Introduction

The fiscal year (FY) 2021 U.S. Department of Energy (DOE) Hydrogen Program (the Program) Annual Merit Review and Peer Evaluation Meeting (AMR) was held June 7–11, 2021, online as a virtual meeting because of COVID-19 and government-wide travel restrictions. The AMR consists of a detailed merit review and technical expert peer evaluation of DOE's Hydrogen and Fuel Cell Technologies Office (HFTO), in addition to an overview of the entire Hydrogen Program, which includes activities across multiple DOE offices—including Energy Efficiency and Renewable Energy (EERE), Fossil Energy and Carbon Management (FECM), Nuclear Energy (NE), Electricity (OE), Science (SC), and the Advanced Research Program Agency–Energy (ARPA-E). In addition, the AMR provides an update of hydrogen activities across other federal and state agencies involved in key hydrogen- and fuel-cell-related activities.

Consistent with prior AMRs over more than two decades, this year's AMR included detailed independent review of projects funded by HFTO and peer review of the overall activities within the office and the Program. The peer review results take the form of comments and scores provided by AMR peer reviewers in response to presentations on Program and project progress, as shown in the project review chapters and in Appendix A of this report. A representative selection of hydrogen and fuel cell programs and projects funded by other DOE offices comprising the Program are also presented at the AMR, and these presentations are included (together with the HFTO project presentations) in the 2021 AMR Proceedings.[1]

DOE uses the results of this merit review and peer evaluation, along with additional review processes, to help shape priorities and plans for upcoming fiscal years and to help guide ongoing performance improvements to existing projects and the overall strategy of the Program.

The objectives of the AMR include the following:

- Review and evaluate FY 2021 accomplishments and FY 2022 plans for DOE hydrogen programs and projects, including laboratory programs; industry–university cooperative agreements; and related research, development, demonstration, and deployment (RDD&D) efforts, including through rigorous and systematic tracking of progress against targets and metrics.
- Provide an opportunity for stakeholders (hydrogen and fuel cell system developers and manufacturers, component developers, integrators, end users, and others) to provide input to help shape the Program so that it addresses the highest-priority barriers, facilitates technology transfer and market impact, and continually improves its effectiveness in enabling progress toward national goals.
- Foster interactions among national laboratories, industry, and universities conducting RDD&D to enhance collaboration and coordination, leverage resources and talents, and provide a venue for advancing early career development in STEM (Science, Technology, Engineering, and Mathematics) fields, strengthening diversity, equity, and inclusion (DEI) as well as engagement within the energy and environmental justice community.
- Provide transparency regarding the use and impact of taxpayer funding, including on concrete deliverables such as innovations, patents, commercialized or near-commercial technologies, and enabling activities such as manufacturing; safety, codes and standards; and workforce development.

Organization of the Report

This report introduction provides a brief overview of the Program, including highlighted accomplishments in FY 2020–2021. This section includes an introductory 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 by subprogram: Hydrogen Technologies; Fuel Cell Technologies; Technology Acceleration; Safety, Codes and Standards; and Systems Analysis. Each of these sections begins with a brief subprogram overview, including a

[1] DOE, "2021 Annual Merit Review Proceedings," energy.gov, https://www.hydrogen.energy.gov/annual-review/annual_review21_proceedings.html.

summary of key FY 2020–2021 accomplishments. The subprogram overviews are followed by the results of individual project reviews, including the scores and qualitative comments for each project.

Appendix A provides a summary of review comments on the overall Program and HFTO subprograms. Appendix B provides a complete list of the meeting participants. Appendix C provides the evaluation criteria used for the program and project reviews, and Appendix D provides a list of projects that were presented at the AMR but not peer-reviewed, including those funded by other DOE offices or external stakeholders.

Overview of the DOE Hydrogen Program

The Program provides funding and strategic direction for RDD&D activities to advance the production, transport, storage, and use of hydrogen across multiple applications and different sectors of the economy. The Program, which is led through HFTO, coordinates activities within EERE, FECM, NE, OE, SC, and ARPA-E. A growing network of stakeholders informs the Program, including industry representatives across applications and sectors, state and regional organizations, other federal agencies, and international counterparts. The Program's activities are authorized by Title VIII of the Energy Policy Act of 2005[2] and the Energy Act of 2020.[3] This section provides a brief overview of the Program through the 2021 AMR meeting held in June 2021. More information on the activities of the DOE offices and subprograms can be found in the plenary presentations included in the 2021 AMR Proceedings and through the information and links at the Program webpage.[4]

Activities within the Program are aligned with the Biden Administration's goals,[5] including the most recent goal, announced April 22, 2021, for the "United States to achieve a 50–52 percent reduction from 2005 levels in economy-wide net greenhouse gas pollution in 2030—building on progress to-date and by positioning American workers and industry to tackle the climate crisis." This "2030 target picks up the pace of emissions reductions in the United States, compared to historical levels, while supporting President Biden's existing goals to create a carbon pollution-free power sector by 2035 and net-zero emissions economy by no later than 2050. There are multiple paths to reach these goals, and the U.S. federal, state, local, and tribal governments have many tools available to work with civil society and the private sector to mobilize investment to meet these goals while supporting a strong economy."[5]

All of the Program's efforts are consistent with the above goals, including ongoing RDD&D efforts such as clean hydrogen production scale-up, affordability, durability, and reliability, which are key to jumpstarting new markets for hydrogen, including heavy-duty applications, new industrial uses, energy storage, and grid integration.

In FY 2021, Congress appropriated $150 million for hydrogen and fuel cell activities in EERE's HFTO and $88.7 million for FECM's activities. In addition, funding for NE, SC, and ARPA-E, relevant to hydrogen and fuel cell activities, amounted to $13 million, $17 million, and $10 million, respectively. This represents a total DOE budget for FY 2021 of almost $279 million related to hydrogen and fuel cell technologies (see Table 1 below).

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[2] Energy Policy Act of 2005 (EPACT 2005) Public Law 109-58, Title VIII – HYDROGEN, Sections 801 to 816 (42 USC Sections 16151 to 16165), August 5, 2005.

[3] Consolidated Appropriations Act, Public Law 116-260, Division Z – Energy Act of 2020, Section 9009, December 27, 2020.

[4] DOE, "Hydrogen Program," accessed 2022, https://www.hydrogen.energy.gov/index.html.

[5] The White House, "President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies," April 22, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/.

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

DOE Office / Program	FY 2020 (enacted)	FY 2021 (enacted)	FY 2022 (requested)
Energy Efficiency and Renewable Energy	**$165.5**	**$155.9**	**$226.5**
Hydrogen and Fuel Cell Technologies	$150	$150	$197.5
Advanced Manufacturing	$12.5	$5	$20
Solar Energy Technologies Office	$0	$0	$4
Vehicle Technologies Office	$3	$0	$0
Wind Energy Technologies Office	$0	$0.9	$5
Fossil Energy and Carbon Management	**$53**	**$88.7**	**$141**
Clean Coal and Carbon Management	$53	$87	$111
Oil and Natural Gas	$0	$1.7	$30
Nuclear Energy	**$14**	**$13**	**$13**
Science	**$15.5**	**$17**	**$20**
Advanced Research Program Agency–Energy	**$36.4**	**$10**	**TBD***
TOTAL	**$284.4**	**$284.6**	**$400.5**

**ARPA-E funding is determined annually based on programs developed through office and stakeholder priorities. Therefore, funding for FY 2022 is not available at this time.*

The Program coordinates across all relevant offices, and pertinent activities are identified based on technical and economic analyses, stakeholder workshops, requests for information, and merit-reviewed project proposals that may be selected through competitive funding opportunities, which vary from year to year.

Background: H2@Scale – A Guiding Framework

H2@Scale is a DOE initiative that provides an overarching vision for how hydrogen can enable energy pathways across applications and sectors in an increasingly interconnected energy system, as shown in Figure 1 below. The main priorities of this vision include:

- Low-cost, clean hydrogen generation
- Low-cost, efficient, safe hydrogen delivery and storage
- End-use applications to achieve scale and sustainability, enable emissions reduction, and address Environmental Justice 40 priorities[6]

H2@Scale RDD&D activities are guided by the administration's goal to equitably transition the United States to net-zero greenhouse gas emissions economy-wide by 2050, while creating good paying jobs and ensuring the clean energy economy benefits all Americans. Hydrogen is one part of a portfolio of activities to enable decarbonizing the electricity, transportation, industrial, buildings, and agricultural sectors, particularly for hard-to-decarbonize applications such as heavy-duty transportation and industry. More details may be found on the H2@Scale webpage.[7]

[6] The White House, "The Path to Achieving Justice40," July 20, 2021, https://www.whitehouse.gov/omb/briefing-room/2021/07/20/the-path-to-achieving-justice40/.

[7] DOE, "H2@Scale," accessed 2022, https://www.energy.gov/eere/fuelcells/h2scale.

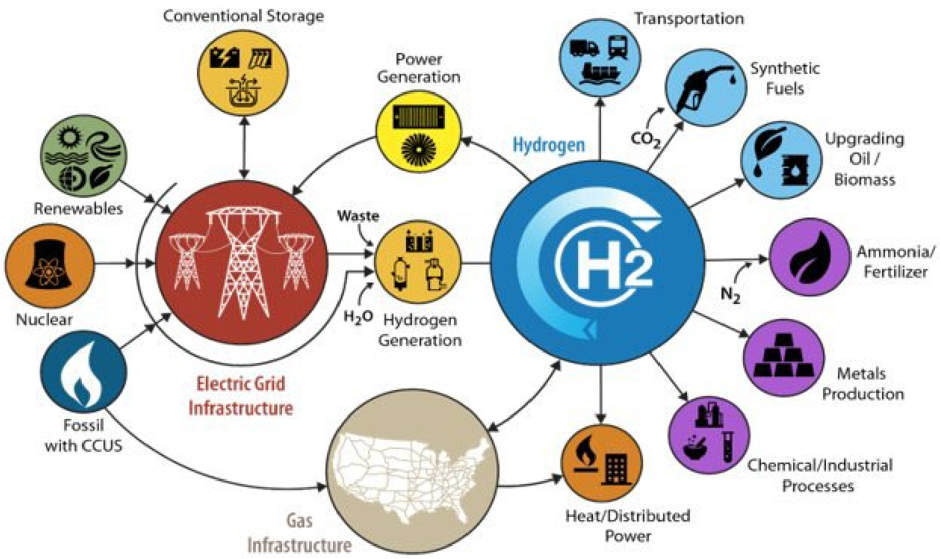

Figure 1. Schematic of H2@Scale

Program Highlights

This year marked an important period in the Program's history, as hydrogen was increasingly recognized globally as an enabler to achieving decarbonization goals. Key Program highlights included the following:

- **DOE-Wide Hydrogen Program Plan:** In November 2020, DOE released its **Hydrogen Program Plan**,[8] providing a comprehensive strategic framework for the Department's hydrogen-related RDD&D. The plan includes input from the offices of EERE, FECM, NE, OE, SC, and ARPA-E and reinforces the Department's commitment to enabling progress in hydrogen technologies in the United States. This overarching Department-wide strategic plan was the first comprehensive update since the previous version published in 2011.
- **Hydrogen Shot:** On June 7, 2021, Secretary of Energy Jennifer M. Granholm launched the DOE **Energy Earthshots Initiative**, a series of bold, ambitious initiatives that will address critical challenges and contribute to achieving net-zero carbon emissions. The first Energy Earthshot—**Hydrogen Shot**—seeks to reduce the cost of clean hydrogen by 80% to $1 per 1 kilogram in 1 decade ("1 1 1"). Hydrogen Shot supports the H2@Scale vision and will contribute to addressing the climate crisis. Achieving Hydrogen Shot's goals could result in at least a five-fold increase in clean hydrogen use and unlock new markets for hydrogen, such as steel manufacturing, clean ammonia, energy storage, and heavy-duty trucks. DOE plans to hold a series of events to engage stakeholders, the first of which is the Hydrogen Shot Summit, planned for August 31–September 1, 2021.
- **DOE-Wide Hydrogen Request for Information:** In June 2021, the Program issued a **request for information**, in support of Hydrogen Shot, to solicit information on potential clean hydrogen demonstration opportunities and locations across the United States. The request for information included questions about infrastructure, end users, emissions reduction potential, and basic science needs, as well as DEI needs to ensure our work takes environmental justice issues and disadvantaged communities into consideration.
- **New Consortia:** HFTO launched the **Million Mile Fuel Cell Truck (M2FCT)** and the Hydrogen from Next-generation Electrolysis of Water (**H2NEW**) consortia to advance fuel cell truck and hydrogen production research and development (R&D). This announcement built upon EERE's intention to invest up

[8] DOE, *Department of Energy Hydrogen Program Plan*, DOE/EE-2128, November 2020, https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf.

to $100 million over five years, subject to appropriations, to reduce the cost of fuel cells for trucks and of electrolyzers for hydrogen production.

- **Funding and Financial Opportunity Announcements:** In FY 2020–2021, DOE announced more than $175 million in funding opportunity announcements (FOAs) for hydrogen-related RDD&D, as shown in Table 2 and Table 3, found at the end of this subsection.
- **Program Records:** To document the source of key numbers or facts that are cited by the Program, **program records** have been developed to explain inherent assumptions, source data, and calculation methodologies. Seventeen new program records were published in FY 2020–2021, including records documenting targets for Class 8 long-haul hydrogen fuel cell trucks, durability-adjusted fuel cell system cost, reversible fuel cell targets, hydrogen production cost from electrolysis, hydrogen fueling station costs, and hydrogen delivery and dispensing cost. The complete list of program records published since 2005 is available on the DOE Hydrogen Program webpage.[9]
- **Workshops:** The research community, government, and the private sector came together in **various DOE workshops** to identify gaps in RDD&D and next steps to enable large-scale hydrogen use. Examples of workshops held by HFTO[10] include the following:
    - The **H2@Airports Workshop** was held November 4–6, 2020, in collaboration with the U.S. Department of Transportation (DOT) Federal Aviation Administration, the U.S. Air Force, and the U.S. Navy. This virtual workshop convened experts from civilian government, the military, academia, and industry to share information on the status of hydrogen and fuel cell technologies for unmanned aerial vehicles, aircraft, and ground support applications.
    - The **Marine Energy to Hydrogen Working Meeting** was held February 17, 2021. Research, industry, and government representatives met virtually to discuss opportunities and challenges of integrating marine renewable energy resources with hydrogen energy storage.
    - The **Ammonia for H2@Scale Virtual Panels** were held May 6–7, 2021. These invitation-only panels focused on the growing opportunities for ammonia as a viable clean-hydrogen carrier serving diverse end uses and supporting important economic and environmental imperatives.
    - The **Advances in Liquid Hydrogen Storage Workshop** was held August 18, 2021, in collaboration with the National Aeronautics and Space Administration (NASA). U.S. and international stakeholders from industry, academia, and government agencies met virtually to discuss DOE liquid-hydrogen-related initiatives and outlook and to learn about recent advances in large-scale liquid hydrogen storage technologies and projects at NASA.
- **Interagency Collaboration:** Collaboration among federal agencies was strengthened in FY 2021 through various mechanisms, including a multi-agency announcement from DOE (with contributions from HFTO and EERE's Vehicle Technologies Office [VTO]), the U.S. Department of Defense, and the U.S. Department of Homeland Security to support the H2Rescue truck that will travel to disaster relief sites and provide power, heat, and water. HFTO also continued to lead the **Hydrogen and Fuel Cells Interagency Working Group**, which consists of multiple federal agencies that meet regularly to exchange information about hydrogen and fuel cell RDD&D projects and collaborate and coordinate on related activities.[11]
- **Global Collaboration:** Increased global collaboration in hydrogen emerged as a predominant theme during multiple international engagements with minister-level participation, including the Hydrogen, Clean Energy, and Group of Twenty (G20) Ministerials. These meetings set key priority areas and provided guidance for working-level participation in partnerships between governments. Below are highlights for the government-led global initiatives with which the Program engaged closely during 2021:
    - **International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE):** The IPHE, established in 2003, brings together more than 20 governments at the technical program level to advance worldwide progress in hydrogen and fuel cells. The HFTO Director served as chair while representing the United States from 2018 to 2020; she has completed her term as elected chair and

[9] DOE, "Program Records," accessed 2022, https://www.hydrogen.energy.gov/program_records.html.

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

[11] DOE, "Hydrogen Program: Hydrogen and Fuel Cells Interagency Working Group," accessed 2022, https://www.hydrogen.energy.gov/hfciwg.html.

currently serves as a vice chair. In addition to convening several meetings, IPHE, with HFTO leadership, established an International Early Career Network[12] to advance STEM and DEI through a collaborative platform for students, post-docs, and early career professionals; the aim is to foster development of the next generation of hydrogen researchers, experts, and leaders. Other key accomplishments include developing a common analytical framework for calculating the hydrogen greenhouse gas emissions footprint across all countries, as well as a compendium of regulations, codes, and standards to identify gaps and foster harmonization in key areas to ensure interoperability across countries and a robust global supply chain.

- **International Energy Agency:** The United States engages with the International Energy Agency (IEA) Hydrogen and Advanced Fuel Cells Technology Collaboration Programmes (TCPs). These TCPs provide a mechanism for member countries to share the results of pre-competitive RDD&D and analysis related to fuel cell and hydrogen technologies through executive committee and annex meetings, topical and outreach meetings, publications from the annexes and other groups, newsletters, and other forms of exchange. Both HFTO and FECM experts are engaged in steering the TCPs aligned with R&D needs and priorities. In support of the Clean Energy Ministerial, IEA also published a key global report on the status of hydrogen and fuel cells; the DOE Hydrogen Program contributed through analysis and peer review.
- **Hydrogen Energy Ministerial Meeting (HEM):** Japan initiated the HEM in October 2018 as a platform to encourage countries worldwide to promote global use of hydrogen and to engage ministerial-level participation. The United States, through HFTO's participation, has been engaged with HEM since its inception, including through support of the HEM's Global Action Agenda to enable worldwide progress on hydrogen. Thousands of stakeholders joined the 2021 HEM meeting, held October 4, 2021, which included ministers as well as recordings and moderated expert panels, including by the HFTO Director.
- **Clean Energy Ministerial Hydrogen Initiative:** In May 2019, Canada spearheaded the launch of the New Hydrogen Initiative as part of the Clean Energy Ministerial, along with co-leads: the European Commission, Japan, the Netherlands, and the United States. HFTO has been providing leadership and support, as co-lead, and working with the IEA secretariat to ensure resources are leveraged to avoid duplication of efforts already covered under other initiatives and to maximize effectiveness. Key activities in 2021 included the launch of the Global Ports Initiative, led by the European Commission, and development of the H2 Twin Cities initiative, through leadership from HFTO, in collaboration with other countries.
- **Mission Innovation's Clean Hydrogen Mission:** In 2021, Mission Innovation, which was initiated in 2015 as part of the Paris Climate Agreement, launched three new missions: Clean Hydrogen, Power, and Shipping. HFTO is a key contributor to the Clean Hydrogen Mission and serves as co-lead. In addition to the United States, co-leads include Australia, Chile, the European Commission, Saudi Arabia, and the United Kingdom. The key research and innovation goal of the Clean Hydrogen Mission is achieving a target of $2/kg for clean hydrogen across the system, from hydrogen production to the point of end use, and thus is well-aligned with the Hydrogen Shot goal of $1/kg for the production portion of clean hydrogen. Other goals include a commitment to establishing hydrogen "valleys," or clusters of hydrogen initiatives across the complete hydrogen value chain, from production through end use. FY 2021 marked the inception of the mission with broad stakeholder engagement and identification of the path forward through three pillars: Research and Innovation, Demonstrations, and the Enabling Environment. HFTO provides leadership in ensuring this new effort avoids duplication with other initiatives, leverages synergies, and maximizes effectiveness toward common goals.

[12] IPHE, "IPHE E&O WG Early Career Chapter," accessed 2022, iphe.net/early-career-chapter.

Table 2. FY 2021 DOE Hydrogen-Related FOAs

EERE HFTO	**Hydrogen and Fuel Cell RD&D – $36 million** • Fuel Cell R&D for Heavy-Duty Applications ($15 million) • Efficient and Innovative Hydrogen Production ($10 million) • High-Flow Fueling Applications ($7 million) • Cost and Performance Analysis for Fuel Cells, Hydrogen Production, and Hydrogen Storage ($4 million) HFTO FOA Project Selections
EERE VTO	**SuperTruck** • Joint SuperTruck FOA with VTO – anticipated HFTO funding of $60 million over five years ($5 million in FY 2021 and $15 million, pending appropriations, in FY 2022)
FECM	**Fossil-Based Hydrogen Production, Transport, Storage and Utilization – $15.5 million (FECM with HFTO Collaboration)** • Solid Oxide Electrolysis Cell (SOEC) Technology Development for Hydrogen Production ($7 million) • Advanced CCUS Systems ($4 million) • Hydrogen Combustion Systems for Gas Turbines – Industrial Class ($4.5 million) FECM FOA Project Selections **University Turbines Systems Research (UTSR) – Focus on Hydrogen (H_2) Fuels – $7 million** • Hydrogen Combustion Fundamentals for Gas Turbines ($3 million) • Hydrogen Combustion Applications for Gas Turbines ($2.4 million) • Hydrogen–Air Rotating Detonation Engines ($1.6 million) FECM FOA Project Selections
NE, EERE HFTO	**Hydrogen Production and End Use Demonstration – $20 million** • HFTO contribution: $12 million • NE contribution: $8 million FOA Announcement
SC	**DOE Early Career Research Program for FY 2021** SC Announcement

Table 3. FY 2020 DOE Hydrogen-Related FOAs

EERE HFTO	**H2@Scale New Markets – $58.2 million** • Electrolyzer Manufacturing R&D ($13.8 million) • Advanced Carbon Fiber for Compressed Hydrogen and Natural Gas Storage Tanks ($10.4 million) • Fuel Cell R&D for Heavy-Duty Applications ($10 million) • H2@Scale New Markets R&D – Hysteel ($8 million) • H2@Scale New Markets Demonstrations ($14 million) • Training and Workforce Development for Emerging Hydrogen Technologies ($2 million) HFTO FOA Project Selections
FECM (FECM–HFTO)	**Small-Scale Solid Oxide Fuel Cell [SOFC] Systems and Hybrid Electrolyzer Technology Development – $34 million** • Hybrid Systems Using Solid Oxide Systems for Hydrogen and Electricity Production ($26 million) • Small-Scale Distributed Power Generation SOFC Systems ($8 million) FECM FOA Project Selections

Office Overviews and Updates

Hydrogen and Fuel Cell Technologies Office

HFTO conducts comprehensive efforts to overcome the technological, economic, and institutional barriers to the development of hydrogen and fuel cells. Key focus areas include hydrogen production from renewables; hydrogen storage, delivery/infrastructure, and utilization; fuel cells for transportation and small stationary applications; and hydrogen and fuel cells for energy storage and end use (industrial/chemical).

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

- Overcome technical barriers through R&D of hydrogen production, delivery, and storage technologies, as well as fuel cell technologies for transportation, distributed stationary power, and portable power applications.
- Address safety issues and facilitate the development of model codes and standards.
- Validate and demonstrate hydrogen and fuel cells in real-world conditions.
- Educate key stakeholders whose acceptance of these technologies will determine their success in the marketplace.

HFTO's RDD&D activities are organized into the following subprogram/activity areas in this report: Hydrogen Technologies; Fuel Cell Technologies; Technology Acceleration; Safety, Codes and Standards; and Systems Analysis. Overviews of the subprograms are provided below, and highlights of key HFTO RDD&D accomplishments and progress are shown in Table 4. More detailed information on each subprogram is provided in the introductions to each section of the merit review results in this report.

Hydrogen Technologies

The Hydrogen Technologies subprogram focuses on research, development, and demonstration (RD&D) to reduce the cost and improve the reliability of technologies used to produce, deliver, and store hydrogen from diverse domestic feedstocks and energy resources. In support of needs identified through H2@Scale efforts, the subprogram is developing a set of hydrogen production, delivery, and storage technology pathways and addressing technical challenges through a portfolio of projects in three RD&D areas:

- **Hydrogen production** addresses low-cost, highly efficient hydrogen production technologies that utilize diverse domestic sources of energy. RD&D activities include advanced water splitting and innovative concepts such as biological hydrogen production. The former is predominantly coordinated through the HydroGEN Advanced Water Splitting Materials consortium (HydroGEN) and the H2NEW consortium to accelerate RD&D of advanced water splitting technologies for clean, sustainable hydrogen production.
- **Hydrogen infrastructure** addresses low-cost, high-efficiency technologies to move hydrogen from the point of production to the point of use. RD&D activities study liquefaction, pipelines, chemical carriers, and tube trailers to transport hydrogen over long distances, as well as compressors, pumps, dispensers, and stationary storage to support the development of hydrogen stations serving fuel cell electric vehicles. The Hydrogen Materials Compatibility Consortium (H-Mat) coordinates RD&D on accelerated test methods and novel, low-cost, durable metals and polymers for use in hydrogen infrastructure.
- **Hydrogen storage** addresses cost-effective onboard and off-board hydrogen storage technologies with improved energy density and lower costs. RD&D activities study high-pressure compressed storage, materials-based storage, and hydrogen carriers. The latter two are coordinated through the Hydrogen Materials–Advanced Research Consortium (HyMARC) to accelerate the discovery and development of breakthrough hydrogen storage materials.

Fuel Cell Technologies

The Fuel Cell Technologies subprogram applies innovative RD&D, with the main goal of developing a diverse portfolio of low-cost, durable, and efficient fuel cells that are competitive with incumbent and emerging technologies across applications.

The subprogram develops targets based on the ultimate lifecycle cost of using fuel cell systems in diverse applications. While the subprogram has previously developed comprehensive technical targets in areas such as light-duty vehicles, it continues to develop and refine additional targets for emerging and high-impact applications. These include heavy- and medium-duty vehicles, maritime applications, stationary power generation (primary and backup), and reversible fuel cells for energy storage.

Cross-cutting challenges for fuel cell development are strategically addressed by the subprogram through focus on materials and components (especially low-platinum-group-metal [low-PGM] and PGM-free catalysts and electrodes); systems and manufacturing (design, standardization, improved supply chains); and analysis and modeling.

Technology Acceleration

The Technology Acceleration subprogram[13] aims to address technology barriers, systems development and systems integration challenges, and other crosscutting activities to enable the H2@Scale vision and support Hydrogen Shot. The subprogram pursues this goal by identifying hydrogen applications and system configurations that can provide more affordable and more reliable clean energy; validating and testing integrated system development; and bridging the gaps between component-level R&D and industry's role in commercialization by integrating technologies into functional systems, reducing costs, and overcoming other barriers to deployment. The subprogram is currently focused on four technology application areas: (1) grid energy storage and power generation, (2) chemical and industrial processes, (3) transportation, and (4) enabling activities such as manufacturing; safety, codes and standards; and workforce development.

Safety, Codes and Standards

The Safety, Codes and Standards (SCS) activity area, as part of the Technology Acceleration portfolio, supports RD&D to improve the fundamental understanding of the relevant physics and to provide the critical data and safety information needed to develop and revise technically sound and defensible codes and standards. These codes and standards provide the technical basis to facilitate and enable the safe and consistent deployment and commercialization of hydrogen and fuel cell technologies in multiple applications. SCS activities include identifying and evaluating safety and risk management measures that are used to define requirements and close the knowledge gaps in codes and standards in a timely manner. SCS activities also focus on promoting safety practices among DOE projects and developing information resources and best practices.

In FY 2021, SCS focused on validating liquid hydrogen release models to help reduce separation distance requirements for liquid hydrogen storage, developing sensor use guidance and wide-area monitoring capabilities to address improper or inadequate deployment of safety sensors, developing low-cost contaminant detection technology to address fuel quality assurance issues, and analyzing component failure modes and quantifying leak size to address component reliability. Most of these activities are not specific to any particular application but provide information that will enable safe hydrogen use across multiple sectors.

Systems Analysis

The Systems Analysis subprogram funds crosscutting analyses to identify technology pathways that can enable large-scale hydrogen use to enable decarbonization, advance environmental justice, and enhance flexibility and resilience of the energy system. To perform these foundational analyses, the subprogram uses a diverse portfolio of both focused and integrated models and tools that characterize technology costs, performance, impacts, and cross-sector market potential. These tools and capabilities are continuously updated and enhanced, while new tools are also developed as needed. Analyses in FY 2021 focused on identifying the role of hydrogen in hard-to-decarbonize sectors, characterizing factors such as the role of hydrogen in long-duration energy storage, the impact of hydrogen use on lifecycle emissions of industrial applications, market segmentation in medium- and heavy-duty transportation, and the impact of growth in hydrogen and fuel cells on global sustainability.

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[13] Technologies Acceleration as referred to in the congressional budget request was renamed Systems Development and Integration.

Table 4. Selected Examples of HFTO RDD&D Progress and Accomplishments, FY 2020–2021

Hydrogen Technologies

Hydrogen Production

- ✓ Launched the H2NEW consortium, convening national labs, industry, and academia, to enable meeting hydrogen production cost and performance targets.
- ✓ Demonstrated improved anion exchange membrane electrolysis durability over ~750 hours at relevant current density.
- ✓ Established a promising interconnect protective coating for the air–O_2 side of high-temperature electrolysis stacks.
- ✓ Achieved a 2.5× higher solar-to-hydrogen efficiency than state-of-the-art perovskite cells in an integrated 3D-printed photoelectrochemical reactor.

Hydrogen Storage

- ✓ Selected four new carbon fiber RD&D projects to address the cost of carbon fiber composite vessels for hydrogen storage.
- ✓ Synthesized the best-performing metal–organic framework (MOF) for room-temperature hydrogen adsorption and the first MOF with a binding enthalpy in the optimal range for ambient temperature storage (-15 to -25 kJ/mol).
- ✓ Improved MgB_2-$Mg(BH_4)_2$ hydrogenation conditions by 100°C and 200 bar over state of the art.
- ✓ Demonstrated 2× (de)hydrogenation rates for high-capacity Li/Mg-amides through nanoconfinement in carbons.

Hydrogen Infrastructure

- ✓ Launched the HyBlend initiative with national labs, industry, and academia to address challenges to hydrogen blending with natural gas.
- ✓ Accelerated progress in materials compatibility through H-Mat:
    - Used advanced imaging and chemical analysis to identify causes for damage to seals in hydrogen service.
    - Determined that ductility was reduced by 50% in austenitic stainless steels in a cryogenic (20 K) hydrogen environment.
- ✓ Completed design and construction of a high-flow hydrogen fueling system at the National Renewable Energy Laboratory (NREL) Energy Systems Integration Facility. The facility will be capable of fueling at 10 kg/min, enabling a first-of-its-kind facility for testing high-flow hydrogen fueling.
- ✓ Developed the publicly accessible H2FillS model, allowing users to simulate the impact of varying fueling methods on the thermodynamics of fueling equipment and on-board hydrogen storage.

Fuel Cell Technologies

- ✓ ***Established the Million Mile Fuel Cell Truck (M2FCT) Consortium:*** This coordinated effort across national labs, academia and industry will enable meeting durability, cost, and efficiency targets for fuel cells in long-haul, heavy-duty truck applications.
- ✓ ***Determined Heavy-Duty Vehicle Fuel Cell Targets and Costs:*** Based on extensive industry input and peer review, Class 8 long-haul tractor–trailer cost targets were determined to be $80/kW (by 2030), and $60/kW ultimately. Current (2019) heavy-duty vehicle fuel cell technology was estimated to cost ~$190/kW (at manufacturing volume of 1,000 units per year).[14]
- ✓ ***Improved Catalyst Activity***: Achieved over 2× improvement in PGM-free catalyst activity over the 2016 baseline of 16 mA/cm^2. Performance exceeded the FY 2021 catalyst activity target (38 mA/cm^2 vs. 35 mA/cm^2). Over 190 unique catalysts were synthesized, with 30% enhancement in oxygen reduction reaction (ORR) activity performance vs. the highest ORR activity reported in 2020.
- ✓ ***Developed Accelerated Stress Testing Protocols***: The Accelerated Stress Test Working Group (ASTWG) was formed to recommend test protocols and performance targets for fuel cells in heavy-duty vehicle applications. M2FCT has developed a membrane electrode assembly durability accelerated stress test, incorporating relevant degradation mechanisms for catalyst, support, electrodes, and membrane, and the test is being validated in coordination with the ASTWG.
- ✓ ***Improved Fuel Cell Bus Durability***: Fuel cell bus durability was determined to be 17,000 hours, with less than 20% degradation, approaching the DOE–DOT interim fuel cell bus target of 18,000 hours.
- ✓ ***Developed Reversible Fuel Cell Targets***: Performance, cost, and durability targets for unitized reversible fuel cells (for electric energy storage applications) were developed and disseminated to stakeholders. These include targets for both low- and high-temperature technologies, at both the cell/stack and system levels, with the same stack operating in both fuel cell and electrolyzer modes.

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[14] DOE, Hydrogen Class 8 Long Haul Truck Targets, Hydrogen Program Record #19006, October 31, 2019, https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf; Dimitrios Papageorgopoulos, "Fuel Cell Technologies Overview," presentation at the DOE 2021 Hydrogen Program Annual Merit Review and Peer Evaluation Meeting, June 7, 2021, https://www.hydrogen.energy.gov/pdfs/review21/plenary8_papageorgopoulos_2021_o.pdf.

Table 4 (cont.)

Technology Acceleration

- ✓ Launched new demonstration projects using clean hydrogen to decarbonize industry and power generation:
  - In California, initiated a demonstration for first-of-its-kind maritime hydrogen refueling on a floating barge with up to a half ton of hydrogen per day.
  - In Missouri, kicked off two HySteel projects to demonstrate using hydrogen to decarbonize iron and steel production, with a reduction of 30% in energy and 40% in emissions vs. conventional processes.
  - In Washington, initiated the first-ever at-scale demonstration of hydrogen fuel cell power for data centers to provide reliable and resilient power.
  - In New York, demonstrated a megawatt-scale electrolyzer integrated with a nuclear power plant (in collaboration with NE).
- ✓ Validated two high-temperature electrolyzers from industry, including a 25 kW stack that surpassed 4,000 hours with <0.5% degradation per 1,000 hours.
- ✓ Established an integrated megawatt-scale hydrogen production, storage, and fuel cell system at NREL's Advanced Research on Integrated Energy Systems (ARIES) facility.
- ✓ Supported the launch of global initiatives, including Mission Innovation:
  - Shipping – supported an international effort on decarbonizing marine applications.
  - Clean Hydrogen Mission – co-led initiatives and co-hosted a workshop on hydrogen for mining, agriculture, and construction equipment/vehicles.

Safety, Codes and Standards

- ✓ Developed a comprehensive federal regulatory map to identify gaps across agencies related to the hydrogen value chain.
- ✓ Through collaboration with the Center for Hydrogen Safety, created new safety courses and updated safety best practices.
- ✓ Through ASME Code Case 2938, enabled up to 3× longer life for Type I and II tanks.

Systems Analysis

- ✓ Developed the StoreFAST tool to evaluate the cost of hydrogen energy storage relative to alternatives in user-defined scenarios. Analyzed current and future costs of long-duration energy storage in high-renewable grids.
- ✓ Evaluated the total cost of ownership of batteries, fuel cells, and combustion engines in medium- and heavy-duty vehicles, with varying ranges and operating conditions.
- ✓ Partnered with over 20 countries to develop a common analytical framework for calculating the emissions footprint of hydrogen to enable a harmonized approach and facilitate international trade of clean hydrogen.

Workforce Development and DEI

- ✓ Expanded partnerships enabling national lab engagement with students from historically black colleges and universities to build a diverse hydrogen and fuel cell workforce pipeline.
- ✓ Contributed $2.6 million to a partnership between the University of Tennessee and Oak Ridge National Laboratory in creating a national model for workforce development in energy-related disciplines, enhancing interdisciplinary R&D.
- ✓ Aligned FOAs, lab calls, and cooperative research and development agreements (CRADAs) to encourage broader engagement and demonstrate DEI benefits.

Office of Fossil Energy and Carbon Management

In FY 2021, FECM's hydrogen-focused funding was $88.7 million. Related focus areas were low-cost, carbon-neutral hydrogen production and utilization technologies (turbines, gasification, reforming/pyrolysis, SOFCs, and point source carbon capture R&D) and low-cost, reliable, and safe options for bulk hydrogen transport (pipelines) and subsurface storage. Key activities and accomplishments through June 2021 included:

- Developing hydrogen combustion fundamentals and analysis tools to enable low-nitrogen oxide hydrogen combustor designs and zero-carbon power generation.
- Conducting successful commercial demonstration of the world's largest clean hydrogen facility (Port Arthur, Texas), which is based on steam methane reforming with carbon capture and utilization and has been in operation for seven years.
- Completing pre-front-end engineering design (pre-FEED) studies for a clean hydrogen production facility, which is now shifting the design to using waste coal, biomass, and plastic feedstocks.
- Developing several pre-combustion (CO_2/H_2) separation technologies at a small pilot scale.
- Developing reversible SOFC technologies to produce either hydrogen or electricity, depending on grid demand.

Office of Nuclear Energy

In FY 2021, NE focused on RD&D to support hydrogen production applications for the existing nuclear fleet and advanced reactors. Ongoing research includes five projects demonstrating hydrogen production capabilities at four existing nuclear power plants, including efforts to test human interfaces for integrated plant operation using real operators in a control room environment.

Key activities and accomplishments in FY 2021 included the following:

- Completed high-fidelity technical and economic modeling for integrated design and operation (electricity and hydrogen) of energy systems using a suite of dynamic analysis and optimization tools.
- Confirmed system design and probabilistic risk assessment of commercial-scale heat delivery and hydrogen production at a nuclear plant site.
- Completed the development of a full-scope simulator for a nuclear power plant coupled to a high-temperature steam electrolysis hydrogen plant.
- Developed a prototype human–system interface and used it to test operating concepts for dispatching thermal energy and electrical power to a high-temperature steam electrolysis plant. An interdisciplinary team of operations experts, nuclear engineers, and human factors experts evaluated the performance of previously licensed nuclear plant operators enlisted to test the possible tie of a nuclear reactor to a hydrogen plant.
- Initiated preliminary operational testing of a thermal energy distribution system, an electrically heated system that will allow demonstration of a wide array of integrated energy system configurations, at Idaho National Laboratory. In collaboration with EERE, NE will also establish interconnection with SOECs for hydrogen production at a scale of up to 250 kWe (~125 kg H_2/day).

Office of Science, Basic Energy Sciences

In FY 2021, SC focused on fundamental chemical and materials science research to advance understanding and transformative approaches for hydrogen generation and use. Recent accomplishments included:

- Materials discovery and mechanistic study of semiconductor–electrolyte interfaces, which led to an efficiency of 19% for photoelectrochemical production of hydrogen.
- Demonstration of high activity and durability of a novel electrocatalyst in a fuel cell membrane electrode assembly.

Planning is under way for an SC-led Roundtable on Foundational Science for Carbon-Neutral Hydrogen Technologies, to be held in August 2021.[15]

Advanced Research Projects Agency–Energy

ARPA-E FY 2021 funding was $10 million. ARPA-E catalyzes transformational energy technologies to enhance the economic and energy security of the United States. The agency 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 have sought to develop technologies involving renewable energy, carbon-neutral liquid fuels, 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. Focused R&D programs relevant to hydrogen or related technologies include:

- Range Extenders for Electric Aviation with Low Carbon and High Efficiency (REEACH)
- Duration Addition to electricitY Storage (DAYS)
- Methane Pyrolysis Cohort
- Innovative Natural-gas Technologies for Efficiency Gain in Reliable and Affordable Thermochemical Electricity-generation (INTEGRATE)
- Integration and Optimization of Novel Ion-Conducting Solids (IONICS)
- Renewable Energy to Fuels through Utilization of Energy-dense Liquids (REFUEL)
- Reliable Electricity Based on ELectrochemical Systems (REBELS)

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[15] The roundtable was held in August 2021: https://science.osti.gov/-/media/bes/pdf/reports/2021/Hydrogen_Roundtable_Brochure.pdf

In Closing…

Despite unprecedented challenges due to COVID-19, including the inability of researchers to return to the laboratory to perform experimental work and supply chain delays, the Program continued to see significant progress during FY 2020 and FY 2021. On the global front, hydrogen continues to gain momentum, with multiple countries developing national hydrogen strategies recognizing the need for hydrogen to meet their climate goals. Large-scale hydrogen use applications are ramping up, with significant public- and private-sector investment across sectors.

The progress is encouraging, but important work remains to be done on multiple fronts: cost needs to be reduced in several areas—without compromising performance—for technologies to be competitive, infrastructure needs to be addressed, and scaling up is key. The next few years will be critical to moving the needle toward sustainable market adoption and realization of the environmental, energy, and economic benefits that can be enabled by hydrogen technologies across the nation.

New flagship initiatives such as the Hydrogen Energy Earthshot will pave the way to success in enabling low-cost hydrogen and its ability to decarbonize applications across sectors. Since the previous AMR, development of the DOE-wide Hydrogen Program Plan set the strategic direction for our activities; the establishment of new consortia and projects set the stage to address the challenges; and collaboration across government, industry, labs, academia, and the environmental and energy justice communities––with emphasis on diversity, equity, and inclusion—will set the stage for continued progress.

DOE will continue to work in close collaboration with key stakeholders and will continue its strong commitment to effective stewardship of taxpayer dollars in support of its mission to enable the energy, environmental, and economic security of the nation. In support of these efforts, the following several hundred pages document the results and impacts of the Program since the previous AMR.

Peer Review Introduction/Methodology

The AMR peer review process followed the guidelines in the Peer Review Guide developed by EERE. Project reviewers provided comments about selected HFTO-funded projects presented during the event. (Not all ongoing HFTO-funded projects were reviewed, particularly those that had just started and made little progress. Appendix D provides a list of projects that were presented at the AMR but not reviewed, including those funded by other DOE offices or external stakeholders.) Panel members included experts from a variety of backgrounds related to hydrogen and fuel cells. As shown in Table 5, 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 subset of the reviewers was also asked to provide feedback on the overall DOE Hydrogen Program and HFTO subprograms; a summary of the Program review results is included in Appendix A.

Table 5. Peer Review Panel: Represented Organizations

3M Company	National Institute of Standards and Technology
A.V. Tchouvelev & Associates Inc.	National Renewable Energy Laboratory
Advanced Materials Testing & Technologies	National Research Council Canada
Air Products and Chemicals, Inc.	National Science Foundation
Argonne National Laboratory	Nel ASA
Arizona State University	New Energy and Industrial Technology Development Organization, Japan
Atrex Energy, Inc.	New Jersey Fuel Cell Coalition
AvCarb Material Solutions	Nexceris, LLC
AVL Fuel Cell Canada	Nikola Motor Company
Ballard Power Systems	Northeastern University
Bar-Ilan University	Nuclear Regulatory Commission

Booz Allen Hamilton	Nuvera Fuel Cells, LLC
Boston University	Oak Ridge National Laboratory
California Air Resources Board	Pacific Northwest National Laboratory
California Energy Commission	Pajarito Powder, LLC
California Fuel Cell Partnership	PH Matter
California Governor’s Office of Business and Economic Development	Plug Power Inc.
Carnegie Mellon University	Praxair, Inc.
Center for Transportation and the Environment	Precision Combustion, Inc.
Chevron Corporation	Princeton University
Colorado School of Mines	Raytheon Technologies
Commissariat à l’énergie atomique et aux énergies alternatives (CEA, French Atomic Energy Commission)	Redox Power Systems, LLC
Commonwealth Scientific and Industrial Research Organisation, Australia (CSIRO)	Rutgers University
Compagnie de Saint-Gobain S.A.	Sandia National Laboratories
Connecticut Center for Advanced Technology, Inc.	Savannah River National Laboratory
CSA Group	SBC Global Alliance
Cummins Inc.	Schaeffler Technologies AG & Co. KG
Department of Science and Innovation (South Africa)	Secat, Inc.
DJW Technology, LLC	Shell
Drexel University	Somerday Consulting, LLC
DuPont Company	Southern California Gas Company
Exelon Corporation	Southern Company Services, Inc.
Exxon Mobil Corporation	Stellantis
Ford Motor Company	Stottler Development LLC
Form Energy, Inc.	Strategic Analysis, Inc.
Frontier Energy	Strategic Marketing Innovations
Fuel Cell and Hydrogen Energy Association	T2M Global
Fuel Cells and Hydrogen Joint Undertaking (FCH JU)	The Chemours Company
FuelCell Energy, Inc.	The Pennsylvania State University
FuelScience, LLC	Toyota Motor North America
General Dynamics Information Technology	U.S. Army, Tank Automotive Research, Development and Engineering Center (TARDEC)
General Motors Company	U.S. Department of Energy, Bioenergy Technologies Office
Georgia Institute of Technology	U.S. Department of Energy, Office of Fossil Energy
Giner, Inc.	U.S. Department of Energy, Office of Science
Graz University of Technology	U.S. Department of Transportation
GVD Corporation	U.S. Department of Transportation, Maritime Administration
Hawaii Natural Energy Institute	U.S. Environmental Protection Agency
Hawaiian Electric Company, Inc.	U.S. Naval Research Laboratory
Helmholtz-Zentrum Geesthacht	University of Arizona
Hyzon Motors Inc.	University of California, Berkeley

Indiana University–Purdue University Indianapolis	University of California, San Diego
International Energy Agency	University of Connecticut
Ion Power, Inc.	University of Illinois at Urbana-Champaign
Largo Clean Energy	University of Maryland
Lawrence Berkeley National Laboratory	University of Michigan, Ann Arbor
LIFTE H2, Inc.	University of New Mexico
Los Alamos National Laboratory	University of South Carolina
Louisiana State University	University of Virginia
Ludlow Electrochemical Hardware	University of Colorado Boulder
Michigan State University	Vanderbilt University
Ministry of the Interior and Kingdom Relations (Netherlands)	Versogen
Nanosonic, Inc.	West Virginia University
NASA, Glenn Research Center	WPCSOL, LLC
NASA, White Sands Test Facility	Xergy, Inc.
National Energy Technology Laboratory	Zero Carbon Energy Solutions

Analysis Methodology

A total of **125** HFTO-funded projects were reviewed at the meeting. A total of **189** review panel members participated in the AMR process, providing **534** project evaluations.

The projects were evaluated using pre-established criteria. Reviewers were asked to provide numeric scores (on a scale of 1–4, including half-point intervals, with 4 being the highest) for five aspects of the work presented. For all projects, reviewers were also asked to provide qualitative comments regarding the five criteria, 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 the significant majority of projects, allowing for easy comparison within and across subprograms. There were slight differences in the evaluation forms for HydroGEN Seedling projects and some Fuel Cell Technologies projects that were recently awarded. This section explains these 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: Relevance/potential impact on DOE Program goals and RD&D 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 key aspects. 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 to 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 following five criteria and weights:

Score 1: Approach to performing the work (20%)

Score 2: Accomplishments and progress toward overall project and DOE goals and the HydroGEN Consortium mission (30%)

Score 3: Collaboration effectiveness with HydroGEN and, as appropriate, other research entities (25%)

Score 4: Relevance/potential impact on DOE Program goals and RD&D objectives and the HydroGEN Consortium mission (15%)

Score 5: Proposed future work (10%)

The 2021 AMR also included some recently awarded projects that were placed in a separate scoring panel with modified scoring criteria and weights. The scores for new projects were based on the following five criteria and weights:

Score 1: Approach to performing the work (40%)

Score 2: Accomplishments and progress toward overall project and DOE goals (5%)

Score 3: Collaboration and coordination with other institutions (10%)

Score 4: Relevance/potential impact on Hydrogen Program goals (20%)

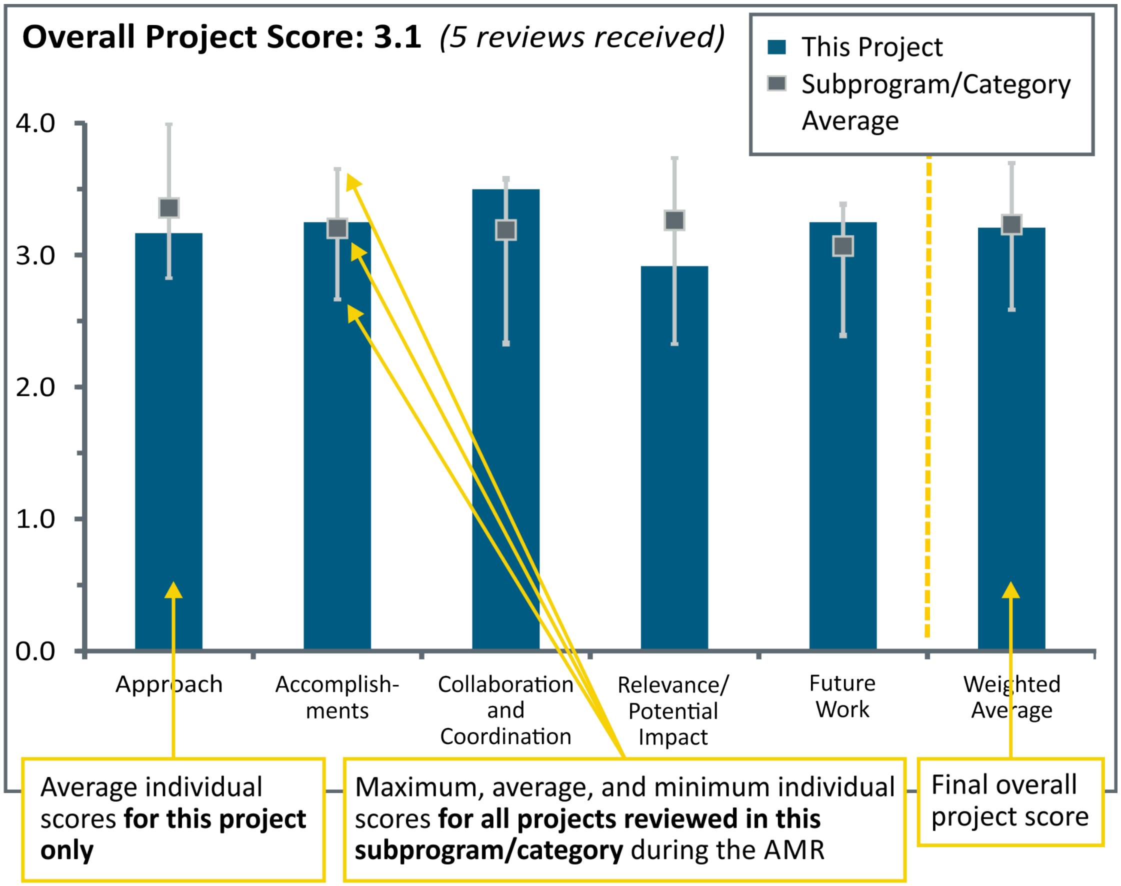
Score 5: Proposed future work (25%)

For this new projects panel, reviewers were given the option not to evaluate Score 2: Accomplishments. (In such instances, the other criteria were re-weighted to total 100%.)

For the Fuel Cell Technologies panel, overall scores were developed in stages. Scores for new projects were first calculated separately, using the weighting above. Scores for projects in the remainder of the panel were computed using normal weighting. Then the two sets of scores were combined so that the minimum, average, and mean scores could be computed for the entire Fuel Cell Technologies panel (new projects included).

Each individual project report also includes a graph showing the overall project score and a comparison of how each project aligns with all of the other projects in its subprogram or category. Projects are compared based on the consistent set of criteria described above. Each project report includes a chart with bars representing that project's average scores for each of the five designated criteria. The gray vertical hash marks that overlay the blue bars represent the corresponding maximum, average, and minimum scores for all of the projects in the same subprogram or category. A sample graph is provided.

Sample Project Score Graph with Explanation



For clarification, consider a hypothetical review in which only five projects were presented and reviewed in a subprogram. Table 6 displays the average scores for each project according to the five rated criteria.

Table 6. Sample Project Scores

	Approach (20%)	Accomplishments (35%)	Collaboration and Coordination (10%)	Relevance/ 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 6. 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 6) 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