Introduction

The U.S. Department of Energy (DOE) Hydrogen Program Annual Merit Review and Peer Evaluation Meeting (AMR) convenes key stakeholders and participants to enable a technical expert peer evaluation of projects funded by the DOE Hydrogen and Fuel Cell Technologies Office (HFTO) and a high-level evaluation of the hydrogen activities conducted by multiple DOE offices, as well as interoffice and interagency collaboration on hydrogen and fuel cells.

The Fiscal Year (FY) 2024 AMR was held in Arlington, Virginia, May 6–9, 2024. All AMR presentations are available online to the public in the 2024 AMR Proceedings.[i]

The AMR provided an overview of the entire DOE Hydrogen Program (the Program), which includes activities across multiple DOE offices, including the Office of Energy Efficiency and Renewable Energy (EERE), Office of Fossil Energy and Carbon Management (FECM), Office of Nuclear Energy (NE), Office of Electricity (OE), Office of Science (SC), Loan Programs Office (LPO), Office of Manufacturing and Energy Supply Chains (MESC), Office of Clean Energy Demonstrations (OCED), and the Advanced Research Projects Agency–Energy (ARPA-E). In addition, the AMR highlighted relevant activities across other federal and state agencies involved in the field of hydrogen and fuel cells. Twenty Program reviewers provided comments and scores on progress toward Program goals; these results are presented in Appendix A.

The AMR technical session included tracks on each of HFTO's subprograms: Hydrogen Production Technologies; Hydrogen Infrastructure Technologies; Fuel Cell Technologies; Systems Development and Integration; and Analysis, Codes and Standards. Detailed evaluations of 106 HFTO-funded projects were completed by 134 peer reviewers. These reviews make up the body of this report.

DOE uses the results of this merit review and peer evaluation to help shape priorities and plans for upcoming fiscal years, improve project performance, and guide ongoing improvements to the overall Program strategy.

The goals of the AMR include the following:

- Review and evaluate FY 2024 accomplishments and plans for HFTO subprograms, and rigorously and systematically track progress against targets and metrics.
- Provide an opportunity for input from stakeholders* to help shape the Program so it addresses the highest-priority barriers, facilitates technology transfer and market impact, continually improves its effectiveness and efficiency in making progress toward national goals, and ensures benefits are maximized, including for all communities affected by hydrogen and fuel cell research, development, demonstration, and deployment (RDD&D) activities (especially communities that have been disproportionately burdened by the energy practices of the past).
- Foster interactions among national laboratories, industry, and universities conducting RDD&D activities, as well as federal and state agencies, to enhance collaboration and coordination and leverage resources and talents.
- Provide opportunities for early career development in science, technology, engineering, and mathematics (STEM) fields through exposure to cutting-edge DOE-funded research, as well as strengthen diversity, equity, inclusion, and accessibility and engagement within the energy and environmental justice community.
- Provide transparency regarding the use and impact of taxpayer funding, including specific outcomes from that funding, such as innovations; patents; commercialized or near-commercial technologies; and progress in manufacturing, safety, codes and standards, workforce development, and other key enabling activities.

* The Program considers "stakeholders" here in the broadest sense, including component and system developers and manufacturers, integrators, end users, and all other communities and groups that may be affected by hydrogen and fuel cell projects and installations.

Organization of the Report

This report introduction provides a brief overview of the Program, including highlighted 2024 accomplishments and high-level activities and accomplishments within each Program office. This section also includes a discussion of the peer review process and analysis methodology.

Following the introduction are the detailed peer review results. The HFTO project peer review results are grouped into five subprograms, as follows:

- **Hydrogen Production Technologies**
  - Production
  - Production–HydroGEN Seedling
- **Hydrogen Infrastructure Technologies**
  - Hydrogen Infrastructure
  - Hydrogen Storage
- **Fuel Cell Technologies**
- **Systems Development and Integration**
- **Analysis, Codes and Standards**
  - Systems Analysis
  - Safety, Codes and Standards.

Each of these sections begins with a brief subprogram overview, including summaries of key activities in 2024, goals, milestones, and budget. The subprogram overviews are followed by individual reports for projects reviewed during the 2024 AMR. These reports include brief summaries and review results, including the scores and qualitative comments for each project.

The main body of the report is supplemented by five appendices:

- **Appendix A:** AMR Program reviewers' comments and scores on the overall DOE Hydrogen Program
- **Appendix B**: List of the meeting participants
- **Appendix C:** Evaluation criteria used for the Program and project reviews
- **Appendix D**: List of projects that were presented at the AMR but not reviewed, including those funded by other DOE offices or external stakeholders
- **Appendix E:** List of the Program's funding opportunity announcements and project selections since the 2023 AMR Report.

Overview of the Hydrogen Program

The Program provides funding and strategic direction for RDD&D activities to advance the production, transport, storage, and use of clean hydrogen across numerous applications and multiple sectors of the economy. These activities are authorized by Title VIII of the Energy Policy Act of 2005[ii] and the Energy Act of 2020.[iii] As the Program's lead office, HFTO coordinates hydrogen activities across EERE, FECM, NE, OE, SC, LPO, MESC, OCED, and ARPA-E. The Program's participating offices pursue a broad range of hydrogen-related activities, guided by input from several rigorous processes in addition to the AMR, including technical, economic, and environmental analyses; stakeholder workshops; requests for information; and others. Most of the Program's individual projects are selected through competitive, merit-based funding opportunities. In addition, a growing network of stakeholders helps inform the Program's strategy and direction; this community includes industry representatives across applications and sectors, state and regional organizations, other federal agencies, environmental justice communities, and the Program's international counterparts.

Program activities are aligned with the *U.S. National Clean Hydrogen Strategy and Roadmap,*[iv] which was released in 2023. They span the full range of RDD&D to reduce the cost and improve the performance and durability of hydrogen technologies, while also enabling scale-up of clean hydrogen production. Progress in these areas is key to

jump-starting markets for clean hydrogen, including heavy-duty transportation applications, decarbonized industrial and chemical processes, and long-duration energy storage.

In FY 2024, Congress appropriated a total of $393.9 million for DOE hydrogen and fuel cell activities (see Table 1, which shows the funding published in the FY 2025 congressional budget request[v]). This funding includes $203.6 million for EERE activities and $122 million for FECM activities. Funding for hydrogen and fuel cell activities in NE and SC amounted to $23 million and $45.3 million, respectively, with additional hydrogen-related funding within ARPA-E to be determined pending end-of-year project selections.

The Infrastructure Investment and Jobs Act (also known as the Bipartisan Infrastructure Law, or BIL), signed into law in November 2021, also includes $9.5 billion over five years for clean hydrogen.[vi] Of this funding, $8 billion is for regional clean hydrogen hubs; $1 billion for electrolysis research, development, and demonstration (RD&D); and $500 million for clean hydrogen technology manufacturing and recycling RD&D.

Table 1. Hydrogen-Focused Funding Across DOE ($ in millions)

DOE Office / Program	FY 2023 (enacted)	FY 2024 (enacted)	FY 2025 (requested)
Energy Efficiency and Renewable Energy	**$216.2**	**$203.6**	**$210.1**
Hydrogen and Fuel Cell Technologies Office	$170.0	$170.0	$170.0
Advanced Materials and Manufacturing Office	$25.0	$25.0	$0.0
Industrial Efficiency and Decarbonization Office	$0.0	$0.0	$25.0
Solar Energy Technologies Office	$7.5	$7.5	$3.5
Vehicle Technologies Office	$10.0	$0.0	$10.5
Water Power Technologies Office	$2.6	$0.0	$0.0
Wind Energy Technologies Office	$1.1	$1.1	$1.1
Fossil Energy and Carbon Management	**$122.0**	**$122.0**	**$110.4**
Energy Asset Transformation	$1.0	$1.0	$1.0
Hydrogen with Carbon Management	$95.0	$95.0	$85.0
Natural Gas Decarbonization and Hydrogen Technologies	$26.0	$26.0	$24.4
Nuclear Energy	**$23.0**	**$23.0**	**$6.0**
Integrated Energy Systems	$12.0	$12.0	$5.0
Light Water Reactor Sustainability	$11.0	$11.0	$1.0
Science	**$50.3**	**$45.3**	**$50.7**
Advanced Research Program Agency–Energy	**$20.0**	**TBD[a]**	**TBD[a]**
TOTAL	**$431.5**	**$393.9**	**$377.2**

[a] ARPA-E funding is determined annually based on programs developed through office and stakeholder priorities. Therefore, funding for FY 2024 and 2025 is not available in the FY 2025 congressional budget request.

Background: National Clean Hydrogen Strategy and H2@Scale

Released in 2023, the *U.S. National Clean Hydrogen Strategy and Roadmap* is a comprehensive national framework for accelerating large-scale production, processing, delivery, storage, and use of clean hydrogen to help meet bold goals for energy innovation, resilience, and stability across virtually all sectors of the economy. The *Strategy and Roadmap* was informed by extensive stakeholder feedback, and the document will be updated at least every three years, as required by the BIL. The *Strategy and Roadmap* provides a snapshot of hydrogen production, transport, storage, and use in the United States today and examines future demand scenarios—with strategic opportunities to expand domestic production of clean hydrogen to 10 million metric tonnes (MMT) annually by 2030, 20 MMT annually by 2040, and 50 MMT annually by 2050. The *Strategy and Roadmap* prioritizes three key strategies to ensure that clean hydrogen is developed and adopted as an effective decarbonization tool—see Figure 1.

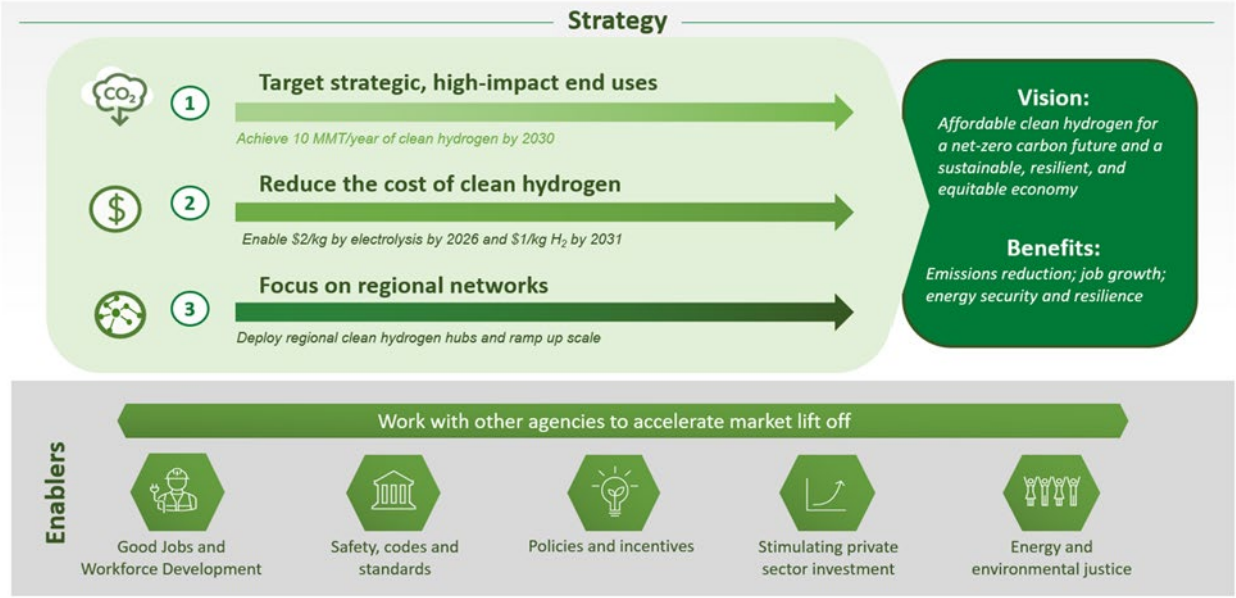
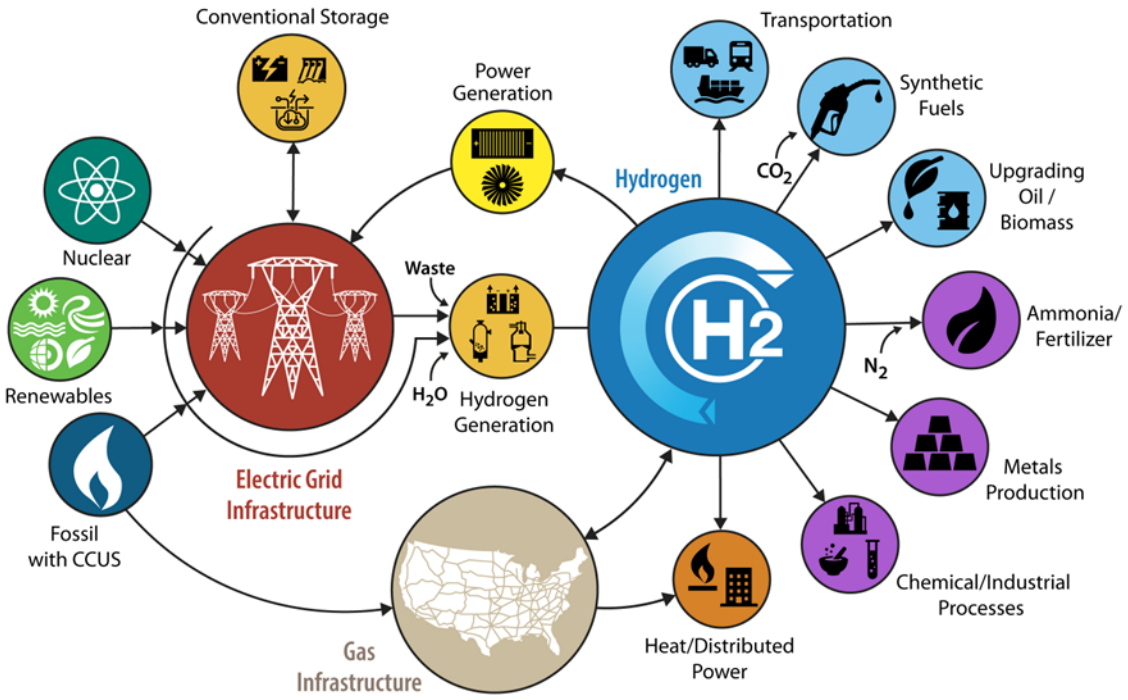


Figure 1. Strategies and key enablers for realizing the clean hydrogen vision

Federal agencies—in partnership with state, local, and tribal governments and other stakeholders—are taking action to develop and deploy technologies to ensure a sustainable, resilient, and equitable clean hydrogen economy.

The national strategy described above builds upon the DOE H2@Scale initiative, which provided an overarching vision for how hydrogen can enable clean energy pathways across applications and sectors in an increasingly interconnected energy system, as shown in Figure 2. More details are provided on the H2@Scale webpage.[vii]



CCUS = carbon capture, utilization, and storage

Figure 2. Schematic of H2@Scale

Program Highlights

Over the last year, the Program accelerated its efforts in all areas, as demonstrated by key highlights and accomplishments below.

Actions in Response to the Bipartisan Infrastructure Law

The BIL provides $9.5 billion in funding over five years for regional clean hydrogen hubs, electrolysis RD&D, and clean hydrogen manufacturing and recycling RD&D. Below are relevant Program actions related to the BIL provisions in 2024.

- **Regional Clean Hydrogen Hubs:** In FY 2024, OCED allocated $131.7 million in funding for five of the regional clean hydrogen hubs (H2Hubs) to begin Phase 1. Announced by DOE in October 2023, seven H2Hubs will receive $7 billion in funding authorized by the BIL.[viii] Managed by OCED, the selected H2Hubs span the nation and will accelerate the commercial-scale deployment of low-cost clean hydrogen technologies.
- **Hydrogen Demand-Side Initiative:** In January 2024, OCED announced the selection of a consortium to help develop robust demand-side support measures to facilitate purchases of clean hydrogen produced by the H2Hubs.[ix] This initiative will help bridge the gap between producers and end users to enhance the early commercial viability of the H2Hubs and de-risk long-term investments. The consortium consists of the EFI Foundation, a leader in clean hydrogen economy development, in partnership with the commodity markets information experts S&P Global and the financial exchange operator Intercontinental Exchange.
- **Electrolysis and Clean Hydrogen Manufacturing and Recycling Programs:** In March 2024, DOE announced the selection of 52 projects across 24 states to receive $750 million to conduct RD&D to advance electrolysis technologies and improve manufacturing and recycling capabilities for clean hydrogen systems and components. These efforts will help to drive down costs and build the domestic supplier base, providing support for DOE H2Hubs and other large-scale deployments.[x] The selected projects include a

first-of-its-kind consortium, H_2CIRC, to develop domestic capabilities for recovery and recycling of electrolyzers and fuel cells.

- **Roll-to-Roll (R2R) Consortium:** In March 2024, HFTO announced a renewed Roll-to-Roll (R2R) Consortium of national laboratories to advance efficient, high-throughput, and high-quality manufacturing processes to accelerate domestic manufacturing and reduce the cost of durable, high-performance fuel cell and electrolyzer systems.[xi] The R2R Consortium was originally launched as a manufacturing consortium in 2016 by the DOE Advanced Manufacturing Office in response to feedback from industry stakeholders seeking broad collaboration on a range of clean energy technologies. Now, through BIL funds, R2R will focus exclusively on clean hydrogen technologies.
- **Manufacture of Advanced Key Energy Infrastructure Technologies (MAKE IT) Prize:** In April 2024, the DOE Office of Technology Transitions awarded a total of $5 million to 21 Phase 1 winners of the MAKE IT Prize[xii] to accelerate the development of clean energy manufacturing facilities and strategies. The Phase 1 winners included several clean hydrogen projects related to electrolyzer manufacturing, fuel cell engine manufacturing, components for fuel cell trucks, conformable hydrogen tanks, and hydrogen storage vessels.

Hydrogen Shot and Related Developments

Since the launch of the Hydrogen Shot in June 2021, the Program has ramped up efforts to meet the aggressive goal of $1 per kilogram of clean hydrogen in one decade. The Program has implemented several actions and initiatives focused on the Hydrogen Shot in the last year.

- In December 2024, HFTO released the ***Hydrogen Shot: Water Electrolysis Technology Assessment*** report.[xiii] The report presents a thorough assessment of key electrolysis technologies, including technology status and potential approaches for realizing the significant cost reductions needed to achieve the Hydrogen Shot goal. It is the second of three assessments of clean-hydrogen production pathways.
- In June 2024, FECM announced six projects selected to receive approximately **$9.3 million to develop advanced hydrogen systems that convert varied waste feedstock materials into clean energy** with superior environmental performance.[xiv] Since January 2021, FECM has committed an estimated $138 million in projects that support the DOE Hydrogen Shot initiative by exploring new, clean methods to produce hydrogen and improve the performance of hydrogen-fueled turbines.
- The **Hydrogen Shot Incubator Prize**[xv] is a $2.6 million competition to foster innovative concepts for producing clean hydrogen. In April 2024, DOE announced four phase-two winners of the Hydrogen Shot Incubator Prize competition.[xvi] In this phase (*Prove!*), the winning teams each received $400,000—$100,000 in cash and $300,000 in vouchers to spend at national laboratories—to support their demonstration efforts in preparation for the final stage in 2025 (*Pitch!*), in which competing teams will present their innovations to potential investors and commercial partners.
- The **Hydrogen Shot Fellowship**[xvii] recruits diverse talent to make the Hydrogen Shot a reality. Funded through HFTO, Hydrogen Shot fellows engage in related work from one or more HFTO technical subprograms—including Hydrogen Production Technologies, Hydrogen Infrastructure Technologies, Fuel Cell Technologies, Systems Development and Integration, and Analysis, Codes and Standards—as well as other functional areas including communications, workforce development, and stakeholder engagement and inclusion. The application period is currently open until all positions are filled.

Inflation Reduction Act

The Inflation Reduction Act[xviii] (IRA), signed into law in August 2022**,** includes several incentives for hydrogen and fuel cell technologies, including the Clean Hydrogen Production Tax Credit, which will provide credits of up to $3/kg of clean hydrogen based on the carbon intensity of production. The U.S. Department of the Treasury coordinated with DOE and the U.S. Environmental Protection Agency on the tax credit and issued a notice of proposed rulemaking in December 2023.[xix] Treasury issued a supplemental notice of proposed rulemaking in April 2024 to invite comment on the information collection proposed for the Emissions Value Request Process. In September 2024, DOE opened its Emissions Value Request Process in support of Treasury's implementation of the tax credit.[xx] In the process, taxpayers whose hydrogen production technology and/or feedstock is not included in the most recent version of the 45VH2-GREET model[xxi] can use the Emissions Value Request Process to request an emissions value from DOE.

In March 2024, DOE released details for 35 projects across 20 states that received allocations of the Qualifying Advanced Energy Project Credit (48C).[xxii] The 48C program, which was established by the American Recovery and Reinvestment Act of 2009 and expanded with a $10 billion investment under the IRA, provides an investment tax credit of up to 30% of qualified investments for certified qualifying advanced energy projects that meet prevailing wage and apprenticeship requirements. The 48C projects self-disclosed by applicants include more than $300 million in credits for seven hydrogen-related electrolyzer and fuel cell projects.[xxiii]

Funding for Hydrogen and Fuel Cell RD&D

The Program employs a comprehensive portfolio of tools to spur innovation across all aspects of the hydrogen value chain and through the entire life cycle of emerging technologies. **S**ince the publication of the 2023 AMR report, DOE has announced more than $1.5 billion in available funding to support hydrogen and fuel cell topics. In calendar year 2024, DOE selected projects to receive funding totaling more than $1.75 billion for hydrogen-related RDD&D and issued a $1.6 billion conditional loan guarantee. This funding has come from offices across DOE: HFTO, FECM, NE, SC, LPO, MESC, OCED, ARPA-E, the Office of Technology Transitions, the Joint Office of Energy and Transportation, and the EERE offices of Industrial Efficiency and Decarbonization, Solar Energy Technologies, and Vehicle Technologies. Appendix E provides more details on these funding opportunities and the projects selected through them.

Reports, Program Records, and Tools

- **Reports and Publications:** The following reports and publications were also released or updated in 2024:
  - The updated *Department of Energy Hydrogen Program Plan*—released in December 2024—identifies and articulates strategic, high-impact areas of RDD&D focus across the Program.[xxiv] This updated version of the *Hydrogen Program Plan* explains how DOE offices work collaboratively to efficiently implement the broader strategies outlined in the *U.S. National Clean Hydrogen Strategy and Roadmap*. The plan also includes updated supporting data and analysis, a description of the H2Hubs, information about ambitious DOE-wide goals established through the Hydrogen Shot, and examples of DOE-wide efforts to establish a strong workforce, maximize technology efficiency, and accelerate innovation in the transition to a hydrogen economy.
  - A series of transportation modal action plans[xxv]—released by EERE in December 2024—address challenges and present opportunities to dramatically reduce emissions across the rail, maritime, light-duty vehicle, medium- and heavy-duty vehicle, aviation, and off-road vehicle sectors, while improving U.S. competitiveness in a rapidly changing transportation sector. These action plans build on the *U.S. National Blueprint for Transportation Decarbonization* released in 2023, which provided a roadmap for innovative transportation fueling and vehicle technologies, including hydrogen and fuel cells, across every mode of transportation.
  - The *HFTO Multi-Year Program Plan (MYPP)*[xxvi]—released in May 2024—sets forth HFTO's mission, goals, and strategic approach relative to broader DOE clean energy priorities. Aligned with the priorities in the *U.S. National Clean Hydrogen Strategy and Roadmap*, the *MYPP* identifies the challenges that must be overcome to realize the full potential of clean hydrogen and fuel cells and explains how HFTO's RD&D activities will help to overcome those challenges in the near, mid, and longer term.
  - *Alaska Hydrogen Opportunities Report*[xxvii]—released in 2024 by the Alaska Hydrogen Working Group and supported by the DOE Arctic Energy Office and the Alaska Center for Energy and Power—explores the hydrogen economy in Alaska and establishes understanding of Alaska's hydrogen-related resources. The report also outlines key opportunities to develop workforce programs, policy and regulatory frameworks, future research, and more.
- **Program Records:** The Program develops and publishes records to document key numbers, facts, and calculation methods that are often cited or referenced by the Program's plans, reports, webpages, announcements, speeches, presentations, and news releases. Four new Program records have been published since the 2023 AMR:
  - Heavy-Duty Fuel Cell System Cost–2023
  - Clean Hydrogen Production Cost Scenarios with PEM [proton exchange membrane] Electrolyzer Technology

  - Electrolyzer Installations in the United States
  - Hydrogen Liquefaction Capacity in the United States.
- The full library of Program records (published since 2005) is available on the Program website.[xxviii]

Workshops

The research community, government, and the private sector continue to convene in various workshops to identify gaps in RDD&D, determine next steps to enable large-scale hydrogen use, and inform the planning and design of Program responses to BIL provisions. A complete list of all workshops held by HFTO, including links to the proceedings of each workshop, can be found on the HFTO website.[†]

Interagency Collaboration

Launched in August 2023, the **Hydrogen Interagency Task Force** (HIT)[xxix] is a collaboration among U.S. federal agencies to further advance a whole-of-government approach to executing the national clean hydrogen strategy, including development of a robust market supported by domestic supply chains and sustainable jobs. Activities are conducted under staff-level working groups, which include Supply and Demand at Scale; Infrastructure, Siting, and Permitting; and Analysis and Global Competitiveness, along with other crosscutting teams.

The HIT aims to provide a single portal for information reflecting the expertise of multiple federal agencies. In October 2024, the HIT released two plain-language information resources[xxx] for the public to expand understanding of hydrogen and its potential role in a future clean, affordable, resilient, and equitable economy. "Introduction to Clean Hydrogen" is a two-page primer on clean hydrogen, and "Responses to Frequently Asked Questions and Common Concerns About Clean Hydrogen" is an online resource that provides an opportunity for readers to dive deeper into important questions about clean hydrogen—as identified through extensive stakeholder feedback.

The following are selected examples of progress and accomplishments from other HIT member agencies in 2024:

- The U.S. Small Business Administration opened loan programs for clean energy projects—including the clean hydrogen industry—to new green lenders to help small businesses advance the clean energy economy.[xxxi]
- The U.S. Pipeline and Hazardous Materials Safety Administration (PHMSA), an agency within the U.S. Department of Transportation, joined the Center for Hydrogen Safety as a strategic partner.[xxxii] PHMSA is the second federal agency to join the Center, following DOE, and adds technical and policy expertise to support the Center's mission of promoting hydrogen safety and best practices worldwide.
- The U.S. Environmental Protection Agency (EPA) announced 55 grants for a total of nearly $3 billion from the Clean Ports Program, funded through the IRA. Six port authorities will receive $475 million in EPA funding to expand the use of hydrogen-based equipment and technologies in port operations.[xxxiii]
- The U.S. Department of Transportation's Federal Railroad Administration announced more than $2.4 billion in BIL funding for 122 rail improvement projects in 41 states and Washington, D.C. The funded activities include three projects in California, Colorado, and Pennsylvania to support deployment of hydrogen-related transportation technologies and applications.[xxxiv]

International Collaboration

HFTO leads the Program in engaging with hydrogen and fuel cell efforts around the world through a range of multilateral and bilateral partnerships. A key priority is to sustain a coordinated framework for international engagement that will accelerate technical and market progress by leveraging complementary activities to focus on gaps and avoid duplication of efforts. The Program continues to take a leadership role in this area by co-leading the **Hydrogen Breakthrough** (along with counterparts from the United Kingdom and India). The Hydrogen

[†] For more information on these and other HFTO workshops, see https://www.energy.gov/eere/fuelcells/workshop-and-meeting-proceedings.

Breakthrough, one of the initiatives of the Breakthrough Agenda,‡ aims to strengthen international collaboration in specific areas to accelerate progress toward the goal of making "affordable renewable and low-carbon hydrogen globally available by 2030."

The Hydrogen Breakthrough currently focuses on five priority-action areas: *Standards and Certification ("H.1"),* which aims to accelerate delivery of a coordinated portfolio of international standards and certification solutions for clean hydrogen.; *Demand Creation and Management ("H.2")*, which aims to strengthen demand for clean hydrogen through coordinated commitments and policies that accelerate deployment in existing and new priority application sectors; *Research and Innovation ("H.3")*, which aims to increase global clean hydrogen research and demonstration projects across diverse sectors and regions, with mechanisms to share learnings rapidly; *Finance and Investment ("H.4")*, which aims to strengthen international assistance for clean hydrogen projects by identifying financing opportunities and de-risking mechanisms, along with supporting programs to mobilize catalytic funding in emerging markets and developing economies; and *Landscape Coordination ("H.5")*, which aims to improve coordination among international initiatives to enhance global efforts and foster alignment.

The Program continues to engage with a number of multilateral organizations and initiatives, including the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE); the Clean Energy Ministerial Hydrogen Initiative (CEM H2I); Mission Innovation's Clean Hydrogen Mission; the International Renewable Energy Agency's Collaborative Framework on Green Hydrogen; the International Energy Agency's (IEA's) Hydrogen Technology Collaboration Program (TCP) and Advanced Fuel Cells TCP; and the Center for Hydrogen Safety.

Examples of notable international activities in 2024 include:

- **Announcing the winners of the CEM H2I H2 Twin Cities program:** The 2023–2024 H2 Twin Cities round focused on mentor–mentee pairings—uniting cities at significantly different levels of hydrogen implementation to enable effective knowledge transfer and facilitate the relationships needed to establish global hydrogen infrastructure and technology adoption. HFTO, in collaboration with CEM H2I, announced the winners from this round at the Hydrogen America 2024 Summit and Exhibition. Winners included regions in the United States, Mexico, and Colombia.
- **Hosting the first CEM H2I H2 Twin Cities showcase webinar:** HFTO, in collaboration with CEM H2I, held the first public webinar to highlight the value of H2 Twin Cities to the global hydrogen community and to showcase projects by all H2 Twin Cities teams, which represent regions in the United States, Japan, United Kingdom, Mexico, and Colombia.
- **Publishing a 101 hydrogen certification paper:** As an active member in the IPHE and the IEA's TCP, HFTO provided technical input to this paper, which provides clarity on the terminology used in hydrogen certification. The paper aligns with the Hydrogen Breakthrough Agenda's H.1 priority, focusing on standards and certification.
- **Publishing a report on international hydrogen certification mechanisms:** HFTO also provided technical input into the IPHE report *Comparison of Hydrogen Certification Mechanisms*, which examines 17 certification schemes at global scale, addressing hydrogen and its derivatives. It presents the methodology and results and introduces recommendations from the IPHE Hydrogen Certification Mechanisms Task Force. These efforts, along with IPHE's ongoing engagement with ISO to enable international standards, are laying essential groundwork to enable global trade of clean hydrogen. DOE's active engagement ensures a strong U.S. voice helping to guide the evolution of this emerging global market.

Workforce Development; Diversity, Equity, Inclusion, and Accessibility; and Environmental Justice

The Program continued its efforts to address workforce needs and improve diversity, equity, inclusion, accessibility, and environmental justice through various outreach efforts, initiatives, and funding opportunities. In addition to

‡ The Breakthrough Agenda (https://climatechampions.unfccc.int/breakthrough-agenda/) is a commitment made by countries to make clean technology solutions the most affordable, accessible, and attractive option in each emitting sector, by the end of this decade.

ongoing workforce development programs and deployment programs that benefit disadvantaged communities, the Program's efforts in 2024 include the following:

- **Historically Black Colleges and Universities (HBCU) Clean Energy Education Prize:** In February 2024, DOE announced the first 10 prize winners in the inaugural HBCU Clean Energy Education Prize Partnerships Track.[xxxv] Each team will receive $100,000 to support partnerships to build new clean energy programs at HBCUs and provide professional opportunities for students.
- **EnergyTech University Prize:** In March 2024, the student team ECHO Solutions from the University of Houston was selected as the HFTO Bonus Prize finalist in the Office of Technology Transitions' EnergyTech University Prize (EnergyTech UP) competition.[xxxvi] This competition challenged collegiate student teams to develop and present a business plan that leverages national-laboratory-developed or other emerging energy technologies. The ECHO Solutions team was awarded $3,000 and went on to compete alongside 27 other student teams in the EnergyTech UP National Pitch Event in April, where the team was awarded an additional $22,000 bonus prize from HFTO for its outstanding commercialization plans around hydrogen adoption.
- **Clean Hydrogen and Environmental Justice Web Resource:** In June, HFTO launched a new web resource, "Clean Hydrogen and Environmental Justice," underscoring the DOE commitment to a just and equitable clean energy transition benefitting all communities.[xxxvii] The new webpage and related links provide a centralized resource that serves both to present DOE and HFTO environmental justice work externally and to solicit input from stakeholders.
- **Hydrogen and Community Benefits Public Forums:** DOE has developed materials for two public forums[xxxviii]—"Harnessing Hydrogen" and "Community Benefits Planning"—to use for engaging communities, civic organizations, educators, and businesses in deliberative and structured public conversations about clean hydrogen deployments. These forums are based on open-source materials available free of charge for anyone to use. In April 2024, DOE hosted a forum-based training session at the Boston Museum of Science titled Harnessing Hydrogen for a Just Transition.[xxxix] This full-day event convened nearly 100 participants interested in building stronger engagement platforms with local communities affected by clean energy deployments.
- **HFTO Postdoctoral Recognition Award:** This award recognizes outstanding postdoctoral fellows working to advance hydrogen and fuel cell technologies at DOE national laboratories. DOE announced the 2024 winner of this award during the AMR.[xl] The current round of this award is in progress and will be announced in 2025.
- **Webinars:** HFTO conducts a monthly webinar series, covering a variety of hydrogen-related topics.[xli] In 2024, the following webinars were focused specifically on environmental justice or workforce development topics: "H2IQ Hour: H2EDGE Workforce Development," "H2IQ Hour: Hydrogen and Community Benefits Public Forums," and "H2IQ Hour: Spotlight on Los Alamos," which highlighted a research collaboration between Los Alamos National Laboratory and Navajo Technical University. HFTO also hosted a special webinar to provide a "live look-in" at a public forum on hydrogen.

Office Overviews and Updates

Hydrogen and Fuel Cell Technologies Office in Collaboration with Relevant Offices in the Office of Energy Efficiency and Renewable Energy

HFTO pursues a broad portfolio of activities to overcome the technological, economic, and institutional barriers to the large-scale adoption of hydrogen and fuel cell technologies. These activities address all aspects of the hydrogen value chain and span many stages of current and emerging technologies.

HFTO leverages other activities across relevant EERE offices that play a role in advancing hydrogen and fuel cell technologies, including the offices of Advanced Materials and Manufacturing Technologies, Bioenergy Technologies, Building Technologies, Geothermal Technologies, Industrial Efficiency and Decarbonization, Solar Energy Technologies, Vehicle Technologies, Water Power Technologies, and Wind Energy Technologies.

HFTO is responsible for coordinating the RDD&D activities for the Program and works in close partnership with multiple offices at DOE, as well as other federal agencies, industry, academia, and national laboratories, to:

- Conduct RD&D to advance clean hydrogen and fuel cell technologies.
- Develop and integrate complete operational hydrogen and fuel cell systems.
- Demonstrate and validate hydrogen and fuel cell systems in real-world conditions and conduct commercial readiness assessments to inform and guide RD&D efforts.
- Support the development of manufacturing technologies and processes, supply chains, and the workforce to enable industry to achieve scale and associated cost reductions.
- Address safety issues and facilitate development of codes and standards.
- Conduct crosscutting analyses of hydrogen and fuel cell technologies and markets to help guide RD&D and deployment priorities.

HFTO coordinates with:

- FECM on various topics including reversible solid oxide fuel cells and carbon-negative hydrogen production.
- NE and OE on integrating renewables into the grid using hydrogen as an energy storage medium.
- FECM and ARPA-E on hydrogen sensing.
- SC and ARPA-E on basic science and next-generation technologies.

In addition to working closely with the Program's participating offices, HFTO actively coordinates with other crosscutting and partner DOE offices such as the Offices of Technology Transitions, Policy, Energy Justice and Equity, International Affairs, Arctic Energy, and others. For example, HFTO chairs the DOE-wide Hydrogen Joint Strategy Team, with OCED serving as vice chair, to ensure strong coordination across the spectrum of activities from basic research through deployment.

In August 2024, HFTO announced $62 million for new projects to accelerate RDD&D of next-generation clean hydrogen technologies to advance the national clean hydrogen strategy and build a strong domestic clean hydrogen industry.[xlii] The projects, located across 15 states, will advance critical elements of hydrogen fueling infrastructure; develop and demonstrate hydrogen-powered container-handling equipment for use at ports; and improve processes essential to the efficient, timely, and equitable deployment of hydrogen technologies, including first-of-a-kind efforts to improve community engagement.

Highlights of key HFTO RDD&D accomplishments and progress are shown in Table 2. A brief overview of each subprogram is provided in its respective chapter.

Table 2. Selected Examples of HFTO Progress and Accomplishments – 2024

Hydrogen Production Technologies

- ✓ Developed a new roll-to-roll-processable, thinner commercial PEM with a gas recombination layer that enables meeting DOE 2026 PEM water electrolysis performance targets. (Chemours)
- ✓ Developed a microporous transport layer for PEM electrolyzers that provides a uniform interface to the catalyst and membrane, enabling a 50% reduction in iridium catalyst loading versus baseline membrane electrode assembly loadings of 2 mg/cm^2. (Nel Hydrogen)
- ✓ Developed a single-piece anode support structure for PEM electrolyzers that enables a significant decrease in the time to coat a megawatt-size area while maintaining performance and durability. (Plug Power)
- ✓ Used a comprehensive multi-lab research approach involving in-cell studies, electrochemical half cells, modeling, and advanced characterization to advance fundamental understanding of iridium dissolution mechanisms and quantify its impact on cell degradation in PEM electrolyzers, providing substantial value to the PEM electrolyzer community. (H2NEW)
- ✓ Identified stable N-terminated GaN photoabsorbers for photoelectrochemical hydrogen production resulting in 3,000-hour operation of two-electrode configurations with no discernible performance degradation. (University of Michigan)
- ✓ Used a newly developed and trained machine-learning model with significantly increased materials screening speed to identify and synthesize 10 novel compounds of interest for thermochemical hydrogen production, resulting in the discovery and validation of two new water-splitting materials, setting the starting point for 2nd-generation model screening and testing efforts. (HydroGEN)
- ✓ Launched the national-lab-led R2R Consortium to advance efficient, high-throughput, and high-quality manufacturing processes for PEM electrolyzers and fuel cells. (in collaboration with the Fuel Cell Technologies subprogram)
- ✓ Launched the pilot H2LinkSc program to enable improved connections between applied electrolyzer research and development (R&D) and basic science efforts. (LLNL, INL, PNNL)
- ✓ Held a Hydrogen Shot Advanced Pathways Technical Experts Meeting in conjunction with the Office of Science, covering photoelectrochemical, thermochemical, and biological hydrogen production pathways—to discuss knowledge gaps and address applied science/engineering needs to accelerate progress.

Hydrogen Infrastructure Technologies

Hydrogen Storage

- ✓ Installed and commissioned a new metal hydride storage system to demonstrate and validate the performance and techno-economics of bulk materials-based hydrogen storage at the megawatt scale. (GKN Hydrogen, NREL)
- ✓ Issued a request for proposals for an engineered subsurface bulk hydrogen storage demonstration at NREL's Flatirons Campus that will store 10 metric tons of hydrogen to support at-scale demonstrations of clean hydrogen production and end uses. (NREL)
- ✓ Designed and fabricated a first-of-its-kind affordable tank for large-scale liquid hydrogen storage, which will be installed and demonstrated at NASA's Marshall Space Flight Center. (Shell, CB&I, NASA)
- ✓ Began construction of a pilot plant to demonstrate a cost-effective, high-performance end-to-end (production, distribution, and dispensing) clean liquid hydrogen carrier supply chain using formic acid as the liquid hydrogen carrier. (OCOchem Inc., PNNL)
- ✓ Designed and built a scaled-up reactor, process, and control system to demonstrate 25 kg/day production of fuel-cell-grade hydrogen using renewable dimethyl ether as a hydrogen carrier. (LANL, Oberon Fuels, Inc.)
- ✓ Produced >100 m of continuous carbon fiber with a tensile strength >750 ksi and tensile modulus >35 Msi, with a projected carbon fiber cost of $15–$20/kg and a projected tank cost of $12.8/kWh. (Hexagon, Cytec, ORNL, PNNL)
- ✓ Launched Bridge-to-Graduate School and Bridge-to-Career Programs with first-in-the-nation models for underrepresented/minoritized (URM) groups, funded summer internships for URM students, and hosted HyMARC's first visiting faculty member from a primarily undergraduate institute. (HyMARC, Metropolitan State University Denver)

Hydrogen Infrastructure

- ✓ Identified material design strategies to reduce the expansion of seals in hydrogen by 70% and prolong the life of storage vessels by 50% through improved understanding of crack nucleation. (H-Mat)
- ✓ Developed accelerated fatigue crack growth test method in gaseous hydrogen and submitted to the ANSI/CSA CHMC 1-2014 subcommittee for consideration as a proposed update to the testing standard. (Hy-Performance, H-Mat seedling project)
- ✓ Released HELPR, a pipeline structural integrity tool used to better evaluate the structural risk of hydrogen and hydrogen/natural gas blends on existing pipeline infrastructure. (HyBlend)
- ✓ Formulated pressure-dependent hydrogen-assisted fatigue design curves for steel pipelines and pressure vessels adopted under ASME B31.12 Code Case 220 (pipelines) and proposed revision of ASME Boiler and Pressure Vessel Code Case 2938-1 (pressure vessels) based on fatigue crack growth rate test data. (HyBlend, H-Mat)
- ✓ Developed a system to observe and characterize hydrogen swelling of polymers up to 90 MPa higher pressure than existing methods, employing digital image correlation and contour detection techniques for more accurate volume swelling measurements. (H-Mat)
- ✓ Released BlendPATH, a Python-based techno-economic analysis model that estimates the costs of upgrading natural gas pipelines to accommodate higher hydrogen concentrations (up to 50% by volume) and that can interact with a commercial pipeline network modeling tool. (HyBlend)
- ✓ Implemented and validated a heavy-duty fast-flow hydrogen fueling protocol (SAE J2601/5) in a real-world environment, completing a 70.5 kg fill in 7 minutes with preproduction heavy-duty refueling hardware and advanced wireless communications. (NREL)

Table 2. Selected Examples of HFTO Progress and Accomplishments – 2024 (cont.)

Fuel Cell Technologies

- ✓ Developed innovative catalysts for heavy-duty fuel cells with over 55% improved performance in a membrane electrode assembly compared with the commercial baseline. (M2FCT)
- ✓ Developed and published a 25,000-hour equivalent accelerated stress test to evaluate heavy-duty fuel cell catalyst durability. (M2FCT)
- ✓ Reduced the projected heavy-duty vehicle fuel cell system durability-adjusted cost to $170/kW at 50,000 systems/year versus the baseline of $196/kW.
- ✓ Improved platinum-group-metal-free cathode initial fuel cell performance, in H_2-air, by over 90% compared with the 2021 baseline. (ElectroCat)
- ✓ Selected 16 fuel cell manufacturing and recycling projects with $540 million total funding to enable 14 GW of fuel cell manufacturing and strengthen the domestic supply chain.
- ✓ Launched the national-lab-led R2R Consortium to advance efficient, high-throughput, and high-quality manufacturing processes for fuel cells and electrolyzers. (in collaboration with the Hydrogen Production Technologies subprogram)
- ✓ Launched a pilot project with Tribal colleges to strengthen national lab and Tribal collaboration on clean hydrogen manufacturing RD&D and support development of careers in clean hydrogen. (LANL)

Systems Development and Integration

- ✓ Completed prototype/demonstration vehicle builds for multiple Class 4–8 fuel cell electric trucks through SuperTruck 3. (Daimler, GM, and Ford)
- ✓ Launched a new heavy-duty fuel cell test facility to serve as a national resource for independent testing and validation of up to 600 kW PEM fuel cell systems and up to 1.2 MWh fuel cell/battery hybrid systems for ultra-heavy-duty offroad, rail, marine, and aviation applications. (ANL)
- ✓ Completed a total cost of ownership analysis for medium-duty vehicles to identify vehicles and vocations best suited for hydrogen fuel cells. (ANL)
- ✓ Initiated two new hydrogen fuel cell rail projects to demonstrate high-flow liquid hydrogen fueling for rail applications and a short-haul freight locomotive powered by hydrogen fuel cells. (Linde, South Coast Air Quality Management)
- ✓ Initiated an interagency project demonstrating fuel cells for battery electric vehicle fast charging. (DOD, DHS, GM)
- ✓ Designed, developed, integrated, and tested a 1.5 MW backup power fuel cell system at a Microsoft data center. (Caterpillar)
- ✓ Completed 20,000 hours cumulative stack/system testing on integrated high-temperature electrolysis stacks and systems at Idaho National Laboratory with minimal degradation. (INL)
- ✓ Completed commissioning of the integrated 1.25 MW electrolyzer and 1 MW fuel cell systems at the NREL Flatirons Campus to support the Advanced Research on Integrated Energy Systems (ARIES) platform. (NREL)
- ✓ Initiated commissioning of the H2@Scale integrated system demonstration at University of Texas at Austin's J.J. Pickle Research Campus, which includes multiple co-located hydrogen generation sources and end-use applications, including fueling fuel cell electric vehicles and powering the Texas Advanced Computing Center. (Frontier Energy)
- ✓ Developed a reference design and techno-economic analysis of low-carbon hydrogen pathways for decarbonizing steel and ammonia production through the GreenHEART model. (NREL)
- ✓ Initiated three new projects to demonstrate low-carbon steel production, including use of methane pyrolysis, a novel reactor using lower-grade ore, and integration of a high-temperature electrolyzer with a commercial direct-reduction-of-iron furnace. (Molten, Hertha, and University of Wisconsin)

Analysis, Codes and Standards

Systems Analysis

- ✓ Released the 45VH2-GREET model to characterize emissions associated with hydrogen production pathways in support of the Section 45V Clean Hydrogen Production Tax Credit. (ANL)
- ✓ Launched a GREET "Train the Trainer" program to increase the accessibility of the GREET model by training individuals with previous life cycle assessment experience to provide on-demand training and lead workshops in their communities. (ANL)
- ✓ Published a techno-economic analysis of the potential early market cost of clean hydrogen, characterizing cost under varying use rates and station sizes.
- ✓ Updated the Annual Technology Baseline for Transportation to include cost of driving medium- and heavy-duty trucks. (NREL, ANL)
- ✓ Completed a hydrogen sustainability assessment, including a review of existing sustainability metrics and a proposed framework for applying these metrics to hydrogen projects, to guide real-world deployments.

Safety, Codes and Standards

- ✓ Developed and demonstrated new world-class experimental capabilities at Sandia National Laboratories to release liquid hydrogen at rates rapid enough to enable pooling. These capabilities will inform future risk analysis of liquid hydrogen, relevant to international codes and standards.
- ✓ Collaborated with NOAA to model atmospheric levels of hydrogen, understand soil uptake, and inform estimates of the indirect impact of atmospheric hydrogen on global warming.
- ✓ Launched the Hydrogen Component Reliability Database (HyCReD) to collect high-quality data that will inform component R&D to improve safety, reduce failure rates and maintenance costs, and reduce hydrogen emissions.
- ✓ Completed a unique liquid hydrogen pooling experiment that will enable model development and validation to establish safety requirements for larger liquid hydrogen systems in emerging technologies. (SNL)

Table 2. Selected Examples of HFTO Progress and Accomplishments – 2024 (cont.)

Safety, Codes and Standards (cont.)

- ✓ Launched the Hydrogen Safety Codes and Standards Applicability Navigator (HySCAN), a user-friendly online tool to enable new hydrogen stakeholders to identify current codes and standards so they can move quickly and safely into the hydrogen market.
- ✓ Trained engineering professionals and university students for career opportunities in hydrogen through the Hydrogen Education for a Decarbonized Global Economy (H2EDGE) program. The program includes 16 partner and affiliate universities and has reached more than 400 university students to date.

Workforce Development and Diversity, Equity, and Inclusion

- ✓ Launched the "Clean Hydrogen and Environmental Justice" web resource to present HFTO's environmental justice work externally and to solicit input from stakeholders.
- ✓ Published "Responses to Frequently Asked Questions and Common Concerns about Clean Hydrogen" to inform stakeholder conversations about clean hydrogen in response to an initial collection of high-priority questions asked in a range of community engagements.
- ✓ Collaborated with the Office of Energy Justice and Equity to develop "Harnessing Hydrogen" and launch the forum at the Boston Museum of Science. This innovative public forum is a tool to engage with communities and improve awareness about clean hydrogen technologies and community benefits plans.

Office of Clean Energy Demonstrations

The Office of Clean Energy Demonstrations (OCED) was established to help scale the emerging technologies needed to tackle our nation's most pressing climate challenges. OCED's mission 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. OCED manages a more than $25 billion portfolio of demonstration projects that include clean hydrogen, carbon management, advanced nuclear reactors, long-duration energy storage, and other industrial decarbonization technologies.

As part of its portfolio, OCED manages the H2Hubs Program, which includes up to $7 billion to establish H2Hubs across the nation, as well as a demand-side support mechanism to help encourage early adoption of hydrogen from the H2Hubs, totaling $8 billion. Funded through the BIL, the H2Hubs will accelerate the commercial-scale deployment of clean hydrogen, helping to generate clean, dispatchable power, create a new form of energy storage, and decarbonize heavy industry and transportation. Together, the H2Hubs will kickstart a national network of clean hydrogen producers, consumers, and connective infrastructure while supporting the production, storage, delivery, and end use of clean hydrogen. The H2Hubs will also help to enable the development of diverse, domestic clean energy pathways across multiple sectors of the economy and serve as a central driver in helping communities benefit from clean energy investments, good-paying jobs, and improved energy security.

In FY 2024, OCED allocated $131.7 million in funding for five H2Hubs to begin Phase 1. Recent accomplishments include the following:

- Awarded the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES, the California Hydrogen Hub),[xliii] Appalachian Regional Clean Hydrogen Hub (ARCH2),[xliv] Pacific Northwest Hydrogen Hub (PNWH2),[xlv] Gulf Coast Hydrogen Hub,[xlvi] and Midwest Hydrogen Hub to begin Phase 1.
- Continued negotiations for the other two selected H2Hubs.
- Selected the Hydrogen Demand Initiative (H2DI) consortium to develop robust demand-side support measures to facilitate purchases of clean hydrogen produced by the H2Hubs.[xlvii]

Office of Fossil Energy and Carbon Management

In FY 2024, funding for hydrogen in FECM's **Office of Resource Sustainability** was $23 million. The Office's hydrogen efforts were focused on:

- Advancing novel, low-cost catalytic conversion processes that can further enable clean hydrogen production.
- Working to ensure the suitability of existing natural gas pipelines and infrastructure for the safe, resilient, and efficient transportation of hydrogen at scale.

- Exploring low-cost, reliable, and safe options for bulk underground hydrogen storage.

In FY 2024, funding for hydrogen in FECM's **Office of Carbon Management Technologies** was $102 million. The Office's hydrogen efforts were focused on developing:

- Advanced gasification systems for co-gasification of waste feedstocks with biomass to achieve net-zero clean hydrogen.
- Advanced turbine combustor systems for firing natural gas/H_2 blends and zero-carbon fuels (H_2, ammonia) while maintaining NO_x emissions equivalent to or lower than NO_x emissions on natural gas.
- Reversible solid oxide fuel cells for clean hydrogen production and electricity production in a single system for energy storage and back-up power applications.
- Advanced materials R&D for high-temperature hydrogen compatibility, hydrogen-fired turbines, and clean hydrogen production systems.
- Advancement of commercial readiness of clean hydrogen production by conducting site-specific front end engineering design (FEED) and pre-FEED studies for retrofit of carbon capture and storage systems to reforming and gasification industrial sites.

Table 3 shows selected examples of FECM's 2024 RDD&D progress and accomplishments.

Table 3. Selected Examples of FECM 2024 Progress and Accomplishments

Office of Resource Sustainability

Natural Gas Decarbonization and Hydrogen Technologies

- ✓ Used a catalyst patented by the National Energy Technology Laboratory to demonstrate a natural gas conversion process called catalytic methane pyrolysis, which outperformed other catalysts and achieved unprecedented kilogram-scale hydrogen production.
- ✓ Published two models that estimate the costs of building new pure hydrogen pipelines or reusing existing natural gas pipelines for transporting natural-gas–hydrogen blends.
- ✓ Hosted a workshop for the Subsurface Hydrogen Assessment, Storage, and Technology Acceleration (SHASTA) project—which was supported by multiple national labs—to connect key research and implementation stakeholders and help clarify "state of the art" for underground hydrogen storage.
- ✓ Developed a forthcoming *Multi-Year Program Plan*[xlviii] for the Natural Gas Decarbonization and Hydrogen Technologies Program, including research focused on advanced materials and sensors, natural gas conversion and clean hydrogen products, clean hydrogen system evaluation, and subsurface storage characterization and demonstration.

Office of Carbon Management Technologies

Hydrogen with Carbon Management

- ✓ Completed pre-FEED and FEED studies for repurposing the retired Wabash Valley Gasification plant to gasify petcoke and local biomass for a clean ammonia production facility. These FEED outputs, including air permits and construction permits, led to the plant's receiving conditional approval from LPO for a $1.56 billion loan to develop a commercial-scale waste-to-ammonia production facility using carbon capture and storage technology.[xlix]
- ✓ Solicited stakeholder feedback on advanced gasification through a request for information and workshop that informed the funding opportunity announcement, "Gasification of Alternative Feedstocks," released in September 2024.
- ✓ Conducted pilot-scale research on construction and demolition waste gasification, feedstock preparation, bio-oil and plastic-oil feedstock preparation, and solid waste and biomass co-feedstock preparation.
- ✓ Continued multiple existing projects to develop and test combustor systems for hydrogen and/or ammonia to determine the potential to meet NO_x emissions goals.
- ✓ Demonstrated a reversible solid oxide cell system to document performance and degradation in both hydrogen and electricity production modes.

Point Source Carbon Capture

- ✓ Awarded FEED and pre-FEED studies for carbon capture and storage system retrofits to multiple steam methane reforming and autothermal reforming hydrogen production facilities.

Office of Nuclear Energy

The Office of Nuclear Energy (NE) works to advance nuclear power to meet the nation's energy, environmental, and national security needs. RD&D objectives include enhancing the long-term viability and competitiveness of the existing U.S. reactor fleet and developing advanced nuclear reactor technologies. As part of these efforts, NE is working with partners in EERE and industry to conduct RD&D to enable commercial-scale hydrogen production using heat and electricity from nuclear energy systems. In addition to emissions-free electricity, nuclear reactors produce large amounts of heat, which can be used to improve the economics of hydrogen production.

Clean hydrogen production has been a priority in the United States for several years because of the rising interest in reducing pollutant emissions across all energy sectors. NE research focuses on integrating nuclear power plants with large-scale hydrogen production via electrolysis, offering a potential higher revenue stream for nuclear plants while enhancing U.S. energy security. Efforts are in collaboration with industry partners, including utilities, hydrogen gas suppliers, and regulatory bodies. The Office aims to support early adopters of hydrogen production, facilitating the inclusion of high-temperature steam electrolysis in near-term projects and leveraging incentives from the IRA and other federal initiatives. NE's efforts related to hydrogen production include:

- Demonstration of both high-temperature and low-temperature electrolysis systems at operating light water reactors that can provide reliable, low-cost heat and electricity necessary to produce hydrogen economically, in collaboration with EERE.
- Development of the necessary control systems to readily apportion energy and electricity based on market demand, in coordination with industry, utilities, and vendors.
- Modeling, simulation, and experimentation to develop and advance technologies needed to integrate hydrogen production methods with existing and future reactors in ways that optimize the economic performance as they operate in concert with other generation sources and grid loads.
- Development of advanced reactors that will operate at high temperatures, making them well suited for promising new thermally driven hydrogen production processes.
- Development of probabilistic risk assessments and hazards analyses for siting electrolysis units near nuclear reactors. These studies will help inform regulatory processes and reduce the time to commission and operate co-located electrolysis units.
- FEED studies to scale up electrolysis to 500 MW at nuclear plants.

In FY 2024, NE funding for hydrogen-related activities was $15 million. Recent accomplishments include the following:

- The Light Water Reactor Sustainability program issued a report, "Guidance on Near-Term Hydrogen Production using Nuclear Power." This report includes a completed set of evaluations that provide guidance for subsequent project-specific analysis to assess modifications to the nuclear power plant in consideration of multiple factors.
- Three nuclear power plant companies—Constellation, Vistra (formerly Energy Harbor), and Xcel Energy—were awarded DOE cost-shared funding to evaluate and test hydrogen production at their sites. Constellation completed its demonstration at the Nine Mile Point Plant in New York in 2024. Vistra's and Xcel Energy's projects are planned to begin in late 2025, following modifications to their plant sites to utilize electrical power and steam.
- Four of the seven H2Hubs announced in 2023 include nuclear hydrogen production. While the future implementation of hydrogen production at nuclear plants will depend on market incentives and grid operation and regulatory conditions, NE research will help utilities and U.S. industries make informed investment decisions, accelerating the early and successful installation and coordinated operation of hydrogen plants.
- Idaho National Laboratory developed and completed two valuable computational tools in 2024 for utility planners and nuclear plant owners to assist with technical and economic assessments, supporting investment decisions based on plant-specific conditions. The first tool is a market prospector tool that identifies potential industrial and transportation markets for hydrogen near each nuclear plant. The second tool allows utilities to evaluate the cost sensitivity of producing hydrogen versus continuing traditional electricity generation.

- Idaho National Laboratory and Argonne National Laboratory completed technical and economic evaluations funded by petrochemical industries interested in producing clean hydrogen using nuclear energy to produce low-carbon chemicals and fuels.

Office of Science, Basic Energy Sciences

The mission of the DOE Office of Science is to deliver scientific discoveries and major scientific tools to transform our understanding of nature and advance the energy, economic, and national security of the United States. The Basic Energy Sciences (BES) program within the Office of Science supports fundamental research addressing critical challenges, including research related to hydrogen storage, production, utilization, and conversion. These efforts, which include work conducted by the Solar Fuels Hub program and the Energy Frontier Research Centers, complement the technology-specific RD&D supported by other DOE offices and provide foundational knowledge that can bring advances to many areas of technology development.

Recent advances offer exciting new research opportunities for addressing both short-term and long-term challenges for hydrogen and related technologies. These include advances in synthesis, catalysis, modeling, artificial intelligence/machine learning, analytical instrumentation at user facilities, high-performance computing, and bio-inspired approaches. Key basic research focus areas include:

- Novel materials for hydrogen storage
- Membranes for separation
- Purification
- Ion transport
- Design of catalysts at the nanoscale
- Bio-inspired materials and processes
- Solar hydrogen production.

Recent accomplishments include the following:

- Modeled and created novel catalysts for the hydrogen evolution reaction with very low precious metal loading. Transition metal nitrides were used as a scaffold for monolayer-thick noble metals and were found to be effective at producing hydrogen molecules.
- Utilized electron paramagnetic resonance to resolve the interplay of electronic coupling and free-energy properties of an FeS cluster network in an [FeFe]-hydrogenase that is strongly biased for catalyzing the H_2 oxidation reaction.
- Demonstrated the ability to give metal catalysts a new electronic identity allowing the fine tuning of catalytic sites and making abundant metals behave like precious metals. This was accomplished by precisely controlling the electron density around the metal atoms via a so-called catalytic condenser.

Advanced Research Projects Agency–Energy

The Advanced Research Projects Agency-Energy (ARPA-E) catalyzes transformational energy technologies to enhance the economic and energy security of the United States. ARPA-E funds high-potential, high-impact projects that are at too early a development stage for private-sector investment but could disruptively advance the ways energy is generated, stored, distributed, and used. Some programs at ARPA-E seek to develop technologies involving renewable energy and natural gas, with applications in the transportation, commercial, and industrial power sectors.

In these areas, there are a number of efforts related to hydrogen. Through a Methane Pyrolysis Cohort, ARPA-E funded eight teams to make hydrogen and solid carbon through a variety of thermal and thermal/catalytic processes. Several teams have received follow-on funding from DOE, private industry, and/or venture capital to move from lab to pilot testing. In parallel, ARPA-E funded a team focused on upgrading the solid carbon co-product to make high-strength carbon fibers, such as those used in advanced hydrogen storage tanks. Revenues from selling co-product carbon could help drive hydrogen costs below the Hydrogen Shot target.

Current and upcoming activities specifically related to clean hydrogen and fuel cell technologies include:

- Pioneering Railroad, Oceanic and Plane ELectrification with 1K energy storage systems (PROPEL-1K).[l]
- H2SENSE.[li] In September 2024, ARPA-E announced $18 million for nine projects to accelerate research that supports the detection and quantification of hydrogen emissions throughout the supply chain. Projects selected under this exploratory topic will work to create a new generation of sensors to detect and quantify concentrations of hydrogen in the range of parts per billion and enable a systems-level approach to large-area monitoring of hydrogen emissions.
- Project portfolio to explore potential of geologic hydrogen.[lii] In February 2024, ARPA-E announced $20 million for 16 projects across eight states to accelerate the natural subsurface generation of hydrogen. The projects fall under two exploratory research topics:
  - Technologies that stimulate hydrogen production from mineral deposits found in the subsurface, including developing understanding of hydrogen-producing geochemical reactions and ways to enhance or control the rate of hydrogen production.
  - Technologies relevant to the extraction of geologic hydrogen, including subsurface transport methods and engineered containment, reservoir monitoring and modeling during production and extraction, and risk assessment of hydrogen reservoir development.

Introduction to the AMR Peer Review Process and Methodology

The AMR peer review process follows the guidelines in the *Peer Review Guide* developed by EERE. Project reviewers provide comments about selected HFTO-funded projects presented during the event. (Note that not all ongoing HFTO-funded projects were reviewed; Appendix D provides a list of projects that were presented but not reviewed.) Panel members include experts from a variety of backgrounds related to hydrogen and fuel cells. As shown in Table 4, this year, these experts represented national laboratories; universities; various government and non-government organizations; and developers and manufacturers of hydrogen production, storage, delivery, and fuel cell technologies. Each reviewer was screened for conflicts of interest, as prescribed by the *Peer Review Guide*. The project comments, recommendations, and scores are provided in the following sections of this report, grouped by subprogram.

A selection of reviewers was also asked to provide feedback on the overall DOE Hydrogen Program and HFTO subprograms; a summary of the Program review results is provided in Appendix A.

Table 4. Peer Review Panel: Represented Organizations

3M Company	National Institute of Standards and Technology
ACS Industries, Inc.	National Renewable Energy Laboratory
AcuTech Consulting Group	Nedstack
Advanced Research Projects Agency–Energy	Nel Hydrogen
Advent Technologies, Inc.	Nexceris, LLC
Air Liquide	Nikola Corporation
Air Products and Chemicals, Inc.	Nuvera Fuel Cells LLC
Argonne National Laboratory	Oak Ridge National Laboratory
Arizona State University	Orlando Utilities Commission
Bosch	OxEon Energy
Bureau of Ocean Energy Management	Pacific Northwest National Laboratory
Carnegie Mellon University	pH Matter / Power to Hydrogen, LLC
Caterpillar Inc.	Pipeline and Hazardous Materials Safety Administration
CSA Group	Plug Power, Inc.
CSIRO Energy	Sandia National Laboratories
Cummins Technical Center	Savannah River National Laboratory
Electro-Active Technologies, Inc.	SBC Global
Energetics	SLR Consulting
ENTRUST Solutions Group	Solve Global
Envision Energy	Southern Company
European Commission	Strategic Analysis, Inc.
Faurecia	T2M Global
Faurecia Hydrogen Solutions	Tedeschi Consulting Solutions, LLC
Flow Cell Tech	Tetramer Technologies
Flow State Analytics	The Chemours Company
Ford Motor Company	U.S. Army Corps of Engineers
French Alternative Energies and Atomic Energy Commission	U.S. Army Tank Automotive Research, Development and Engineering Center
Fuel Cell and Hydrogen Energy Association	U.S. Department of Energy
General Motors Company	U.S. Department of Transportation
Georgia Institute of Technology	U.S. Naval Research Laboratory

Global Decarbonisation Advisory Pty Ltd	University at Buffalo
Greenko	University of California, Irvine
GTI Energy	University of California, San Diego
H-Tech International, LLC	University of Connecticut
Hydrogen Fuel Cell Partnership	University of Dayton Research Institute
Idaho National Laboratory	University of Hawaii
Indiana University–Purdue University Indianapolis	University of Illinois, Urbana-Champaign
International Trade Administration	University of Maryland
Ion Power, Inc.	University of North Dakota Energy and Environmental Research Center
ITA Research	University of Pittsburgh
Johns Hopkins University	University of South Carolina
Johnson Matthey	University of Texas at Austin
Lawrence Berkeley National Laboratory	University of Virginia
Lawrence Livermore National Laboratory	Upstart Power
Los Alamos National Laboratory	Versogen
Louisiana State University	Washington State University
Methylennium Energy	West Virginia University
NASA	World Bank
National Energy Technology Laboratory	

Analysis Methodology

At this year's AMR, 106 HFTO-funded projects were reviewed. A total of 134 review panel members participated in the AMR process, providing 561 project evaluations.

The projects were evaluated using pre-established criteria. Reviewers were asked to provide numeric scores for five aspects of the work presented (scores were on a scale of 1–4, including half-point intervals, with 4 being the highest). For all projects, reviewers were also asked to provide qualitative comments regarding the five criteria, including specific strengths and weaknesses of the project and any recommendations relating to the work scope. Scores and comments were submitted to a private online database.

The five criteria and weighting were identical for most projects, allowing for easy comparison within and across subprograms. There were slight differences in the evaluation forms for HydroGEN Seedling projects; this section explains those small variations. Sample evaluation forms are provided in Appendix C.

For most projects, scores were based on the five criteria and weights provided below.

- Score 1: Approach to performing the work (20%)
- Score 2: Accomplishments and progress toward overall project and DOE goals (35%)
- Score 3: Collaboration and coordination with other institutions (10%)
- Score 4: Potential impact on Hydrogen Program goals and objectives (20%)
- Score 5: Proposed future work (15%)

The individual reviewer scores for each question were averaged to provide information on each of the five criteria. In addition, an overall score was calculated for each project, as follows: individual reviewer scores for each of the five criteria were weighted using the formula in the box below to create an overall score for each reviewer for that project; then, the overall scores from individual reviewers were averaged to determine one overall project score. In this manner, a project's final overall score can be meaningfully compared with that of another project.

Final Overall Score = [Score 1 x 0.20] + [Score 2 x 0.35] + [Score 3 x 0.10] + [Score 4 x 0.20] + [Score 5 x 0.15]

A perfect overall score of "4" indicates that a project satisfied the five criteria to the fullest possible extent; the lowest possible overall score of "1" indicates that a project did not satisfactorily meet any of the requirements of the five criteria.

The evaluation form for HydroGEN Seedling projects (included in Appendix C) was modified to address their unique features; the scores for these projects were based on the five criteria and weights below.

- Score 1: Approach to performing the work (20%)
- Score 2: Accomplishments and progress toward overall project and DOE goals as well as the HydroGEN Consortium mission (30%)
- Score 3: Collaboration effectiveness with HydroGEN and, if applicable, other research entities (25%)
- Score 4: Potential impact on Hydrogen Program goals and objectives and in advancing the HydroGEN Consortium mission (15%)
- Score 5: Proposed future work (10%)

Each individual project report includes a comparison of how that project aligns with all the other projects in its subprogram or activity area. Projects are compared based on the consistent set of criteria described above. To enable these comparisons, average scores were calculated across all the projects in each of the following panels: Hydrogen Infrastructure, Hydrogen Storage, Hydrogen Production Technologies, Production–HydroGEN Seedling, Fuel Cell Technologies, Systems Development and Integration, Systems Analysis, and Safety, Codes and Standards.

Each project report includes a chart showing these comparisons. The chart includes bars representing that project's average scores for each of the five relevant criteria. The gray vertical hash marks that overlay the blue bars represent the corresponding maximum, average, and minimum scores for all the projects in the same subprogram or category. A sample graph is provided in Figure 3.

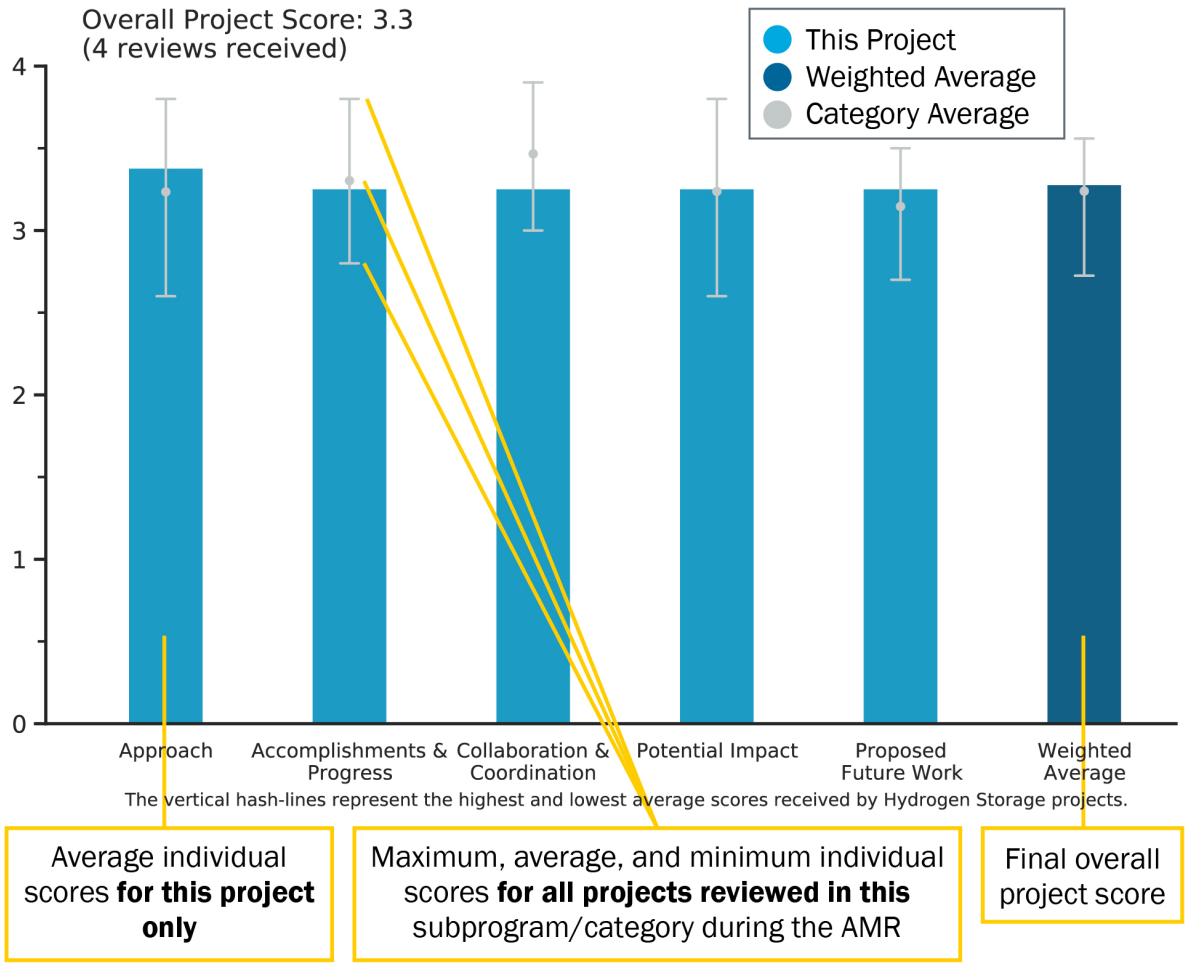


Figure 3. Sample project score graph with explanation

For clarification, Table 5 illustrates a hypothetical review in which five projects in a subprogram were presented and reviewed. Table 5 displays the average scores for each of these hypothetical projects, according to the five criteria.

Table 5. Sample Project Scores

	Approach (20%)	Accomplishments (35%)	Collaboration and Coordination (10%)	Potential Impact (20%)	Future Work (15%)
Project A	3.4	3.3	3.3	3.2	3.1
Project B	3.1	2.8	2.7	2.7	2.9
Project C	3.0	2.6	2.7	2.8	2.9
Project D	3.4	3.5	3.4	3.2	3.3
Project E	3.6	3.7	3.5	3.4	3.4
Maximum	3.6	3.7	3.5	3.4	3.4
Average	3.3	3.2	3.1	3.0	3.1
Minimum	3.0	2.6	2.7	2.7	2.9

Using these data, the chart for Project A would contain five bars representing the values listed for that project in Table 5. A gray hash mark indicating the related maximum, average, and minimum values for all of the projects in Project A's subprogram or category (the last three lines in Table 5) would overlay each corresponding bar to facilitate comparison. In addition, each project's criteria scores would be weighted and combined to produce a final, overall project score that would permit meaningful comparisons to other projects. Below is a sample calculation for the Project A weighted score.

Final Score for Project A = [3.4 x 0.20] + [3.3 x 0.35] + [3.3 x 0.10] + [3.2 x 0.20] + [3.1 x 0.15] = 3.3

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