OCED

Office of Clean Energy Demonstrations

OFFICE OF

CLEAN ENERGY DEMONSTRATIONS

MULTI-YEAR PROGRAM PLAN

2023

Acknowledgements

The plan was developed under the leadership of OCED's Principal Deputy Director and Acting Director, Kelly Cummins, and former OCED Director, Undersecretary for Infrastructure David Crane. It was brought to fruition by a core team led by David Sholl, Melissa Klembara, and Andrew Dawson.

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List of Acronyms

ARDP	Advanced Reactor Demonstration Program
ARL	Adoption Readiness Level
BIL	Bipartisan Infrastructure Law
BTU	British Thermal Unit
CBP	Community Benefits Plan
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization, and Storage
CDR	Carbon Dioxide Removal
DAC	Direct Air Capture
DDAB	Demonstration and Deployment Advisory Board
DEIA	Diversity, Equity, Inclusion, and Accessibility
DOC	Direct Ocean Capture
DOE	Department of Energy
EEJ	Energy and Environmental Justice
EGS	Enhanced Geothermal Systems
EPA	Environmental Protection Agency
EV	Electric Vehicle
FEED	Front-End Engineering Design
FOA	Funding Opportunity Announcement
FOAK	First of a Kind
FORGE	Frontier Observatory for Research into Geothermal Energy
GDO	Grid Deployment Office
GEH	General Electric-Hitachi
GHG	Greenhouse Gas
HTGR	High-Temperature Gas Reactor
IEDO	Industrial Efficiency & Decarbonization Office
IRA	Inflation Reduction Act

IIJA	Infrastructure Investment and Jobs Act
LCA	Life Cycle Analysis
LCFFES	Low-Carbon Fuels, Feedstocks, and Energy Sources
LPO	Loan Programs Office
MESC	Manufacturing and Energy Supply Chain Office
MT	Metric Ton
MWe	Megawatt Equivalent
NE	Office of Nuclear Energy
NERC	North American Electric Reliability Corporation
NRC	Nuclear Regulatory Commission
OCED	Office of Clean Energy Demonstrations
OTA	Other Transactional Authorities
PIA	Partnership Intermediary Agreements
PMD	Project Management Division
PSH	Pumped Storage Hydropower
RFI	Request for Information
R&D	Research and Development
RD&D	Research, Development, and Demonstration
SFR	Sodium Fast Reactor
SMR	Small Modular Reactor
TCF	Technology Commercialization Fund
TES	Technical and Engineering Support
TRISO	Tristructural Isotropic
TRL	Technology Readiness Level
USDA	U.S. Department of Agriculture

Executive Summary

A key challenge in advancing transformative clean energy technologies is proving their performance in real world settings and thereby generating the experience, social trust, and impetus for the widespread market adoption that must take place to have an impact on a national scale. The Department of Energy's (DOE) Office of Clean Energy Demonstrations (OCED) directly addresses this challenge.

> ***The mission of the Office of Clean Energy Demonstrations is to deliver clean energy demonstration projects at scale in partnership with the private sector to accelerate deployment, market adoption, and the equitable transition to a decarbonized energy system.***

The United States has committed to two ambitious goals that will transform the nation's energy system and economy: to generate 100% of electricity without carbon dioxide emissions by 2035 and to reach net zero greenhouse gas (GHG) emissions by 2050. The International Energy Agency has estimated that $90 billion worth of demonstration projects are needed globally this decade to achieve net zero emissions by 2050. OCED's ability to rapidly commit more than $26 billion to clean energy demonstration projects will help catapult the United States to global leadership in the clean energy revolution. OCED's investments will also impact the degree to which the United States is successful in securing an equitable transition. By prioritizing energy and environmental justice (EEJ), quality job creation, and equitable workforce development, OCED seeks to provide project benefits to workers and communities while mitigating harms and demonstrating replicable models to advance equity and justice.

OCED builds confidence in the private sector by addressing technical, commercial, social, and other risks experienced in first-of-a-kind (FOAK) demonstrations at scale for clean energy technologies, and it plays a key role in DOE's mission to ensure America's security and prosperity. These demonstrations will create new facilities and retrofit existing facilities that will continue operating well beyond the period of Federal funding. Demonstrating these energy solutions will resolve critical commercial adoption risks, ensuring bankability, marketability, and replicability as well as providing tangible and meaningful community benefits. These demonstrations will also strengthen domestic manufacturing and supply chains for these vital technologies, creating good jobs across the nation and enhancing national competitiveness and security.

OCED will manage a portfolio of demonstration projects relevant to the full spectrum of America's energy sector, including electricity generation and delivery, transportation and fuels, and the diverse energy needs of industry, buildings, and agriculture.

OCED will invest in large-scale clean energy projects that reduce industrial emissions; advance clean hydrogen (H_2), carbon capture from point sources and direct air capture (DAC), advanced nuclear reactors, grid-scale energy storage, and grid technologies and solutions; and improve energy systems in rural and remote areas and on current and former mine lands.

OCED will also use a structured process to identify, prioritize, and support additional clean energy solutions where large-scale demonstrations and/or demand-side measures could make a significant contribution to achieving the nation's goals.

A core aim of OCED is to rapidly reduce the technical, economic, and systemic uncertainties associated with pre-commercial technologies. Effectively managing projects of this kind requires robust due diligence, including independent assessments of outcomes and the dissemination of techno-economic and other data to show progress and impacts and to catalyze private sector adoption. OCED will also support other DOE programs as they manage capital-intensive, large-scale demonstration projects to ensure a consistent approach to project management oversight across the agency. A driver of OCED's creation was for it to be a center of excellence for large-scale demonstrations. As such, OCED will share its expertise and learnings to continually improve technology demonstration projects across DOE.

In addition to executing existing programs and funding, OCED will seek to identify future topics and potential programs on an ongoing basis. The energy sector is complex, and any energy transition is multifaceted and challenging, so new technical programs are likely to be critical to OCED's ability to position the United States as a global leader in clean energy technology. All potential investments will be carefully vetted for readiness, suitability, timeliness, and impact. To accelerate an equitable energy transition, OCED will seek to move with urgency to support key areas where demonstrations and demand-side measures can address critical commercialization and implementation risks. Examples of future opportunities include accelerating and expanding deployment of clean energy generation and storage, transportation infrastructure transitions (particularly for subsectors that are difficult to decarbonize), low carbon fuel and energy carrier production, agricultural energy systems, and land use.

The U.S. clean energy transition will inevitably impact the communities hosting energy infrastructure and the workforce involved in energy generation and use. Who is impacted and whether these impacts are positive or negative will depend on how proactively the transition prioritizes equity and justice. To maximize the equitable distribution of environmental, social, and economic benefits and minimize negative impacts, OCED will embed Community Benefits Plans (CBPs) in its funding opportunity announcements (FOAs). CBPs include requirements for all projects to incorporate meaningful, two-way community and workforce engagement; invest in the American workforce, support diversity, equity, inclusion, and accessibility (DEIA); and advance EEJ.

Aligned with the Justice40 Initiative, OCED will ensure at least 40% of the benefits derived from projects flow to overburdened, underserved communities and create good jobs in communities across the country that support a just energy transition. The vast size and complexity of the nation's energy system means that lasting changes in use of clean energy technologies will require participation by the entire energy ecosystem. Ongoing, targeted, and purposeful engagement and collaboration is critical to OCED's long-term success, helping to manage project, program, and portfolio risk.

OCED will engage in sustained dialogue with host communities; project performers; Tribal, State, and local governments; and other stakeholders. OCED will also coordinate closely with the many relevant activities within DOE's applied and infrastructure offices and with interagency partners on program alignment and opportunities to amplify and leverage other efforts. This approach will strengthen OCED's program design and implementation by bringing in diverse perspectives to foster widespread support for complex clean energy solutions that can ultimately achieve commercial liftoff.

Contents

1 OCED Mission and Vision

Access to clean, reliable, and affordable energy underpins every aspect of the nation's economy. The nation must continually enhance and modernize the myriad of technologies associated with energy generation, delivery, access, and use. This challenge is especially urgent now because of the imperative to transition to an energy system with greatly reduced GHG emissions to avoid catastrophic impacts from climate change. A key challenge in advancing clean energy technologies is proving their technical, economic, and environmental performance in real-world settings; demonstrating this generates the experience and impetus needed for widespread market adoption, which is essential for a national impact and an equitable energy transition.

OCED directly addresses this challenge for DOE. OCED fills a critical innovation gap between the research, development, and early-stage demonstration projects within DOE technology offices and the initial deployments supported by the private sector or other DOE programs, such as the Loan Programs Office (LPO). *The mission of the Office of Clean Energy Demonstrations is to deliver clean energy demonstration projects at scale in partnership with the private sector to accelerate deployment, market adoption, and the equitable transition to a decarbonized energy system.*

The International Energy Agency has estimated that $90 billion worth of demonstration projects are needed globally this decade to achieve net zero emissions by 2050.[1] Through the Infrastructure Investment and Jobs Act (IIJA) (commonly known as the Bipartisan Infrastructure Law (BIL)), the Inflation Reduction Act (IRA), and annual appropriations, the United States has committed more than $26 billion in Federal funds toward this goal through the establishment of OCED. The Office's strategy is motivated by the nation's ambitious goals of achieving a carbon-free electricity supply by 2035 and an equitable transition to a net-zero-emission economy by 2050.

These bold climate goals will only be possible if technologies that are not currently implemented at commercial scales become widely adopted. Energy transitions are characterized by enormous capital investments in long-lived infrastructure. Near-term efforts that reduce operational, economic, social, and environmental uncertainties of new technologies have outsized value in addressing climate impacts. By successfully demonstrating FOAK clean energy technologies at scale, OCED plays a pivotal role in DOE's mission to ensure America's security and prosperity.

[1] "The Need for Net Zero Demonstration Projects," International Energy Agency, June 2022, https://www.iea.org/reports/the-need-for-net-zero-demonstration-projects.

OCED will execute a portfolio of demonstration projects and demand-side mechanisms relevant to the full spectrum of America's energy sector, including electricity generation and delivery, transportation and fuels, and the diverse energy needs of industry, buildings, and agriculture. Working closely with other DOE offices and relevant Federal agencies, OCED will invest BIL and IRA funding in large-scale clean energy projects and demand-side mechanisms across technologies that include hydrogen, carbon capture, advanced nuclear reactors, grid-scale energy storage, advanced grid technologies and solutions, industrial emissions reductions, and demonstration projects in rural and remote areas and on current and former mine lands.

In addition to efforts to decarbonize the economy through clean power, efficiency, and industrial innovation, OCED will invest in carbon dioxide (CO_2) transport and storage infrastructure and net negative technologies including DAC of carbon dioxide. The Office plans to invest in additional technology and deployment programs as it pursues an all-of-the-above strategy for achieving the nation's net zero emissions and equitable energy transition goals.

Beyond its economic benefits, a secure and resilient energy sector has enormous impact on the workforce associated with energy generation and use and the communities that host and are adjacent to energy infrastructure. OCED invests in clean energy programs that reduce GHG emissions, support job creation, advance energy justice, and facilitate the energy transition in all communities while ensuring benefits flow to disadvantaged communities. Meaningful engagement with communities and key stakeholders is embedded in OCED's approach and required for successful implementation. OCED's programs will create jobs and help transition workers in communities across the United States as local workforces will be needed to build and operate cutting edge technologies in clean energy demonstrations. All of OCED's financial assistance awards will require a CBP that includes project-specific community and labor engagement, investing in the American workforce, DEIA, and Justice40 activities and outcomes.

A driver for creating OCED was for it to be a center of excellence for large-scale demonstrations and project management oversight. To advance the Department's ability to manage complex projects, OCED will develop strong capabilities for project management oversight and use-phased approaches that align with and leverage industry best practices to manage portfolio risk from project development through operations. A core aim of OCED demonstration projects is to rapidly reduce the technical, economic, and systemic uncertainties associated with pre-commercial technology, including techno-economic performance, life cycle impacts, market acceptance, safety, regulatory, and community, workforce, and energy justice issues. Effectively adopting projects of this kind requires robust due diligence, including independent assessments overseeing the dissemination of techno-economic and other data to show progress and impacts and catalyze private sector adoption.

OCED will ensure appropriate front-end planning and due diligence to account for lessons learned from prior demonstration projects. This front-end planning will benefit from close coordination with DOE's applied energy offices to leverage their deep subject matter expertise. In addition to managing its own portfolio of demonstration projects, OCED will support other DOE programs as they manage capital-intensive, large-scale demonstration projects to ensure a consistent approach to implementation across the agency. Further, OCED will share its expertise and learnings to continually improve technology demonstration projects throughout DOE.

2 OCED Scope and History

OCED is set forth in Section 41201 of the BIL.[2] DOE announced the establishment of OCED in December 2021[3] after OCED was authorized in November 2021. OCED is a multi-technology office dedicated to accelerating clean energy technologies from lab to market and filling a critical innovation gap on the path to the nation's climate goals. To do this, OCED collaborates with stakeholders to build clean energy demonstration projects that will prove the value of new technologies in the real world and deliver economic, social, and environmental benefits across the United States.

OCED's programs will strategically de-risk technologies via FOAK investments to reduce the timeline to commercial uptake and the rate of at-scale implementation and deployment of follow-on projects. Demonstrations of this kind are needed to establish U.S. leadership in clean energy technologies that will be adopted globally in coming decades. Strengthening domestic supply chains for these vital technologies will create good jobs across the nation, and OCED will work closely with other relevant other DOE Offices toward this goal.

2.1 The Current and Future U.S. Energy System

The reliable availability of low-cost energy is critical for every part of the U.S. economy and the health and wellbeing of every American. From 1990 to 2020, the nation's primary energy production grew by 35% from 71 quads to 96 quads (1 quad = 1 quadrillion BTU).[4] In the same 30-year period, the fraction of energy generated from fossil fuel sources decreased only slightly, from 82.7% to 79.1%.

The dominant role of fossil fuels in the nation's energy sources makes energy by far the largest source of the nation's anthropogenic GHG emissions. U.S. GHG emissions peaked around 2005 at 6.5 billion tons CO_2eq (carbon dioxide equivalent), with approximately 80% of this total from carbon dioxide created by fossil fuel use, 7% from other non-carbon dioxide GHGs from energy generation and industry, and 13% from non-carbon dioxide GHGs from non-energy sectors such as agriculture.[5]

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[2] 42 U.S.C. §18861.

[3] U.S. Department of Energy (DOE), "DOE Establishes New Office of Clean Energy Demonstrations Under the Bipartisan Infrastructure Law," Energy.gov, December 21, 2021, https://www.energy.gov/articles/doe-establishes-new-office-clean-energy-demonstrations-under-bipartisan-infrastructure-law.

[4] "Annual Energy Review," U.S. Energy Information Administration, https://www.eia.gov/totalenergy/data/annual.

[5] U.S. Department of State and U.S. Executive Office of the President, *The Long-Term Strategy of the United States: Pathways to Net Zero Greenhouse Gas Emissions by 2050*, The White House, November 2021, https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf.

The nation's end uses of energy can be broadly divided into transportation, buildings, and industry (see Fig. 2.1). In 2020, these three sectors used 26, 40, and 34% of total U.S. primary energy, respectively, and these proportions have changed only slightly over the previous 30 years.[6] The three sectors differ considerably in their current reliance on fossil fuels. The transportation sector derived 94.2% of its energy from direct use of fossil fuels in 2020,[7] with almost all of the balance coming from biomass energy. In contrast, 46% of energy use in buildings was electricity, so reliance on fossil fuels in this sector is closely tied to the amount of electricity generated by emissions-free sources. In 2020, 13.4% of energy used in the industrial sector came from electricity, with an additional 9.6% of energy coming from biomass and the remaining 77% from fossil fuels.[8]

The major energy-related sectors and the overall U.S. emissions of GHGs, including carbon dioxide and other species such as CH_4 and fluorinated gases, are summarized in Figures 2.1 and 2.2, respectively. Electricity generation is a cornerstone because the growth in carbon-free electricity offers a well-defined path toward decarbonization that can directly impact the end-use sectors of industry, transportation, and buildings. The other GHG emissions associated with these three end-use sectors in Figure 2.1 are from sources that today do not involve electricity. As noted in Figure 2.2, agriculture makes a significant contribution to net GHG emissions. Agriculture and land use also have significant potential as net sinks for GHG emissions. For this reason, agriculture and land use are included in Figure 2.1 in addition to the three main end-use sectors for energy.

The United States has committed to two ambitious goals that will transform the nation's energy system and economy: to generate 100% of electricity without carbon dioxide emissions by 2035 and to reach net zero GHG emissions by 2050.[9] Achieving the first of these goals would remove the GHG emissions associated with a significant percentage of the total emissions shown in Figure 2.2. Although U.S. GHG emissions have decreased incrementally since 2005, no plausible "business as usual" scenario will lead to changes to achieve these two goals. These challenging goals stem from the robust scientific evidence that anthropogenic GHG emissions are driving global climate change and that deep reductions in these emissions will make it possible to limit the greatest impacts of this phenomenon.[10,11]

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6 U.S. Energy Information Administration, "Annual Energy Review."
7 Ibid.
8 Ibid.
9 U.S. Department of State and U.S. Executive Office of the President, *The Long-Term Strategy*.
10 Valérie Masson-Delmotte et al., eds., *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (New York: Cambridge University Press, 2021).
11 Rajendra K. Pachauri et al., eds., *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva, Switzerland: IPCC, 2014).

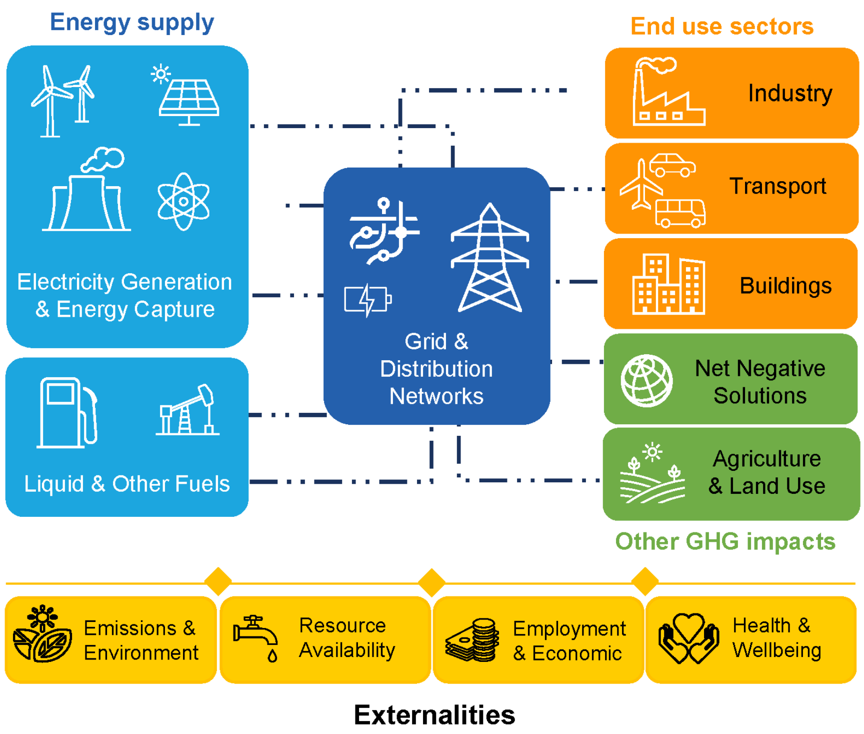

Figure 2.1: *Schematic illustration of U.S. energy sources (blue), end uses (orange), and related current and future economic sectors (green). The blue and purple boxes indicate energy generation and delivery into the key energy sectors of industry, transportation, and buildings. Economic externalities (yellow) surround all aspects of the energy system, and net negative solutions (green) will underpin each sector in a future decarbonized economy. Agriculture and land use (green) is shown separately to emphasize their vital current and future role in GHG emissions.*

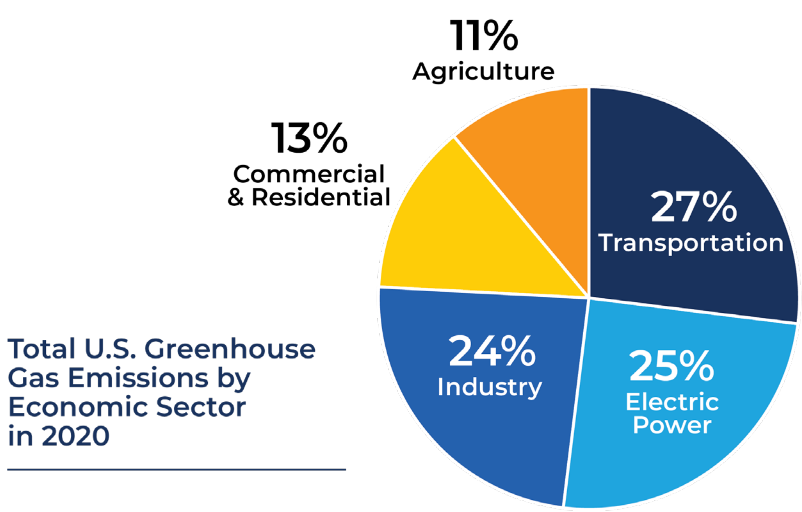

Figure 2.2: *Proportion of U.S. GHG emissions from electricity generation, agriculture, and non-electricity sources in industry, transportation, and commercial and residential buildings in 2020. Total GHG emissions in 2020 were 5.98 gigatons CO_2eq. [Data source: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions]*

Many scenarios have been explored as paths to meet the 2035 and 2050 decarbonization goals.[12,13] Although these scenarios vary in their assumed societal and policy choices, a number of robust principles have emerged as being vital. As summarized by *The Long-Term Strategy of the United States: Pathways to Net Zero Greenhouse Gas Emissions by 2050*, these principles are: (1) decarbonize electricity generation, (2) electrify energy end uses, (3) enhance energy efficiency, (4) scale up carbon dioxide removal (CDR), and (5) reduce non-carbon dioxide GHG emissions. Decarbonizing electricity generation is embodied in the 2035 goal, and electrification of end uses takes advantage of this approach. The prominent placement of electricity and the grid in Figure 2.1 reflects the central status of emission-free electricity in decarbonization.[14]

Some end uses can be electrified with existing technology, such as using electric vehicles (EVs) and heat pumps in transportation and buildings, respectively, although significant barriers exist to economy-wide adoption of these electrified approaches. Other sectors such as high temperature industrial processes or aviation will be much more challenging or in some cases impractical to electrify. To widely electrify end uses, decarbonized generation capacity must be added not only to replace current fossil fuel sources of electricity but to augment the total supply of electricity.

Many scenarios suggest that the United States will need to add more than 60 gigawatts of capacity per year in the coming decades, a rate higher than any seen this century.[15] CDR, the net removal and durable storage of carbon dioxide from the atmosphere,[16] will be necessary to reach net zero GHG emissions to offset persistent ongoing and legacy emissions. A range of scenarios project that both U.S. energy sector emissions reductions of approximately 4.5 billion tons CO_2/year and atmospheric reductions through CDR of approximately 1 billion tons CO_2eq/year are necessary to reach net zero emissions for the United States by 2050 relative to today's economy.[17]

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[12] U.S. Department of State and U.S. Executive Office of the President, *The Long-Term Strategy*.
[13] National Academies of Sciences, Engineering, and Medicine, *Accelerating Decarbonization of the U.S. Energy System* (Washington, DC: The National Academies Press, 2021).
[14] Ibid.
[15] U.S. Department of State and U.S. Executive Office of the President, *The Long-Term Strategy*.
[16] Jennifer Wilcox, Ben Kolsz, and Jeremy Freeman, eds., *CDR Primer*, 2021, https://cdrprimer.org/.
[17] U.S. Department of State and U.S. Executive Office of the President, *The Long-Term Strategy*.

2.2 Economic and Community Benefits

One key challenge to decarbonization is the long asset life of large-scale energy infrastructure. The economic viability of large facilities such as coal-fired power plants, chemical factories, or renewable electricity generators is typically judged based on their use for multiple decades.[18]

Nuclear power, which currently provides approximately 20% of U.S. electricity, comes from a fleet of 96 plants that all began operation before 1990.[19] Similar timescales apply in buildings and transportation. Buildings constructed in the next decade will be in use long beyond 2050. The average age of a light-duty vehicle in the United States is more than 11 years,[20] suggesting that many new vehicles sold today will still be in use in 2040. Choices that are made today about new energy infrastructure have implications on decadal timescales.

The significant capital costs and long lifetimes of new energy infrastructure create strong barriers to commercial liftoff of emerging technologies. Before widespread commercial adoption of new energy technologies can occur, technical risks associated with performance and reliability and commercial risks associated with value proposition (e.g., delivered cost), market acceptance (e.g., product demand), resource maturity (e.g., manufacturing and the supply chain), and social license to operate (e.g., community perception) must be addressed. Real world demonstration projects that operate for sustained periods at scales relevant to future commercial facilities are by far the most efficient means of confronting and reducing these risks. Public–private partnerships can play a pivotal role in driving demonstration projects, since the cost, and hence, financial risk, of a FOAK facility is inevitably higher than later installations of the same technology after maturation.[21] OCED will lead DOE's efforts to implement demonstration projects in partnership with the private sector with the goals of reducing technical and commercial risks associated with new energy technologies and catalyzing future private sector investment.

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[18] Emily Grubert, "Fossil Electricity Retirement Deadlines for a Just Transition," *Science* 370, no. 6521 (2020): 1171–73.
[19] U.S. Energy Information Administration, "Annual Energy Review."
[20] DOE, "FOTW #1095, August 19, 2019: The Average Age of Light-Duty Vehicles Has Increased to 11.8 Years," Vehicle Technologies Office, Energy.gov, https://www.energy.gov/eere/vehicles/articles/fotw-1095-august-19-2019-average-age-light-duty-vehicles-has-increased-118.
[21] Alan McDonald and Leo Schrattenholzer, "Learning Rates for Energy Technologies," *Energy Policy* 29, no. 4 (2001): 255.

The large-scale development of infrastructure, supply chain shifts, and workforce restructuring that accompanies the United States' clean energy transition will transform local environments and communities. Without proactive effort, these changes are likely to follow historical patterns[22] that have disproportionally concentrated many of the harms of the energy, transportation, and industrial systems in low-income communities, communities of color, and Indigenous communities while simultaneously concentrating many of the benefits in wealthier communities.[23,24,25,26] Siting is often a major determinant of how project burdens are distributed and experienced. Proximity to energy or industrial infrastructure often increases exposure to pollution; safety concerns; changes in land, energy, and water use; and impacts on wealth and quality of life.

The impact of these burdens may vary dramatically from one community to another based on local history and cumulative burdens.[27,28] Prioritizing equity and justice by engaging community, workforce, and Tribal stakeholders and responding to their needs and priorities can support project success, reducing the risk of local pushback, protests, and lawsuits that may delay, or even cancel, projects. Ultimately, these factors will impact market liftoff for new technologies, which depend in part on the real and perceived social acceptance of clean energy.

The next wave of clean energy infrastructure projects will have a significant impact on the economies of host communities and especially on the lives of workers. The clean energy transition will create millions of new jobs,[29] and the success of innovative new energy industries depends on the preparedness and well-being of U.S. workers. A successful clean energy transition requires providing support for labor through workforce development and good jobs as an investment in the efficiency, ingenuity, and high skill of the American workforce and, ultimately, projects' viability and success.

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[22] Benjamin Sovacool et al., "Decarbonization and Its Discontents: A Critical Energy Justice Perspective on Four Low-Carbon Transitions," *Climatic Change* 155 (2019): 581–619.
[23] Chetana Kallakuri, Shruti Vaidyanathan, Meegan Kelly, and Rachel Cluett, "The 2016 International Energy Efficiency Scorecard," American Council for an Energy-Efficient Economy, July 19, 2016, https://aceee.org/research-report/e1602.
[24] Eric Scheier and Noah Kittner, "A Measurement Strategy to Address Disparities Across Household Energy Burdens," *Nature Communications* 13, no. 1 (2022): 288.
[25] Christopher W. Tessum et al., "$PM_{2.5}$ Polluters Disproportionately and Systemically Affect People of Color in the United States," *Science Advances* 7, no. 18 (2021), eabf4491, https://doi.org/10.1126/sciadv.abf4491.
[26] Christopher. W. Tessum et al., "Inequity in Consumption of Goods and Services Adds to Racial-Ethnic Disparities in Air Pollution Exposure," *Proceedings of the National Academy of Sciences* 116, no. 13 (2019): 6001–06.
[27] Frederica Perera, "Pollution From Fossil-Fuel Combustion is the Leading Environment Threat to Global Pediatric Health and Equity: Solutions Exist," *International Journal of Environmental Research and Public Health* 15, no. 1 (2018): 16.
[28] Joan A. Casey et al., "Climate Justice and California's Methane Superemitters: Environmental Equity Assessment of Community Proximity and Exposure Intensity," *Environmental Science & Technology* 55, no. 21 (2021): 14746–57.
[29] Energy Innovation: Policy and Technology and Silvio Marcacci, "Clean Energy Jobs Are Booming, Making Up For Rising Fossil Fuel Unemployment," *Forbes*, June 29, 2022, https://www.forbes.com/sites/energyinnovation/2022/06/29/clean-energy-jobs-are-booming-making-up-for-rising-fossil-fuel-unemployment/?sh=108829b11c13.

One of the major challenges for cutting-edge clean energy projects is to develop, attract, and retain an appropriately skilled workforce. A strong, well-skilled American workforce is foundational to the United States' competitive advantage in the global energy industry and related supply chains.

2.3 OCED Structure

OCED will fund and manage a portfolio of projects and demand-side mechanisms in a broad range of solutions that will drive advances in key energy sectors shown in Figure 2.1. A number of these projects focus on the need to rapidly decrease the nation's dependence on carbon dioxide-emitting sources for electricity, including demonstrations of advanced nuclear reactors and the capture of carbon dioxide associated with electricity generation. Growth in the end use of electricity and increased reliance on variable generation sources means that the nation's electricity grid must evolve to be more flexible and resilient. To this end, a set of projects will focus specifically on grid reliability and resilience. A second broad group of topics focuses directly on GHG emissions across multiple sectors. This work includes demonstrations aimed at reducing GHG emissions from industrial processes and pilot and demonstration projects for carbon dioxide capture.

In addition, OCED will implement demonstrations focused on DAC of carbon dioxide, a key example of the crosscutting net-negative methods shown in Figure 2.1. A third group of topics considers energy associated with specific locations and communities, including clean energy demonstrations associated with mine lands and energy technologies for rural and remote areas. Finally, OCED is managing a portfolio of demonstration activities related to clean hydrogen, an energy carrier that has a diverse range of possible sources, has an equally diverse collection of potential end uses, and is valued by the industrial, transportation, building, and agricultural sectors. Many interdependencies exist among the topics listed above, and OCED's work will be structured to recognize and capitalize on these connections. Section 6 further details these areas and discusses additional future areas of interest for OCED.

OCED's organization chart is shown in Figure 2.3. OCED's Director reports to DOE's Under Secretary for Infrastructure. OCED was designed to be a highly matrixed organization across its divisions and with other DOE offices. For example, the Project Management Division (PMD) operates as a center of excellence for project management oversight of the Office's demonstration projects. The PMD works closely with subject matter experts across DOE's applied offices and the LPO, and it also provides support to other DOE offices for large-scale demonstrations. Technical and Engineering Support (TES) provides expeditious and consistent technical evaluations to inform critical decision-making, such as reviews of engineering designs and techno-economic, financial, and life cycle impacts for projects being managed under the PMD.

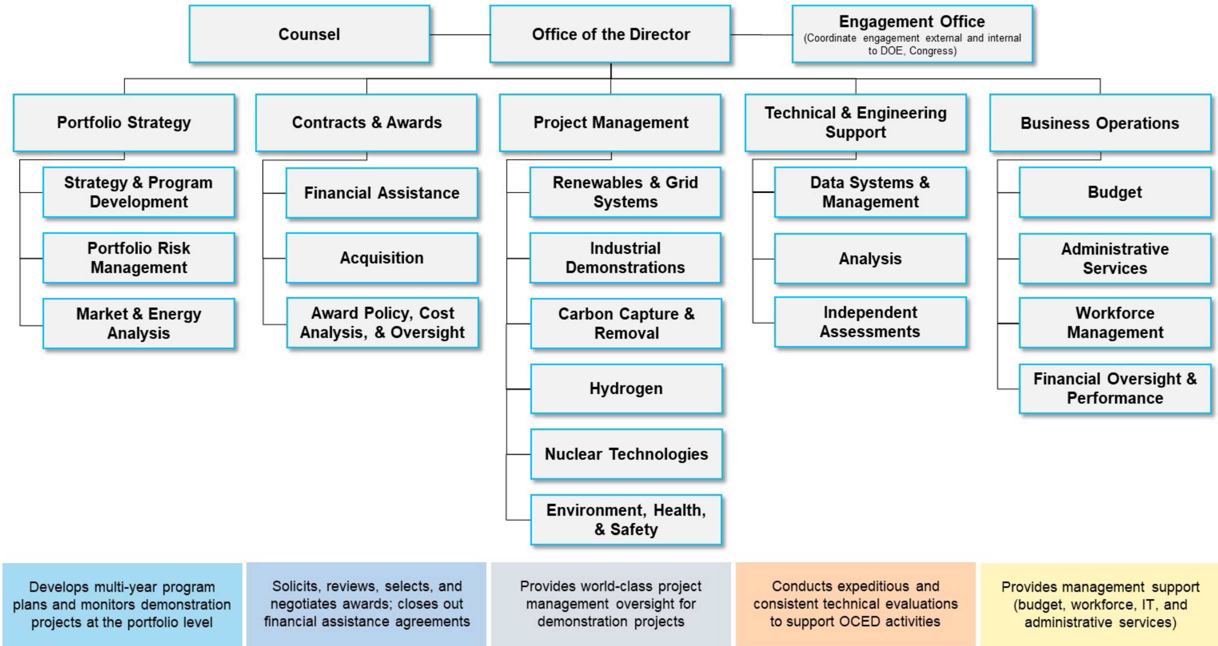

Figure 2.3: *OCED organizational chart.*

The Portfolio Strategy Division monitors demonstration projects to assess portfolio performance and risks in collaboration with the Technical Engineering Support and Program Management teams. The Portfolio Strategy Division also leads forward-looking analysis (including supporting the Pathways to Commercial Liftoff Reports[30]) in coordination with other DOE offices and external stakeholders that informs demonstration and deployment commercialization pathways, multi-year planning efforts, and program development to address any systemic and emergent risks stemming from the portfolio in support of the large demonstration programs.

The Contracts and Awards Division supports the execution of funding programs to solicit, review, select, and negotiate awards and close out financial assistance agreements, procurements, and acquisitions. The Business Operations Division provides the entire OCED with support for financial oversight, performance, and budget, workforce, IT, and administrative services. The Engagement Office supports and facilitates OCED's mission by structuring internal and external engagement to help manage portfolio risk, increase direct and indirect program outcomes, and achieve scaling and commercialization objectives.

[30] DOE, "Liftoff Reports," Energy.gov, https://liftoff.energy.gov/.

To achieve its aim of de-risking clean energy technologies, OCED is working closely with many other DOE offices. These include the applied offices in the Office of the Under Secretary for Science and Innovation that support R&D and early-stage demonstration efforts, as well as other offices within the Office of the Under Secretary for Infrastructure such as the LPO, which provides loans to drive commercial uptake of proven technologies. This matrixed organization outlined above is intended to build an enduring collaboration model based on continuous input and feedback from other DOE offices to coordinate and inform new programs, share project- and portfolio-level progress, and develop joint strategies.

OCED manages its portfolio of projects with a variety of funding mechanisms and authorities. Most demonstration projects will be managed through financial assistance awards, specifically, cooperative agreements between DOE and a private sector partner or consortium of partners. These public–private partnerships will require significant levels of matching funds to augment Federal funds – 50% or more cost share from the private sector in most cases. Cooperative agreements will typically be executed through a series of four phases: (1) detailed planning; (2) project development, permitting, and financing; (3) installation, integration, and construction; and (4) ramp-up, operation, and validation. Each phase will have well-defined go/no-go decision and/or downselect points to assess whether projects should advance to the next phase, as described in Section 3.

OCED will also use other funding mechanisms and authorities such as prizes, Other Transactional Authorities (OTA), and Partnership Intermediary Agreements (PIA), when appropriate, to address barriers to commercialization and unlock private sector investments. These other funding mechanisms could allow OCED to design programs that address the demand-side challenges faced by its technology sectors in addition to the supply-side support from traditional financial assistance. For many clean energy technologies, the absence of long-term offtake is a critical barrier to unlocking large-scale investment and deployment. In many industries (e.g., hydrogen, steel, and cement), buyers are not willing to commit to the kind of long-term, fixed-price offtake agreements for less carbon-intensive products that were a cornerstone of wind and solar's successful scale-up. In many cases, private investors would be comfortable funding deployment of these technologies if they had a more certain revenue profile. Respondents to a 2023 OCED Request for Information (RFI)[31] highlighted these issues and called on DOE to develop tools to address demand barriers that clean energy technologies face.

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[31] Office of Clean Energy Demonstrations, "DE-FOA-0002995: Request for Information on the Department of Energy's Use of Demand-Side Support for Clean Energy Technologies," OCED Funding Opportunity Announcements, https://oced-exchange.energy.gov/Default.aspx#FoaId5f313e9b-4b18-4dd0-bd36-17b58e8d2417.

Demand-side measures like advance market commitments and long-term pay-for-delivery contracts that guarantee revenue certainty for clean energy projects can be an effective complement to OCED cooperative agreements in bringing clean energy technologies to scale. By providing revenue certainty, these tools can unlock low cost-of-capital private sector investment in these technologies. Demand-side measures can help OCED manage risks because they will only pay when projects successfully produce clean energy products, in contrast to infrastructure funding that pays well before production targets are met.

OCED will also contribute to the Technology Commercialization Fund (TCF) program, administered by the Office of Technology Transitions. This program targets complimentary activities to support the success of clean energy demonstrations, especially in instances when crosscutting technical challenges need to be rapidly addressed.

3 The Role of Demonstration Projects in Development of Clean Energy Technology Solutions

To achieve the nation's energy transition objectives, a variety of technologies and solutions must be rapidly deployed at very large scales. The large capital costs and long infrastructure lifetimes associated with energy technologies demand high levels of performance and market certainty before widespread commercial investment will take place. A common feature of many technologies is that their unit cost diminishes over time as the number of installed units increases, also known as a learning rate. Part of the advances captured in a learning rate arise from cumulative experience with a technology, an observation that highlights the critical role of R&D. The most common models for learning rates note a fixed fractional reduction in cost for each cumulative doubling of production,[32] although more complex models have also been explored for energy technologies.[33] These learning rates are due to economies of scale, incremental product engineering, manufacturing improvements, and project integration repeatability but also to the establishment of investor confidence, community acceptance, and markets for products. This means that FOAK installations and early operations of new clean energy technologies are almost inevitably more economically challenging than implementation of established technologies.

DOE has a broad array of programs to generate innovative technologies and aid their progression toward commercial investment and commercial adoption, as illustrated in Figure 3.1. OCED plays a pivotal role in filling a gap between the R&D activities of Office of Science and DOE's applied offices and the private sector and the deployment-oriented mission of the LPO. Activities early in the technology commercialization continuum shown in Figure 3.1 are typically characterized by a focus on technical risks, that is, how well the technology works. In contrast, the deployment end of the commercialization continuum is typically dominated by questions of finance and operations, with the aim of proving that a clean energy solution is economically viable.

[32] McDonald and Schrattenholzer, "Learning Rates," 255.

[33] Edward S. Rubin et al., "A Review of Learning Rates for Electricity Supply Technologies," *Energy Policy* 86 (2015): 198.

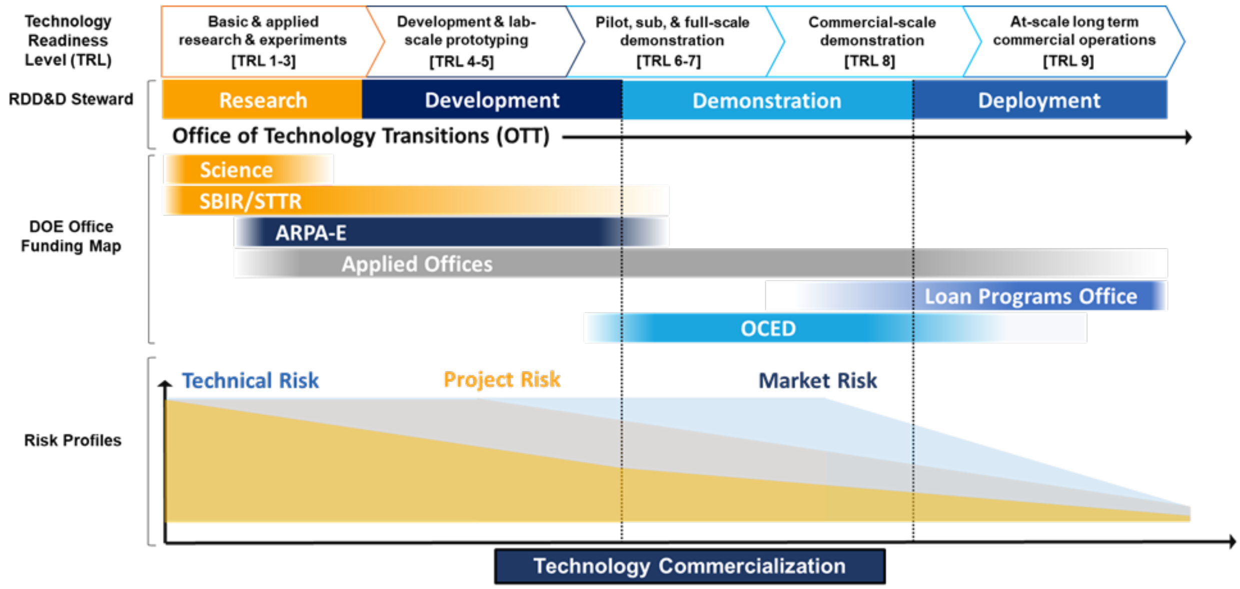

Figure 3.1: *Roles of key DOE Offices in the continuum of technology development from basic research to at-scale commercial deployment of new technologies (RDD&D = research, development, demonstration, and deployment; SBIR/STTR = Small Business Innovation Research/Small Business Technology Transfer; ARPA-E = Advanced Research Projects Agency–Energy).*

The demonstration projects executed by OCED will bridge these two aspects of technology development. More details on OCED's approaches to de-risk clean energy solutions and drive efficient decisions by commercial investors are given in Section 4. OCED's demonstration projects are intended to establish enduring infrastructure that continues in operation well beyond the period of initial Federal funding. The primary distinction between the demonstration and commercial operations phases shown in Figure 3.1 is the risk profile at the outset of a project, not whether the facilities that are installed are used in a sustained way. For this reason, OCED will deliberately fund projects with complex risk profiles including technical, commercial, and other adoption risks. It is desirable for all demonstration projects to achieve sustained use, but de-risking technology may in some cases identify additional design elements or other systemic improvements and changes that are required to fully achieve this goal.

The costs for the various stages of technology commercialization shown in Figure 3.1 typically increase rapidly as a technology moves toward commercial use for energy infrastructure. Full-scale demonstrations have several important attributes that make them a key element in a long-term commercialization strategy. First, a demonstration allows validation of the performance of a clean energy solution in a sufficiently complex environment, ensuring that the project encounters a full range of operational conditions, variations over time, and interactions.

This makes it possible to surface emergent issues that can arise during scaling, systems integration, and commercial adoption. Second, demonstrations allow learning by doing, which leads directly to cost reductions for future installations and building of capacity in workforce and supply chains. Third, results obtained from the development and continued operations of a demonstration build confidence in industry and financial sectors and permitting and regulatory groups that the approach has sustained value, thus activating additional capital for scaling and replication. Demonstration projects can also be used to showcase the highest standards of community and labor engagement, investing in the American workforce, DEIA, and Justice 40 actions and their contributions toward project success, as well as demonstrating entirely new mechanisms for ownership, oversight, and involvement in projects that will result in more equitably shared benefits.

The complex nature of the nation's energy systems means that OCED's overall portfolio will involve multiple technology demonstration programs as key pathways to decarbonization that may also be interdependent. A strength of OCED's broad portfolio is that it will allow interconnections and dependencies between different clean energy solutions to be identified and leveraged as solutions are scaled and integrated.

The distinction between OCED's portfolio, programs, and projects is shown in Figure 3.2. Figure 3.2 indicates that each program will develop and manage a primary set of demonstration scale projects but also make use of additional funding mechanisms and prizes that can efficiently address crosscutting challenges within a program. Achieving this mission requires adoption of a new solution not just by the specific partners who participate in an OCED demonstration but by a wider cross section of the private sector as well. To this end, OCED will strategically develop an overall portfolio of programs and execute programs of multiple demonstration projects in each technology or solution area of interest.

The program approach requires the selection of a diversified portfolio of demonstration projects within each area to adequately explore variations in the technical performance, project costs, life cycle assessments, markets, and regulatory and community benefits affected by local or regional factors. This approach also provides the ability to resolve these challenges through knowledge exchange among projects. The scale of the programs and the focus on enabling liftoff also send a signal to associated manufacturing and supply chains and local and regional workforces to support these new clean energy industries, ramping up over time in support of getting to scale and replication nationally.

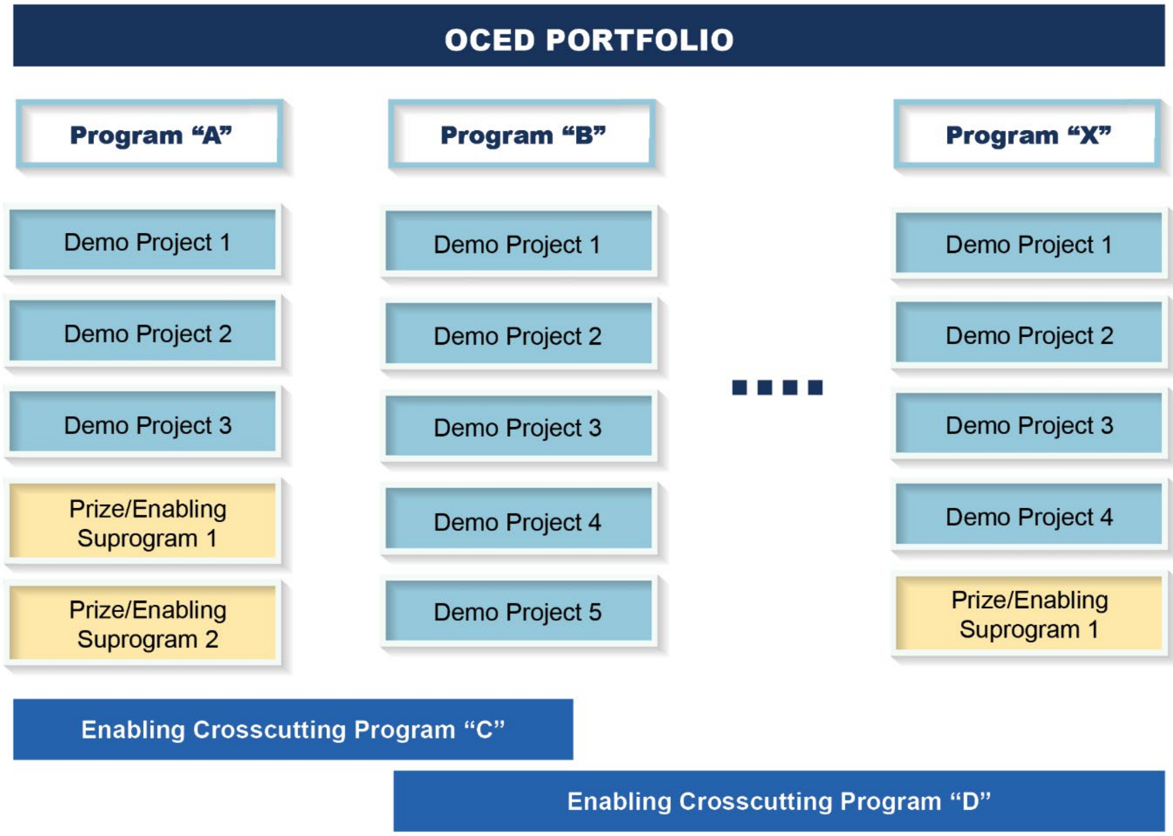

Figure 3.2: *Diagram showing the distinction between OCED portfolio, programs, and individual projects. A program operates a collection of projects with the aim of accelerating de-risking of clean energy solutions in a focused technical or end-use sector. OCED's overall portfolio is comprised of the collection of programs and will seek to identify and leverage connections between programs. Support and enabling programs include the TCF, small business programs, technical assistance, competitions, demand-side measures, and similar.*

The program approach is also efficient in building confidence in industry, investors, regulators, and communities, since successful operation of a new technology by multiple independent teams is valuable in de-risking clean energy solutions. In addition to taking advantage of learnings within the set of projects in a program, OCED will evaluate outcomes at a portfolio level, addressing synergies, competition, and interdependencies that exist among different sectors and technologies.

Although OCED's demonstration projects will vary in scope, they will be defined by a number of common characteristics. Demonstrations will typically be structured to have four funded phases, as shown in Figure 3.3: (1) detailed project planning; (2) project development that includes siting, permitting, and financing; (3) installation, integration of component processes, and commissioning; and (4) ramp up, operations, and validation. This phase approach was adopted from the DOE's extensive previous experience at managing demonstration projects.

Each phase will include activities associated with promoting quality job creation and workforce development, EEJ, community and labor engagement, and DEIA since these critical goals can only reach fruition if the overall project is developed to prioritize them. FOAK installations will face distinct challenges in each of these project phases. For this reason, project phases will be coupled with strong decision points and performance metrics that must be achieved before advancing to the next phase. A more detailed example of the structure shown schematically in Figure 3.3 is given in Section 5.

Figure 3.2 shows an illustrative structure for a portfolio of individual projects addressing a program area, and Figure 3.3 shows the typical phase structure of an individual demonstration project. The lengths of phases and start dates for individual projects will be adapted to enable projects to advance expeditiously based on evidence of readiness. It is typically not necessary or even desirable for all projects in a portfolio to move through the phases in Figure 3.3 at the same time. As noted above, projects that receive funding in Phase 4 will operate in a sustained way for an extended period after the federally funded phases in Figure 3.3 are complete. In typical OCED projects, Federal funding will provide up to 50% of the total project cost, with the remaining funds coming from non-Federal cost share.

Smaller projects may focus on demonstration of specific processes or key bottlenecks in the maturation of a technology. Larger projects will often focus on technologies that require a system of systems and will include approaches that combine a variety of feedstock and product streams. The specific scale appropriate for OCED's demonstrations will be determined by a careful assessment of the current state of the art in the technology area and the projected size of future commercially viable installations.

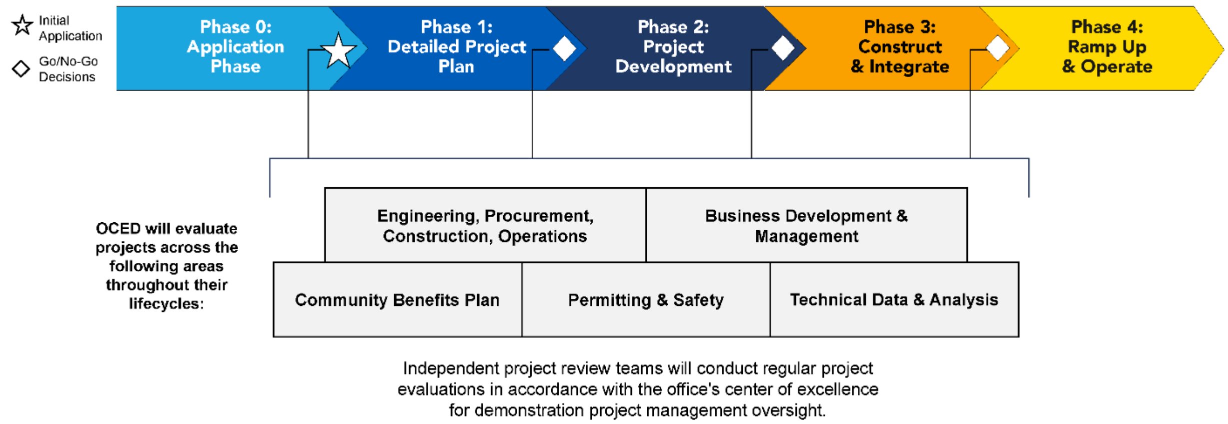

Figure 3.3: *Schematic illustration of phased approach for OCED projects, indicating go/no-go decisions at the end of each phase.*

In many cases, the assessment and projection will lead to minimum requirements for participation in an OCED program, for example, the capacity needed to commercially produce and sell a specified quantity of a key product per year to generate a sustainable return on investment. OCED demonstrations aim to enable FOAK installations that achieve ongoing operation beyond the initial period of Federal funding. It will typically take 5–10 years to complete all phases of a demonstration. This extended duration accounts for the time horizons required for installing new capital facilities and the important goal of operating the new technology for an extended period to gain experience with a wide range of operating and market conditions.

4 OCED's Approach to Portfolio Risk Management

As described in Section 3, demonstration projects play a pivotal role in driving clean energy technologies toward market adoption because these projects are the only viable way to de-risk pre-commercial technologies. De-risking the commercialization of technologies is critical to unlocking the large-scale private investment needed for widespread infrastructure deployment. Central to this effort is the accurate and consistent characterization of the multiple dimensions of risk that slow or prevent commercial adoption and OCED's strategic approach to reducing these risks through its programs. A rigorous approach to this portfolio risk management will underpin OCED's role for enabling execution of demonstration projects across DOE.

One widely accepted framework for categorizing technology risk is the Technology Readiness Level (TRL). DOE's definition of TRLs move from TRL 1 ("basic principles observed and reported") to TRL 9 ("actual operation of the technology in its final form, under the full range of operating conditions").[34] The characteristics of the 9 TRLs are summarized in Table 4.1. As indicated by its name, the TRL scale focuses on the technical risks associated with a new technology. There are, however, many non-technical risks than can limit or prevent market adoption. For example, the robustness of the supply chain needed for widespread deployment, the availability of a skilled workforce, the policy and regulatory environment impacting the solution, and the market size and structure across different end uses. Because OCED's programs target technologies at the demonstration phase with the goal of catalyzing commercial liftoff, these risks are just as important as the technology risks.

While there are several frameworks that discuss barriers to market adoption, OCED will categorize these factors using a composite scale developed by DOE's Office of Technology Transitions (OTT), the Adoption Readiness Level (ARL) framework.[35] The ARL framework lays out 17 risk dimensions in four categories (see Figure 4.1), to comprehensively characterize key risks to commercial adoption for a technology solution.

[34] *Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects* (GAO-20-48G), U.S. Government Accountability Office, January 2020, https://www.gao.gov/assets/gao-20-48g.pdf, Appendix X.

[35] DOE, "Adoption Readiness Levels (ARL): A Complement to TRL," Office of Technology Transitions, Energy.gov, https://www.energy.gov/technologytransitions/adoption-readiness-levels-arl-complement-trl.

Table 4.1: *Characteristics of DOE definitions of the nine Technology Readiness Levels (TRLs).*

	TRL	Characteristics
Low	1	Scientific research begins to be translated in applied R&D
	2	Analytical or paper studies with emphasis on understanding science
	3	Analytical or experimental proof of concept
Medium	4	Basic components integrated to show they work together
	5	Laboratory-scale validation in relevant environment
	6	Engineering-scale prototype validation
High	7	Actual system prototype operated in relevant environment
	8	Actual system completed and qualified through test and demonstration
	9	Actual system operated over the full range of expected conditions

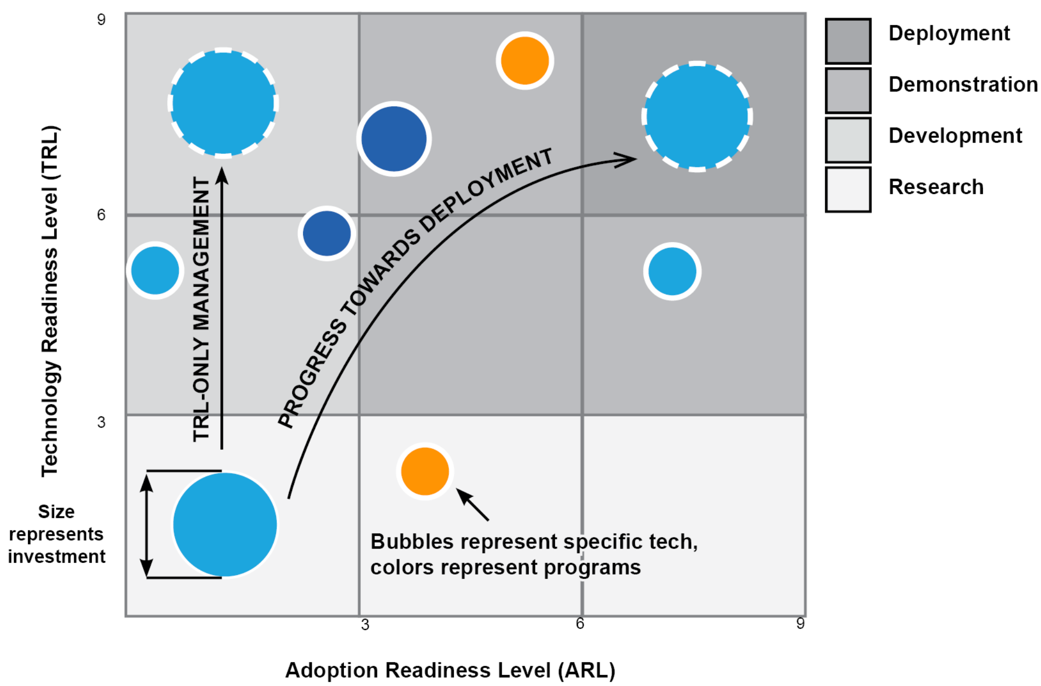

Figure 4.1: *Summary of the ARL risk dimensions as of March 2023*

OTT's online Commercial Adoption Readiness Assessment Tool (CARAT) makes it possible to arrive at a single ARL score (on a scale of 1–9 similar to TRL) by evaluating each risk dimension as high, medium, or low (each rating is defined in the online tool). While the single score can be useful for a technology solution, the true value of the framework comes through understanding which of the risk dimensions are the key barriers to a given technology solution's commercial adoption. For example, a solution rated high risk in Manufacturing and Supply Chain might require creation of new processes or methods that are not currently in commercial practice, whereas a solution rated low risk might only need off-the-shelf components. Similarly, if deployment of a solution is possible with minimal changes to regulations and standards, Regulatory Environment would be rated low risk, whereas a solution requiring substantial changes in regulations or standards would be rated high risk. To achieve full commercial liftoff, a technology solution must be rated low risk across all risk dimensions. ARL and TRL are complementary frameworks, as illustrated in Figure 4.2.

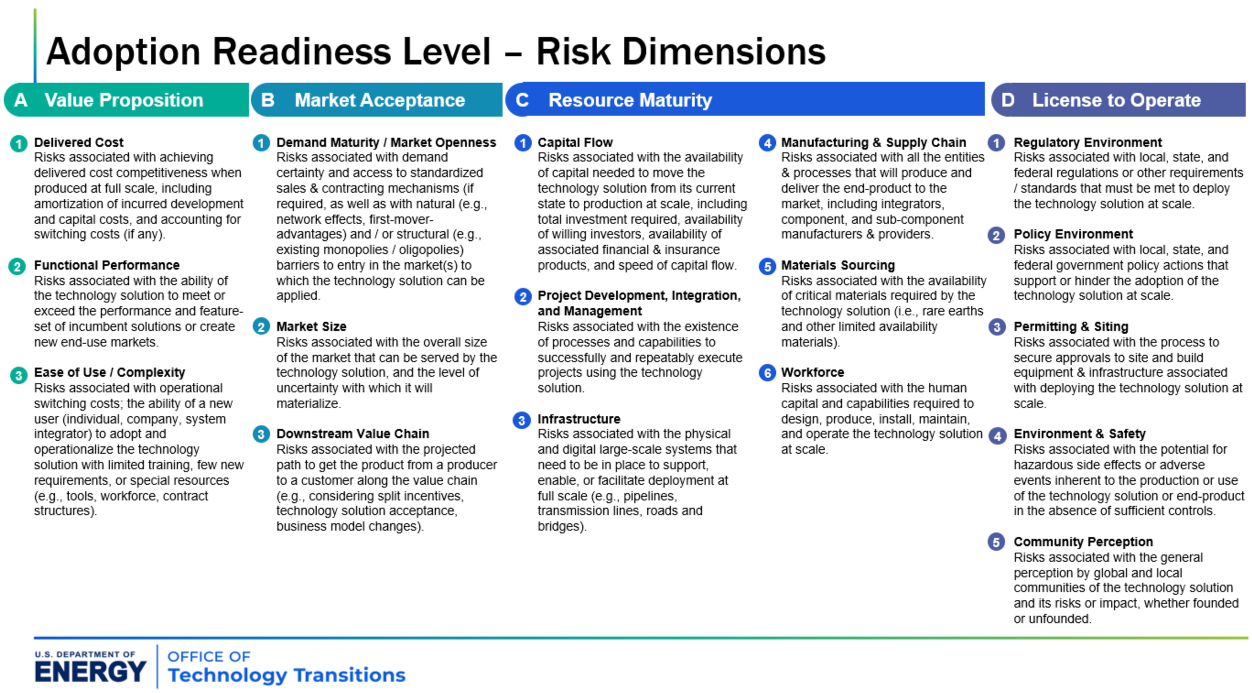

Figure 4.2: *Illustration of typical path through the research, development, demonstration, and deployment continuum in the TRL/ARL matrix.*

Figure 4.3 emphasizes that de-risking the clean energy challenges associated with OCED's programs (e.g., OCED's activities to advance clean hydrogen technologies) will have a more holistic industry impact than the granular aspects of de-risking individual projects.

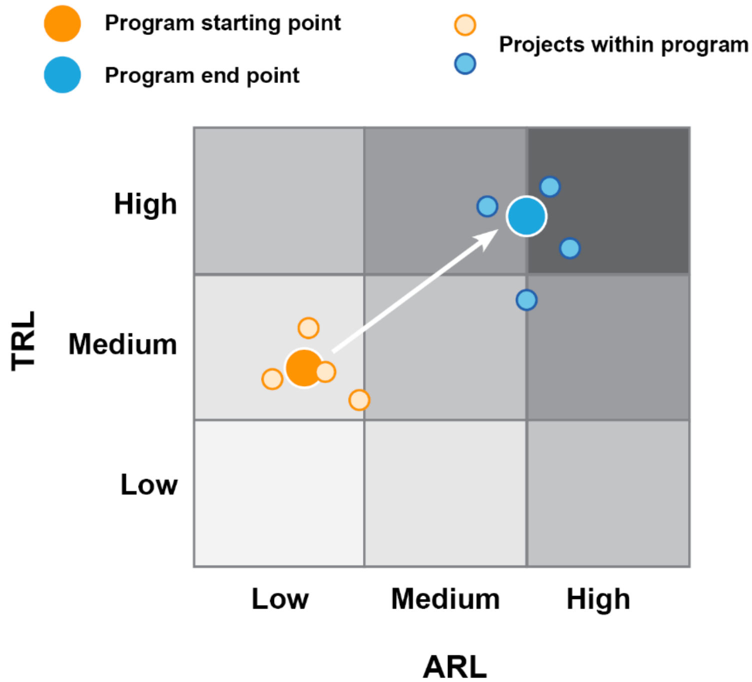

Figure 4.3: *Illustration of a representative trajectory over time of a program (large circles) of demonstration projects (small circles) assessed using Technology Readiness Level (TRL, vertical axis) and Adoption Readiness Level (ARL, horizonal axis). Both TRL and ARL need to reach "High" for a clean energy solution to be well positioned for significant commercial investment and rapid deployment.*

At the same time, however, the risk profile of individual projects must be carefully assessed to draw conclusions about the status of a program. In many cases, the actions needed to lower risk across the ARL dimensions will be closely related among the projects that comprise a program (e.g., many clean hydrogen projects may face similar permitting challenges). As a result, coordination and comparison by OCED, among projects making up a program, will accelerate the program's overall progress toward buying down these risks.

To this end, OCED will systematically assess and compare the TRL and ARL of demonstration and pilot projects throughout their lifetime and compare these factors across projects in a program. Learnings from these evaluations will be used to inform priorities across the DOE research, development, and demonstration (RD&D) continuum and to work with stakeholders on progress and remaining challenges to fully de-risk clean energy solutions.

Given the FOAK commercial stage of OCED's investments, not all individual projects will achieve sustained commercial operation and serve as replicable blueprints for the private sector. Nevertheless, OCED's programs and portfolio can be successful by accelerating commercial liftoff in its technology solution areas. Furthermore, projects that fail to achieve sustained commercial operation may still contribute meaningfully to program and portfolio success.

Table 4.2: *Selected characteristics of successful outcomes for OCED portfolios.*

	Technology Successes	Commercial Adoption Successes
Tier I	Achieved substantially improved performance and/or cost Enabled financing for next generation or larger scale projects	Secured contracted offtake and debt financing required for commercial scale Financing and deployment of technology beyond OCED-funded partners Sufficient workforce development programs to support deployment needs Positive reception and strong local support from host communities
Tier II	Successful demonstrations in new environments Achieved performance and/or cost reductions and identified RD&D focuses for further improvements	Robust datasets available to improve development of insurance products Increased participation of private capital in adjacent technology areas Maturation of workforce and evidence of scope for equitable deployment Demonstrated community benefits in new environments
Tier III	Sufficient learnings to substantially refine upstream R&D portfolios Sufficient learnings to substantially refine OCED and LPO strategies and future programming	New understanding of market, redirection of early-stage private sector capital Workforce training developed that is transferable to adjacent technology areas

The complementary TRL and ARL scales provide a useful framework for defining successful outcomes for each of the technology programs that OCED will execute (see Figure 4.2). Table 4.2 defines successful outcomes for OCED at the program level in three tiers, with Tier I being the most successful. In each tier, successful outcomes are described separately for technology and for commercial adoption.

A key aspect of the successes in Tier I is the development of financing that goes beyond the lifetime and scope of direct OCED funding, either for the partners involved in OCED projects or others driving commercial deployment. This metric of success will typically occur multiple years after the initiation of OCED funding in a specific area, emphasizing the need to monitor and assess these outcomes over long time horizons (see Figure 3.3).

The phased project structure shown in Figure 3.3 emphasizes that not all projects in a program will progress past each go/no-go decision or a downselect point. Rigorous assessment of project status and implementation of a downselect or go/no-go decision is a key tool in managing risk within projects and programs. The outcomes in Table 4.2 highlight the observation that even OCED projects that do not achieve Tier I goals or do not progress through all phases of available OCED funding can still contribute to the overall success of an OCED program and portfolio.

Similar to the discussion of Figure 4.3, quantification of the successes of a program and the portfolio will require assessment of individual projects. The characteristics listed in Table 4.2 are also applicable to individual projects. Notably, a program may achieve a higher level of success than some of the individual projects in the program. For example, an overall program could demonstrate financing for next-generation or larger-scale projects even though this target was not reached by every individual project.

The framework outlined above will be used to systematically identify and communicate risk elements for demonstration projects and programs, to refine plans to reduce or retire these risks, and to enable effective project-, program-, and portfolio-level evaluations. Program development is informed by extensive stakeholder engagement with DOE and across the private and non-profit sectors, ongoing systems analysis, and research, including inputs from the Pathways to Commercial Liftoff Reports.

During program development, OCED will use these inputs and the TRL and ARL assessments to establish baselines for candidate clean energy technology solutions and to identify key barriers to adoption. OCED will also develop theories of change for how specific programs or solicitations can buy down those barriers, select a portfolio of projects that can realize that theory of change, and generate risk registers at the program and portfolio level to evaluate progress in reducing those barriers to commercial liftoff. These approaches will aid in defining information to require in applications, to develop detailed risk registers to be used in program management and oversight, and to refine specific gating objectives and deliverables in individual projects.

As projects progress, ongoing data collection will be used to update risk registers and readiness evaluations. Aggregating this information will allow OCED to track deviations from expectations in theory of change, particularly in identifying persistent risks, emergent risks, and possible points of portfolio weakness that are not being effectively mitigated through current strategies.

The focus of this section has been OCED's efforts to define and quantify risk within its programs and portfolios. As actionable information emerges from these efforts it will be vital to clearly communicate these learnings to RD&D partners and potential commercial adopters. OCED's strategy for maintaining these channels of communication is described in Section 8.

5 Project Management Oversight in OCED

OCED's demonstration projects aim to rapidly reduce the technical and nontechnical uncertainties associated with pre-commercial technology, including techno-economic performance, life cycle impacts, market acceptance, safety, regulatory, and community acceptance and impact issues. OCED will seek the best possible outcomes for individual demonstration projects by making critical decisions in a consistent and transparent way to assess and enhance project performance. DOE has well-established procedures for management of capital-intensive projects in settings where the project outcome is owned and operated by DOE.

These approaches will be tailored within OCED in the context of financial assistance to fit OCED's operating model of public–private partnerships, where the desired outcome is an installation that is owned and operated by commercial partners well beyond the time horizon of DOE funding. OCED's approach will align with and leverage industry best practices to manage portfolio risk and project performance. A central feature of OCED's project oversight is that it will balance review of technical aspects of project performance with factors associated with operations and finance. It is expected, for example, that a significant fraction of resources and weighting associated with project assessment will be linked to the ARL factors described in Section 4.

Overall management of individual OCED demonstration projects from solicitation to completion will be the responsibility of the PMD. PMD performs overall project management oversight activities in a collaborative fashion by developing an integrated project team for each project. PMD will maintain substantial involvement in each project funded through a cooperative agreement to ensure that it is meeting the terms and conditions of the agreement and legislative, DOE, and OCED objectives. Part of PMD's active program management oversight will be in defining project performance milestones during negotiation of cooperative agreements.

OCED will regularly use independent engineers and other technical experts to assess project performance and risk, especially to support critical go/no-go decision points during the phased project structure outlined in Section 3. OCED's TES provides expertise that will allow consistent assessment among projects in a portfolio and enable cross-comparisons for projects within a program.

The capabilities of PMD, supported by TES, will allow OCED to function as a center of excellence for project management oversight of demonstration projects within DOE. These capabilities will enable OCED to serve as an expert resource for demonstrations in other DOE offices.

Individual projects within OCED will typically be structured in a series of phases with well-defined mechanisms for review and assessment of go/no-go decisions before a project advances from one phase to the next. Figure 3.3 gives a schematic illustration of this phased approach. Each OCED program will define a balanced set of objectives for each phase. An example drawn from OCED's Clean Hydrogen program is shown in Figure 5.1, highlighting the multiple facets of project development that will be considered in each phase. The example in Figure 5.1 is likely to be representative of most programs, tailored where appropriate. In particular, Figure 5.1 highlights the role of community and labor engagement, quality jobs and workforce development, EEJ, and DEIA within every phase of a project.

The time required for capital-intensive aspects of installing and operating demonstration facilities will vary from project to project. For this reason, it is more important to define the length of project phases to drive project success than it is to exactly align the timing of phases among all projects in a portfolio. The speed at which each project is capable of progressing will be factored into project selection, negotiation, and other critical decision points. Renegotiation of the time allowed for a project phase may in some instances be appropriate if doing so would allow an awardee to resolve a critical challenge to project performance, but the firm application of go/no-go decisions will be vital to ensuring that completed projects reach their full potential on time and on budget. It will also be possible in instances where projects have successfully completed the objectives of a phase to reduce its length prior to moving to the next phase.

To be effective, OCED project oversight must go beyond evaluation of go/no-go decisions at the end of project phases. As part of maintaining substantial involvement in each project funded through a cooperative agreement, OCED project managers will have continued engagement with awardees throughout a project's execution. It is expected that each project will be evaluated through a standardized process reflecting technical, operational, and financial risks on a regular basis. This active engagement approach uses independent engineers and other experts from TES to inform decisions about project outcomes. An important goal for each program group within PMD (see Figure 2.2) will be to collect data in a consistent way across projects to enable the multifactor assessment of programs and the overall portfolio shown in Figure 4.1.

Consistent metrics and methods of assessment within technology programs and OCED's overall portfolio will make it possible to efficiently identify emergent, crosscutting issues where ancillary funding mechanisms (e.g., TCF, OTAs, PIAs, or prizes) can quickly address barriers to commercialization. OCED's approach will also facilitate collection of portfolio-wide information to enable future commercial uptake of technology (by the private sector or through DOE's LPO) and to refine future R&D goals in DOE's applied offices.

☆ Initial Application

◇ Go/No-Go Decisions

$0.4B - $1.25B Total DOE Funding; Non-Federal Cost Share ≥ 50%

	Application	Phase 1: Detailed Plan	Phase 2: Develop, Permit, Finance	Phase 3: Install, Integrate, Construct	Phase 4: Ramp Up & Operate
	Pre - DOE funding	Up to $20M DOE Funding, ~12-18 Months	Up to 15% of Total DOE Funding, ~2-3 Years	DOE Funding To Be Negotiated, ~2-4 Years	DOE Funding To Be Negotiated, 2-4 Years
Business Development & Management	Technical Volume: • H2Hub Summary • Business Plan (BP), including preliminary site selection • Management Plan (MP) • Financial Plan (FP)	• Market, feedstock, & offtake letters of commitment • Final site selection • Financial model • Updated BP, MP, FP	• Teaming, offtake, & feedstock agreements • Site access secured • Confirmed project financing • Updated BP, MP, FP • Labor agreements	• Regular progress/status reporting for all agreements • Regular financial status reports • Other reporting per terms & conditions (T/Cs) • Updated BP, MP, FP covering Phases 3-4	• Financial model updated with offtake & production data • Revised growth plan & projections • Updated BP, MP, FP covering ramp-up & steady state operations
Engineering, Procurement, Construction, & Operations	• Engineering concept (~5%) • Technology Readiness Level (TRL) descriptions • Integrated Project Schedule (IPS): Full Project - L1; Phase 1 - L2 • Class 4 Total Project Cost (TPC) estimate • Operating & disposition concepts	• Engineering & Design (~30%) & related documents • Performance model • TRL analysis & uncertainties • IPS: Full Project - L2; Phase 2 - L3 • Class 3 TPC estimate	• Engineering & Design (~90%) & related documents • TRL updates • IPS: Full Project - L3 • Class 1 TPC estimate • Standard project management tool in use • Updated Operating Plan • Updated Disposition & Decommissioning (D&D) Plan	• Progress execution reporting • Integrated project completion testing	• Regular operations status reporting • Performance ramp verification & validation (V&V) • Validated performance model • Final TPC accounting
Safety, Security, & Regulatory Requirements	• Safety history/culture description • Permitting workflow overview • Environmental Considerations Summary	• Initial Safety Plans (hydrogen & site; 30% design) • Cybersecurity Plan • Environmental Information Volume	• Execution-ready Safety Plans (hydrogen & site; 90% design) • Final Cybersecurity Plan • Permits in place for construction • Complete environmental reviews/assessments	• Status reporting on required permits & environmental • Safety & security incident reporting & audits • Permits for operations	• Ongoing permit, safety, & security reporting
Risk Analysis & Mitigation	• Risk Management Plan (RMP) • Risk Register	• RMP, Risk Register updates	• Quantitative risk analysis • RMP, Risk Register updates	• RMP, Risk Register updates • Periodic quantitative updates	• Tech risk updated for operations • Ongoing risk reporting
Technical Data & Analysis	• Preliminary Techno-economic Analysis (TEA) • Preliminary Life Cycle Analysis (LCA)	• Updated TEA • Updated LCA	• Mature LCA • Mature TEA w/ risk analysis • Technical Verification & Validation (V&V) Plan	• Periodic TEA & LCA updates • V&V data collection & analysis	• LCA & TEA incorporating operational data • Ongoing data collection & dissemination
Community Benefits: Job Quality & Equity	Community Benefits Plan (CBP): Initial plan, including: • Community & Labor Engagement • Investing in the American Workforce • Justice40 Initiative • Diversity, Equity, Inclusion, & Accessibility (DEIA)	• Implement Phase 1 scope of CBP • Update CBP for future phases based on activities & lessons learned, including documentation of stakeholder engagement status, workforce development, Justice40 implementation, & documentation of extent of community consent	• Implement Phase 2 scope of CBP • Measure & report on all CBP metrics • Update CBP for future phases based on activities & lessons learned	• Implement Phase 3 scope of CBP • Measure & report on all CBP metrics • Update CBP for future phases based on activities & lessons learned	• Implement Phase 4 scope of CBP • Measure & report on all CBP metrics • Final report including accomplishments, findings, & plans for steady state operations

Figure 5.1: *The activities and outcomes associated with each phase of OCED's H2Hub projects.*[36]

[36] DOE, "Funding Notice: Regional Clean Hydrogen Hubs" (DE-FOA-0002779), Office of Clean Energy Demonstrations, Energy.gov, September 2022, https://www.energy.gov/oced/funding-notice-regional-clean-hydrogen-hubs.

OCED was established to be a center of excellence for project management oversight within DOE. To this end, OCED will use lessons learned from previous DOE demonstration projects to develop effective procedures and processes tailored to the size and risks of projects. This will be supported by hiring a diverse workforce from across Government and industry with an emphasis on experience in project management, project oversight, and regulatory compliance. OCED will develop a comprehensive training program for its staff that includes project management skills, financial assistance oversight, EEJ training, and other professional development.

As appropriate, OCED will work with other parts of DOE to provide project management oversight services or advice for demonstration-scale projects. Additionally, in January 2023, OCED established a Demonstration and Deployment Advisory Board (DDAB), chaired by DOE's Under Secretary for Infrastructure and with OCED serving as the Executive Secretariat. The DDAB provides advice to ensure risk management and accountability for large clean energy demonstration projects across DOE that are funded through financial assistance. DDAB and OCED project review activities will examine each DOE clean energy demonstration and deployment project that receives more than $100 million in Federal funding through financial assistance.

6 Demonstration Programs

OCED's mission is to lead DOE's efforts to deliver clean energy demonstration projects at scale in partnership with the private sector to accelerate deployment, market adoption, and the equitable transition to a decarbonized energy system. Because of the size and complexity of the nation's energy system, strategic choices must be made in investing in clean energy solutions that can best contribute to this challenge. If a particular technology pathway has been de-risked in multiple commercial settings, then direct commercial financing or assistance from the DOE LPO is an appropriate path toward widespread market adoption. Early-stage technical concepts, in contrast, may require testing and development at small scales (e.g., lab or bench) before meaningful assessment of performance or financial risks is possible. Between these two scenarios, however, many potential clean energy solutions require simultaneous advances in their TRL and ARL that can often only be achieved with FOAK, at-scale demonstrations. OCED will operate technical programs on a range of topics where demonstrations of this kind can de-risk operational, financial, and market-based barriers to commercial use.

Figure 6.1 reiterates the schematic view of the U.S. energy system shown in Section 2. This diagram indicates how energy moves from generation and capture (top) into end-use sectors via a complex infrastructure associated with the electricity grid and fuels. As the reliance on electricity generation from fossil fuel sources is displaced by carbon-free electricity and end uses are increasingly electrified, the importance of electricity in the overall energy system will increase. Despite this change in the source of energy, the approximate relative size of the industry, transportation, and buildings sectors in terms of primary energy use is likely to remain similar for many years. The ease with which net carbon dioxide emissions from each end-use sector can be addressed varies. Heavy duty transportation and industry applications such as iron and steel manufacturing, for example, will make complete decarbonization of industry and transportation high cost with existing solutions even when abundant carbon-free electricity is available. These hard to decarbonize applications mean that net negative solutions to carbon dioxide management will be needed to reach net zero emissions across the economy. This sector is highlighted in Figure 6.1 to emphasize its role in a future net zero economy. These net negative solutions will also be important to address GHG emissions associated with agriculture and land use, indicated in parallel with the energy end-use sectors in Figure 6.1 to emphasize the importance of these topics to the nation's economy.

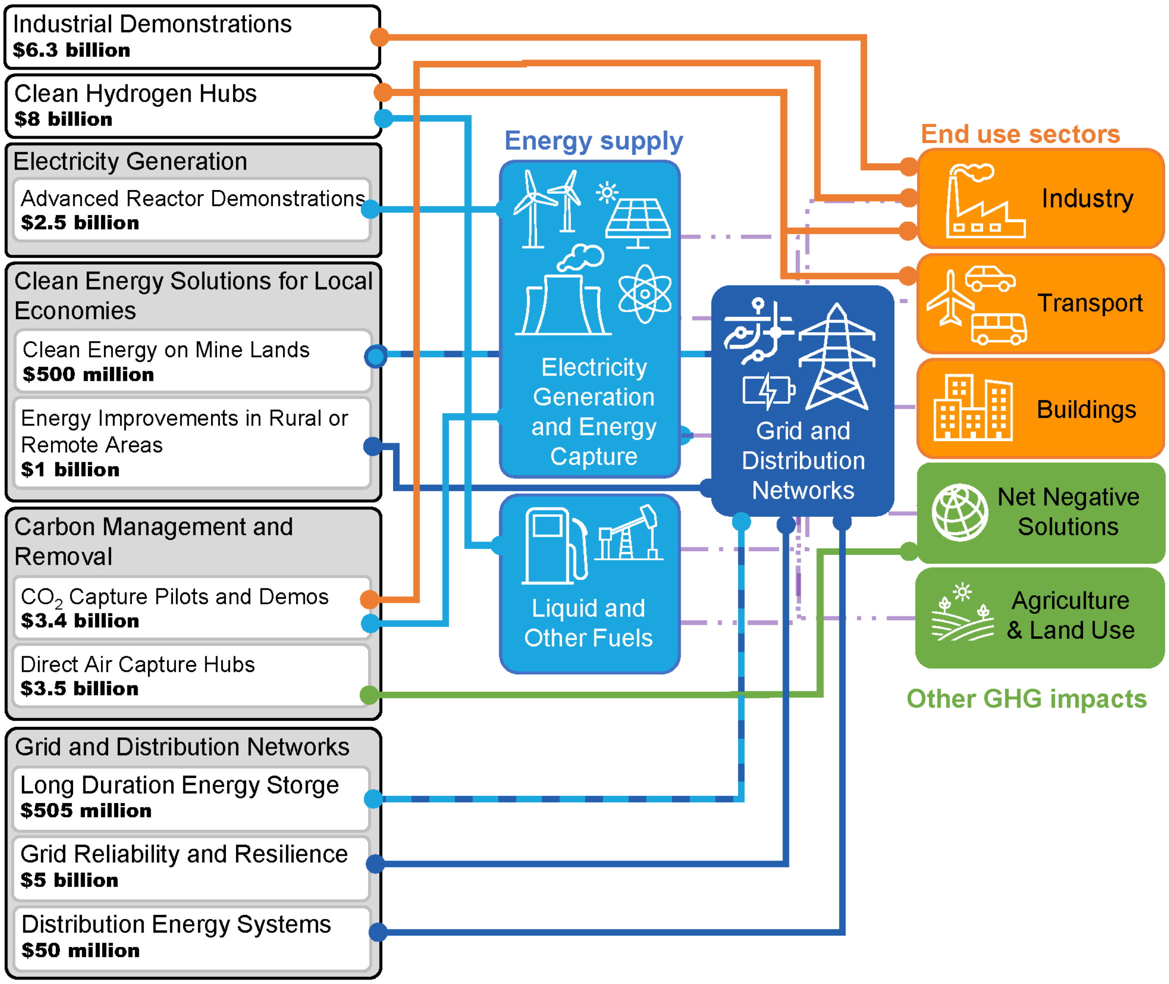

Figure 6.1: *A schematic view of the nation's energy system, showing energy generation (blue) and distribution (purple) and the broad end-use sectors of industry, transportation, and buildings (orange). Agriculture and land use are also shown to emphasize their importance in the nation's economy, and net negative solutions are included to highlight their role in a future net zero economy (green). Current OCED technical programs are listed on the left, with lines that indicate their key users and markets within the energy system. Some programs are jointly supported with other DOE offices.*

Each sector of the energy system shown in Figure 6.1 involves enormous levels of current or future economic activity and presents many challenges. A non-exhaustive summary of some core challenges for decarbonization in each sector is given in Table 6.2. OCED's existing portfolio addresses many of these challenges, although the breadth of the energy system means that additional challenges also exist. OCED's process for identifying future challenges and creating programs to address them is described in Section 7.

OCED's current technical programs are highlighted in Figure 6.1, with positions on the diagram that indicate the primary users and markets that each program will affect (although a number of programs will have broader coverage than what is indicated in the figure). Each technical program is described in more detail below. OCED's current programs are also summarized in Table 6.1, which indicates the statutory authority for each program.

Table 6.1: *Current OCED programs, indicating their statutory authority in the Bipartisan Infrastructure Law (BIL), Inflation Reduction Act (IRA), or annual appropriations.*

OCED Program	MYPP Section	Associated Solicitations	Statutory Authority
Advanced Reactor Demonstrations	6.1.1	DE-FOA-0002271	BIL Section 41002
Energy Storage and Long-Duration Demonstrations	6.2.1	DE-LC-000L001 DE-FOA-0002867	BIL Section 41001
Grid Reliability and Resilience (Grid Deployment Office)	6.2.2	DE-FOA-0002740	BIL Section 40103(b)
Distributed Energy Systems	6.2.3	Under Development	FY 2023 OCED Appropriations
Industrial Demonstrations	6.3	DE-FOA-0002936	BIL Section 41008 & IRA Section 50161
Regional Clean Hydrogen Hubs (H2Hubs)	6.4	DE-FOA-0002779	BIL Section 40314
Carbon Capture Large-Scale Pilot Projects and Carbon Capture Demonstrations	6.5.1	DE-FOA-0002962 DE-FOA-0002963	BIL Section 41004(a) & 41004(b)
Regional Direct Air Capture Hubs	6.5.2	DE-FOA-0002735	BIL Section 40308
Clean Energy on Current or Former Mine Land Demonstrations	6.6.1	DE-FOA-0003009	BIL Section 40342
Energy Improvement in Rural and Remote Areas	6.6.2	DE-FOA-0002970 DE-FOA-0003045 Energizing Rural Communities Prize	BIL Section 40103(c)

OCED's main activity that is wholly in electricity generation is with the Advanced Reactor Demonstration Program (ARDP) (Section 6.1.1), which is focused on construction and deployment of advanced nuclear reactors. Advanced nuclear reactors are an excellent example of a clean energy solution that requires development and operation of demonstration facilities to retire technical, regulatory, workforce, supply chain, and related risks. The program on energy storage (Section 6.1.2) will address challenges associated with the intermittency of renewable electricity generation on time scales from hours to seasons. Some aspects of the technical programs for clean energy on mine lands (Section 6.6.1), energy improvements in rural and remote areas (Section 6.6.2), and clean hydrogen (Section 6.4) will also impact electricity generation decarbonization. As the United States moves toward a decarbonized energy system, maintaining and upgrading a reliable electricity grid and energy distribution network will be of paramount importance. OCED's grid resilience program (Section 6.2) will directly tackle key challenges associated with the electricity grid as it expands and adapts to changes in the electricity generation mix. Together, these programs addressing aspects of electricity generation and delivery will impact every end-use section in Figure 6.1.

The diverse applications that make up the industry end-use section in Figure 6.1 make decarbonization of this sector challenging. DOE's recent Industrial Decarbonization Roadmap[37] highlighted four "pillars" needed to achieve this transition: (1) energy efficiency; (2) industrial electrification; (3) low-carbon fuels, feedstocks, and energy sources (LCFFES); and (4) carbon capture, utilization, and storage (CCUS). The second of these pillars needs to occur in parallel with the increased availability of carbon-free electricity enabled by the topics already mentioned. OCED's industrial decarbonization program (Section 6.3), in tandem with an integrated program strategy leveraging other existing DOE programs, will address each of these pillars. In addition, OCED's carbon dioxide capture program will specifically feature demonstration projects associated with capturing the carbon dioxide associated with non-electricity use of fossil fuels in industrial settings.

Clean hydrogen (that is, H_2 produced with a low net GHG footprint) can play a powerful role in a broadly decarbonized economy as an energy carrier that complements the more familiar role of electrons as energy carriers. As indicated in Figure 6.1, clean hydrogen can be used in industrial end uses (e.g., in manufacturing ammonia), in transportation, and in electricity generation. OCED's Regional Clean Hydrogen Hubs (Section 6.4), or H2Hubs, will execute demonstration projects in all these areas.

[37] DOE, *Industrial Decarbonization Roadmap* (DOE/EE-2635), Energy.gov, September 2022 https://www.energy.gov/oced/funding-notice-regional-clean-hydrogen-hubs.

Carbon capture and removal will play an important role in moving toward a net zero emission economy. The role of carbon capture and storage (CCS) was mentioned above in the context of decarbonizing industry, but this concept also will be vital in reducing emissions from electricity generation. OCED's carbon dioxide capture program (Section 6.5.1) will manage at-scale demonstrations in multiple sectors currently associated with significant carbon dioxide emissions. DAC of carbon dioxide coupled with durable carbon storage is a net negative technology that can offset future carbon dioxide emissions and remove legacy pollution. OCED's DAC program (Section 6.5.2) will accelerate at-scale demonstrations of integrated DAC solutions.

OCED's programs target real-world applications that will unlock future commercial investment, creating jobs and economic opportunities. Two of OCED's programs (Section 6.6) place special emphasis on clean energy solutions associated with specific local economies. OCED's program on Clean Energy on Current and Former Mine Land (Section 6.6.1) will manage projects that take advantage of existing infrastructure and/or siting of abandoned or current mine lands. OCED's program on Energy Improvements in Rural or Remote Areas (Section 6.6.2) will address the challenge of delivering reliable clean energy to these locations and communities.

Each of the programs listed above represents areas in which DOE's applied or infrastructure offices have strong expertise, activities, and history. In every case, OCED will coordinate closely with other relevant offices in DOE and with interagency partners to jointly work toward the goal of de-risking clean energy solutions and unlocking future private sector investment. More details on OCED's plan to create strong connections with these ongoing efforts is described in Section 8.

Principles of equity and justice will guide implementation of all OCED programs, consistent with commitments to ensure that overburdened, underserved, and underrepresented individuals and communities have access to Federal resources. Implementation efforts will work toward the goal that 40% of the overall benefits from Federal investments in climate and clean energy, including all OCED programs, will flow to disadvantaged communities and not exacerbate existing inequalities such as disproportionate exposure to environmental hazards and harms. OCED's programs will advance equity for all, including people of color and others who have been historically underserved, marginalized, and adversely affected by persistent poverty and inequality.

Table 6.2: *Examples of opportunities and needs in national energy sectors.*

Electricity generation/ Energy capture	Clean generation is a critical near-term need to decarbonize not only the grid but other sectors through electrification and fuel production. OCED plans to prioritize programming in this area for the next several fiscal years to support 2035 objectives and beyond. Likely topics include accelerating deployment and demonstrating next-generation technologies and systems at large scales (100s MW+).
Grid and distribution networks	Reliable, resilient, and flexible grid operations are critical to manage cost and operations as carbon-free electricity capacity increases. OCED will work closely with GDO and the Office of Electricity to execute on BIL programming and annual appropriations and to identify future demonstration opportunities. OCED will also continue to support enabling solutions such as Energy Storage
Industry	Industrial decarbonization is challenging given the heterogeneity of the sector. Solutions across multiple sectors, energy input types (heat, electricity), and process types will be required. OCED will leverage BIL and IRA funding and establish additional programming as needed to further address this sector.
Transportation	Electrification of light-duty transport is occurring, but supporting infrastructure and systems to decarbonize other transportation subsectors remain a challenge. OCED will perform more detailed evaluation to identify demonstration-scale opportunities in collaboration with GDO, the Office of Electricity, the Vehicle Technologies Office, and the Joint Office of Energy and Transportation. Key areas for demonstration may include electrification of infrastructure operations, port and airport infrastructure, and fuel production.
Buildings	Decarbonization of the building sector will rely heavily on increased electrification of residential and commercial buildings and development of widely available low-carbon building materials. Near-term OCED activities in this space will likely focus on buildings as part of the distribution system to demonstrate improved grid performance and value.
Agriculture and land-use	Multiple opportunities exist in this sector, including balancing land use between agriculture, land-based carbon management, and distributed energy generation. Some near-term opportunities may be supported by BIL provisions and OCED plans to conduct more detailed scoping prior to launching additional programming in this area.
Net negative solutions	Key opportunities include infrastructure and validation associated with CO2-negative solutions implemented on a path toward a gigaton scale. OCED plans to support DAC programs and conduct additional scoping to identify opportunities for future funding of other CO2 removal pathways.
Support opportunities	Other demonstration opportunities may primarily fall into the mission spaces of other DOE offices, including supply chains, critical materials, grid resilience, and the energy–water nexus. OCED will support relevant offices in these areas.

6.1 Electricity Generation

6.1.1 Advanced Reactor Demonstrations

Reliable access to carbon-free electricity is the cornerstone of decarbonizing the nation's economy. Nuclear energy plays a vital role in the United States in producing carbon-free, load-following electricity that is independent of the intermittency issues that challenge renewable electricity generation. As of 2022, 92 commercial nuclear reactors are licensed by the Nuclear Regulatory Commission (NRC) for power operation. These units contribute almost 20% of total U.S. electrical generation, with an installed capacity of more than 90 GW.[38] Due to aging, economics, and other factors, the number of operating nuclear facilities in the United States has declined from 112 in 1990 to the 92 units operating currently.[39]

A major barrier to the deployment of new nuclear power is the substantial up-front capital cost of large plant designs. Commercialization of smaller, simpler, safer, yet more flexible nuclear plants with reduced capital costs allowing for incremental additions of new generating capacity would greatly enhance the affordability and accessibility of nuclear power for domestic and international utilities. This observation has prompted development of advanced reactor designs that could take advantage of factory fabrication of major systems and components that can be delivered to a plant site by truck, rail, or barge and that utilize modular construction techniques. Successful deployment of designs with these properties could lead to replicable and scalable manufacturing of future units.

Advanced reactors have multiple advantages relative to conventional, large nuclear plants. They are designed to include passive cooling mechanisms and inherent reactivity control, which will allow these reactors to shut down safely in extreme conditions. Advanced designs allow for scalability, from large baseload power to microgrids for remote communities to remote industrial operations such as mining. Advanced reactor fuels may be designed to have a higher utilization of their fuel and reduced fission products in their spent fuel. The potential for high temperature designs may increase revenue streams by providing process heat for industry as either a primary or secondary output.

Any private utility or power company, domestic or international, seeking to incorporate FOAK advanced reactor designs into their generation portfolio faces considerable risks. Uncertainty of FOAK costs from technology development, engineering, and licensing can significantly inhibit investment in new nuclear projects. Successful deployment of initial demonstration units will benefit the entire nuclear industry by proving that advanced reactors can be constructed and operated in a safe, secure, timely, and economical manner, providing assurance to regulators and customers that these designs are competitive with existing generation costs. These demonstrations can also stimulate and sustain necessary construction, labor, and craft skills.

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[38] "Annual Energy Outlook 2022," U.S. Energy Information Administration, U.S. Energy Information Administration, March 3, 2022, https://www.eia.gov/outlooks/aeo/IIF_carbonfee/.
[39] U.S. Energy Information Administration, "Annual Energy Review."

Cost-shared support from the Federal Government to defray the upfront technical and regulatory risk is vital to encouraging domestic utilities to incorporate nuclear energy in their long-range planning (i.e., Integrated Resource Plans). The reactor deployment plan under the ARDP is an example of how OCED, in coordination with DOE's Office of Nuclear Energy (NE), can drive private/public partnerships that will enable initial demonstration projects and unlock future commercial investment and expansion of key clean energy technologies.

The U.S. industry remains at a disadvantage in the development of advanced reactor designs because of competition from primarily state-supported nuclear developers in countries such as China and Russia, who are currently ahead of the United States in demonstrating and deploying gas and liquid metal reactor designs. There is a continued need for programs such as the ARDP to establish private–public partnerships to level the international playing field and to promote the competitiveness of domestic advanced designs. Achieving this goal will help develop nuclear power within the United States and also allow it to offer options to state-sponsored technology suppliers in the international market.

In the early 2000s, DOE initiated the Nuclear Power 2010 (NP 2010) program to spur commercial development of nuclear power. The Department worked with NRC and the domestic industry with the goal of identifying viable sites for deployment, demonstrating untested regulatory processes, and creating private–public partnerships to support the design and licensing of new GEN III+ designs with over 1,000 MWe output. As the domestic industry identified the value of smaller, scalable nuclear generation in the late 2000s, DOE initiated the Small Modular Reactor (SMR) Licensing Technical Support program in 2012 to support the design, certification, and licensing of promising domestic SMR designs. The program resulted in the certification and design finalization of the NuScale SMR design. Subsequent awards under other NE programs are currently supporting the deployment of NuScale technology at a site near the Idaho National Laboratory.

In FY 2020, Congress directed DOE to assure deployment of advanced nuclear reactors through the ARDP by forming partnerships with industry to focus on construction and operation of advanced reactor designs. Congress called for an ambitious 7-year goal for two demonstrations and supported development of future demonstrations by reducing risk for less mature designs. The ARDP aimed to develop advanced energy options for domestic utilities with capabilities and characteristics beyond the current fleet, to enable the market environment for nuclear energy, and to stimulate the development of the domestic nuclear manufacturing enterprise to support a fleet of advanced reactors.

To execute the ARDP, in 2020 NE solicited industry proposals across three stages of advanced reactor maturity: (1) Advanced Reactor Demonstrations (Demos), focused on the most mature advanced designs that had the potential to complete an NRC licensing process, finalize designs to a commercial state, and work with a domestic customer to achieve construction and operation in the 7-year window; (2) Reduction for Future Demonstrations (Risk Reduction), for designs with deployment horizons expected to be about 5–10 years beyond the Demos, in the early to mid-2030s; and (3) Advanced Reactor Concepts 2020 (ARC-20) for the least mature designs. In FY 2021, NE selected two Advanced Demonstration awards (TerraPower's Natrium Sodium Fast Reactor (SFR) and X-energy's Xe-100 High-Temperature Gas Reactor), five Risk Reduction projects, and three ARC-20 projects. These projects provide a diverse set of technology options, establishing an advanced technology pipeline that can meet the requirements of the domestic and international utility industry.

Initial funding for the ARDP was provided in the NE budget in FY 2020–2021. The BIL appropriated funding to OCED for the two ARDP Demonstration projects, and in FY 2022, management of the projects transferred to OCED. The awards executed under the program are financial assistance cooperative agreements with each awardee required to provide at least 50% cost share. The BIL funding ($2.477 billion through FY 2025) provides a significant portion of the total project costs for the two projects, but additional appropriations will be required to meet the full Government commitment. Funding responsibility for all other ARDP elements, including the Risk Reduction projects, remains with NE.

The Advanced Reactor Demonstrations projects managed by OCED aim to deliver safe and affordable advanced reactors that are sited at a domestic location and licensed by the NRC. Per the ARDP FOA, demonstrations were defined as advanced reactors operated as part of the power generation facilities of an electric utility system or in any other manner for the purpose of demonstrating suitability for commercial application of an advanced nuclear reactor. These demonstrations will help create market demand and domestic manufacturing jobs.

The Natrium demonstration project builds on significant prior design and development work performed on SFR technologies over the previous decade, specifically the Traveling Wave Reactor by TerraPower and the PRISM SFR design by General Electric-Hitachi (GEH). The Natrium team currently consists of TerraPower of Bellevue, WA, and partners GEH, Bechtel Power Corporation, Global Nuclear Fuels, and multiple domestic utilities, national laboratories, and universities. The Natrium demonstration plant will be a 345 MWe, pool-type SFR that employs a Uranium-Zirconium metallic high burnup and high temperature fuel to improve economics. The commercial design is coupled with a molten-salt thermal storage system with the potential to provide up to 500 MWe for five hours to meet peak power demands. The energy storage and secondary-side power conversion equipment will be decoupled from the nuclear island through a tertiary heat exchange system to allow compartmentalization of licensing requirements.

In January 2022, Natrium announced a partnership with PacifiCorp to construct and operate the plant near a retiring coal plant site in Kemmerer, WY. The existing infrastructure associated with retiring coal sites make these sites attractive for new nuclear plant builds, especially advanced designs with modular construction. The skill base of the staff supporting current coal plants may be transferable to the workforce needed to support these new reactors, particularly designs with distinct nuclear island and conventional island layouts.

The X-energy Xe-100 demonstration project leverages decades of previous experience in high-temperature gas reactor (HTGR) design. The Xe-100 demonstration plant will be a four-unit (320 MWe total) high-temperature, helium gas-cooled reactor that uses a robust Tristructural Isotropic (TRISO) pebble fuel form. Previous DOE investments of more than $700 million include development and testing of TRISO-coated fuel particles. In July 2022, X-energy announced the selection of the Zachry Group and the combined team of Burns & McDonnell and Day & Zimmermann as constructors that will work with the company on the next phases of design and deployment of the Xe-100 advanced reactor fleet. Beneficial characteristics of the Xe-100 design include on-line fueling to increase availability and improve economics, high turbine thermal efficiency, and a comprehensive safety-by-design approach. The project also includes the construction of a TRISO fuel fabrication facility sited in Oak Ridge, TN, to meet the fuel requirements of the demonstration and additional Xe-100 reactors as well as TRISO fuel forms for other vendors.

OCED's ARDP will develop connections with a number of other OCED programs. The Natrium demonstration project already involves an energy storage facility, and additional connections between ARDP and OCED's energy storage program (Section 6.1.2) will be explored. ARDP will also inform OCED's industry decarbonization program (Section 6.2) on future prospects for providing industrial heat from small or micro reactors. At least one of the H2Hubs established in OCED's clean hydrogen program (Section 6.3) will receive inputs from nuclear energy.

OCED, in cooperation with the NE, will continue to explore ways to support the domestic industry in developing and deploying advanced nuclear energy technologies that can meet domestic energy, environmental, and national security needs. *Pathway to Commercial Liftoff Report: Advanced Nuclear* provides a more detailed description of the commercialization pathways for nuclear technologies.[40] The U.S. Government has a unique role to play in reducing risk for developers and reducing the time required to develop new technology, specifically by addressing financial risk and providing facilities and capabilities that the private sector cannot maintain alone.

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[40] DOE, *Pathways to Commercial Liftoff: Advanced Nuclear*, Energy.gov, March 2023, https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Advanced-Nuclear-vPUB.pdf.

By establishing programs to support a diverse set of domestic technologies with different power outputs and characteristics that can match the needs of energy-intensive processes that currently rely on fossil fuels, such as hydrogen production, desalination, district heating, petroleum refining, and fertilizer production, the Department is helping to open up important markets for domestic nuclear developers. As an ongoing and future strategy, the Department will continue to monitor industry developments for power requirements and to focus on demonstrating those designs in the advanced reactor pipeline that best serve these needs. OCED will execute a time-phased approach to program planning and budget formulation to assure that it is supporting future demonstrations that have the highest impact on achieving national goals.

6.2 Grid and Distribution Networks

Modernizing the nation's electricity grid and improving operational flexibility will be pivotal to deeply decarbonizing the U.S. economy. Two of the five technology transformations highlighted by the Department of State and the White House as key elements of a path to net zero emissions explicitly focus on electricity:[41] decarbonizing electricity using clean energy sources and electrifying end uses from cars to buildings to industrial processes. These transformations will involve large changes in both the sources of electricity relative to today's grid and the total capacity of the grid. Estimates of multiple pathways to net zero emissions indicate that new capacity additions in the United Sates of 60–70 GW/year will be needed for multiple decades, a much higher rate than the 15–40 GW/year added from 2010–2020.[42]

A traditional grid architecture is based on large-scale generation, limited energy storage, and passive loads. Rapid growth in distributed and clean energy generation will radically change this model. As the nation's grid infrastructure is updated to accommodate these changes, it is critical that it maintains and enhances resilience to hazards of all kinds and improves reliability for everyday operations.[43] Simultaneously, the grid must remain flexible to variability in conditions at multiple timescales and facilitate affordability to support and promote economic prosperity.

[41] U.S. Department of State and U.S. Executive Office of the President, *The Long-Term Strategy*.

[42] Ibid.

[43] National Academies of Sciences, Engineering, and Medicine, *Enhancing the Resilience of the Nation's Electricity System* (Washington, DC: The National Academies Press, 2017).

The President's National Infrastructure Advisory Council defined resilience as the ability to prepare for and adapt to changing conditions and reduce the magnitude and/or duration of disruptive events.[44] This definition is more expansive that the North American Electric Reliability Corporation (NERC) definition of reliable operation, which focuses strictly on avoiding instability, uncontrolled separation, or cascading failures of the grid.[45] Disruptive events could arise from equipment failures, weather impacts, or cyber or physical attacks.

Grid infrastructure must be implemented in a complex regulatory and market environment in a way that will seamlessly deliver affordable electricity to individual and industrial consumers. The wide-reaching changes in the grid described above will require innovations in physical technology (e.g., sensors, inverters, and transformers), modeling and analysis tools for monitoring and optimizing grid performance, and frameworks for improving business and ownership models that can deliver benefits to consumers.

Because of the centrality of electricity in efforts to decarbonize the nation's energy system, OCED's Grid Reliability and Resilience program will influence and benefit from several other OCED programs, including programs in electricity generation (Section 6.1). It will also be beneficial for close contact to exist with OCED's Industrial Decarbonization efforts (Section 6.3) since success in electrifying industrial end uses such as process heat will lead to large increases in electricity demand from manufacturing sites with complex safety and reliability constraints. Similarly, producing hydrogen with electrolyzers (Section 6.4) may be associated with significant electricity demands. The complexities associated with reliable delivery of carbon-free electricity to the manufacturing sector have not been fully explored to date, a situation that can be at least partially addressed by combining OCED's expertise in these two distinct areas.

OCED is directing and participating in multiple programs to improve grid reliability, resilience, cost and operational flexibility, addressing transmission, distribution, and energy storage. Future development of OCED's Grid and Distribution Networks program will be motivated by the vast scale and complexity of the nation's electricity grid and the inherently unpredictable nature of many disruptive events. It will be important to develop future demonstrations that steadily increase a project's geographic scope and number of stakeholders and that address the variability in grid reliability, resilience, and costs across the United States. Future projects should also incorporate emerging insights into potential climate impacts (e.g., leveraging data from the insurance industry) to anticipate resiliency needs driven by incremental climate changes and extreme weather events.

[44] The President's National Infrastructure Advisory Council, *Surviving a Catastrophic Power Outage: How to strengthen the Capabilities of the Nation*, Cyberstructure & Infrastructure Security Agency, December 2018, https://www.cisa.gov/sites/default/files/publications/NIAC%20Catastrophic%20Power%20Outage%20Study_FINAL.pdf

[45] "Glossary of Terms Used in NERC Reliability Standards," North American Electric Reliability Corporation, March 8, 2023. https://www.nerc.com/pa/Stand/Glossary%20of%20Terms/Glossary_of_Terms.pdf.

6.2.1 Energy Storage

An unavoidable feature of solar or wind generation of electricity is that they are intermittent. To fully realize the reductions in GHG emissions possible by increasing the contributions of these sources to the nation's grid, a greatly expanded capacity for energy storage will be necessary. The dominant current form of energy storage is pumped storage hydropower (PSH), which comprises more than 90% of current U.S. energy storage capacity.[46] Existing PSH plants have a total power capacity of 21.9 GW, and projects with additional capacity of more than 50 GW are being evaluated or developed.[47] Scenarios for deep decarbonization suggest that storage capacity as large as 1,600 GW could be needed by 2050,[48] so extensive facilities for cost-effective and flexible energy storage in addition to PSH need to be developed. A fully decarbonized, reliable, and resilient energy system will require energy storage on time scales of hours to address diurnal intermittencies in renewable generation capacity but also on sufficient time scales to address extreme weather events and potentially seasonal variability.

Bidirectional energy storage methods, which both receive and deliver electricity, include electromechanical approaches, such as PSH and compressed air, and electrochemical devices, such as batteries and capacitors. Energy can also be stored with thermal or chemical energy carriers such as phase change materials, ammonia, or hydrogen. These technologies vary widely in the duration of storage that is possible. In 2021, DOE's Long Duration Storage Earthshot[49] set 2031 as the target for reducing energy storage costs for grid-scale storage by 90% from a 2020 Li-ion battery baseline in storage systems that deliver more than 10 hours of storage. DOE's Energy Storage Grand Challenge Roadmap also identified achieving $0.05/kWh levelized cost of storage for stationary long-duration applications as a key performance target.[50]

A wide range of technologies are available to enable long duration energy storage.[51] One broad classification of energy storage technologies separates bidirectional methods, which both receive and deliver electricity, and storage based on thermal or chemical energy carriers. Bidirectional approaches can be further divided into electrochemical and electromechanical methods. Electrochemical methods include redox flow batteries; reversible fuel cells; electrochemical capacitors; and batteries based on sodium ions or sodium metal, lead acid, zinc, or other metals such as magnesium or aluminum. Examples of electromechanical storage approaches include modular pumped hydro, compressed air, liquid air, flywheels, and gravitational and geomechanical storage.

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46 Water Power Technologies Office, "U.S. Hydropower Market Report, January 2021," Energy.gov, https://www.energy.gov/sites/default/files/2021/01/f82/us-hydropower-market-report-full-2021.pdf.
47 Ibid.
48 DOE, "Solar Futures Study," Solar Energy Technologies Office, Energy.gov, https://www.energy.gov/eere/solar/solar-futures-study.
49 DOE, "Long Duration Storage Shot," Office of Energy Efficiency & Renewable Energy, Energy.gov, www.energy.gov/eere/long-duration-storage-shot.
50 DOE, "Energy Storage Grand Challenge: Roadmap," Energy.gov, December 2020, https://www.energy.gov/sites/default/files/2020/12/f81/Energy%20Storage%20Grand%20Challenge%20Roadmap.pdf
51 Ibid.

Thermal energy storage can be achieved with phase change materials, low-temperature storage, and thermos-photovoltaic devices. Chemical energy carriers, including hydrogen and ammonia, convert energy into durable chemical bonds that can later be released via fuel cells, combustion, or other chemical transformations. The differing characteristics of these multiple approaches mean that their suitability for end uses varies depending on the end-use application and location (see Figure 6.2). *Pathways to Commercial Liftoff Report: Long Duration Energy Storage* provides further details on challenges associated with commercialization and scaling of energy storage.[52]

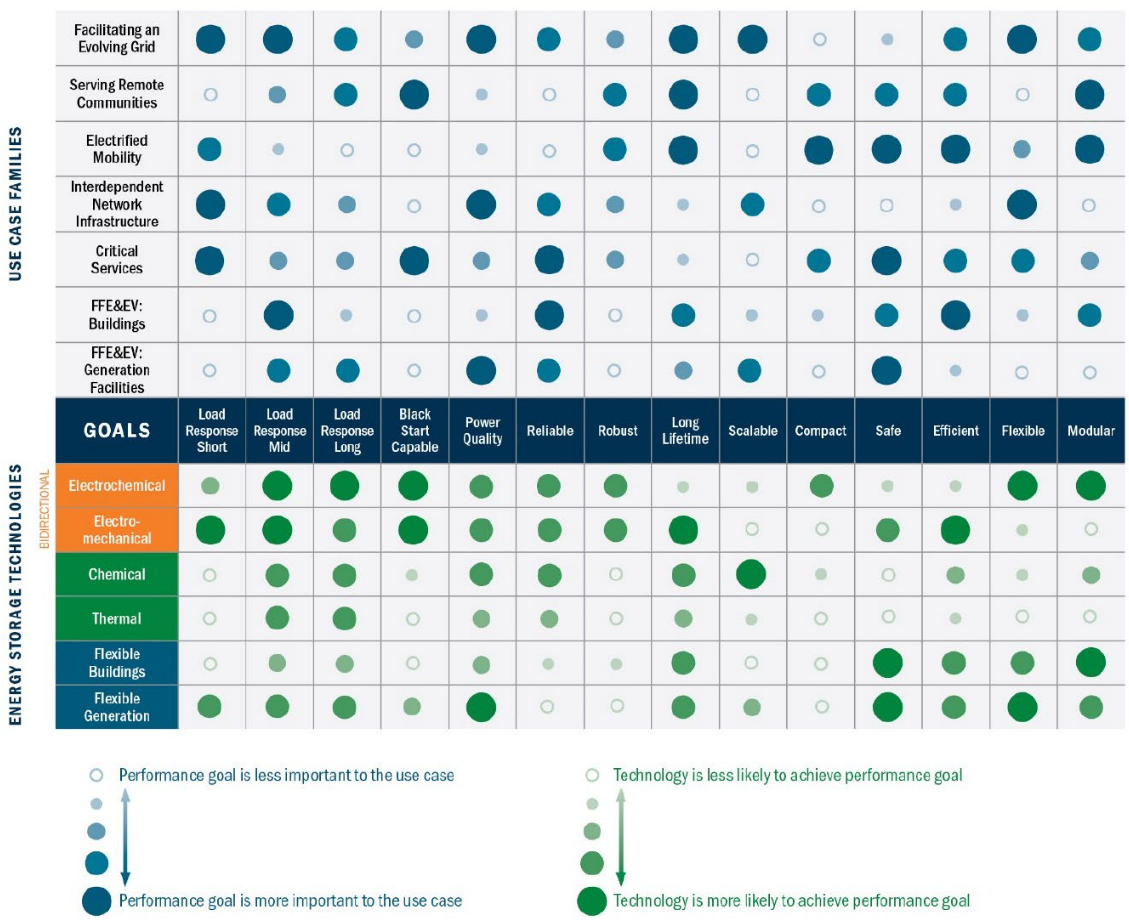

Figure 6.2: *Performance characteristics (green circles) and applicability to use cases (blue circles) of multiple classes of energy storage technologies. Figure reproduced from DOE's Energy Storage Grand Challenge Roadmap (2020). (FFE&EV = Facility Flexibility, Efficiency, and Enhanced Value)*

[52] DOE, *Pathways to Commercial Liftoff: Long Duration Energy Storage*, Energy.gov, March 2023, https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-LDES-vPUB.pdf.

OCED’s Energy Storage program will develop a set of projects by demonstrating a range of new, innovative energy storage technologies with regional diversity. The projects will provide opportunities for communities to overcome regulatory and institutional barriers associated with the deployment of long-duration energy storage. In addition, in collaboration with the Department of Defense, OCED will develop projects that use energy storage to increase the resilience of critical government facilities.

While a wide range of technologies can provide energy storage, OCED will exclude some approaches from this program. Hydrogen-based technologies will not be considered since they can be better addressed in OCED’s Regional Clean Hydrogen Hubs program (see Section 6.3). Furthermore, non-bidirectional technologies whose specific aim is to increase flexibility in electricity generation by nuclear or fossil energy will be considered in other programs.

OCED will develop a regionally diverse program of energy storage demonstrations that will yield data on technical performance, reliability, lifetime, and integration of components in systems suitable for at-scale use. These projects will include a range of technologies and use cases, ensure regional diversity among projects, and consider bulk power level, distribution power level, behind-the-meter, microgrid, and off-grid applications. These projects could include systems that will allow low voltage AC input and output (<1000 V) as well as projects that include plans for medium voltage AC input and output (up to 20 kV) to the bulk power system, including compliance with reliability, market, and operational requirements. At least one of these projects will advance technologies for storage with weekly or monthly durations or for seasonal durations to address seasonal variations in supply and demand, and at least one project will demonstrate second-life applications of EV batteries providing services to the electric grid. These demonstrations will be expected to substantiate a pathway to a levelized cost of storage of $0.05/kWh and build enduring institutional, analytical, and financial capabilities for communities to invest in storage resources with local benefits. Each project will be focused on a specific innovative application to meet a market need, with the aim of generating commercial confidence to catalyze market deployment.

The efforts described above will also inform and benefit from other OCED programs in which energy storage plays a part, including Clean Energy on Mine Land (Section 6.5.1) and Energy Improvements in Rural and Remote Areas (Section 6.5.2). OCED’s energy storage activities will be closely coordinated with other relevant efforts in DOE, particularly with the Office of Electricity.

The current scale of OCED's energy storage program is relatively small in comparison to other OCED programs and relative to the need to exponentially increase energy storage to meet the nation's climate goals. This situation, combined with the numerous energy storage technologies that exist for energy storage with different storage durations, suggests that significant opportunities will be present in the future for demonstration projects that expand beyond the scope of the current program (Section 7). A key objective of the projects in the current program will be to identify and de-risk barriers that would slow the transition of energy storage solutions to a status where direct commercial funding or assistance from DOE's LPO is possible.

6.2.2 Grid Reliability and Resilience

A reliable and resilient grid is crucial on both the national and community scale. DOE is executing multiple programs to enhance grid flexibility and improve the resilience of the power system against growing threats of extreme weather and climate change. These efforts are organized under the Grid Resilience and Innovation Partnership (GRIP) Program,[53] specifically the Grid Innovation Program.[54] This program will be managed by Grid Deployment Office (GDO) and the funds will remain in the originally appropriated account.[55] The Grid Innovation Program is currently focused on three major opportunity areas.[56]

1. **Transmission system:** The transmission system in operation today is the backbone of the electricity delivery system that connects all grid resources and acts as the path for electricity to flow from generation to demand. Transmission capacity constraints and congestion can prevent delivery of clean, cost-effective electricity to consumers, harming overall system reliability. Advanced transmission technologies, coupled with advanced computational and dynamic situational awareness, are a suite of tools that can help address transmission challenges, improve the efficiency and effectiveness of electricity delivery, and increase the reliability and resilience of the system. Innovative project approaches, including those leveraging advanced transmission technologies, can reduce or remove the existing technical, economic, and/or regulatory barrier(s) necessary to accelerate widescale transmission expansion and renewable energy interconnection.

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[53] DOE, "Grid Resilience and Innovation Partnerships (GRIP) Program," Grid Deployment Office, Energy.gov, https://www.energy.gov/gdo/grid-resilience-and-innovation-partnerships-grip-program.
[54] DOE, "Grid Innovation Program," Grid Deployment Office, Energy.gov, https://www.energy.gov/gdo/grid-innovation-program.
[55] DOE, "FY 2024 Budget Justification," Office of the Chief Financial Officer, Energy.gov, https://www.energy.gov/cfo/articles/fy-2024-budget-justification.
[56] "Opportunity: BIL Grid Resilience and Innovation Partnerships (GRIP), FedConnect, https://www.fedconnect.net/FedConnect/default.aspx?ReturnUrl=%2ffedconnect%2f%3fdoc%3dDE-FOA-0002740%26agency%3dDOE&doc=DE-FOA-0002740&agency=DOE.

2. **Distribution system:** The distribution system is a highly interconnected system providing reliable electricity to consumers. The integration of variable distributed energy sources such as wind and solar power, new loads such as EV charging, and energy storage into these networks is creating new challenges and opportunities for power system control and operation. Solutions should demonstrate improved cost–value characteristics relative to alternative approaches, managing distribution grid integration costs and traditional asset upgrade costs while maintaining or enhancing system reliability and service provision. In addition, extreme weather events have led to an increase in the frequency and duration of de-energization events. These occurrences, along with other experienced or potential disruptions of the distribution grid highlight the importance of improved system resilience.
3. **Combination systems**: While there is a clear differentiation between transmission and distribution systems in the current electrical grid, they both function within the same overall systems. There are opportunities to improve joint resilience and functionality across both grid sectors. This could involve using assets in one sector to provide services to the other in a manner that reduces upgrade or expansion requirements, or efforts to improve visibility and communication across sectors to allow for more complete optimization of grid operations.

OCED will cooperate closely with DOE's GDO in supporting GDO's mission to provide electricity to everyone, everywhere. It will be especially important for OCED to mesh closely with GDO's Building a Better Grid Initiative,[57] which will support the development of nationally significant transmission lines to improve access to cheaper energy sources and inform regional and interregional planning for electricity transmission.

Because of the centrality of electricity in efforts to decarbonize the nation's energy system, OCED's Grid Reliability and Resilience program will influence and benefit from several other OCED programs, including the programs in electricity generation (Section 6.1). It will also be beneficial for close contact to exist with OCED's Industrial Decarbonization efforts (Section 6.3) since success in electrifying industrial end uses such as process heat will lead to large increases in electricity demand from manufacturing sites with complex safety and reliability constraints. Similarly, producing hydrogen with electrolyzers (Section 6.4) may be associated with significant electricity demands. The complexities associated with reliable delivery of carbon-free electricity to the manufacturing sector have not been adequately explored to date, a situation that can be at least partially addressed by combining OCED's expertise in these two distinct areas.

[57] DOE, "Building a Better Grid Initiative," Grid Deployment Office, Energy.gov, https://www.energy.gov/gdo/building-better-grid-initiative.

6.2.3 Distributed Energy Systems

In addition to the BIL provisions for energy storage and grid reliability and resilience, OCED has also received annual appropriations in FY 2023 to support a new $50-million Federal demonstration program.[58] Public details of this program are currently limited, but the intent is to de-risk solutions needed to manage variable generation, control flexible loads, and integrate energy storage EV charging and other facilities into the U.S. transmission and distribution grids. The intended impact is to build confidence among industry and investors for commercial adoption and expansion of new clean energy solutions and their ability to replicate these projects to meet customer demands while also achieving a decarbonized grid. This program will be developed in collaboration with the Office of Energy Efficiency & Renewable Energy, Office of Electricity, and GDO and will be structured as part of an integrated set of programs, leveraging efforts underway in the GRIP program and the Clean Energy to Communities Program,[59] among others.

6.3 Industrial Demonstrations

U.S. industry is a backbone of the nation's economy, producing the goods critical to everyday life, employing millions of Americans in high-quality jobs, and providing an economic anchor for thousands of communities. Yet the energy- and carbon-intensity of the sector poses a significant challenge as the economy transitions toward net zero.[60]

Industrial emissions primarily arise from the combustion of fossil fuels on site for direct use or for steam (e.g., for process heating), the generation of electricity on site or off site (e.g., for motor-driven systems), and non-energy-related process emissions (e.g., carbon dioxide emissions from calcination in the production of cement). More detailed manufacturing energy consumption survey (MECS) data from the U.S. Energy Information Administration (EIA) illustrate the energy- and process-related CO_2eq emissions for the major manufacturing sectors in 2018 (Figure 6.3).[61] Energy-intensive industrial subsectors listed in section 50161(g)(3) of the IRA account for approximately 75% of all manufacturing-related CO_2eq emissions.

[58] *See* U.S. Congress, House, "Clean Energy Demonstrations," Title III, Division D, *Consolidate Appropriations Act of 2023,* H.R. 2617, https://www.congress.gov/bill/117th-congress/house-bill/2617/text,

[59] DOE, "Clean Energy to Communities Program," Office of Energy Efficiency & Renewable Energy, Energy.gov, https://www.energy.gov/eere/clean-energy-communities-program.

[60] Total projected energy-related carbon dioxide emissions for the industrial sector in 2020 was 1,360 million MT CO_2 compared to 4,563 million MT CO_2 for all sectors. "Annual Energy Outlook 2021 with Projections to 2050," U.S. Energy Information Administration, February 2021, https://www.eia.gov/outlooks/archive/aeo21/, Table 19, Energy-Related Carbon Dioxide Emissions by End Use.

[61] DOE, "Manufacturing Energy and Carbon Footprints (2018 MECS)," Industrial Efficiency & Decarbonization Office, Energy.gov, December 2021, https://www.energy.gov/eere/amo/manufacturing-energy-and-carbon-footprints-2018-mecs. Figure 6.3 does not include fuel used as feedstock.

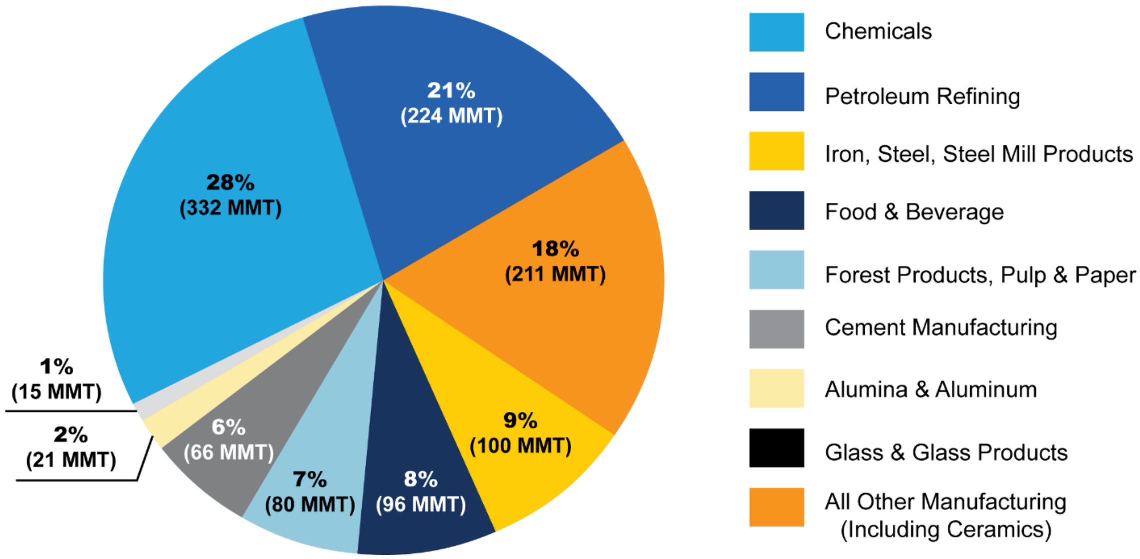

Figure 6.3: *U.S. primary energy- and process-related CO_2eq emissions (millions of metric tons (MMT) of CO_2eq) for manufacturing industries (NAICS 31-33). Energy-intensive industrial sectors, along with food and beverage, account for approximately 80% of manufacturing-related emissions. Figure derived from DOE's Manufacturing Energy and Carbon Footprints; source of data for footprints from Energy Information Administration's 2018 Manufacturing Energy Consumption Survey.*

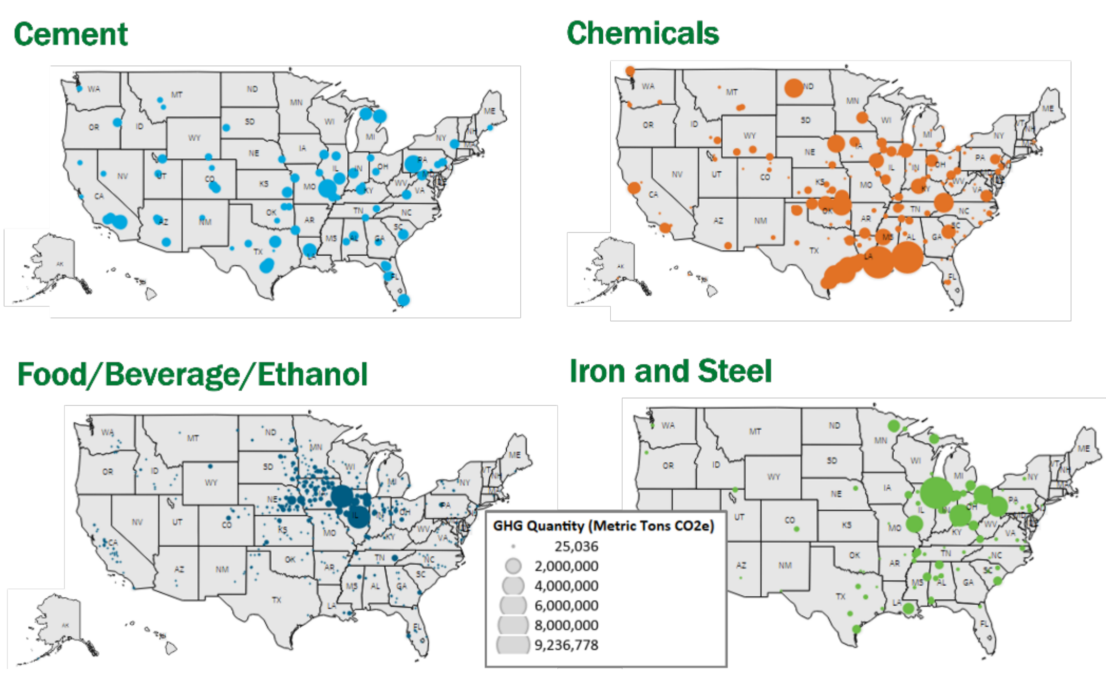

Figure 6.4: *Industrial facilities in four industrial sectors emitting more than 25,000 tons CO_2eq annually (facility-level data from the EPA's Greenhouse Gas Emissions from Large Facilities; figure reproduced from DOE's 2022 Industrial Decarbonization Roadmap). The fours sectors shown here are representative examples that collectively represented 35% of U.S. carbon dioxide emissions from industry in 2020 (cf. Figure 6.2).*

As industrial decarbonization proceeds, it will be important for the purposes of environmental justice to mitigate adverse impacts on communities near large facilities. Although industrial processes occur within site boundaries, their impacts can significantly affect surrounding communities. As indicated by Figure 6.4, the nature of the relevant industrial facilities and, as a result, the relevant environmental justice issues will be based on geography, history, and other factors. Lifecycle GHG emissions will be a key consideration in assessing project viability and performance, and projects will also be expected to quantify changes in criteria pollutants associated with new technologies. Projects will be expected to bring benefits and mitigate harms to their host communities, especially historically underserved, underrepresented, and overburdened groups. More broadly, OCED's projects will aim to strengthen the domestic work force and associated supply chain that will allow widespread commercial adoption of new technologies well beyond the specific sites receiving Federal funds.

OCED's program will seek to make an impact on all industry sources of carbon dioxide, with prioritization being given to projects with the deepest decarbonization potential that can also achieve timeliness, replicability, and market viability and benefit communities. The energy sector and industry are significant sources of non-carbon dioxide GHG emissions. In 2019 approximately 7% of U.S. contributions to global warming came from methane and fluorinated gases emitted in energy production or by industry.[62] Projects that will allow reduced emissions of these non-carbon dioxide GHG emissions will also be suitable for this program.

The DOE's recent Industrial Decarbonization Roadmap[63] identified four key "pillars" of industrial decarbonization: (1) energy efficiency, (2) industrial electrification, (3) LCFFES, and (4) CCUS. Energy efficiency presents the greatest opportunities for short-term decarbonization solutions, many of which can be achieved without major changes to industrial processes. Examples of energy efficiency strategies include recovery of thermal energy and expansion of energy management practices by increased implementation of smart manufacturing strategies designed to reduce energy consumption and increase circularity of materials use. The DOE's Better Plants Program is partnered with a wide range of U.S. manufacturers who have to date achieved cost savings of more than $10.6 billion and saved 2.2 quadrillion BTU of energy.[64] Industrial electrification aligns strongly with the broad strategy of electrifying energy end uses to achieve decarbonization.[65] Over 50% of manufacturing energy is used for thermal processing, but less than 5% of these operations are currently electrified.[66]

[62] U.S. Department of State and U.S. Executive Office of the President, *The Long-Term Strategy*.
[63] DOE, *Industrial Decarbonization Roadmap*.
[64] DOE, "Better Plants 2022 Progress Update," Better Buildings, Energy.gov, September 19, 2022, https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/2022%20Better%20Plants%20Progress%20Update_0.pdf.
[65] U.S. Department of State and U.S. Executive Office of the President, *The Long-Term Strategy;* National Academies of Sciences, Engineering, and Medicine, *Accelerating Decarbonization*.
[66] DOE, "Manufacturing Energy and Carbon Footprints (2018 MECS)," Industrial Efficiency & Decarbonization Office, Energy.gov, December 2021, https://www.energy.gov/eere/iedo/manufacturing-energy-and-carbon-footprints-2018-mecs.

As the nation's electricity grid undergoes a transformation to carbon-free electricity, electrifying industrial processes is a key opportunity to reduce GHG emissions associated with current on-site fossil fuel use. LCFFES are an important complementary strategy to electrification. Chemicals manufacturing and refining rely today on fossil fuel feedstocks. Substituting these feedstocks with bioderived feedstocks can potentially lead to significant lifecycle GHG emission reductions. Clean hydrogen can be used to reduce iron ore, displacing the carbon-based reductants used today. Carbon-free heat sources such as concentrated solar power and nuclear and geothermal energy can supply process heat.

Although these three pillars have enormous scope to transform U.S. industry, they will not be sufficient to remove all GHG emissions from industry. For this reason, the fourth pillar of industrial decarbonization is capture, utilization, and storage of carbon dioxide from emissions associated with manufacturing. Because OCED also has a specific program focused on carbon dioxide capture and management, industrial carbon capture-specific projects should be transformative and specific to the industrial decarbonization objectives.

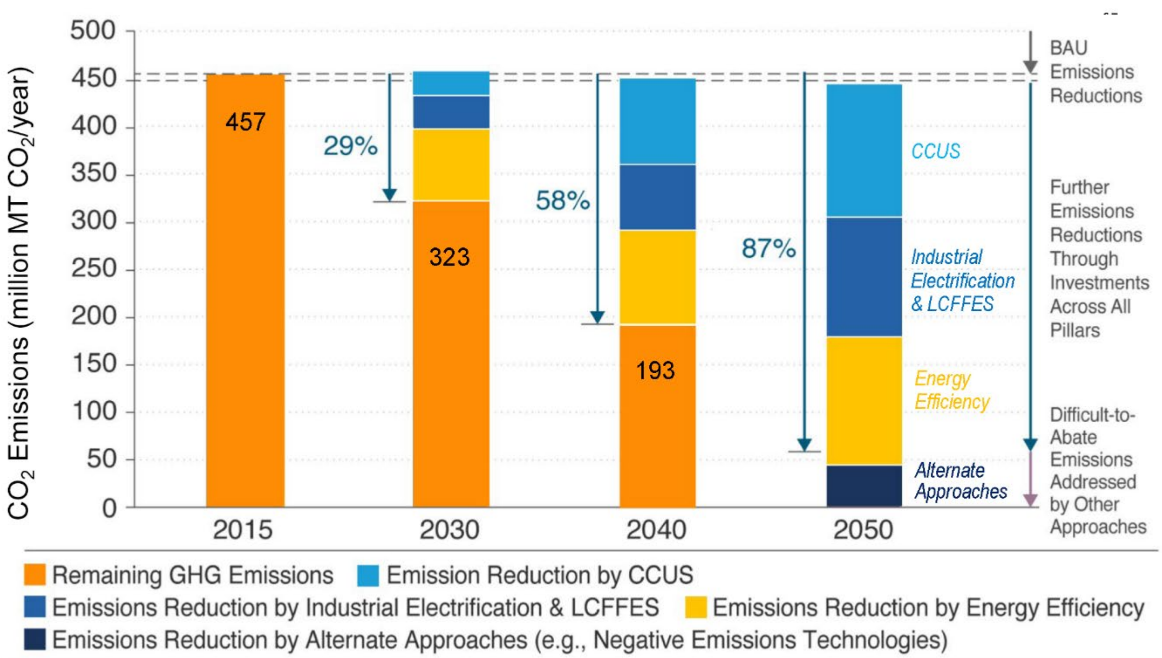

Figure 6.5: *A representative path toward net zero industrial carbon dioxide emissions for five industry sectors (iron and steel, chemical manufacturing, food manufacturing, petroleum refining, and cement), with carbon dioxide emissions in millions of MT/yr. The emissions reductions associated with key pillars of industrial decarbonization are shown, as well as future reductions associated with net negative technologies and other alternate approaches. Details of the scenarios and definitions are available in DOE's 2022 Industrial Decarbonization Roadmap,*[67] *and the figure is reproduced from that source. (BAU = business-as-usual)*

[67] DOE, *Industrial Decarbonization Roadmap*.

Significant activities associated with all four of the pillars listed above will be necessary to fully decarbonize U.S. industry, and this process will take decades. A representative scenario for five key industry sectors (iron and steel, chemical manufacturing, food manufacturing, petroleum refining, and cement) reaching net zero emissions by 2050 is shown in Figure 6.5. Similar to Figure 6.4, these sectors are representative examples, not a comprehensive list; these sectors accounted for 52% of U.S. industry carbon dioxide emissions in 2020 (see Figure 6.3). Figure 6.5 combines the pillars of electrification and LCFFES into a single category and indicates that the long-term impact of these two approaches is likely to be similar in magnitude to gains in energy efficiency. Figure 6.5 notes that some industrial GHG emissions will still occur in 2050, even with aggressive deployment of the four pillars of industrial decarbonization. Achieving net zero emissions will require that these remaining emissions are offset by alternate approaches,[68] including net negative technologies such as DAC and other CDR strategies (see Section 6.5.2). The scenario in Figure 6.5 reflects the long-lived nature of industrial infrastructure; major manufacturing facilities can cost billions of dollars to develop, and their economic viability is typically judged based on assumptions of operations on decadal time scales.

Using the analysis above as a foundation, OCED's Industrial Demonstrations program, in close collaboration with the Manufacturing and Energy Supply Chain Office (MESC) and the Industrial Efficiency & Decarbonization Office (IEDO), released the Industrial Decarbonization and Emissions Reduction Demonstration-to-Deployment Funding Opportunity Announcement on March 8, 2023. This FOA will execute projects with significant levels of funding that were authorized by the BIL ($500 million)[69] and the IRA ($5.8 billion).[70] These projects offer a critical opportunity to solidify a "first-mover" advantage for U.S. industry, bolstering its competitiveness globally for decades into the future. DOE seeks first- or early-of-a-kind commercial-scale projects. These could include new technologies that have been proven at a pilot scale but have yet to be deployed commercially, technologies that are being pursued internationally but do not have a foothold in the United States, or other early-of-a-kind projects that face market or adoption risks (Table 6.3). All projects will incorporate a path from demonstration to deployment that includes sustained operation after completion and substantiates the projects' ability to meet priority criteria.

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[68] National Academies of Sciences, Engineering, and Medicine, *Accelerating Decarbonization*.
[69] Section 41008 of the BIL that authorizes appropriations of $500 million for demonstrations in the Industrial Emissions Reduction Technology Development Program at section 454(d)(3) of the Energy Independence and Security Act of 2007 (42 U.S.C. §17113(d)(3)) that are appropriated by Title III of Division J of the BIL.
[70] Section 50161 of the IRA (42 U.S.C. §17113(b)) that authorizes and appropriates $5.812 billion, which is available through September 30, 2026, in support of advanced industrial facilities projects.

Table 6.3: *Topic areas and descriptions of the Industrial Decarbonization and Emissions Reduction Demonstration-to-Deployment Funding Opportunity Announcement.*

Topic Area	Description	Funding Provision	TRL	Anticipated Awards		
				#	Years	Federal Funding
1. Near-Net-Zero Facility Build Projects	World-leading, first- or early-of-a-kind, full facility builds resulting in significant emissions reductions up to net zero operations. *Target Metric: 75% carbon intensity reduction at the facility*	BIL §41008	7–9	2–5	8–12	\$100M–250M
2. Facility-level Large Installations and Overhaul Retrofit Demonstrations	Large-scale overhauls for existing facilities, common technologies across multiple facilities, or new builds with accelerated planning, development, permitting, and financing strategies. *Target Metric: 50% carbon intensity reduction at the facility*	IRA §50161	7–9	10–30	3–7	\$75M–500M
3. System Upgrades and Retrofits for Critical Unit Operations or Single Process Lines Within Existing Facilities	Upgrades, retrofits, and operational improvements that target decarbonization within a unit operation or process line at an existing facility. *Target Metric: 75% carbon intensity reduction for the process*	IRA §50161	7–9	10–30	3–7	\$35M–75M

Note: All values anticipated. Details to be determined through merit reviews and project negotiations. FOA is available for review on OCED Exchange.

Based on the timeline outlined in the FOA, OCED anticipates projects will be underway in FY 2024 with shorter projects funded under Topic Areas 2 and 3, potentially completing within 5 years. When completed, OCED will share project outcomes with a larger group of industrial stakeholders to encourage and support widespread adoption of successful GHG reduction technologies while helping to support a market for low-carbon products. In addition, outcomes will be shared with DOE's industrial applied RD&D offices to improve technologies as needed for the next generation.

Beyond five years, the future development of OCED's Industrial Demonstrations Program will focus on the long-term goal of retiring risks for full facility builds and larger installations. OCED will continue to partner with the Office of Energy Efficiency & Renewable Energy's Industrial Efficiency and Decarbonization Office and other DOE applied offices to support the further demonstration and deployment of successful pilot-scale demonstrations of technologies that will enable energy-intensive industries to achieve net zero carbon manufacturing.

6.4 Regional Clean Hydrogen Hubs

In the United States today, hydrogen is used almost exclusively as a chemical in large-scale chemical processes, including oil refining and synthesis of ammonia and methanol. Almost all the approximately 10 million tons H_2/year produced in the United States comes from fossil fuel sources, either from reforming of methane or as a byproduct from other industrial processes.[71] When hydrogen produced with a small GHG footprint is widely available, this clean hydrogen will be a key factor in enabling a broadly decarbonized economy. The diverse aspects of this future hydrogen economy are encapsulated in DOE's H2@Scale vision (see Figure 6.6) and DOE's recently released National Clean Hydrogen Strategy and Roadmap.[72] Using clean hydrogen as a chemical would allow decarbonization of existing large-scale processes, including ammonia synthesis and metals production, and other rapidly emerging chemical processes.[73] Clean hydrogen can be used as an energy carrier and enable decarbonization of combined heat and power and transportation. It can also be used for power generation, potentially smoothing intermittencies associated with renewable electricity generation, especially by using hydrogen for long-term energy storage addressing seasonal production mismatches. When used in this way clean hydrogen complements other modes of energy storage.

This diverse array of end uses for hydrogen can only be realized if clean hydrogen can be produced at large scales. Viewed broadly, hydrogen production requires a source of hydrogen atoms and a source of energy. A wide variety of production routes exist, with the GHG emissions associated with each route often described using a color-coded scale.[74] Current hydrogen production technologies based on reforming of fossil fuels can potentially lead to clean hydrogen if coupled with CCS. Alternative pathways use water as a source of hydrogen atoms in combination with electrical energy from low or zero carbon sources. A further alternative is to use wastes such as biogas as a source of hydrogen.

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[71] DOE, *Department of Energy Hydrogen Program Plan,* Hydrogen and Fuel Cell Technologies Office, Energy.gov, November 2020, https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf.

[72] DOE, "U.S. National Clean Hydrogen Strategy and Roadmap," Hydrogen and Fuel Cell Technologies Office, Energy.gov, September 2022 https://www.hydrogen.energy.gov/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf.

[73] Craig Bettenhausen, "Flying the Low-Carbon Skies on Sustainable Aviation Fuel," *Chemical & Engineering News*, June 13, 2022.

[74] Michel Noussan et al., "The Role of Green and Blue Hydrogen in the Energy Transition – A Technological and Geopolitical Perspective," *Sustainability* 13 (2021): 298; "Hydrogen Colours Codes," H2 Bulletin, 2023, https://www.h2bulletin.com/knowledge/hydrogen-colours-codes/.

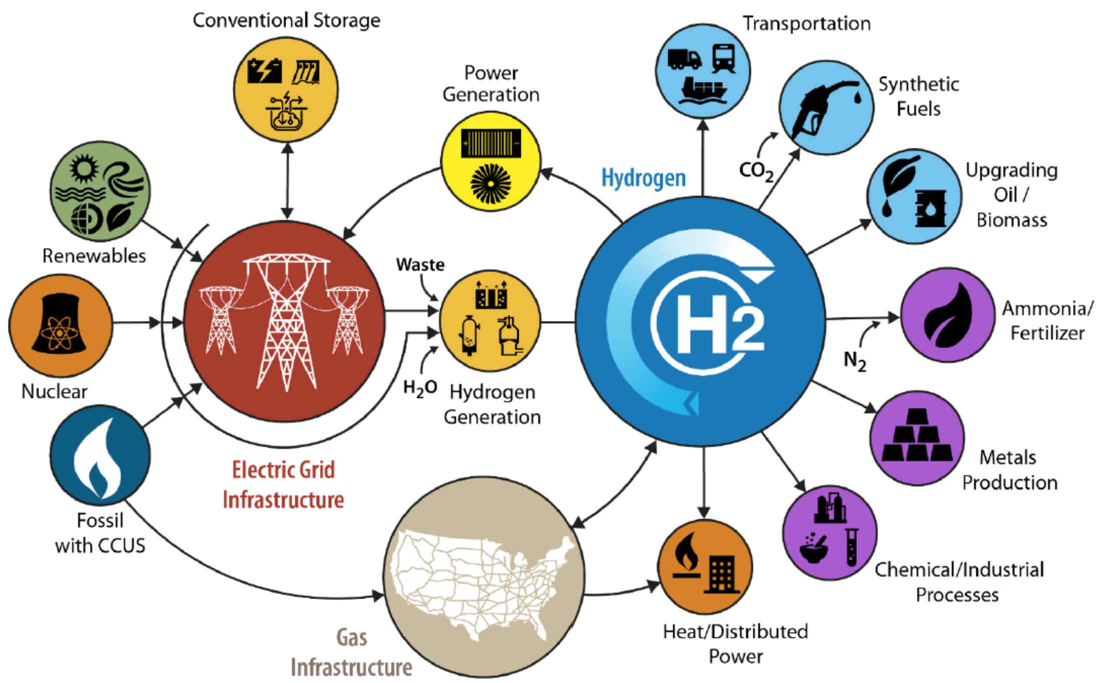

Figure 6.6: *The H2@Scale energy system, illustrating key end uses of hydrogen and the potential connections between large-scale hydrogen production and existing electricity and natural gas grids. Figure reproduced from the 2020 Department of Energy Hydrogen Program Plan.*

Because of its low density and safety characteristics, storage and delivery of hydrogen is more challenging than liquid fuels or natural gas. A hydrogen pipeline network of 1,600 miles currently exists in the U.S. Gulf Coast region, connecting producers and industrial users.[75] For clean hydrogen to reach its full potential in decarbonizing the U.S. economy, a much larger and more geographically diverse delivery and storage infrastructure will need to be established. The diversity of end uses of hydrogen allows for infrastructure that could be shared by multiple industries and the possibility of smoothing of production demands. *Pathways to Commercial Liftoff: Long Duration Energy Storage* provides more detailed information on barriers associated with commercializing hydrogen in the United States.[76]

75 DOE, *Department of Energy Hydrogen Program Plan*.

76 DOE, *Pathways to Commercial Liftoff: Long Duration Energy Storage*, Energy.gov, March 2023, https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf.

The BIL amended the Energy Policy Act of 2005, adding Section 822, which instructs DOE to develop an initial standard for the carbon intensity of clean hydrogen production. Section 822(b)(1)(B) defines "clean hydrogen" to mean "hydrogen produced with a carbon intensity equal to or less than 2 kilograms of carbon dioxide-equivalent produced at the site of production per kilogram of hydrogen produced" (2 kg CO_2eq/kg H_2). The clean hydrogen production standard will take this definition into account while also supporting clean hydrogen production from diverse sources and taking into account technological and economic feasibility. The draft clean hydrogen production standard proposes a lifecycle GHG emission of 4.0 kg CO_2eq/kg H_2.[77] Current estimates place the current production cost of clean hydrogen at around $5/kg. The DOE's Hydrogen Shot[78] aims to establish production of clean hydrogen for less than $1/kg by 2031. The BIL defines an intermediate goal on the path to the Hydrogen Shot target of producing hydrogen with electrolyzers for less than $2/kg by 2026. The 2022 IRA introduced the 45V tax credit for hydrogen produced in the United States, with tax credits determined depending on the lifecycle GHG emissions associated with hydrogen production.

Achieving diversification and growth of the clean hydrogen economy in a commercially successful way will require co-development of hydrogen production, distribution, and end uses as well as development of a trained workforce and cultivation of community buy-in. OCED's ability to develop demonstrations based on public–private partnerships will play a critical role in fostering the integrated facilities that are required in this area. To manage the resources made available from the BIL, OCED has initiated an H2Hubs program, which will execute a portfolio of demonstration projects that will significantly advance production of clean hydrogen at commercial scales and further development of a national clean hydrogen economy. Each H2Hub will be a network of clean hydrogen producers, potential clean hydrogen consumers, and connective infrastructure located in close proximity, demonstrating balanced hydrogen supply and demand and a plan to be financially viable after DOE funding is completed.

Recognizing the diverse feedstock, end use, and regional aspects of the future hydrogen economy, the BIL directed DOE to develop a portfolio of H2Hubs and authorized $8 billion for at least four. The BIL instructs that to the maximum extent practicable, DOE will incorporate the following requirements in selecting Hubs. H2Hubs will be in different regions within the United States and leverage energy resources abundant in their region. At least two Hubs will be located in regions with abundant natural gas resources. Diversity of feedstocks will be achieved by operating at least one Hub each deriving clean hydrogen inputs from fossil fuels, renewable energy, and nuclear energy. Diversity of end use will be achieved by operating at least one Hub each for industrial uses, residential and commercial heating, and transportation, with the Hubs using clean hydrogen primarily for electric power generation.

[77] DOE, "U.S. Department of Energy Clean Hydrogen Production Standard (CHPS) Guidance," Energy.gov, https://www.hydrogen.energy.gov/clean-hydrogen-production-standard.html.
[78] DOE, "Hydrogen Shot," Hydrogen and Fuel Cell Technologies Office, Energy.gov, https://www.energy.gov/eere/fuelcells/hydrogen-shot.

In addition to statutory requirements, each Hub will be expected to produce clean hydrogen at a rate of at least 50–100 MT/day. These Hubs will markedly increase the volume of clean hydrogen that is produced in the United States, but at these minimum production rates, they will account for less than 2% of U.S. total hydrogen production relative to today's hydrogen industry.

H2Hubs will demonstrably aid the achievement of the clean hydrogen production standard, which focuses on the carbon intensity of hydrogen production at the site of production. DOE will also, however, evaluate the full lifecycle emissions performance of each H2Hub.. Using hydrogen and fuel cells to generate electricity can offer reduction in criteria pollutants and offer resiliency through reliable power, especially in remote locations. H2Hubs will be expected to maximize lifecycle social and environmental benefits. DOE will require H2Hubs to track and report outcomes related to EEJ, consent-based siting, labor and community engagement, DEIA, job quality, labor standards, and workforce development.

The central aim of each H2Hub will be to demonstrate engineering, design, and execution of large-scale hydrogen production, distribution, and end use for the purpose of stimulating significant follow-on private sector investment by reducing uncertainties and risks that currently, or will in the future, inhibit private investment. Each H2Hub will verify and validate technology performance (including production, processing/handling/storing, and end use), GHG emissions, and market uptake. Data and analyses from each Hub will be distributed to inform future projects, technology, and engineering and design improvements. Hubs will be expected to show how the benefits of DOE investments are shared by the Hub's host communities, especially historically underrepresented, underserved, and overburdened groups.

Following OCED's model for project management (see Section 5), each Hub will be structured with a phased approach, including attracting strategic private partners with the capacity for continued investment. OCED will monitor projects closely and make use of independent engineers. Data obtained from each project will be used to track the progress of each Hub and to evaluate the overall program of projects. Crosscutting challenges that are identified via this program-wide assessment could potentially be tackled in an accelerated way using H2Hubs funding or TCF funding. In addition to techno-economic analysis of the technologies advanced by each Hub, it will be vital to perform reliable assessment of GHG lifecycle emissions using GREET[79] or an analogous tool.

[79] Energy Systems and Infrastructure Analysis, "Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model," Argonne National Laboratory, https://greet.es.anl.gov.

Future development of OCED's Clean Hydrogen Program will focus on the long-term goal of retiring risks so hydrogen facilities can achieve commercial viability without ongoing Federal funding. It is likely that market development will lead to end-use cases that have not been fully anticipated in the current H2Hub program. OCED's program will need to understand these future scenarios by sustained engagement with a broad community of stakeholders and potential end users and with other activities in DOE's broader activities associated with hydrogen. It is likely that successful growth of the hydrogen industry will bring some issues to the fore that have less immediacy at the scale of initial H2Hubs. For example, some H2Hubs may produce hydrogen at scales that are not large enough to require new pipeline infrastructure. Future activities in OCED's program should anticipate future challenges of this kind and develop efforts to enable significant future growth of the nation's hydrogen economy.

6.5 Carbon Management

Carbon dioxide is a direct product of hydrocarbon combustion and other chemical processes, and carbon dioxide emissions accounted for 79% of net U.S. GHG emissions in 2020.[80] The United States currently emits approximately 5 billion tons of anthropogenic carbon dioxide per year. One way to appreciate the scale of these emissions is to note that they are equivalent to an average of 41 kg (90 lb) of carbon dioxide emissions *per day* for each person in the nation. As already noted above, a wide range of scenarios charting possible paths toward a net zero emission economy by 2050 have been developed. A robust conclusion from these scenarios is that emissions of carbon dioxide in the United States on the scale of billions of tons per year may continue for decades. These observations imply that in addition to aggressively developing carbon-free energy sources, it is necessary to simultaneously demonstrate and scale approaches that directly capture current and future carbon dioxide emissions.

A key factor in determining what methods can be used to capture carbon dioxide is the concentration of carbon dioxide in the source being considered. Carbon dioxide capture is more economical for point sources where large quantities of carbon dioxide are emitted from a single location, typically an industrial process or energy generation facility. In some cases, such as bioethanol refineries, streams of carbon dioxide that are relatively pure are available for capture with minimal processing.

[80] "Inventory of U.S. Greenhouse Gas Emissions and Sinks," United States Environmental Protection Agency, April 19, 2023, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

A more common situation associated with combustion is that carbon dioxide is present at levels of 10–15% in a gas stream that is predominately humid N_2 with other impurities.[81] In these cases net energy is required to separate carbon dioxide from the remaining components in a gas stream. An advantage of performing carbon dioxide capture from point sources is that the industrial nature of these sources opens possibilities for leveraging existing infrastructure and process integration. Carbon dioxide emissions from vehicle tailpipes are not considered available for point source capture because of the highly spatially disperse and small scale of the individual emission sources.

Carbon dioxide can also be captured from the atmosphere through a variety of processes, one of which is known as DAC. DAC has advantages relative to point source capture because it has more flexible siting requirements and, more importantly, it can indirectly address any source of carbon dioxide emissions, both from legacy and active sources. The dilute nature of carbon dioxide in the atmosphere, currently 0.04% (approximately 420 ppm), inherently means that more energy is required to capture carbon dioxide from air than from more concentrated point sources. However, the relationship between these increasing energy needs and decreasing carbon dioxide concentration does not fundamentally prohibit DAC from being feasible.[82] Carbon dioxide is also present in a dilute form in seawater, where it is present in millimolar concentrations as carbonate and bicarbonate ions. The absorption of gigatons of anthropogenic carbon dioxide every year by the upper layers of the earth's oceans is the cause of ocean acidification while also significantly mitigating the warming effects of increasing atmospheric concentrations of carbon dioxide. Technologies to capture carbon dioxide from seawater, known as direct ocean capture (DOC), are being developed, although they are relatively less advanced than DAC.[83]

DAC and DOC are two major strategies in a broader set of approaches known as CDR.[84] CDR has the goal of removing carbon dioxide from the atmosphere, directly or indirectly, and durably storing the resulting carbon. Other examples of CDR strategies include afforestation and similar land use changes, which aim to store carbon as stable biomass, and mineralization, in which carbon dioxide is converted to a solid form such as calcium carbonate (limestone). The emphasis on the durability of stored carbon when considering CDR highlights that any carbon dioxide removal approach must define the end state of captured carbon dioxide. Once captured, carbon dioxide can potentially be used as a chemical feedstock to make other products (carbon dioxide utilization) or be stored in a physical location that will not release it to the atmosphere (carbon dioxide sequestration).

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[81] David S. Sholl and Ryan P. Lively, "Exemplar Mixtures for Studying Complex Mixture Effects in Practical Chemical Separations," *Journal of the American Chemical Society Au* 2, no. 2 (2022): 322.

[82] Matthew J. Realff and Peter Eisenberger, "Flawed Analysis of the Possibility of Air Capture," *Proceedings of the National Academy of Sciences* 109, no. 25 (2012): E1589.

[83] National Academies of Science, Engineering, and Medicine, *A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration* (Washington, DC: National Academies Press, 2021).

[84] Wilcox, Kolsz, and Freeman, *CDR Primer*.

Utilization and sequestration both have advantages and disadvantages. The value created from new products in carbon dioxide utilization can reduce the net cost of carbon dioxide capture, but the total volume of carbon dioxide that can be harnessed in this way may be limited relative to the objective of capturing carbon dioxide at gigaton scales. The lifecycle impact of carbon dioxide utilization can differ substantially depending on the longevity and use of the resulting product. Carbon dioxide sequestration requires appropriate geographical sites,[85] and though the United States has many potentially suitable sites, these sites are not necessarily co-located with the sites most suitable for carbon dioxide capture.

OCED's efforts in carbon management currently comprise two complementary programs in carbon dioxide capture from point sources and DAC, each described below. In both cases, OCED's demonstration-stage projects need to capture carbon dioxide and demonstrate the disposition of the resulting carbon dioxide in an integrated manner. OCED's efforts in this area will be closely coordinated with DOE's Office of Fossil Energy and Carbon Management, which has a long history of developing technologies and operating field demonstrations for carbon dioxide capture, utilization, and storage. *Pathways to Commercial Liftoff: Carbon Management* provides additional detail on future pathways for carbon management in the United States.[86]

6.5.1 Carbon Dioxide Capture From Point Sources

CCUS refers to capturing carbon dioxide emissions from point sources like industrial facilities and using that carbon dioxide or durably sequestering it underground so that it stays out of the atmosphere. There are currently 20 million MT/year of carbon capture capacity installed in the United States. Natural gas processing (approximately s16 million MT/year), ethanol production (2 million MT/year), and fertilizer production (0.73 million MT/year) account for almost all this capacity due to their highly concentrated carbon dioxide exhaust streams. As carbon dioxide streams get more dilute, the cost of capturing carbon dioxide increases.[87] Most carbon dioxide capture systems deployed today use amine solvents, which have been in use for decades. Improved capture technologies could meaningfully improve performance and cost if they are able to scale up.

[85] National Energy Technology Laboratory, *Carbon Storage Atlas 5th Edition*, September 2015, https://www.netl.doe.gov/sites/default/files/2018-10/ATLAS-V-2015.pdf.
[86] DOE, *Pathways to Commercial Liftoff: Carbon Management*, Energy.gov, April 2023, https://liftoff.energy.gov/carbon-management/.
[87] Jennifer Wilcox, *Carbon Capture* (New York: Springer, 2012).

Currently, purified carbon dioxide produced in the United States is primarily used for enhanced oil recovery and applications such as food and beverages.[88] The United States has vast resources that can allow long term below ground sequestration of carbon dioxide; DOE estimates of these resources exceed 2600 billion tons of carbon dioxide, far exceeding the nation's current annual anthropogenic carbon dioxide emissions of approximately 6 billion tons of carbon dioxide.[89] Multiple field demonstrations have been performed injecting carbon dioxide at the scale of hundreds of thousands of tons of carbon dioxide into the subsurface for sequestration,[90] and carbon dioxide has been injected in geological formations for many years for enhanced oil recovery. Furthermore, novel conversion and utilization applications integrating captured carbon dioxide into a wider array of products are emerging as complements to existing storage and utilization pathways.

CCUS is a key pillar of DOE's Industrial Decarbonization Roadmap,[91] recognizing the role that CCUS will play in reducing direct GHG emissions from hard-to-decarbonize sectors such as cement and steel manufacturing. CCUS is also expected to play a key role in decarbonizing electricity generation, even as generation capacity from renewable sources increases rapidly.[92] OCED may encourage various storage and utilization pathways to meet the specific objectives of a particular FOA, all applicable statutory authorities, and the broader goals of OCED's Carbon Management program.

The availability of tax credits and incentives will need to be accounted for in a detailed way in planning the scope of prospective OCED projects and their ability to catalyze future commercial adoption. The economic viability of CCS projects has been strongly influenced by 45Q tax credits, which incentivize CCS. Prior to the passage of the IRA, 45Q had previously been worth \$50/ton-CO_2 for geologic sequestration, a cost at which only applications with relatively pure carbon dioxide streams (like those mentioned above) were economic with current technologies. The 2022 IRA extended the 45Q tax credit and also increased the credit to \$85/ton for geologic sequestration in qualifying projects, a change that could make many new project types economically viable.

All projects within the CCS Demonstration portion of this program will be expected to integrate storage and capture of carbon dioxide, so the business model for a project will need to address capture from an existing facility through to injection of carbon dioxide with the intent to leave it below ground.

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[88] Craig Bettenhausen, "U.S. Faces CO_2 Shortage," *Chemical & Engineering News,* August 17, 2022.
[89] National Energy Technology Laboratory, *Carbon Storage Atlas 5th Edition*.
[90] Ibid.
[91] DOE, *Industrial Decarbonization Roadmap.*
[92] U.S. Department of State and U.S. Executive Office of the President, *The Long-Term Strategy*.

Additionally, OCED will expect projects to refine approaches to attract financing and partnerships for future installations that take advantage of cost savings associated with learning-by-doing in the project. This program will seed a sizeable cohort of front-end engineering design (FEED) studies for integrated carbon dioxide capture and storage projects. As noted in Section 3, it is likely that not all these FEED studies will advance to later phases of permitting, financing, and installation, although information from the full set of FEED studies will be useful for better understanding the risks associated with CCS projects. It is also likely that the duration and timing of FEED studies may vary from project to project. It may be appropriate, for example, to solicit a second set of FEED studies after the program has been in operation for several years and information developed from the initial FEED studies and subsequent projects can be used to improve future projects.

As project economics improve, the availability of adequate carbon dioxide transportation and storage infrastructure may limit the deployment of CCS. Although abundant physical resources exist for potential geologic storage, infrastructure access to these resources and permitting and validation measures to allow large-scale operations are prerequisites for implementing carbon dioxide capture and storage. Development and planning of this enabling infrastructure will be critical to the scale up of CCS.

The BIL appropriated $2.537 billion for Carbon Capture Demonstration Projects and $937 million for Carbon Capture Large-Scale Pilot Projects that will be executed by OCED.[93] The Carbon Capture Demonstration Projects will demonstrate transformational technologies that will significantly improve the efficiency, effectiveness, costs, emissions reductions, and environmental performance of coal and natural gas use, including in manufacturing and industrial facilities.

These projects will demonstrate and de-risk CCUS at commercial scale. As mandated by the BIL, the program will support CCUS demonstrations at two coal generation facilities, two natural gas generation facilities, and two industrial facilities not purposed for electric generation. In parallel, the Carbon Capture Large-Scale Pilot Projects will accelerate the scale-up of next-generation capture technology such that a wider range of use cases are economically viable. In both the demonstrations and pilots, GHG lifecycle emissions will be carefully assessed in the design phase and then measured during implementation, and techno-economic analysis will be used to determine the cost-of-capture in real-world deployments and to identify paths to improving process economics. As an example of the differentiation between the two programs, a demonstration project in this program would need to be able to capture carbon dioxide from a complete generation train at a power plant that operates multiple trains,3 while a pilot project could potentially capture carbon dioxide from a slip stream rather than a complete generation train.

[93] Section 41004 and Title III of Division J of the BIL.

6.5.2 Direct Air Capture of Carbon Dioxide

Many of the clean energy technologies addressed by OCED will contribute to overall decarbonization goals by displacing current fossil fuel-based energy uses with low emissions energy resources or, as in the previous section, by capture and sequestration of carbon dioxide emissions. However, it will be extremely difficult to completely avoid GHG emissions from some sectors such as agriculture and aviation. To counterbalance these residual emissions and achieve net zero GHG emissions or address legacy emissions, carbon dioxide must be removed from the atmosphere or oceans. Deliberate removal of carbon dioxide from the environment into physical forms that are durable over periods of decades or far longer is referred to as CDR.[94] It is notable that conversion of carbon dioxide into products that are then combusted, such as aviation fuel, may contribute to reaching net zero but cannot be described as CDR because the carbon dioxide involved is not durably stored. CDR includes a wide variety of techniques, ranging from enhancing natural carbon sinks (e.g., planting trees, exposing certain types of rock to the air, restoring soils, and leveraging the carbon dioxide uptake of oceans) to engineered technologies that capture carbon dioxide directly from the air and then permanently store it.[95,96] It is critical to remember that CDR is an essential supplemental decarbonization strategy that should not be considered a replacement for emissions avoidance or reduction.[97]

One rapidly emerging engineered CDR approach is DAC, where carbon dioxide is taken out of ambient air using chemicals (or other media) that can then be regenerated to release concentrated carbon dioxide and prepared for reuse.[98] The captured carbon dioxide from DAC, like carbon dioxide captured from more concentrated point sources, can be compressed and geologically sequestered, or it can be integrated into long-lived products such as concrete to achieve CDR. Because of the low concentration of carbon dioxide in air, efficient approaches for DAC must differ from approaches that are viable for carbon dioxide capture from concentrated point sources. DAC intrinsically requires a net input of energy, and many current processes require significant energy input[99] and face other resource challenges.[100]

[94] Mustafa Babiker et al., "Cross-sectoral Perspectives," in *IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change,* eds. Priyadarshi R. Shukla et al. (New York: Cambridge University Press, 2022), 1245–1354.
[95] National Academies of Sciences, Engineering, and Medicine, *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda* (Washington, DC: The National Academies Press, 2019).
[96] Wilcox, Kolsz, and Freeman, *CDR Primer*.
[97] Babiker et al., "Cross-sectoral Perspectives."
[98] Noah McQueen et al., "A Review of Direct Air Capture (DAC): Scaling Up Commercial Technologies and Innovating for the Future," *Progress in Energy* 3, no. 3 (2021): 032001.
[99] Eloy S. Sanz-Perez et al. "Direct Capture of CO_2 from Ambient Air," *Chemical Reviews* 116, no. 19 (2016): 11840–76.
[100] Christoph Beuttler, Louise Charles, and Jan Wurzbacher, "The Role of Direct Air Capture in Mitigation of Anthropogenic Greenhouse Gas Emissions," *Frontiers in Climate* 1 (2019): 10.

A potential advantage of DAC relative to point source carbon dioxide capture is that DAC is much more flexible with respect to siting and can therefore be located at sites that reduce overall costs associated with transport of captured carbon dioxide and/or supply of the necessary energy inputs. Because the input to DAC is ambient air, differences between climate zones and annual and diurnal conditions could play an important role in the effectiveness of individual installations.

While DAC technologies are more advanced than many other CDR approaches, DAC is still in early stages of development relative to other clean energy sector technologies, with current global capacity less than 15,000 tons of carbon dioxide per year.[101] Significant opportunities exist for cost and performance improvements,[102] but realizing these advances will require deployment of existing technologies and continued RD&D for new technologies. The success of renewable energy technologies such as wind turbines and solar photovoltaics offers an analogy for DAC, where costs are likely to dramatically decrease with increased deployment capacity.[103]

The BIL appropriated $3.5 billion between 2022 to 2026 for up to four regional DAC hubs. These DAC hubs will greatly accelerate capacity additions, enabling cost reductions, and position the United States as a clear global leader in DAC. Each regional DAC hub is intended to be a connected network of DAC projects, potential carbon dioxide utilization off-takers (e.g., for durable products), connective carbon dioxide transport infrastructure, subsurface resources, and geologic storage infrastructure. Specific goals for these Hubs include:

- Having the capacity to utilize, capture and sequester, or sequester and utilize at least 1,000,000 MT of carbon dioxide from the atmosphere annually from a single unit or multiple interconnected units;
- Demonstrating the capture, processing, delivery, and sequestration or end use of captured carbon dioxide; and
- Creating pathways to develop a regional or interregional network to facilitate carbon dioxide sequestration or utilization.

For each Hub, Life Cycle Analysis (LCA) of the entire project will be performed to evaluate the net carbon dioxide-equivalent removal that includes all mass and energy inputs and outputs required to construct, operate, monitor, and close the facility; emissions from land use change; and long-term retention of the carbon dioxide. Further evaluation criteria for the DAC hubs will also be evaluated on additional criteria, including the carbon intensity of local industry, geographic diversity, carbon potential, proximity to fossil-production regions, scalability, community engagement, and workforce opportunities. Reaching the goals of the DAC Hubs will dramatically increase the installed capacity that exists for DAC.

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[101] Klaus S. Lackner and Habib Azarabadi, "Buying Down the Cost of Direct Air Capture," *Industrial & Engineering Chemistry Researc*h 60, no. 22 (2021): 8196–208.
[102] McQueen et al., "A Review of Direct Air Capture."
[103] Lackner and Azarabadi, "Buying Down the Cost."

As emphasized in Figure 6.7, such rapid growth in installed capacity will need to be replicated many times over to reach the full potential for DAC contributing to a net zero energy system.

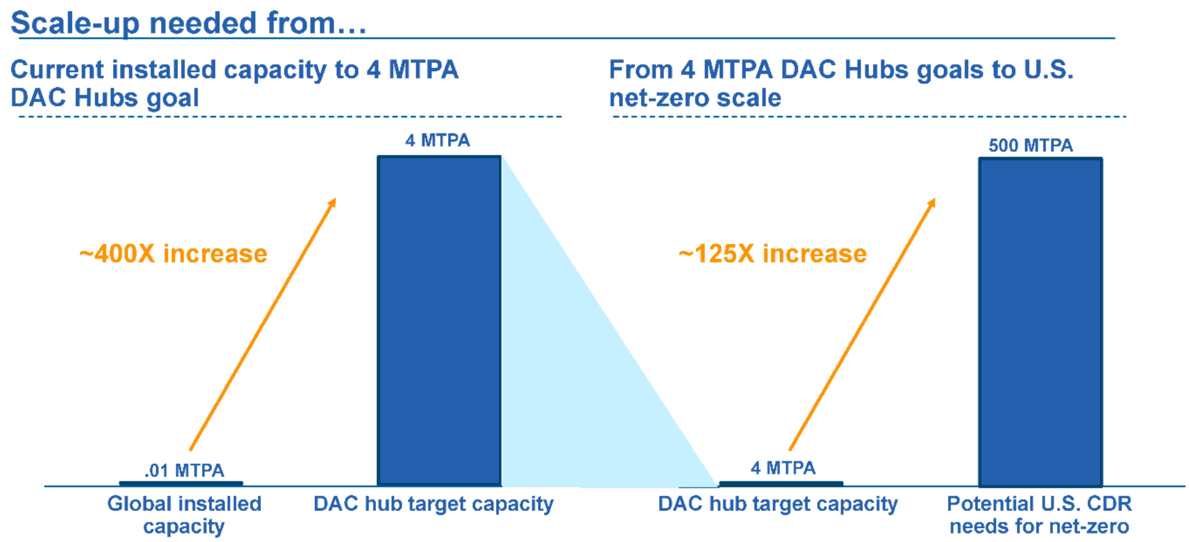

Figure 6.7: *Schematic illustration of the increase in installed capacity in megatons carbon dioxide per annum (MTPA) for DAC that will be achieved upon reaching the DAC Hubs goal (left) and the subsequent capacity growth that will be needed to reach the full potential for DAC contributing to a future U.S. net zero energy system.*

Meaningful community engagement will be central to the successful development and implementation of all phases of regional DAC hubs. In addition to the technical criteria outlined above, DAC Hubs will incorporate environmental justice, community engagement and consent-based siting, and equity and workforce development as project evaluation criteria. Effective community engagement will take place throughout the lifecycle of a project, and it is likely that the types of engagement will change as the phase of the project progresses. Because DAC is a new approach that currently has a limited installed base, these aspects of the DAC Hubs will be vital to advancing the ARL of this core CDR approach.

As with other OCED demonstration projects, DAC Hubs will be executed using a phased approach. Because DAC is less technologically mature than other topics being developed by OCED, the portfolio of DAC projects will have scope for some projects that are initiated at phases associated with conceptual design or pre-FEED studies in addition to projects that have already completed FEED studies and can already demonstrate relevant permitting. OCED will closely coordinate with DOE's Office of Fossil Energy and Carbon Management to streamline early-stage testing and validation of DAC technologies.

A key goal of OCED's efforts with DAC is to de-risk a portfolio of specific DAC approaches to enable future commercial implementation. Important contributions to this goal will be the use of a common set of phases to rapidly drive project teams from conceptual design to the implementation phases that will follow FEED studies and the establishment of quantitative benchmarks allowing decisions on the viability of developing concepts. As part of OCED's ability to efficiently evaluate performance of emerging DAC approaches, it may be valuable to establish physical facilities that can provide independent verification of the effectiveness of DAC technologies in multiple climate zones.

Once fully operational, OCED's regional DAC Hubs will increase the global installed capacity of DAC many fold. These regional DAC hubs will be essential for facilitating cost reductions through economies of scale and learning-by-doing, but additional development efforts in the future will still be required to achieve CDR at the scale needed to reach net zero goals. It is too early to know which technologies, pathways, business models, and other conditions will provide the best CDR solutions, so a broad portfolio of CDR technologies should be considered. Future enhancements to OCED's portfolio of CDR technologies could include expanding beyond a focus on only DAC to other CDR approaches such as biomass carbon removal and storage and technologies for capturing carbon dioxide from ocean water. Similar to the emerging nature of DAC, other CDR approaches also face technical, economic, and other adoption risks that need to be reduced to evaluate and prepare these approaches for commercial deployment. Encouraging exploration of a range of CDR solutions will be invaluable in identifying region-specific pathways suited for local environments and communities that are most effective at responsibly deploying CDR as a supplement to direct decarbonization methods for achieving long-term deep decarbonization.

6.6 Clean Energy Solutions for Local Economies

Although community impact is a key element of all OCED programs, the technical programs outlined above are primarily described in terms of the technology solutions they will advance (e.g., advanced nuclear reactors or carbon dioxide capture and storage). The geographic and cultural diversity of the country and the strong intersections that exist between energy availability and economic prosperity mean that opportunities also exist for effective technical programs that are focused on particular land types or population centers. The two programs described below, Clean Energy on Mine Lands and Energy Improvements in Rural or Remote Areas, both take this approach. In each of these programs, a range of possible clean energy technologies will be considered. As with all OCED programs, they aim to demonstrate replicable at-scale solutions that not only bring benefits to the communities and locales in which projects are completed but unlock future commercial investment by reducing key risks.

6.6.1 Clean Energy on Mine Lands

Active mine lands, reclaimed lands, and abandoned mine sites are abundant in many areas of the nation. The Environmental Protection Agency (EPA) has estimated, for example, that there are 1.5 million acres of mine lands that could be utilized for energy development.[104] Repurposing of industrial land often has a more positive climate impact than greenfield development and creates economic opportunities and jobs in locations that have lost industrial operations. In addition, building on mine lands can reduce community opposition to energy projects by building on previously disturbed land rather than greenfield sites that may result in the loss of agricultural, forested, or other community-valued land. Using mine lands can reduce land-use conflicts and avoid equivalent clean energy development on undisturbed and agricultural land, potentially reducing impacts on wildlife and ecosystems. In many cases, using mine land can take advantage of existing infrastructure, including roads and electricity transmission. Importantly, using mine lands can create economic opportunities for nearby communities and may enjoy easier social license to operate and accelerate permitting. Opportunities also exist for providing clean energy to existing mining operations, reducing the GHG impact of these operations.

Mine lands have challenges that can increase construction and operation costs for clean energy projects. Regulatory and environmental issues associated with clean energy development on mine land can be complicated by fragmented data on site locations, ownership, or status, all of which may contribute to lack of clarity around liability issues. Costs associated with environmental remediation may also need to be addressed. In all cases, environmental and economic impacts on the surrounding community must be carefully considered and will require meaningful community engagement from the earliest stages.

The BIL authorized a $500 million program to demonstrate two to five clean energy demonstrations on current and former mine lands. As with OCED's other programs, these demonstrations will be structured to de-risk the implementation of clean energy solutions and to unlock future private investment. The demonstration projects must be located on active, inactive, or abandoned mine land (defined as land claimed or patented under the Mining Act of 1972 or the Surface Mining Control and Reclamation Act of 1977). These laws cover coal and hard rock (e.g., gold, copper) mines.

[104] *RE-Powering America's Land Initiative: RE-Powering Mapper Fact Sheet*, EPA, April 2022, https://www.epa.gov/system/files/documents/2022-04/re_powering_mapper_factsheet.pdf.

A variety of clean energy technologies are eligible for these demonstrations, including solar energy, geothermal energy, microgrids, DAC of carbon dioxide, fossil-based energy generation with carbon capture, energy storage, and advanced nuclear reactors. Demonstrations may include more than one of these technologies, and opportunities may exist to implement two or more approaches in a synergistic way that realizes greater benefits than one approach alone. As defined in the BIL, at least two of the demonstration projects shall be solar projects. In selection, projects will be prioritized based on the degree to which they provide job creation, GHG emission reduction, and economic activity, particularly in distressed areas and including dislocated workers previously employed in manufacturing, coal power plants, or coal mining.

The diversity of clean energy technologies and mine lands that will be considered in this program underlines the importance of maintaining strong connections between this program and allied programs in OCED, elsewhere in DOE, and other Federal agencies, including the Bureau of Land Management, EPA, Office of Surface Mining Reclamation and Enforcement, U.S. Fish and Wildlife Service, Appalachian Regional Commission, Economic Development Agency, Mine Safety and Health Agency, and Bureau of Indian Affairs. Management and assessment of these demonstration projects will draw on lessons learned from OCED's parallel programs in advanced reactor demonstrations and energy storage (Section 6.1), carbon storage and DAC (Section 6.3), and demonstrations in rural and remote areas (section 6.6.2). The program will also coordinate with the Interagency Working Group on Coal and Power Plant Communities, the DOE LPO, and with the DOE offices who will support the Advanced Energy Manufacturing and Recycling Grant Programs authorized by the BIL.

In FY 2022, OCED began conducting stakeholder engagement and data collection on clean energy on mine lands. Based on this information, experts at the national laboratories will identify technical, market, and regulatory barriers and challenges to deploying clean energy on mine lands. Public resources, such as data and tools, will be developed to help stakeholders, including local communities near mine land, evaluate opportunities for clean energy projects on that land. In addition, the demonstration projects will develop and test business models that benefit local mining communities through jobs and other economic development.

The ARL of the eligible clean energy technologies varies, so OCED's initial program of demonstrations may not include every technology. It will be important to identify and understand the difficulties associated with using mine land (e.g., addressing environmental concerns in siting and permitting) in OCED's initial program so this knowledge can be extended to future demonstrations of more challenging technologies.

6.6.2 Energy Improvements in Rural or Remote Areas

Rural and remote areas often face a high energy cost burden and less reliable electricity for several reasons. These areas have a disproportionately higher share of low- and moderate-income families who have limited ability to cope with high energy costs. Energy costs are high because many rural areas are weakly connected to larger grids, which requires added redundancy and expensive transportation of fuels, and the low population densities of rural communities require long transmission and distribution lines. This leads to high capital and operational expenses for rural electricity providers.[105] This, coupled with a relatively low revenue stream from the small population served, often results in challenges when local providers attempt to secure funding for energy improvements. For these reasons, energy infrastructure in rural and remote areas may be out-of-date and cause more frequent outages.

Section 40103(c) of the BIL authorized DOE to establish a program for energy improvement in rural or remote areas. An appropriation of $1 billion for the 5-year period FY 2022–FY 2026 was granted to improve the resilience, safety, reliability, and availability of energy and increase environmental protections from adverse impacts of energy generation. This program will benefit cities, towns, or unincorporated areas that have populations of fewer than 10,000 inhabitants. OCED may provide Federal financial assistance to rural or remote areas for the purpose of (1) overall cost-effectiveness of energy generation, transmission, or distribution systems; (2) siting or upgrading transmission and distribution lines; (3) reducing GHG emissions from energy generation by rural or remote areas; (4) providing or modernizing electric generation facilities; (5) developing microgrids; and (6) increasing energy efficiency. OCED may also carry out activities beyond Federal financial assistance, such as prizes, to improve rural or remote areas.

In support of OCED's mission to deliver clean energy demonstration projects at scale, this program will focus on projects in rural or remote areas and communities that demonstrate and de-risk replicable and scalable development models and accelerate market adoption and the equitable transition to a decarbonized energy system. Accomplishing these goals requires centering community needs in program design, forging trusting partnerships between rural communities and energy project partners, and facilitating lasting connections between communities to help each other with similar energy challenges. Strong community engagement will be pivotal in ensuring that OCED's projects bring enduring value well beyond the period in which Federal assistance is provided.

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[105] DOE, *Transforming the Nation's Electricity System: The Second Installment of the QER*, Office of Energy Policy and Systems Analysis, Energy.gov, January 2017, https://www.energy.gov/sites/prod/files/2017/02/f34/Quadrennial%20Energy%20Review--Second%20Installment%20%28Full%20Report%29.pdf.

To maintain a clear focus on community needs, justice, and equity, the program and subsequent funding opportunities will:

- Be designed to address the energy needs and capacity of rural or remote communities;
- Facilitate forming effective and trusting project partnerships between communities with similar energy challenges, with DOE, and with the energy project partners required for successful implementation (communities must also trust that their needs will be served through these partnerships); and
- Consider the capacity of project teams, including communities and other relevant partners, to participate in the program, before, during, and after financial assistance and to access the technical assistance necessary to identify and address energy needs.

In addition to the goal of accelerating the equitable transition to a decarbonized energy system, it is important to accelerate market adoption to impact rural or remote areas beyond those participating in this program. This can happen through replication of successful solutions demonstrated here. Achieving replicability requires that real or perceived barriers to installing and operating energy projects in rural or remote communities are mitigated. Potential barriers include many of the factors encapsulated in the ARL described in Section 4. While all aspects of ARL will be relevant to projects in this program, key challenges will include workforce risk mitigation, such as demonstrating training programs for workers in rural or remote communities to operate and maintain specific types of projects that have not historically been present in their community, and community impact risk mitigation, such as demonstrating pollution prevention strategies or novel community engagement methods, especially for communities of color and others who have been historically underserved, marginalized, and adversely affected by persistent poverty and inequality. It is also likely that the ability and capacity of entities to identify, scope, and finance project proposals may be very different than the entities that will lead projects in many of OCED's other programs. OCED will explore the use of technical assistance programs and other strategies to address this issue.

In order to accomplish the goals stated above, program design must consider feedback from disadvantaged communities, and other stakeholders, including the clean energy industry and its investors, Federal and State regulatory agencies, Tribal governments, State and local governments, labor unions, environmental justice and energy justice organizations, community-based organizations, economic development organizations, conservation and environmental groups, and academic and other research institutions. OCED will solicit feedback from these groups throughout the lifetime of the program via requests for information, community-based listening sessions, workshops, and other mechanisms.

In initiating the program and in future years, OCED will pursue ongoing engagement and relationship building with a broad cross section of stakeholders. Community input from these sources, coupled with analysis of existing and potential energy programs in rural or remote areas will help DOE and partners categorize and understand energy demonstration needs, learn from past energy demonstration projects, and better understand the national landscape for energy improvements in rural or remote communities, ultimately ensuring appropriate program execution. OCED may also use one or more prize competitions to address barriers to entry by communities and project partners. These prize competitions will solicit new ideas for investing in business models for rural and remote community deployment, communication strategies, and ways of working with partners supporting communities readying for deployment or demonstration of systems. These activities will build capacity and relationships between entities required for successful demonstration projects in rural or remote areas, including communities, utilities, private capital, project developers, and DOE. It may also be necessary for OCED to consider changes in the format and dissemination of FOAs and competitions to make OCED's programs more accessible to partners who do not have extensive experience with DOE funding mechanisms.

OCED will coordinate with interagency partners at the Department of Interior, the EPA, the Department of Agriculture (USDA), the Rural Partners Network, and elsewhere in the Federal Government to maximize the effectiveness of this program. Long-term success in this program will mean the replication of similar projects throughout the United States without OCED investment. This outcome will likely require demonstration of novel business models to incentivize private sector investment and connecting project partners to private or public funding sources for more mature technology, such as the DOE LPO or USDA Loans.

7 Considerations for Future Clean Energy Demonstrations

The technical programs described in Section 6 will allow OCED to initiate public–private partnerships that will drive advances in multiple clean energy solutions toward long-term operations and commercial uptake. This portfolio of programs will enable growth at scale in key clean energy technologies. As already highlighted in Section 6, there are multiple ways in which OCED's current programs will benefit from interactions among programs and from collaboration with other DOE offices. These ongoing activities will identify key opportunities where additional future investment in OCED's existing programs will be beneficial.

The economic consequences associated even with short-lived disruptions in energy supply caused by weather events or geopolitical developments are a reminder of the central role that reliable, affordable energy plays in the nation's wellbeing and productivity. The vast size and complexity of the nation's energy system means that OCED's existing programs cannot address every technical opportunity where clean energy solutions can bolster the economy and tackle the challenge of dramatically reducing GHG emissions. It is therefore important that OCED has a well-defined approach to selecting impactful topics for the development of future technical programs.

Section 3 described several characteristics of at-scale demonstrations that make them a critical tool in the commercialization and deployment of clean energy solutions, including validation of performance in complex real-world environments, allowing learning by doing and building confidence among industry, the financial sector, and communities where facilities will be located. Any new technical area developed by OCED will aim to embody these characteristics. OCED's approach to creating technical programs that execute multiple individual demonstration projects within a well-defined application area is an important component of the goal of building confidence among key stakeholders, since successful operation of a new technology by multiple independent teams is a direct indication of robustness.

Several criteria should be met for any future technical topic to be selected for development by OCED. These include the following:

1. The principles and operation of the clean energy solution have been repeatedly established and validated at pre-commercial (up to pilot) scales.
2. The clean energy solution should have a well-defined potential commercial market but be at an ARL where commercial lenders are unwilling to provide future financing without substantial retirement of technical, operational, and market risks.
3. The clean energy solution should have capacity to make a significant contribution to the nation's clean energy goals or GHG emission targets if broadly implemented in a future market setting.

4. A regulatory environment exists in which the clean energy solution could operate or at-scale demonstrations could plausibly motivate necessary regulatory changes.
5. The key risks associated with advancing the clean energy solution to high TRL and ARL levels are understood by the Government and private sector, allowing demonstration programs to be developed that focus on reducing these risks.
6. At-scale demonstrations of the clean energy solution would enable the United States to establish international leadership with a scalable energy technology and bolster domestic supply chains and jobs.
7. The solution is not sufficiently supported by existing or planned DOE, other public programs, or the private sector.

To identify and evaluate possible topics for future programs, OCED will conduct technology, industry, and market analysis and collaborate and consult with subject matter experts across the clean energy and decarbonization research, development, demonstration, and deployment community, including:

- Applied technology offices within DOE's Office of Science and Innovation (S4),
- Deployment and infrastructure offices within DOE's Office of Infrastructure (S3),
- Interagency partners in various sectors, and
- The private sector, including but not limited to technology developers, industry, commercial lenders, and other potential financial partners, advisory groups, non-profits, states, universities, national labs, community organizations, local and Tribal governments, and labor unions.

OCED will conduct formal annual engagement as well as ad hoc concept discussions to evaluate DOE's existing portfolio of activities across the technology commercialization continuum (see Figure 3.1), and it will catalog existing and planned facilities with the relevant technology in the United States and around the world. OCED will conduct listening sessions, RFIs, and other mechanisms to seek input from a broad range of stakeholders.

OCED's Portfolio Strategy Division (PSD) will evaluate potential future topics on an ongoing basis, initiating new technical programs and the use of new mechanisms at regular intervals as OCED establishes its enduring mission within DOE. PSD will carefully vet program concepts for readiness, suitability, and impact utilizing OCED frameworks to establish relative investment value and identify priority programs and timelines. These criteria and evaluation processes can be used to identify both high priority opportunities as well as areas that may not be suitable for immediate OCED programs. For example, fusion energy is a topic of significant international investment and activity by startup companies, but criterion 1 implies that fusion devices at any scale are not currently well suited to OCED.

Manufacturing of batteries for light passenger vehicles has enormous implications for electrification of the transport sector, but the active commercial investment taking place in facilities for this purpose means that applying criterion 2 excludes this area from OCED's purview. These two examples highlight a feature of considering clean energy solutions in terms of their ARL, namely that once a technology has reached commercial deployment, it is unlikely that the core technology will ever be a topic appropriate for OCED, though supporting systems and utilization of the technology could be. For a pre-commercial technology like fusion, however, it is conceivable that future developments will occur that address criterion 1 that will change the technology's applicability to OCED's mission space. Criterion 3 helps filter out solutions that will have only limited impact on a national scale. A technology solution that would only apply to a class of chemicals produced at scales of hundreds of kilograms a year, for example, may have significant value to the industry focused on this product, but it likely would be an inappropriate topic for consideration by OCED.

Below are examples of possible future technical areas of interest for OCED that are associated with each of the key sectors illustrated in Figures 2.1 and 6.1. Development of future programs in these or other areas will follow more detailed consideration using the process outlined above, with an initial survey of the state of the art. Further, engagement with key subject matter experts from within and external to DOE suggests that criteria 1–7 above may be satisfied now or in the foreseeable future. The list of examples below is not intended to firmly commit OCED to a future program or to be an exhaustive list of possible future topics.

Electricity Generation/Energy Capture: A striking feature of Figure 6.1 is that apart from the ARDP, OCED's current portfolio has limited activity specifically associated with new resources for electricity generation and energy capture. To widely electrify end uses, decarbonized generation capacity must be added not only to replace current fossil fuel sources of electricity but to augment the total supply of electricity. Many scenarios suggest that the United States will need to add more than 60 gigawatts of capacity per year over the coming decades, a rate higher than any seen this century to date.[106] Thus, a natural consideration for future OCED programs is the generation of carbon-free electricity and accelerated deployment of these solutions.

One possible set of topics for OCED to work on will be the operational barriers associated with speeding the deployment of wind, solar, or geothermal energy. The core technologies in each of these cases may be well established, but the transformative approaches to accelerate deployment may not be. For solar energy, it may be useful to develop methods using automation to speed installation and maintenance of utility-scale solar arrays, where many processes still involve manual labor. For wind energy, seeking solutions to the complex issues associated with transportation and installation could accelerate deployment. Deployment of geothermal energy would be aided by improvements in methods to characterize potential sites, as well as regulatory issues, community acceptance, and effective coupling with end uses.

[106] U.S. Department of State and U.S. Executive Office of the President, *The Long-Term Strategy.*

OCED could also consider programs to de-risk carbon-free electricity generation methods that have not yet achieved commercial application, including floating offshore wind energy, advanced hydropower, and enhanced geothermal generation.

- Floating Offshore Wind Energy: A majority of U.S. offshore wind energy capacity is located in waters where floating platforms are needed to overcome performance and cost issues with fixed-bottom platforms. DOE recently launched the Floating Offshore Wind Earthshot, which aims to reduce the cost of floating offshore wind energy to $45 per megawatt-hour by 2035 for deep sites far from shore.[107] As this effort matures it may be appropriate for OCED to work in partnership with the Wind Energy Technologies Office to de-risk floating offshore wind via at-scale demonstrations.
- Advanced Hydropower: Hydropower has been a key component of U.S. electricity generation for decades, and additional domestic hydropower resources could be developed if appropriate advanced hydropower solutions were available. These new hydropower resources are typically smaller and have lower energy density than existing installations. New hydropower installations must also navigate challenging socio-environmental impacts. OCED, in collaboration with DOE's Water Power Technologies Office, may seek demonstration programs that advance key hydropower technologies and work with coalitions of industry partners, end users, and community and local groups.
- Enhanced Geothermal: It also may be appropriate for OCED to work with DOE's Geothermal Technologies Office to de-risk Enhanced Geothermal Systems (EGS) as the feasibility of this approach becomes fully established. EGS has been estimated to have the potential to unlock resources on the order of 100 GWe within the United States alone.[108] DOE's Frontier Observatory for Research in Geothermal Energy (FORGE) project[109] has invested significant resources into site characterization, development, and implementation of EGS.

The enormous growth that will be needed in capacity for solar and wind energy to reach the nation's carbon-free electricity goals will create important opportunities in developing a circular economy associated with the materials and high-value components used in these technologies. Recycling or repurposing materials from, for example, wind turbines, is attractive but challenging because of the physical scale of the materials involved.[110]

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[107] DOE, "Floating Offshore Wind Shot," Wind Energy Technologies Office, https://www.energy.gov/eere/wind/floating-offshore-wind-shot.

[108] John Ziagos et al. "A Roadmap for Strategic Development of Enhanced Geothermal Systems Technologies," in *Proceedings of Thirty-Eighth Workshop on Geothermal Reservoir Engineering* (Stanford, California: Stanford University, 2013), https://www.energy.gov/eere/geothermal/downloads/technology-roadmap-strategic-development-enhanced-geothermal-systems.

[109]DOE, "FORGE," Geothermal Technologies Office, Energy.gov, https://www.energy.gov/eere/geothermal/forge.

[110] Mitch Jacoby, "Recycling Wind Turbine Blades," *Chemical & Engineering News* 100, no. 27 (2022): 26–30.

OCED may explore programs that develop commercial ecosystems that could dramatically increase circularity in materials for wind and solar electricity generation to reduce or even eliminate the lifecycle emissions and materials challenges associated with these clean energy solutions.

Grid and Distribution Networks: OCED's existing Grid and Distribution Networks and H2Hubs Program already incorporate strong elements focused on the electricity grid and energy distribution networks. It is very likely that additional efforts by OCED in tight coordination with DOE's GDO will be appropriate in the future. In connection with the transport-related topics mentioned below, efforts that couple clean hydrogen production with other chemical energy carriers such as ammonia may be appropriate. The importance of ammonia and related chemicals in the agriculture sector means that it may be valuable to explore connections between uses in this sector and use of ammonia as an energy carrier in transportation. Some of the electricity generation methods mentioned above, such as floating offshore wind, also have adoption risks associated with transmission and distribution that would need to be tackled in tandem with the challenges associated with electricity generation. OCED's current program on energy storage (Section 6.1.2) is relatively small compared to its other programs. Energy storage will play a vital role in many aspects of the nation's suture grid and energy distribution networks, so developing future programs to de-risk new approaches to this issue will be valuable.

Transportation: It was mentioned above that light vehicle transportation is already on a path toward decarbonization via the market penetration of EVs. Although significant challenges will need to be overcome to follow this path, the considerable commercial investments already taking place, along with support from other Federal, State, and local agencies, means that electrification of light vehicles is not currently an area of direct interest for OCED. The GHG emissions associated with medium and heavy-duty vehicles and marine and air transport, however, will be more challenging to reduce. Each of these subsectors presents potential opportunities for coordinated at-scale demonstrations to advance commercial uptake of relevant clean energy technologies. Fleet applications with medium- or heavy-duty vehicles could offer opportunities for electrification or alternative fuels to reduce GHG emissions but would require large infrastructure investments by a coordinated group of energy providers and end users. Ports and airports are both locations that will be critical infrastructure hubs if marine or air transportation is to be adapted to alternative fuels. There may be important advantages that can arise from the intermodal nature of transportation infrastructure centered at ports or airports. OCED will coordinate with the Bioenergy Technologies Office as efforts from that office mature in providing sustainable aviation fuel. Similarly, clean energy solutions that specifically address major freight corridors (e.g., inland waterways, trucking, and rail) may be well suited to be the focus of future OCED programs. For solutions that rely on electrification, these topics will of course intersect closely with the electricity generation and grid topics mentioned above.

Industry: OCED's Industrial Demonstrations program (see Section 6.3) already covers topics within the key pillars of industrial decarbonization laid out in DOE's recent Industrial Decarbonization Roadmap.[111] It is projected that decarbonization of U.S. industry will take decades (see Figure 6.5), in part because of the long-lived nature of industry infrastructure and the complexity of this sector. It is likely that adaptations and expansions of OCED's current program will be developed in future years, especially in seeking to expand the successes of initial projects from the particular industry sub-sector in which they have been demonstrated to technologically adjacent sub-sectors. It will also be valuable to seek relevant opportunities in industries that will grow significantly as the economy becomes increasingly decarbonized – such as the manufacturing of low carbon-intensity structural materials – anticipating the key sources of industrial GHG emissions in the future economy as well as addressing known sources of emissions in today's economy.

Buildings: The buildings sector shown in Figures 2.1 and 6.1 includes both residential and commercial buildings. Although non-electricity energy use in buildings currently accounts for an appreciable fraction of U.S. GHG emissions (see Figure 2.2), the buildings sector is better placed than industry or transportation to achieve decarbonization through electrification. In addition, by its nature, the buildings sector is highly decentralized and modular, creating challenges for defining cases in which at-scale demonstrations can play the same pivotal role as in many of the other energy solutions considered by OCED. For these reasons, OCED's impact on the buildings sector in the foreseeable future will likely take place through the Office's programs associated with energy generation and distribution rather than the end uses of energy in buildings.

Agriculture and Land Use: Although few of OCED's current programs are focused on agriculture or land use, these areas will be of significance in aiming to reach the nation's net zero emissions goals. Agriculture contributed 11% of U.S. GHG emissions in 2020 (see Figure 2.2). Bioenergy crops can potentially lead to large emissions reductions from the transportation sector,[112] with much current interest associated with very rapid growth in the nation's capacity to produce sustainable aviation fuels.[113] Land-use changes, including afforestation and management of soil carbon, are candidates as CDR strategies.[114] Land use also has strong implications for water use and is a key element of the energy–water nexus.[115]

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[111] DOE, *Industrial Decarbonization Roadmap*.
[112] DOE, "2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy," Bioenergy Technologies Office, Energy.gov, 2016, https://www.energy.gov/eere/bioenergy/2016-billion-ton-report.
[113] Bettenhausen, "Flying the Low-Carbon Skies."
[114] Wilcox, Kolsz, and Freeman, *CDR Primer*.
[115] DOE, "Takeaways from the 2015 DOE Energy–water Nexus Roundtable Series," Energy.gov, 2015, https://www.energy.gov/articles/energy-water-roundtables.

For all these reasons, it will be appropriate for OCED to consider, in close consultation with other relevant Federal agencies and stakeholders, topic areas in which future demonstrations could deconflict land use – especially as related to bioenergy crops, energy generation, and other aspects of the energy–water nexus – and/or reduce the energy intensity and direct emissions associated with agriculture. Programs on these topics should maintain a focus on giving communities more options for adopting transitional technologies without losing elements of their community and space that are highly valued.

Net-Negative Solutions: As discussed in Section 2, many scenarios charting paths toward net zero GHG emissions in 2050 indicate that large levels of net negative methods will need to be implemented to offset persistent GHG emissions from hard-to-decarbonize sources. In the scenarios envisioned in *The Long-Term Strategy of the United States: Pathways to Net Zero Greenhouse Gas Emissions by 2050,*[116] net negative solutions amounting to approximately 1 billion tons of CO_2eq/year are anticipated. Reaching this state will require creating a large new industry similar in scale to today's complete national petrochemical industry.

OCED's existing program on DAC Hubs, described in Section 6.4, will lead to important advances in using DAC to directly remove carbon dioxide from the atmosphere. DAC is not the only approach, however, to removing carbon dioxide from the atmosphere. A range of technologies and methods have been considered for the task of CDR, where the aim is to remove carbon dioxide from the atmosphere and durably store it.[117] The DOE's Carbon Negative Earthshot, launched in 2021, set the goal of establishing approaches that could capture and durably store 1 ton of CO_2eq for $100 within 1 decade.[118] As their scalability and viability becomes established, OCED will support a broader portfolio of CDR methods that complement existing investments in DAC.

Externalities: Because the energy system is inextricably linked with the nation's economy, externalities exist that are relevant to many individual energy generation and use sectors. These issues are typically complex and affect many existing and future stakeholders. The role of externalities should be considered as a key element in developing any new programs in OCED. To give just one example, future programs associated with agriculture and land use should consider future changes in water availability and weather conditions associated with climate change, both incremental changes over time and extreme weather events. Lessons learned from OCED and GDO's programs on grid resilience may create a useful starting point for addressing these issues in other sectors. It will also be useful in considering the scope of activities in this area to take advantage of DOE's excellent programs in earth systems modeling, as well as relevant activities in the private sector (e.g., in the insurance industry).

[116] U.S. Department of State and U.S. Executive Office of the President, *The Long-Term Strategy*.
[117] Wilcox, Kolosz, and Freeman, *CDR Primer*.
[118] DOE, "Fact Sheet: Carbon Negative Shot," Office of Fossil Energy and Carbon Management, Energy.gov, July 13, 2022, https://www.energy.gov/fecm/articles/fact-sheet-carbon-negative-shot.

OCED will also be open to supporting DOE programs associated with crosscutting clean energy challenges, either by running programs in partnership with other offices or by providing expertise in program design or management. The strong connection mentioned above between OCED and GDO's work on grid resilience is one example of a partnership of this type. A second example of this type is MESC's efforts leading DOE's work to strengthen supply chains for critical materials. Future collaboration between OCED and MESC may be appropriate to develop FOAK demonstration projects focused on either production or recycling of critical materials since critical materials are highly vulnerable to geopolitical upsets and supply disruptions or price spikes could hamper the market penetration of key clean energy technologies.

8 Engagement and Collaboration for Continuous Improvement

Ongoing, meaningful, and purposeful stakeholder engagement (both within DOE and externally) is critical to the long-term success of OCED demonstrations. Engaging with affected stakeholders, including industry, communities, investors, unions, and State, local, and Tribal governments is critical to OCED's mission. This approach requires meaningful stakeholder engagement that ensures OCED clearly understands the needs of each key stakeholder group and how they can be addressed and supported. This approach will strengthen OCED's program design and implementation by bringing in diverse stakeholder perspectives to maximize benefits and deliver widespread support. Without such support, OCED demonstrations could be hampered from the beginning and risk delays or legal challenges as projects move forward. The stakeholder engagement specialists of OCED's Engagement Office will coordinate closely with OCED programs and project managers to aid program design and project execution.

External Industry, Community, and Public Engagement: OCED's Engagement Office works closely across OCED to deliver on OCED's mission. By aggregating to the portfolio level, the Engagement Office can help to drive a center of excellence approach across the programs by reducing duplication of effort; creating standardized methods and tools; providing a more consistent OCED voice; reducing the burden on engaged stakeholders; and building broader and more comprehensive stakeholder relationships with a greater depth of engagement.

OCED has applied a rigorous strategic framework and planning process to guide engagement activities and accommodate the:

- Breadth of mandates,
- Size of OCED's portfolio,
- Diverse nature of demonstrated technologies,
- Expected broad geographic coverage of OCED programs, and
- Centering of justice across OCED's work.

Drawing on these sources, OCED identified five engagement objectives. These objectives help to establish engagement activities for each program, identify the groups and individuals to engage, and define the topics and areas engagement must focus on to meet objectives. Each is further explained in subsequent sections.

Objective 1: Build awareness of OCED's portfolio of programs and technologies, approach to demonstrations, and the progress made at the program and project levels. Commit to transparency in communication on approach and progress.

Objective 2: Engage applicants, project performers, tribes, and impacted communities throughout the demonstration process to enable an equitable approach to implementation. Commit to fairness, clarity, and candor to the maximum extent possible in every demonstration phase.

Objective 3: Consistently monitor progress of demonstration projects to identify risks to successful demonstration and recommend actions for greater impact.
Objective 4: Identify, illuminate, and help mitigate obstacles to future scaling, including those related to market rules and regulation, investment and commercialization, jobs and workforce, and equitable transitions. Engage decision makers to build momentum for scale.
Objective 5: Leverage DOE and interagency resources to deepen program impact and enable greater scale.

Engagement is central to the OCED mandates for demonstration excellence, EEJ, economic development, and commercialization. Engagement activities are designed to both proactively and passively ingest learnings and feedback from a diverse base of stakeholders, synthesize and share findings across OCED, and mobilize specific resources that can help to manage risk and deepen program outcomes and impact. See Figure 8.1 for an overview of the actionable engagement process.

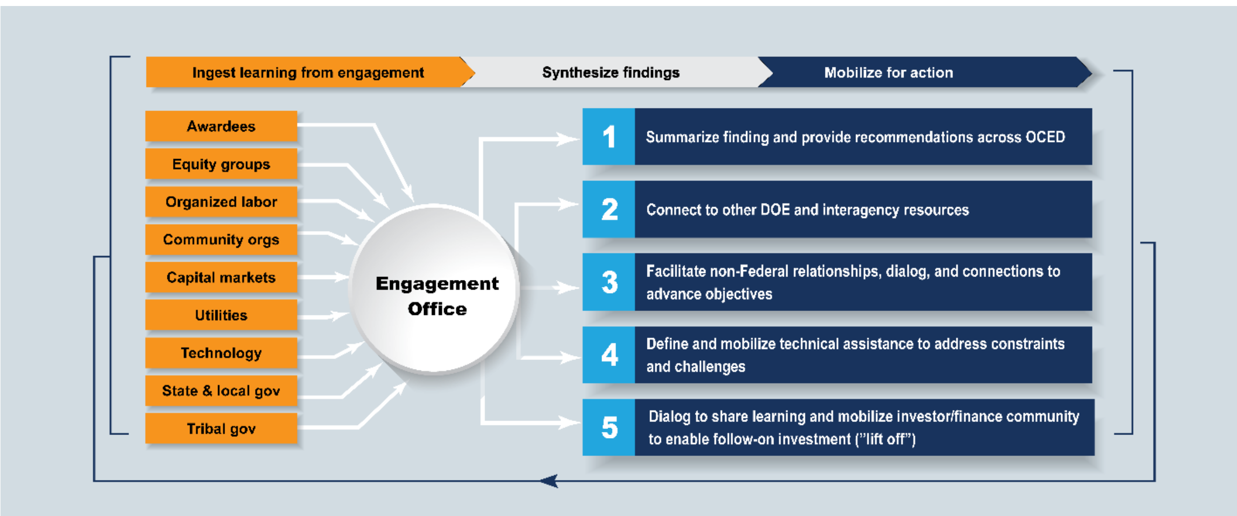

Figure 8.1: *OCED's actionable engagement process.*

Actionable engagement requires the ability to mobilize resources in support of OCED programs. A wide variety of technical assistance, training, and financial support is available across DOE's applied offices, the National Labs, and other Federal agencies that is relevant to OCED programs. Illustrative examples of such mechanisms, including from OCED, are described below. As OCED's portfolio matures and stakeholder needs are identified, new technical assistance mechanisms or areas for and training will be designed, developed, and deployed. The Engagement Office will help spur this through engagements and continuous feedback.

Legislative engagement: OCED will steward significant levels of taxpayer funds. OCED's Engagement Office will work closely with OCED leadership, program teams, the Portfolio Strategy group and budget office teams, and with DOE's Office of Congressional and Intergovernmental Affairs to communicate effectively and provide insights to legislative partners. The Engagement Office will work to consistently and proactively communicate OCED's approaches to de-risking clean energy solutions, project outcomes, and efforts to establish itself as a project management oversight center of excellence. Additionally, as OCED leadership and the Portfolio Strategy group develop scope for possible new technical programs using the approach described in Section 7, engagement strategies for having meaningful two-way discussions about these proposals with legislative partners will be developed with DOE's Office of Congressional and Intergovernmental Affairs.

DOE and interagency engagement: As shown in Figure 3.1, a range of organizations exist within DOE to span the continuum from basic research to at-scale commercial deployment of clean energy technologies. OCED's technical programs will partner closely with the relevant applied offices. Some key partnerships of this type are listed in Table 8.1, although this is not intended to be an exhaustive list. As described in Section 7, the consideration of possible future technical areas for OCED demonstrations will be accomplished in partnership with subject matter experts and other collaboration with the relevant applied offices. There will also be multiple examples in which OCED Technical Programs will need to coordinate closely with Federal partners outside the DOE; for example, OCED's program on Clean Energy on Mine Lands will work with the Bureau of Land Management, EPA, Office of Surface Mining Reclamation and Enforcement, U.S. Fish and Wildlife Service, Appalachian Regional Commission, Economic Development Agency, Mine Safety and Health Agency, and Bureau of Indian Affairs.

A core aim of OCED's entire portfolio is to unlock commercial investment in clean energy technologies. DOE's LPO provides access to debt capital to help deploy innovative clean energy, advanced transportation, and Tribal energy projects. LPO's mission dovetails well with OCED's goals, with LPO focused on completing the so-called bridge to bankability[119] that connects FOAK commercial deployments with commercial scale-up, commercial debt market education, and ultimately full market acceptance. OCED's Portfolio Strategy group, along with program managers from individual technical programs, will regularly work with LPO to identify collaboration and alignment opportunities to jointly reach the goal of commercial market acceptance for clean energy solutions. This activity will take place in parallel with strong connections to the private sector since many OCED programs will seek to move solutions directly in commercial deployment.

[119] DOE, "Mission," Loan Programs Office, Energy.gov, https://www.energy.gov/lpo/mission.

Table 8.1: *Key intra-DOE partnerships between OCED technical programs and DOE applied and infrastructure offices.*

OCED Technical Program	Example DOE Partner Offices
Clean Hydrogen	Hydrogen and Fuel Cell Technologies Office
Carbon Dioxide Capture/Direct Air Capture	Fossil Energy and Carbon Management
Industrial Decarbonization	Industrial Efficiency and Decarbonization Office, Office of Manufacturing and Supply Chains
Advanced Reactor Demonstrations	Office of Nuclear Energy
Grid Reliability and Resilience	Grid Deployment Office, Office of Electricity
Energy Storage	Office of Electricity, Advanced Manufacturing and Materials Technologies Office
Clean Energy for Local Economic Development	Office of State and Community Energy Programs and others

An example of using intra-DOE partnerships to coordinate DOE's strategy with extensive external engagement are the Pathways to Commercial Liftoff that have been developed recently for several key areas of interest to OCED. To date, these reports have been developed for advanced nuclear, clean hydrogen, carbon management, and long duration energy storage.[120]

[120] DOE, "Liftoff Reports."

9 Conclusion and Path Forward

OCED’s mission is to lead the DOE's efforts to deliver clean energy demonstration projects at scale in partnership with the private sector to accelerate deployment, market adoption, and the equitable transition to a decarbonized energy system. OCED’s programs will be underpinned by a well-defined approach to quantifying and reducing risks associated with technical demonstration and commercial adoption of clean energy solutions. This Multi-year Program Plan has described a broad set of programs based on current funding that OCED will pursue to achieve this mission, as well as strategies for assessing success at the program and portfolio level and criteria for identifying new opportunities and developing impactful programs in the future. OCED’s demonstration, supporting, and demand-side programs will aim to enable new installations, retrofits, and operation of facilities that continue their operation beyond the initial period of Federal funding and to simultaneously develop technical, commercial, and community confidence in clean energy solutions, enabling uptake of these solutions in future installations.

OCED’s current programs address complex operating, economic, and community issues and are currently early in the timeline of project development, construction, and operation. Moreover, these programs share technical aims with multiple other DOE offices and interagency partners. It will therefore be imperative for OCED to continually refine its strategy and processes and to do so in a collaborative manner that emphasizes two-way information sharing with DOE, interagency partners, and the many external commercial and community stakeholders who will ultimately make decisions regarding the implementation of clean energy solutions to transform the nation’s energy system.

Office of Clean Energy Demonstrations