administratively and on a pilot basis to complement and not impede current program implementation activities. Longer-term, they point toward the need for further changes in DOE organizational structure to provide a stronger end-use application focus that spans the entire innovation spectrum.

> “Many can be implemented administratively and on a pilot basis to complement and not impede current program implementation activities.”

01 Framing the Challenges and Opportunities of the Energy Innovation Enterprise

The challenges facing the energy sector are multifaceted and increasing in scope, severity, and urgency. These challenges place the Department of Energy at one of the most distinct inflection points in its 45-year history—the opportunity and need for effective action is unprecedented. This report examines and makes recommendations on how, given these challenges, DOE can best enable both rapid and sustained energy innovation through adjustments in its structure and processes.[a] The analysis identifies the near-term innovation opportunities to meet the challenges of transition to a clean energy economy in the coming decades.

[a] The scope of this report focuses on the science, research, and energy technology innovation programs of DOE. It does discuss the role of the three National Nuclear Security Administration (NNSA) and the single Environmental Management (EM) National Laboratories as they contribute to the science and energy missions of the Department, but the study does not address organizational and management issues within NNSA and EM.

1.1 The Imperative of Accelerating Energy Innovation

Over its nearly half-century history, DOE has had overarching mission objectives for national security, energy security, scientific discovery, and environmental remediation. Science and technology are the foundation shared by all DOE programs. The energy mission is driven by innovation—across technologies, policy, business models, and finance.

While the specific challenges within each of these broad mission areas have varied over time, current events and global issues are key drivers for DOE's energy security and environmental remediation missions. These include Russia's invasion of Ukraine, the growing climate crisis, and increased challenges to economic competitiveness from countries such as China; all underscore the urgent need for effective actions within the DOE mission space.

- The February 2022 Russian invasion of Ukraine exposed the global energy security risks associated with growing European dependence on Russian natural gas. It highlighted the need for diversification of energy supplies, improved energy efficiency management, and further innovation in alternative technologies. The Group of Seven (G7) recently reaffirmed the role of energy technology innovation in addressing these issues, stating in an April 2023 Communique, "We emphasize the importance of research, development, and demonstration (RD&D) of technologies designed and integrated to address the triple crisis, the energy crisis and other related issues and to achieve sustainable development."[3]
- The 2020-2023 COVID-19 pandemic and resulting global economic lockdowns exposed serious weaknesses in the global supply chains in many industries. The extended lockdown of the Chinese economy further revealed U.S. dependence on Chinese exports in parallel with growing concerns about China's domestic industrial policy and increasing competition in both the global world order and the global economy. The flagship initiative to address these issues is the new focus on domestic manufacturing of semiconductors established in the CHIPS and Science Act. DOE has launched several efforts, discussed later in this report, to enhance the security of various energy technology supply chains.
- The most recent (March 2023) report from the U.N. Intergovernmental Panel on Climate Change (IPCC) concluded that global average temperatures are on a path to exceed the 1.5 degree Celsius increase that has been widely accepted as the benchmark for triggering significant adverse climate change impacts if critical mitigation actions are not in place by the end of the decade.[4] The International Energy Agency (IEA) estimates that nascent technologies currently in the demonstration or prototype phase play an increasingly important role in reaching net zero greenhouse gas (GHG) emissions, providing 35% of the needed GHG savings in 2050.[5]

The position of the U.S. in the global economy is also challenged by the desire for economic growth to serve the rapidly expanding populations in developing economies. Such developments increase the demand for capital, labor, and all forms of resources, including energy. Energy innovation will be essential to support economic and human development in these economies that are equitable and sustainable.

1.2 | The Unprecedented Opportunity Space for Energy Innovation

Over three years, Congress enacted five laws that have created a broad new platform for energy innovation. These actions include:

- the **Energy Act of 2020**, providing DOE with broad new energy innovation tools;
- the **Bipartisan Infrastructure Law** (BIL), providing additional authorities as well as statutory advance appropriations covering multi-year periods;[b]
- the **CHIPS and Science Act** (CHIPS), authorizing an expansion of DOE fundamental research programs and regional innovation initiatives as part of a government-wide innovation effort including the National Science Foundation (NSF) and the Department of Commerce;[c]
- the **Inflation Reduction Act** (IRA), establishing a broad array of tax and other financial incentives to support demonstration, deployment, and diffusion of innovative energy technologies into commercial markets;[d] and
- the fiscal **2023 Consolidated Appropriations Act**, providing increased annual funding for the ongoing DOE portfolio of fundamental and applied energy research, development, and demonstration (RD&D) programs, continuing a trajectory established in 2016 to double the level of public investment over a 10-year period.

1.3 | The DOE Organizational Response

While it has given DOE significant new authorities and resources, Congress did not organize these new authorities and resources into an overarching framework, providing, in part, the motivation for this analysis and its recommendations.

To address these and other challenges of the energy transition, DOE has implemented major structural changes and management process improvements.

In 2021, DOE implemented a structural reorganization at the Under Secretary level, consolidating the Office of Science and the existing applied energy RD&D programs within the Office of the Under Secretary for Science and Innovation and establishing a new Office of the Under Secretary for Infrastructure. With the enactment of the BIL and IRA, DOE filled out the Office of the Under Secretary for Infrastructure, combining existing programs, such as the Loan Programs Office, with new Offices, including the Office of Clean

[b] The Infrastructure Investment and Jobs Act (IIJA, Nov. 15, 2021), or Bipartisan Infrastructure Law (BIL), provides $1.2 trillion in total spending, with $550 billion in new spending for infrastructure (e.g., airports, roads, and trains), including $80 billion for a variety of green technologies, such as more than $60 billion for energy, power and the grid.

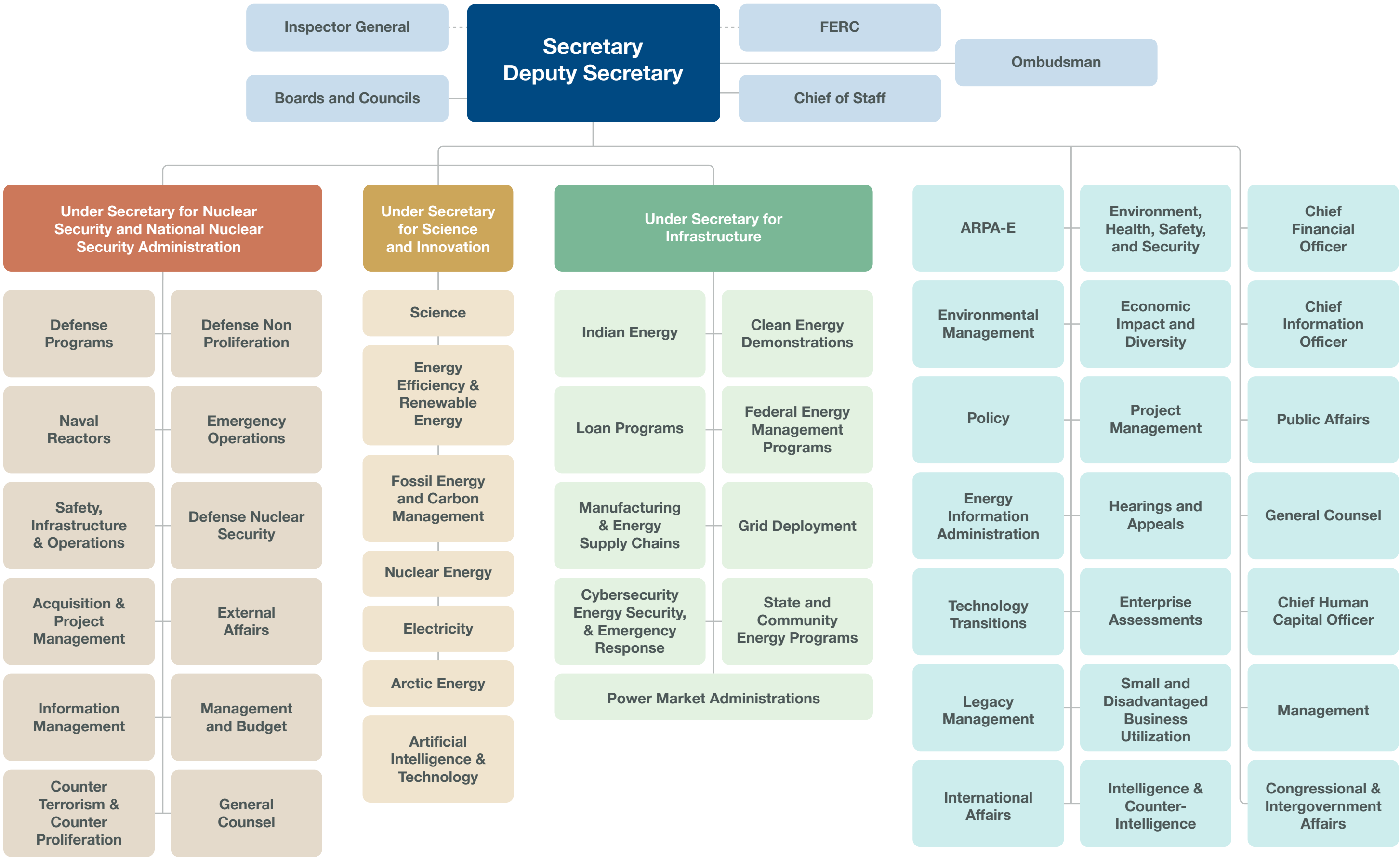
[c] Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act (Aug. 9, 2022) provides $52.7 billion for investments in U.S. semiconductor businesses and $10 billion in regional innovation and technology hubs. The CHIPS and Science Act also authorizes the expansion of use-inspired research at the DOE Office of Science and at the National Institute of Standards and Technology; and enlarges the NSF's mission by creating a technology and innovation directorate focusing on semiconductors, quantum information systems, artificial intelligence, and advanced energy technologies.

[d] The Inflation Reduction Act (IRA, Aug. 16, 2022) provides $737 billion for health care and reducing the size of the deficit, but it has as its centerpiece $369 billion in green tax credits, manufacturing investments, and other initiatives.

Energy Demonstrations (OCED), authorized in the BIL, the Office of Grid Deployment and the Office of Manufacturing and Energy Supply Chains. This new structure complements DOE's existing and substantial strengths in fundamental and applied science and technology research while enabling a much sharper focus on critical demonstration and deployment responsibilities and the need for new infrastructure to enable the clean energy transition. The current DOE organizational structure is seen in Figure 1.[6]

FIG. 01

Current U.S. Department of Energy Organizational Structure



Energy innovation takes place in the Under Secretary for Science and Innovation and Under Secretary for Infrastructure organizations, as well as in Department-level offices such as the Advanced Research Projects Agency–Energy (ARPA-E) or the Office of Technology Transitions (OTT).

Source: See first figure mention in text for sources.

Recognizing the need for more effective coordination of the innovation process that cuts across organizational lines, DOE also established new informal coordination processes. The most notable was the establishment of Joint Strategy Teams to address key innovation challenges, such as the formation of a new hydrogen fuels industry. The Joint Strategy Teams focus on end-to-end innovation within their respective technology areas, supporting the development of comprehensive strategy documents, such as the hydrogen roadmap and the Commercial Liftoff Reports, as well as issues of Funding Opportunity Announcements (FOAs) supported with funding from multiple DOE program offices. The establishment of Energy Earthshot™ initiatives, such as the Hydrogen shot and the Carbon Negative shot, further underscored the need for crosscutting program coordination.

While significant progress has been achieved, the new DOE is still a work in progress. For example:

- The new organization creates an imbalance in senior policy officials appointed by the President, subject to Senate confirmation (PAS positions). The Office of the Under Secretary for Science and Innovation organization has six major offices headed by PAS appointees; the Office of the Under Secretary for Infrastructure organization has only two. As key senior positions at both the PAS level and other senior non-career levels are not filled on a permanent basis, the vacancies and the politics of confirmation and congressional oversight could have uneven impacts on the two organizational lines.
- Issues that span multiple organizations are currently being organized through a variety of coordination mechanisms whose roles and responsibilities vary in the decision-making authority. In addition to the specially formed Joint Strategy Teams, DOE also uses other coordination mechanisms, such as the Science and Energy Technology Teams.
- None of the 17 National Laboratories have an organizational linkage or formal programmatic relationship to the Office of the Under Secretary for Infrastructure.[e] The National Laboratories have substantial personnel expertise, cutting-edge research facilities, and demonstrated experience addressing complex technical challenges that can be harnessed to support the expanded DOE program responsibilities for demonstration and deployment. The lack of a clear linkage also impairs the ability of DOE (and the broader energy community) to garner the benefits of learning by doing that can be reflected in planning and priority setting in the fundamental and applied energy RD&D programs.

Going forward, DOE faces further challenges in integrating its existing and new authorities and programs across the entire spectrum of innovation, including working with the National Laboratories to redefine their role in support of the full scope of the Department's missions. Additional structural organizational changes may be required to achieve a durable strategic framework that can be sustained across succeeding Congresses and Presidential and Secretarial administrations.

[e] Thirteen of the National Laboratories report to four different offices within the Office of the Under Secretary for Science and Innovation organization, three report to the National Nuclear Security Administration and one reports to the Office of Assistant Secretary for Environmental Management.

1.4 | Integrating DOE Organization Structure Across the Full Innovation Cycle

Accelerating the pace of energy innovation will require closer integration of programs across the entire innovation spectrum, i.e., end-to-end integration. Looking forward, the Department's organizational and management structure will need to not only understand the science and invent the technology faster than ever before but also bring the new technologies to market more quickly and effectively.

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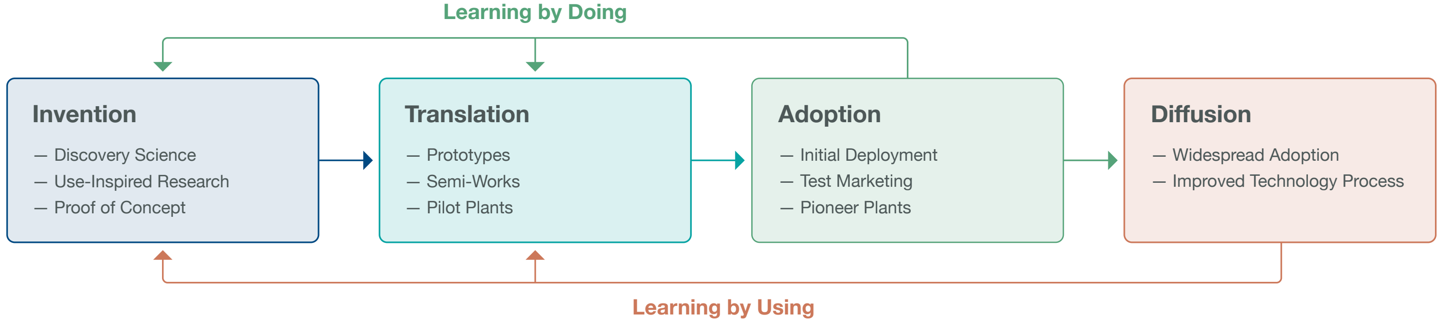
The challenges in the energy technology innovation process have grown increasingly complex. Historically, the energy technology innovation process was viewed as a relatively linear process, dating back to the post-World War II role of the federal government in support of basic (or discovery) search, with the expectation that new scientific discoveries would generate private sector action to convert discoveries into new commercial processes and products.[7] Major innovations now depend upon multidisciplinary collaborations that span, among others, the physical sciences, materials research, computational sciences, process engineering, and construction management. Innovations also require closer integration of fundamental research from the laboratory with real-world operational experience, enabled by rapid two-way flows of information through complex feedback loops. Learning by doing and learning by using can identify the need for further work in addressing underlying unresolved scientific and technical issues. A 2010 Report by the President's Council of Advisors on Science and Technology (PCAST) highlighted the complexity of the multiple pathways in the energy innovation process, as shown in Figure 2.[8]

FIG. 02

A Stylized Model of the Interactive Innovation Process



Innovation is a complex process, with transitions between stages and feedback loops, requiring distinctive support mechanisms and involving the interaction of multiple actors.

Adapted from: See first figure mention in text for sources.

In this interactive model, both ends of the innovation process take on increased importance.

- In the case of adoption and diffusion, demonstration and early deployment activities play an important role as both an *outcome* of the innovation process as well as an *input* for new invention and translation.
- Fundamental research is shaped not only by the motivation of *discovery science* but also by the *learning* resulting from learning by doing and learning by using.

In this model, the establishment of the new Office of the Under Secretary for Infrastructure plays the key role of both accelerating the pace of adoption and diffusion through demonstration and early deployment and by providing the learning by doing to guide the fundamental and applied RD&D programs.

Fundamental research can be driven by the need to understand the scientific basis for observed phenomena in commercial market operations. The combination of discovery science and use-inspired research as drivers for fundamental research is further illustrated in the Quadrant Model of Scientific Research, illustrated in Figure 3.[9] In this model, the fundamental research programs expand beyond the traditional discovery science in the Bohr quadrant to include the additional research scope in the Pasteur quadrant.

FIG. 03

Quadrant Model of Scientific Research

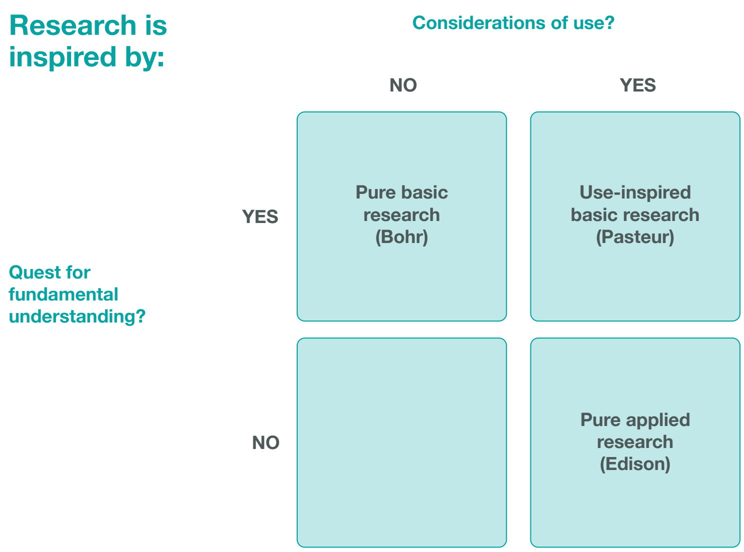


Figure 3 illustrates how scientific research is motivated by the need to fundamentally understand natural phenomena, by applied goals, and by the combination of both, represented in the upper right-hand quadrant ("Pasteur's Quadrant"). The bottom left quadrant is not considered "empty." Research in this quadrant can be motivated by curiosity for particular phenomena instead of general things or to enhance the skills of the researchers.

Source: See first figure mention in text for sources.

The stylized innovation models illustrated in Figure 2 and Figure 3 have noteworthy implications for the current DOE organizational structure. Foremost, the models clearly delineate the importance of a holistic approach to managing the innovation process. Additionally, the models identify a significant challenge to the Department's current organizational structure: improving the integration of RD&D program portfolio planning across the full innovation spectrum of the fundamental research, applied energy RD&D programs, and demonstration and deployment.

- Demonstration of the next generation of energy technologies will depend upon a more rapid translation of fundamental research and applied technology development (including rapid prototyping) into demonstration-ready projects.
- The longer-term success of the new DOE demonstration and deployment model will depend upon the technical support that can be provided by the fundamental and applied energy RD&D programs supported by the National Laboratories.
- The fundamental research and applied RD&D program portfolios will, in turn, be better informed by the learning by doing and learning by using that will emerge from the demonstration and deployment programs that support adoption and diffusion, as illustrated in Figure 2. This point is exemplified by the DOE Office of Science series of basic research needs (BRN) workshops to identify priority needs for fundamental research to support advances in applied energy technologies. These workshops led to the very successful Energy Frontier Research Centers, which in turn led to many early-stage companies. The learning experience from the new demonstration and deployment activities in advanced nuclear reactor demonstrations, the direct air capture (DAC) hubs, the hydrogen hub program, and the long-duration energy storage demonstrations will help identify where additional fundamental research support is most needed.

The new authorities and resources provided in the BIL, CHIPS and Science Act, and IRA intensify the need for a strategic framework for energy innovation that spans the entire Department. In the near term, the needs can be addressed through internal process improvements, such as the current planning, budgeting, and execution of crosscutting technology programs described earlier. Over time, these efforts will need to

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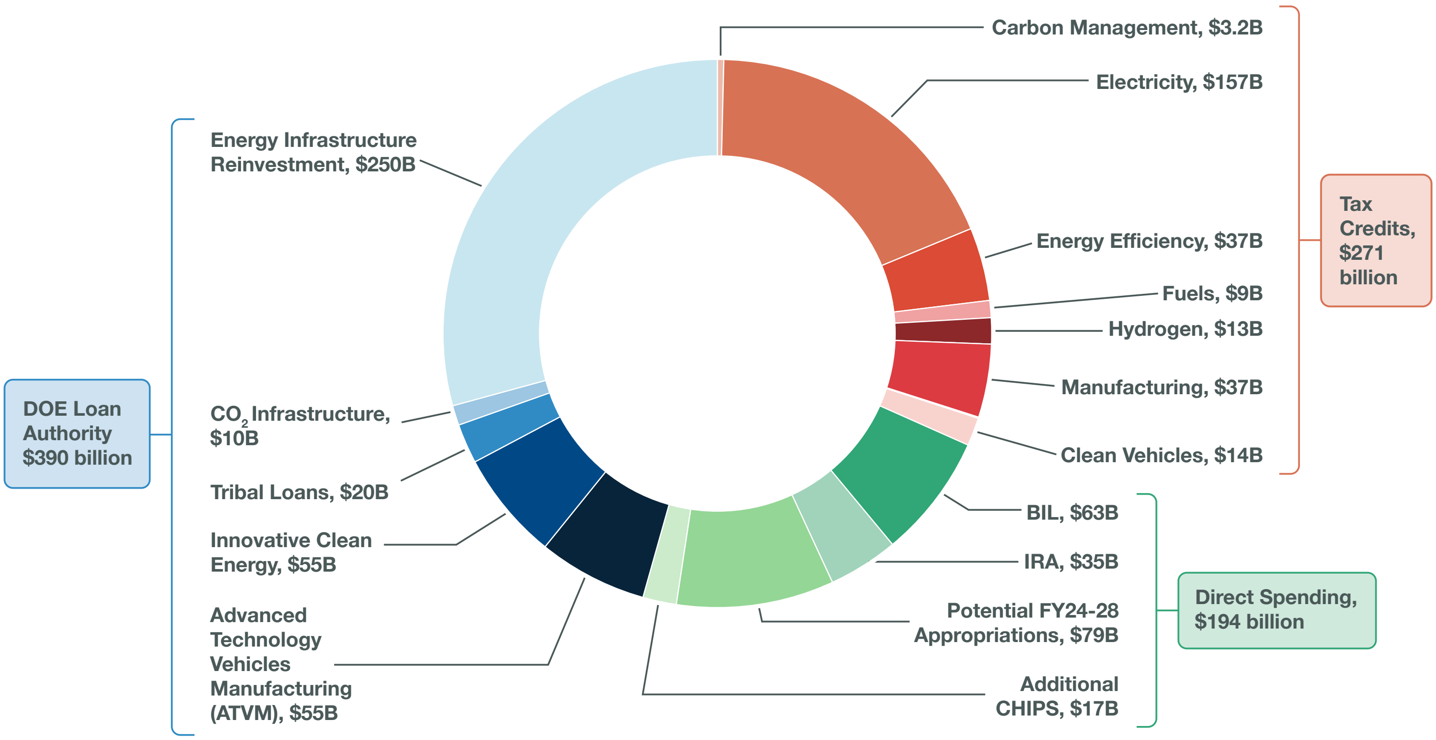
evolve into a comprehensive multi-year planning process that encompasses the full innovation spectrum across all energy technology pathways. Longer term, the experience gained from these initial efforts may lead to the need for further structural changes in the DOE organization, reflecting an applications-based clean energy organization with tighter organizational integration across the innovation cycle. These ideas are discussed further in succeeding chapters of this report.

1.5 | Financial Resources to Accelerate the Energy Transition

As a result of recent Congressional legislation, the federal government has a potential resource base, in the most optimistic case, approaching $900 billion to invest in accelerating the clean energy transition within the near-term future. This estimate includes tax expenditures currently estimated at $271 billion over the next ten years, $390 billion in credit support (loans and loan guarantees), and a projected $194 billion in direct expenditures over the next five years if annual appropriations increase at recent historical rates and the CHIPS and Science Act authorizations are fully funded. The breakdown of these resources is seen in Figure 4.[10] Further growth will be needed to complement the initial BIL and IRA funding, including funding to implement the CHIPS and Science Act (that provided authorizations but not appropriations of funding), as well as funding to sustain future rounds of the programs and projects jump-started in the BIL and IRA. The Fiscal Responsibility Act of 2023, however, marks a new pathway that may severely restrict further increases in annual appropriations funding over the next six years (through fiscal year [FY] 2029).[11]

FIG. 04

Composition of Financial Resources – Tax Incentives, Loan and Loan Guarantee Authority, and Direct Spending to Accelerate the Clean Energy Transition



The estimates in this figure represent a set of assumptions and could vary depending upon future actions by Congress and the private sector. The estimate of DOE loan authority is dependent upon the number and creditworthiness of future private sector loan and loan guarantee applications. Estimates of tax expenditures are dependent upon the magnitude and timing of private sector clean energy investments that may qualify for the tax incentives. Spending estimates assume future Congressional appropriations to fully fund the authorizations in the CHIPS and Science Act and other authorizations, as well as increasing funding across the entire DOE energy and science portfolio at a rate consistent with recent historical experience. Note that the specific time scales vary across spending categories and programs. Generally, direct spending and loan authority expire by FY 2026, and tax credits by FY 2032. Spending and credit authority estimates based on EFI Foundation analysis of the Energy Act of 2020, IRA, BIL, and CHIPS and Science Act. Tax credit estimates based on Joint Committee on Taxation (JCT) analysis, prepared at time of IRA enactment. April 2023 JCT re-estimates totaled $570 billion, but detailed breakdown was not made public. Reports from the financial community estimate even higher amounts.

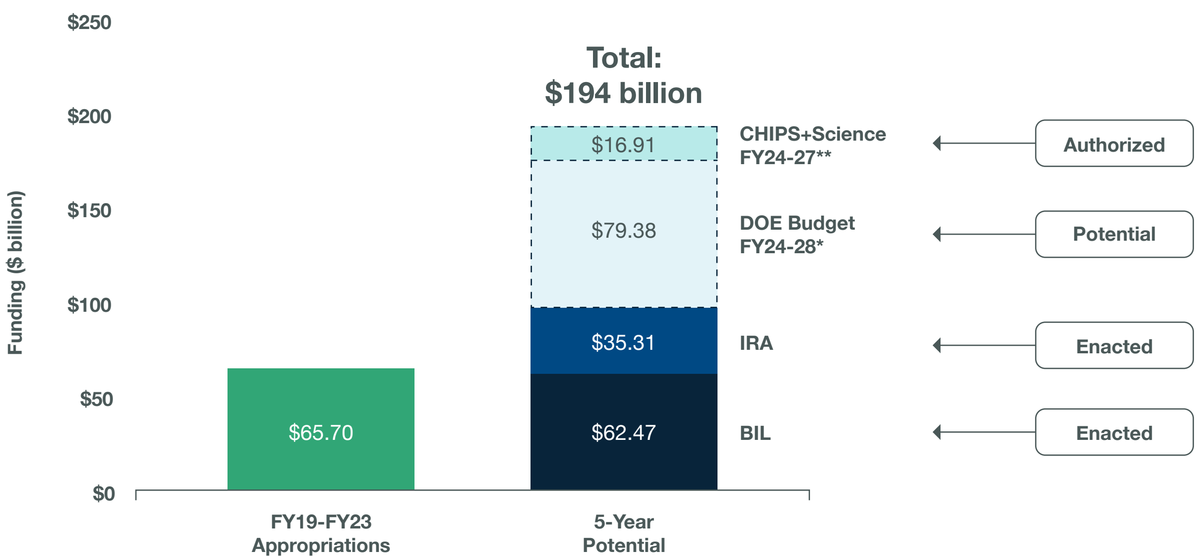
These forward-looking estimates are subject to change depending upon future decisions by government policymakers and private sector investors.

The estimated value of the tax expenditures will depend upon the scale and pace of private sector investments. Recent estimates from the financial community, for example, suggest that utilization of the various new tax credits will lead to larger future tax expenditures than estimated by Treasury because credits are uncapped, meaning they can increase further than previously projected. In other words, the cost of the IRA tax credits could have been underestimated by as much as 300%.[12]

Estimates of future levels of DOE direct spending will be dependent upon annual appropriations provided by Congress. As illustrated in Figure 5, DOE cumulative total spending could reach $194 billion over the next five years, triple the cumulative spending level over the past five years.[13]

FIG. 05

Estimated Future DOE Spending Levels (excluding loans and loan guarantees) to Accelerate Energy Innovation



* Assumes historical annual average growth rate resumes after FY2024-2025 caps in FRA
**Assumes additional CHIPS authorizations are fully funded

These estimates include the total budgets for all Office of Science research programs, all applied energy RD&D program offices, and all DOE demonstration and deployment activities, including OTT and ARPA-E. Estimates for loan and loan guarantee programs are excluded. The cumulative total DOE budget for these programs could triple over the next five years if the BIL and IRA are fully implemented, annual appropriations resume growth at historical rates beginning in FY 2026, and if CHIPS and Science Act authorizations are fully funded. The estimates of future year annual appropriations assume growth of only one percent per year in FY 2024 and FY 2025 as a result of the government-wide statutory caps in the Fiscal Responsibility Act, followed by a resumption of annual growth at the historical average rate of 6.8% per year beginning in FY 2026. Further increases in annual appropriations would be required to fully fund the CHIPS and Science Act in addition to supporting current programs. Figure based on the EFI Foundation analysis of DOE budget data and assessment of IRA, BIL, and CHIPS and Science Acts.

This estimate depends upon an optimistic set of assumptions, including:

- The BIL and IRA enacted multi-year appropriations, totaling $97.78 billion over the next five years, are fully funded;
- New annual appropriations are assumed to increase by only 1% per year in FY 2024 and FY 2025 due to the government-wide statutory caps enacted in the Fiscal Responsibility Act (FRA) of 2023;
- Annual appropriations resume growth in FY 2026 at the historical annual average rate of 6.8% achieved in recent years; and
- Additional appropriations are provided to fully fund the levels authorized in the CHIPS and Science Act.

Recent Congressional action points to a less robust outcome than illustrated in Figure 5. The Fiscal Responsibility Act (FRA) established stringent statutory caps on total appropriations spending for FY 2024 and FY 2025, followed by a projection of annual growth of government-wide spending of 1% per year from FY 2026 through FY 2029. In addition, the pending FY 2024 Energy and Water Development Appropriations bills reported by House and Senate Appropriations Committees include several measures that would rescind or repurpose portions of the monies previously appropriated to DOE in the BIL and IRA.

The pace of future annual appropriations would not only affect the top-line DOE budget but also could have a significant impact on the balance among DOE fundamental research, applied RD&D, and demonstration and deployment program activities. The CHIPS and Science Act authorized a total of $67.1 billion in new and expanded research programs over five years, mostly targeted to fundamental research programs. These authorizations are subject to future annual appropriations. By comparison, the BIL and IRA provided multi-year appropriations in advance for demonstration and deployment programs.

If future years' annual appropriations (in FY 2026 and beyond) increase at the recent historical average rate of 6.8%, as assumed in Figure 5, a significant level (about 75%) of the new authorizations in the CHIPS and Science Act can be funded within this envelope without major reallocations within the current DOE RD&D portfolio. The remaining 25% ($16.91 billion) would require a higher rate of growth in annual appropriations. By contrast, if future years' appropriations are constrained to a rate of 1% annual increases through FY 2029, as envisioned in the FRA projections (but not statutorily capped), then most of the CHIPS and Science Act new and expanded program authorizations might not be funded. Since the CHIPS and Science Act authorizations are largely targeted to the fundamental research programs in the Office of Science (SC), this could cause a substantial tilt in the overall DOE R&D portfolio towards demonstration and deployment activities. Members of the House Science, Space and Technology Committee recently wrote to Secretary Granholm raising concerns about the potential for imbalance in the DOE research and development program if no further action is taken to provide increased annual appropriations to augment the BIL and IRA funding, noting "While the Office of Science accounts for nearly 20% of DOE's annual funding profile, it received less than 2% of DOE's Infrastructure Investment and Jobs Act (IIJA) and Inflation Reduction Act (IRA) appropriations."[14] Issues related to planning, RD&D portfolio composition, and priority setting are discussed in more detail in Chapter 6 of this report.

The immediate challenge and opportunity is for DOE to manage the time-limited resources provided by the BIL and IRA to maximize impact rapidly and cost-effectively. It will also be essential for DOE to obtain sufficient annual appropriations to pick up the pace of fundamental research and early-stage applied RD&D on next-generation technologies that can capture the learning benefits of the initial round of demonstration and deployment projects funded through the BIL and IRA. The importance of maintaining a balanced innovation investment portfolio that spans all stages of the innovation cycle highlights and reinforces the need for a longer-term funding path that will significantly increase federal investment in the clean energy transition on a sustained trajectory. Several studies have called for significant growth in the level of federal investment in energy innovation, which could triple total federal investment in the U.S. energy innovation portfolio over five years (for more details, see Box 3 in Chapter 6).

Recommendation

DOE should work with the Administration to seek increases in annual discretionary appropriations to achieve and maintain a balanced end-to-end energy innovation investment portfolio. The principal focus should be to fund the new authorizations in the Energy Act of 2020 and CHIPS and Science Act. Increases in annual discretionary science and energy funding at a rate at least as high as the recent historical rate of 6.8% annually will be needed.

1.6 Organization of the Balance of This Report

The chapters that follow examine in more detail the issues, opportunities, and recommendations to enhance DOE organizational structure and management processes to enhance the pace, agility, effectiveness, and efficiency of the energy innovation enterprise. The discussion is organized around five major themes, each addressed in a separate chapter:

1. Establishing a Comprehensive Framework for End-to-End Innovation
2. Enhancing the Role of the DOE National Laboratories as Strategic Partners
3. Strengthening Department-wide Support Functions
4. Clarifying the Protocols for International Energy RD&D Engagement
5. Envisioning a Future DOE for Long-term Success

02 Establishing a Comprehensive Framework for End-to-End Innovation

This chapter discusses specific ways in which the U.S. Department of Energy (DOE) can build upon initial implementation of the BIL, IRA, and CHIPS and Science Act to establish a robust and comprehensive framework to accelerate end-to-end innovation. The chapter highlights current DOE initiatives that have the potential for significant impact and identifies additional measures that could further build upon these efforts.

The individual sub-sections in this chapter discuss discrete actions that are organized by four specific sub-themes. These include:

2.1 - Accelerating Demonstration and Deployment at Scale

- Enhancing Implementation of demonstration projects (principally through the Office of Clean Energy Demonstrations)
- Expanding from First-of-a-kind Demonstrations to nth-of-a-kind Deployment through supply-side incentives (Loan Programs Office) and demand-side market formation

2.2 - Expanding the Innovation Pipeline for Next Generation of Demonstrations

- Fast Track: Rapid Prototyping of New Technologies and Concepts
- Enhancing Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) as Seed Fund Programs

2.3 - Applying New Tools to Enhance Public-Private Partnerships in the Innovation Process

- Using Other Transaction Authority (OTA) to Create New Partnerships
- Using Prize Programs to Stimulate Innovation
- Standing Up the Foundation for Energy Security and Innovation (FESI)

2.4 - Sector-Specific and Place-Based Innovation

- Establishing a comprehensive and coordinated approach to industrial energy innovation programs
- Fostering regional and place-based energy innovation ecosystems

2.1 Accelerating Demonstration and Deployment at Scale

Enhancing Implementation of Demonstration Projects (Principally Through the Office of Clean Energy Demonstrations)

The Office of the Under Secretary for Infrastructure is responsible for the portfolio of energy technology demonstration and initial deployment programs and activities. The Office of Clean Energy Demonstrations (OCED) plays the lead role in this effort.

Unlike many of the other demonstration and deployment offices in the Office of the Under Secretary for Infrastructure organization, OCED was established by statute in the BIL. The concept was the outgrowth of several studies of implementation issues arising from past DOE demonstration programs. The 2019 EFI-IHS Markit Innovation Landscape report, for example, recommended: "Strengthened management of demonstration projects through stage-gated project management, risk-based cost sharing, and assignment of project oversight to a single office."[15] The concept and design were further refined in a report by the Information Technology and Innovation Foundation.[16]

In its authorizing language, Congress gave OCED a broad mandate, including:

- Evaluating proposals across dimensions, including technical maturity, cost certainty, financial feasibility, performance milestones, and potential for broad commercial application;
- Conducting oversight of project execution via evaluating costs and reviewing progress based on milestones and schedule; and
- Assessing and sharing lessons learned from demonstration projects and coordinating across government.

The BIL and IRA provided a total of over $39 billion, spread over five years, to implement a series of demonstration projects across multiple technologies, as shown in Table 1. Most of these programs are administered by the OCED.

TABLE 01

Technology Demonstration Programs and Funding in BIL and IRA

FUNDING AREA	FUNDING ($MILLION)	LEAD OFFICE**
Electricity Grid	11,000	OCED/GDO
Regional Clean Hydrogen Hubs	8,000	OCED
Carbon Capture and Storage Demonstrations	5,974	OCED
Advanced Industrial Facilities Deployment Program	5,812	OCED
Direct Air Capture Hubs	3,500	OCED/FECM
Advanced Reactor Demonstrations	2,477	OCED/NE
Clean Hydrogen Electrolysis	1,000	EERE
Energy Storage Demonstrations	505	OCED
Industrial Emissions Reduction Demonstrations	500	OCED
Mine Land Clean Energy Demonstrations	500	OCED
EV Battery Second-life Applications*	200	EERE
Rare Earths Demonstration Facility	140	MESC
Enhanced Geothermal Demonstrations	84	EERE
Marine Energy Demonstrations	70	EERE
Total	**39,762**	

*Includes other EV-related R&D activities
** GDO: Grid Deployment Office; FECM: Fossil Energy and Carbon Management; NE: Nuclear Energy; EERE: Energy Efficiency and Renewable Energy; MESC: Manufacturing and Energy Supply Chains

DOE will be responsible for more than $39 billion of demonstration funding, most of which expires in three to four years. Data based on the EFI Foundation analysis of the Inflation Reduction Act and Infrastructure Investment and Jobs Act of 2021, also known as the Bipartisan Infrastructure Law.

In July 2023, OCED released a Multi-Year Program Plan for the implementation of its responsibilities under the BIL and IRA. The Program Plan highlights three major attributes of the need for a federally funded demonstration program, including (1) "…validation of the performance of a clean energy solution in a sufficiently complex environment… of operational conditions, variations over time, and interactions;" (2) allow learning by doing; and (3) "…build confidence in industry and financial sectors and permitting and regulatory groups that the approach has sustained value."[17] To advance these goals, the Program Plan describes the program structure that OCED intends to follow in the implementation of its authorities.

The principal elements include:

- A **portfolio framework** comprised of individual cost-shared demonstration projects combined with additional funding mechanisms and prizes addressing crosscutting challenges;
- A **four-stage funding process** for each demonstration project, including (1) planning, (2) development, (3) implementation, and (4) operations, with go/no-go decision points at the end of each phase;
- A **framework for portfolio risk management** that is based on the application of Technology Readiness Levels (TRLs) and Adoption Readiness Levels (ARLs), including a framework of three separate tiers to measure technology successes and commercial adoption successes.[18,19] The ARL metric was developed by the Office of Technology Transitions (OTT) to complement the TRL metric often used to assess the status of new technologies in the innovation pipeline.[20] The ARLs identify "… important factors for private sector uptake beyond technology readiness, and can be determined by performing a qualitative, but fact-based, risk assessment across 17 dimensions of adoption risk spanning four core risk areas" including value proposition, market acceptance, resource maturity and license to operate;[21]
- A **project management oversight program** that includes: (1) defining project performance milestones during the negotiation of cooperative agreements; (2) use of independent engineers and other technical experts to assess project performance and risk, especially to support go/no-go decisions; (3) development of consistent metrics and methods of evaluation to enable portfolio-wide consistency and integration; and (4) establishing integrated project teams for each project that will have substantial involvement in them; and
- Identification of seven criteria that should be met in the future selection of **additional technology areas** for OCED support.

These elements provide a firm foundation for effectively governing the OCED demonstration programs established in the BIL and IRA, as well as laying the groundwork for potential future demonstration programs and projects. The OCED framework can be further enhanced from efforts currently underway with additional flexibilities and details in several areas, including flexibility in the application of cost-sharing

"The OCED framework can be further enhanced from efforts currently underway with additional flexibilities and details in several areas, including flexibility in the application of cost-sharing requirements, further enhancements to project management oversight, additional definition and transparency in the portfolio risk framework, and use of the expertise of the National Laboratories to provide technical support, assist in garnering the technical value arising from completed projects, and applying learning by doing to shape future fundamental and applied RD&D efforts."

requirements, further enhancements to project management oversight, additional definition and transparency in the portfolio risk framework, and use of the expertise of the National Laboratories to provide technical support, assist in garnering the technical value arising from completed projects, and applying learning by doing to shape future fundamental and applied RD&D efforts. These enhancements are discussed in more detail below.

Robust Project Management Oversight: A major rationale for the establishment of OCED was to consolidate and concentrate robust DOE project management oversight of commercial-scale demonstration projects in a single organization. OCED is in the process of building this capability to be prepared to exercise oversight as proposed new demonstration projects are awarded. Effective project oversight will be essential to building confidence in the program among stakeholders. The House Energy and Water Development Appropriations Act Committee Report for fiscal 2024, for example, earmarked $10 million "… to support OCED's continued efforts to develop improved oversight of project engineering, construction, and operations of demonstration projects."[22]

It appears that the current OCED effort will be drawing upon DOE best project management practices applied to federal facilities, with less reliance on the private sector cost-share partner's project management expertise, which had been the norm with previous DOE cost-shared demonstration programs. In response to poor historical experience with the management of some large-scale projects, DOE has developed world-class guidelines and procedures to govern the management of construction projects at its own facilities. DOE Order 413.3b established a stage-gate process to govern project development, including provisions for independent cost estimates, cost control, and project management. The requirements and procedures of this Order have proven to be effective in improving accountability, performance, and completing acquisition projects within budget and on time.[23] The project management oversight elements outlined in the OCED Program Plan appear similar to the project management guidelines in DOE Order 413.3b, which have continued to evolve in effectiveness.

There are other project management oversight processes that could be considered as well, which could further strengthen the ability of OCED to deliver major demonstration projects on schedule and within budget. These processes include milestone-based project management and the use of integrated project delivery agreements.

- The Energy Act of 2020 provided DOE with new authority to implement **milestone-based demonstration projects,** where DOE payments are tied to accomplishments rather than to cost reimbursement. Section 9005 of the Act states that DOE "…may carry out demonstration projects as a milestone-based demonstration project that requires particular technical and financial milestones to be met before a participant is awarded grants by the Department through a competitive award process." The milestone-based approach has been used successfully by the National Aeronautics and Space Administration (NASA) through Space Act agreements, a form of Other Transactions Authority, which will be discussed later in this chapter. Milestone-based payments could provide a stronger ongoing incentive throughout each phase of project performance compared with a prospective go/no-go decision at the end of each phase.
- DOE could require that demonstration projects be executed through **Integrated Project Delivery (IPD) Agreements.** An IPD is a multi-party agreement among all participants (project owner, designer, constructor, and key trade providers) that establishes a comprehensive framework for project implementation.[24] The elements of an IPD agreement that could provide value to OCED-supported demonstration projects include shared risk/reward based on project outcomes; pre-defined and limited liability; a comprehensive, early, and clear definition of project goals, scope budget, and schedule; and fully integrated project personnel, business systems and reporting. The IPD framework could also allow OCED to become a formal participant in the agreement, allowing for a clear up-front delineation of OCED risks, liabilities, and benefits in a manner that could be more detailed than the milestone metrics specified in a typical cooperative agreement. Implementing DOE-funded demonstration projects through IPD agreements likely would require a change from the current cooperative agreement structure to some form of Other Transaction Authority agreement.

In addition to these basic approaches, there are a number of specific recommendations for enhancing project oversight identified in reports by the Governmental Accountability Office (GAO) and the DOE Inspector General (IG). An ad hoc group of non-governmental organizations, organized by the Information Technology and Innovation Foundation (ITIF), has provided several letter reports to OCED with specific recommendations on project oversight measures such as milestone-based project management.[25] A key element identified in several of these reports is the need for periodic transparent reporting of project and portfolio performance.

Portfolio Risk Management: Regardless of the degree of rigor in proposal development and evaluation and project management oversight, no demonstration project is risk-free. Within a portfolio of first-of-a-kind commercial-scale demonstrations of innovative technologies, it should be expected that some projects will fall short of meeting one or more key project objectives. DOE should consider how best to identify, assess, monitor, and communicate the risk profile of its portfolio with stakeholders and policymakers.

Portfolio Risk Management encompasses both the process of project selection as well as the process of project oversight during implementation. The OCED Program plan appears to focus on portfolio risk management in the post-selection phase.

- The OCED Program Plan discusses portfolio risk management from the perspective of post-project selection, and it identifies TRLs and ARLs as factors that would be used in portfolio risk management. The Plan states that "…OCED will systematically assess and compare TRL and ARL of demonstration and pilot projects throughout their lifetime and compare these factors across projects in a program." The Plan, however, does not discuss the frequency of these assessments, nor does it discuss how the various elements of a TRL and ARL will be combined into a composite assessment at either the project or the portfolio level. It will be challenging to develop a composite risk assessment using ARLs since there are 17 dimensions of adoption risk, all qualitative, in the ARL methodology. Regarding frequency, it could be beneficial to update the risk profile (as measured by the TRL and ARL scores) at more frequent points in the project implementation process than simply at the go/no-go decision points at the end of each phase.
- Whether and how the OCED proposed risk management profile will be applied in the project selection process is unclear. The current FOAs include an evaluation of technical viability but do not specifically use TRLs as a scoring metric. ARLs are not specifically discussed in the Funding Opportunity Announcement (FOA) selection criteria. It may be appropriate to apply ARL scores at the project selection stage and thus facilitate a broader suite of projects that may have lower initial TRL scores but higher ARL scores if there is a strong value proposition or market acceptance potential. A recent Resources for the Future (RFF) workshop report recommends, for example, that DOE project evaluation "…should use metrics that maximize the spillover benefits of a project, which may be much more significant than the direct costs and benefits."[26] Doing so could lead to projects that may be unsuccessful in meeting their specific technical objectives but may increase the learnings from projects.

Finally, there are uncertainties regarding the form, content, and frequency of public communication of program portfolio risk to policymakers, stakeholders, and the general public. Risk communication can be misinterpreted and misused by opponents of demonstration projects as an argument against the program, but full disclosure of the benefits and risks of projects, as in any investment portfolio, can help frame and support the overall value proposition.

Technology-Neutral Demonstration Programs: The BIL earmarked DOE demonstration project funding in OCED and other program offices to a select group of specific technology areas. While the technology areas were extensive, a number of areas were not targeted, such as advanced wind technologies, advanced nuclear microreactors, fusion, and advanced solar technology. The OCED Program Plan discusses the need for and the process for future technical topics for development. The overall approach is to create a future "… technical program that executes multiple individual demonstration projects within a well-defined application area." The Plan identifies seven criteria that should be met for any future technical topic selected for development. These criteria are largely technology-specific, as illustrated by the discussion of possible future candidates such as floating offshore wind energy, advanced hydropower, enhanced geothermal, sustainable aviation fuels, and specific industrial sub-sectors. Possible examples also include several crosscutting technical areas such as grid and distribution networks.

In addition to the selection of specific technologies or application areas, OCED could also consider future technology demonstration programs that are designed to be technology neutral. An OCED open technology solicitation, modeled after the ARPA-E open solicitations, could accelerate innovation across a broader array of energy technologies and system solutions. An open technology FOA process would allow any and all innovative technologies to apply for assistance if they meet certain technology neutral eligibility criteria, drawing from the seven criteria identified in the Program Plan but applied across technologies and not simply within any specific technology area. The DOE FY 2024 budget proposed new OCED funding to support additional industrial decarbonization demonstration projects. This proposal, however, was not adopted in the currently pending House and Senate Energy and Water Development Appropriation Acts. An open, technology neutral solicitation strategy may have the potential to garner stronger support from policymakers.[27,28]

Flexible Cost Sharing: The variation in financing structures may require flexibility in the application of federal cost-sharing arrangements. The financial structures of energy demonstration projects will vary by technology based on a variety of factors, including capital intensity (CAPEX vs. OPEX), the pricing structures in offtake agreements, and site-specific factors (e.g., greenfield vs. retrofit). Reducing project execution risk may, in some instances, require greater flexibility in the structure of the financial agreements among the stages of project execution. Section 988 of the Energy Policy Act of 2005 established general cost-sharing requirements applicable across all DOE applied RD&D projects, including a requirement for at least 50% non-federal cost-sharing for demonstration projects. Most statutory authorizations and appropriations for demonstration programs direct compliance with Section 988 cost-sharing requirements.[29] The Act also authorized Secretarial-level waivers of cost-sharing requirements on a case-by-case basis if it is determined that "…the reduction to be necessary and appropriate, taking into consideration any technological risk relating to the activity."[30] There is a lack of formal criteria for establishing such waivers, creating uncertainties for project sponsors, DOE program managers, the Office of Management and Budget (OMB), and Congress for when cost-sharing waivers might be appropriate. Clarification of the application of waivers in cost-sharing arrangements could expedite the implementation of new demonstration projects and reduce project execution risk.

National Laboratory Expert Science and Technology Support Teams for Major Demonstration Projects: As noted, none of the DOE National Laboratories has a formal reporting relationship to the new Office of the Under Secretary for Infrastructure organization. National Laboratory expertise has provided critical technical support for previous commercial projects supported by LPO, such as modeling support to improve the technical and financial performance of early commercial wind and solar energy projects. OCED can extend this process for new demonstration projects by utilizing National Laboratory technical support teams for the technology demonstration projects. These teams could assist OCED staff experts in providing independent reviews of issues that may arise in project planning and execution. These teams also could play an important role in achieving the learning by doing objectives for OCED demonstration projects. The National Laboratory teams could undertake data analyses and modeling of the results from the operation of the initial demonstration projects to capture and disseminate the learning experiences. The analyses also could identify priorities for further innovation in follow-on deployments, informing needs that can be addressed in earlier stage RD&D programs. These activities would align well with the role of the National Laboratories as integrators across DOE program offices—a topic discussed in more detail in Chapter 3.

Recommendations

DOE should consider additional measures, such as milestone-based payments and integrated project delivery agreements, to build upon its proposed project management oversight plan. DOE also should consider recommendations from the GAO, the DOE Office of Inspector General (OIG), and external organizations.

DOE should consider the form, content, and frequency of its proposed portfolio risk management approach, including measures to communicate to policymakers, stakeholders, and the public risk/reward considerations that constitute the value proposition of the demonstration projects in its portfolio.

DOE should seek funding from the OMB and Congress to establish an open, technology-neutral FOA process for additional OCED technology demonstration projects in addition to technology-specific programs.

DOE should develop a formal set of criteria and procedures to enable case-by-case modifications of project cost-sharing requirements that allow greater flexibility among the stages of project execution, consistent with existing statutory authority in Section 988 of the Energy Policy Act of 2005.

OCED should work with the National Laboratories to establish teams of National Laboratory experts to provide independent science and engineering support for DOE-funded demonstration projects and capture the learning by doing from these projects to inform future DOE RD&D activities.

Expanding from First-of-a-kind Demonstrations to nth-of-a-kind Deployment through supply-side incentives (Loan Programs Office) and demand-side market formation

The BIL and IRA funding for DOE is focused on FOAK demonstration projects. These projects will establish technical feasibility at or near commercial scale. In some cases, the FOAK demonstration may be adequate to spur widespread market adoption organically or supported by tax incentives. In others, additional policy and financial incentives may be needed to support widespread commercial deployment.

The transition from initial demonstration (FOAK) to market deployment (NOAK) depends on a range of factors, including, but not limited to, performance improvements and cost competitiveness. The FOAK demonstration may establish a technical performance baseline but will not be sufficient to determine other technical parameters, such as longer-term durability or operations and maintenance requirements. More importantly, the cost of a FOAK facility may not be economically competitive in the market, absent additional cost reductions from multiple repetitions, economies of mass manufacturing, or further technological improvement. DOE refers to this learning process as "technology liftoff."

DOE published six "Pathways to Liftoff": long-duration energy storage, clean hydrogen, advanced nuclear fission, carbon management, industrial decarbonization, and virtual power plants.[31] The reports provide frameworks for the public and private sectors to assess the commercial needs for energy technology, including the financial, technological, and policy gaps that inhibit "liftoff" (full commercial adoption) in key low-carbon technologies.

These studies identify a comprehensive set of options for both supply-side incentives (technology push) and demand-side support tools (market pull). Supply-side policies could include funding for multiple demonstration projects of the same technology or credit support (i.e., loan guarantees) from the DOE Loan Programs Office for the initial three deployments of innovative technologies. Demand-side policies can supplement technology push measures by creating and enhancing points of entry into broad market applications. For example, the federal government could induce demand for innovative clean products or processes through federal purchase requirements (e.g., electric vehicles or clean electricity purchase power agreements). It could also incentivize others to induce such demand through grants, infrastructure deployment requirements, or direct payments to end users in the form of rebates or contracts for differences, a mechanism that commits the federal government to fund the difference between actual costs of supply and the market clearing price paid by customers.

Supply-side Deployment - Leveraging the DOE Loans Programs Office: The Loan Programs Office (LPO) is the principal DOE program to support the deployment of innovative clean energy technologies and associated supply chains beyond the stage of initial commercial demonstration. One of LPO's main benefits to innovation policy is its ability to support supply-side or "push" innovation policy. By providing better financing options for proven and technically sound but under-deployed technologies, LPO helps increase the "supply" of clean technologies by reducing their cost to demonstrate or deploy. A recent White House Issue Brief explicitly identifies the LPO loan authority as a key part of supply-side policies for clean technologies.[32]

> "One of LPO's main benefits to innovation policy is its ability to support supply-side or "push" innovation policy. By providing better financing options for proven and technically sound but under-deployed technologies, LPO helps increase the "supply" of clean technologies by reducing their cost to demonstrate or deploy."

The role of LPO can overlap with the role of OCED, where OCED can provide cost-sharing support in some instances for multiple demonstration projects, while LPO provides credit support for commercial deployments. LPO-supported projects typically take into account federal tax incentives as part of the overall financial structure that would be supported by the loan guarantee. LPO, however, is currently prohibited by statute from integrating federal direct cost sharing or other forms of federal assistance such as purchase commitments with loans and loan guarantees (known as the "Federal Support Restriction").

LPO states that its mission is to provide a bridge to bankability for innovative technologies from demonstration to full market acceptance. This mission includes:

- Initial commercial-scale deployments to demonstrate technology effectiveness at scale;
- Follow-on commercial-scale deployments to optimize cost and performance through learning by doing and learning by using; and
- Real-world experience to better inform financial markets of the value proposition of innovative energy technologies to investors.

The DOE Loan Programs Office includes several types of loan and loan guarantee programs.

- The Principal Loan Guarantee program was established in Section 1703 of Title 17 of the Energy Policy Act of 2005. The Section 1703 program supports the deployment of innovative, clean energy technologies. The program is authorized to support a wide spectrum of innovative clean energy technologies across all end-use applications.
- The Energy Independence and Security Act of 2007 established the Advanced Technology Vehicles Manufacturing (ATVM) loan program, supporting the manufacturing of fuel-efficient advanced technology vehicles and qualifying components. The IRA expanded this program, targeting the manufacturing of electric vehicles and associated supply chains.
- The Tribal loan program is a technology-neutral, place-based loan program. The program supports the deployment of a wide variety of energy technologies on or near tribal lands. Eligibility of projects is not limited to innovative technologies.
- The IRA added an additional new program, the Energy Infrastructure Reinvestment Program (EIRP), the new Title 17 Section 1706 program. The EIRP program provides up to $250 billion in loan guarantees for projects that retool, repower, repurpose, or replace energy infrastructure that has ceased operations or enable operating energy infrastructure to avoid, reduce, utilize, or sequester air pollutants or greenhouse gas emissions.[33] Projects supported by the EIRP program are not restricted to innovative technologies; they can support multiple deployments of various commercially available energy technologies. The program is place-based rather than technology-specific.

The LPO currently has a total authorized loan level estimated at $390 billion to support innovative technology deployment, as shown in Figure 4. Within the authorization total, DOE is required to set aside funding for a loan loss reserve, designated as the cost of the loan guarantee. The methodology for determining the cost of the guarantee is governed by the Federal Credit Reform Act of 1990; it is funded either by direct appropriations or by an upfront cash payment from the project sponsor (so-called direct pay).[f] A breakdown of this estimate among the various loan and loan guarantee program categories is summarized in Table 2.[34]

The LPO FY 2022 report shows that LPO currently holds a portfolio of nearly $40 billion in loans, loan guarantees, and conditional commitments to 30 projects spanning 20 states. An additional $16.5 billion in new conditional commitments have been announced since the time of the FY 2022 report.[35,36] The report also shows that, through FY 2022, LPO has disbursed $31.6 billion, with a portfolio loss rate of only three percent. The overall creditworthiness of the LPO portfolio, including loss rate, is comparable to commercial lending performance, although it should be recognized that the risk profile for the LPO program differs significantly from commercial lending. The LPO program was established to overcome technology cost and performance risk of early commercial deployments, while the risk exposure in commercial lending is primarily associated with business model success or failure.

[f] The credit subsidy cost is estimated as the net present value of the expected future streams of loan disbursements and repayments, including probability of default and estimated residual value of the project in the event of a default. The actual cash flows of disbursements and repayments are not counted in federal budget deficit totals.

TABLE 02

Summary Description of the Portfolio of LPO Loan Programs

PROGRAM	LOAN AUTHORITY	CREDIT SUBSIDY AMOUNT	PROGRAM SCOPE
Innovative Energy and Innovative Supply Chain Program (Title 17)	$55 billion	$3.492 billion (IRA) + Prior Appropriations	Authorized in the Energy Policy Act of 2005 with a focus on innovative technologies; BIL expanded its scope to include critical materials; IRA appropriated $3.492 billion for credit subsidies (~$40 billion in additional loan authority)
State Energy Financing Institutions Program (Title 17)	Included Above	Included Above	Authorized in BIL to support State clean energy credit programs; allows applicants to bypass innovation requirement
Energy Infrastructure Reinvestment Program (EIRP) (Section 1706 of Title 17)	$250 billion	$5 billion (IRA)	Authorized in IRA to facilitate deployment of new clean energy projects at energy sites that have been closed
Advanced Technology Vehicles Manufacturing (ATVM) Program	~$55 billion*	$3 billion (IRA)	Authorized in the Energy Independence and Security Act of 2007 to support the deployment of manufacturing facilities for advanced technology vehicles and components; Scope of eligible technologies expanded in BIL
Tribal Energy Loan Guarantee Program	$20 billion	$2 billion (IRA)	Authorized in the Energy Policy Act of 1992 to support Tribal energy projects
CO_2 Transportation Infrastructure Program**	$10 billion*	$2.1 billion (IIJA)	Authorized in the Energy Policy Act of 2005 to support the buildout of CO_2 infrastructure

* Authority not established in law but estimated based on the level of appropriated credit subsidy
** Administered in coordination with the Office of Fossil Energy and Carbon Management (FECM)

Source: See first table mention in text for sources

The LPO programs represent a critical and highly effective means for moving innovative clean energy technologies from first-of-a-kind (FOAK) to nth-of-a-kind (NOAK) applications.[37,38] Several challenges remain, however, that could be addressed through further program enhancements.

- Projects in the deployment pipeline from FOAK to NOAK may have some remaining cost and risk premiums until the full learning benefits of NOAK deployment are achieved. While favorable credit financing terms can help mitigate the residual cost premium, favorable credit terms alone may not be sufficient, and some form of bridge financing that blends federal cost sharing and credit support may be needed. The Federal Support Restriction currently prohibits LPO from providing such blended financing. Consequently, some potential customers for innovative clean energy technologies may decide to wait until NOAK is fully achieved before placing orders. A package of "blended" financial incentives could improve risk allocation and expedite project implementation.
- The current administrative restriction on the number of LPO funded projects per technology may limit the full realization of the learning curve benefits from advancing innovative technologies from FOAK to NOAK. The current LPO Title 17 regulations set a limit of three projects per technology that can be supported with Title 17 loan guarantees. For some technologies, such as advanced small and micro modular reactors, a larger order book may be needed to establish a commercially viable manufacturing supply chain.
- There may be instances where an innovative clean energy technology also requires some form of market conditioning if the innovative technology is providing a product or process that is not a direct drop-in substitute in an existing market. Deployment of clean hydrogen fuels is one such example, where potential market applications will require modification of current applications, such as installation of new fuel handling and combustion equipment. Other examples include new products, such as concrete manufactured with captured CO_2. In such cases, demand-side policies and program initiatives may be needed to complement the supply-side incentives to support the deployment of innovative clean energy technologies. (Demand-side measures to support deployment are discussed further in the next section).
- Finally, despite a number of administrative reforms, there remain uncertainties and potential impediments in the application process that may discourage potential applicants from utilizing the LPO programs. LPO has reduced application fees, posted more application information on-line and has set up outreach efforts to advise potential applicants on the loan guarantee process. Nonetheless, some companies are unfamiliar or uncertain regarding the additional strings attached to all forms of federal financial assistance. Further improvements in the interface process remain a continuing work in progress.

A recent EFI Foundation report focusing on improving the investability of carbon capture and sequestration (CCS) offers guidelines that can be generalized to a broader suite of energy technologies.[39] Put simply, Congress should allow DOE to issue LPO loans to projects receiving grants as part of FOAK deployments. LPO should also administratively allow loans to be provided to technologies that are in the early stages of coming down the cost curve but not yet fully proven. For example, CCS projects are currently administratively limited if a particular technology has been used in three separate projects with five years of operating history.[40] Each of these steps would allow the LPO sizable loan authority to be used for a greater variety of projects and accelerate cost declines and learning by doing (thus also accelerating innovation).

Recommendations

LPO should modify its current regulations to clarify that it can provide Title 17 loan guarantees to multiple projects deploying the same or similar technology through the learning process until NOAK is achieved.

DOE, with Administration support, should work with Congress on legislative action to rescind or modify the Federal Support Restriction. Possible modifications could include allowing flexibility for LPO to combine other forms of federal assistance with LPO loans and loan guarantees if: (1) the combination reduces project execution risk and enhances prospects for repayment of the loan, and (2) the cost and risk factors associated with the supplemental forms of federal assistance are appropriately reflected in the credit subsidy estimate process. (LPO could revise its current credit subsidy methodologies to incorporate any risk associated with the combination of federal grants and loans in a project financing structure. Federal tax incentives are not subject to the statutory prohibition on double federal benefits, and the methodologies currently used to underwrite projects with both federal tax incentives and LPO credit support could be extended to other forms of federal funding assistance as well).

Demand-side Market Pull Strategies

There are several nascent efforts underway to foster demand-side market development policies for innovative products and processes. The General Services Administration is seeking to develop new strategies to be incorporated into the procurement of goods and services it provides to federal agencies. The Department of Defense (DOD) is also pursuing similar efforts in its various acquisition and facilities management programs. Other approaches could include price support assistance in the form of rebates or contracts for differences.

The DOE OCED is currently exploring the possibility of advancing demand-side policy and program measures to complement supply-side subsidies. Key actions undertaken to date include:

- In February 2023, OCED issued a Request for Information (RFI) to help inform the development of demand-side support measures for the deployment of clean energy technologies, with a focus on advanced market commitments, direct procurement, and guaranteed offtake.[41,42]
- In July 2023, the President's Council of Economic Advisers released an Issue Brief: "*The Economics of Demand-Side Support for the Department of Energy's Clean Hydrogen Hubs.*" The issue brief notes that there are market challenges, such as uncertainties among developers, investors, and customers about future demand and future cost trajectories, that can lead to underinvestment in deployment, even if supply-side incentives are in place. The brief states that "The hesitation from the private sector to make long-term demand commitments creates opportunities for the government to use demand-pull mechanisms...These include advance market commitments, prizes, and contract for differences agreements."[43]
- In parallel with the release of the Issue Brief, OCED released a Notice of Intent stating that it is considering establishing a Demand-side Support Mechanism to support reliable demand for

hydrogen at DOE-supported Regional Clean Hydrogen Hubs. OCED indicated that it could provide up to $1 billion to support the use of this mechanism.[44]

- In September 2023, OCED released a Request for Proposals (RFP) to enter into one or multiple agreements with independent, not-for-profit U.S. entities to create demand certainty for clean hydrogen market formation. (Implementation of this effort likely will require the use of Other Transaction Authority, discussed in more detail in a subsequent section).[45]

"Demand-side signals are an essential tool for accelerating innovation, but they can be cost-prohibitive if applied at large scale. However, they can be particularly effective where they leverage supply-side incentives, such as production tax credits, or can be combined with other private sector initiatives to promote market development."

Demand-side signals are an essential tool for accelerating innovation, but they can be cost-prohibitive if applied at large scale. However, they can be particularly effective where they leverage supply-side incentives, such as production tax credits, or can be combined with other private sector initiatives to promote market development. They can also be useful tools to support supply chain development that otherwise could limit the adoption of a new technology. A key role for DOE is to identify where demand-side policy can be effective and use its findings to accelerate innovation and demonstration and deployment of energy technology.

Recommendations

DOE should establish a central analytical capability to analyze market adoption issues and support the development of strategies to complement current and planned demonstration and deployment programs.

DOE should build on the Liftoff reports to assess the need for, and the feasibility of, the additional supply-side and demand-side options identified in those reports.

DOE should expand efforts to work with DOD, the General Services Administration, and the Office of Federal Procurement Policy to develop pilot programs for the use of federal government purchasing power to create markets for new clean energy technologies and systems.

2.2 Expanding the Innovation Pipeline for Next Generation of Demonstrations

Fast Track: Rapid Prototyping of New Technologies and Concepts

The current OCED efforts are focused on large-scale demonstration of technologies that have emerged from the technology maturation process. There is a companion need to fill the innovation pipeline that can support succeeding rounds of demonstration and deployment projects. A key component is to accelerate

"Accelerated technology maturation can enable new technologies to move to demonstration faster; they also could help to more quickly eliminate technologies that fail to show promise of commercial feasibility."

mid-stage technology maturation (i.e., innovation at the mid-levels on the Technology Readiness scale) through prototyping and pilot-scale testing. Accelerated technology maturation can enable new technologies to move to demonstration faster; they also could help to more quickly eliminate technologies that fail to show promise of commercial feasibility.

The need for a rapid prototyping initiative was initially identified in the 2019 EFI-IHS Markit Report on the Landscape of Energy Innovation. That report concluded:

> "DOE should set aside a small portion of its existing applied energy RD&D funding to support accelerated de-risking of near-commercial innovative energy technologies and systems on an accelerated basis, to make these options more attractive for private capital investment."[46]

In 2020, the DOE Advanced Research Projects Agency–Energy (ARPA-E) launched a new initiative, *Seeding Critical Advances for Leading Energy Technologies with Untapped Potential* (SCALEUP), that could serve as a possible model for a broader rapid prototyping effort. SCALEUP was designed to provide follow-up funding for ARPA-E grantees whose initial projects showed significant promise for demonstration and deployment and attracted interest and involvement from potential private sector partners, including both investors and customers. The SCALEUP program was a $150 million initiative to provide 50-50 cost-sharing for follow-on development of successful ARPA-E RD&D projects over a three- to five-year period, with a federal funding share in the range of $5 million to $20 million per project.

A 2022 Report by the American Energy Innovation Council (AEIC) recommended a major expansion of this program as a vehicle "…to address the dearth of support for pre-pilot demonstration efforts (before large-scale demonstration)."[47] The AEIC also recommended that the expanded program be implemented through a rolling funding opportunity and open to applicants regardless of whether they had previously received ARPA-E funding.

Recommendations

DOE should establish a "fast track" program to accelerate the rapid prototyping of new energy technologies that have achieved early proof of concept but require additional technology maturation at pilot scale to achieve readiness for commercial-scale demonstration. The program should incorporate flexible program implementation measures similar to those in the ARPA-E SCALEUP program. The proposed new "fast track" initiative should have an evergreen, technology-neutral solicitation process that will allow projects to move forward at a pace appropriate for the technology. The initiative should be conducted as a pilot program, depending upon the level of funding, with carefully monitored performance and expanded as experience is gained. The initial scale of the program should be resourced to support about 10 to 20 projects per year, with a range of $5 million to $25 million total cost per project. The pilot effort should be subject to a third-party independent review and evaluation three to five years after initiation.

ARPA-E should increase the size and frequency of SCALEUP funding opportunities for ARPA-E grant recipients.

Enhancing Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) as Seed Fund Programs

The Small Business Innovation Research (SBIR) Program was established in 1982 through the Small Business Innovation Development Act, funding small businesses to work on commercially relevant R&D. Federal agencies with extramural R&D budgets of $100 million or more are required to earmark a portion of their funds to finance targeted SBIR programs. In 2021, 11 federal agencies operated SBIR programs. In FY 2023, the portion of RD&D funding dedicated to these programs was set by legislation at 3.2%.

The Small Business Research and Development Enhancement Act of 1992 authorized the Small Business Technology Transfer (STTR) program. STTR requires agencies with extramural R&D budgets of $1 billion or more to devote a portion of these funds towards demonstration and deployment efforts of university and federal R&D projects by small companies. In 2021, five federal agencies operated STTR programs. In FY23, the earmarked portion was 0.45%.

Both the SBIR and STTR programs are implemented in three phases. The initial two phases are funded from the earmarked funds, with the expectation that Phase II funding is provided to a subset of successful Phase I projects. Phase III–commercialization–is not supported with earmarked SBIR/STTR funding; the project sponsors need to compete for funding from other existing programs. Both programs were recently amended and reauthorized.[48]

The DOE SBIR and STTR programs fund approximately 600 grants to small businesses at a total of about $300 million annually; 400 of these grants are Phase I awards.[49] A total of 13 separate R&D program budgets support SBIR and STTR funding, including: Cybersecurity, Energy Security and Emergency Response; Electricity; Fossil Energy and Carbon Management; Energy Efficiency and Renewable Energy; Nuclear Energy; Advanced Scientific Computing Research; Basic Energy Sciences; Biological and Environmental Research; Fusion Energy Sciences; High Energy Physics; Nuclear Physics; Defense Nuclear Nonproliferation; and Environmental Management.[50]

Each program office establishes the scope of activities to be supported with their respective funding allocations. This process can lead to sub-optimal outcomes due to potential inconsistencies and gaps in the specified areas of technology eligibility. As noted in a 2019 ITIF report, "DOE releases solicitations for specific subtopics that change with every solicitation cycle, which are developed by subject-matter experts from within the agency, often in collaboration with its National Laboratories, universities, and private industry."[51] DOE topics are broad, ranging from advanced turbine technology to cybersecurity.[52] Rather than a coordinated effort, SBIR programs within each DOE office are executed independently, creating inconsistencies in implementation, topic specificity, and overall mission alignment, factors that do not necessarily support market-oriented efforts.

The evolution in SBIR/STTR implementation in other federal agencies could serve as a model for reinventing the DOE efforts. NSF, for example, has reinvented its SBIR program to specifically target growth-focused startups and to emphasize commercializing innovations derived from federal R&D, characterizing it as "America's Seed Fund."[53] Most companies that receive NSF Phase II SBIR awards have not previously received SBIR funding for another project, enabling a steady stream of new companies and ideas. The NSF Seed Fund website, including videos, is clear, helpful, and compelling.[54]

Another example of innovation-enabling reform is illustrated in the SBIR/STTR reforms adopted by the U.S. Air Force and the U.S. Space Force, establishing new initiatives – AFWERX and SPACEWERX, respectively. These efforts, beginning with administrative actions in 2017 and eventually enacted into authorizing legislation, included:

- **Rapid contracts and payments,** combining open-topic solicitations, pitch events, and contracting sprints;
- **Public-private investment** matching, including tiered investment with private sector matching capital; and
- **Single investment acquisition authority** with direct control of SBIR/STTR funding and direct reporting to Program Managers.[55]

The ITIF report documented some improvements in DOE SBIR/STTR program management, noting that "DOE has recently adopted several improvements to its SBIR and STTR programs, some of which have been modeled on innovations pioneered by NSF, including pre-decision feedback opportunities, faster review timelines, and more flexible collaboration terms and support programs, but more could be done to spur the pace of innovation more toward commercialization."[56]

A recent Bipartisan Policy Center (BPC) report recommended a number of improvements that could better leverage these programs to accelerate innovation and improve the diversity of cofounders, including: prioritizing projects with commercialization potential throughout all phases; upholding better metrics to assess impacts aligned with innovation; targeting efforts to attract more new entrants and expand participation to a more diverse set of applicants and awardees; increasing flexibility of funding timelines and terms to support resource-limited entities; and speeding up timelines.[57]

A follow-on BPC study recommended that OCED re-purpose its SBIR and STTR funding to target pilot-scale demonstration, which requires less than $25 million. These pilot-scale demonstrations would "…aim to prove that larger investments are worthwhile," including follow-on commercial-scale OCED demonstration funding.[58] The BPC recommendation is similar to the "Fast Track" initiative for rapid prototyping described earlier in this chapter.

The Senate Energy and Water Development Appropriations bill report for fiscal year 2024 encourages DOE to focus SBIR/STTR solicitations on decarbonization and emissions reductions. The report also directs DOE "…to develop program processes that are not burdensome to small businesses at the application stage and during grant management."[59]

Recommendation

DOE should seek to better leverage SBIR and STTR programs as a seed fund for startups focused on technologies relevant to DOE's mission. This can be accomplished by building upon other federal agency experience and the BPC and ITIF recommendations, including greater flexibility in applicant eligibility to encourage new and diverse entrants, use of open, evergreen solicitations with shorter review timelines, and emphasis on proposals that may have greater demonstration and deployment potential.

2.3 Applying New Tools to Enhance Public-Private Partnerships in the Innovation Process

Using Other Transaction Authority (OTA) to Create New Partnerships

Other transaction authority (referred to as OT or OTA) is a special authority to enable federal investment in a broad array of private sector RD&D activities, including support for prototyping and manufacturing. OTAs can be an effective replacement for the traditional cooperative agreement framework utilized in most DOE RD&D funding agreements. OTAs likely will be essential for implementing new market development programs such as the released RFP to support efforts to create demand certainty for clean hydrogen.

OTAs speed up government acquisitions by providing a more flexible process to tailor federal procurement terms and conditions to project-specific circumstances in lieu of blanket application of the requirements (both substantive and procedural) specified in the Federal Acquisition Regulation (FAR).[60] OT authority has been used extensively and successfully by DOD, NASA, the National Institutes of Health (NIH), and the Department of Transportation (DOT). For example, the Department of Health and Human Services (HHS) and NIH awarded $12.5 billion via OT agreements to speed the development of COVID-19 vaccines, including research, prototypes, and production.[61] The DOD Defense Innovation Unit has invested $4.9 billion in

OT authority agreements over the last six years, with an emphasis on the rapid prototyping of innovative technologies for possible national security applications.[62] NASA executes thousands of OT authority agreements annually, and other agencies execute OT authority agreements in the hundreds per year.[63]

> “OTAs speed up government acquisitions by providing a more flexible process to tailor federal procurement terms and conditions to project-specific circumstances in lieu of blanket application of the requirements (both substantive and procedural) specified in the Federal Acquisition Regulation (FAR). OT authority has been used extensively and successfully by DOD, NASA, the National Institutes of Health (NIH), and the Department of Transportation (DOT).”

DOE has had OT authority on its books since 2005 (it was renewed by Congress in 2020), but it has entered into only a few actual agreements. An underlying issue is the structure of the DOE regulations that implement OT agreements through narrowly focused Technology Investment Agreements (TIAs). DOE's guidance for implementing OTs through TIAs, issued in 2006, operates under the DOE financial assistance regulations for grants and cooperative agreements rather than as a separate, stand-alone regime.[64] This construct leaves many of the requirements for contracts and cooperative agreements unchanged. Further, it is reported that DOE does not have adequate contracting officer staff with the necessary warrant to satisfy the certification requirements for an OT agreement.

Effective use of OT authority by DOE could significantly enable the energy innovation process in several ways, including:

Speed: OT authority, if appropriately framed and implemented, can be executed much more quickly than contracts or cooperative agreements. This feature is especially important in cases where speed is paramount (e.g., COVID-19 vaccines) or where speed is critical to ensuring ventures do not fail due to lack of funds. The Defense Innovation Unit, for example, executed OT agreements on average in 142 days in 2022, with a goal to reduce that time to 60 to 90 days. By comparison, the execution of DOE cooperative agreements can take 12 months to 18 months after projects are selected for cost sharing.

Facilitation of New Entrants: OT authority can facilitate broader participation in federal programs because it allows flexibility to modify or exclude contract clauses and requirements in traditional federal procurements (e.g., termination clauses, cost accounting standards, payments, audit requirements, intellectual property, and contract disputes) that can be especially challenging for entities that are not experienced federal contractors. Many innovators and entrepreneurs have limited federal contracting expertise or experience and perceive the process as overly burdensome. The unique needs and challenges of energy innovation for broad application make some standard requirements governing government acquisition of goods and services or government use unnecessary or inappropriate.

Performance-Based Payment Terms: The payment terms in OT authority agreements can be tailored to performance objectives or milestones. NASA OT authority has been implemented through Space Act agreements that have successfully used performance and milestone-based payments to create private sector launch capabilities. By contrast, the payment terms in DOE cooperative agreements are largely on a cost-reimbursable basis within preset time periods of performance.

Flexible Business Model Structures: OT authority provides more flexibility to structure agreements with joint ventures, partnerships, or consortia. OTAs also could facilitate multiple funding entities joining together to fund an agreement.

The application of a DOE OTA with private companies under Project Pele provides an important illustration of how OTAs also can facilitate involvement of the DOE National Laboratories. The objective of Project Pele is to develop a transportable microreactor for military use. The project will employ a commercial design to deliver 1MW to 5 MW of electrical power for a minimum of three years of full power operation.[65] Idaho National Laboratory (INL) is partnering with private firms that have OT agreements with DOD. In a parallel and supporting role, DOD entered into an Interagency Agreement (IAA) with DOE to develop and demonstrate an inherently safe, mobile nuclear power reactor that would produce 1MW to 5 MW of electrical power and be transportable by truck. This IAA work flowed down to INL under a DOE Strategic Partnership Project. INL, in turn, extended its work to engage with Los Alamos National Laboratory (LANL) and Oak Ridge National Laboratory (ORNL). This hybrid arrangement, initiated via a partnership under the umbrella of the DOD OT authority, has enabled Project Pele to proceed more rapidly than if it were organized by DOE under its traditional procurement practices.

After a fast-paced effort to study the issue further and develop a working plan, it appears that DOE now has put in place the framework for effective OTA implementation. For example, OTT has worked with the Institute for Defense Analysis (IDA) to identify the main challenges that discourage the broader application of OT authority and potential enhancements. A Departmental task force co-led by the DOE Office of Management and the DOE General Counsel has been working to develop new guidelines for OTA implementation. On August 31, 2023, DOE released a new Guide to Other Transaction Authority.[66]

In parallel with the Departmental activities, the DOE National Laboratories have been working to identify potential "use cases" that may benefit from improved contracting processes.[67] These efforts provide the opportunity for DOE to make early tangible progress on OT authority implementation.

Recommendations

DOE should establish a targeted pilot program for early implementation of the new OTA Guide. In addition to the hydrogen market development project, OCED should also consider whether a small number of demonstration projects selected for funding under previous FOAs with cooperative agreement requirements could be expedited through the use of OTAs. DOE should also consider the use cases developed by the National Laboratories as early candidates for the OTA pilot implementation effort.

As may be needed to enable the rapid startup of this effort, DOE should consider entering into an interagency agreement to acquire OT authority services from another federal agency that has extensive established OT authority expertise and experience.

Using Prize Programs to Stimulate Innovation

The use of prizes can complement the more traditional mechanisms of grants and contracts as a means to accelerate innovation opportunities. Prize program competitions are appropriate in instances where a certain technical outcome is desired, but where the pathway to that outcome is uncertain, or where there may be a number of very different pathways to success. Prize programs have been of particular value where the desired outcome represents a significant stretch from current knowledge. Prize programs also can be beneficial in instances where there are likely to be a relatively large number of viable contestants, exceeding the number of entities who otherwise would be able to obtain federal grant or contract funding.

Prize programs have been popular in the private sector.[68] Innovators and entrepreneurs often pursue the notable venture capitalist-led "XPRIZE" not only for its award amounts but also because of the prestige and publicity created by the prize, viewed as an important lever to attract additional investment.

DOE authority to issue prizes has been progressively expanded by Congress. The Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007 both authorized prize authority for DOE. These efforts were further expanded in the America COMPETES reauthorization of 2010.[69] The Energy Act of 2020 and CHIPS and Science Act of 2022 specified additional new prize competitions in specific technology areas, such as carbon removal.[70,71]

DOE has implemented an average of nine programs per year since 2014, most of which fall under the COMPETES Act authorities.[72] DOE has since consolidated most of its prize activities under the "American-Made" Challenges Program, which has increased both the number of prize competitions completed and the award amounts since late 2020. Under this program, DOE has completed or is currently running 48 American-Made Challenges.[73] Existing prizes often set a prescribed number of semifinalists and finalists at the outset of the prize.[74] Some key technology areas (e.g., nuclear, CCS) are not represented at all in current programs, and others have only implemented only a small number of prizes.[75]

DOE prize programs have differed from private sector prize programs, such as the XPRIZE, in several ways.

- There are differences in the definition of the **scope of the prize challenge**. For example, a current XPRIZE provides $20 million for storing as much CO_2 as possible into the most valuable product they can; by comparison, a recent DOE prize sought, among other goals, "a detailed conceptual design for an integrated, bench-scale proof of concept system with appropriate monitoring, reporting, and verification (MRV) method."[76] A narrow, more technical scope can raise questions as to whether the use of a prize is the appropriate vehicle for advancing innovation.
- There also are differences in the **size of prize awards**. Establishing the size of a prize award requires expert judgment on the amount of effort that a competitor might need to undertake in order to qualify for the prize, plus a premium to provide motivation. DOE prize awards are typically much smaller than private sector prizes and are more closely linked to the level of effort needed to accomplish the work scope, which, as noted above, is typically narrower than in private sector prizes. Under current authorizations, Secretarial-level approval is required for any prize over $1 million.[77] In practice, this requirement may have acted as a cap on final prize awards in many cases, potentially limiting interest from innovators. The size of technical assistance voucher amounts to support participants are also typically capped at $75,000.

Notwithstanding these differences, the DOE prize programs provide other benefits relative to traditional DOE applied RD&D FOAs that are cost-shared through cooperative agreements. Prizes offer innovators a simpler pathway to engage with government and access public funding, which is especially important for innovators without prior experience interacting with government programs. Simply stated, a prize competition can be designed to encourage private sector RD&D effort in a manner similar to how a cooperative agreement might work, without all of the contractual and procedural requirements. A DOE prize program also could provide a simpler pathway that could expand the diversity of prize teams.

Well-designed prize programs can provide a valuable and flexible tool to supplement the use of grants and cooperative agreements in accelerating energy innovation. However, there does not appear to be a clearly developed methodology within DOE to determine when and how prize programs should be implemented. Though useful for their flexibility, prizes could create the risk of inefficiently allocating funds for minimal returns on innovation or on technologies that may be developed without the prize incentive. Also, largely because of their novelty, the effectiveness of prize programs is yet to be determined; they have not been rigorously evaluated, and best practices are generally unclear.

Recommendations

DOE should develop formal Departmental guidelines on the use of prize authority, as required by Section 9004 of the Energy Act of 2020. The guidelines should address: the justification for the use of prize authority; the scope of the prize challenge; the size of the prize award levels commensurate with the scope of the prize challenge; the number of awards at each stage of the prize competition, particularly at the early stages; and the size of associated technical assistance vouchers.

DOE should establish an evaluation program to assess the effectiveness and efficiency of prize programs relative to applied energy RD&D programs funded through grants, contracts, and cooperative agreements and identify best practices for future application.

Standing Up the Foundation for Energy Security and Innovation (FESI)

The CHIPS and Science Act authorized the establishment of the Foundation for Energy Security and Innovation (FESI), a government-chartered non-profit charitable foundation. FESI provides a new vehicle for expanding public-private partnerships by securing donations from the private sector to invest in programs and projects that augment DOE-funded activities.[78]

FESI will seek to support the DOE energy innovation mission by facilitating increased private and philanthropic investments to commercialize and deploy innovative energy technologies. FESI joins the ranks of 12 other agency-related foundations that have found ways to complement and advance the missions of their respective agencies with notable success. On average, these entities have garnered and applied nearly $70 in external funding per dollar of federal agency support.[79]

FESI will be managed by a Board of Directors consisting of public voting members and non-voting DOE officials. The Act directs the National Academies of Science, Engineering, and Medicine to assist DOE in developing a slate of non-federal voting Board members. The ex officio DOE members include the Secretary, the Under Secretary for Science and Innovation, the Under Secretary for Nuclear Security, and the Chief Commercialization Officer.

In February 2023, DOE issued a Request for Information with seven broad questions seeking public input.[80] DOE is currently planning to launch FESI in the fall of 2023 and is currently developing potential use cases for possible FESI implementation. The DOE FY 2024 budget includes $30 million for FESI startup activities.

FESI is a novel concept and consequently will need to demonstrate early success if it is to establish a supporting constituency. Three factors that could facilitate early action include:

- Identification of initiatives that are new or complementary to existing DOE programs rather than simply augmenting existing programs;
- Ability to attract significant contributions of private investment; and
- Ability to achieve tangible impacts within a relatively short time.

Several recommendations included in this report could satisfy these criteria, including recommendations for:

- Providing funding support to the National Laboratories to assist in forming regional energy innovation consortia (discussed in Chapter 3);
- Launching the proposed Laboratory-directed Technology Maturation Program (discussed in Chapter 3); and
- Initiating the proposed new DOE fast track initiative for rapid prototyping of advanced technologies.

Recommendations

DOE should expeditiously stand up FESI, identify opportunities for actions beyond the scope of current DOE programs that could provide early, tangible benefits for energy innovation, and provide a starting set of recommendations to the new FESI Board for consideration.

Congress should approve DOE budget requests for appropriations funding to enable start-up implementation of FESI.

2.4 | Sector-Specific and Place-Based Innovation

Establishing a Comprehensive and Coordinated Approach to Industrial Energy Innovation Programs

The industrial sector is critical to security, the economy, and global economic competitiveness. Domestic manufacturing, the principal sub-component of the industrial sector, employs 14.7 million workers and accounts for about 12% of Gross Domestic Product (GDP). It comprises 24% of total domestic energy use and accounts for about 17% of net U.S. GHG emissions.[81,82,83,84]

The industrial sector also plays a key role in the innovation process. It provides a robust, secure, and adaptable supply chain and serves as an essential element in the innovation chain for the development and deployment of new products and processes across all other sectors of the economy.

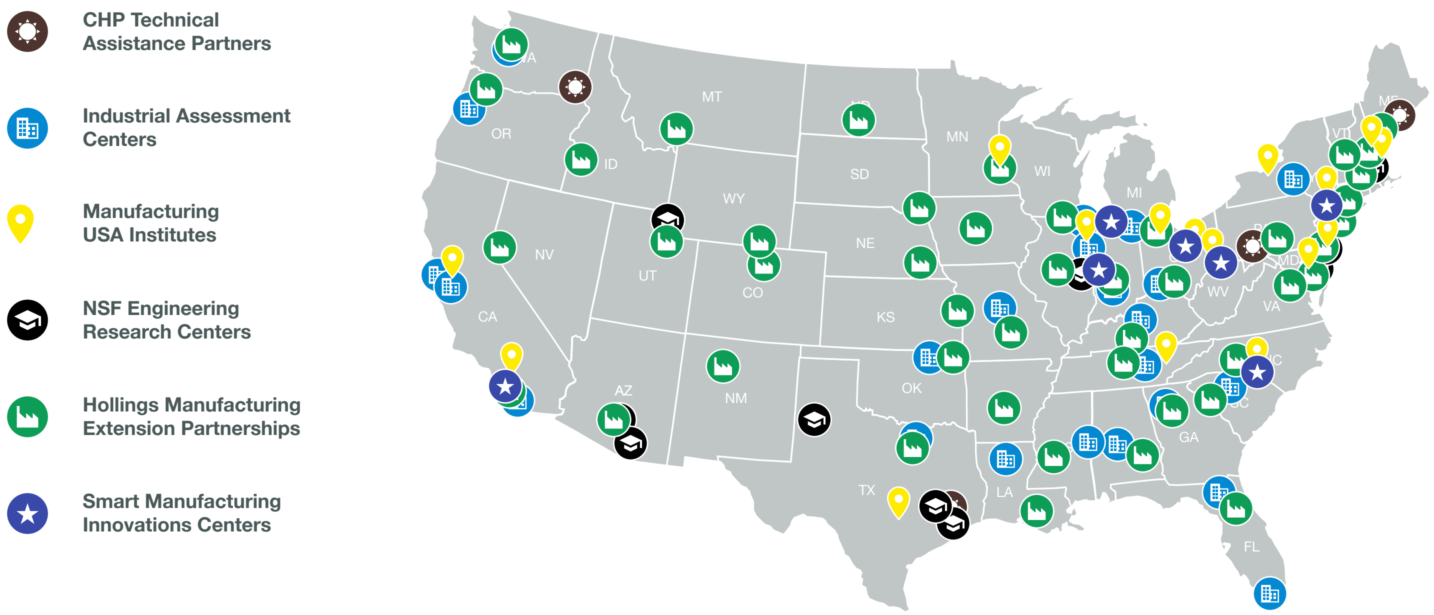
Federal policies and programs to foster innovation in the industrial sector have generally sought to address industry-wide issues, but notable instances of government intervention exist to target support to specific industries in cases of overarching national objectives. Current programs focusing on industrial and manufacturing technologies that benefit industry-wide applications (or applications to large industrial and manufacturing sub-sectors) include:

- **Technology Translation and Maturation:** DOE, through the Office of Science, the former Office of Energy Efficiency & Renewable Energy (EERE) Advanced Manufacturing Office, and other offices, has supported technology translation and maturation investments in technologies such as computing, machine learning, sensors, and controls, applicable across a broad spectrum of the industrial sector. NSF also supports fundamental research in the industrial sector through 15 current Engineering Research Centers.
- **Technology Applications:** DOE and the Department of Commerce have supported technology transfer and technical assistance programs, implemented through regional centers, applicable to many industrial and manufacturing uses, with a focus on the more energy-intensive industries. The Department of Commerce supports Manufacturing Extension Partnerships (MEP) in every state. DOE supports 37 Industrial Assessment Centers (IAC) and seven Centers under the Clean Energy Smart Manufacturing Innovation Initiative.
- **National Security Applications:** DOD, in collaboration with the Department of Commerce and DOE, has supported Manufacturing USA institutes focused on innovation and security of supply for national security applications. Areas of focus include technologies such as robotics, lightweight and advanced materials, fibers, textiles, and additive manufacturing. These technology programs support fundamental industrial applications in the defense supply chain that also have important benefits for commercial markets. NASA also supports programs and projects for innovation in advanced materials and manufacturing focused on its space and aeronautics mission responsibilities.

Combined, these programs have established an extensive national footprint of federally supported regional centers, as seen in Figure 6.[85,86,87,88,89,90]

FIG. 06

Landscape of Current Federally Funded Industrial Innovation Centers



Federally funded industrial research and development and extension service centers are widespread nationally and supported by multiple agencies, including DOE, NSF, and the Department of Commerce (DOC). Each federal agency has distinct mission objectives that apply to its respective regional centers. Data adapted from program websites.

While these regional centers serve multiple industry sub-sectors, many have single-purpose objectives, such as the DOE combined heat and power (CHP) centers and its industrial energy efficiency assessment centers. The Hollings MEP supports a variety of industry sub-sectors but is focused on the diffusion of commercial technologies and practices and not innovation at the stages of technology translation and maturation.

The recent new authorities enacted by Congress expand federal programs to support industrial innovation in several dimensions. The new authorities:

- support multiple industrial innovation objectives that include but are not limited to clean energy and energy efficiency;
- provide direct funding, credit support, and tax credits across the full innovation spectrum, with an emphasis on demonstration, deployment, and widespread market diffusion;
- support *technology-focused* innovation programs, as well as *industry-specific* demonstration and deployment.

The *technology-focused* industrial technology innovation programs encompass a wide range of technology solutions applicable to more than one industry sector. Examples include electric heat pumps, carbon capture and storage, clean fuels, and application of platform technologies such as robotics, machine learning, cybersecurity, additive manufacturing, and others. *Industry-specific* industrial innovation programs typically focus on a single industry or end-use market application, such as electrification of light-duty vehicles. Further, there are programs that focus on existing heavy industries such as steel, cement, chemicals, etc.

and those focused on newly emerging industries, such as semiconductors, hydrogen and electric vehicle manufacturing. The Administration refers to industry-specific innovation and investment programs as part of a "Modern American Industrial Strategy" that "… identifies specific sectors that are foundational to economic growth, strategic from a national security perspective, and where private industry on its own isn't poised to make the investments needed to secure our national ambitions."[91]

There are a number of new, broad-based *technology-focused* industrial energy technology innovation programs authorized in recent Congressional legislation, including:

- The Energy Act of 2020 authorizes $35 billion in RD&D spending on clean energy innovation across a broad range of technologies critical to energy and national security, long-term economic competitiveness, the U.S. industrial base, and environmental protection.
- The BIL (2021) provides $5.8 billion for demonstration and deployment projects targeted at clean energy innovation across all industrial sub-sectors.
- The CHIPS and Science Act (2022) authorizes an expansion of DOE Office of Science use-inspired fundamental research; expansion of research programs at the National Institute of Standards and Technology; and establishment of a new technology and innovation directorate at NSF focused on designated critical technology areas including semiconductors, quantum information systems, artificial intelligence, and advanced energy technologies. The CHIPS and Science Act also authorized new regionally focused innovation programs, the $10 billion Regional Innovation and Technology Hubs program, and the NSF Engines program to address innovation across all sectors of the economy, including the industrial sector.
- The IRA (2022) provides more than $369 billion total, applicable industry-wide, in tax credits, manufacturing investments, and other financial incentives and initiatives that will advance a broad suite of clean energy technologies, address climate change, and strengthen the U.S. industrial base, as well as position U.S. manufacturing to compete effectively in emerging markets, supporting the global transition to a clean energy future.

The most notable example of *industry-specific innovation and investment policy* is the provision of a total of nearly $53 billion in the CHIPS and Science Act to rebuild the domestic base of semiconductor manufacturing and innovation. This action was justified as essential for national security, but most of the new manufacturing capability will service non-defense commercial application markets. In the energy sector, *industry-specific* innovation programs include:

- The BIL $8 billion investment in the establishment of regional hydrogen market development hubs; and
- The IRA tax credits for market development of electric vehicles, supported by more than $8 billion BIL investments in support of critical minerals supply chains and electric vehicle (EV) battery manufacturing and recycling, combined with refocusing of the existing Loan Program Office resources to support EV supply chain projects.

The discussion of broader national industrial policy and strategy is not likely to reach a consensus in the near term. This broader debate, however, should not prevent efforts to develop a more strategic approach to planning and coordinating federal investment programs for technology innovation that have industry-wide benefits. The multitude of current federal agency programs creates a fragmented landscape, in both

"The multitude of current federal agency programs creates a fragmented landscape, in both Washington and across the many federally funded regional industrial centers, that may not enable the most effective and efficient use of federal resources."

Washington and across the many federally funded regional industrial centers, that may not enable the most effective and efficient use of federal resources.

Within DOE, a number of program offices are currently addressing industrial technology innovation, each with a particular set of objectives and a differing perspective of industry needs.

- The Office of the Under Secretary for Infrastructure includes OCED and the Office of Manufacturing and Supply Chains (MESC). The MESC Office has responsibility for deployment incentives such as the Defense Production Act support to Treasury for implementation of the Section 48C manufacturing tax credits. MESC has also been assigned responsibility for Department-wide energy supply chain issues, but the current focus is primarily on the deployment of the supply chain of batteries for electric vehicles.
- The Office of the Under Secretary for Science and Innovation includes two separate manufacturing applied RD&D programs: the Advanced Manufacturing and Materials Technology Office (AMMTO), focused on manufacturing technology innovation, and the Industrial Energy Decarbonization Office (IEDO), focused on industrial decarbonization. The Office of Nuclear Energy (NE), the Office of Fossil Energy and Carbon Management (FECM), ARPA-E, the Office of Clean Energy Demonstrations (OCED), the Loan Programs Office (LPO), and the Office of Science (SC) also support activities with a focus on industrial innovation.

Improved planning and better coordination would need to work in three dimensions:

- Broadening the perspective of current single-purpose industrial innovation and modernization programs to consider multiple objectives of global competitiveness, decarbonization, and increased energy efficiency, productivity, and workforce development;
- Integration across the entire innovation spectrum to bring advances in broad-based platform technologies, such as machine learning and artificial intelligence (AI), synthetic biology, advanced materials, and robotics more quickly to commercial industrial applications and to bring learning by doing and learning by using to the planning of new use-inspired fundamental research; and
- Coordination across the federal agencies to improve opportunities for mutual leveraging of federal investments.

DOE has established an Industrial Technology Joint Strategy Team for Industry to address these and other issues within the Department. On an interagency level, coordination responsibility resides with the Office of Science and Technology Policy (OSTP)-led Interagency National Science and Technology Committee (NSTC). Currently, the NSTC divides its responsibilities across the Committee on Technology, the Committee on Science and Technology Enterprise, and the special and temporary Industries of the Future Coordination Council. Each committee consists of high-level representatives from key agencies and has more specifically focused subcommittees such as the Subcommittee on Advanced Manufacturing. It is not clear how these NSTC activities will come together on a comprehensive strategic framework.[92]

The need for an innovation strategy for high-temperature industrial heat is a case in point. The DOE Industrial HeatShot™ has the goal to develop cost-competitive industrial heat decarbonization technology with at least 85% lower greenhouse gas emissions by 2035. This will be a major challenge that will require collaborative efforts among many DOE program offices. The combustion of fossil fuels to produce high-temperature industrial heat is a major source of CO_2 emissions within the industrial sector, and it is considered by many to be a hard-to-abate challenge. Numerous ideas exist for addressing this issue: continuation of the use of fossil fuels combined with carbon capture and storage; electrification of process heat combined with innovation to increase the temperatures attainable economically through electrification; replacement of fossil energy with clean fuels including hydrogen and nuclear; and new lower temperature conversion processes including those that rely on other approaches such as biochemical rather than thermochemical conversion. An industry partner seeking to decarbonize high-temperature process heat through one or more of these approaches may need to interact with an alphabet soup of DOE offices, including SC, FECM, NE, AMMTO, IEDO, OCED, LPO, and MESC. In addition, in all cases, the industry partner would not only have to assess the technical and economic feasibility of the decarbonization options but also assess the implications for product quality, competitiveness, productivity, supply chain security, operational compatibility, reliability, and durability, return on investment, workforce development, customer value, and other factors.

The fragmentation of existing programs within DOE and across the federal agencies would make any form of structural reorganization difficult. Such fragmentation does call for the need for a comprehensive government-wide, coordinated industrial innovation strategy with a central role for clean and efficient energy use. The Industrial HeatShot™ represents a significant step forward in the realization of a comprehensive, coordinated government wide innovation strategy in this area. Additional actions could build upon this initiative. For example, Title VI of The Energy Act of 2020 authorizes a comprehensive effort led by the Secretary of Energy, in consultation with the Director of the Office of Science and Technology Policy, the heads of relevant federal agencies, National Laboratories, industry, and institutions of higher education, to establish a crosscutting industrial program to advance innovative technologies that will: (a) increase the technological and economic competitiveness of industry and manufacturing in the U.S.; (b) increase the viability and competitiveness of U.S. industrial technology exports; and (c) achieve emissions reduction in non-power industrial sectors. It also calls for creating an Industrial Technology Innovation Advisory Committee, the duties of which include establishing strategic goals and developing a plan for achieving them.

The DOE September 2022 Industrial Decarbonization Roadmap Report provides a potential additional starting point for this effort. This report focuses on existing heavy industry sub-sectors and provides a very detailed analysis of technology options to advance the decarbonization of five energy-intensive industrial sub-sectors: Iron and Steel Manufacturing, Chemical Manufacturing, Food and Beverage Manufacturing, Petroleum Refining, and Cement Manufacturing. The substantial effort that went into this report, however, illustrates the fragmentation issues that require greater integration and coordination. The roadmap, for example, focuses solely on a single objective (decarbonization), addresses only five industries, is not linked to specific program office RD&D plans and budgets, requires the involvement of ten separate DOE offices, and excludes the industrial innovation program offices in NSF and the Department of Commerce in industrial innovation.

In the pending Senate Energy and Water Development Appropriations bill for fiscal year 2024, the Senate Appropriations Committee recommended that DOE "…develop a Department-wide Multi-Year Program Plan (MYPP) as an operational guide to implementing the Industrial Decarbonization Roadmap and ensure coordination across all participating offices." The bill establishes a new appropriations account with a separate appropriation of $3.5 million to accomplish this effort.[93]

In addition to DOE and interagency efforts, there are voluntary efforts led by the private sector to systematically evaluate industrial technology innovation pathways. A notable example is Mission Possible, an alliance of climate leaders focused on supercharging efforts to decarbonize some of the world's highest-emitting industries in the next ten years. Integration of federally funded industrial energy innovation programs with voluntary private sector initiatives could leverage and accelerate U.S. leadership in clean energy manufacturing and industrial processes.

Recommendations

DOE, building on the work of the Industrial Technology Joint Strategy Teams (JST), should develop a comprehensive multi-year industrial innovation program plan as recommended in the Senate FY 2024 Energy and Water Appropriations committee report. DOE should consider appointing a dedicated, full-time chair (or co-chairs) to lead this effort.

DOE should work with the NSTC to establish an interagency process to establish a comprehensive government-wide industrial innovation strategy, as called for in Title VI of the Energy Act of 2020.

The NSTC should consolidate industrial energy innovation issues into one of its existing committees or as a new standalone subcommittee.

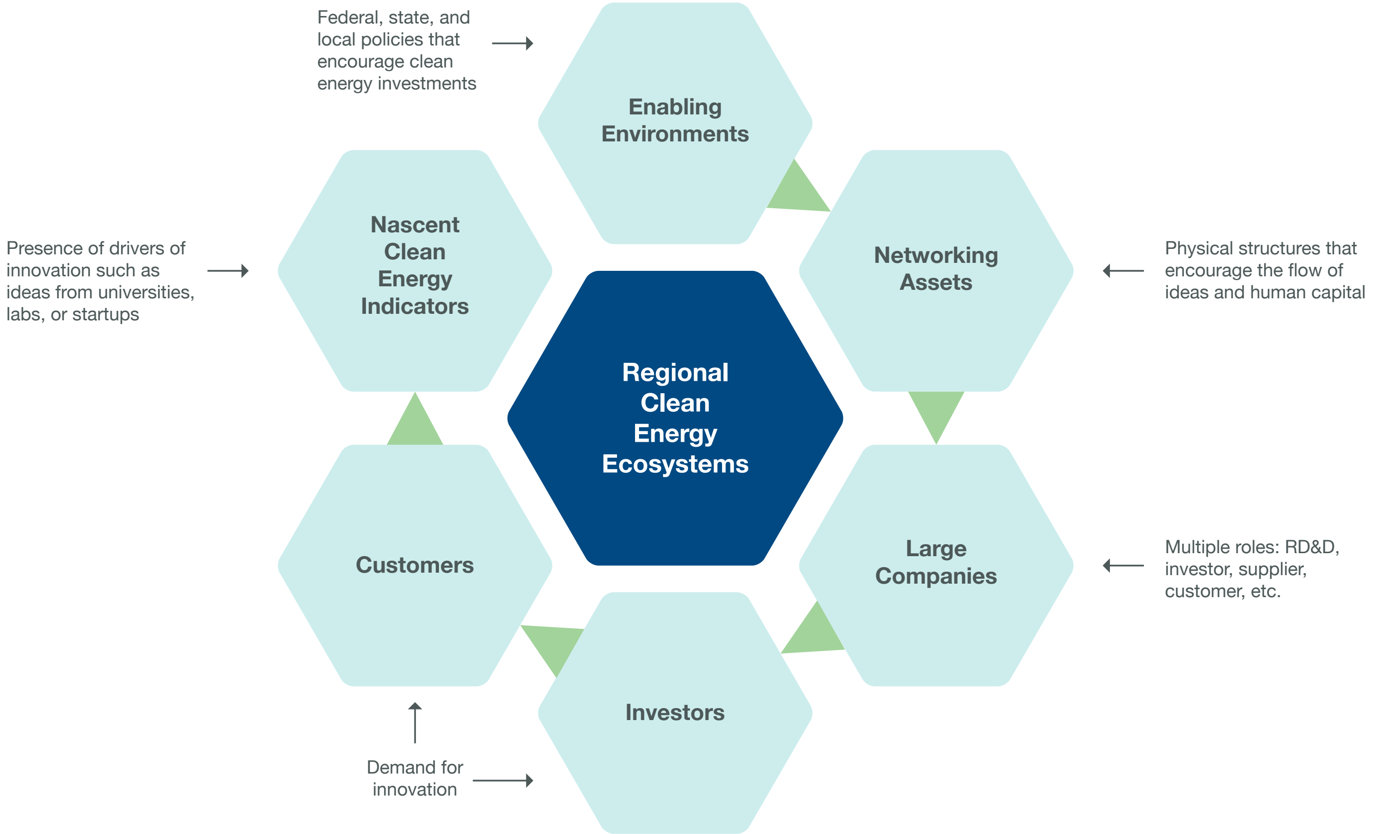
Fostering Regional and Place-Based Energy Innovation Ecosystems

Energy production, infrastructures, and end-use markets vary across regions, resulting in different challenges and priorities for energy innovation. The current capabilities for energy innovation, including research infrastructures and innovation investment resources, are not well developed and aligned in many regions. The recent legislation seeks to expand the geographic landscape of innovation across all areas of critical technologies, including clean energy, through the formation of **broad-based regional innovation initiatives** and through **targeted place-based initiatives.** Both are discussed in this section.

Regional Innovation Initiatives: Six principal elements of an effective regional energy innovation ecosystem are illustrated in Figure 7.[94] These six elements capture the interplay among energy innovators, investors (of all types), large companies (that can provide early markets), customers and end users, networking assets (physical infrastructure and human resources), and an enabling policy environment.

FIG. 07

Principal Elements of a Regional Clean Energy Innovation Ecosystem



Regional clean energy ecosystems require multiple elements to be effective in creating and/or accelerating innovation. These elements require actions from multiple policymakers, including states, universities, and the private sector, and typically benefit from federal support or coordination.

Source: See first figure mention in text for sources.

The role of regionally based innovation ecosystems in economic development draws from historical academic work on the cluster theory of competitive advantage.[95] More recent studies have focused on the need for stronger federal policies and programs to foster regional energy innovation. A 2012 Report by the National Research Council (NRC) discussed the need to bridge the gap between federally funded RD&D to state and regional development, and a subsequent 2016 NRC report recommended the formation of Regional Energy Innovation and Development Institutes (REIDI).[96,97]

Historically, DOE has sought to address regional differences within the confines of individual fuel-based or technology-based programs, but it has not addressed region-specific energy innovation in a holistic manner at any appreciable scale. In 2015, DOE conducted a series of 14 regional workshops, providing the foundation for a proposed $110 million initiative in the FY 2017 budget to fund up to 10 regional energy innovation partnerships. The program was not funded. Congress expressed support for the DOE National Laboratories to expand their outreach to regional initiatives but did not provide specific resources for this purpose.

In 2020, Congress initiated a DOE/OTT pilot program of $5 million annually "…for a competitive funding opportunity for incubators supporting energy innovation clusters…".[98] OTT initiated the Energy Program for Innovation Clusters (EPIC) with $1 million awarded as prizes (20 winners with $50,000 apiece) and ten cooperative agreement awards totaling $9.5 million (with supplemental funding from other DOE program offices) to support entities spanning 32 states.[99]

The CHIPS and Science Act authorizes new and notably expanded regional innovation programs across three agencies: the Department of Commerce, the NSF, and DOE. These programs are specifically targeted to build new and expanded innovation capabilities in more areas of the country. The NSF and Commerce programs have broad science and technology objectives; energy innovation is an important but not a principal objective. The programs include:

- **Commerce Regional Technology and Innovation (RTI) Hubs:** The CHIPS and Science Act authorized $10 billion in federal funding over five years for the Department of Commerce Economic Development Administration (EDA) to initially select 20 geographically distributed regional innovation hubs distributed among the 10 EDA regions.[g] The hubs are intended to translate research findings into new applications and serve as a driver to bring technological innovation to regions that are in need of economic development, i.e., with an emphasis on underserved communities and groups historically underrepresented in science, technology, engineering, and mathematics (STEM) fields. The hubs are open to all areas of technology and will be selected on a competitive basis. The FY 2023 Consolidated Appropriations Act provided an appropriation of $500 million to initiate the program.[100] In May 2023, EDA issued a Notice of Funding Availability (NOFO) for Phase 1 of the program, with applications due in mid-August 2023.[101] The program received 378 applications and 31 hubs were selected. Seven of the 31 hubs selected are specifically focused on energy innovation objectives, such as batteries, offshore wind, climate resilience, and critical materials for energy supply chains. Several others are focused on key platform technologies that have significant potential energy applications, including quantum computing, biotechnology, and autonomous systems.[102] Designation in Phase 1 itself does not come with any funding, although EDA may award a Strategy Development Grant of up to $0.5 million to a Designate Hub. Potential locations for some of these hubs are in areas of DOE National Laboratories.[103] National Laboratories are eligible to join consortia applying for the Phase 1 Hub designation, but there is no requirement or preference for participation.
- **NSF Regional Innovation Engines:** The CHIPS and Science Act also authorized $6.5 billion over five years for the NSF Engines program, which originated in the newly formed Technology, Innovation and Partnerships Directorate.[h] The NSF Engines program was initiated in early 2022, intended to provide grants of up to $160 million over 10 years to foster and catalyze regional ecosystems "…that will cultivate and sustain activities in use-inspired research and development; the translation of the resulting innovations to practice through entrepreneurship, stakeholder development, and meaningful partnerships: and workforce development at all levels."[i,104] The program will support test beds and other translation-focused or coordinating activities in "…regions that do not currently have well-established innovation ecosystems or, of particular interest, regions of the country where the prospective ecosystem members exist, but where innovation activities are only loosely connected."[105]

[g] The new EDA program builds upon the former EDA Build Back Better Regional Challenge, funded with pandemic relief funds that supported 21 regional awards spanning 24 states.

[h] The $6.5 billion five-year authorization is to cover both the NSF Engines program and a companion Translation Accelerators Program. A funding announcement of $60 million for the companion program, Accelerating Research Translation, was released on February 3, 2023.

[i] The Engines program was based in part on an NSF-funded workshop on the National Network of Research Institutes in May 2021 and developed in parallel with congressional deliberations that led to the final CHIPS and Science Act.

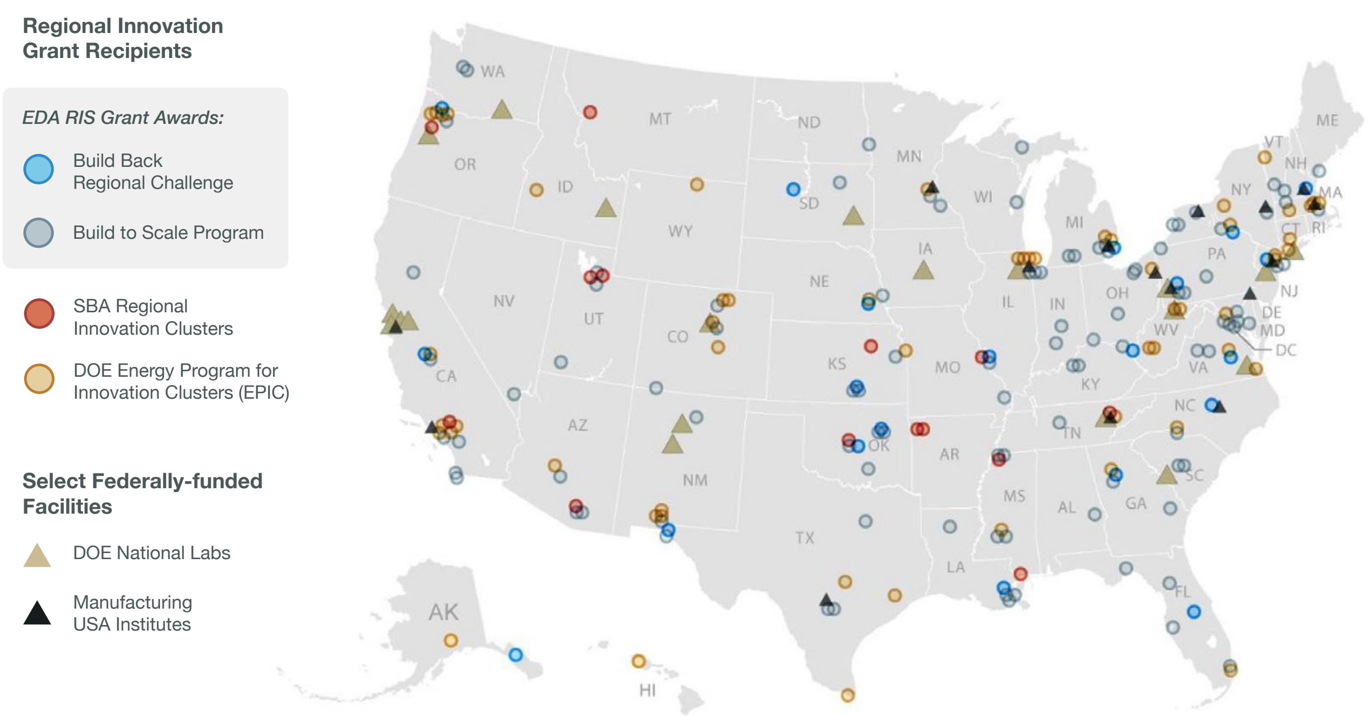
NSF implementation efforts are moving quickly. In June 2023, NSF selected 34 semifinalists to move on in the NSF Engines competition – spanning multiple technology areas and including businesses, universities, and nonprofits. In August 2023, NSF downselected 16 finalists for the final round of competition in the NSF Engines competition.[106] It is anticipated that the winning teams will each receive about $15 million over two years.

- **DOE Regional Clean Energy Partnerships:** Finally, the CHIPS and Science Act authorized a new regional innovation initiative at DOE with a total of $250 million over five years to support competitively awarded regional partnership grants. The purpose of the program is to improve the competitiveness of clean energy technology RD&D through the development of tools and technologies best suited for application in diverse regions of the U.S. Partnership grants are capped at $10 million annually and can extend up to five years with phased-in requirements for cost sharing. The Act also establishes a grant program of planning grants to seed initial planning activities that can lead to the formation of a regional partnership.

These new programs, combined with the existing suite of regional innovation and economic development programs and facilities, have created a nationwide footprint that can lead to the development of new regional innovation ecosystems. A recent Congressional Research Service (CRS) Report mapped the geographical footprint of current regional innovation, shown in Figure 8.[107]

FIG. 08

Congressional Research Service Map of Multiple Regional Innovation Awards and Facilities



Regional innovation programs and facilities from multiple agencies have a nationwide footprint with clear clusters of activity. Information as of January 26, 2023. Marker locations are approximate.

Source: See first figure mention in text for sources.

The CRS report also addressed the importance of federal interagency coordination to improve prospects for success. The report noted: "For example, a lack of coordination could result in duplicative efforts, in addition to missed opportunities to leverage or complement supported activities."[108] In this regard, Congress instituted several new coordination and planning requirements for regional innovation and economic development in the CHIPS and Science Act to improve coordination and enhance prospects for successful regional ecosystem development. They include:

- Requiring the Secretary of Commerce to coordinate with relevant agencies before designating or funding regional technology and innovation hubs;
- Creating multiple requirements for NSF and the Department of Commerce to avoid duplication and consult with each other on the regional Engines and technology and innovation hubs programs; and
- Directing OSTP to create a new interagency working group (housed in the NSTC) to further coordinate and avoid duplication on various regional innovation programs, including the NSF Regional Innovation Engines program, the National Institute of Standards and Technology (NIST) Manufacturing USA and Manufacturing Extension Partnership programs, and the EDA Regional Technology and Innovation Hub program.

The Economic Development Administration (EDA) of the Department of Commerce and NSF have discussed efforts to improve the interface between the NSF Engines and the Commerce RTI hubs as innovation proceeds from fundamental research into technology translation and maturation.[109] In July 2023, the two agencies entered into a formal interagency Memorandum of Understanding (MOU) to strengthen coordination.[110] The NSF-EDA MOU establishes high-level guidance for the coordination of specific projects, programs, and facilities. The coordination may include research and education activities, facilities, centers, data infrastructure, and outreach.

The role of DOE is not explicitly delineated in the CHIPS and Science Act provisions for interagency coordination. The DOE National Laboratories are authorized to join as a member of a team in applying for Commerce or NSF grant funding; the eligibility of National Laboratories for CHIPS and Science Act funding is explicitly called out in the initial funding opportunity announcements, including language noting that National Laboratory partnerships can be advantageous for regions and coalitions in successful grant applications.[111,112] Commerce and NSF senior program managers have also made public statements that indicate they are giving serious consideration for how to leverage existing national innovation assets, including DOE and the National Laboratories, in the RTI hubs and Engines program development.[113]

> "The strategic relationship between DOE and the EDA-NSF collaboration is not yet clearly defined. In addition, the role that DOE envisions for the National Laboratories in these emerging regional innovation ecosystems is not fully outlined. DOE currently has not provided formal guidance to the National Laboratories, nor has it provided any specific seed funding for the Laboratories to be proactive in forming regional innovation initiatives."

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DOE appears to be in the early stages of planning its regional and place-based energy innovation strategy. In January 2023, the DOE Office of Science and OTT jointly released an RFI inviting the submission of information addressing "DOE's National Laboratories as Catalysts of Regional Innovation."[114] The RFI requested input from all stakeholders about opportunities for place-based innovation activities that leverage research institutions—particularly the National Laboratories and Sites—to catalyze innovation ecosystems, contribute to DOE's mission in energy, environment, and national security, and ensure our nation's vibrant economic future. The current effort is planned to develop policy recommendations in the 2023/2024 timeframe.

OTT also has established a Regional Ecosystem Analysis Tool to assess facets of innovation ecosystems across the U.S. to assist DOE in creating a data-driven regional engagement strategy. The DOE Office of State and Community Energy Programs (SCEP) also administers multiple local- and state-focused programs, such as the State Energy Grant Program, that could become a vehicle for promoting intrastate regional energy innovation activities.

DOE did not request funding in its FY 2024 budget request to Congress to implement its new CHIPS and Science Act for regional energy partnerships. The House and Senate Appropriations Acts for fiscal year 2024 do not provide funding for the regional energy partnerships program, but the House did allocate $5 million to continue the smaller-scale EPIC program initiative.[115]

Place-based initiatives: Place-based initiatives are a form of regional partnerships that are targeted to specific locations selected based on specified criteria. Place-based initiatives are typically focused on communities undergoing significant energy transition issues, underserved communities, or communities with less advantageous socioeconomic conditions. The focus of place-based initiatives is less on innovation per se and more on the application of innovative technologies to promote economic development and job creation. Congress also authorized several new DOE-led place-based initiatives where implementation is moving at a faster pace. The BIL provided $500 million for a new targeted Clean Energy Demonstration program on Current and Former Mine Land in addition to other technology hub-focused funding. DOE issued an RFI in June 2022 to help guide the design of the program and issued an RFP, releasing $450 million, in April 2023. The IRA also reflects the emphasis on place-based policy by providing a 10% "bonus" tax credit for projects located in Energy Communities (communities with historical fossil fuel economic activity). In addition, the OTT Technology Commercialization Fund (TCF) has funded a National Laboratory-led demonstration program, the Boost Platform, targeted to "building ventures around actionable challenges identified by underserved communities that is underpinned by a mentorship program."[116] The Interagency

> "A key issue will be crafting a regional and place-based energy innovation strategy that complements and does not dilute the primary innovation mission of the DOE technology programs."

Working Group on Coal and Power Plant Communities and Economic Revitalization has been active in policymaking for locations that will be impacted by the clean energy transition.

A key issue will be crafting a regional and place-based energy innovation strategy that complements and does not dilute the primary innovation mission of the DOE technology programs. Unlike the BIL and IRA-funded initiatives, the new regional innovation programs in the CHIPS and Science Act include only funding authorizations, and they will require follow-on annual appropriations to enable implementation. The FY 2023 Consolidated Appropriations Act provided a notable down payment on the Commerce Regional Technology and Innovation Hubs and the NSF Engines initiative. The President's budget proposals for FY 2024 include additional new funding for the Commerce and NSF program but not the DOE Regional Clean Energy Innovation Partnerships program. Table 3 shows the funding levels for regional innovation programs.[117,118,119,120]

TABLE 03

FY2022-2023 Appropriations and FY2024 Budget Requests for Regional Innovation Programs

AGENCY	OFFICE*	PROGRAM	FY22 APPROPRIATIONS ($ MILLIONS)	FY23 APPROPRIATIONS ($ MILLIONS)	FY24 REQUEST ($ MILLIONS)
NSF	TIP	Regional Innovation Engines	$0.7	$200.0	$300.0
NSF	EPSCoR	Established Programs to Stimulate Competitive Research (EPSCoR)	$215.1	$255.0	$280.7
		NSF Total	**$215.8**	**$455.0**	**$580.7**
DOC	EDA	Recompete Pilot Program	n/a	$200.0	$195.5
DOC	EDA	Regional Technology and Innovation Hubs	$40.0	$500.0	$1,548.5
DOC	EDA	Build to Scale	$45.0	$50.0	$45.0
DOC	NIST	Manufacturing USA Program	$16.5	$51.0	$97.7
DOC	NIST	Hollings Manufacturing Extension Partnership (MEP)	$158.0	$188.0	$277.2
		DOC Total	**$259.5**	**$989.0**	**$2,163.9**
DOE	OTT	Energy Programs for Innovation Clusters (EPIC)	$5.0	$5.0	$5.0
DOE	TBD	Regional Clean Energy Innovation Program	n/a	$0.0	$0.0
DOE	OCED	Regional Direct Air Capture Hubs	$700.0	$700.0	$700.0
DOE	OCED	Regional Hydrogen Hubs	$1,600.0	$1,600.0	$1,600.0
DOE	SC	DOE EPSCoR	$25.0	$25.0	$25.0
		DOE Total	**$2,330.0**	**$2,330.0**	**$2,330.0**
SBA	OED	Regional Innovation Clusters	$5.7	$10.0	$10.0
		SBA Total	**$5.7**	**$10.0**	**$10.0**
		All Agencies Total	**$2,595.2**	**$3,329.0**	**$4,503.9**

Regional innovation programs span four agencies and have received $3.3 billion in total in FY 2023. The FY2024 request seeks a 35% increase, largely from an expansion of the DOC Regional Technology and Innovation Hubs program.

*TIP: Directorate for Technology, Innovation and Partnerships; EDA: Economic Development Administration; NIST: National Institute of Standards and Technology; SBA: Small Business Administration; OED: Office of Entrepreneurial Development.

Source: See first table mention in text for sources.

Recommendations

DOE should develop a department-wide regional and place-based energy innovation strategy. The strategy should:

- identify and provide guidance for elevating the role of the National Laboratories in regional innovation ecosystems, building upon current National Laboratory local, state, and regional partnerships;
- identify opportunities to build upon the regional hydrogen hubs and regional direct air capture hubs initiatives as a test bed for broader regional innovation efforts; and
- clarify the roles and responsibilities among the appropriate DOE offices.

DOE should also seek dedicated budget resources to support the implementation of these efforts.

DOE should seek to leverage the new Commerce and NSF authorities in the CHIPS and Science Act by entering into formal Memoranda of Understanding (MOUs) with Commerce and NSF. The MOUs could support four objectives: (1) define a strategic role for DOE coordination with Commerce and NSF in the implementation of their respective programs; (2) highlight energy innovation as an area of emphasis in the Commerce and NSF programs, consistent with statutory authorization language; (3) facilitate the integration of DOE-funded regional innovation initiatives into proposals for Commerce and NSF funding; and (4) establish a process for the DOE National Laboratories to provide strategic advice and technical assistance in the formation of new regional consortia seeking Commerce and NSF funding.




03 Enhancing the Role of the DOE National Laboratories as Strategic Partners

The DOE National Laboratories can play a critical role in both enabling—and accelerating—the clean energy transition. Recent congressional action has increased this critical function. Aligning the role of the National Laboratories as a strategic partner in end-to-end innovation will require new actions at all levels of the National Laboratory enterprise. These actions span from the level of the individual researchers, through laboratory managers and senior laboratory leadership, laboratory management and operating (M&O) contractors, to ultimately the level of the strategic interface with DOE leadership.

The 17 DOE National Laboratories constitute the most comprehensive research and innovation network of its kind in the world. With one exception, all of the National Laboratories are Federally Funded Research and Development Centers (FFRDCs), government-owned and contractor-operated (GOCO) facilities, established to meet the special RD&D needs of the federal government that cannot be met effectively with existing in-house or non-governmental resources.[j] The FFRDC/GOCO arrangement relies on Management and Operating (M&O) contracts where the federal government determines the "what," and the Laboratories determine the "how." The genealogy of this novel approach traces all the way back to the World War II Manhattan Project, where, according to the DOE website, "Civilian organizations played a central role in the development and production of the atomic bomb. From 1939 to the dropping of the bomb in 1945, civilians associated with a variety of civilian organizations—government, business, industry, academia—far outnumbered military personnel at nearly all levels of the Manhattan Project."[121]

The role of the National Laboratories in fundamental research is world-class, pre-eminent, and widely acknowledged. DOE National Laboratory researchers have received 118 Nobel Prizes, discovered 22 elements on the periodic table, unraveled the human genome, developed high-performance computing, invented a science-based approach to nuclear weapons reliability without testing, advanced the understanding of the fundamental forces of the Universe, and most recently achieved a net energy gain from a fusion reaction, initially in December 2020, and in July 2023 for a second time.[122]

As noted, recent legislation authorized increased investments in fundamental research and research infrastructure at the National Laboratories. New authorities were also provided for the Laboratories to expand engagements with innovators, increasing their access to Laboratory resources and facilities to support translational research and development of new energy technologies. The principal thrusts of the Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA), however, are focused on the expansion of Departmental-level mission responsibilities and programs in technology demonstration and deployment. These laws clearly authorized a role for the National Laboratories to participate in contractor teams that could bid on individual projects. The strategic role of the National Laboratories in supporting the Department's end-to-end energy innovation mission requires further definition.

This chapter discusses a series of actions that could fully align the role of the National Laboratories with the end-to-end innovation mission in a manner that can accelerate the pace of innovation outcomes. These actions are organized around two overarching objectives:

1. Enhancing the strategic relationships between the National Laboratories and the Department in advancing end-to-end energy innovation. This also includes establishing a formal strategic collaboration process, combined with further efforts to utilize the capabilities of the National Laboratories in serving as integrators for large-scale crosscutting RD&D initiatives; and
2. Strengthening the role of the Laboratories in technology maturation and transition to the private sector. This includes providing more discretion and resources for Laboratory-directed translational RD&D, enlarging the scope of partnerships, establishing Laboratory test beds to support private sector proof of concept and prototype testing, building a stronger culture of entrepreneurship among Laboratory researchers, and incorporating greater financial incentives in Management and Operating contracts.

[j] The National Energy Technology Laboratory (NETL) is owned by the federal government and operated and managed by DOE career personnel.

3.1 Defining the Role of the National Laboratories as Strategic Partners in the Expanded DOE Mission

The National Laboratories participate in a wide range of activities across the whole of the U.S. government. These activities include establishing effective partnerships and collaborations with each other, academia, industry, other government laboratories, philanthropies, and international partners to provide solutions to a wide range of problems facing the U.S. and the world.

The National Laboratories have historically provided a systems-level perspective on emerging issues that cut across specific fuels, technologies, and stages of innovation. National Laboratory "Big Ideas" workshops provided initial formative framing of emerging issues such as electricity grid modernization and security and development of a hydrogen economy. Strategic guidance to DOE RD&D program planning was provided through a Laboratory Policy Council comprised of a cross-section of Lab Directors and Senior DOE policy officials.

"The National Laboratories have historically provided a systems-level perspective on emerging issues that cut across specific fuels, technologies, and stages of innovation. National Laboratory "Big Ideas" workshops provided initial formative framing of emerging issues such as electricity grid modernization and security and development of a hydrogen economy."

As noted, recent legislation expands DOE mission responsibilities for technology demonstration and deployment. This action prompts the need to address the opportunity for increasing the role of the National Labs in the clean energy transition, enhancing their strategic value, enabling an expansion of their areas of research focus, and providing increased access of the private sector to their facilities and expertise.

Laboratory researchers may join individual project teams competing for DOE cost-share funding. National Laboratory personnel may also participate in assisting DOE program offices in the preparation and oversight of individual Funding Opportunities Announcements (FOAs). Participation by the National Laboratories in the framing of energy RD&D program initiatives, including the planning for individual FOAs, presents possible conflict of interest (COI) concerns. These issues are generally resolved through departmental COI reviews of National Laboratory individuals to ensure that those individuals providing advice and support to DOE personnel are not engaged in the preparation of individual RD&D project proposals.

While the recent legislation establishes a clear role for the National Laboratories as contractors at the program and project level, it does not address an enhanced, cross-cutting, highest-level strategic role for the Laboratories, a role that will likely be critical for the energy transition. Establishing a formal process for strategic engagement between senior National Laboratory officials and senior DOE officials regarding the overall contours of BIL, IRA, and CHIPS and Science Act implementation planning requires further clarification.

The strategic role of the National Laboratories is further complicated by the current management reporting relationships of individual laboratories to Departmental Offices. Currently:

- The three nuclear weapons laboratories are part of the DOE National Nuclear Security Administration (NNSA). The NNSA Administrator, also designated as the Under Secretary for Nuclear Security in the DOE organization, reports directly to the Secretary and Deputy Secretary and is semi-independent of oversight by DOE staff offices.
- Three National Laboratories, the Idaho National Laboratory, the National Renewable Energy Laboratory, and the National Energy Technology Laboratory, report to applied energy RD&D program offices for Nuclear Energy (NE), Energy Efficiency and Renewable Energy (EERE), and Fossil Energy and Carbon Management (FECM) respectively. Each of those offices is headed by a presidentially appointed Assistant Secretary with Senate confirmation, and all within the Under Secretary for Science and Innovation organization.
- One laboratory, Savannah River, reports to the Office of Environmental Management (EM). The EM Office currently reports directly to the Secretary. The EM Office historically has been headed by a presidentially appointed Assistant Secretary, but that position has been left vacant since 2017.
- The remaining ten National Laboratories, both single- and multi-purpose in nature, report to the Office of Science. The Office of Science is headed by a presidentially appointed, Senate-confirmed Director who reports to the Under Secretary for Science and Innovation.

The newly established Under Secretary for Infrastructure organization currently has no formal organizational or management arrangements with any of the National Laboratories.

DOE has multiple offices that provide oversight, management, and coordination of laboratory policy, but none is positioned at a level within DOE to have a laboratory-wide perspective and oversight.[k] The Office of Science, for example, has an Office of Laboratory Policy, which oversees five multi-purpose laboratories and five single-program science laboratories. Its portfolio includes cross-cutting oversight functions such as laboratory planning and appraisal processes; scientific integrity and security; Laboratory-Directed Research and Development (LDRD); laboratory technology transfer activities; and strategic partnership projects (SPP). Similarly, NNSA, EERE, FECM, NE, and EM each oversee their respective programmatic laboratories. The Office of Science's Office of Laboratory Policy seeks to coordinate its activities with these other program offices as provided in Departmental Orders.

In addition, DOE established a Laboratory Operations Board (LOB), responsible for addressing crosscutting administrative and operational matters, such as maintenance of the Laboratory physical plant and M&O contract issues. The LOB is overseen by the DOE Office of Management.[123] The Office of Management can address operational issues at all of the non-NNSA laboratories through its oversight of the policies and procedures governing M&O contracts. Operational issues affecting the NNSA laboratories must be elevated to the attention of the Secretary and Deputy Secretary, pursuant to the provisions of the NNSA Act.

The National Laboratories have established the National Laboratory Directors Council (NLDC) as a mechanism for the Laboratory Directors to address laboratory- and department-wide strategic issues. The NLDC meets periodically with the Secretary and Deputy Secretary to discuss issues and provide advice but otherwise has no formal ongoing organizational function in the Department.

[k] This DOE-wide laboratory policy coordination was once provided, as needed, by an Office of Science and Technology Policy, reporting to the Deputy Secretary. It collaborated with the Lab Policy Offices, reporting to their respective Program Secretarial Officers, and with the DOE-wide RD&D Council, and/or the National Laboratory Directors Council.

Recommendations

DOE should establish an Office of National Laboratory Policy reporting to the Secretary and Deputy Secretary. The new Office would be headed by a senior DOE official, with staff support from a combination of DOE and National Laboratory personnel, and could be assigned several specific areas of responsibility, including:

- Establishing a formal organizational framework for ongoing interaction between the leadership of the National Laboratories and the Department on strategic directions for the Department.
- Engaging with the Laboratories in the formulation development of new, "big idea" Laboratory-wide innovation initiatives that provide strategic direction to the DOE research agenda. Possibilities include:
  - Technologies to enable the future architecture of the electricity system;
  - Managing interdependencies within energy systems and with other infrastructures;
  - Implications of artificial intelligence on energy; and
  - Defining new R&D opportunities for over-the-horizon innovations such as nuclear fusion, synthetic biology, superconductivity, and naturally occurring hydrogen.
- Overseeing guidance for departmental orders and directives that affect all National Laboratories.
- Establishing an ongoing institutional point of contact with the NLDC.
- Directing the work of the existing DOE Laboratory Operations Board (LOB).

The National Laboratories, working through the NLDC and the new Office of National Laboratory Policy, should examine opportunities for how best the laboratories can support the expanded DOE mission responsibilities in end-to-end energy innovation. Two possible ideas to consider are to formalize arrangements to provide laboratory technical support and analysis for OCED-funded demonstration projects and laboratory-led initiatives to assist the formation of regional and place-based initiatives to expand the reach of energy innovation across the U.S.

DOE should review and update, as needed, the COI requirements applicable to National Laboratory personnel and establish expedited review procedures to enable Laboratory personnel to provide support to DOE program offices on an expedited basis consistent with BIL and IRA legislative implementation schedules. DOE should also clarify the roles and responsibilities of National Laboratory personnel on loan to the government, including the criteria for utilizing laboratory personnel as temporary complements and not permanent displacement of federal government personnel.

3.2 The Role of the National Laboratories as Integrators

The National Laboratories also have the capability to support the implementation of new innovation strategies by serving as integrators in program planning, execution, and coordination. The Laboratories have the expertise and capabilities to address the full spectrum of science and technology topic areas, scientific disciplines, and the various participating research entities. This capability can be a powerful tool to enable the achievement of DOE mission objectives.

The National Laboratories have provided strategic leadership and integration of major DOE crosscutting RD&D initiatives. For example:

- The *Grid Modernization Lab Consortium* was established as a strategic partnership between DOE and the National Laboratories to bring together leading researchers, technologies, and resources to collaborate on modernizing the nation's electricity grid. The current portfolio of the Grid Modernization consists of a portfolio of 88 multi-year research projects across 13 National Laboratories.
- The *National Virtual Biotechnology Laboratory* (NVBL) brought together National Laboratories with core capabilities relevant to the threats posed by COVID-19. The laboratories established a coordinated effort to use unique National Laboratory research facilities, including light and neutron sources, nanoscale science centers, sequencing and characterization facilities, and high-performance computing to conduct research, testing, and modeling. Innovations arising from this effort included testing capabilities, new targets for medical therapeutics, and the use of additive manufacturing to address some supply chain bottlenecks.

Additional opportunities may exist to extend these types of integrated initiatives to new challenges. The DOE Hydrogen and Fuel Cells Technologies Office recently published a national roadmap identifying opportunities for clean hydrogen to contribute to national decarbonization goals across multiple sectors of the economy. Hydrogen could be a possible new area for integrating the facilities, skill sets, and experience of the National Laboratories to help enable the energy transition. Another possible focus area is large-scale carbon management.

The recently established DOE Office of the Under Secretary for Infrastructure oversees program offices focused on later-stage technology development, demonstration, and deployment activities. While this Office provides an increased focus on late-stage technology demonstration and deployment, it does not have a formal linkage to fundamental and early-stage applied R&D programs. As described earlier (Chapter 2), the National Laboratories could perform an important role in helping to realize the learning by doing benefits flowing from technology demonstration and deployment projects.

Currently, the integration of separately funded programmatic efforts is dependent upon collaborations among individual researchers on specific research projects. Explicit authorization of the National Laboratories to function as integrators is a step towards increasing rapid technology maturation and accelerating the clean energy transition.

Recommendation

The proposed new DOE Office of Laboratory Policy should work with the Office of the Chief Financial Officer, the Office of Policy, and the program offices to establish roles for the National Laboratories to assist in the planning and implementation of crosscutting RD&D initiatives, including serving as crosscutting program integrators. (DOE management of crosscutting RD&D initiatives is discussed in more detail later in this report).

3.3 Enhancing the Role of the National Laboratories in Technology Maturation and Transition

While the National Laboratories are noted principally for their leadership in science, technology maturation and transition to the private sector has always been part of their mission. The mechanics of how best to accomplish this mission, however, has been a work in progress. The 2015 Report from the Commission to Review the Effectiveness of the National Energy Laboratories (CRENEL), for example, recommended the Laboratories "fully embrace the technology transition mission and continue improving the speed and effectiveness of collaborations with the private sector."[124]

Historically, the National Laboratories have utilized mechanisms such as Cooperative Research and Development Agreements (CRADAs) and Agreements to Commercialize Technology (ACTs) as a principal mechanism for collaboration with the private sector to apply National Laboratory expertise and translate scientific developments to commercial application. These arrangements work best for collaborations with larger size entities with larger innovation budget resources. With the establishment of the Office of Technology Transitions (OTT) has come a greater emphasis on technology collaborations with smaller-size innovators. In recent years, OTT implemented two new initiatives targeted at technology transition, the Practices to Accelerate the Commercialization of Technologies (PACT) program, and the implementation of the Technology Commercialization Fund (TCF).

The PACT program is intended to help the transition of research developed at the Labs to the marketplace by supporting innovative approaches to reduce barriers to accessing the Laboratories, with a focus on lowering transaction costs and increasing the effectiveness of working with the private sector.[125] One notable initiative funded under the PACT program is the "Safari" program at Oak Ridge National Laboratory. "Safari" is an entrepreneurial start-up program that aims to match entrepreneurs to National Lab-developed technologies for licensing. Once entrepreneurs identify technologies of interest, the lab technology transfer team hosts a technology "safari" at the lab –a series of "discovery meetings with researchers, laboratory tours, and demonstrations."[126] "Safari" received an initial award of $72,000 from OTT in October 2019.[127]

The TCF is the Department-wide fund managed by OTT to support technology transfer and commercialization. The TCF base program is an estimated $35 million annual initiative that supports the commercialization of National Laboratory technologies and builds out of Laboratory commercialization ecosystems. Allocations from the BIL funding will provide an additional increment (BIL-TCF), as the BIL will provide roughly an additional $150 million in new funding for a BIL-TCF program over the next five years.[128] The OTT implements the funding through defined "lab calls" for project proposals. Two recent sets of awards are noteworthy. The first is the award of $21 million towards 30 clean energy projects in response to the

Core Laboratory Infrastructure for Market Readiness (CLIMR) Lab Call.[129] The second is a recent award of over $15 million to two projects from a joint OTT-OCED Collaborative Alignment for Critical Technology Industries Lab Call. In October 2023, OTT issued a Notice of Intent (NOI) for the FY2023 BIL-TCF CLIMR Lab Call with an estimated $37.7 to $44 million in funding. The new NOI expands the scope of the TCF to address crosscutting technology partnership issues, including eligibility for a broad suite of technologies.[130]

The nature of the winning proposals under the prior solicitations and the broader scope of the new NOI are indicative of the potential for new and creative approaches to foster technology transition from the National Laboratories, including opportunities to build institutional capabilities. These advances, however, also illustrate the limitations of current programs. In particular, the size of individual awards is very small relative to National Laboratory capabilities, and the scope and eligibility criteria for project selections, as well as final decision-making, are set on a top-down basis by the DOE program offices that may restrict other approaches that may not otherwise meet the terms of the lab call.

Realizing further potential for technology transition will require not only increasing the level of funding for current efforts but also expanding the scope to allow for other approaches. One area for further expansion is in proof of concept and initial scaling of National Laboratory bench-scale science into technology prototypes. This need may be especially true when new innovations are derived from national nuclear security-related research, where additional proof of concept may be necessary to establish feasibility for commercial applications.

A Laboratory-directed technology maturation program could enable the Laboratories to extend their role in applied RD&D efforts to enhance opportunities for transitioning to the private sector. **A Laboratory-directed Technology Maturation (LDTM)** initiative could be modeled after the highly successful program of Laboratory Directed Research and Development (LDRD), which relies on the creative capacity of the research staff of the Laboratories. The purpose of LDRD is to provide the Laboratories with the required

“A Laboratory-directed technology maturation program could enable the Laboratories to extend their role in applied RD&D efforts to enhance opportunities for transitioning to the private sector.”

flexibility needed to anticipate and respond quickly to mission needs and to explore potentially revolutionary advances in science and technology. The guidelines for the program are established in DOE 413.2c, which stipulates that LDRD projects must be “experiments and analyses directed towards “proof of principle” or “early determination of the utility of new scientific ideas, technical concepts, or devices.”[131] The funding level established for LDRD must be within the congressionally mandated limits of a laboratory’s total operating and capital equipment budget for the year.

Currently, the Laboratories can set aside up to six percent of their eligible budget allotments to fund LDRD activities (national security laboratories typically set aside up to the full amount authorized; by contrast, Office of Science laboratories typically set aside only two percent). Current funding allocated to LDRD is about $0.7 billion annually. The Laboratories are required to report metrics (publications, patents, and postdocs) associated with LDRD projects, and DOE is required to provide an annual report to Congress on LDRD activities. The track record of the LDRD program indicates that the program has been highly successful in generating novel research results.

A separate program for **Laboratory-directed Technology Maturation** could be modeled on the same concepts as the LDRD program. The new initiative would enable the Laboratories to allocate funding for technology maturation projects to translate scientific discoveries into technology applications that have great potential for demonstration and deployment. The program could have a specific focus on cross-cutting or platform technologies needed for the clean energy transition.

Key issues to be addressed are the scope of the program; oversight and management; and funding.

- The program scope should be focused on taking ideas at the earliest Technology Readiness Levels (TRLs) and translating them to proof of concept (from TRL 1 and 2 to 3) in order to provide sufficient information for DOE program managers or private sector investors, to make an initial assessment of technical, economic and market feasibility to justify further funding.[I] This scope should be feasible within time limits of 2-3 years.
- Decisions on the selection of projects for funding under this initiative should be made by senior managers within the laboratories themselves. This can be accomplished by adopting decision processes similar to those in effect for the selection of LDRD projects. Laboratory senior managers would have the deepest knowledge of the technologies proposed for maturation. DOE Program Office oversight also could be modeled on the Laboratory reporting requirements to DOE and Congress in the LDRD program.
- Finally, a key issue is how to fund this new initiative. The program should not detract from or dilute the existing LDRD program by drawing against the current congressionally authorized funding allotments. Possible new sources of funding could include a new program budget line item with dedicated annual appropriations funding, a set aside from the BIL funding allotted to the existing DOE Technology Commercialization Fund (BIL-TCF), and/or possible non-federal funding through the National Laboratory-affiliated Foundations or the implementation of the Foundation for Energy Security and Innovation (FESI). New budget line-item funding would enhance the visibility of the initiative and lessen the possibility of adversely impacting the funding for existing programs. A set of BIL-TCF funding could also accomplish these purposes but would require devolution of planning and decision-making from the DOE Office level to the National Laboratory Director level. Another option for funding LDTM initiatives is to seek private sector funding through the National Laboratory-affiliated foundations. These foundations have a broad charter in their approaches to fundraising and in how those funds can be applied to Laboratory initiatives.

Recommendations

DOE should work with the Administration to seek increased annual appropriations for the OTT PACT program to enable larger-scale technology transition projects that take full advantage of National Laboratory capabilities and opportunities.

DOE should establish a new initiative for Laboratory-Directed Technology Maturation (LDTM). The program could be modeled on elements drawn from the current LDRD program, but it would be separate in scope, management, and funding from the LDRD program.

[I] The Technology Readiness Level measures the maturity of a given technology. The TRL scale goes from 1 to 9, with 9 being the highest level of maturity.

3.4 Expanding Test Beds at National Laboratories for Use by Energy Innovators

The urgency of energy security and the energy transition has created an increased need for and value in enhancing access to the facilities and capabilities of the National Laboratories by the emerging clean energy industry. The DOE Office of Science is renowned for its basic research user facilities. These are typically large-scale, costly scientific facilities that universities and private firms cannot afford to build and operate; providing these entities with access has helped sustain America's leadership in the frontiers of science. This critical innovation infrastructure is extensive; the DOE Office of Science operates 28 user facilities at National Laboratories, where lab facilities provide significant benefits to the scientific community.

" National Laboratory scientific user facilities have become important platforms for propelling national economic competitiveness. Not only has the knowledge gained from these innovation platforms/services helped power American leadership in fundamental science, but it has also led to important commercial developments as well. About half of the experiments carried out at National Laboratory light sources have, for example, supported advancements in both the life sciences and novel drug development. "

These facilities have become increasingly vital tools for scientific discovery as well as for testing platforms for many key industries. These tools include advanced supercomputers, particle physics accelerators, synchrotron light sources (large x-ray machines), neutron scattering sources, specialized facilities for nanoscience and genomics, and others. Tens of thousands of researchers make use of these facilities each year. There is open access to these facilities, but there is limited time and availability; competitive peer reviews are used to manage the allocation of use time.

National Laboratory scientific user facilities have become important platforms for propelling national economic competitiveness. Not only has the knowledge gained from these innovation platforms/services helped power American leadership in fundamental science, but it has also led to important commercial developments as well. About half of the experiments carried out at National Laboratory light sources have, for example, supported advancements in both the life sciences and novel drug development.

There is a similar need for expanded and new specialized testing facilities that are focused on testing energy technology prototypes. Prototype technology testing facilities, like their scientific user facility analogs, are complex, specialized, and highly instrumented facilities that are technically challenging to operate and expensive to build, maintain, and improve. Their widespread availability would benefit multiple users. While an individual firm may be expected to bear the costs of its own proprietary technology development in the latter stages of RD&D, it is unrealistic to expect it to underwrite the cost of a large-scale test facility that can be adapted to multiple users and multiple purposes.

For example, the only large-scale wind turbine dynamometer testing facility in the U.S. today was built with funds from the American Recovery and Reinvestment Act (ARRA) of 2009. It is sized for designs that are now out of date. Upgrades are expensive, estimated to exceed $70 million, and not amenable to funding from regular programmatic appropriations. Two modern facilities are located overseas (one in Europe and another in China), but the wait time for access by American firms currently exceeds ten years. Text box 1 describes an example of the kind of user-accessible test bed envisioned for facilitating clean energy technology development across a wide variety of applications. Another example under development at the Pacific Northwest National Laboratory (PNNL) is the Grid Storage Launchpad, which will include independent testing and validation of next-generation energy storage materials, devices, and prototype systems under grid operating conditions. The $75 million facility is a collaboration between industry and academia and is expected to be operational in 2024.[132,133]

BOX 01

The NREL Controllable Grid Interface, a World-Class Test Bed

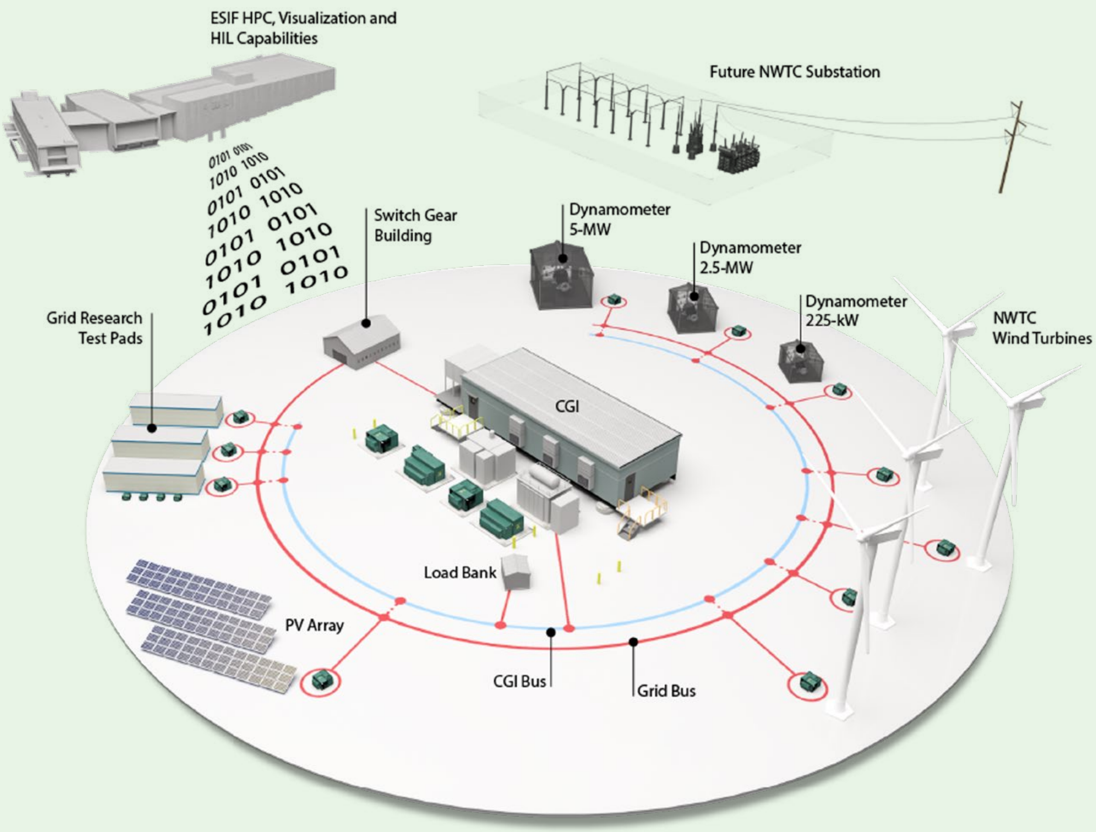
On the equipment scale, about the size of a mobile home, there is a 7-megavolt amperes Controllable Grid Interface (CGI) system located on the NREL Flatirons Campus (Figure 11).[134] The CGI can quickly and cost-effectively verify how wind turbines, photovoltaic systems, inverters, and energy storage systems interact with the grid. It is a world-class, laboratory-wide user facility capable of analyzing the performance of megawatt-scale renewable energy systems at transmission-level voltages, soon to be upgraded to 20 MW.

As the first validation facility in the U.S. with fault simulation capabilities, the NREL CGI allows manufacturers and system operators to certify integrated renewable systems in an offline, controlled environment. It can also be extended beyond renewable energy systems and combined with other energy system assets, such as hydrogen electrolyzers, the 5- and 2.5-megawatt dynamometers, individual or multiple megawatt-scale field research turbines, a matrix of electronic and mechanical storage devices, the wave tank and motion platform, and the Energy Systems Integration Facility located at the NREL main campus.

The CGI is equipped with an impedance measurement system that is the first of its kind worldwide. It can characterize the electrical behavior of multi-megawatt wind turbines and inverters at different frequencies. The test-bed platform can evaluate different dynamic stability problems, including sub-synchronous, super-synchronous, and near-synchronous resonance problems; serve as a platform for high-fidelity model validation; and support the development of new technologies, such as grid-forming inverters.

FIG. 09

NREL's Controllable Grid Interface



Recommendation

DOE should work with industry and universities to identify the need for additional clean energy technology prototype test facilities that can be implemented through the National Laboratories.

3.5 Expanding National Laboratory Partnerships with Industry and with Regional Innovation Initiatives

The CHIPS and Science Act authorized several significant new opportunities to expand National Laboratory partnerships with private sector innovators and with regional and place-based innovation consortia.

Partnerships with Individual Private Sector Entities and Innovators: Historically, the National Laboratories have engaged in many partnerships with industry, universities, and other federal agencies. These partnerships are both technically and geographically diverse. Some examples currently posted on National Laboratory websites include:

- Oak Ridge National Laboratory has teamed with Holocene Climate Corporation to deploy direct air capture of CO_2 technologies;[135]
- The National Renewable Energy Laboratory has teamed with Golden Valley Electric Association to determine the best ways to incorporate new reduced carbon technologies into small, isolated power grids;[136]
- Lawrence Livermore National Laboratory teamed with Seurat Technologies to use additive manufacturing to deliver metal components for turbines;[137] and
- Savannah River National Laboratory teamed with Augusta University to improve global security.[138]

National Laboratory partnerships can take a variety of forms; the two principal vehicles are Cooperative Research and Development Agreements (CRADAs) and Strategic Partnership Projects (SPPs). CRADAs outline programs of joint research projects between a National Laboratory and a partner where each provides its own resources to conduct collaborative research. (A special class of CRADAs, known as funds-in CRADAs, allow private sector partners to fund a portion of the National Laboratory's scope of work). SPPs are a vehicle for non-DOE entities to directly fund research projects at the National Laboratories, where the full scope of the research work is conducted within the National Laboratory. SPPs have been used extensively with other federal agencies to use National Laboratory personnel and facilities to support homeland security and certain national security needs.

The ability to expand the use of CRADAs and SPPs with the private sector, however, has major limitations. For the most part, only very large entities have the resources to partner with a DOE National Laboratory in a CRADA. Given the high cost of National Laboratory research, CRADAs make sense when the National Laboratory is providing research equipment or capability that can be found only at the laboratory. Otherwise, large organizations are likely to forgo the challenge of partnering and instead pursue RD&D internally or with another partner. Several new approaches are underway.

One new approach is the use of **Partnership Intermediary Agreements (PIAs)**. PIAs allow for more nimble collaboration and can broaden the pool of potential partners via simplified processes for engaging in cooperative or joint activities. For these reasons, PIAs can accelerate and expand technology transfer and commercialization activities and can support the diffusion of cutting-edge technologies from the National Laboratories to industry and academia. These agreements have been successfully used by other federal agencies (e.g., Department of Defense—DOD, Department of Homeland Security—DHS, and the U.S. Air Force). Drawing upon the experience of these agencies, OTT developed a model PIA framework for use by DOE. In August 2023, the DOE Office of Management issued the Guide to Partnership Intermediary Agreements and OTT, working with OCED and EERE offices, announced the first ever DOE PIA with

ENERGYWERX to provide vouchers with a total value of $27.5 million of in-kind commercialization support to small businesses, non-traditional partners, and other organizations.[139] The use of the PIA mechanism will enable ENERGYWERX to engage with these entities more quickly and efficiently to speed the innovation process.[140] Expanded use of PIAs by DOE could provide an additional tool to accelerate technology transfer by allowing the National Laboratories to play a more active intermediary role in working with universities and non-profit organizations to support the commercialization of new energy technologies.

The CHIPS and Science Act authorized several additional mechanisms, building on current DOE pilot programs.

- The Act authorized $11 million in funding for the **National Laboratory Partnering Service** pilot program authorized in the Energy Act of 2020. The lab partnering service was initiated in 2018 as a front-door portal to DOE that facilitates connections to national laboratory facilities, intellectual property, lab experts, and research areas. The service is administered by OTT and focuses on simplifying the process for innovators seeking to work with the laboratories as well as investors seeking to commercialize new inventions originating in the laboratories.[141]

- The **Small Business Voucher Program** awards vouchers to small businesses that can be used to fund research activities at National Laboratory facilities. The voucher program builds on existing pilot programs within the EERE as well as the Gateway for Accelerated Innovation in Nuclear (GAIN) program sponsored by the Office of Nuclear Energy (NE).

- The **Laboratory-Embedded Entrepreneurship Program** (LEEP) provides innovators and entrepreneurs the opportunity to access National Laboratory research facilities and consult with Laboratory researchers to test out new ideas. Lawrence Berkeley National Laboratory initiated this program as the Cyclotron Road initiative, and it has since expanded to three other National Laboratories, each with a slightly different business model. Funding for this program is budgeted in EERE, and implementation is coordinated with other program offices.

Fostering Localized and Regional Innovation Ecosystem Partnerships: In addition to partnerships with individual entities, the National Laboratories have worked with state and local governments to establish innovative multi-party strategic partnerships with industry, universities, and other government (non-DOE) agencies located outside the Laboratory fence lines. These partnerships enable the transition of National Laboratory discoveries and know-how to create localized innovation ecosystems. The experience of these partnerships also provides a validated starting point for enabling the National Laboratories to work on a broader regional scale.

There are a number of examples of these beyond-the-fence line partnerships that allow private sector researchers to work with National Laboratory researchers in research activities that facilitate the diffusion of Laboratory research expertise. Sandia National Laboratory has a very successful adjacent industrial park; Los Alamos National Laboratory is a partner in the New Mexico Consortium; Brookhaven National Laboratory is in the process of establishing a Discovery Park aimed at providing access to the Laboratory for regional industries; the Illinois Accelerator Research Center has expanded to include quantum computing; and Idaho National Laboratory has a fairly large industrial park in biofuels and batteries in addition to advance nuclear technologies, hosting both regional universities and industrial partners. Several of these initiatives are described further in the accompanying text box.

BOX 02

National Laboratory Partnerships with State and Local Innovation Initiatives

The **New Mexico Consortium (NMC)** is a non-profit corporation formed by Los Alamos National Laboratory (LANL) and the three New Mexico research universities to expand research capability in the state of New Mexico. The NMC is housed in a facility "outside the fence" of the LANL, financed by the county of Los Alamos through a low-interest loan to the NMC. The NMC facility supports 40 researchers and is used by both start-up businesses and LANL to demonstrate and deploy innovative technologies. The agreement between LANL and the New Mexico Research Universities allows LANL researchers to have a joint appointment with the NMC to participate with the universities in research projects supported with non-DOE funding. As part of its mission to support start-up businesses, the NMC accepts equity interest in companies in lieu of payment for the usage of the facility.

FIG. 10

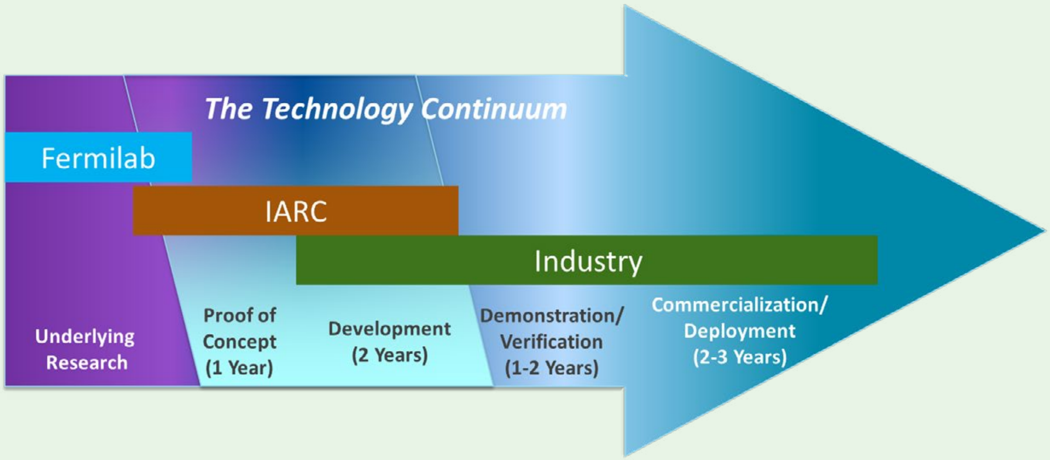
New Mexico Consortium

The Illinois Accelerator Research Center (IARC), jointly funded by DOE, through Fermilab, and the State of Illinois, is facilitating the translation of fundamental science to the marketplace. The IARC fosters partnerships between the Lab, private industry, and the academic community focused on the translation of high-energy physics and accelerator technology for applications in energy, the environment, medicine, and national security. The 83,000-square-foot IARC facility was started as an Illinois-funded facility and houses technical, office, and educational space needed to support project collaborations. As shown in Figure 11, the IARC supports mid-level technology maturation and translation to bridge the gap between scientific research and industrial applications.[142] The IARC recently received an additional $30 million grant for the expansion of facilities.

The Brookhaven National Laboratory Discovery Park is a business model framework for developers, collaborators, and entrepreneurs to propose, build, and operate new facilities that complement the DOE and Brookhaven laboratory missions, leveraging opportunities from close proximity to the Laboratory. The park has been started with a Science and User Support Center. The concept includes the potential for development on approximately 60 acres of previously used, publicly accessible land.[143]

FIG. 11

The Illinois Accelerator Research Center (IARC) at Fermilab: "Bridging the gap between research and industrial applications"



The enactment of new authorities in the CHIPS and Science Act to foster regional technology innovation ecosystems, discussed in detail later in this report, provides further opportunities to link National Laboratory resources and expertise with evolving regional innovation networks. Currently, the National Laboratories are eligible to join regional teams being formed to participate in the new Department of Commerce Regional Technology and Innovation Hubs and the NSF Regional Innovation Engines program. DOE, however, has not provided specific seed funding to the Laboratories to enable them to take a proactive role in working with prospective regional hubs in the implementation of these new initiatives.

A possible new non-federal source of support for National Laboratory-led regional initiatives is the establishment of the new DOE-affiliated foundation, the **Foundation for Energy Security and Innovation** (FESI), also authorized in the CHIPS and Science Act and discussed previously in this report. Among its responsibilities is a mandate to work with the various existing National Laboratory Foundations to develop additional opportunities, such as the New Mexico Consortium.

Recommendations

DOE should work with the Administration to seek a specific budget line-item appropriation to support the expansion of both the LEEP initiative and the small business voucher program. The budget line item should be managed by OTT.

DOE should provide specific line-item funding to the National Laboratories to enable them to take a proactive role in furthering the development of regional energy innovation ecosystems, including working with the Department of Commerce and NSF on the implementation of new CHIPS and Science Act program initiatives.

3.6 Building a Culture of Entrepreneurship at the National Laboratories

One of the challenges to National Laboratories in assuming an expanded role in technology maturation, demonstration, and deployment is the need to support culture change within the Laboratories themselves. DOE could help enable such change by appropriately adjusting the incentive structures for innovators at the National Laboratories.

The CHIPS and Science Act provides the National Laboratories with new tools to enable a paradigm shift in their culture. These new tools include:

- **Entrepreneurial Leave:** The CHIPS and Science Act gives Lab Directors the authority "to carry out an entrepreneurial leave program" to allow a leave of absence of up to three years. At the end of the leave, the employee would have the option to return to a comparable position.[144] The new authority builds upon the current Energy I-Corps initiative that provides an immersive two-month training program partnering teams of researchers with industry mentors. The I-Corps program enables laboratory researchers to assess real-world opportunities for their research while building commercialization and entrepreneurial skills.
- **Entrepreneur in Residence Program:** The CHIPS and Science Act authorizes a new Entrepreneur in Residence Program that enables entrepreneurs to obtain term appointments at the National Laboratories. Oak Ridge National Laboratory (ORNL), with funding support from several program offices within EERE and in collaboration with the Tennessee Valley Authority, recently launched Innovation Crossroads, a program to provide two-year fellowships awarded on a national competition, to embed entrepreneurial-minded fellows into ORNL research on energy and manufacturing challenges.[145]
- **Royalty Sharing:** The Laboratories could modify royalty-sharing formulas to increase the rewards for innovators who successfully contribute to technology diffusion through licensing of patents and other Intellectual Property.
- **Award Programs:** Special recognition could be offered to innovators who develop particularly successful or critical innovations. Annual awards, lifetime titles, or fellowships could elevate a demonstration and deployment effort from the domain of busy work into a career-defining endeavor. DOE already awards the Ernest O. Lawrence Awards for "exceptional scientific, technical, and engineering achievements." A parallel prestigious awards program for demonstration and deployment specifically would signal to everyone at the Laboratories that work on technology demonstration and technology transfer is highly valued at DOE, and it would also provide the Laboratories with an opportunity to promote their capabilities with a broad audience.
- **Expanded Post-Doctoral Programs:** Post-Doctoral programs at the National Laboratories play a key role in both recruiting new talent to the labs and in familiarizing new scientists and engineers with Laboratory capabilities that could facilitate future collaborations for post-docs who go on to careers in universities and industry. Many National Laboratories have also developed partnership agreements with universities to allow faculty and sponsored Ph.D. students to participate in the LDRD program. These partnerships bring multiple benefits, including encouraging participants to go on to pursue a start-up venture. The proposed LDTM initiative also could provide an environment to expand these types of partnerships.

Building a more entrepreneurial culture at the National Laboratories should also include expanding opportunities to increase the diversity of the science and technology workforce. One new initiative for leveraging the National Laboratory's capabilities to expand the aperture for the science and technology workforce is

> "Building a more entrepreneurial culture at the National Laboratories should also include expanding opportunities to increase the diversity of the science and technology workforce."

the DOE Office of Science's Reaching a New Energy Sciences Workforce (RENEW) program. This initiative uses the infrastructure and resources of the National Laboratories, user facilities, and other research infrastructures to provide training opportunities for undergraduate and graduate students, postdoctoral researchers, and faculty at academic institutions not currently well represented in the U.S. science and technology ecosystem. The hands-on experiences gained through the RENEW initiative could open career paths for the participants to join the DOE science and energy innovation enterprise.

Recommendations

The proposed new DOE Office of National Laboratory Policy should work with the National Laboratory Directors on measures to enhance a culture of entrepreneurship at the National Laboratories while also expanding the demographic distribution of its workforce. Possible measures could include:

- Provide funding to Increase the number of clean energy Post Doc positions at the Laboratories;
- Encourage greater migration of mid-career research staff from the Laboratories to the private sector as a means to enhance the process of technology transitions;
- Expand term-limited researcher exchange opportunities with both the private sector and university research programs; and
- Incorporate entrepreneurship into National Laboratory management training and advancement programs, such as the Oppenheimer Fellows program.[m]

[m] The Oppenheimer Fellows program "is designed to bring together exceptional professionals who have the potential to contribute significantly to DOE's work, whether at DOE or in the National Labs, academia, or industry."
Source: Oppenheimer Science and Energy Leadership Program (OSELP), "About OSELP," accessed 9/15/23, https://oselp.org/about-1

3.7 Incentivizing Technology Translation and Demonstration and Deployment in National Laboratory M&O Contracts

The government-owned contractor-operated (GOCO) concept has been successfully used since the Manhattan Project for not only cutting-edge scientific research but also the production of critical assets. From nuclear weapons to life-saving vaccines, GOCOs have demonstrated their capability to address high-priority challenges. The GOCO model ensures that federally funded assets will be operated in the best interest of the government while benefiting from the skill set of the contractor to guarantee effective and efficient implementation of the government's goals.

The GOCO model has structural advantages over other public-private models, particularly when it comes to deployment. The GOCO Management & Operation (M&O) agreement includes a fee structure that incentivizes the contractor through a set of goals and objectives. The level of fee awarded to the contractor is based on the contractor's performance relative to the prescribed goals. If the incentive fee structure is not aligned with specific metrics to track the pace of transition of technologies to the marketplace, it could create a disconnect between Laboratory personnel and the parent contractor.

> "The GOCO model ensures that federally funded assets will be operated in the best interest of the government while benefiting from the skill set of the contractor to guarantee effective and efficient implementation of the government's goals."

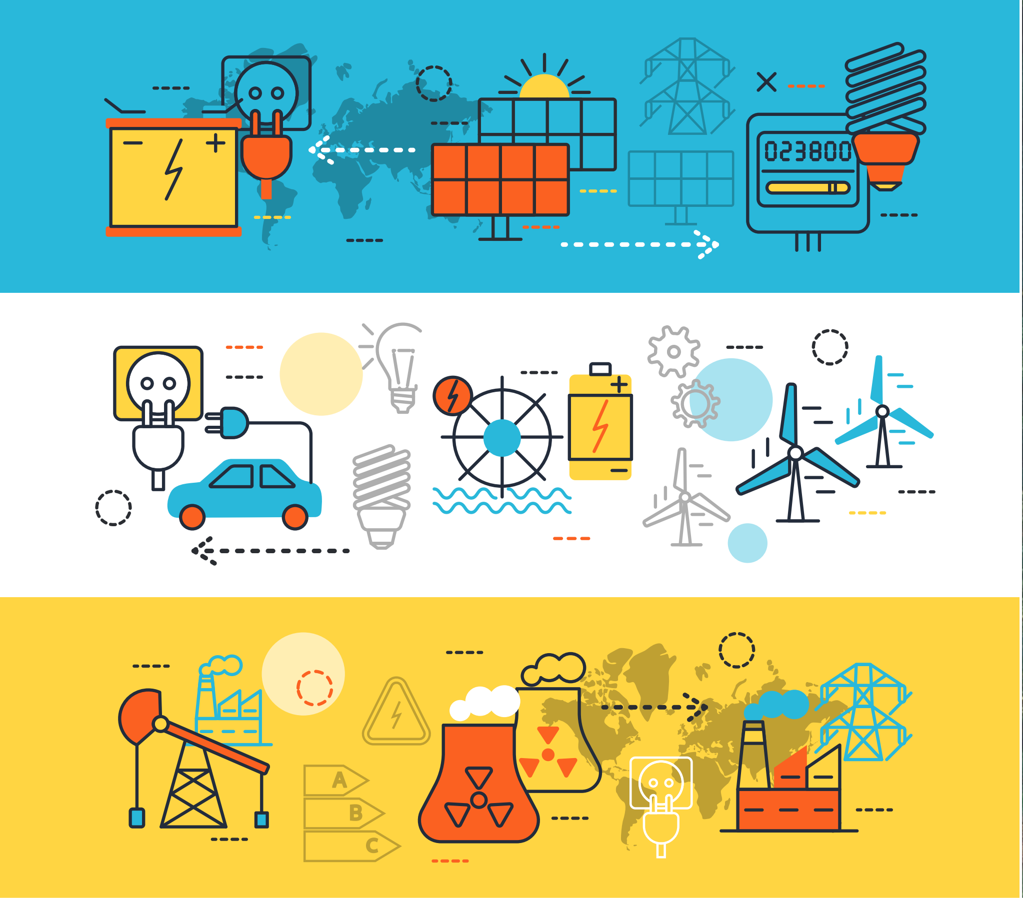
The Laboratories can earn royalties from the licensing of technology and other intellectual property, but they do not earn incentive fees based on technology transfer metrics. Identifying the metrics most appropriate for technology transfer can not only measure the performance of the National Laboratories in energy innovation but also provide a clearer basis for rewarding success in this area.

Finally, there may be opportunities to further encourage the National Laboratory M&O contractors to pursue follow-on investments in the commercialization of innovations emerging from the Laboratories. These actions may be outside the scope of the M&O contracts themselves, but they could be considered as a factor in the selection of M&O contractor teams. There also may be opportunities to develop new forms of partnership models between DOE and the M&O contractors.

Recommendations

The proposed new DOE Laboratory Policy Office should identify performance metrics that can incentivize technology transfer and commercialization, and it should seek to incorporate them into the Laboratory M&O contract award fee structure.

The proposed new DOE Laboratory Policy Office should seek to develop new policies, including M&O contractor selection criteria, to encourage private investment by Laboratory M&O contractors to expand technology transfer and demonstration and deployment activities. These policies could include pilot efforts to develop specific new DOE-M&O contractor partnerships.



04 Strengthening Department-wide Support Functions

Rapid, relevant, and impactful technology development, demonstration, and deployment require a range of supporting resources and services. Five areas in particular are highlighted in this section: (1) secure supply chain resources management; (2) human resources and workforce development; (3) data collection and information management resources and services; (4) financial resources management; and (5) performance measurement and impact assessment. The additional initiatives outlined in this chapter can further strengthen the underpinnings of an energy innovation process that moves more rapidly and is more agile and capable of delivering results at a larger scale.

4.1 Expanding Supply Chain Resources: Energy Supply Chain Policy and Program Strategies

More secure and resilient supply chains are essential for U.S. national security, economic security, technological leadership, industrial competitiveness, and a clean energy future. Recent experience precipitated by the COVID-19 pandemic, geopolitical factors, and extreme weather has proven that the global supply chain is not robust.

- Supply chains are concentrated in sensitive areas overseas. The IEA notes, for example, that China possesses at least 60% of global manufacturing capacity for mass-manufactured technologies, such as solar photovoltaics, wind systems, and batteries;[146]
- Clean energy supply chains' reliance on imports contributes to vulnerability to production shortages, trade disruptions, and natural disasters;[147] and
- Supply chains can be manipulated by coordinated strategies of competitor country suppliers. In its Annual Threat Assessment of the U.S. Intelligence Community for 2023, the Office of the Director for National Intelligence stated that countries will attempt to compete to control resources essential to low-carbon energy technologies.[148]

> "A more diversified and resilient energy supply chain would support an ecosystem of material flows, skills, and production facilities essential to U.S. energy innovation that, in many cases, the U.S. currently lacks or needs strengthening."

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The Energy Act of 2020 established new and expanded responsibilities to DOE and the Department of Interior on critical *minerals* and *materials*. The Act directed the Department of Interior to update its methodology for assessing *critical minerals* and to update the resource assessments for these minerals over a four-year period. The Act assigned new responsibilities to DOE to designate *critical materials* that can incorporate some or all of the list of critical minerals developed by the Department of the Interior, as well as add additional materials. The designation by DOE of critical materials is based on two primary criteria, including whether a material: (1) has a high risk of a supply chain disruption; and (2) serves an essential function in one or more energy technologies that produce, transmit, store, and conserve energy.

In response to the President's E.O. 14017, *American Supply Chains*, DOE published in 2022 a Critical Materials Strategy that incorporated a set of 13 reports evaluating the potential vulnerabilities to the supply chain supporting the U.S. energy sector industrial base.[149] The *Strategy* mapped out key elements of the energy supply chains across 11 energy technology sectors and two related crosscutting topics. The *Strategy* identified risks, vulnerabilities, and information needs. In some cases, the concerns vary with each technology and require technology-specific actions. In others, they may be generalized to a common set of vulnerabilities that call for coordinated actions across a broad front.

The DOE *Strategy* identified seven "strategic opportunities" for action.

1. **Increase domestic raw materials availability:** Areas of concern include cobalt for batteries; rare earth elements, such as neodymium for generators and motors; platinum group metals for catalysts; tellurium for solar photovoltaic (PV) panels; and uranium for nuclear energy. *Actions* include updating federal mining laws and regulations to provide for more effective and efficient permitting; promoting consensus-built labor standards for mineral extraction and processing; expanding demonstration and deployment of technologies for secondary/recycled sources; supporting innovation for next-generation critical minerals and materials extraction, processing, refining, and substitution; and establishing multilateral stockpiling, including through the International Energy Agency.

2. **Expand domestic manufacturing capabilities:** Areas of concern include neodymium-based magnets for wind and EV motors; large castings for wind and hydropower turbines and nuclear reactor components; specialized steel plate for offshore wind; grain-oriented electrical steel for transformers; High-Assay Low-Enriched Uranium (HALEU) and advanced fuels for nuclear energy; and silicon wafers for solar PV. *Actions* include expanding manufacturing programs in strategic areas; pursuing next-generation industrial facilities (e.g., steel mills, processing, and fabrication sites); leveraging foreign direct investment; promoting regional clean energy industrial clusters; and revising trade policy.

3. **Diversify and secure reliable foreign supply chains:** Areas of concern include technologies dependent on foreign suppliers, especially fuel cells, electrolyzers, carbon capture, offshore wind, hydropower, nuclear reactors, and grid transformers. *Actions* include promoting diverse and reliable foreign supply chains in non-sensitive regions; and supporting U.S. companies that secure sources that fill critical materials gaps.

4. **Increase the adoption and deployment of clean energy:** Areas of concern include uncertain demand signals for fuel cells, electrolyzers, carbon capture, offshore wind, hydropower, nuclear reactors, and transformers. *Actions* include federal purchasing of clean energy products produced domestically; establishing preference lists for critical materials used in federal procurement; promoting sustainable transportation fuels industries; shaping U.S. export strategy to stimulate a demand signal in international markets; and authorizing agencies to enter into utility service contracts and power purchasing agreements that extend 10 years.

5. **Improve end-of-life waste management:** Areas of concern include cadmium in thin-film solar PV, disposition of used nuclear fuel, decommissioning mining and manufacturing facilities, disposal of wind turbine blades; and health impacts on nearby communities. *Actions* include using federal purchasing power to support recycled content products.

6. **Grow a skilled U.S. workforce for the clean energy transition:** Areas of concern include recruiting, training, and replacing retiring workers in energy-related technical areas, such as nuclear energy and electric grid operation. *Actions* include convening stakeholders to advance energy workforce development; engaging organized labor in attracting skilled workers to the energy sector industrial base; and embedding fair labor standards in federal workforce supporting activities.

7. **Enhance supply chain knowledge and decision-making tools:** Areas of concern include lack of data on the energy sector industrial base; no comprehensive supply chain tracking, prioritization, and analyses; lack of a common nomenclature for understanding the life cycle flows of critical materials in components; and lack of visibility of interdependencies, such as integration of distributed energy resources into a digital grid. *Actions* include creating and maintaining an energy supply chain

database with supporting analytical and modeling capabilities; assessing impacts of energy supply disruptions; securing a digital component supply chain; and creating national requirements for the security of energy-related software, firmware, virtual platforms and services, and data.

Collectively, the crosscutting strategic opportunities and technology-specific strategies identify 62 discrete actions to address the identified areas of concern. Two-thirds of these actions (40 in total) could be undertaken under existing authorities within DOE or with interagency collaboration. Of the remaining 22 actions, 11 are crosscutting, and 11 others are technology-specific actions requiring congressional action.

Following this effort, DOE updated its Critical Materials Assessment, a forward-looking assessment of the criticality of materials based on their importance to the energy sector and their supply risk. DOE released a draft report in June 2023 for public comment and issued the final report in August 2023.[150] The final Critical Materials Assessment Report identified seven materials as “critical” in the short term and another nine materials as “near critical.” Over the medium term (2025-2035), the assessment found a shift in the rankings, with the list of critical materials expanding to 13 materials, with an additional six materials designated as near critical. Drawing from the 13 deep dive supply chain reports, the assessment process examined a total of 38 materials that support 13 energy technology areas.

Critical materials RD&D is an important component of a comprehensive energy supply chain strategy. An initial implementation step in this area was the launch in September 2023 of the DOE Critical Materials Collaborative (CMC), led by the Offices of Energy Efficiency and Renewable Energy (EERE) and Fossil Energy and Carbon Management (FECM). Its stated goal is “To integrate critical minerals and materials applied research, development, and demonstration (RD&D) across the U.S. Department of Energy (DOE) and the federal government to accelerate the development of domestic critical material supply chains for the nation.”[151] One of several pathways developed through CMC is the Critical Materials Accelerator, which “will prototype and mature technologies or processes to address critical material challenges in high impact areas.” The Critical Materials Accelerator is being supported with $10 million through a research and development FOA.[152] While this is a notable step forward, the small scale of the initial effort and the lack of clarity as to how the goals and priorities of the CMC will be integrated with the larger supply chain strategy suggest the need for further efforts.

The Energy Act of 2020 directs DOE to develop a program of research, development, demonstration, and commercialization to “… promote the efficient production, use and recycling of critical materials, with special consideration for domestic critical materials, throughout the supply chain.” The program also should “… develop alternatives to critical materials that do not occur in significant abundance in the United States.”[153]

DOE is also directed to coordinate its critical materials supply chain program with other federal agencies, the National Laboratories, private industry, academia, and other relevant stakeholders. Such coordination can be best provided by expanded staff capacity focused exclusively on the full scope of supply-chain issues within the context of the circular economy, with an organizational focus that allows it to span the full breadth of innovation programs Department-wide.

Responsibility for oversight and coordination of DOE supply chain activities is currently assigned to the Office of Manufacturing and Energy Supply Chain (MESC), a new office within the Under Secretary for Infrastructure organization. As stated in its FY 2024 budget request to Congress, MESC “…includes two major mission areas: supporting the private sector in increasing U.S. manufacturing capacity for critical energy technologies and supporting the U.S. industrial sector in efforts to increase competitiveness by increasing efficiency and reducing emissions.” As part of this mission, MESC proposes to undertake “… supply chain modeling, mapping, and analysis tools that are instrumental for assessing vulnerabilities, strengths, and opportunities for U.S. supply chains and aligning and prioritizing investments by MESC and other part of DOE and the Federal government across all advanced energy technologies."[154] The FY 2024 budget requested funding primarily for battery and critical materials and support for strategic investments using Defense Production Act authorities. The request was for new activities not supported in pending House and Senate appropriation bills; only the continuation of the current Industrial Assessment Centers (IAC) program was funded.

Recommendation

The DOE Manufacturing and Energy Supply Chain (MESC) office should develop a critical materials supply chain roadmap consistent with the requirements of Section 7002(g) of the Energy Act of 2020, with appropriate milestones and funding estimates. The roadmap should expand upon the supply-focused issues in the DOE supply chain strategy report and critical materials assessment to also address opportunities for critical materials recycling and substitution. The roadmap should also be used as a basis for setting priorities for the expansion of the DOE Critical Materials Collaborative.

4.2 | Expanding Human Resources: Workforce Development

In January 2022, DOE announced the creation of a Clean Energy Corps to support DOE efforts to accelerate the deployment of clean energy projects and to reduce planet-warming emissions.[155] The plan is to include current career staff as well as hire 1,000 new employees. This initiative will be the largest expansion of the Energy Department's workforce since its establishment. The Department will rely on a special hiring authority included in the BIL to expedite this process and has been achieving steady progress.

While DOE has been achieving steady progress, staff have identified two recurring challenges affecting the pace of new hires: 1) a significant number of the applicants were not qualified, and 2) even with special hiring authority, the process of onboarding personnel is slow.[156,157]

Implementation of the BIL and IRA within the context of a changing clean energy landscape will also require recruiting personnel with a broader suite of skill sets, such as in the social sciences and community affairs, that historically have not been a consequential element of the DOE personnel resource base. Recruitment initiatives could include further expanding the use of the Presidential Management Fellows (PMF) program, Intergovernmental Personnel Act (IPA), American Association for the Advancement of Sciences (AAAS) Fellows Program, and the Oak Ridge Institute for Science and Education (ORISE) fellowship. Improvements in the onboarding processing of new hires can be addressed by adding staff with human resources management expertise and by acquiring personnel services from other federal agencies.

Over the longer term, the principal challenge is to expand the pipeline of students in science, technology, engineering, and mathematics (STEM) to educate the next generation of energy innovation personnel, with a strong emphasis on diversifying the workforce. The 2022 National Science Board report recommended potential areas that could strengthen and diversify STEM capacity within the U.S. to meet future challenges.[158] The data indicate areas that would improve the position of the U.S.: (1) "investing in RD&D and supporting innovation activities that translate the resulting knowledge into products and services; (2) improving STEM education at the K–12 level; (3) increasing participation in STEM fields of study and careers to include all socioeconomic and demographic groups and U.S. geographic regions; and (4) building a strong STEM labor force by training and educating domestic talent and by recruiting and retaining foreign talent."[159]

Women and minorities are underrepresented in all STEM fields. While women constitute 50.5% of the U.S. population, they occupy only 28% of the STEM workforce.[160] For African Americans and Hispanics, the combined share is 30% of the population and 16% of the STEM workforce.[161] Expanding participation in STEM education and in the STEM workforce will significantly increase the number of qualified applicants for clean energy jobs. The challenges of expanding the STEM workforce are universal across the public and private sectors and require broad-based action; DOE, however, has unique resources, such as the National Laboratories, that can make a notable contribution to this issue.

Student research participation programs are an important conduit for the retention of students once they enter the STEM educational pipeline. The Senate Committee Report accompanying the Energy and Water Development Appropriations Act for fiscal 2024 directs the Department to report "…on the resources required and opportunities to triple the number of student participant placements within its current participant programs to support the cross-cutting Department-wide initiatives, such as cybersecurity, artificial intelligence, and quantum information science, and basic and applied research programs."[162]

Recommendations

DOE should consider strengthening its recruiting efforts in the near term, such as by enhancing the terms of tour of service programs for National Laboratory personnel by strengthening job reinstatement policies.

DOE should ensure the effective use of National Laboratory personnel detailed to DOE Program Offices, including the use of executive rotation programs. The process for the use of Laboratory employees could be facilitated by improving policies and procedures for resolving conflict of interest (COI) issues and by reducing the overhead cost charged to these employees.

To address the longer-term challenge of expanding the pool of personnel with appropriate backgrounds in science, technology, engineering, and mathematics (STEM), DOE should encourage efforts by the National Laboratories, including targeting funding support for National Laboratory initiatives to:

- expand the number of fellowships to draw new graduates into clean energy innovation;
- support expanded internship programs at the undergraduate and high school levels; and
- develop educational material on clean energy innovation for inclusion in educational curricula at all levels of education.

4.3 Improving Information Resources: Energy-Related Data Collection and Information Management

The Energy Information Administration (EIA) was established in the DOE Organization Act as a semi-independent office within DOE to provide independent and unbiased data, information, and supporting analysis to the Executive Branch and congressional policymakers.[163] It was established during a period of national energy emergencies focused on oil disruptions, energy price shocks, and concomitant economic recessions. Reliable and independent oil-related data information and analyses, separate from industry-supplied data, were needed to inform policy and gauge effects. Data was also collected on other fossil fuels (gas and coal) and traditional forms of power generation.

> "The increasing integration of new energy technologies into the energy system of today, however, calls for an expanded framework of energy information extending beyond commodity fuel supplies."

The increasing integration of new energy technologies into the energy system of today, however, calls for an expanded framework of energy information extending beyond commodity fuel supplies. Energy markets are moving rapidly toward new paradigms of energy supply and demand. The expansion of the DOE mission into the demonstration and deployment of innovative technologies presents new challenges for the DOE/EIA information collection and management portfolio.

Currently, data surveys, collection methods, and systems dedicated to non-conventional forms of energy production, distribution, storage, and end-use pale by comparison in terms of sources, breadth, depth, and frequency.[164] Current EIA data collection surveys include:

- 26 separate surveys of data on petroleum supplies, including 9 weekly surveys as well as monthly, annual and a quadrennial survey;
- 5 separate surveys of the domestic coal industry, including weekly, quarterly and annual reporting;
- 2 surveys of alternative fuels, including biodiesel;
- 2 surveys of renewable energy—biomass fuel and solar PV module shipments; and
- only 3 surveys of energy end-use consumption by customer segment, and due to budget restrictions, the surveys are conducted only once every four years.

Data on deployment of renewable electricity, as well as other end-use customer data, is collected by the National Laboratories, primarily at the National Renewable Energy Laboratory (NREL) and Lawrence Berkeley National Laboratory (LBNL), funded through various program offices within the DOE EERE organization. Other National Laboratories also collect and maintain specialized databases funded by program offices, such as the data on carbon sequestration maintained by the National Energy Technology Laboratory (NETL). It is not clear what methodologies and data quality standards are applied, and how they compare to general EIA protocols.

The expansion of the DOE mission space in technology demonstration and deployment resulting from the BIL and IRA will mean new requirements for data collection and information management. For example:

- Creating **new jobs in new energy industries** will require further evolution of the DOE Energy and Employment Report annual survey, as well as ongoing work with the Department of Labor to work toward establishing new job categories that reflect the clean energy transition;
- Collecting data on **domestic metals and minerals production, processing, and markets** will require substantial expansion of the current U.S. Geological Survey (USGS) data collection on mineral resources and reserves, updates to the methodologies for characterization of reserves, integration into DOE supply chain policies and programs, and coordination of data collection with Canada;
- Electricity markets encompass increasingly complex behind-the-meter and off-grid applications. Smart Grid Deployment and its attendant policy and regulatory issues will require expanded data sets on both **distributed electricity generation and energy use patterns behind the meter**;
- Carbon Capture, Utilization, and Storage (CCUS) technology demonstrations, Hydrogen and DAC Hubs, and other Carbon Dioxide Removal (CDR) activities will require more comprehensive data sets on **direct carbon capture and storage and carbon removals** than currently provided through the EIA Voluntary Reporting of Greenhouse Gases program and related the Environmental Protection Agency (EPA) national emissions inventories; and
- Monitoring administration policy directives and congressional mandates to ensure that BIL and IRA investments are fostering **energy community benefits** and meeting social and environmental justice policy objectives may require a new program of community surveys.

Finally, additional data collection will be required in order to better monitor, evaluate, and ***project the scope and pace of energy innovation throughout the economy***. The pace of innovation—introduction of new technologies, rates of market diffusion, and cost reduction potential—plays heavily in the EIA Annual Energy Outlook and related assessments. As the pace of energy innovation quickens, these factors will become even more important to the energy projections that form the basis for national energy policy deliberations. More comprehensive and transparent data collection and assessment programs will be required to improve the technological innovation inputs to these projections and assessments.

The BIL provided specific, detailed authorizations for new EIA data collection and information management programs in several of these areas.[165] In particular, the BIL authorized:

- expansion of data collection on the bulk power system, including the establishment of a “Dashboard;”
- expansion of the scope and frequency of energy consumption surveys, including the Manufacturing Energy Consumption Survey, the Commercial Building Energy Consumption Survey, and the Residential Energy Consumption Survey;
- a plan for the modeling and forecasting of demand for minerals used in the energy sector. (EIA is currently finalizing an interagency agreement with the U.S. Geological Survey to coordinate data collection and information on domestic energy-related metals and minerals); and
- a data collection program on electric vehicle integration with the electricity grids.

The legislation also encourages EIA to adopt new data collection methods and tools to implement its new and expanded responsibilities. For example, the requirements for the consumption surveys should consider methods and tools to obtain more comprehensive data and reduce the burden on survey respondents, including the use of existing data sources and online and real-time reporting systems.

Recommendation

EIA, working in collaboration with stakeholders, should lead a comprehensive, top-to-bottom review of its existing data collection, analysis, and information programs. The review should include all current on-going data collection and information management programs within the Department. The review should identify priority needs for new and expanded data collection and information management activities aligned with the energy transition. The review should also identify lower-priority existing data collection and information management activities that could be curtailed in order to repurpose existing resources and capabilities.

4.4 Financial Resources: Strengthening Financial Management and Accountability

The BIL and IRA provide new, firm, multi-year funding authority for specific major demonstration and deployment initiatives. Such funding supplements the ongoing annual discretionary appropriations funding for the base DOE fundamental and applied energy RD&D programs. While this new funding authority provides greater certainty for cost-sharing of large demonstration and deployment projects, it creates new challenges for planning, budgeting, and managing an integrated energy innovation portfolio.

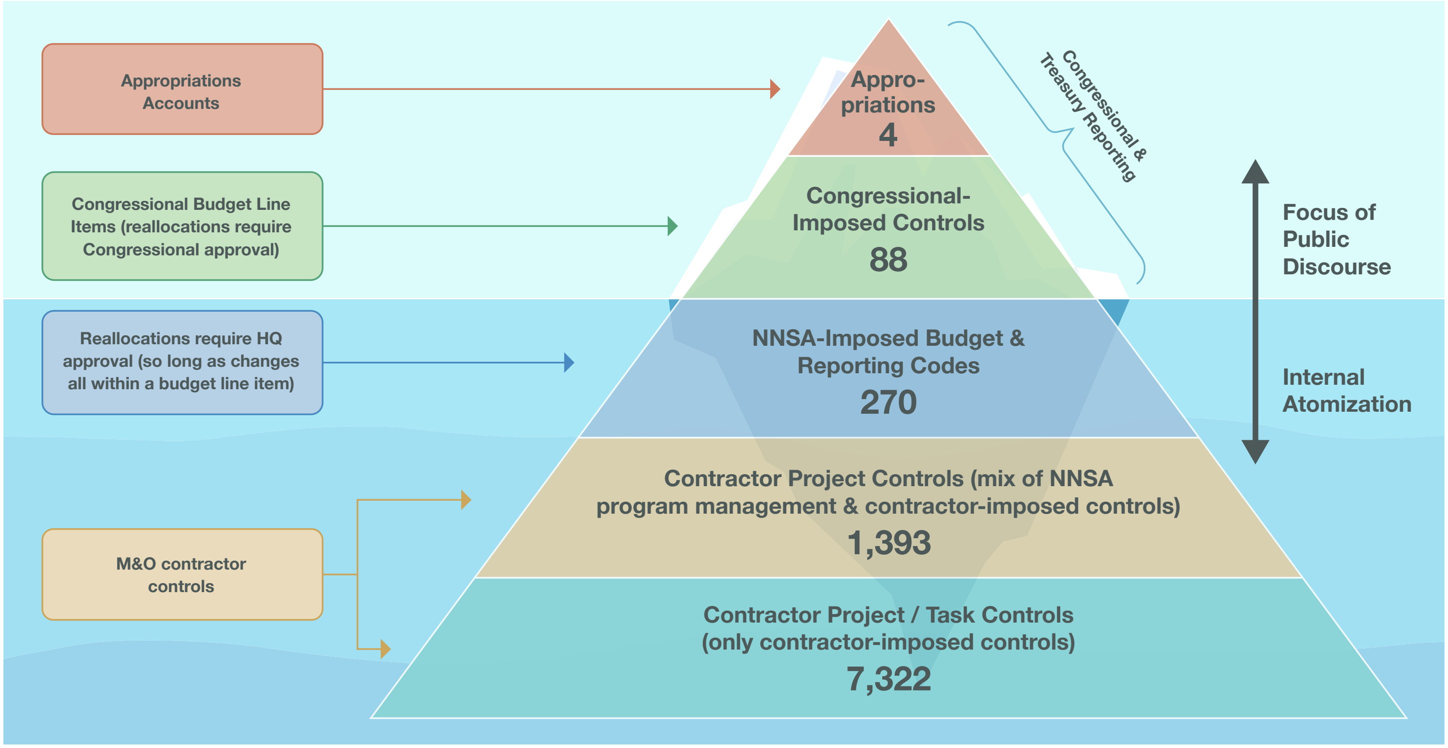
The *budget planning* process will require a well-defined multi-year budget that incorporates both annual funding needs as well as expenditure plans for the multi-year appropriations provided in BIL and IRA. The budget plan should flow from and support a comprehensive energy innovation RD&D portfolio strategy. It will also need to reflect a performance plan that links the requirement for increased financial resources to the potential for more rapid and robust energy innovation outcomes. The principal challenge has been the inability to fit bottom-up energy innovation program planning and budget estimates into constrained top-down government-wide spending caps needed to meet budget deficit reduction targets. The lack of agreed-upon multi-year budget caps further hinders the ability to conduct multi-year budget planning.

DOE financial management processes (i.e., *budget execution*) will also require new approaches to enable managing an expanded energy innovation budget that includes both firm multi-year funding as well as annual discretionary appropriations. Sound financial management requires a balance between flexibility and accountability.

The current DOE financial management framework is organized around an ever-increasing number of discrete budget control points. While most of the attention is drawn to congressionally imposed budget control points, these are only the tip of the iceberg; control points are further disaggregated by the DOE program offices (at both Headquarters and the field office level) and further disaggregated by the Management and Operating contractors at the National Laboratories. This process of disaggregation, sometimes referred to as budget atomization, was examined in detail by the *Commission to Review the Effectiveness of the National Laboratories.* Figure 12, drawn from that report, illustrates the process of budget atomization in NNSA and exemplifies how controls can dramatically increase as funding management is delegated in the organization.[166]

FIG. 12

DOE Control Levels for a Representative Contractor within the National Nuclear Security Administration (NNSA)



Budget controls can rapidly grow as they flow down to the contractor level. These controls can stifle innovation and limit program flexibility and effectiveness. Public discourse and appropriators tend to focus on congressional controls, while internal atomization is much less visible.

Adapted from: See first figure mention in text for sources.

Budget atomization provides reporting detail and accountability in budget execution. It also can provide insights to identify opportunities for re-prioritization. However, if the process for reallocation across these control points is too cumbersome, it can diminish the ability to optimize funding across an integrated suite of RD&D projects, as well as the agility to reposition funding to adapt to rapid changes in the innovation landscape.

The budget execution framework can be further restricted by OMB controls (i.e., apportionments) over the obligation of appropriations, including restrictions on the rate at which funds can be obligated within a fiscal year.

DOE has sought to balance the needs of flexibility and accountability by aligning allotments of funds for execution to only the control points established in Congressional Appropriations Committee Reports and OMB apportionments. This approach provides greater flexibility for program managers in headquarters, field offices, and at the National Laboratories to adjust spending levels during the course of the fiscal year.

Any proposed reallocation of appropriated funds among congressionally established control points (typically the budget line items specified in appropriation committee reports) requires a reprogramming action that must be reviewed and approved by the DOE Chief Financial Officer (CFO), by OMB, the relevant congressional authorizing committees, and ultimately the congressional appropriations committees. The Congressional review process statutorily is no less than one month, but it can be much longer. If the proposed reprogramming requires the movement of funds from one appropriations account to another, then a legislative amendment must be enacted by Congress. The problems with budget execution and sound financial management are further exacerbated by the breakdown of the annual budget and appropriations process and the increasing reliance on continuing resolutions to provide temporary government-wide funding solutions.

The challenges of adapting financial management and controls to an increasingly fast paced innovation environment is not unique to DOE. The Department of Defense (DOD) faces similar challenges in adapting its R&D and acquisition programs to exploit the rapid pace of innovation in technologies that have significant potential benefits to national security. This issue has been examined in depth by the Congressionally chartered Commission on Planning, Programming, Budgeting, and Execution Reform. The Commission's Interim Report identified 10 potential recommendations for stakeholder inputs and further assessment. These recommendations include steps such as consolidating the number of line items in the DOD budget and modifying the thresholds governing reprogramming actions.[167] Resetting reprogramming guidelines also was identified as one of 10 recommendations needed to accelerate innovation within DOD by another special panel, the Atlantic Council Commission on Defense Innovation Adoption.[168]

Accountability for efficient expenditure of taxpayer funds is a paramount objective. Accountability can be maintained and enhanced through performance-based metrics to assist management oversight. The magnitude of new spending and loan programs from the BIL, IRA, and CHIPS and Science Act require close monitoring. An internal analysis from the DOE Office of Inspector General (OIG) identified that previous DOE programs had overlooked project controls such as performance measurement due to, among other things, insufficient federal staffing. However, the BIL caps administrative expenditures at 3%.[169] The report and supporting analyses do not make recommendations but state that it is imperative that DOE implement adequate oversight procedures given that substantial BIL funding is already moving through the Department. OIG concludes that "Department officials have informed the OIG that the Department is taking steps to improve its fraud prevention and detection controls, interagency collaboration, project management, and technical assistance, among other things."[170] For instance, the Office of the Chief Financial Officer (OCFO) will develop a new data dashboard to support the reporting of life cycle funding for IIJA and IRA.[171]

Other efforts to increase accountability in financial management are: establishing a more formalized effort to periodically evaluate program implementation performance; and providing independent advice to the Secretary and information to policymakers and stakeholders on program and budget realignment.

Recommendations

DOE should develop an integrated multi-year budget plan to support a strategic, integrated energy innovation RD&D portfolio plan. Recognizing the uncertainties in the overall federal budgetary outlook, the DOE budget plan should identify optional funding paths to prioritize RD&D needs at alternative funding levels and identify strategies for agile implementation to respond to changes in the fiscal outlook. (The role and the content of a multi-year budget plan to support an energy innovation strategic portfolio plan is discussed in more detail in a subsequent section).

The Administration (DOE and OMB) should work with the appropriations committees to establish a process to enable administrative action to transfer funding across appropriation accounts and develop a streamlined process for acting on reprogramming requests, with particular focus on greater flexibility to reallocate funding within defined crosscutting RD&D initiatives.

DOE, through the CFO, should enhance transparency in program implementation and performance by expanding the content and the frequency of its program performance and financial management reporting to OMB, Congress, and the public.

DOE, through the CFO, should strengthen the current performance management and evaluation processes, including: (1) increasing the staffing and budget resources for performance management and evaluation programs; and (2) establishing outcome-based program performance measures with particular emphasis on BIL and IRA expenditures.

4.5 Performance Measurement and Impact Assessment

Ensuring financial integrity in the implementation of the BIL, IRA, and Chips and Science Act is a paramount objective, as discussed in the previous section. Tracking expenditures and providing accurate and timely reporting on financial performance is essential. Equally essential will be reporting on the impact of those expenditures.

“Tracking expenditures and providing accurate and timely reporting on financial performance is essential. Equally essential will be reporting on the impact of those expenditures.”

The long-term value of these investments will be realized in terms of macroeconomic, energy, and environmental measures such as greenhouse gas emissions reductions, energy security indices, measures of job creation and job quality, collateral economic development, economic competitiveness, consumer benefits, and socio-economic dynamics.

Historically, LPO and ARPA-E have developed and applied metrics to measure the impact of their respective programs. ARPA-E reports on metrics such as follow-on funding of successful ARPA-E projects and patents and IP licensing agreements resulting from successful ARPA-E projects. LPO reports climate (metric tons of CO_2 displaced) and job impacts attributable to LPO-supported projects.[172] OCED is currently developing similar metrics for reporting on its demonstration projects. Such efforts should be expanded in scope and applied uniformly across all programs receiving BIL, IRA, and CHIPS and Science Act funding. In addition, DOE could periodically update and make public such information on program impacts. The Government Performance and Results Act (GPRA) Modernization Act of 2010 provided statutory direction for federal agencies to strengthen performance management by setting outcome-oriented performance goals and objectives. This framework could provide a starting point for developing and implementing a more robust performance management and reporting program. The reporting regime that was put in place for the implementation of the American Recovery and Reinvestment Act of 2009 also could provide a model.

The project-specific reporting can be expanded to include broader studies on the impacts of various programs as a whole. Such studies would become feasible in the future as projects are implemented and learning experience is gained, disseminated, and incorporated into broader-scale deployment. The history of the National Academy of Sciences retrospective and prospective reports on the benefits of DOE energy efficiency and fossil energy research could be instructive in the planning of such future studies.[173,174]

The ability to measure outcomes resulting from RD&D investments is challenging. NSF is exploring new methodologies to do so as part of a new $30 million initiative, Assessing and Predicting Technology Outcomes, or APTO.[n] The program will fund research to evaluate the effectiveness of research and development investments and create models and information for decision-makers to optimize investments and advance U.S. competitiveness in the long term. APTO will be managed by the new NSF Directorate for Technology, Innovation and Partnerships (TIP), and will focus on the key technology areas outlined in the CHIPS and Science Act, including energy. A collaboration between DOE and NSF could be beneficial in developing new tools for assessing the impact of new DOE RD&D investments under the BIL, IRA, and CHIPS and Science Act.

Recommendations

DOE should develop and implement a Department-wide program of impact metrics to measure the impact of the BIL, IRA, and CHIPS and Science Act, such as GHG emissions reduction and job creation.

DOE, through the CFO, should develop and implement a plan of program evaluation studies that can provide a comprehensive assessment of the impacts of BIL, IRA, and CHIPS and Science Act investments over time.

[n] Assessing and Predicting Technology Outcomes (APTO)
Source: NSF - National Science Foundation: https://new.nsf.gov/funding/opportunities/assessing-predicting-technology-outcomes-apto

05 Clarifying the Protocols for International Energy RD&D Engagement

International collaboration is one of the essential building blocks that can be used to accelerate progress in creating, piloting, demonstrating and deploying, and disseminating innovative clean energy technologies. International collaboration in energy innovation RD&D plays an integral role in the success of American clean energy innovation. Nonetheless, international collaboration in energy RD&D faces numerous challenges and complications.

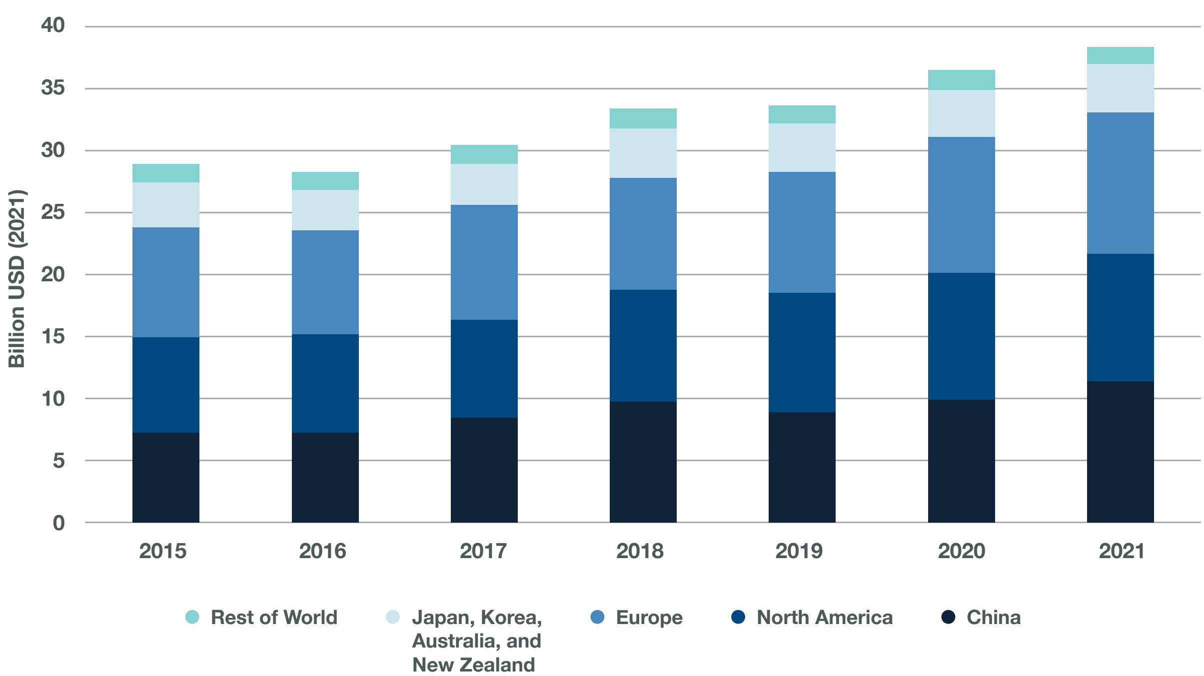
The COVID-19 pandemic, compounded by the Russian invasion of Ukraine, has exposed the national security and energy security risks that can arise in cases of disruption of global supply chains and import dependence. In turn, congressional action in both the Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA) incentivizes increasing domestic content in U.S. infrastructure and in emerging domestic energy technology markets such as offshore wind, energy storage, electric grid modernization, and electric vehicles. In this sensitive context that surrounds international collaboration, a careful pursuit of American strategic priorities is merited. It is timely to adjust how, with which partners, and on what terms taxpayer-supported collaborations are maximized, but international collaborations remain a core tool for achieving national objectives on clean energy.

5.1 The Current International Landscape of Clean Energy Innovation RD&D

The International Energy Agency (IEA) estimates the total global public investment in the energy RD&D portfolio to be $38.4 billion in 2021, with a cumulative total public investment of $230 billion over the past 6 years, as shown in Figure 13.[175,176]

FIG. 13

Global Government Spending on Energy RD&D, 2015-2021



This figure shows how various governments around the world invest in energy RD&D.

Adapted from: See first figure mention in text for sources.

Among the most visible international collaborations in energy RD&D is Mission Innovation (MI), a global initiative to accelerate public and private clean energy innovation to address climate change, make clean energy affordable to consumers, and create new clean energy jobs and economic development opportunities. Launched at the UNFCCC Conference of the Parties (COP21) meeting in Paris in November 2015 in concert with its private sector companion Breakthrough Energy, one core initial objective of MI was to significantly increase – double – the level of public investment in clean energy RD&D. It is estimated that the MI members combined account for over 80% of the world's clean energy RD&D investment. MI now includes 23 countries and the European Commission.

In June 2021, MI members launched Mission Innovation 2.0, intended to guide an ambitious second phase effort.[177] The Vision Statement for MI 2.0 calls for stronger collaborative measures, including the development of National Innovation Pathways by each member, the establishment of an Innovation Platform for tracking and analyzing global innovation progress and enhancing knowledge-sharing, and the establishment of a new Technical Advisory Group.

Mission Innovation 2.0 provides a strong foundation for DOE international energy RD&D collaboration over the next five years, in particular by promoting close alignment of several Mission Innovation Challenge areas with DOE Earthshots™ initiatives.[o]

5.2 The Benefits and Risks of International Clean Energy RD&D Collaboration

International collaboration today already brings powerful benefits to the U.S. as a whole and to the American clean energy innovation enterprise in particular. These benefits include: available and talented personnel; enhanced research bandwidth; cross-fertilization of ideas and approaches; the ability to leverage foreign support for pilot studies and demonstrations; cost-sharing with foreign partners; market opportunities that can help yield economies of scale; openings for diplomatic leadership; and the ability to build soft power.

The global clean energy market is potentially the largest-ever strategic opportunity for American innovators and companies. To tap into this market, thereby accelerating the decarbonization of global energy systems, international collaboration in clean energy innovation must be sustained and indeed expanded with a new sense of ambition.

The U.S. supports clean energy collaboration with foreign countries and international organizations for a variety of reasons and through a variety of programs. Sometimes, the achievement of specific clean energy objectives is the singular goal of a given collaboration. In other cases, clean energy topics form only part of ongoing diplomatic, science and technology, or energy dialogues with certain countries. In some instances, these dialogues enable the U.S. government to engage with clean energy dialogue partners for whom climate protection is not a prime policy objective but who are open to exchanging ideas on clean energy as part of a broader agenda.

International collaboration entails a number of risks that must be managed with a clear-eyed focus in order to make good on the promise of effective international collaboration. These risks include threats to American innovators' intellectual property and economic competitiveness and even threats to national security. Countries supporting international clean energy collaboration, particularly the U.S. and China, sometimes have conflicting motivations for approaching potential energy innovation collaborations. On

o Mission Innovation Challenge areas can be found here: http://mission-innovation.net/missions/

the one hand, each country can learn and leverage the other's technical capabilities and knowledge. Many international philanthropic institutions and investment funds engage international partners as funders, implementers, and recipients of grants or investments.

On the other hand, each country, to a certain degree, is competing to develop the next generation of energy technologies and systems that can advance their respective domestic economies and expand export markets to the rest of the world. China has also established, through its *Made in China 2025* policy, formal goals for dominating a variety of high-technology industries in a way that creates critical clean energy supply chain vulnerabilities for the U.S. and its allies.

5.3 Guiding Principles for International Clean Energy RD&D Collaboration

A clear set of guiding principles is needed to navigate future international clean energy RD&D collaborations in the current challenging political environment. The following are objectives that should motivate and guide redoubled international collaboration for clean energy innovation:

1. **Promote mutual familiarity with international innovation processes, innovative U.S. technologies, and global markets.** Technical assistance (including through bilateral programs of DOE, the National Laboratories, the United States Agency for International Development [USAID], and the State Department) can foster understanding, especially in developing countries, of clean energy technologies and practices. Many of these technologies or practices originate in the U.S. Voluntary multilateral initiatives such as the Clean Energy Ministerial, Mission Innovation, and State's First Movers Coalition can serve as enablers that prove decarbonization is within reach for countries with limited resources and industries that have often been referred to as "hard-to-abate." By engaging with international partners through these technical and policy initiatives, the U.S. can make innovative U.S. clean energy technologies familiar and well-known to buyers around the globe, facilitating forward progress on a more global basis. Equally important, such engagements can facilitate American innovators' awareness of the specific needs of global markets—especially in developing countries, where emissions will otherwise increase as young and dynamic economies grow.
2. **Protect national security and U.S. competitiveness.** While it is the interest of the U.S. to leverage the scientific knowledge, technical advances, and deployment experiences of other country governments' investments in clean energy, a prerequisite for collaboration is the protection of national security and U.S. competitiveness. The benefits of a well-designed and effectively managed collaboration can be significant and may be essential. In each case, however, the risks of such collaboration must be reviewed by informed officials and weighed against sensitivities and expected benefits.
3. **Lead in international standard-setting.** International energy RD&D collaborations can put the U.S. in a leadership role in establishing worldwide technology standards, protocols, and data for clean energy, as these standards will create the frameworks for American clean energy innovators' interaction with global competitors. This effort will require intensified engagement by DOE, the National Laboratories, the Department of Commerce (especially the National Institute for Standards and Technology), the Department of State, and other agencies. Standards, protocols, and data are the foundations upon which clean energy innovation and deployment will rest. Pace-setting voluntary initiatives like the *First Movers Coalition* and the *Clean Energy Ministerial Industrial Deep Decarbonization Initiative* can help build the case for strong and ambitious standards (in addition to encouraging the dissemination of industry-leading practices). DOE investments in personnel, diplomacy,

funding, and technical analysis in collaborations can drive technically sound, objectively defined clean energy technology standards so that U.S. innovators can thrive and lead.

4. **Help other countries identify and solve problems.** U.S. institutions (federal agencies, National Laboratories, research universities, and companies) can make the greatest contribution to the widespread, global adoption of innovative clean energy technologies by assisting other countries in meeting their specific national and regional needs for the clean energy transition. Innovative clean energy technologies face inherent obstacles because of the very fact that they are innovative—and thus less familiar to the average decision-maker. Deploying clean energy solutions successfully requires a variety of inputs: familiarity with innovative technologies, effective policies, sufficient finance, and trained personnel. DOE leadership in assisting foreign partners in identifying and addressing their own needs and choices can yield significant benefits for the U.S. by, among other things, creating export opportunities, reducing global emissions, and enhancing soft power. The *Net Zero World Initiative* aims to focus its efforts on this space. Delivering finance tools for developing countries' clean energy projects is another vital but particularly challenging requirement. Fostering and sustaining sound business practices is also vital for support of innovation in emerging economies.

5. **Recognize trade as an enabler for climate solutions.** American clean energy innovation can bring new technologies to the U.S. market, an important and sizable source of both GHG emissions reductions at present and business opportunities going forward. However, only through international trade can American innovation reach foreign markets, the playing field on which the global climate challenge will be won or lost. Trade policy is thus an essential tool for success in creating, demonstrating, refining, and disseminating clean energy solutions. At present, trade policy is subject to criticism in the U.S., some of which are for good reasons, e.g., unequal market access and non-observance of human and worker rights.

5.4 | Outlook for International Engagement in Clean Energy RD&D Collaboration

U.S.-China interactions in energy innovation have emerged as the single most challenging issue in the field of international energy RD&D collaboration.

The outstanding concerns over Chinese foreign and domestic policy issues cannot and should not be overlooked. Nonetheless, China is the single largest emitter of greenhouse gases in the world. It invests heavily in clean energy innovation and deployment. Its industrial base plays a dominant role in most clean energy technology niches—from critical minerals to solar panels and from electrochemical batteries to nuclear power plants. Moreover, as has been demonstrated so vividly by the scores of coal-fired power plants constructed under the *Belt and Road Initiative*, China's engagements with foreign partners have the potential to have significant impacts on global GHG emissions trajectories. For all these reasons, a targeted dialogue with China on climate mitigation and adaptation is in the interests of the U.S. Maintaining channels of communication with China can allow for a better mutual understanding of each other's priorities and concerns.

While not as acute, new tensions have also emerged with the European Union (EU). The passage of the IRA, with its broad array of new federal incentives combined with domestic labor and content requirements, is causing the EU to consider similar measures. Ongoing discussions within the EU on possible carbon border adjustments also give rise to concerns about diminished international trade flows. These efforts have the potential to create spillover effects that could dampen clean energy RD&D collaboration and information sharing at a time when emerging markets for innovative energy technologies such as hydrogen and carbon capture and storage could greatly benefit from information sharing. On the other hand, the U.S. and the EU are working to find ways to accommodate the different policy structures in their respective jurisdictions. If they succeed in this effort, they may establish models that enable new, high-quality trade in clean energy technologies, which might even be expanded to involve other countries over time (such as through the proposed Global Arrangement on Sustainable Steel and Aluminum).

The larger foreign policy issues affecting relationships within the global community will have an ongoing impact on policies for international collaboration in energy innovation RD&D. Nonetheless, collaboration in clean energy RD&D can have net benefits to the U.S. if risks are clearly identified and carefully managed. With proper risk management, the benefits to American innovation and to the nation as a whole can far outweigh the risks. The U.S. should play "offense" in order to build policymaker and public awareness of the positive impacts that can result from well-planned and well-executed international collaboration on energy innovation. In view of the current concerns, especially with China, clearer rules of the road, with appropriate guardrails, are needed.

Recommendations

The White House Office of Science and Technology Policy (OSTP), with advice from the President's Council of Advisors on Science and Technology (PCAST) and the staff of the National Security Council, should lead an interagency effort to develop a new Presidential Executive Order to enable and guide international clean energy innovation RD&D collaborations of DOE and other federal agencies. This order should mandate and guide actions by federal agency leaders to establish policies and procedures to manage risks effectively in order to allow the U.S. to reap the benefits of prudently executed international clean energy collaborations.

The U.S. should continue to support Mission Innovation as a principal vehicle for international clean energy RD&D collaboration.[p] The U.S. should develop a proposal and seek to build support from other country participants in Mission Innovation for a third phase of the initiative (MI 3.0) that includes greater emphasis on demonstration and deployment. In addition, the U.S. should continue to permit its research community to enter into individual research collaborations within each of the MI focus areas based on the merits of each individual collaboration.

The U.S. should renew its commitment to increase public investment in clean energy RD&D and expand the scope of that commitment to include all public investment in its calculus, including federal, state, and local governments.

DOE should develop department-wide policies and procedures to share information on the results of DOE-funded energy technology demonstration projects with other countries willing to share the results of their own demonstration projects. The initial focus of these efforts should be sharing information on hydrogen deployment projects, CCUS technology demonstrations, and CDR projects.

[p] Under the previous Federal Administration (2017-2021), the U.S. elected not to deliver on Mission Innovation's initial goal of doubling public investment, although other MI partners did. Such a formalized budgetary goal will no longer secure support from MI partner countries, especially in the wake of the fiscal strains arising from the COVID-19 pandemic, Russia's invasion of Ukraine, and the current energy crisis. However, an agreement to press for a general increase in public investment may be attainable.

06 Envisioning a Future DOE for Long-term Success

The experience gained by implementing the new authorities and programs, combined with the lessons to be learned from the continued evolution of cross-Department planning efforts such as the Joint Strategy Teams and the RD&D crosscuts, will further elucidate opportunities for realigning the U.S. Department of Energy (DOE) organizational structure. The development and implementation of a portfolio-based RD&D strategic plan framework will also help in identifying organizational challenges and opportunities. Together, they can provide a pathway to an even more effective future energy innovation enterprise.

6.1 | Establishing a National Energy Innovation Strategy and Comprehensive Energy RD&D Portfolio Plan

The DOE Organization Act of 1977 required the President to prepare and submit to Congress a National Energy Plan every two years.[178] This requirement has been met at least once by each Presidential administration, but the nature and timing of each submission has varied considerably.

In 2010, the President's Council of Advisors on Science and Technology (PCAST) recommended the Administration establish a Quadrennial Energy Review (QER) process.[179] In 2014, the Obama administration turned this recommendation into action.[180] The QER was developed in two installments (2015 and 2016) through an interagency process directed by President Obama and co-chaired by the Director of the Office of Science and Technology Policy and the Director of the Domestic Policy Council, with the Secretary of Energy serving as the "executive agent" and the DOE Office of Energy Policy and Systems Analysis leading the analytical work and writing. The QER process was highly transparent, with a number of public workshop meetings and whitepapers, and the recommendations received a positive response. Eighteen months after the release of the first QER installment, addressing Energy Transmission, Storage, and Distribution Infrastructure, 29 of the 63 recommendations were fully implemented, and another 21 were underway; 21 recommendations were fully or partly enacted into law.[181] There have since been calls from private sector energy innovation leaders to reinstate the QER process.[182]

A comprehensive national energy strategy can provide the foundation for the development of goal-driven energy innovation RD&D portfolio planning. The Energy Policy Act of 2005 provided congressional guidance on the development of a strategic portfolio plan. The Act required DOE to develop and submit to Congress a *"Strategic Research Portfolio Analysis and Coordination Plan"* every four years.[183]

A multi-year strategic portfolio RD&D plan provides a strong justification for obtaining congressional approval of significant resource increases. A number of major studies have called for doubling or tripling energy innovation RD&D. Many of these recommendations were based on external top-down benchmarks such as percentage of GDP rather than a detailed bottom-up set of RD&D program plans and priorities. Since the initiation of Mission Innovation in 2015, Congress has provided continued growth in annual appropriations funding for DOE Science and Energy RD&D budgets, but at a rate that would approach the Mission Innovation doubling commitment over a 10-year period rather than the 5-year period called for the initiative (See Text Box 3).

The Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA) provide a significant one-time infusion of funding for an initial round of demonstration projects. Further growth in future DOE energy science and energy RD&D budgets will be needed to complement the initial BIL and IRA programs and to appropriate funding authorized in the CHIPS and Science Act.

BOX 03

The DOE Science and Energy RD&D Budget

A number of major studies have called for significant increases in the level of federal investment in energy innovation.

- A 2010 report by the President's Council of Advisors on Science and Technology (PCAST) recommended a target level of federal investment in energy innovation of 0.8% of the U.S. economy.[184] This target would have required more than a doubling of federal investment at that time.
- A 2015 report from the American Energy Innovation Council recommended an increase of two times to three times the 2015 energy RD&D budget.[185]
- In 2015, the U.S., along with 19 countries (now 25) and the European Commission, formed Mission Innovation, pledging to double each country's public investment in energy innovation over the five-year period from 2015 to 2020. The U.S. estimated at that time a federal government-wide baseline of $6.4 billion in FY2015.[186]
- A 2020 joint report by the Columbia University Center for Global Energy Policy and the Information Technology and Innovation Foundation recommended tripling total federal investment in the U.S. energy innovation portfolio over five years, with a first-year increase of $3 billion, or 30%, from a FY2020 estimated base year level.[187] The proposed RD&D portfolio was organized around ten technology pillars that included four other federal agencies in addition to DOE.

The DOE science and energy RD&D budget has continued to receive increased annual appropriations from Congress over this time, rising by almost two-thirds over an eight-year period, as shown in Figure 14.[188]

FIG. 14

Historical Trends in the U.S. Department of Energy Science and Energy Innovation Budget

This figure shows appropriations to the U.S. Department of Energy science and energy innovation programs over 10 years. The horizontal dotted line indicates a doubling of the FY15 budget. FY24 numbers are a budget request only and will likely change in the Congressional appropriations process.

Adapted from: See first figure mention in text for sources.

Over a decade ago, the FY2012 Appropriations Act report directed DOE to submit to Congress with its annual budget request a future year's RD&D program and budget, beginning with the FY2014 budget.[189] Only one such plan was submitted to Congress, with the FY2018 budget at the end of the Obama Administration.[190] The Portfolio Plan provided five-year projections that supported the Administration's Mission Innovation commitment to double the level of public investment in energy RD&D over five years. It became infeasible to submit plans in other years because the President's budget out-year projections have been typically set by OMB on a largely top-down and sometimes formulaic basis, making it difficult to reconcile with program plans developed on a bottom-up basis. This continuing issue has now led to directives from both the House and Senate Appropriations Committees for a follow-up investigation by the Government Accountability Office.

A principal outcome of a comprehensive portfolio planning process is the identification of priority RD&D areas. Recent studies have identified many areas of consensus on energy innovation priorities, but differences remain that could have noteworthy implications for resource allocation. A comparison of the priority energy technology areas identified in several reports from various government and energy policy research organizations is presented in Table 4.[191,192,193,194,195]

TABLE 04

Energy Innovation Priorities Identified in Government and Energy Policy Sources

INNOVATION OPPORTUNITIES	DOE CROSSCUT	EFI/IHS REPORT	COLUMBIA/ITIF ENERGIZING AMERICA STUDY	WHITE HOUSE US INNOVATION REPORT	SPECIFIED IN FY23 APPROPRIATIONS BILL	DOE EARTHSHOTS™
Advanced Manufacturing	+	+				
Biotechnology	+					
CO_2 Removal	+	+	+	+	+	+
Critical Minerals and Metals	+				+	
Energy Storage	+	+	+	+	+	+
Water-Energy Nexus	+				+	
Grid Modernization	+	+	+	+	+	
Hydrogen	+	+	+	+	+	+
Non-Hydrogen Clean Fuels		+	+	+		+
Industrial Decarbonization	+		+	+	+	+
Advanced/ Offshore Wind			+	+		+
Enhanced Geothermal	+		+	+		+
Advanced Nuclear		+	+	+		

Table 4 shows a variety of technologies and sectors identified as areas of importance for continued innovation and deployment across a variety of sources.

Source: See first table mention in text for sources.

As can be seen from the table, there are areas of consensus as well as areas of differences among the recommendations. The differences arise from the criteria applied in the analytical process.

- The priority areas identified in the 2019 EFI-IHS Markit report were based on the application of four broad criteria viewed as indicators of technologies with breakthrough potential. These criteria included technical merit (i.e., performance potential); market viability; compatibility (e.g., existing infrastructures, flexibility, and extensibility); and consumer value. Five priority areas were identified, including: energy storage, advanced nuclear reactors, difficult-to-decarbonize applications in buildings and industry, electricity grid modernization, and large-scale carbon management. Four of the five (except for nuclear) align with the 10 DOE crosscut areas.

- The November 2022 Administration Report, *U.S. Innovation to Meet 2050 Climate Goals*, identified a total of 37 "Net-Zero Game changers," including ten areas identified as crosscutting initiatives.[196] The report was largely developed by an interagency group of Administration policy experts. The principal criterion for identifying the crosscutting initiatives appears to have been an emphasis on new technological solutions to achieve net zero GHG emissions across all major sectors of the economy. Of the 37 net zero RD&D opportunities, the Administration then prioritized five areas to launch the *Net-Zero Game Changers Initiative.* These areas include: efficient building heating and cooling; Net-Zero aviation; Net-Zero Power Grid and Electrification; Fusion Energy at Scale: and Industrial Products and Fuels for a Net-Zero, Circular Economy. While these initiatives are interagency in scope, the primary locus is in DOE.

The comparison indicates the importance of establishing clear goals and objectives, as well as a set of planning criteria, in guiding the development of a clean energy RD&D portfolio plan. It is also extremely important that the portfolio planning process be transparent and reflective of a broad range of stakeholder perspectives in order to build consensus for support among policymakers.

The strategic RD&D portfolio planning process can be carried out in various ways.[197] In all cases, there is a need for technically qualified staff working at a senior level with the policy and CFO offices. This need could be met under the auspices of a staff-supported RD&D Council comprised of senior DOE leadership; a joint staff within the Offices of the Under Secretaries for Science and Innovation and Infrastructure; or a new staff unit that could operate within the policy office and report directly to the Office of the Secretary. Proven models exist, including processes within DOD and other agencies, as well as prior experiences within DOE.[q]

Recommendation

DOE should develop a comprehensive multi-year energy innovation RD&D portfolio plan with strategic goals, a prioritized portfolio of technologies organized with end-use applications in mind, and alternative pathways to reflect a range of resource needs and potential budgetary outcomes. The planning process should provide for broad stakeholder input. A strategic portfolio plan also will illuminate opportunities for further organizational improvements.

[q] For example, the work of the Office of Program Review and Analysis, reporting to the Assistant Secretary for Policy, DOE, 1990-1993. Another interagency effort, which was supported by a Cabinet-level committee and led by the Secretary of Energy, was the work of DOE's Office of Science and Technology Policy (2002-2006), resulting in the 13-agency "U.S. Climate Change Technology Program Strategic Plan" (https://www.globalchange.gov/reports/us-climate-change-technology-program-strategic-plan). Across the main RD&D funding agencies, this work led to a strategic prioritization of investments and a 3-fold increase in related RD&D budgets, peaking in FY 2008.

6.2 | Analysis of the Current DOE Organizational Structure

Historical Evolution of DOE Organizational Structure: When first established in 1977, DOE was organized along the lines of the linear innovation model, with three major organizational units: an Office of Energy Research, an Office of Energy Technologies, and an Office of Resource Applications (a euphemism for demonstration and commercial deployment). The Energy Research Office was focused on fundamental research and was further subdivided by scientific disciplines such as chemistry and biology. The Office of Energy Technologies supported applied research and development across a broad program portfolio that encompassed all energy fuels and technologies. The Office of Resource Applications supported demonstration and commercial application programs that cut across all energy technology areas and a broad array of energy end-use applications. All three offices reported separately to the Office of the Secretary.

Within the first several years of its existence, constituent pressures led to restructuring the DOE applied technology RD&D programs to delineate and highlight individual fuel sources (e.g., fossil fuels, nuclear, solar). This restructuring diminished competition and integration of the energy technology RD&D portfolio at mid- and senior-level RD&D management and instead enabled each fuel-based constituency to compete for prioritization at the Secretarial level. Each of the fuels-based applied energy RD&D programs is currently headed by a presidentially appointed Assistant Secretary with Senate confirmation. For much of their history, each fuels-based office reported separately to the Office of the Secretary, giving each office a high degree of latitude.

The Reagan administration made significant changes to restrict the role of DOE in later-stage demonstration and deployment activities, abolishing the Office of Resource Applications and adopting a policy of focused long-term, high-risk research that sought to significantly reduce the scope of the applied energy RD&D programs as well. (The Reagan administration subsequently sought to dismantle DOE entirely). This DOE organizational structure remained largely intact through subsequent administrations and congresses. The limited demonstration and deployment activities that survived in DOE were embedded within their respective fuel and technology RD&D program offices.

During the Clinton Administration, Congress enacted legislation to reorganize the nuclear weapons program into a semi-autonomous unit, the National Nuclear Security Administration (NNSA). This change had a ripple effect on the National Laboratories, as they were assigned to report to the semi-autonomous NNSA.

Also, near the end of the Clinton Administration, DOE initiated a major effort to establish a formal Department-wide energy R&D program portfolio planning process. One result of this planning effort was the recognition that the organization of electricity RD&D programs by generating source left a gap in grid-related technologies and solutions. This effort led to a crosscutting assessment of grid-related R&D activities that was subsequently converted to a new Office of Electricity in the Bush Administration.

In 2013, tracking a PCAST recommendation, the DOE Office of Science was co-located with the applied energy RD&D programs under a single Under Secretary to enable closer integration of DOE fundamental research with the other major elements of the innovation process.[198] By comparison, for most of the DOE history, the Office of Energy Science was a separate office that reported directly to the Secretary. The combination was in place for fewer than four years before the Trump administration ended it; the Biden administration has since restored it. The Trump Administration, as part of its policy push to restrict DOE to only early-stage research, also proposed to consolidate all current applied energy technology RD&D offices into a single new Office of Energy Innovation, parallel to the Office of Science.[199]

Current DOE Organizational Structure: The current DOE organizational structure was put in place in 2021 and expanded in 2022, following the enactment of the BIL and in anticipation of what ultimately was enacted in the IRA. The current structure includes an Under Secretary for Science and Innovation that recombined the Office of Science and fuels-based applied energy RD&D programs. The current structure also established a new Under Secretary for Infrastructure.

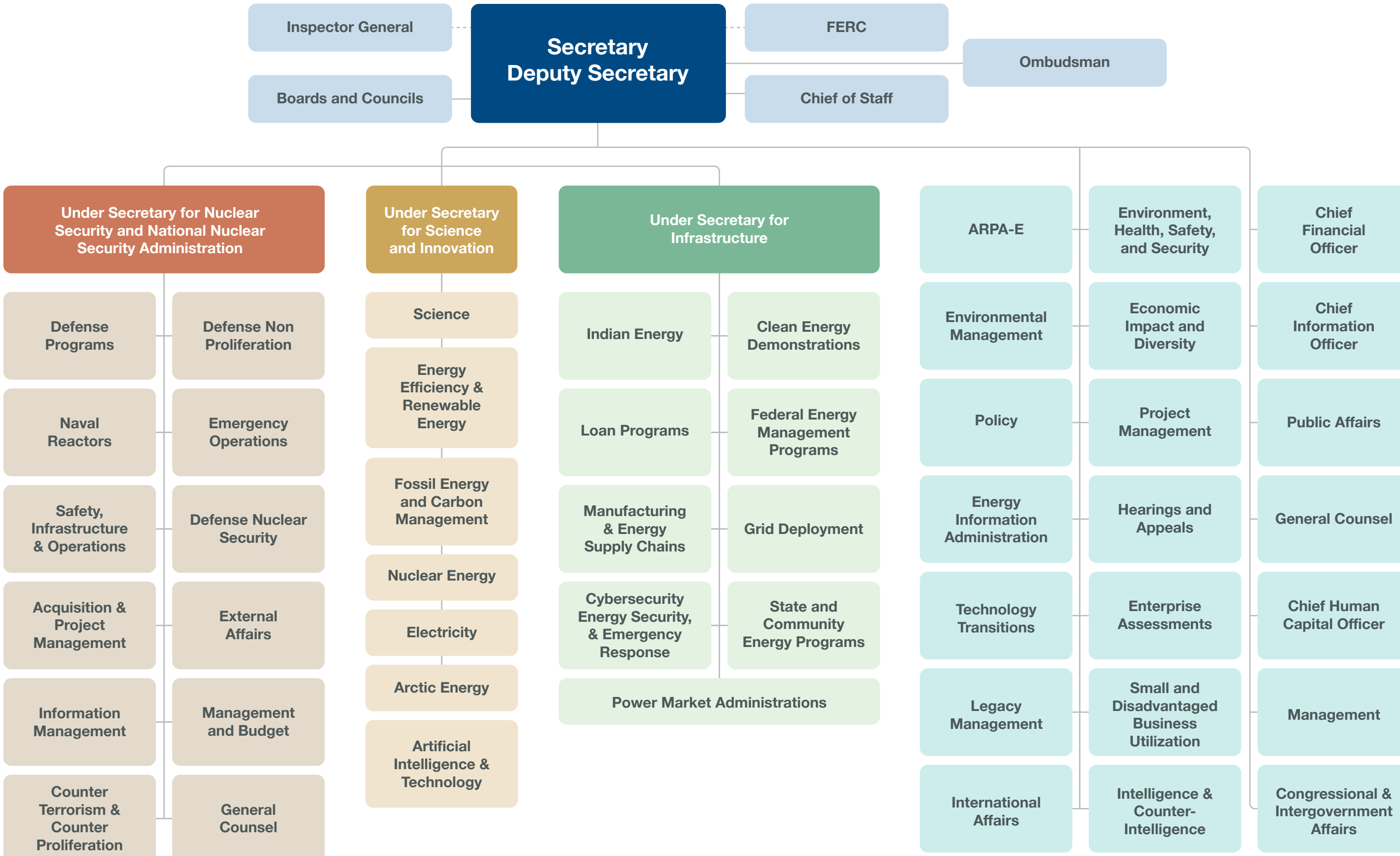
The Office of the Under Secretary for Infrastructure contains a mix of programs that are more market-facing and are focused on demonstration and deployment missions. The individual offices within the Office of the Under Secretary for Infrastructure organization include a mix of some existing programs transferred from the applied energy RD&D offices together with new offices designed to implement the new authorities and programs in the BIL and IRA. These offices include offices with crosscutting technology demonstration and deployment responsibilities (e.g., the Grid Deployment Office, the Loans Program Office) or other crosscutting energy policy and management functions (e.g., Cybersecurity, Federal Agency Energy Management, Supply Chains, State and Local energy programs). Unlike the Office of the Under Secretary for Science and Innovation organization, with multiple presidentially appointed offices, the new Office of the Under Secretary for Infrastructure does not have any presidentially appointed officials, subject to Senate confirmation, below the level of the Under Secretary position itself.

One of the new offices within the Office of the Under Secretary for Infrastructure organization, the Office of Clean Energy Demonstrations (OCED), was established in statute in the BIL. OCED was assigned authority to consolidate management of energy technology demonstration projects, previously the responsibility of the individual fuels-based and end-use-based applied energy RD&D program offices. The OCED establishment was based on analysis and recommendations in the EFI-IHS Markit Energy Innovation Landscape Report and a subsequent report by the Information Technology and Innovation Foundation.[200]

The current DOE organization, shown in Figure 15, reflects a mix of fuels-based, technology-based, and innovation cycle-based program offices.[201]

FIG. 15

Current U.S. Department of Energy Organizational Structure



Innovation-related activities take place across the organization in all three Under Secretary organizations, with energy innovation primarily concentrated in the Under Secretary for Science and Innovation and Under Secretary for Infrastructure organizations, as well as in Department-level offices such as Advanced Research Projects Agency-Energy (ARPA-E) or the Office Technology Transitions.

Source: See first figure mention in text for sources.

The current structure reflects a hybrid of organizational concepts:

- Within the Office of the Under Secretary for Science and Innovation, the applied energy RD&D offices are further subdivided by either fuel sources (e.g., nuclear, fossil), by technologies (e.g., solar, wind), or by end-uses (e.g., buildings, transportation, electricity grid).
- Within the Office of the Under Secretary for Infrastructure, there is a mix of organizational concepts, with a single office of clean energy demonstration projects with a multi-technology portfolio; offices for particular end-use markets (e.g., grid deployment, manufacturing); offices for place-based programs (state and local development, Indian Energy), and offices for crosscutting technologies and supporting services (e.g., supply chain, cybersecurity, and energy emergency management).

Functional Taxonomy of the Current DOE Organizational Structure: Figure 16 presents a taxonomy that illustrates how the current DOE program offices can be classified according to their organizing concept (i.e., fuels, technologies and crosscuts, stage of innovation, and end-use applications).

FIG. 16

Functional Taxonomy of U.S. Department of Energy Programs and Relationship to Organizational Structure

Fuels

- Nuclear
- Solar
- Wind
- Water
- Coal
- Petroleum and Natural Gas
- Geothermal
- Bioenergy

Technology & Crosscuts

- Electricity and Grid Technologies
- Cybersecurity, Energy Security, and Emergency Response
- Energy Storage
- Carbon Management
- Artificial Intelligence and Technology
- Arctic Energy
- State and Community Energy Programs
- Materials

Stage of Innovation

- Science
- OCED
- ARPA-E
- OTT
- LPO

End-Uses

- Building Technologies
- Vehicle Technologies
- Advanced Manufacturing
- Industrial Efficiency and Decarbonization
- Indian Energy
- Grid Deployment Office
- FEMP

Figure 16 illustrates how the current DOE program offices can be classified according to their primary organizing concept – fuels, technologies and crosscuts, stage of innovation, and end-uses. The complex interplay between organizational structure and function underscores the need for effective crosscutting planning and coordination.

Managing Crosscutting Energy RD&D Initiatives within the Current Organizational Structure:

The complexity of organizational structure gives rise to the need for various crosscutting analyses. In some cases, crosscutting analyses are merely compilations of the budgets for activities that are largely managed on a decentralized basis; examples include information technology, cybersecurity, pension cost, training, and education. In the clean energy technology areas, however, crosscutting analyses play a key role in guiding effective program management.

> "Many emerging energy innovation challenges require collaboration across multiple scientific and engineering disciplines. They also require collaboration across the complex organizational structure of DOE Program Offices."

Many emerging energy innovation challenges require collaboration across multiple scientific and engineering disciplines. They also require collaboration across the complex organizational structure of DOE Program Offices that, as illustrated in Figure 16, reflects a hybrid of fuel-specific, technology-specific, innovation-stage specific, end-use specific, and functional-support offices that have been layered into the organization over decades.

The DOE FY 2024 budget request to Congress identified ten crosscutting energy innovation issues. The list of DOE crosscuts, proposed funding levels, and involved program offices are presented in Table 5.[202]

TABLE 05

Crosscutting Technology Programs in the FY2024 U.S. Department of Energy Budget Request to Congress

OFFICE	BIOTECHNOLOGY	CARBON DIOXIDE REMOVAL*	CLEAN ENERGY TECHNOLOGY MANUFACTURING†*	CRITICAL MINERALS AND METALS	ENERGY STORAGE*	WATER-ENERGY NEXUS	GRID MODERNIZATION	HYDROGEN*	INDUSTRIAL DECARBONIZATION*	SUBSURFACE INNOVATIONS*	AFFORDABLE HOME*
ARPA-E	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
EERE	$$	$	$$ ◊	$$ ◊	$$ ◊	$$ ◊	$$ ◊	$$ ◊	$$ ◊	$$ ◊	n/a
FECM		$$ ◊	$ ◊	$ ◊	$		$	$$ ◊	$$ ◊	$	
NE			$	$$ ◊	$	$	$	$	$		
SC	$$	$$	$	$	$$	$		$	$$	$	n/a
OCED		◊	◊		◊			◊	$$ ◊		
OE					$$		$$ ◊				
GDO							$$ ◊				
OTT					$			$			n/a
CESER							$				
NNSA	$										
SCEP											n/a
ED											n/a
FEMP											n/a
OP											n/a
FY24 Proposed Total	907.2	188.0	464.2	403.6	619.7	146.8	785.9	381.7	1,257.9	247.3	n/a
FY23 Appropriations	839.2	163.9	354.9	363.4	600.5	100.6	944.1	417.5	1,006.5	191.2	n/a

* Also an Energy Earthshot™
† Formerly Advanced Manufacturing

▲ TBD (ARPA-E funding determined annually based on priorities)

◊ Received BIL/IRA Funding

$ <$50 million requested in FY24
$$ >$50 million requested in FY24

Crosscutting initiatives typically involve multiple DOE program offices and have a varying degree of investment overall and from specific program offices. Several crosscuts also received funding in the Bipartisan Infrastructure Law and Inflation Reduction Act. Data adapted from FY24 U.S. Department of Energy budget request.

Note - ARPA-E: Advanced Research Projects Agency–Energy; EERE: Energy Efficiency and Renewable Energy; FECM: Fossil Energy and Carbon Management; NE: Nuclear Energy; SC: Science; OCED: Office of Clean Energy Demonstrations; OE: Office of Electricity; GDO: Grid Deployment Office; OTT: Office of Technology Transitions; CESER: Cybersecurity, Energy Security, and Emergency Response; NNSA: National Nuclear Security Administration; SCEP: State and Community Energy Programs; ED: Economic Impact and Diversity; FEMP: Federal Energy Management Program; OP: Office of Policy.

Adapted from: See first table mention in text for sources.

Embedded within the ten crosscutting RD&D initiatives are the 8 DOE Earthshots™ initiatives. The parameters of the Earthshots™, including their association with the larger crosscutting initiatives, are summarized in Table 6 below.

TABLE 06

U.S. Department of Energy Earthshots™

EARTHSHOT	GOAL	TIMEFRAME	ASSOCIATED FY24 BUDGET CROSSCUT
Hydrogen	80% Cost reduction (to $1/kg)	1 Decade*	Hydrogen
Long Duration Storage	90% Cost Reduction (to $0.05/kWh)	1 Decade*	Energy Storage
Carbon Negative	$100/ton	1 Decade*	Carbon Dioxide Removal
Enhanced Geothermal Energy	$45/MWh	2035	Subsurface Energy Innovation
Floating Offshore Wind	$45/MWh	2035	Clean Energy Technology Manufacturing
Industrial Heat	85% GHG reduction (and cost competitive)	2035	Industrial Decarbonization
Clean Fuels & Products	85% GHG reduction (and cost competitive)	2035	TBD (aligns with Sustainable Aviation Fuel Grand Challenge)
Affordable Home	At least a 50% decrease in energy-efficient retrofits in affordable homes and at least a 20% decrease in residential energy costs	1 decade**	TBD

*From Announcement (2021); **(2023)

Table 6 shows basic information on the 8 Energy Earthshots™ announced in the last two years by the Department of Energy and how these Earthshots™ are incorporated into broader crosscuts. Data based on EFI Foundation analysis of the U.S. Department of Energy Earthshots™.

Effective Management of Crosscutting RD&D Initiatives

Effectively planning and implementing crosscutting RD&D initiatives requires intensive management. A clear template delineating formal management structures, coordination processes, and underlying program plans and technology roadmaps is required.

Recognizing the need for more effective coordination of crosscutting initiatives, DOE has evolved a hierarchy of coordination mechanisms. Joint Strategy Teams (JST) have been chartered at the Deputy Secretary level to develop strategies and RD&D roadmaps for priority energy innovation initiatives. The Office of Science and Innovation has established Science and Energy Technology Teams (SETT) to coordinate RD&D planning, primarily focused on the programs and projects within the Science and Innovation organization contributing to the Earthshots™. Other DOE organizations are also involved in SETT teams. Finally, a number of informal coordination teams have been formed to foster collaborations on specific energy innovation topics.

Effective coordination of crosscutting issues can provide significant value in leveraging the resources of various program offices, avoiding unnecessary duplication, and aligning the capabilities of the National Laboratories. Achieving these outcomes, however, requires a well-defined program-level mechanism with clear rules of the road.

A particular focus of increased coordination is the integration of the new responsibilities of the Office of the Under Secretary for Infrastructure for demonstration and deployment programs with the fundamental and applied energy RD&D activities in the Office of the Under Secretary for Science and Innovation. Realization of the benefits of a full end-to-end innovation cycle, including learning by doing, requires effective coordination across these two organizations. The Chairs of the House Committee on Science, Space, and Technology and the Subcommittee on Energy have raised concerns regarding the effectiveness of coordination mechanisms, noting, "Open lanes of communication between the management of demonstration projects and core research and development programs are essential to the success of these investments."[203]

The Senate Appropriations Committee also expressed concerns about a lack of clarity in current coordination mechanisms. The Committee Report on the FY 2024 Energy and Water Development Appropriations bill stated: "…the Committee has grown concerned with the proliferation of coordination mechanisms —such as crosscuts, Energy Earthshots™, Joint Strategy Teams, Science and Energy Technology Teams, and Coordination Teams—that may actually result in confusion and redundancy instead of increase coordination. The Department is directed to align, simplify, and consolidate these coordination mechanisms into one function so the resulting coordination mechanism includes clear leadership, articulates the roles and responsibilities of each participating program office, and plays a leading role in budget formulation and execution across program offices."[204]

The Committee report does help in providing further structure to the current DOE crosscut management efforts by explicating earmarked funding across the relevant DOE program offices for seven crosscutting initiatives, including Grid Modernization, Carbon Dioxide Removal, Critical Minerals, Industrial Decarbonization, Energy Storage, Alternative Modes of Transportation (including shipping, aviation, agricultural and long-distance transportation), and hydrogen.[205]

The successful experience of several major interagency RD&D crosscutting initiatives is instructive in identifying the characteristics of effective coordinated program planning and execution that could be considered for incorporation into DOE crosscut management procedures. Two such effective energy-related crosscutting research initiatives have been the EPA-led Acid Rain Program, originating in the 1980s, and the U.S. Global Change Research Program, originating in 1990.[206,207] Both programs shared key characteristics, including: multi-year legislative authorizations; clearly defined agency roles and responsibilities; delineated program management responsibilities; dedicated senior management leadership; formal, transparent multi-year research plans with stakeholder input; and favorable budgetary treatment (i.e., increased budgetary resources that were insulated from competing budget priorities within their respective agencies). Applying these same principles to DOE crosscutting RD&D programs would provide the essential ingredients to maximize the potential for successful outcomes.

Recommendations

Within the current organizational structure, DOE should establish a common framework for planning and implementing the priority crosscut areas that include the following seven elements (summarized below and described further in Text Box 4):

1. A specific mission statement of work with a broad, flexible scope
2. A formal multi-year charter
3. Dedicated senior-level crosscut management leadership
4. Strategic DOE/National Laboratory co-management and collaboration
5. Transparent RD&D roadmap with stakeholder input
6. Dedicated (and protected) budgetary resources
7. Streamlined administrative processes

The framework could be implemented on a pilot basis to gain experience, focusing on several innovation challenges that are high priority for the clean energy transition and require tight integration among multiple program offices. Initial priorities could include electricity grid modernization, carbon management, advanced manufacturing, and clean fuels, including hydrogen.

BOX 04

Elements for Effective Management of Energy Innovation Crosscutting RD&D Initiatives

Broad Scope: Each crosscut should have a broad scope that includes the ability to explore and challenge new concepts and design for performance, safety, security, environmental impacts, cost, value chain/supply chain viability and sustainability, and infrastructure requirements, and rigorously quantify and qualify risks coherently across the initiative.

Multi-Year Charter: A multi-year charter, perhaps up to 10 years, will enable implementation across the full innovation spectrum, including demonstration and deployment at scale, to ensure that emerging concepts and technological innovations will meet requirements in the key dimensions (safety, security, performance, cost, environment, etc.).

Senior-level Program Management Leadership: Each crosscut should be coordinated by a senior manager or co-manager designated by the Secretary. The crosscut leaders should have full-time responsibility for the management of the crosscut, requiring that they should be seconded from current responsibilities.

Strategic National Laboratory Collaboration: Each crosscut should provide a strategic role for the National Laboratories in crosscut planning and implementation. The scope of the strategic collaboration could include having National Laboratory co-managers as part of the DOE team, as well as National Laboratory personnel participation in the development of the crosscut RD&D roadmaps.

Specific RD&D Roadmap: Each of the pilot priority crosscuts should have a detailed multi-year RD&D roadmap with resource estimates. The roadmap should be developed through a transparent process with active involvement of all interested stakeholders. The road mapping process should seek to achieve broad consensus on roadmap objectives and schedules, risk identification and mitigation milestones, and go/no-go decisions. The roadmap also should be flexible and able to accommodate new additions, deletions, or modifications as new information is developed.

Dedicated Budgetary Resources: Each of the pilot priority crosscuts should have detailed multi-year budget estimates. The budgets for each crosscut should be specifically identified and "fenced" by DOE, in coordination with OMB and the Appropriations committees, so that the resources would not readily be reallocated into other departmental programs. In addition, DOE and OMB should work with relevant congressional committees to establish a fast track procedure to enable shifting of funds within the boundaries of the defined crosscut when needed to adjust to changing research priorities. This procedure should address the transfer of funds across appropriations accounts as well as the reprogramming of funds within an appropriations account. Implementation of more flexible procedures for crosscutting RD&D initiatives could serve as a pilot effort to assess the feasibility of applying such procedures to all DOE programs and budgets.

Streamlined Administrative Processes: The crosscuts also could serve as a model for the implementation of streamlined processes, such as the use of Other Transaction Authority agreements.

6.3 Options for a Future DOE Organizational Structure

The complex nature of the energy innovation challenges will always require some form of crosscutting RD&D coordination across multiple program offices. Improvements in organizational structure, however, can reduce or simplify the crosscut challenges.

Two broad organizing themes exist for longer-term consideration of DOE organizational structure: organize by the innovation cycle or organize by end-use market application, with each market-oriented organizational unit responsible for the full innovation cycle within that market segment. Other concepts or sub-concepts that could be considered are regionally focused program organizations and cross-cutting functionally based organizational units.

Several major reports have pointed toward a reorganization by end-use applications. A 2010 Report from PCAST stated, "A larger step in the future would be to align the energy offices closer to end-use and delivery rather than 'fuels'; this shift would recognize the different business structures that will evolve with new technology (e.g., electricity and biomass as transportation 'fuels')."[208] Recognizing the challenges associated with such a change, the report further recommended that the Secretary should evaluate new organizational arrangements with appropriate congressional consultation.

The 2019 EFI-IHS Markit report also discussed the merits of an organizational construct based on end-uses, with each organizational unit responsible for a soup-to-nuts purview of energy innovation. The report cited as rationale that a new "applications-based structure" would put "…energy production, distribution and applications in logical groupings that enable comparative analyses and prioritization among technologies serving similar needs." Such a portfolio structure could be organized by electricity supply, fuels supply (including the use of hydrogen as an energy carrier), and end-use applications (in transportation, building systems, and industry).[209] The end-use or applications-based organizational model would also facilitate a greater focus on systems-level issues within each end-use market. The EFI-IHS Markit report concluded that:

> "Congress and the Administration should initiate efforts to reorganize the Federal energy RD&D portfolio and the Department of Energy toward a fuel- and technology-neutral structure that (1) aligns with the highest priority opportunities, (2) enables systems-level integration, and (3) avoids gaps in crosscutting projects."[210]

Moving toward a new structure that emphasizes end-use applications, combines technology and systems issues, and is fuel- and technology-neutral can be accomplished in several ways.

- A report by the Energy Innovation Reform Project, for example, recommended reconstituting the applied energy RD&D offices into an Office of Power and Grid Technologies, an Office of Transportation and Fuels Technologies, and an Office of Advanced Energy Efficiency Technologies.[211]
- In one of his blog posts, Bill Gates suggested using NIH as the model, reorganizing DOE into a set of National Energy Innovation Institutes.[212] Each Institute would be organized around a particular

challenge, either an end-use application or technology-specific, and with the flexibility and autonomy to pursue a broad-based portfolio of innovation ideas ranging across the innovation process. The Institute's idea also would have a strong regional focus.

- Another approach would be to structure main energy uses—transportation, buildings, industrial processes—with companion organizations focused on clean fuels and clean power alternatives that are more interchangeable and more competitive in their end-use applications.

6.4 Options for Energy Demonstration and Deployment Programs

The BIL and IRA firmly establish a federal role to support clean energy technology demonstration and deployment at the stage of large-scale demonstration and initial commercial deployment. The statutes assign these responsibilities to DOE, primarily through the establishment of the OCED and the expansion of the LPO.

These legislative actions can be viewed as the outgrowth of Congressional consideration in the late 2000s and early 2010s of several legislative proposals to establish a new quasi-government entity to finance and manage clean energy technology demonstration and deployment. These actions included establishing a national Clean Energy Bank or a Clean Energy Deployment Administration (CEDA). Alternative proposals for CEDA provided for a new federal government entity that could be semi-autonomous either within DOE or a completely separate quasi-governmental corporation.

As experience is gained with the implementation of OCED and LPO, the issue of transferring these programs to a new entity outside DOE could re-emerge. One possible concept involves establishing a quasi-public organization for the sole purpose of executing large-scale energy demonstration projects.[213] The new entity could be headed by a governing board comprised of both Government and outside independent directors.

> "The case for creating new institutions, as opposed to strengthening and upgrading the Department of Energy, mainly rests on two arguments: (1) the difficulties facing DOE, as an executive branch agency, in recruiting and keeping people with the knowledge—of financial markets and markets for capital goods and energy services – needed for effective decision-making in the downstream stages of the innovation process; and (2) the value of insulating these decisions from the annual Congressional appropriations process and from legislative and executive branch debates about general budget priorities and the deficit."[214]

It could cooperate outside the usual government management and budget framework, and in particular, with dedicated funding outside the annual appropriations process. The drivers for these proposals are best summarized in a report by the MIT Energy Innovation Project:

A possible step in this direction could involve forming a board structure within DOE comprised of senior DOE officials and modeled after the DOE Credit Review Board to assist in overseeing the implementation of demonstration and deployment projects. Depending upon the nature of the responsibilities assigned to this Board, consideration could be given to including senior National Laboratory managers as members. The OCED established a Demonstration and Deployment Advisory Board (DDAB) in January 2023. Its functions include providing "…advice to ensure risk management and accountability for large clean energy demonstration projects across DOE that are funded through financial assistance.[215] It is not clear whether this Board will play a role in demonstration project program planning, prioritization of new focus areas, or individual project selection.

6.5 Path Forward

DOE is actively in the process of implementing major programs from recent legislation (Energy Act of 2020, BIL, CHIPS and Science Act, and IRA), and further, major changes to the agency's organizational structure in the near term could be disruptive to these implementation efforts. Once current programs are implemented, the desirability of further structural changes on a larger scale can be better understood.

This process could be initiated through launching one or more pilot programs. Two major end-use applications—the built environment and industrial innovation – are areas that involve complex optimization of energy and non-energy considerations. For example:

- In the case of the built environment, the design of new commercial and residential buildings, as well as the rehabilitation of existing structures, must serve many different objectives. Opportunities to integrate clean energy and energy efficiency measures into these buildings require an applications-

> "DOE is actively in the process of implementing major programs from recent legislation (Energy Act of 2020, BIL, CHIPS and Science Act, and IRA), and further, major changes to the agency's organizational structure in the near term could be disruptive to these implementation efforts. Once current programs are implemented, the desirability of further structural changes on a larger scale can be better understood."

focused portfolio of RD&D, from early-stage concepts through broad demonstrations, all designed to mesh with other priority objectives. A pilot program in this area could focus on establishing a new innovation organizational unit, such as an Institute, focused on single-family or multi-family residential applications. The built environment RD&D agenda should also be structured so as to inform the development of building standards, policies, and regulations in different climate conditions across the country.

- Similarly, industrial innovation must support a broad range of objectives, including global competitiveness, supply chain security, workforce utilization, and clean energy and energy-efficient operation. Such an organizational framework could integrate the application of new platform technologies such as robotics, machine learning, and additive manufacturing with process technology innovation for decarbonization and modernization. A pilot program in this area could be establishing a separate organization unit devoted to one or more of the energy-intensive trade-exposed (EITE) industries such as iron and steel, petrochemicals, cement, mining, non-ferrous metals and minerals, and pulp and paper.

Recommendations

DOE should consider establishing one or more pilot organizational units organized to support a comprehensive innovation solution to a particular end-use application. Possible candidates could include, for example, a residential building (single-family or multi-family) innovation organization and/or an innovation organizational unit focused on innovation in one or more existing EITE industry sectors.

Over the longer term, DOE should consider opportunities to move toward an applications-focused organizational structure that more closely integrates the various stages of innovation within each end-use application. While crosscutting issues will remain, an applications-focused organizational structure could reduce the demands on crosscutting and coordination issues and deliver results more rapidly and efficiently.

Any major structural change to the DOE organization should be shaped with broad stakeholder and policymaker input.

Appendix: Table of Recommendations

CH	SECTION	RECOMMENDATION	PG
01	**Financial Resources to Accelerate the Energy Transition**	DOE should work with the Administration to seek increases in annual discretionary appropriations to achieve and maintain a balanced end-to-end energy innovation investment portfolio. The principal focus should be to fund the new authorizations in the Energy Act of 2020 and CHIPS and Science Act. Increases in annual discretionary science and energy funding at a rate at least as high as the recent historical rate of 6.8% annually will be needed.	30
02	**Enhancing Implementation of Demonstration Projects (Principally through the Office of Clean Energy Demonstrations)**	DOE should consider additional measures, such as milestone-based payments and integrated project delivery agreements, to build upon its proposed project management oversight plan. DOE also should consider recommendations from the GAO, the DOE Office of Inspector General (OIG), and external organizations.	39
		DOE should consider the form, content, and frequency of its proposed portfolio risk management approach, including measures to communicate to policymakers, stakeholders, and the public risk/reward considerations that constitute the value proposition of the demonstration projects in its portfolio.	
		DOE should seek funding from the OMB and Congress to establish an open, technology-neutral FOA process for additional OCED technology demonstration projects in addition to technology-specific programs.	
		DOE should develop a formal set of criteria and procedures to enable case-by-case modifications of project cost-sharing requirements that allow greater flexibility among the stages of project execution, consistent with existing statutory authority in Section 988 of the Energy Policy Act of 2005.	
		OCED should work with the National Laboratories to establish teams of National Laboratory experts to provide independent science and engineering support for DOE-funded demonstration projects and capture the learning by doing from these projects to inform future DOE RD&D activities.	
	Expanding from First-of-a-kind Demonstrations to nth-of-a-kind Deployment through supply-side incentives (Loan Programs Office) and demand-side market formation	LPO should modify its current regulations to clarify that it can provide Title 17 loan guarantees to multiple projects deploying the same or similar technology through the learning process until NOAK is achieved.	44
		DOE, with Administration support, should work with Congress on legislative action to rescind or modify the Federal Support Restriction. Possible modifications could include allowing flexibility for LPO to combine other forms of federal assistance with LPO loans and loan guarantees if: (1) the combination reduces project execution risk and enhances prospects for repayment of the loan, and (2) the cost and risk factors associated with the supplemental forms of federal assistance are appropriately reflected in the credit subsidy estimate process. (LPO could revise its current credit subsidy methodologies to incorporate any risk associated with the combination of federal grants and loans in a project financing structure. Federal tax incentives are not subject to the statutory prohibition on double federal benefits, and the methodologies currently used to underwrite projects with both federal tax incentives and LPO credit support could be extended to other forms of federal funding assistance as well).	
	Demand-side Market Pull Strategies	DOE should establish a central analytical capability to analyze market adoption issues and support the development of strategies to complement current and planned demonstration and deployment programs.	45

CH	SECTION	RECOMMENDATION	PG
		DOE should build on the Liftoff reports to assess the need for, and the feasibility of, the additional supply-side and demand-side options identified in those reports.	
		DOE should expand efforts to work with DOD, the General Services Administration, and the Office of Federal Procurement Policy to develop pilot programs for the use of federal government purchasing power to create markets for new clean energy technologies and systems.	
	Fast Track: Rapid Prototyping of New Technologies and Concepts	DOE should establish a "fast track" program to accelerate the rapid prototyping of new energy technologies that have achieved early proof of concept but require additional technology maturation at pilot scale to achieve readiness for commercial-scale demonstration. The program should incorporate flexible program implementation measures similar to those in the ARPA-E SCALEUP program. The proposed new "fast track" initiative should have an evergreen, technology-neutral solicitation process that will allow projects to move forward at a pace appropriate for the technology. The initiative should be conducted as a pilot program, depending upon the level of funding, with carefully monitored performance and expanded as experience is gained. The initial scale of the program should be resourced to support about 10 to 20 projects per year, with a range of $5 million to $25 million total cost per project. The pilot effort should be subject to a third-party independent review and evaluation three to five years after initiation.	47
		ARPA-E should increase the size and frequency of SCALEUP funding opportunities for ARPA-E grant recipients.	
	Enhancing Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) as Seed Fund Programs	DOE should seek to better leverage SBIR and STTR programs as a seed fund for startups focused on technologies relevant to DOE's mission. This can be accomplished by building upon other federal agency experience and the BPC and ITIF recommendations, including greater flexibility in applicant eligibility to encourage new and diverse entrants, use of open, evergreen solicitations with shorter review timelines, and emphasis on proposals that may have greater demonstration and deployment potential.	49
	Using Other Transaction Authority (OTA) to Create New Partnerships	DOE should establish a targeted pilot program for early implementation of the new OTA Guide. In addition to the hydrogen market development project, OCED should also consider whether a small number of demonstration projects selected for funding under previous FOAs with cooperative agreement requirements could be expedited through the use of OTAs. DOE should also consider the use cases developed by the National Laboratories as early candidates for the OTA pilot implementation effort.	51
		As may be needed to enable the rapid startup of this effort, DOE should consider entering into an interagency agreement to acquire OT authority services from another federal agency that has extensive established OT authority expertise and experience.	
	Using Prize Programs to Stimulate Innovation	DOE should develop formal Departmental guidelines on the use of prize authority, as required by Section 9004 of the Energy Act of 2020. The guidelines should address: the justification for the use of prize authority; the scope of the prize challenge; the size of the prize award levels commensurate with the scope of the prize challenge; the number of awards at each stage of the prize competition, particularly at the early stages; and the size of associated technical assistance vouchers.	53

CH	SECTION	RECOMMENDATION	PG
		DOE should establish an evaluation program to assess the effectiveness and efficiency of prize programs relative to applied energy RD&D programs funded through grants, contracts, and cooperative agreements and identify best practices for future application.	
	Standing Up the Foundation for Energy Security and Innovation (FESI)	DOE should expeditiously stand up FESI, identify opportunities for actions beyond the scope of current DOE programs that could provide early, tangible benefits for energy innovation, and provide a starting set of recommendations to the new FESI Board for consideration.	54
		Congress should approve DOE budget requests for appropriations funding to enable start-up implementation of FESI.	
	Establishing a Comprehensive and Coordinated Approach to Industrial Energy Innovation Programs	DOE, building on the work of the Industrial Technology Joint Strategy Teams (JST), should develop a comprehensive multi-year industrial innovation program plan as recommended in the Senate FY 2024 Energy and Water Appropriations committee report. DOE should consider appointing a dedicated, full-time chair (or co-chairs) to lead this effort.	60
		DOE should work with the NSTC to establish an interagency process to establish a comprehensive government-wide industrial innovation strategy, as called for in Title VI of the Energy Act of 2020.	
		The NSTC should consolidate industrial energy innovation issues into one of its existing committees or as a new standalone subcommittee.	
	Fostering Regional and Place-Based Energy Innovation Ecosystems	DOE should develop a department-wide regional and place-based energy innovation strategy. The strategy should: – identify and provide guidance for elevating the role of the National Laboratories in regional innovation ecosystems, building upon current National Laboratory local, state, and regional partnerships; – identify opportunities to build upon the regional hydrogen hubs and regional direct air capture hubs initiatives as a test bed for broader regional innovation efforts; and – clarify the roles and responsibilities among the appropriate DOE offices.	67
		DOE should also seek dedicated budget resources to support the implementation of these efforts.	
		DOE should seek to leverage the new Commerce and NSF authorities in the CHIPS and Science Act by entering into formal Memoranda of Understanding (MOUs) with Commerce and NSF. The MOUs could support four objectives: (1) define a strategic role for DOE coordination with Commerce and NSF in the implementation of their respective programs; (2) highlight energy innovation as an area of emphasis in the Commerce and NSF programs, consistent with statutory authorization language; (3) facilitate the integration of DOE-funded regional innovation initiatives into proposals for Commerce and NSF funding; and (4) establish a process for the DOE National Laboratories to provide strategic advice and technical assistance in the formation of new regional consortia seeking Commerce and NSF funding.	

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<tr><th>CH</th><th>SECTION</th><th>RECOMMENDATION</th><th>PG</th></tr>
<tr><td rowspan="4">03</td><td rowspan="3">Defining the Role of the National Laboratories as Strategic Partners in the Expanded DOE Mission</td><td>DOE should establish an Office of National Laboratory Policy reporting to the Secretary and Deputy Secretary. The new Office would be headed by a senior DOE official, with staff support from a combination of DOE and National Laboratory personnel, and could be assigned several specific areas of responsibility, including:
– Establishing a formal organizational framework for ongoing interaction between the leadership of the National Laboratories and the Department on strategic directions for the Department.
– Engaging with the Laboratories in the formulation of new, “big idea” Laboratory-wide innovation initiatives that provide strategic direction to the DOE research agenda. Possibilities include:
  – Technologies to enable the future architecture of the electricity system;
  – Managing interdependencies within energy systems and with other infrastructures;
  – Implications of artificial intelligence on energy; and
  – Defining new R&D opportunities for over-the-horizon innovations such as nuclear fusion, synthetic biology, superconductivity, and naturally occurring hydrogen.
– Overseeing guidance for departmental orders and directives that affect all National Laboratories.
– Establishing an ongoing institutional point of contact with the NLDC.
– Directing the work of the existing DOE Laboratory Operations Board (LOB).</td><td rowspan="3">72</td></tr>
<tr><td>The National Laboratories, working through the NLDC and the new Office of National Laboratory Policy, should examine opportunities for how best the laboratories can support the expanded DOE mission responsibilities in end-to-end energy innovation. Two possible ideas to consider are to formalize arrangements to provide laboratory technical support and analysis for OCED-funded demonstration projects and laboratory-led initiatives to assist the formation of regional and place-based initiatives to expand the reach of energy innovation across the U.S.</td></tr>
<tr><td>DOE should review and update, as needed, the COI requirements applicable to National Laboratory personnel and establish expedited review procedures to enable Laboratory personnel to provide support to DOE program offices on an expedited basis consistent with BIL and IRA legislative implementation schedules. DOE should also clarify the roles and responsibilities of National Laboratory personnel on loan to the government, including the criteria for utilizing laboratory personnel as temporary complements and not permanent displacement of federal government personnel.</td></tr>
<tr><td>The Role of the National Laboratories as Integrators</td><td>The proposed new DOE Office of Laboratory Policy should work with the Office of the Chief Financial Officer, the Office of Policy, and the program offices to establish roles for the National Laboratories to assist in the planning and implementation of crosscutting RD&D initiatives, including serving as crosscutting program integrators.</td><td>74</td></tr>
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CH	SECTION	RECOMMENDATION	PG
	Enhancing the Role of the National Laboratories in Technology Maturation and Transition	DOE should work with the Administration to seek increased annual appropriations for the OTT PACT program to enable larger-scale technology transition projects that take full advantage of National Laboratory capabilities and opportunities.	76
		DOE should establish a new initiative for Laboratory-Directed Technology Maturation (LDTM). The program could be modeled on elements drawn from the current LDRD program, but it would be separate in scope, management, and funding from the LDRD program.	
	Expanding Test Beds at National Laboratories for Use by Energy Innovators	DOE should work with industry and universities to identify the need for additional clean energy technology prototype test facilities that can be implemented through the National Laboratories.	79
	Expanding National Laboratory Partnerships with Industry and with Regional Innovation Initiatives	DOE should work with the Administration to seek a specific budget line-item appropriation to support the expansion of both the LEEP initiative and the small business voucher program. The budget line item should be managed by OTT.	83
		DOE should provide specific line-item funding to the National Laboratories to enable them to take a proactive role in furthering the development of regional energy innovation ecosystems, including working with the Department of Commerce and NSF on the implementation of new CHIPS and Science Act program initiatives.	
	Building a Culture of Entrepreneurship at the National Laboratories	The proposed new DOE Office of National Laboratory Policy should work with the National Laboratory Directors on measures to enhance a culture of entrepreneurship at the National Laboratories while also expanding the demographic distribution of its workforce. Possible measures could include: – Provide funding to Increase the number of clean energy Post Doc positions at the Laboratories; – Encourage greater migration of mid-career research staff from the Laboratories to the private sector as a means to enhance the process of technology transitions; – Expand term-limited researcher exchange opportunities with both the private sector and university research programs; and – Incorporate entrepreneurship into National Laboratory management training and advancement programs, such as the Oppenheimer Fellows program.	85
	Incentivizing Technology Translation and Demonstration and Deployment in National Laboratory M&O Contracts	The proposed new DOE Laboratory Policy Office should identify performance metrics that can incentivize technology transfer and commercialization, and it should seek to incorporate them into the Laboratory M&O contract award fee structure.	86
		The proposed new DOE Laboratory Policy Office should seek to develop new policies, including M&O contractor selection criteria, to encourage private investment by Laboratory M&O contractors to expand technology transfer and demonstration and deployment activities. These policies could include pilot efforts to develop specific new DOE-M&O contractor partnerships.	

CH	SECTION	RECOMMENDATION	PG
04	**Expanding Supply Chain Resources: Energy Supply Chain Policy and Program Strategies**	The DOE Manufacturing and Energy Supply Chain (MESC) office should develop a critical materials supply chain roadmap consistent with the requirements of Section 7002(g) of the Energy Act of 2020, with appropriate milestones and funding estimates. The roadmap should expand upon the supply-focused issues in the DOE supply chain strategy report and critical materials assessment to also address opportunities for critical materials recycling and substitution. The roadmap should also be used as a basis for setting priorities for the expansion of the DOE Critical Materials Collaborative.	91
	Expanding Human Resources: Workforce Development	DOE should consider strengthening its recruiting efforts in the near term, such as by enhancing the terms of tour of service programs.	92
		DOE should ensure the effective use of National Laboratory personnel detailed to DOE Program Offices, including the use of executive rotation programs. The process for the use of Laboratory employees could be facilitated by improving policies and procedures for resolving conflict of interest (COI) issues and by reducing the overhead cost charged to these employees.	
		To address the longer-term challenge of expanding the pool of personnel with appropriate backgrounds in science, technology, engineering, and mathematics (STEM), DOE should encourage efforts by the National Laboratories, including targeting funding support for National Laboratory initiatives to: – expand the number of fellowships to draw new graduates into clean energy innovation; – support expanded internship programs at the undergraduate and high school levels; and – develop educational material on clean energy innovation for inclusion in educational curricula at all levels of education.	
	Improving Information Resources: Energy-Related Data Collection and Information Management	EIA, working in collaboration with stakeholders, should lead a comprehensive, top-to-bottom review of its existing data collection, analysis, and information programs. The review should include all current on-going data collection and information management programs within the Department. The review should identify priority needs for new and expanded data collection and information management activities aligned with the energy transition. The review should also identify lower-priority existing data collection and information management activities that could be curtailed in order to repurpose existing resources and capabilities.	95
	Financial Resources: Strengthening Financial Management and Accountability	DOE should develop an integrated multi-year budget plan to support a strategic, integrated energy innovation RD&D portfolio plan. Recognizing the uncertainties in the overall federal budgetary outlook, the DOE budget plan should identify optional funding paths to prioritize RD&D needs at alternative funding levels and identify strategies for agile implementation to respond to changes in the fiscal outlook.	98

CH	SECTION	RECOMMENDATION	PG
		The Administration (DOE and OMB) should work with the appropriations committees to establish a process to enable administrative action to transfer funding across appropriation accounts and develop a streamlined process for acting on reprogramming requests, with particular focus on greater flexibility to reallocate funding within defined crosscutting RD&D initiatives.	
		DOE, through the CFO, should enhance transparency in program implementation and performance by expanding the content and the frequency of its program performance and financial management reporting to OMB, Congress, and the public.	
		DOE, through the CFO, should strengthen the current performance management and evaluation processes, including: (1) increasing the staffing and budget resources for performance management and evaluation programs; and (2) establishing outcome-based program performance measures with particular emphasis on BIL and IRA expenditures.	
	Performance Measurement and Impact Assessment	DOE should develop and implement a Department-wide program of impact metrics to measure the impact of the BIL, IRA, and CHIPS and Science Act, such as GHG emissions reduction and job creation.	99
		DOE, through the CFO, should develop and implement a plan of program evaluation studies that can provide a comprehensive assessment of the impacts of BIL, IRA, and CHIPS and Science Act investments over time.	
05	**Clarifying Protocols for International Energy RD&D Engagement**	The White House Office of Science and Technology Policy (OSTP), with advice from the President's Council of Advisors on Science and Technology (PCAST) and the staff of the National Security Council, should lead an interagency effort to develop a new Presidential Executive Order to support and guide international clean energy innovation RD&D collaborations of DOE and other federal agencies. This order should mandate and guide actions by federal agency leaders to establish policies and procedures to manage risks effectively in order to allow the U.S. to reap the benefits of prudently executed international clean energy collaborations.	105
		The U.S. should continue to support Mission Innovation as a principal vehicle for international clean energy RD&D collaboration. The U.S. should develop a proposal and seek to build support from other country participants in Mission Innovation for a third phase of the initiative (MI 3.0) that includes greater emphasis on demonstration and deployment. In addition, the U.S. should continue to permit its research community to enter into individual research collaborations within each of the MI focus areas based on the merits of each individual collaboration.	
		The U.S. should renew its commitment to increase public investment in clean energy RD&D and expand the scope of that commitment to include all public investment in its calculus, including federal, state, and local governments.	
		DOE should develop department-wide policies and procedures to share information on the results of DOE-funded energy technology demonstration projects with other countries willing to share the results of their own demonstration projects. The initial focus of these efforts should be sharing information on hydrogen deployment projects, CCUS technology demonstrations, and CDR projects.	

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<tr><th>CH</th><th>SECTION</th><th>RECOMMENDATION</th><th>PG</th></tr>
<tr><td rowspan="5">06</td><td>Establishing a National Energy Innovation Strategy and Energy R&D Portfolio Plan</td><td>DOE should develop a comprehensive multi-year energy innovation RD&D portfolio plan with strategic goals, a prioritized portfolio of technologies organized with end-use applications in mind, and alternative pathways to reflect a range of resource needs and potential budgetary outcomes. The planning process should provide for broad stakeholder input. A strategic portfolio plan also will illuminate opportunities for further organizational improvements.</td><td>111</td></tr>
<tr><td>Effective Management of Crosscutting RD&D Initiatives</td><td>Within the current organizational structure, DOE should establish a common framework for planning and implementing the priority crosscut areas that include the following seven elements (summarized below and described further in Text Box 4):
1. A specific mission statement of work with a broad, flexible scope
2. A formal multi-year charter
3. Dedicated senior-level crosscut management leadership
4. Strategic DOE/National Laboratory co-management and collaboration
5. Transparent RD&D roadmap with stakeholder input
6. Dedicated (and protected) budgetary resources
7. Streamlined administrative processes
The framework could be implemented on a pilot basis to gain experience, focusing on several innovation challenges that are high priority for the clean energy transition and require tight integration among multiple program offices. Initial priorities could include electricity grid modernization, carbon management, advanced manufacturing, and clean fuels, including hydrogen.</td><td>119</td></tr>
<tr><td rowspan="3">Options for a Future DOE Organizational Structure</td><td>DOE should consider establishing one or more pilot organizational units organized to support a comprehensive innovation solution to a particular end-use application. Possible candidates could include, for example, a residential building (single-family or multi-family) innovation organization and/or an innovation organizational unit focused on innovation in one or more existing EITE industry sectors.</td><td rowspan="3">124</td></tr>
<tr><td>Over the longer term, DOE should consider opportunities to move toward an applications-focused organizational structure that more closely integrates the various stages of innovation within each end-use application. While crosscutting issues will remain, an applications-focused organizational structure could reduce the demands on crosscutting and coordination issues and deliver results more rapidly and efficiently.</td></tr>
<tr><td>Any major structural change to the DOE organization should be shaped with broad stakeholder and policymaker input.</td></tr>
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