Appendix A. 2024 Hydrogen Program Review Summary

This appendix shows the results of the Hydrogen Program (Program)-level peer review for the 2024 Annual Merit Review and Peer Evaluation Meeting (AMR), including feedback from a subset of the reviewers attending the AMR. A total of 20 Program-level reviewers provided feedback. As shown in the table below, 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.

Peer Review Panel: Represented Organizations

California Fuel Cell Partnership	National Aeronautics and Space Administration (NASA)
Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA, the French Alternative Energies and Atomic Energy Commission)	National Energy Technology Laboratory (NETL)
Commonwealth Scientific and Industrial Research Organisation (CSIRO) Energy	NEL Hydrogen
Energy & Environmental Research Center (EERC)	Plug Power Inc.
Energetics, CLEAResult Energy Sustainability Solutions	SBC Global Consulting, LLC
Fuel Cell and Hydrogen Energy Association (FCHEA)	SLR Consulting Limited
Greenko Group	Southern Company
H-Tech International, LLC	U.S. Army, Tank Automotive Research, Development and Engineering Center (TARDEC)
Idaho National Laboratory	University of Illinois Urbana-Champaign

1. The Hydrogen Program plan and strategy are well-aligned with the missions and goals of the National Clean Hydrogen Strategy and Roadmap and the Hydrogen Shot.

Responses rated on a scale of 1 through 10, with 1 indicating strongly disagree and 10 indicating strongly agree.

	Hydrogen Program Overall Strategy
Average Score	**9.25**
Number of Responses	20

Please explain the reason for your rating and comment on strengths and/or improvement opportunities related to the Program's plan and strategies, as well as the Program's portfolio of projects.

- The Hydrogen Program is one of the very best organized, closely managed, and carefully executed programs in U.S. Department of Energy (DOE). The Hydrogen and Fuel Cell Technologies Office (HFTO) director and leadership, as well as the other managers, provide the highest-quality leadership for the Program. They masterfully integrate the entire government-wide hydrogen effort to ensure the attainment of 2026, 2030, and 2050 goals. The Program was given a huge job through the Bipartisan Infrastructure Law (BIL). It was a big job well done. This very influential Program will have a long-term impact. Congratulations to the entire Program and its managers and leadership. In the electrolysis area, DOE has set viable 2026 goals and specifically identified very clear target performance parameters, including cost, cell area-specific resistance, and current density (hydrogen production rate), to be able to achieve those goals.

- The Program plan directly relates to and actively works to address the identified challenges of strategic, high-impact applications, reduce costs, and focus on regional networks. From a traditional DOE perspective (i.e., one focused on research and development [R&D]), these efforts are appropriate, targeted, and well-balanced. The reviewer recognizes and appreciates the efforts to be multi-focused, systematic, and inclusive on the many complex interactions and needs. An area of improvement is breaking the next step in drilling down into the necessary details and minutiae of the next milestones and activities to address more near-term progress toward the overarching goals and objectives of the roadmap and the Hydrogen Shot. In other words, those documents are necessary and provide a great high-level overview, yet by their nature, their scope is too large to enable industry to make final investment decisions against them. Greater commitment toward the immediate next steps/milestones (and showing commitments at this lower level) will be needed to advance near-term progress (beyond just the winning hubs and projects). This comment is a larger critique of what is needed next, not a direct knock on the DOE Program plan (which is very good).
- The Program plan relevantly covers all necessary phases of action from advanced research to deployment to the goal. Previously, the DOE Program plan was limited to only pre-competitive, advanced research areas that are at a low technology readiness level (TRL). The deployment phase was recently added (e.g., Regional Clean Hydrogen Hubs [H2Hubs] and domestic manufacturing programs for electrolyzers and fuel cells). These programs are large enough to stimulate industry's (the private sector's) investment and gain momentum. It is good to distinguish the government share in the Program; non-competitive advanced research is 80:20, and deployment is 50:50.
- The Program is multipronged, attacking the main concerns of reducing cost at the pump, or point of industrial use, and driving to commercialization on technologies supporting both production and use of hydrogen. To accomplish the goals of the *National Clean Hydrogen Strategy and Roadmap* and the Hydrogen Shot, there needs to be both scientific and engineering advancement, as well as technology development; part of the excellent alignment of the DOE Program is a wise balance of supported projects at many TRLs. Early-phase TRLs advance the basics to a point where the advanced engineering can bring forth prototype technology, and then the technology advancement helps companies implement those technologies until they are through, or mostly through, the so-called "valley of death," with loans and co-funding of product development.
- The Program plan and strategy very closely align (often using very similar language and/or writing styles). The clearest evidence can be found in the portfolio organization of five offices and the growing utilization of academic, professional (e.g., American Institute of Chemical Engineers), and intergovernmental (Hydrogen Interagency Task Force [HIT]) organizations to disseminate information and coordinate activities.
- Based on the presentations made on various ongoing projects, it has been observed that all of them are registering substantial progress. Previous AMRs' reviewer comments were considered, and course corrections were made wherever necessary to achieve the stated goals of the projects. Many projects are long-term in nature, but the progress is in the right direction.
- The Program has devoted R&D to reduce the cost of hydrogen and make the storage and fuel cell technologies competitive with baseline industries. The Program is working with many industries, such as steel, to gain economies of scale.
- The Program is very well-aligned with the different priorities of the U.S. *National Clean Hydrogen Strategy and Roadmap*. Each subprogram completes a part of the strategy using a very structured approach that includes clear objectives, clear key performance indicators, and reporting.
- The Program plan is well-constructed and followed/referenced the *National Clean Hydrogen Strategy and Roadmap*, as well as the Hydrogen Shot, frequently. The portfolio of projects is well-aligned and clearly supports the referenced strategies.
- The Program plan is consistent with the *National Clean Hydrogen Strategy and Roadmap*, and the HFTO director is committed to making sure the Program is consistent with the *National Clean Hydrogen Strategy and Roadmap*.
- The Program is mature and forward-moving. Importantly, the HFTO director and her team are experts who seem to know fully what it takes for the hydrogen economy to take root and evolve in the best possible way.

- The plan and strategy are substantially covering all the bases needed for the hydrogen strategy. There is good cross-department coordination.
- The presentation shows direct alignment and highlights strong interagency collaboration and interest at all levels.
- HFTO generally has a good mix of activities across R&D, technology demonstration, and deployment. This is the first time that enough funding has been available enable supporting this range of activities. The main drawback is that most of this funding has not yet been contracted to projects. The next 12 months should be very informative regarding the success of the portfolio.
- The Program is supporting a comprehensive suite of activities in some, but not all, of the "high-impact uses" identified in the strategy. Mobility, in particular, is a strong focus, which likely reflects the historical emphasis of U.S. hydrogen programs, but industrial uses of hydrogen (including ammonia production) seem underrepresented in the project portfolio. Given the global shift toward uses of hydrogen in hard-to-abate industrial sectors, supporting additional research in this area should be considered, particularly where aligned with and in support of the recently announced H2Hubs.
- HFTO provided great opportunities for researchers and commercial developers to develop advanced technology, reduce costs for potential products, develop domestic supply chains, mature advanced processing techniques, and demonstrate new technologies to accelerate hydrogen production and applications. HFTO provided good funding to support 18 projects for advanced materials and technology development. Hopefully, HFTO is considering a plan for next steps on how to support these projects to demonstrate the technology at higher TRLs three years later.
- The Program plan is well-aligned with the *National Clean Hydrogen Strategy and Roadmap*, both of which build on many years of impactful research, development, demonstration and deployment (RDD&D) by HFTO and other offices and agencies. It seems that the Hydrogen Shot of $1/kg will not be possible, but $2/kg is very reasonable. A target of $1/kg represents $20/MWh clean power at 50 kWh/kg, assuming free capital, installation, and maintenance. A cost of $20/MWh is much too cheap for baseload power, and even though some intermittent power is at or below this price, that does not reflect the true costs that would be associated with using that power (i.e., intermittency, storage). Therefore, while the plan and roadmap are well-aligned, the Hydrogen Shot of $1/kg is not physically possible unless significant costs are borne elsewhere in the energy system.
- As usual, the Program, under the director's steady leadership, has done an excellent job in developing the portfolio of R&D projects and communicating its vision and targets consistent with the *National Clean Hydrogen Strategy and Roadmap* and the Hydrogen Shot. However, going forward, the urgency of meeting the Hydrogen Shot targets set in 2021 needs to be conveyed upfront, say, as $1 per 1 kg in 0.7 decades ("1,1,0.7").
- HFTO has worked meticulously over the last two years to get feedback on its programs via requests for information (RFIs) and workshops, and the plan and strategies reflect that input well. The DOE targets are very aggressive but are needed to keep pace with hydrogen development in the world. The only weakness is the speed of implementation; industry is relying on government support to build out the hydrogen economy. Also, the strict ruling on the 45V tax credits will interfere with HFTO roadmap progress.
- The Program follows the roadmaps and policies and actively both reviews and realigns efforts to the plans. This is a real strength. Especially in this time of great growth in the sector, it would be helpful if knowledge and staff could be made available to industries that are trying to determine opportunities and barriers to entry (e.g., consultants who could advise companies on needs and possibly highlight areas in the companies' portfolios that could be adjusted to hydrogen technology needs).

2. The Hydrogen Program is well-aligned with industry and stakeholder needs and appropriately complements private-sector, state, and other non-DOE investments and research, development, demonstration, and deployment (RDD&D).

Responses rated on a scale of 1 through 10, with 1 indicating strongly disagree and 10 indicating strongly agree.

	Hydrogen Program Stakeholder Alignment
Average Score	**8.65**
Number of Responses	20

Please explain the reason for your rating and comment on whether the Program's funding is adequate to achieve its goals.

- Hydrogen from Next-generation Electrolyzers of Water (H2NEW) really needs to be tied to funding opportunity announcement (FOA) projects. While it has an advisory board, H2NEW has now been operating for nearly four years with no true integration with industry. Some of the work (particularly mechanistic and characterization work) the consortium is doing is great; other parts (particularly the more applied aspects) could potentially benefit from more discussion with industry experts and ties to industry projects. The HydroGEN Advanced Water Splitting Materials Consortium (HydroGEN), as a more fundamental, early-stage consortium, is doing well and actually does have new projects associated with it. H2Hubs, while slow to start, represents a huge and important investment. Coordinating the hubs into something cohesive will be the challenge.
- The Program is well-aligned with industry and stakeholders' needs. Through intense communication and integration, DOE is ensuring that information, including DOE objectives and program goals, is conveyed to all stakeholders clearly and in a timely manner. DOE must make sure that funding goes to diverse corporations and entities to achieve DOE goals. The Program realizes that fact and is executing intense integration to ensure goals are achieved.
- Many of the projects have industrial partners that provide input and calibration for the Program's targets. Industry is focused on reducing its carbon emissions. The Program technologies are working on key components and systems to enable industry to incorporate the technologies into operations. It is exciting to have major manufacturing companies and industries participating with major cost-share contributions to make the technologies viable and scalable.
- The technical managers within the various portfolio offices spoke intelligently about the needs and objectives of both established and new participants in the hydrogen sector. These participants ranged from academic researchers to industrial infrastructure magnates. The managers were able to tie these needs and objectives directly to applicable projects funded by DOE.
- The Program takes into account both industry and the stakeholders that stand to be impacted the most by this energy plan. Private, state, and other federal entities are engaged and have opportunities to participate and contribute to the success of the hydrogen economy.
- The Program aligns first with the U.S. strategy, for which supporting a strong hydrogen industry and private sector is important. The Program thus also supports well the needs of the private sector, from basic research to deployments.
- The proof is the judicious funds allocation to a diverse cohort of industries and the excellent demonstration projects all around the country. Industries with hydrogen knowledge and experience are involved (e.g., Cummins Inc., GTI Energy, Plug Power Inc., Linde p.l.c., BP p.l.c.).
- The presentation demonstrated a high level of stakeholder engagement, including listening sessions and collaborative initiatives. The Program's funding appears to be sufficient to achieve its goals, barring unforeseen challenges.
- The Program responds well to industry/stakeholder needs in project selection and execution. If anything, more of the same needs to be done quicker, but that is a resource limitation beyond DOE purview.

- Many projects are being pursued in consortia with non-DOE entities (e.g., Cummins Inc.), for fuel cell truck durability, thus establishing faster field validation and deployment of technologies.
- H2Hubs will strongly support industry needs to demonstrate technology. There are several projects aimed at supporting industry manufacturing scale-up.
- The Program plan is solid, yet more attention is needed on near-term progress and actions. To get the private investment needed to scale up the market, there needs to be much greater commitment to both the higher role for hydrogen (seen in the roadmap) and the market commercialization needs industry must address to make investment decisions. There are many aspects to this:
- There is a need to see greater commitment to the entire hydrogen ecosystem (akin to the gusto federal government shows for battery electric vehicle technologies, and inclusive of all applications, such as not writing off light-duty fuel cell electric vehicles [FCEVs]) for industry to believe the DOE commitment.
- Greater commercialization-focused efforts are needed. (R&D is critical, yet the marathon to creating a sustainable marketplace requires stronger transition to and focus on commercial impacts today if fleets are to transition and industry is to commit more.)
- The entire federal effort must begin transitioning to more market-building mechanisms that create stronger market signals, derisk private investment, and give greater confidence to industry (all players, not just winning hubs and projects) to invest today to achieve the longer-term objectives.
- The initial Program plan and efforts are strong in traditional R&D and vision-setting yet need more in specific metrics and commitments to make the near-term work, across applications, really align with private-sector needs.
- In general, the Program is aligned with stakeholder needs. Information-gathering meetings give stakeholders a chance to express the specifications that will allow them to advance or meet their goals (e.g., pollution reduction for states), and the use of such meetings helps to keep DOE aligned with the constituents' needs. In addition, subject experts inform DOE at many stages. Globally, all nations still strive to solve the major problems and thus wish to hold the patents and technology know-how, and DOE is no exception. This results in a suboptimal allocation of global resources, but this is likely unavoidable in a competitive atmosphere. The major area for improvement is better integrating earlier-TRL projects to the ultimate ends in the technology advancement projects and the H2Hubs. Of course, the hubs are just starting up, so integrating with their work and facilities may be a little challenging, but few projects outside the hubs seem to be seeking the advantages and synergies possible by working actively with one or more hubs.
- It is good to see that the Program identifies the early market sectors, such as hydrogen blending with existing infrastructure, and end uses that can benefit the most from large-scale hydrogen deployments, such as those hard-to-electrify industries. However, it is not clear how the Program is aligned with industry and stakeholder needs. It would be useful to present the aggregate non-DOE RDD&D investment levels categorized by end use, together with their potential market share, as an additional metric for evaluating the Program's effectiveness in meeting the 2030 or 2050 targets. This can help the Program to laser-focus on the most impactful projects to stimulate the hydrogen economy.
- The Program is supporting the development of a range of "common user" facilities at national labs, which will allow industry to assess and progress technology developments. There also appears to be a good range of research projects that involve industry partners, providing a path to commercial impact for many of the technology developments that the Program is supporting. The funding allocations appear to be generally realistic to allow achievement of the project goals. However, it would be good to see more focus on industrial uses of hydrogen, and such projects would likely need to be of a fairly large scale and require significant additional funding to match.
- Funding areas are strategically selected based on the technology roadmap, rather than sporadic. It is recommended, for now, to put more resources into early adoption areas that can absorb higher costs and become lighthouse usage of hydrogen, even though at small volume. For example, in the transportation sector, on-road, heavy-duty long-haul is the largest market segment but is difficult to ramp up quickly. Off-road heavy-duty, like mining haul, is small-volume, but it can absorb the high cost of new technology and seems to be an early-stage deployment target. Technically, domestic bipolar plate manufacturing for the Fuel Cell Technologies subprogram is not adequate to ramp up domestic fuel cell manufacturing.

- Good progress has been made in demonstrating hydrogen production at 50 kW–1 MW scale using a variety of electrolyzers developed by private companies. This is a good start. HFTO may want to conduct an in-depth review of these projects focusing on issues, lessons learned, and technology gaps between current technology and commercial products. This valuable information may then be shared with a broader community of researchers and developers.
- The present RDD&D funding is adequate, but there are concerns about what will happen in 2027–2028 when the BIL investments run out. The concept was to shift support to the 45V tax credit, but if that is implemented without a slow progression to meet the demands of "three pillars," much of the present government investment may be wasted.
- The main issue observed with regard to the adequacy of funding to achieve goals is too much workload for the number of employees.
- The intellectual property and priorities of the national lab component of the project and funding make working with the highly knowledgeable staff and excellent facilities really hard.

3. The Hydrogen Program is effectively collaborating across DOE program offices and other federal agencies to reach national hydrogen goals.

Responses rated on a scale of 1 through 10, with 1 indicating strongly disagree and 10 indicating strongly agree.

	Hydrogen Program Collaboration
Average Score	**8.85**
Number of Responses	20

Please explain the reason for your rating and comment on strengths and/or improvement opportunities related to interoffice and/or interagency collaborations.

- The Program now considers sectors beyond pure DOE activities. Twelve agencies from different departments are involved in the U.S. *National Clean Hydrogen Strategy and Roadmap*. The creation of the HIT ensures the collaboration of all these actors. Some of them are discovering the hydrogen sector, whereas others can be seen as pioneers with decades of activities. Coordination appears thus as critical; this seems to be very well done by the HFTO director.
- A case in point is work on hydrogen production technologies; HFTO is actively collaborating with non-DOE and DOE labs such as Argonne National Laboratory, National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, and Sandia National Laboratories and with industry partners such as Nel Hydrogen, Plug Power Inc., pH Matter LLC, etc., leveraging the collective strengths in achieving the overall targets set by DOE.
- HFTO has been working on interoffice and interagency collaborations for years, and with the recent influx of funding, this has become more important. The collaboration with the new Office of Clean Energy Demonstrations (OCED) will be very important as the hydrogen hubs become dominant funding sources and hydrogen producers/users. The engagement of other departments is also key so that the hydrogen community is not siloed within DOE. The collaborations with non-DOE departments will be critical for early adopters of the technology.
- The Program has instituted the HIT, which is an excellent example of interagency collaboration. This type of collaboration will calibrate the Program RDD&D and check the demonstration projects about key barriers. Many of the technologies and pathways to commercialization will encounter barriers and hurdles that cross government agencies. The HIT can immediately address these barriers.
- The Program has one of the best interoffice and interagency collaboration efforts across DOE. One clear and very significant collaboration is with the newly formed OCED on the unprecedented H2Hubs funding announcement last year. It was not highlighted enough in the presentations, but it is clear that HFTO played a critical role supporting OCED in drafting the FOA and the proposal review process. The HFTO director

and Systems Development and Integration subprogram manager should be commended for their leadership in this impactful collaboration.

- There are several examples of projects co-funded by HFTO and other agencies. The interagency AMR session is also a good means of understanding what the other agencies are doing. There has also been significant improvement in coordination across the agencies, largely driven by HFTO.
- Participation from the DOE program offices made it clear there is a lot of collaboration and coordination happening. There was clear familiarity between the offices and knowledge of the developments and projects within each.
- There is no second to the marvelous integration and coordination within the United States and worldwide by these program managers. HIT is coordinating interoffice and interagency across the government.
- Collaboration has been a hallmark of the Program and HFTO for many years, and it remains as true as ever today.
- Efforts on integrating are evident throughout the spectrum, from defense, to agriculture, to education, to foreign policy.
- There appears to be excellent cross-office collaboration.
- Collaboration, or at least close plan-sharing, is excellent inside individual offices; for example, the fuel cell and hydrogen storage subprograms are in their own groups, yet everyone from the lowest-ranking project manager all the way to the HFTO director understands the progress and needs of both groups and could spot synergy opportunities because of that understanding. Across offices, the understanding of what other offices need and have to offer seems to be more acute at the higher levels of management than for the project managers in the trenches. The principal investigators (PIs) funded by one office seem to have little to no understanding of what PIs funded by other offices are doing or how they might benefit each other. The subprograms across departments seem more complementary (which is good—no duplication) and less cooperative. There is room for a better national outcome if there were more cooperation, e.g., the fuel cell or hydrogen storage knowledge generated for vehicles could benefit marine and rail applications funded by departments outside DOE. That said, the HIT does try to coordinate everything done in the area of hydrogen, and the Small Business Administration (SBA) loans will help with hydrogen firm growth by providing capital at rates that banks could not. Better integration of unaffiliated projects with the hydrogen hubs would apply across departments as well as within DOE. This is the opportunity for improvement, making PIs more aware of opportunities across offices and departments and coordinating PIs with related projects funded by different offices or departments.
- This is still a work in progress. The words and efforts appear genuine, yet the massive growth in funding, staffing, and program activities is still chaotic, and it is unclear if there is sufficient and effective communication. Also, it is clear that some of the new offices and programs are not fully leveraging or aware of historic hydrogen activities or knowledge, which is nice from an “open green space” approach to throw off old habits yet is also retreading some worn ground that appears duplicative and unnecessary. Furthermore, many interactions with the growing federal groups working on hydrogen appear to be positive at the onset and then slip into black holes without follow-up. Industry recognizes the growth challenges, yet this will be an ongoing challenge that must be addressed to avoid repeating mistakes and not fully enabling what is possible.
- The already strong DOE interagency collaboration has been growing stronger. The growth pace appears to be limited by a combination of bureaucratic inertia and legal constraints surrounding fiscal transfers and the specifics of interagency collaboration. As a note, not all agencies have internal mechanisms to track expenditures on hydrogen-related activities (purchases, infrastructure, projects, R&D, etc.). If all agencies had mechanisms to track governmental expenditures on hydrogen, it would more accurately reflect the scope of the government’s reliance on hydrogen and help identify areas most likely for beneficial collaboration.
- It is evident that HFTO has strong collaboration with other DOE offices, e.g., Fossil Energy and Carbon Management (FECM). However, based on this year’s review, it seems that there is too much overlap between HFTO and other DOE offices. For example, NETL/FECM held a project review in Pittsburgh, Pennsylvania, April 23–25, 2024, and some of the projects were presented again at the AMR in Washington, DC.

- There has been an obvious transformation of interagency coordination. When the HIT first started, some other agencies were new to hydrogen and fuel cell technologies. Now, they all seem engaged and interested in specific applications. It would be good to see a push to update the Occupational Safety and Health Administration rules for working with hydrogen. They are decades out of date. Companies must choose between being compliant by following the published regulation, despite their not representing industry best practices or current codes and standards, or facing a *de minimis* violation for following current codes and standards and best practices.
- The HIT is an excellent initiative and should allow the many department/agency stakeholders to create hydrogen opportunities within their portfolios. That said, some of the interagency presentations did seem a little one-dimensional, suggesting that more work needs to be done in identifying and supporting such opportunities. Deeper collaboration between DOE and other portfolio leaders should enable this. This observation may stem from the fact that the task force is just getting started, so it will be good to see the initiatives that flow from it in future.
- There is coordination between the HFTO subprograms and the various DOE offices such as FECM, Office of Nuclear Energy, and Basic Energy Sciences (BES). However, the HFTO–BES collaboration and interaction needs to become stronger so that hydrogen research continues to grow in the university system for the continuous production and development of future educators and research and industry leaders in the new hydrogen economy.
- The Program is doing its best to collaborate with the other offices, and with the push for interagency collaboration, it is improving.

4. The Hydrogen Program is effectively collaborating with other countries through international partnerships, such as the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), Clean Energy Ministerial, Mission Innovation, International Energy Agency, and others.

Responses rated on a scale of 1 through 10, with 1 indicating strongly disagree and 10 indicating strongly agree.

	Hydrogen Program International Collaborations
Average Score	**8.1**
Number of Responses	20

Please explain the reason for your rating and identify (1) actions DOE can undertake in conjunction with these or other international activities to effectively accelerate U.S. progress in hydrogen and fuel cell technologies, and (2) opportunities for the Hydrogen Program to strengthen its national leadership and maintain global competitiveness.

- The Program fully supports collaboration with international partnerships by ensuring the presence of DOE in meetings and/or steering committees and by sharing the best practices and the key achievements of the U.S. Program. It also supports the active participation of U.S. experts in numerous working groups of international partnerships. International collaboration is key, as one country alone will not be able to develop a hydrogen economy. Through exchange on numerous topics (research; skills development; deployments; diversity, equity, inclusion and accessibility [DEIA]), DOE contributes to reaching the global objectives.
- The quality of these collaborations is evident in Japan and the excellent job that the DOE office within the U.S. Embassy to Japan is doing to coordinate convergence of the Japan–U.S. technology goals in hydrogen. DOE can further advance cooperation with Japan on data-sharing in all areas of technology, e.g., hydrogen material compatibility data, fuel cell membranes, catalysts. By way of example, joint international workshops in Tokyo do attract the attention of the industry in Japan.
- The United States has traditionally been an international leader in hydrogen technology development activities. The United States is increasing its focus on international collaboration, which is essential for the

world to advance technology as rapidly as possible. One excellent example of international collaboration is the International Durability Working Group for fuel cell durability, led by the Million Mile Fuel Cell Truck consortium (M2FCT).

- The AMR included a very large contingent of international attendees. Many, but not all, of these attendees were active participants in DOE activities, either directly funded or externally funded as part of cost-share activities.
- Collaboration is world-class. There is no second to the marvelous integration and coordination worldwide done by these program managers through IPHE and other entities.
- Collaboration, or at least close plan-sharing, is excellent inside individual offices; for example, the fuel cell and hydrogen storage subprograms are in their own groups, yet everyone from the most junior project manager all the way to the HFTO director understands the progress and needs of both groups and could spot synergy opportunities because of that understanding. Across offices, the understanding of what other offices need and have to offer seems to be more acute at the higher levels of management than for the project managers in the trenches. The principal investigators (PIs) funded by one office seem to have little to no understanding of what PIs funded by other offices are doing or how they might benefit each other. The subprograms across departments seem more complementary (which is good—no duplication) and less cooperative. There is room for a better national outcome if there were more cooperation, e.g., the fuel cell or hydrogen storage knowledge generated for vehicles could benefit marine and rail applications funded by departments outside DOE. That said, the HIT does try to coordinate everything done in the area of hydrogen, and the Small Business Administration (SBA) loans will help with hydrogen firm growth by providing capital at rates that banks could not. Better integration of unaffiliated projects with the hydrogen hubs would apply across departments as well as within DOE. This is the opportunity for improvement, making PIs more aware of opportunities across offices and departments and coordinating PIs with related projects funded by different offices or departments.
- International organizations can collaborate with DOE and U.S. national labs on basic science questions (pre-commercial) around hydrogen production, electrolyzer durability/performance, hydrogen safety, and infrastructure technology (whether that is physical infrastructure or liquid organic hydrogen carrier, ammonia [NH_3], etc.). The United States should use its significant funding of these research activities to strengthen its global leadership in this technology space by encouraging international partnerships and their stakeholders to co-invest in U.S.-led research. The development and active licensing of U.S.-developed technologies and research can become the genesis of new U.S. companies and manufacturing. One specific area that labs can spin out technology is on durability/aging protocols and on infrastructure protocols. If U.S. manufacturers implemented the lab-developed protocols, it would strengthen the value of these U.S. products in global markets.
- International partnership is an important element for a successful hydrogen market takeoff and for meeting the national objectives. This is especially critical with respect to setting safety and other operational standards and protocols, given the global nature of materials and equipment manufacturing and intellectual property space. Indeed, the Program already established many such international partnerships, but the nature or impact of these collaborations is not clear, partly because the AMR may not be the right forum for such discussion.
- From the information presented, it seems there is good international collaboration. One area for consideration may be leveraging partnerships with U.S. Department of Defense (DOD) international installations. Working with DOD installations to produce clean hydrogen and stable electrical grids could have a positive impact on the surrounding communities that do not have stable grids. This could further clean hydrogen availability, as well as support emerging technologies in developing countries and communities.
- International collaborative actions were not adequately mentioned in the session. Hydrogen investment in the United States is significantly larger than that of the other IPHE countries. But a solo country's action is not enough to make global momentum. International collaboration is imperative to enhance effectiveness of the Program. DOE can make an effort to influence other IPHE countries' aggressive investment in hydrogen programs and encourage them to act in lockstep with DOE actions—for example, massive investment to form regional hydrogen usage, i.e., hydrogen hubs. In the European Union, we see an action similar to the H2Hubs program. Synchronizing these actions, such as timing and volume of investment, can make synergistic momentum globally. Also, it should be expanded to other areas. Current energy-importing

areas can be energy-exporting areas if they are in the hydrogen energy loop. In the meanwhile, global demand of hydrogen production and usage can enhance our domestic competitiveness in the electrolyzer/ fuel cell manufacturing market, which the hydrogen plan is enhancing.

- International partnerships were not discussed extensively at the review. DOE will have to be careful with international relationships, as BIL and Inflation Reduction Act (IRA) funding is focused exclusively on manufacturing in the United States. DOE and the federal government should be wary not to alienate European vendors, as Europe will likely be an early adopter of hydrogen. The strict rules, for instance, in FOA 2922 about restriction of foreign collaborations might be deleterious to the Program in a few years, as other nations will retaliate with similar policies. To maintain global competitiveness, DOE should be more welcoming of using BIL and IRA funding for foreign partnerships.
- Whilst the Program's involvement in and strong support for the various international forums is known, not much discussion was included of progress/achievements that have stemmed from these during the AMR. Similarly, the overall project portfolio appeared to have a mainly domestic focus with a limited number of instances of international collaboration. Joint international projects could play a key role in accelerating global uptake of hydrogen technologies, and DOE could consider this as a future opportunity.
- While DOE cannot be directly involved in policy, there are huge challenges facing the industry that are often driven by misinformation or half-information, for example, some of the proposed 45V guidelines and per- and polyfluoroalkyl substances (PFAS) restrictions. DOE can and should act as a neutral, fact-based resource to actively provide appropriate modeling, data, and information related to these issues, including understanding international positions on similar topics.
- The energy market is so globally integrated that it would be great for the United States to be more actively developing alliances and opportunities.
- Many of these groups and interactions are known to the reviewer, yet many of the details were not shared or understood. DOE should keep up on these and share more when possible. The hydrogen community is both growing rapidly and shrinking globally, making this communication and sharing even more important.
- The Program participates in and leads the IPHE, which facilitates hydrogen R&D and demonstration. The Safety, Codes and Standards subprogram leads the way with international engagement.
- There seems to be effective collaboration, though there is little public information available on specific opportunities or actions.
- The IPHE initiative across nations can be further intensified to achieve global competitiveness.
- The amount of collaboration was unclear.

5. The Hydrogen Program is sufficiently addressing energy and environmental justice (EEJ) and diversity, equity, inclusion, and accessibility (DEIA) in the execution and impacts of its RDD&D activities.

Responses rated on a scale of 1 through 10, with 1 indicating strongly disagree and 10 indicating strongly agree.

	Hydrogen Program EEJ and DEIA
Average Score	**8.2**
Number of Responses	20

Please explain the reason for your rating and comment on strengths and/or improvement opportunities related to engaging and leveraging stakeholders, external groups, and/or resources to address EEJ and DEIA within the Program's portfolio of projects.

- The discussion and emphasis placed on EEJ and DEIA was encouraging. With hydrogen hub placement selections, there is an opportunity to ensure the discussions and plans are followed through. Continuing to

engage with the local communities and leaders of the areas that will be impacted is essential. The reviewers are encouraged to keep this portion of the rating as highly important.

- The Program director tirelessly advocates for all, especially for women and minorities, as it should be. Coordination with the Office of Environmental Justice and Justice40 is outstanding. The newly appointed director of the Office of Environmental Justice and Justice40 may help ensure things are done correctly this time. More than any other single person, the new director may be able to ensure the seven hydrogen hubs never destroy the environment or human communities.
- The hydrogen hubs and manufacturing projects have large components of DEIA and EEJ activities, with extensive workforce development and outreach. It will be important to see how HFTO helps to coordinate and connect these activities so regions are learning from each other and not repeating unsuccessful approaches.
- DEIA and EEJ emphasis is in the early phases of being incorporated in the subprograms. The Program has developed tools to assess opportunities for investment and impacts of emissions and decarbonization to communities. The projects are encouraged to develop community engagement plans and address community impacts.
- The Program has placed strong emphasis on increasing efforts and mandating efforts to address EEJ and DEIA, including in funded projects. The actual implementation is just beginning in many cases, but the focus appears appropriate.
- This was clearly demonstrated during the plenary session by Dr. Shalandra Baker's presentation. Additional proof is the initiatives her office has undertaken and is advancing and the fact that EEJ is a significant component in all hydrogen hubs.
- The intrinsically more distributed and clean nature of hydrogen-based technology holds improved quality of life and access. In addition, the now-required components in all projects have required all people involved to both consider and act on these.
- All speakers and all DOE projects included some EEJ and DEIA components. This was a universal theme throughout the AMR and appears to be continuing throughout the year.
- There has been a change in which EEJ and DEIA have become important parts of FOAs and their selection criteria, as well as making them part of existing projects.
- Not only is hydrogen a great tool for slowing climate change, but the Program proactively considers justice issues in project selection and development.
- EEJ and DEIA are mentioned in all the projects.
- This is an area that is still new to many project proposers, as is the idea that not only should the long-range goal benefit all people (cleaner air, new jobs) but also some of the money from DOE should directly benefit the underserved—and the new energy economy should serve, not be built to the detriment of—the poorest Americans. DOE is definitely pushing these aspects and specifically asked for details of progress in the report template. DOE has a group focused solely on this work that has developed web tools and a game to help convey the desired outcomes. Only a few projects had meaningful advantages flowing to the community that were directly traceable to the project being funded. While this requirement is new, relative to requirements such as technical value and program management goals, it has been three years now, and there is not enough progress in selected projects building the community into the benefits of the funding of their work. It seems like all government agencies need to help proposers do better, but let us focus on DOE for the moment. Perhaps, to submit a proposal, the individual or group would be encouraged to go through a brief (say, an hour or less) training on what is expected in terms of EEJ and DEIA at the level of funding and type of project for which that individual is requesting support. Even if examples of what is wanted are not provided (because that is all that will likely be proposed back to DOE), at least DOE can point out, in a more general way, what is wanted, to emphasize authentic benefits—or at least what is not a good community benefits plan (CBP). To be clear, DOE is clearly working to make this transition reflect our best aspects as humans. The Department is, for example, hiring tribal interns and a diverse set of people for the workforce, and it is supporting science, technology, engineering, and mathematics (STEM) education in disadvantaged communities. DOE is making good effort internally, but that is diminished some by the funded projects' lower level of embracing these principles.

- The current administration and the BIL have put a significant emphasis on EEJ and DEIA requirements on many clean energy and hydrogen projects. Given that the majority of hydrogen RDD&D project managers and decision makers come from technical or scientific backgrounds with little or no background in environmental justice and equity, it is understandable most people find this topic particularly challenging. It is important that the hydrogen community recognize this and seek outside support. The invitation of the director of the Office of Energy Justice and Equity and, following her lead, the Program and its director seem to do exactly that and set a good example for the project managers. The site visit by a high-level delegation to Louisiana's "Cancer Alley" is an important message about learning from past actions and about the potential benefits to society of doing things right.
- This is an area of growing interest and a new consideration for some projects. Continued focus on this aspect will lead to improvement opportunities. There may be some value in evaluating potential opportunities in these areas for every project in the portfolio going forward. There may be value in having project leads work specifically to evaluate potential improvement opportunities. Perhaps a fact sheet or checklist could be developed to help ensure that a broader set of considerations and opportunities are integrated into project goals from the outset.
- There is still much work to be done, but initiatives such as embedding CBPs within the H2Hub proposals are to be applauded. Research in these areas was not strongly represented in the AMR presentations, and going forward, it would be good to see the Program supporting tangible projects that address these issues, perhaps in collaboration with other agencies through the HIT.
- To respond to FOA 2922, HFTO has made it clear that all proposals need to have CBPs to make sure that DOE funding will benefit communities, especially underrepresented communities. These fundings will help encourage students to pursue STEM as a career to become qualified engineers. However, during hiring and job assignment, high standards should be set.
- Efforts appear to be underway to address these needs. If nothing else, the attention to these issues is greatly expanded and much appreciated. This topic is another ongoing challenge on which to continue working.
- The sentiment of the Justice40 initiative is excellent; however, it is too early to tell if the technical programs can have an impact. It is also not clear how DEIA communities will benefit from the influx of hydrogen/energy funds into the communities, if the residents even want hydrogen built out in their communities. It is also unclear if the technical leads on DOE-funded projects are the best people to implement social programs. EEJ and DEIA issues in the United States are extremely complex by any measure. It is not clear how the hydrogen technical community can solve issues that have been entrenched in the United States for decades, if not centuries. Also, there is presently a backlash against DEIA in the private sector. Perhaps it is good that DOE is continuing to invest in Justice40/DEIA while others pull back. Hopefully, DOE has some good social scientists and statisticians who will be able to make sense of this socio-technical experiment, although the true impact may not be known for years or decades.
- One of the missing areas in the Program is about PFAS concerns, which might make a negatively large impact on the use of proton exchange membranes (PEMs) in fuel cells and electrolyzers. It is necessary to research actual effectiveness of PFAS use for a hydrogen area before it becomes a large concern. This is also an opportunity to collaborate with other IPHE countries, including the European Union.

6. The Hydrogen Program's efforts to advance workforce development and education in science, technology, engineering, and mathematics (STEM) through its current projects and activities are effective and sufficient to meet the Program's goals.

Responses rated on a scale of 1 through 10, with 1 indicating strongly disagree and 10 indicating strongly agree.

	Hydrogen Program Workforce Development
Average Score	**7.74**
Number of Responses	19

Please explain the reason for your rating and comment on strengths and/or improvement opportunities related to workforce development and STEM education efforts across the Program, its offices, and its portfolio of projects, including engagement of stakeholders, external groups, and/or resources to address workforce development and STEM education.

- The Program appears to have many activities addressing STEM education and promotion of hydrogen technologies within STEM.
- Notable resources include the hydrogen education card game, as well as university projects and student involvement.
- There are some projects dedicated to the development of capacity-building and skills development.
- Based on some of the summaries, there is hope and high expectations for the efforts.
- The support of STEM goals is implicit in every contract.
- It is a little early to comment on this until the workforce development efforts are kicked off and coordinated. Generally, HFTO does a good job with outreach around hydrogen (e.g., Hydrogen and Fuel Cell Day), has opportunities for fellows, etc., but the effort will be hugely increased with the funding available from the BIL.
- The DOE programs are focused on STEM education, which is highly commendable and should be mandatory for all government programs. This is a difficult question to answer, as the outcome of STEM investments may not be known for decades—and a success would be any student trained in hydrogen, who might then go to work in another field. It is not clear how DOE will keep statistics on its STEM investments, for instance, if a STEM student in hydrogen goes on to work on water, semiconductors, batteries, etc.
- The overall Program is doing well in encouraging the performing project organizations to engage in STEM activities and workforce education. It seems to be just starting, and there is a lot of education that needs to take place. It seems some projects hold a class or two and consider the box checked. More encouragement from HFTO or more consistent engagement within communities should be encouraged.
- Workforce development is a key component in all hydrogen hubs. On STEM education, attention should be directed to high schools and community colleges and how high school students who hear about the hydrogen economy can transition to community colleges in order to develop the required skills for future employment.
- This facet was referenced in many project presentations this year. There are opportunities to extend workforce development opportunities more into the middle and high school levels. The board game is a great start and a good example of lateral thinking to address this issue.
- There is fair degree of involvement of academia in all DOE programs. There may need to be a provision explored to hire more student interns in DOE laboratories from various graduate programs of various universities.
- Activities in this area were not clearly represented in the AMR project presentations, and hence it is not clear that this is or has been a focus for the Program.
- Education efforts in STEM are strong. Improvements are needed to ensure that technicians will have suitable training to develop the workforce beyond engineers.
- This Program is utterly dependent on experts highly trained in STEM and other areas as well. And yet, it is simply impossible for the Program to make sure there is quality instruction in STEM nationally or to be sure that enough high-talent and creative students choose a science and/or engineering career path. The budget could never spread to achieve that “filling of the people pipeline” and fund the science and engineering that is the Program mandate. Nonetheless, the Program and its awardees do make meaningful efforts. A single example is the 120 students funded by Nel Hydrogen to bring them the skills at Macomb Community College, helping build the local ability Nel Hydrogen will need to build electrolyzers. Because the Program could never ensure the people needed on its own, it is very hard to say whether the Program efforts in STEM human resource development are or are not sufficient to meet its needs. The work that is done in this area is well-designed but only encouraging and facilitating those already wishing to follow such careers. The overall task of workforce development and STEM education is really the job of the U.S. Department of Education.

- In recent years, most proposals requested CBPs to advance workforce development and education in STEM. Generally, the Program should be able to achieve the goal if enough effort is given to the area. However, it is a transition period to most researchers and developers. CBPs are an extra responsibility and effort for researchers. It is hoped that HFTO can set aside an extra budget for the CBPs above the budget for technology development.
- More active work with re-training existing technical labor forces is recommended, for example, retraining mechanics to work on electrolyzers, or perhaps a program to retrain various union labor organizations such as electricians, plumbers, carpenters, and so on.
- One gap that remains is qualified field technicians and contractors to work on electrolyzers, fuel cells, and other electrochemical equipment.

7. The Hydrogen Program adequately emphasizes safety in RDD&D across its portfolio.

Responses rated on a scale of 1 through 10, with 1 indicating strongly disagree and 10 indicating strongly agree.

	Hydrogen Program Safety Emphasis
Average Score	**8.9**
Number of Responses	20

Please explain the reason for your rating and comment on (1) gaps and/or strengths in the Program's approach to addressing safety and (2) the adequacy of the Program's efforts to engage and leverage stakeholders, external groups, and/or resources to address safety.

- It is obvious that safety is important to many of the projects. Safety reviews are being employed before projects begin. The Safety, Codes and Standards subprogram is providing important information. The Hydrogen Risk Assessment Models (HyRAM) tool is employed to analyze setback distances. As a result, more accurate cost and safety analysis is being conducted.
- Safety is a key component of HFTO projects, and that shows in every project presented at the AMR. Even many of the paper studies included a safety component for completeness. Funding of the Center for Hydrogen Safety (CHS) is a key component and the right, industry-inclusive approach to addressing safety.
- The CHS poster provided more information about the Hydrogen Safety Panel (HSP) and the resources available to researchers and institutions. Through HFTO, researchers have access to a variety of tools and resources.
- In addition to long-supported efforts to improve safety, codes and standards, the Program also initiated new R&D projects on developing new sensor systems for monitoring hydrogen leaks.
- The safety record of hydrogen is adequately addressed with the help of national laboratories and organizations such as Idaho National Laboratory's Human Factors, Controls, and Statistics (HFCS) department.
- It seems clear that safety and codes and standards have always been at the center of DOE interactions with communities and industrial stakeholders.
- Safety has always been well-maintained and rooted throughout DOE programs. The continued efforts are properly emphasized and appreciated.
- Safety appears to be adequately addressed in most projects. The Program's push to utilize resources to review safety plans is clearly evident.
- Each project is required to refer to the safety culture. It is important to evaluate outcomes of safety culture and lateral implementation.
- It has been noted and appreciated that a specific slide on safety was added into the presentation template this year.

- Safety is clearly emphasized throughout the Program. The tools to ensure safety are provided.
- Safety is receiving a new emphasis in the funded projects.
- The projects are working to develop required safety practices.
- Hydrogen safety is integral to the Program.
- The HFTO subprograms are emphasizing safety and putting in place mechanisms to enforce safety, for instance, by requiring work with the CHS. The presentation format requiring PIs to report on safety was not very effective, though. Most of the presentations made vague references to alignment with their own internal safety plans. The lessons learned were not helpful or useful for listeners to implement. For instance, the safety plan slides included minimal information, which was representative of most of the presentations at the AMR; and while it was good to know that the team complied with its hydrogen safety review, it raised more questions than answered, including whether the team did not have any safety plans before the start of the project and what international standards were implemented. Most safety reviews take hours, if not days, and a one-minute summary as part of a technical briefing was confusing and disconcerting. It is recommended that handling safety and reporting on integration of CHS activities be thoroughly reviewed by HFTO, as the present briefing mechanism is not helpful. Perhaps it would be more helpful to have a plenary session talk from the CHS, whose representative can discuss lessons learned and suggestions to new teams.
- This is a major facet for implementing within industry what was developed in the lab. The larger presentations and side conversations during the AMR illustrated that DOE staff are actively working with industry to create jointly funded RDD&D projects to help develop a viable bridge between the labs and industry for demonstrating the technologies and generating necessary data validating technoeconomic model analyses. These models strongly suggest commercial benefits from implementing these technologies, but the real industry capital sources require hard data.
- Safety is emphasized—and much more obviously this year than ever before. It is clear that DOE staff are driving safety in the management of the portfolio. As an example, safety reviews were mentioned frequently in presentations during the week. At the level of information shown at AMR, there seems to be no evidence of any undue risk; but it would not hurt to do more. The world-class experts who have not been in the lab themselves for more than a few hours in the last years, especially, can be lax themselves because a few of them feel they are too expert to make mistakes. This is obviously wrong, but that attitude can trickle down to the interns and graduate students. Here is the only improvement suggested is the following: if a PI wins funding, the PI must allow a lab safety review by an independent DOE safety team to get that funding, and funds can be pulled if significant hazards are found and not fixed.
- Most presentations highlighted safety planning and culture and discussed safety plans and health and safety panels, where appropriate. NREL presentations, in particular, were strong in this regard. That said, actual research relating to hydrogen safety was not strongly represented in the project portfolio and might be a future opportunity. It was good to meet the CHS at the meeting, and there seems to be a strong opportunity for international collaboration through the center. It was not clear if CHS is directly supported by the DOE Program, however.
- The HSP has been active for many years and can serve as a helpful guide to performers, if engaged. It is not clear how pushy the HSP is in soliciting project operators to require them to have reviews. Also, there was much more discussion of safety, with a required slide, but many current projects were not required to have safety plans. It seems like this area is evolving and growing, which is good.
- Well-thought-out safety targets in terms of leak detection and sensor technology are in place. In many field validation studies (e.g., M2FCT), testing of fuel cell stack efficiency and efficacy of sensors in refueling stations may be included.

8. The Hydrogen Program's portfolio of projects is appropriately balanced across (1) research areas, (2) technology readiness levels, and (3) research organization types (i.e., industry, academic, and national laboratory) to help achieve its mission and goals.

Responses rated on a scale of 1 through 10, with 1 indicating strongly disagree and 10 indicating strongly agree.

	Hydrogen Program Balance
Average Score	**8.16**
Number of Responses	19

Please explain the reason for your rating and identify strengths and/or gaps in the Program's project portfolio, including over- or under-represented research areas, technology readiness levels, and/or research organization types.

- More than ever before, DOE funds or helps the advancement of a hydrogen economy at every TRL level and in many ways (science, engineering, analysis, integration across technologies). There are even efforts, like the Hydrogen Shot Incubator Prize, to tempt people with only an idea to enter the research path at very low TRL. Everyone has an idea of a perfect balance, and that best balance will change over time. Additionally, the multiple orders-of-magnitude cost increase in each jump, going from lab to prototype and prototype to device and device to hydrogen economy, can give the appearance that a properly balanced set of projects is in fact overbalanced toward the economy-scale work; but, in fact, the Program is well-balanced. The fact that most of the early-TRL funds go toward problems to establish the needed science base is evidence of proper funding, while higher-TRL support is at a more substantial level of proposer co-funding, and projects are selected based on odds of success in areas of particular interest for achieving Program goals. As to allocation among institutions, the early-TRL work is heavily in academics, where cutting-edge science expertise is found, and in the national labs, which have world-class researchers and tools universities could not afford on their own. The high-TRL work is heavily weighted to industry consortia and the mid- to mid-high-TRL to individual firms, often with lab or academic partners. All this is highly appropriate, as it takes advantage of the strengths of each institution type needed at each level and also leaves the knowledge with the group best able to use it and pass the advancement up the chain. Finally, the distribution across areas of science engineering (e.g., production or codes or fuel cells) is good. The large funding of H2Hubs to hit a sustainable economy should be that high. Supply chain support is a great addition and makes the balance across areas even better. The large amount of money going to production and infrastructure is needed to meet the goal of $1/kg. Other areas (e.g., fuel cells) get less money, but those technologies are already in early production and really need funds for improvement of catalysts, etc., which the subprogram gets. The balance is good.
- The Program created a good platform for promoting advanced materials and component development, technology demonstration, and commercialization pathways through collaboration between academia and industry with national labs. HydroGEN and H2NEW are great resources for academic researchers and industrial developers to take advantage of available expertise and accelerate new materials and technology development. The reviewer looks forward to the collaboration with H2NEW on the electrolyzer projects.
- The Program displays a healthy balance between multiple, low-cost, long-term technology development projects and a few near-term, high-cost field demonstrations. Rather than attempting all new technology development internally, the Program supports working with other entities (academic, commercial, and governmental) to conduct the fundamental research. This enables the limited DOE staff to focus on the mid- and high-TRL demonstration projects for which they are currently best-suited.
- The Program's portfolio is well-diversified. It includes early-stage R&D and demonstration projects to evaluate the impacts of scale. The demonstration includes producing megawatt-scale projects to study and evaluate large-scale impacts. It includes the evaluation of renewable and nuclear-based energy for hydrogen production from low-temperature and high-temperature electrolysis.
- The program portfolio is well-rounded, and a large percentage of the projects have participation from a broad range of organizations. Continued encouragement of small businesses and low-TRL development is good to see and helps keep the next innovations moving.
- There appears to be a reasonable balance, with activities from BES for fundamentals, consortiums for applied research, industry scale-up funded projects, and H2Hubs for higher-level TRLs.

- The Program covers all the aspects of its portfolio in a well-balanced approach.
- No gaps were identified.
- The Program has a good mix of industry, national laboratory, and university projects (whether as leads or collaborators). The Program emphasizes teaming as part of its project selection criteria. The Program also appears to have a good mix of research areas and TRLs (from basic research through demonstrations). It would be good to know how much requests for information are used to get stakeholder feedback on potentially under-represented research areas (and how much the feedback is implemented) to ensure all research areas are addressed.
- Research areas, TRLs, and research organization types are being adequately addressed. Among research areas, alkaline electrolysis was found to be a little under-focused. In the hydrogen storage area, specifically chemical storage and metal hydrides, there does not seem to be work related to metal–organic frameworks.
- It would be good to see more research on equipment failures, including identifying failure mechanisms in faulty components and systems. For example, we know there have been failures of fueling hoses in the field and that the mechanisms for some of these failures are not currently known. International Organization for Standardization Technical Committee 197 Working Group 22 (ISO/TC 197 WG 22) is working to improve the standard for fueling hoses but needs data and analysis of failure mechanisms to be able to improve the standard to help reduce hose failures. It is not important to know who manufactured the hoses, but it is important to understand how they failed.
- Perhaps unsurprisingly, the Program seems to emphasize support for research in the DOE national labs. Greater evidence for collaboration between the labs and the academic sector was expected, perhaps supported by joint funding programs with other agencies, e.g., the National Science Foundation (NSF). It appears that the Office of Energy Efficiency and Renewable Energy has a partnership with NSF to support collaboration on scientific and engineering research, which could be leveraged in this regard. There is a good spread of industry involvement/leadership of projects within the portfolio, and it would be good to understand whether and how industry is involved in direction-setting for the Program, given that industry is the path to impact for much of the Program's research. Research into industrial uses of hydrogen seems underrepresented in the Program (particularly NH_3, which is emerging as a key hydrogen vector globally), as are social and environmental research. In the latter, research into atmospheric and water impacts of hydrogen production and use appears to be surprisingly limited. Natural hydrogen research also appears surprisingly nascent. Perhaps research of this type is supported by other DOE programs, but it would still be good to see it discussed as part of the AMR.
- The portfolio of projects is heavy on the national labs and, to a lesser extent, the academic organizations. This makes sense in the sense that DOE has been primarily R&D-focused and has invested a great deal in the national labs to conduct this work. However, the lesser role of industry is apparent and will become increasingly so as the need to address more commercialization activities and needs grows (assuming the existing balance does not change). If the objective is to leverage government leadership and initial funding to spark the needed private investment and sustainable market development, much more attention and focus needs to be placed on additional industry input, priorities, and commercial focus than has historically been the case.
- Partly because of the required processes and reviews in an open FOA vs. a lab call, many more lab projects have gotten under contract in the last year than anything else. Deploying the BIL funds will be important to rebalance this.
- A better balance is needed between research in national laboratories and universities. Sometimes, fundamental science questions can be better addressed in academia than in national labs. A metric of collaboration between national labs and academia can be the number of joint publications and their impacts. DOE should not want to see the national labs working in isolation.
- More industry-led research could be done to support the deployment of the technologies, but the 50% cost share for an ostensibly unproven technology is a challenge. If more first-of-a-kind and early-stage deployments were at a smaller scale as research projects, it would increase the amount of federal share to 80% and thus lower barriers for industrial research organizations.
- I'd like to see greater outreach to small businesses that can develop into the supply chain. Large businesses tend to be too risk-averse, so funding small businesses can then effectively derisk a technology, making it

more attractive to larger companies that can then acquire the small business and technology. This is an accelerated market-based approach.

9. The Hydrogen Program's announcements over the last year (e.g., selection of hydrogen hubs, selection of electrolyzer, fuel cell, and manufacturing projects through the Bipartisan Infrastructure Law Funding Opportunity Announcement) are contributing toward achieving commercial liftoff on a timeline consistent with the U.S. opportunity for hydrogen identified in the *U.S. National Clean Hydrogen Strategy and Roadmap*: 10 MMT per year by 2030, 20 MMT per year by 2040, and 50 MMT per year by 2050.

Responses rated on a scale of 1 through 10, with 1 indicating strongly disagree and 10 indicating strongly agree.

	Hydrogen Program Commercial Liftoff
Average Score	**8.6**
Number of Responses	20

Please explain the reason for your rating and identify additional actions DOE can take to accelerate progress toward achieving commercial liftoff.

- Perhaps the Program's greatest strength for many years has been the rigorous and realistic development of technical targets for technology that can guide RDD&D both in the United States and internationally. These are underpinned by deep strength in techno-economic analysis and life cycle analysis, all of which allow a clear focus on technical needs that help close commercial gaps (i.e., enable commercial liftoff). The hubs approach has clear merits in bringing together supply and demand centers to enable the industry scale-up that is a necessity for driving down technology costs. This model is being applied globally for these reasons. The clear commitment to hydrogen industry support, which the recent initiatives underscore, plays an additional role in providing policy certainty that should underpin industry and financial sector investments. Achieving commercial liftoff will also require progress to be made in other countries, and DOE might play a greater role in supporting international RDD&D collaborations, which can help achieve this.
- It is good timing for the Program to invest heavily in H2Hub and electrolyzer/fuel cell projects for both materials/technology development and manufacturing/supply chains. Through these programs, a variety of technologies for hydrogen production will be developed and commercialized in different timelines. Grey (gasification from coal and natural gas) and blue (steam methane reforming with CO_2 capture) hydrogen production are expected to be commercialized earlier. Then green hydrogen production using electrolyzers will follow. The North Dakota blue hydrogen hub at Synfuels Plant of Bakken Energy is expected to be operational by 2026 . By then, the plant could produce 310,000 metric tons of hydrogen per year, using primarily locally sourced natural gas (flare gas). The infrastructure established through H2Hubs will support green hydrogen commercialization. Through these programs, the *U.S. National Clean Hydrogen Strategy and Roadmap* targets will be met.
- The massive investment in these areas is exactly what is needed to achieve liftoff. Without these investments, it would not happen organically because of the prohibitive cost advantage of highly developed energy sources like coal and oil. It is unclear, given the 45V tax credit situation, if the 2050 production targets will be met; they are ambitious, but it is guaranteed they would not be even approached without these programs. There is excellent alignment with the strategy and roadmap.
- The current announcements appear to be meeting the intent and working to get to the yearly metrics. The recent inflation cost implications can possibly impact the timeline for commercial transition; however, there are still opportunities, and the overall Program is working and aware of those targets.
- Selected projects will benefit the goals beyond the progress from the projects directly. They add experience for those who work on the projects, clean energy in communities that benefit from the output, and opportunities to replicate successful projects.

- The Program showed unequaled, excellent communication.
- The recent announcements have entirely changed the hydrogen ecosystem, here in the United States and globally. The positive impact the hubs and other programs and investments have had on the hydrogen industry cannot be understated. Case in point, a prevailing concern before hubs and electrolyzer announcements was whether enough new hydrogen production could be instigated to build the market. Now, it has flipped, and the expectation is that we will have some (if not a great deal) of production, and focus is on ensuring sufficient demand to balance and create a sustainable market. However, the amount of public investment is not likely sufficient to achieve the long-term objectives in the roadmap. It is critical that even more happens in the near term (2030), by both public and private partners, to enable 2050 objectives. More focus on the immediate market needs, addressing market adoption and investment needs now, must occur. We have only hit the starting gate, and the next several years must be equally aggressive to reach those goals. Every option and effort must be made. They are contributing yet must expand further.
- The H2Hubs program has the potential for very high impact toward achieving commercial liftoff. However, running commercial contracts as cooperative agreements has reportedly imposed a bureaucratic burden for which the projects have been generally unprepared. Additionally, very strict rules around hydrogen production tax credits have led some companies to feel there has been bait and switch. Where possible, DOE should advocate for due consideration of the many comments submitted by industry to the Treasury Department. Companies and industry trade groups achieved near-unanimity in their condemnation of these strict draft guidelines. Within the administration of the H2Hubs initiative, DOE should understand that most partners are participating for profits, not investing in a billion-dollar demonstration project to make money on the next one. DOE should keep that in mind when specific issues arise; the companies are looking to turn a profit on their participation in the hub, and if that opportunity is jeopardized, then participating companies will drop out of the hubs.
- The Program has adjusted the R&D to evaluate large power systems for trucks and megawatt-scale operations. These systems will require large volumes of hydrogen, which supports H2@Scale. The Program has key projects linked to demonstrating large-scale production and use, which supports the demonstration of cost reduction through scale. The institution of large-scale hydrogen investment and production is delayed because of the uncertainty of the IRA tax credits. The intention was good, but the vagueness of the language and institution is delaying investment.
- The announcements are all consistent. The confidence of the presenters at the AMR of ~95% to achieve the goals is impressive. However, progress toward achieving the goals has been incremental year-over-year, and the 95% confidence level does not seem reasonable. The investment in carbon capture and storage is consistent with a Plan B on the cost of green hydrogen. What is not immediately clear is how acceptable the use of blue hydrogen is to meet hydrogen production targets and expansion of hydrogen markets.
- It appears that the 2023 announcements, especially the selection and funding size of the hydrogen hubs and electrolyzer manufacturing projects, constitute a significant development toward market liftoff and a necessary step to achieving the national strategy targets. However, these measures alone may not be enough to achieve the 2030 goals. Regulatory delays and uncertainties, especially around the hydrogen tax credit, will likely be detrimental to private investments and commercial liftoff.
- The announcements are important steps in achieving these goals. With the 45V tax credit guidance, it is not clear how some of the hydrogen hubs will respond, which could severely impact electrolyzer deployment. While this is not directly under DOE control, there is likely factual information that could be provided to help show how execution on the existing awards will be consistent with environmental goals.
- The different announcements create the conditions to fully support the achievement of the U.S. strategy. Nevertheless, success will also depend on the resistance to headwinds, such as the financial risks that investors are ready to take, the price that the industry players are ready to pay for clean hydrogen, and the evolution of the cost of energy (COE) and the inflation rate.
- Aside from changing the message from carbon footprint to energy footprint, this reviewer is not aware of any viable additional steps available to DOE. Perhaps by changing the message from an individual's "carbon" footprint, reporting and tracking an individual's "energy" footprint helps individuals reduce activities that still require high energy levels, thereby focusing energy resources on more effective ventures.

- The U.S. green hydrogen subsidies (under IRA) may keep global supply chains rather ineffective, thus depriving the United States of the benefit of testing various technologies other than those available in the United States.
- Yes, the programs are helping liftoff hydrogen technologies, but the 45V tax credit was always part of the support plan, and it has been crippled by heavy-handed rulemaking by groups that are against green hydrogen.
- The announcements and these initiatives are a great step toward the achievement of these goals, but the timeline (and goals) is quite ambitious.
- The ongoing negotiations between DOE and hydrogen hubs could be faster. In a number of hubs, there is no transparency on selected projects and goals. It is recommended that DOE make sure that the regional hubs have taken advantage of the corresponding local best talent and resources that could best contribute to the success of the awarded hubs. DOE should create/establish regional boards independent of the current hub construction and administration that will review the hub activities and directly report findings to DOE. It appears that the individual hubs are projects that are too big to manage and develop at a regional level. Perhaps DOE can redecide the magnitude of individual hubs once Phase 1 is completed based on promise, feasibility, and potential for national impact.

10. The Hydrogen Program has made adequate progress in the last year.

Responses rated on a scale of 1 through 10, with 1 indicating strongly disagree and 10 indicating strongly agree.

	Hydrogen Program Progress
Average Score	**8.6**
Number of Responses	20

Please explain the reason for your rating and identify technology areas that are not making adequate progress.

- There is a desperate need for the hydrogen economy to be in place even at this moment, so the nation and the world are behind. It is not clear if progress can actually be adequate under those circumstances. The progress made by active projects in the Program was substantial in the last year and certainly meets what might be expected at the funding level for those projects. Perhaps even more exciting is the new work that has been recently funded and is gearing up to reduce hydrogen costs and improve the needed structure at the technical, social, financial, and, of course, commercial levels. The HFTO director needed dozens of slides just to begin to point at the progress; and in fact, the hundreds of presentations and posters do not even cover all the progress made in the Program. There is not only good progress but also progress in all focus areas, plus the start-up of the hydrogen hubs and the new electrolyzer efforts. On the planning side, new roadmaps and the Multi-Year Program Plan have been developed, which will ensure proper focus by including guidance from stakeholders. It is easy to focus on technical progress, but the progress on these management tools is the foundation on which future progress will be built.
- Continued evaluation of cost drivers and working on use cases, hydrogen hubs, hydrogen production, and fuel cell development are going well. The reviewer heard many remarks about the progress from just last year being so positive.
- The Program had a huge job through BIL. It was a big job well done. This very influential Program will have a long-term impact. Congratulations to the entire Program and its managers, and leaders.
- The past year (or two) has been the strongest yet in DOE history. While the Program has had many good years, the levels of public investment, attention, and focus are unparalleled and most exciting. Now, the Program is encouraged to keep that going.
- Significant progress has been made in hydrogen technology demonstration and private investment for hydrogen or hydrogen carrier production, e.g., ammonia, in the United States.

- The Program has made significant progress. It has issued new FOAs to encourage industry and other sources of participation in RDD&D projects.
- Many projects, as per the presentations I attended—such as megawatt-scale low-temperature electrolysis, electrocatalysts for fuel cells, and M2FCT—have registered good progress as planned.
- The funding announcements on H2Hubs and electrolyzer supply chain projects are a very significant development toward market liftoff.
- Substantial progress was made on the ARIES (Advanced Research on Integrated Energy Systems) Flatirons Campus and the H2NEW consortium, two key projects of interest.
- Good progress has been made. The hydrogen hubs appeared slow to be announced.
- In general, project progress seems to be on track and delivering milestones as per the plans.
- The Program is progressing as normal.
- The Program is fast advancing its goals and objectives in all areas underlying a vibrant hydrogen economy. In particular, the formation of the HIT under the designated leadership will provide momentum for the mobilization of all national sectors and resources. However, it is not clear how the Hydrogen Shot 1:1:1 is advancing. It seems that the BES office is not playing a key role in this regard. Apart from the economies of scale and the greening of the electric grid, basic science is required to achieve the 1:1:1 target by focusing on issues of electrolyzer degradation, oxygen evolution reaction (OER), and the development of new low-temperature electrolysis concepts.
- H2NEW, HydroGEN, and old projects have made significant progress. Little progress has been made toward the Hydrogen Shot by the private sector because none of the funds are under contract yet. This is not totally under DOE's (or especially HFTO's) control, but there are many administrative hurdles to getting this much funding deployed, and it would be good to do a lessons learned session internally after this to see how similar efforts could be improved in the future.
- The 2024 AMR gave a feeling of excitement at the number and diversity of projects being deployed, the number of inter- and intra-agencies taking part, and the number of new stakeholders engaging in this space. Concerning is the potential for ASME rules on cell stack assemblies to delay deployment timeframes and increase costs for electrolyzers and fuel cells.
- The projects made some progress but have not been completely focused on the hydrogen roadmap. Now that HFTO has refined its focus and has historically high levels of funding, more progress toward the roadmap will be realized. The progress reported this year was only inadequate because of insufficient funding and market readiness.
- There do not appear to be any technological deficits resulting from anything other than bureaucratic sources. Modifying, creating, or removing legal or procedural matters appears to be taking longer than anticipated. From the outside, external factors appear to dominate this lack of progress.
- The presentations given during this AMR demonstrate clear progress since last year, but there is still additional progress needed to achieve the different ambitious objectives.
- Annual progress reports (APRs) are a great way to communicate what the Program has done each year. APRs are a great resource for people to find out information about what the Program is doing, as well as information on individual projects. The slides alone cannot convey that information.

11. Please describe any additional strengths or improvement opportunities in the overall Hydrogen Program, Program offices, and subprograms within offices (e.g., technology development, demonstration, and scale-up; technology transfer; techno-economic and environmental impact assessments; soft costs; management approach; portfolio development; commercial liftoff; outreach and education; impact on industry development).

- The Program is very well-structured in order to achieve all the objectives of the U.S. strategy and roadmap. The organizational structure and the subprogram structure have been well-adapted to fully align with the strategy. Interagency programs and projects are a clear strength of the overall Program. It favors the collaboration of experts from different domains while limiting, as necessary, duplication and overlap. Now that the technology has reached the stage of industrialization and mass deployment, the Program continues

to support low-TRL research. This is vitally important, as hydrogen technologies are still in their infancy, and technological breakthroughs are possible and needed.

- What has occurred in hydrogen in the past one to two years in the United States is incredible, owed in most part to the federal government's new attention and strong DOE activities. That should be recognized and applauded. However, that is only the beginning, and the road gets much harder before payoff will occur. It would be good to see this trend continue. It is also more important than ever, with expectations and objectives so high, that DOE helps the federal government transition more from an R&D focus to commercialization. R&D is critical, yet the transition is the way to scaled deployment and the roadmap objectives. Having even greater public vision and milestones, with accompanying near- and long-term public commitments, will be essential to scale the market and meet objectives. Frankly, this has been the easy part, and with this new attention, the road will be even more challenging. DOE and the hydrogen community have held through worse and can do this.
- Geologic hydrogen is a high-risk–high-reward initiative. The ARPA-E (Advanced Research Projects Agency–Energy) presentation by Doug Wicks was an excellent introduction to mobilize states and private stakeholders in this direction.
- The Program's portfolio of projects and research is focused and well-directed. The demonstration projects will provide valuable information to support the Program.
- All strengths are adequate.
- With the influx of new projects next year to HFTO activities, mainly around FOA 2922 and H2Hubs, it is strongly recommended that HFTO carefully consider how to revamp the AMR and the presentation format. The amount of funding per project will be much higher than in previous years, and the DOE goals are much clearer, so the present presentation format should be streamlined to accommodate these changes. A good portion of the slides in the present template are throw-away slides. Each speaker should not have to repeat the metrics for FOA 2922 next year, nor the goals of H2Hubs. More clarity needs to be given around the funding per budget period and the timing of the budget period relative to the presentations. The overall budget does not really matter as much as the budget for that period and the spending toward that period. Presumably, each project will be fully aligned with the DOE roadmap, and the language of the FOA is clear about which barriers are being addressed, so this does not need to be repeated by each speaker. The other question is how to handle the debriefings of the major projects for FOA 2922, considering that it is focused on building out U.S. manufacturing and the AMR forces international disclosures for each project. It is not clear which information is protected by the International Traffic in Arms Regulations (ITAR) or Commercial Control List (CCL). A possible format for the next year is for the DOE program managers give overviews of the big manufacturing projects, leave the peer reviews to that presentation, and not force 30-minute subprogram briefings. It is strongly recommended that HFTO have a serious discussion about what it wants to accomplish at the AMR next year and make some major changes to the present format.
- The hydrogen hub leaders should be pushed to take active interest in projects both in their geographic areas and those far away that would nonetheless benefit each hub. If the hydrogen hub leaders were not all at this review, DOE should actively consider replacing them; AMR should be a non-negotiable, must-attend event for hub leaders to look for ways to improve their odds of success both technically and financially. Other ideas are the concepts of training on what a good CBP looks like at each level of FOA funding and a lab safety inspection as a condition of funding. Project managers should be educated on the work being done in other offices and other departments (probably by the HIT), with the express purpose of looking for opportunities to introduce their PIs to PIs from other offices and departments where a mutual discussion of their work could help one or both. Also, the managers would look for opportunities for information their projects have or are producing to help other areas of the hydrogen effort across the government portfolio.
- There is a strong Program focus on (and excellence in) technology development but less on technology implementation. The latter is critical for commercial liftoff and encompasses many non-technical aspects, which include environmental and social aspects, as well as financial innovation (e.g., business case development). These aspects were not clearly represented at the AMR and hence not an obvious focus for the Program at present. Thought could perhaps be given to the role of the Program in developing these aspects. A clear strength of the Program is the involvement of technical experts in management and leadership, and this ensures alignment of investment decisions with rigorously understood technical needs, underpinned by excellent techno-economic models.

- It seems DOE should improve in two areas, although the Program is already very well run. First, focus on moving faster on key projects. ARIES and H2NEW are two very valuable projects that come to mind that are needed by industry faster than results will be available. Moving faster and building out more capacity for these types of projects, including through international collaboration, are different ways to achieve the same thing. The second thing is to focus on small-scale demo projects that can have 80% cost share, and for those larger projects with 50% cost share (such as hydrogen hubs), consider that participating companies are looking for a positive return on investment on the project itself, not just a derisking of a technology investment.
- The Program invested heavily to promote technology demonstration and commercialization. It should be noted that there are still technical challenges ahead. Continued investment in hydrogen programs is important to achieving goals of the *U.S. National Clean Hydrogen Strategy and Roadmap*. One question to think about is how to keep a high funding level for the Program. It is not clear if it is possible to establish a hydrogen foundation through private companies' involvement. The Program may want to take the lead to provide human resources for the hydrogen economy by cultivating talent in STEM through programs to provide hands-on experience in hydrogen technology for students.
- A supply chain analysis program is worth consideration. This program would identify industries that could likely develop products needed in hydrogen production or use and could then present reports and even consulting to any companies, states, and parties that are interested in the hydrogen economy. For example, a company that currently makes high-temperature and -pressure seals for natural gas extraction could find out that better seals are needed for hydrogen storage systems, what the seal requirements are, and what the market potential is and receive guidance and product development support through a national lab testing facility.
- The only potential improvement to the overall Program would be to include government-only closed-door meetings at DOE events. Federal staff are all so busy interacting with external entities during these events that opportunities to collaborate internally without the inefficiencies of the virtual environment may be missed. This would be in addition to having in-person meetings of the HIT and its working groups to help put names and faces together for non-DOE staff.
- It is fantastic the multi-year plan was published, but additional target tables need to be developed and communicated so that researchers understand the objectives DOE is trying to achieve with the appropriate amount of detail to direct their work and the direction they pursue.
- The only real comment is ensuring the economic analyses are realistic, given the inflation issues, and determining what real options exist if $1/kg cannot be achieved.
- It is recommended that the community keep up the momentum. It would be good to see more short publications highlighting successes and collaborations shared on social media.

12. The Hydrogen and Fuel Cell Technologies Office (HFTO) is the lead office coordinating activities across the broader Hydrogen Program. Please comment on the effectiveness, strengths, or weaknesses of each subprogram within HFTO and provide any additional suggestions you may have for improvement.

Hydrogen Production Technologies

- Fuel cells and electrolyzers are generally the same platform but operate reversely. The systems may have unique designs to meet different operations. HFTO may collaborate with FECM to identify some focus areas to continue solid oxide fuel cell (SOFC) or reversible solid oxide cell technology development. The new project managers at HFTO are knowledgeable and easy to communicate with. They are good resources for suggestions/improvements.
- The program manager for the Hydrogen Production subprogram has done a remarkable job with the BIL FOA. HFTO selected 36 projects, which if successful, could produce 10 GW/year, 1.3 million MT H2 per year. The subprogram recognizes a need in electrolysis for lower capital cost, scale-up of manufacturing to 1 GW/yr, lower COE (NREL load-following will help if capital cost is low enough), higher volume production, and market penetration beginning at $4/kg H_2. Electrolytic hydrogen cost is $9.35/kg today.

HydroGEN, ElectroCat, and H2NEW support the higher-TRL technologies and integration. Nuclear power may be able to reach COEs of $0.2–$0.3/kWh, which electrolysis needs to meet $2/kg H_2.

- HFTO's effectiveness in running the Program is rated as A+. Activities have progressed since 2005 under strong and visionary leadership. No additional improvements are needed.
- The main strength is the steady guidance and institutional knowledge of the HFTO management team leadership.
- The Hydrogen Production subprogram has a huge portfolio, and management is doing a great job maintaining it.
- HFTO appears to be doing an excellent job. The amount of work and complexity is a significant challenge.
- It is absolutely amazing what this office and staff have done over the last few years and decades.
- HFTO leadership seems effective.
- The subprogram is well-structured. It is relevant to consider the different production pathways. In addition to performance, durability, and cost assessments, it is important to systematically perform a life cycle sustainability assessment (LCSA) to ensure beneficial environmental impacts, the availability of the (critical) materials, and the recyclability at scale. For bio-hydrogen, sustainability criteria (land use, water use, biodiversity) should also be considered. Investing in priority in electrolysis is the right choice. Regarding the advanced pathways (e.g., direct water splitting), before investing too much, it should be clarified whether the reachable production rates are compatible with industrial expectations. The consortia-supported RDD&D is a real strength of the subprogram. Regarding the first feedback from large electrolyzers connected to intermittent sources and the higher degradation than expected, it is critical to understand why. The data analysis of the different demonstrations will be key, as it was done years ago with the deployment of fleets of FCEVs.
- The subprogram supports a range of projects and initiatives (e.g., H2NEW) regarding hydrogen production technologies that span the TRL spectrum, with an appropriate focus on meeting cost, durability, and performance targets. Electrolysis, as the central renewables-driven hydrogen production technology at mid to high TRL, is a strong focus area. Direct photoelectrochemical water splitting is a focus of lower-TRL research, and the subprogram's research in this area seems largely centered in universities, presumably for this reason. There is a strong emphasis on materials science research in this subprogram, and while this is an important area, some diversification might be warranted. Areas such as balance-of-plant development and system control need greater attention. Other production technologies such as natural hydrogen and biological pathways also seem underrepresented.
- The overall HFTO and its subprograms are well-staffed, developed, and prepared for this. None show any significant deficiencies or weaknesses, although the Systems Development and Integration and Hydrogen Infrastructure subprograms may need more support to address the growing, complex market demands and opportunities. More attention to market commercialization needs, greater industry input and prioritization, and generally transitioning from the old "R&D DOE" to more extensive and comprehensive market development is needed (including transitioning some activities to the U.S. Department of Transportation and other agencies as the sector grows and normalizes hydrogen).
- The Hydrogen Production portfolio is solidly constructed around the three less environmentally impactful "green" process technologies. Since these three processes release chemically bound hydrogen from chemicals prior to catalyzing a recombination reaction, perhaps there is room to reconsider hydrogen recovery from other chemical processes not given the significant advances in manufacturing over the last decade. Evaluating, recovering, and monetizing hydrogen from industrial chemical processes may fit more cleanly in this subprogram than in the Systems Development and Integration portfolio, which has different objectives.
- This is vital work for the Earthshot goal. It would be good to see regular reporting to a joint meeting of hydrogen hub leads to give those folks a better idea of the timeline for cost-effective and long-lived hydrogen production, and especially electrolysis, so the hubs can plan better. It would be useful to have hydrogen production analysis to support management decisions depending on the degree of progress on cost as the decade timeline approaches.
- The recent approach that forms consortiums of respective areas seems effective. HFTO oversees consortiums based on the technology roadmap. HFTO can use more external experts to get advice to maintain the roadmap with a high-level technical perspective.

- H2NEW is the most exciting effort seen in this office, and the subprogram should double down on moving faster to really understand the degradation/durability/performance/price of water splitting.
- Anion exchange membrane commercial scale-up and licensing and bio-hydrogen programs should be accelerated.

Hydrogen Infrastructure Technologies

- Hydrogen Infrastructure has many strong initiatives, such as H2@Scale and the Hydrogen Materials Advanced Research Consortium (HyMARC).
- Many excellent projects were presented involving testing and demonstration.
- This subprogram is logically organized, with activities aligning well to the stated objectives. The objectives focus on \$/kg H_2 throughout the hydrogen transportation network. This makes sense as part of the hydrogen economy commercialization effort. From the decarbonization perspective, it is unclear if there is merit in explicitly rather than implicitly considering the energy efficiency of delivered hydrogen (kWh/kg H_2 delivered). This should include both hydrogen losses (vents, diffusion, etc.) and energy required to contain hydrogen during transportation. Therefore, if hydrogen is an energy transportation vector and less energy is required to transport hydrogen, requiring less hydrogen to deliver the same capability saves money and reduces the demand on the hydrogen production infrastructure.
- The subprogram is well-structured. Despite the current trend for NH_3, it is important to continue to develop liquid hydrogen solutions. As hydrogen will be produced more and more with intermittent sources and industries usually need continuous flows of hydrogen, massive storage capacities should become more and more critical. In particular, the cyclability of storage has to be demonstrated. Additional projects on massive underground storage may be needed to speed up the developments in some hydrogen hubs, for example. Hydrogen blending in natural gas with a valorization of a costly molecule only for its calorific properties remains questionable.
- The thinking behind this subprogram is sound; infrastructure cost and availability are key barriers to hydrogen industry development. The greater focus on engineering aspects of hydrogen infrastructure in this subprogram is well-conceived. The subprogram is supporting a range of important projects related to hydrogen storage and distribution, including several in the key area of hydrogen refueling infrastructure. It was surprising to see that no work on ammonia was being presented, however. Given maritime interest in ammonia as a fuel and/or hydrogen carrier, issues such as bunkering will doubtless need to be addressed in the U.S. domestic context.
- The subprogram is well-organized and focused and critical work for meeting roadmap and strategy goals. Also, the subprogram may be able to help the hydrogen hubs prosper with this team's understanding of what is needed to generate a working and viable infrastructure. Every hub will face this, so holding a workshop for the hub leads (or maybe all interested members) could be a good use of manager and PI time.
- It seems that hydrogen-fueled heavy-duty transportation is an area that can kick-start regional hydrogen economies. DOE can work directly with the states to help develop state projects. The regional hubs can also be involved as important contributors though hydrogen production and their projects on heavy-duty transportation. More active participation by the states in hydrogen hub heavy-duty transportation projects may warrant success.
- Pipeline transportation and test methods to check the adequacy of existing natural gas pipelines for injecting hydrogen were noted. Work on liquid organic hydrogen carriers as means of easy transportation of gaseous hydrogen are recommended to be intensified.
- There seems to be too much focus on PEM water electrolysis R&D although its TRL is already high. There are opportunities to deploy more R&D resources to improve the alkaline water electrolysis, advanced proton-solid oxide electrolyzer cell (p-SOEC).
- Focus on technologies across many different scales (i.e., small scale liquefaction) and focus on pure hydrogen are recommended. Carriers have many challenges and blended hydrogen and natural gas is very nearly useless.
- Hopefully there will be more exciting progress through hydrogen hub programs.

Fuel Cell Technologies

- Great strides are being made in finding new catalysts with superior performance.
- There is excellent, solid, consistent leadership.
- Significant investments in fuel cell technologies are continuing. The increased emphasis on manufacturing scale-up is necessary, but the challenge will continue to be the alignment with industry needs, avoiding too much overlap with industry, and respecting industry needs on intellectual property, while trying to force the technology to mature as rapidly as possible. The work of M2FCT needs to continue with strong efforts. The subprogram should continue evaluating Pt targets on a total cost of ownership basis, including the potential for recycling, to ensure the targets are not overly constraining. The use of fluorinated materials needs to be phased out over several years. The fuel cell technologies are increasing emphasis in this area; perhaps more should be done.
- The strong historical focus of U.S. hydrogen research in this area is apparent in the existence of this subprogram. It is good to see much of the research in the subprogram being supported with industrial partners, which likely reflects the relative maturity of this technology area relative to some of the others in HFTO programs. The emphasis on heavy vehicles is consistent with global moves to focus hydrogen mobility efforts on this subsector. The subprogram seems to focus mainly on road transportation, and it might be good to see more work in the more emerging areas of maritime and aviation energy systems.
- The subprogram was well-structured. As for hydrogen production, in addition to performance, durability, and cost assessments, it is important to systematically perform an LCSA to ensure beneficial environmental impacts, availability of the (critical) materials, and recyclability at scale. H2CIRC (the Hydrogen Electrolyzer and Fuel Cell Recycling Consortium) should provide interesting results. The consortia-supported RDD&D is a real strength of the subprogram. Regarding the threat of PFAS and the difficulty finding relevant alternatives, there might be more projects on the topic.
- This is another subprogram that is well-organized, with activities aligning well with the stated objectives. Of particular interest is the reversible/unitized fuel cell research and the limited programmatic information provided. Given the large sensitivity of round-trip system efficiency to hydrogen storage pressure, it was surprising that no pressure target accompanied the system round-trip efficiency target of 70% since a levelized cost of storage does not equate to technical impact of a selected hydrogen storage method.
- The subprogram is well-organized and focused, and critical work is done to meet roadmap and strategy goals. Also, the subprogram may be able to help the hydrogen hubs prosper with this team's understanding of what is needed to generate a working and viable infrastructure. Every hub will face this, so holding a workshop for the hub leads (or maybe all interested members) could be a good use of manager and PI time.
- The fuel cell technologies portfolio was strong but had significant gaps, mainly due to insufficient funding in prior years. Future years should have much more comprehensive development efforts. The DOE labs have been playing a strong role helping industry accomplish progress toward the DOE goals.
- Focus on scale and simple operation is recommended. Reversible fuel cell and electrolysis, along with heat integration of fuel cells and storage systems to improve efficiency, are also recommended.
- Deepening the interaction with the BES office to remove roadblocks associated with materials degradation, intermediate-temperature electrolysis concepts, and catalysts for the OER is recommended.
- The progress is not impressive in fuel cell technologies. An FOA focusing on a specific area every year is recommended, as it may help bring in new ideas and progress during the AMR.
- Domestic bipolar plate manufacturing is one weak area. It is critically important to deploy resources in this area.
- Operating PEM fuel cells with low-purity hydrogen through electro-mechanical interventions is one area of interest.

Systems Development and Integration

- It is clear that significant modeling has been done on scenario analysis. It is important to note that all the factors are taken into account, such as the balance of hydrogen vs. other technologies (e.g., batteries) across the economy; the need for more electricity generation as a function of the balance; the need for more electricity generation based on the production method of hydrogen (e.g., green vs. blue); the projected

availability of precious metals (e.g., fuel cell production using Pt is needed to ensure the availability of iridium, because of the mining co-dependency); and other critical mineral considerations (e.g., battery use).

- As a technology demonstrator, this subprogram has an unfair advantage relative to the other subprograms. The expansion of test capabilities and support of the hydrogen hubs highlight the best of this subprogram. This subprogram appears to face unexpected bureaucratic headwinds in implementing the Program objectives such as supporting the launch of the hydrogen hubs or the HIT. The start of hardware demonstrations illustrates a capability of creative thinking and perseverance by the managers at the subprogram and project levels.
- SuperTruck efforts are a strength of this section. The projects are making progress and will provide great data when they are in the evaluation phase. Larger-scale system efforts are a strength in general because the information helps feed into the more technical and specific program offices on what the current issues and cost drivers are that keep transition and commercialization from happening.
- The subprogram is well-structured. As in Europe with the Hydrogen Valleys projects, the hydrogen hubs will have a critical role in the success of a hydrogen economy in the United States.
- It is good to see more technology demonstration at a system level and receive related reports to help researchers address related issues.
- There is a good breadth of projects, including fueling, total cost of ownership, manufacturing, validation, demonstrations, and modeling.
- There were many excellent projects involving testing and demonstration. The subprogram is world-class.
- There seems to be considerable overlap between this subprogram and the Fuel Cell Technologies subprogram, with a lot of effort devoted to fuel cell mobility here also. The subprogram seems to have an appropriate focus on system deployment and demonstration at various sites, and perhaps these capabilities could be leveraged in the form of training to address an apparent lack of activities in the workforce development space. The addition of more research in areas such as power system integration and control systems (e.g., artificial intelligence) would seem to make sense for this subprogram if it is to live up to its name.
- Several sub-areas are included in this group, and all are important. These demonstrations are predecessors, or perhaps a model, for the hydrogen hubs. Demonstrations really need to be encouraged to work with the closest hub(s) since it would be a natural progression to join the hub if they make serious progress that could soon be commercially viable. That relationship will help both the hub and the project.
- The subprogram is focused and well-led. The subprogram should encourage the projects to examine the impact of key variables on hydrogen costs. This could be provided through tornado charts. Waterfall charts should be developed to show how key areas could reduce the hydrogen cost.
- This is a really impressive subprogram. It would be good to see a more holistic approach from the different integration projects to test hypotheses and drive lessons learned.
- Off-road heavy-duty applications could be an early adoption area. It could be effective to stimulate this area in the way of the SuperTruck projects.
- Here the focus should be on industries with a proven record of accomplishments.
- Sensor technologies for leak detection were noted.

Analysis, Codes and Standards

- Safety, codes and standards are critical to reducing cost, increasing public confidence, and bolstering safety. Analysis is also critical to understanding the possibilities and the exact progress needed to realize the benefits of different scenarios. This subprogram is funding work that enables the codes that will govern the hydrogen economy, so it is well-aligned, and the right work is being done within the area.
- The subprogram is well-structured. It is great to see the development of user-friendly tools and set-up of the GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model) Train the Trainer program as developing sustainability criteria for hydrogen deployments and considering the indirect impact of hydrogen in the atmosphere. This cross-cutting subprogram addresses very sensitive topics such as safety, codes and standards, LCSA, outreach, and education, in addition to cost analysis. All these topics are essential to creating trust and to ensuring transparency, both being essential for the creation

of a hydrogen economy. The knowledge and the data needed to produce and to assess the subprogram budget appear under-evaluated.

- Hydrogen Safety Panel, risk assessment, sensors, and component failure R&D are all projects to strengthen this subprogram.
- The work to understand the different metrics associated with hydrogen technologies and —not just physical parameters but environmental/justice metrics is admirable.
- The safety record of hydrogen is adequately addressed, with the help of organizations and national laboratories such as the HFCS.
- The subprogram is focused and well-led. It is developing tools that are relevant to direct the other programs' subprograms. The subprogram should update the Hydrogen Analysis (H2A) tool with new information from the projects, such as adding the cost of electrical switchyard and transformer equipment for the electrolyzer module. Waterfall charts should be developed to show how key areas could reduce the hydrogen cost. Adding the benefit of oxygen sales from low-temperature and high-temperature should be considered. Oxygen currently is being vented from the equipment. In some of the industries, the oxygen product is being used and could be included as a low-carbon supply.
- The subprogram seems well-coordinated, with significant progress demonstrated on modeling, testing, and validation. It would be good to see more analysis results available to codes and standards working groups, as well as opportunities to describe any additional data and modeling needs so these issues can be resolved to facilitate timely improvements to needed codes and standards.
- Whereas work and progress in this area are excellent, better coordination is needed with state agencies for public engagement and education. By way of example, DOE must help the states establish state regulatory frameworks for safe operation of hydrogen technologies (pipelines, green hydrogen production projects, even carbon capture and storage for blue hydrogen production).
- This subprogram would benefit from more explicitly identifying targeted codes and standards for harmonization. Many organizations and entities maintaining common codes and standards challenge schedules under the best of circumstances, and introducing comparatively novel concepts requiring educational sessions does not help the situation. More explicitly identifying these codes and standards, rather than burying examples in the Multi-Year Program Plan, would give reviewers a better appreciation for the harmonization challenges. Although is it an international rather than a domestic standard, there may be merit in reviewing the International Electrotechnical Commission (IEC) codes on fuel cells and electrolyzers (particularly IEC 62282 and subsidiaries). Along the way, there appears to be an opportunity to close the gap on codes and standards for siting industrial scales of hydrogen or hydrogen carriers in close proximity to ports (naval or aeronautic). Revising the codes and standards to enable universal adoption of a hydrogen economy includes updating building codes and zoning ordinances in proximity to these ports.
- Not enough progress is being made, especially in SOEC testing standards. For green hydrogen production, one of the critical tests of performance is Faradaic efficiency of SOECs during the initial development stage. Such testing, especially using button cells, is not well-established and -implemented. It is recommended to establish a finite element (FE) testing standard by modifying existing SOFC testing stand and perform matrix tests using commercially available SOECs and low-temperature SOECs under development. A comprehensive report could be generated, including detailed testing procedures, system calibration, and FE calculation, which could be shared with other researchers, national labs, and industrial developers within the SOEC community. This small project could benefit the whole Program.
- This is a hugely important area, with regulations and standards frequently cited as major barriers to hydrogen project development, globally. The scale of the portfolio of research in this subprogram seems limited, given this importance. The area of standards development is particularly suited to international collaboration, which might help leverage this subprogram's investments.
- A study for PFAS concerns is needed.