Appendix A: 2023 Hydrogen Program Review Summary

This appendix shows the results of the Hydrogen-Program-level peer review for the 2023 Annual Merit Review and Peer Evaluation Meeting (AMR), including feedback from a subset of the reviewers attending the AMR. A total of 23 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

3M Company	Patturns
Electric Hydrogen	Plug Power Inc.
Energy and Environmental Research Center, University of North Dakota	Toyota Motor North America
Fuel Cell and Hydrogen Energy Association	U.S. Nuclear Regulatory Commission
Hydrogen Fuel Cell Partnership	University of California, San Diego
Hyrax Intercontinental LLC	University of Illinois Urbana-Champaign
Ionomr Innovations Inc.	Victoria University of Wellington
Los Alamos National Laboratory	West Virginia University
Nel Hydrogen	World Bank Group

1. The Hydrogen Program plan and strategy were clearly articulated and well-aligned with mission and goals of the National Clean Hydrogen Strategy and Roadmap and the Hydrogen Shot.

Please rate your response on a scale of 1 through 10, with 1 indicating that you strongly disagree and 10 indicating that you strongly agree, or N/A if you have no opinion.

	Hydrogen Program Overall Strategy
Average Score	**9.2**
Number of Responses	21

General Comments:

- Well described. The H2Hubs program will provide funds and de-risking of much larger deployments of clean energy in the form of hydrogen. This, in essence, is the aim of the national plan—to bring a full-scale hydrogen economy into existence—so the alignment really could not be better. The several smaller research funding opportunity announcements (FOAs), the fairly large clean hydrogen electrolysis and manufacturing FOA, and the tax credits for hydrogen will support work on enabling the research and near-commercial development needed to significantly reduce the cost of hydrogen and its delivery, which of course is what is needed to stabilize those hydrogen ecosystems economically and make them financially and ecologically sustainable. The constant underlying theme of doing this in a way that brings the benefits to the underserved aligns the Program's work with the administration's environmental justice and diversity, equity, and inclusion (DEI) objectives as well.
- The Hydrogen Program is one of the very best organized, closely managed, and carefully executed programs in DOE. Drs. Satyapal and Miller, as well as the other managers, provide excellent leadership—the highest-quality leadership—for the Program. They masterfully integrate the entire government-wide hydrogen effort to ensure attaining 2026, 2031, and 2050 goals.

- The visionary leadership of Dr. Satyapal and her team, along with the persistent and continued efforts over the years, has established a strong foundation that warrants and maintains the Program's health, thus ensuring the meeting of goals and objectives. Another important strength of the Program is mentoring the next generation of managers—an important accomplishment that warrants the continued success of the program.
- In my opinion, this Hydrogen Program is one of the very best programs among all different federal agencies. I was able to attend, in person, all key presentations, from Monday's plenary talks to the very last excellent talk delivered by the National Renewable Energy Laboratory on Thursday late afternoon. I am very impressed with the technical quality of the projects and the different programs presented throughout the 2023 AMR.
- The Office of Energy Efficiency and Renewable Energy (EERE) has done excellent work to articulate the mission and goals of the Hydrogen Program.
- Opening speakers did a good job tying the Hydrogen Program to U.S. goals for decarbonization, climate change action, good paying jobs, and community benefits. It was also great to see the opening speakers and panels discuss safety.
- Very strong integration is clear, both across DOE and across the government. This is a major advancement for the Hydrogen Program across the last few years.
- The Hydrogen and Fuel Cell Technologies Office (HFTO) has done an excellent job managing the multi-dimensional program.
- The plan and strategy were clear and well aligned.
- The hydrogen strategy came out too close to the meeting to be able to tell whether the Program plan is aligned. The Program plan was clearly articulated.
- I think there needs to be some realism about consumption and the smart use of energy rather than looking for a business-as-usual solution that looks for a technology switch rather than a serious reinvention of how society uses energy.

Specific Comments on how well the Hydrogen Program has identified important challenges to meeting goals and articulated plans to address the challenges.

- There is so much here, it could never be captured in 4,000 characters. Let's try to summarize instead. The key barriers for production, delivery, storage, and fuel cell use in light-duty transportation have been in place for over a decade; and while the levels are new, the heavy-duty barriers are the same, just more so. The Program has subsequently expanded its target to be essentially all energy uses and has elucidated the barriers in these many new uses. They are perhaps surprisingly similar qualitatively but in some cases are easier quantitatively (though, for example, cost for rail use is even harder), so the barriers are and have been well understood by the Program for some time. What is new is the plan for meeting the challenges. There is a significantly more product-focused or engineering-guided nature to the research and development (R&D) plans this year and last, with more focus on what could be done with that material that would benefit the taxpayer. Specifically, the transportation focus, while still a part of the Program, no longer dominates it, and there is real work to seek other and, fortunately, easier ways to launch hydrogen applications. There is also a greater emphasis on hard-to-decarbonize applications where electricity is simply not going to help. At the same time, the Program retains its efforts on codes and standards, which are indispensable, critical even, to a functioning economy, because this is what allows predictable and swift permitting and affordable insurance. I think, overall, this is a healthier and more helpful approach for the nation.
- The Hydrogen Program, as in the past, has done a very good job of developing and communicating technology roadmaps for the R&D activities with which I am most familiar: fuel cells and hydrogen infrastructure. The goals are generally stretch goals to challenge the R&D community, and the progress toward these goals is communicated regularly.
- In the electrolysis area, DOE has set the viable 2026 goals and specifically identified very clear target performance parameters—including cost, cell area-specific resistance (ASR), and current density (hydrogen production rate)—to be able to achieve those goals.

- The focus of the Hydrogen Program's goals on the industrial utilization of hydrogen (e.g., blending hydrogen for combustion, green steel, ammonia production and combustion, energy storage) is the strongest facet of the Program beyond its goals in the transportation space.
- Goals are very clear and aggressive. The presentations demonstrated how different pieces of the system (production, delivery, end use, etc.) contribute to success and what the Program is doing to drive down costs and address challenges.
- HFTO has identified technical issues, supply chains, and manufacturing to improve electrolyzers' service life, production rate, processing, and materials cost to meet the cost target.
- It was great to see the opening speakers and panel discuss the challenges for safety and describe the level of coordination involved.
- One of the major issues is that $1/kg in 1 decade may not be a realistic goal, given that, for electrolysis, it requires (at 60% of cost from electricity) that the cost of electricity is far below the long-run marginal cost of renewable energy. The perception that variable renewable energy prices will continue to decrease ad infinitum is not realistic, given realities of commodity costs, supply chains, and labor/soft costs. I worry a bit about setting such a target and then making funding decisions on potentially unrealistic numbers.
- There seem to be significant gaps in correcting and addressing funded projects that are not performing. There are good plans in place for different technology readiness level (TRL) development, but the reliance on established national lab scientists and the "usual" crowd of players seems to belie the concept of enacting change.
- The largest challenge is the need for more staff at HFTO. The office was constrained from hiring in the previous administration, and it shows. The understaffing makes it difficult to get FOAs and funding out on time.

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

Please rate your response on a scale of 1 through 10, with 1 indicating that you strongly disagree and 10 indicating that you strongly agree, or N/A if you have no opinion.

	Hydrogen Program Stakeholder Alignment
Average Score	**8.4**
Number of Responses	19

General Comments:

Please describe any areas that you feel are not well aligned with industry needs or that require more (or less) federal funding support.

- The Hydrogen Program is well aligned with industry and stakeholder needs. Through intense communication and integration, DOE is ensuring that information, including DOE objectives and Program goals, is conveyed to all stakeholders in a clear and timely manner. DOE realizes the approach of funding a few entities and walking away will not work. To achieve the DOE goals, DOE must make sure that funding goes to diverse corporations and entities. The DOE Hydrogen Program realizes that fact and is executing intense integration to ensure goals are achieved.
- I have given about as high a grade as is possible under the new, wider scope of work. Because they have taken on so many more beneficiaries to the work they fund and manage, it becomes increasingly difficult to "align" with all of them. They seek industry input, either via tech teams or project by project, with industrial collaborators offering direction but no funds or goods. There are examples of state and private investment complementing DOE funding, and there is little if any complaint about DOE doing work that

should be done by industry. Of course, there are industrial groups as principal investigators or as subs on larger FOA projects, and of course, the cooperation between industry and DOE is perfect there.

- While there is probably some interagency alignment, the Program feels slightly inward-facing and focused on the national labs. There is tremendous capability there, of course, but in the photoelectrochemical (PEC) area, I would suggest that there is no industry interest because there is no obvious path to market. There is also perhaps too much focus on the United States and little appetite for international collaboration at the top level, though of course individual researchers will have their networks. It was encouraging, however, to read that DOE had provided funding to work with Synhelion; this is the sort of potential win–win that helps better use public money. Natural gas cracking research should be discontinued—you will never get to an emissions-free supply chain, even if the hydrogen production itself does not emit CO_2.
- Industry appreciates the R&D efforts yet has been requesting additional market implementation activities and support. There have been times when industry feedback on this has left the impression that market development and implementation are not as valued or supported as base R&D. The hope is that establishment of the Office of Clean Energy Demonstrations (OCED) is recognition of this change toward driving needed R&D into full market realization (as a partnership between government and industry).
- The integration is good, and cost-sharing efforts are clear. It seems like there is still some struggle to find end uses and adoption for what could be an abundant supply. The "clean energy" market is full of various alternatives for consumers and businesses, so additional effort to spark adoption may be needed.
- The national lab consortium approach limits access to industry participation through FOA-funded projects, very expensive "work for others," and intellectual property (IP)-conflicted cooperative research and development agreements (CRADAs). In addition, there is insufficient responsiveness to stakeholder feedback when weighted by national labs. Examples of this include (1) the ElectroCat (electrocatalysis) program, which has been criticized for relying on iron, a known poison for proton exchange membrane fuel cell (PEMFC) membranes, and (2) the goals for heavy-duty fuel cells, which include inflated system costs and therefore place an unrealistically high burden on materials development. These approaches hinder the national lab projects' relevance.
- The funding for the Inflation Reduction Act (IRA) needs to get out faster. Hydrogen from Next-generation Electrolyzers of Water (H2NEW) had no related FOAs since its inception until the electrolyzer one came out a few months ago. Project selection and contracting needs to happen quickly.
- In the future, the Program may wish to focus more on end users that are the engine of the hydrogen economy. In fact, it is the end users that will lift off the hydrogen economy. Efforts on hydrogen production are already well under way.
- It would be great if the Program could also include the real consumers as one important stakeholder and consider how the Program resources could be invested wisely to let the consumers see/feel the benefits.
- It is not clear from all the presentations how DOE has aligned the Hydrogen Program with industry and stakeholder needs.

Office-Specific Comments:

Please comment on particular strengths and/or improvement opportunities relative to specific DOE Hydrogen Program offices in the table below:

DOE Office	Strengths	Improvement Opportunities
EERE	• Strengths include the organizational structure, active involvement of the technical managers with the technical projects, clear outline of goals and objectives, coordination between national laboratories and industry, a rigorous review program, and the organization and impact of the AMR. • SuperTruck projects are a good example of partnering with industry on helping develop hydrogen versions of medium- and heavy-duty trucks that will sell by having industry leaders develop them with DOE de-risking the effort. • Dr. Satyapal's long tenure translates to a powerful "corporate memory" and a steady hand at operating a very complex set of R&D activities, ranging from rather foundational to demonstration and deployment. • The Hydrogen Program HFTO is providing outstanding leadership under its director, Dr. Satyapal. • The Program is collaborative, with both industry and other DOE program offices, and is building unprecedented collaboration with other government agencies. • EERE activities are centered on the DOE mission. • Strengths include clear leadership and coordination. • A strength is the Program's ability to link the excellent work at national labs and universities with industrial teams able to begin commercialization.	• DOE has put out excellent efforts to drive three or four different fuel cell technologies to demonstration. The historical fact is that the cost of developing a particular fuel cell technology to the demonstration stage has taken at least a $1 billion per technology and decade(s) per technology. To aggressively achieve and possibly exceed the Hydrogen Shot 1-1-1 goal, for now, DOE must be very selective in choosing the most promising and highest-TRL technologies in which to invest. Those must be able to impact 2026 and 2031 goals. Among those fuel cell technologies, the proton-conducting solid oxide electrolysis cell (p-SOEC) is at a very low TRL level and lacks commercial interest worldwide because of the lack of validated, consistent, repeatable results. The low-TRL technologies (p-SOEC, tubular SOEC, direct methanol PEMFC) will each take $1 billion and decade(s) to validate and demonstrate. There are only eight years left to 2031 and only limited funding to reach the Hydrogen Program goals. DOE cannot indulge every distraction, however promising the seedlings claim to be. • There should be more active interactions with the DOE Basic Energy Sciences program and the National Science Foundation toward removing science and engineering roadblocks such as catalyst degradation and materials issues. The Program should focus on end-user small businesses that will advance commercialization. • The Program could provide one-stop shopping for the public to integrate the work of the offices.
FECM		• In the area of high-temperature electrolysis, DOE should leverage the progress and advancement of solid oxide fuel cell (SOFC) technology funded for more than 30 years by the Office of Fossil Energy and Carbon Management (FECM). DOE should continue SOFC work (or at least SOFCs via reversible SOFCs).
NE	• Behind-the-meter hydrogen production at plants is another good example of proper positioning vis-à-vis industry. Years of DOE research made the technology worth trying, and de-risking funds made it worth trying economically. However, a power company actually did the implementation. • Nuclear electricity for electrolytic hydrogen production is a great approach to clean hydrogen production.	• The country's nuclear fleet is old. Can the emerging hydrogen economy be planned on using nuclear electrons for hydrogen production? This question needs to be addressed. Is small modular reactor technology more relevant to hydrogen's future than existing nuclear plants? • Fusion projects could be folded into the fission ones being described.

	• The nuclear energy work is much more integrated than in the past.	
SC	• The AMR did a good job highlighting how basic science efforts are contributing to advancing the hydrogen sector. • There are generally good efforts to promote "scientific" discovery.	• National lab scientists should not review business or marketing FOAs. • It would be helpful to clarify which projects/ advancements are far enough out that they need this basic effort, *vice* later-stage adoption efforts other offices are doing.
ARPA-E	• The focus is on commercial impact and outcomes, as well as disruptive technology. Commercialization is wrapped into the technology. There is active program management, as well as excellent exposure and training to fundraising.	• The SCALE-UP (Seeding Critical Advances for Leading Energy technologies with Untapped Potential) program is a great idea to enable deployment demonstrations; a more guided/couched approach from SEED (Supporting Entrepreneurial Energy Discoveries) to general ARPA-E to SCALE-UP would be helpful.
OCED	• Hubs are the strength. They are not in place yet, of course, but these are a mix of DOE technical developments bringing technical advancement in all aspects of the hydrogen economy, with major groups of companies, state agencies, community groups, and so on designing the implementation to work economically. • The work is market-development-focused, extending EERE's R&D focus into real-world success. • It was great to have OCED involved in the panels in the opening session.	• Opportunities include (1) keeping focused on what the market needs to develop at the upper end of TRLs and (2) helping to de-risk "last-step" industry needs into real market opportunities. • There should be a way to ensure applicants are aware of programs run through this office and other offices. Perhaps there could be a clearinghouse in coordination with EERE.
Other (specify)	• Collaboration with development finance institutions is a strength.	• There is a good deal of scope to leverage DOE efforts in the context of coordinating with the World Bank to further work on this topic.

EERE: Office of Energy Efficiency and Renewable Energy
FECM: Office of Fossil Energy and Carbon Management
NE: Office of Nuclear Energy
SC: Office of Science
ARPA-E: Advanced Research Projects Agency–Energy
OCED: Office of Clean Energy Demonstrations

3. The Hydrogen Program's portfolio of projects is appropriately balanced across research areas to help achieve its mission and goals, and it has an appropriate balance between near-, mid-, and long-term RDD&D (including lab projects and consortia, FOA projects, CRADA projects, etc.).

Please rate your response on a scale of 1 through 10, with 1 indicating that you strongly disagree and 10 indicating that you strongly agree, or N/A if you have no opinion.

	Hydrogen Program Project Portfolio
Average Score	**8.5**
Number of Responses	17

General Comments:

Please describe any over- or under-represented areas, including any gaps in the overall Hydrogen Program project portfolio or any comments you may have on whether funding levels in each area are appropriate.

- The Program encompasses the Basic Energy Sciences program doing TRL 1 and 2 all the way through OCED doing TRL 9, de-risking and supplier–user matchmaking to generate a stable hydrogen economy. Plus, there are Small Business Innovation Research (SBIR) projects and Loan Programs Office work, too. The funding tends to scale with TRL, as is appropriate. The distribution of projects is uniform across TRL, though one might argue there is a little less in the TRL 5 and 6 area, as that seems handled mostly via SBIR projects, which are a small component. This is not a significant flaw, and many would argue this is an area industry should be shouldering anyway. A wide variety of topics is covered—almost every method of production and delivery and many use cases—essentially everything where R&D might move the needle. There are no obvious blank spots.
- I like the broad spread of research areas and the inclusion of some high-risk areas such as solar thermochemical, which has the potential for serendipitous discovery, as it is such a challenging area scientifically and practically. I am less convinced about PEC, as the main progress has been in perovskite photovoltaics (PVs), and successfully connecting this with a wet surface seems unlikely. I also simply cannot see how a large electrolyzer surface could be practically applied. PV and electrolysis with the process intensification of high current density seems so superior that there might not be much point to continuing this area of research.
- There are no gaps. DOE has driven three or four fuel cell technologies to market. The cost of developing a technology to the demonstration stage has taken at least $1 billion per technology and decade(s) per technology. There are only eight years left to 2031. DOE must trim and focus to drive toward its goals with the limited funding and time available.
- A really strong balance has developed.
- Research, development, and demonstration (RD&D) are needed and important, yet even this question leads only to research needs vs. other opportunities and needs the Hydrogen Program *must* include to move R&D into full market reality. Additional activities around connecting and expanding R&D to policy, workforce, community, implementation, and other "market-based" development activities are critical; otherwise, the R&D does not result in full market potential (or not in a timely fashion). Establishment of OCED appears to be the first real recognition of this and is critical to the success of current and previous investments.
- The national lab consortium approach limits access to industry participating through FOA-funded projects, very expensive "work for others," and IP-conflicted CRADAs. In addition, there is insufficient responsiveness to stakeholder feedback when weighted by national labs. Examples of this include (1) the ElectroCat program, which has been criticized for relying on iron, a known poison for PEMFC membranes; and (2) the goals for heavy-duty fuel cells, which include inflated system costs and therefore place an unrealistically high burden on materials development. These approaches hinder the national lab projects' relevance.
- I would put more effort into systemic approaches to get projects to the final investment decision. Socioeconomics of hydrogen remains a difficult and complex issue globally. I recommend putting a bit more effort into global cooperation—the World Bank Hydrogen for Development Partnership (H4D), the Clean Energy Ministerial and Mission Innovation, the International Renewable Energy Agency (IRENA), etc.—given the need to develop a global industry.
- An under-represented area is near-term hydrogen production and infrastructure development, which is critically needed to address the current high hydrogen retail price issue. Lab and consortia projects may be a little over-weighted. Projects from academic groups are underrepresented.
- Besides demonstrations and large-volume manufacturing development, it is recommended that DOE have a significant R&D focus on *transformative* modifications of current *stack* technologies, not development of a brand new technology (e.g., new electrolytes), to meet the DOE goals within the established timeframe (e.g., $2/kg hydrogen in 2026).
- Stronger collaboration between the national labs and academia is essential for roadblock removal, e.g., to meet the "111" goal of the Hydrogen Shot.

Office-Specific Comments:

Please comment on particular project portfolio strengths and/or gaps relative to specific DOE Hydrogen Program offices in the table below:

DOE Office	Project Portfolio Strengths	Project Portfolio Gaps
EERE	• EERE has a wide range of funding portfolios to support different hydrogen programs from RD&D to technology demonstration and manufacturing. The recent $750 million investment in electrolyzer technology, supply chains, manufacturing, and materials recycling will advance green hydrogen production technologies and accelerate commercialization of these technologies. • The hydrogen production, delivery, and infrastructure subprograms are very strong. The safety, codes and standards technical assistance programs are expected to be impactful. Work and contributions from national laboratories are important. The national lab collaborations with industry are very strong. • Breadth and depth of Program R&D activities is accompanied by a strong analysis function of most of the aspects of the Program sectors that allows for tracking progress over the years. • There is a broad portfolio of production, delivery, and use—and at many TRLs from 2–3 to 6 or even 7, with SBIRs counted. • HFTO, with its excellent leadership, is driving, through integration, a diverse set of stakeholders to achieve 2031 goals. • The Program has a well-structured, comprehensive portfolio covering all aspects of hydrogen and fuel cell technology developments. • The Hydrogen Program regularly seeks stakeholder input and addresses RD&D needs.	• I hope to see increased investment in biofuel and its production. For manufacturing and industrial decarbonization, the key driver is the TRL for hydrogen production. For example, the ammonia and steel industry may not need high-purity hydrogen. The hydrogen production from coal/biomass/ waste gasification may have advantages since there is existing infrastructure and lower capital cost investment. • It would be great if more and quicker investments could be guided toward hydrogen infrastructure development to address near-term hydrogen supply and cost issues. • A gap is education of local managers for commerce and economic development at the county level within states. In the end, it is these managers who will work to attract and interact with prospective end users. • There are no gaps.
FECM	• A variety of funding was provided to support gasification of coal, plastic, biomass, agricultural waste to produce syngas, and hydrogen, which can be used as fuel to operate SOFCs to generate clean electricity with higher efficiency or as starting materials to produce chemicals. Based on the characteristics of renewable energy,	• The hydrogen economy relies on multi-level and multi-dimensional technologies, including hydrogen production and applications. Some applications, such as PEMFCs, require high-purity hydrogen. Some, such as high-temperature SOFCs and the ammonia and steel industries, have no strict requirements for hydrogen purity. I hope to see increased investment for hydrogen production from gasification combined with carbon capture to

	FECM also funded the RD&D for reversible solid oxide cells, which can produce both hydrogen and electricity. This funding ensures hydrogen technologies continue advancement in the United States.	provide hydrogen to these industries to achieve Hydrogen Program targets earlier and with lower cost. The combination of gasification and carbon capture is expected to reduce CO_2 by emission by 80%–90%.
NE	• Good work is happening now to demonstrate the advanced electrolyzer technologies by taking advantage of low-cost electricity from nuclear energy. It will generate a good amount of operational data and provide valuable experience to accelerate the commercialization of hydrogen production via electrolyzer. • More on the upper TRL and pretty much on hydrogen production.	• There could be stronger support of local government and nuclear power plants to support more technology demonstrations.
SC	• I did notice the FOA-3003 from SC early this year to provide a variety of funding opportunities for fundamental research, including Energy Earthshots™, which provided good opportunities for researchers/scientists to perform scientific research to help the Hydrogen Program.	• The office may want to provide a more detailed description about the areas of interest for funding to differentiate from EERE funding, such as how to differentiate the electrolysis for the funding opportunities between SC and EERE.
ARPA-E	• ARPA-E provides funding opportunities for transformative research at the $1 million level up to $100 million for disruptive technology demonstrations to promote the technology innovation and commercialization pathway. • Early TRLs and a broad spectrum of possible uses are strengths. • I am happy to see increased funding to support the carbon capture program for natural gas fuel.	• Trucks and cars are moving to hydrogen, aircraft are undergoing experimentation, and there is a driver not to negatively impact the stratosphere. I think it may be a matter of time before railroads are viable. Shipping, according to the panel discussion at the AMR, is still not in a viable mode. This is a significant source of greenhouse gas and criteria pollutants, burning large amounts of less refined fuel across the world. There are some demonstration ferries, but what would it take in hydrogen storage to make the shipping industry confident of global transport? What sort of fuel cell would be best for marine applications, and how do we get there? Can that fuel cell bank that drives a gigagram-mass-loaded freighter through water and massive ocean storms really turn down to hotel power levels in port, or must a second compatible fuel cell be provided for port operations? These are a few open and broad-level questions that ARPA-E might think about taking on.
OCED	• H2Hubs is an excellent program to support clean energy demonstration to accelerate the commercialization pathway. • OCED is not yet active but will be the home of TRL 7–9 work, at least on a money-spent basis.	• OCED seems to have a very nice program to generate nuclei of a full hydrogen economy in a few places and let them grow with the hubs. A few gaps might remain. The main one is that if hydrogen is to become a major power/energy commodity, as electrical power is now, it will need a system to *ensure* continuity of that power or energy, as the current interconnect system does for electricity. This will be complex and will absolutely require input from business, state, and national levels. Also, the current electric

		interconnect with three grids (West, East, and Texas), while conceptually similar, will almost certainly not be the right model because hydrogen does not flow at the speed of light in aluminum; because of travel time, hydrogen produced in Florida cannot help with a supply disruption in Minnesota. Yet there will be a need for at least adjacent geographic areas to support each other in times of supply/demand stress. On the plus side, hydrogen is energy, not power, so a certain amount of lag time can be built into the system with storage at a local, state, and geographic level. The best model may well take aspects of the electric grid and natural gas and oil pipeline systems. Modeling will almost certainly be needed, as will life cycle analysis, all done under a variety of non-standard operating conditions. At a minimum, we need to understand how much pipeline and delivery redundancy is cost-optimal, how much storage capacity is needed at various distance scales from point of use, and whether the eventual national hydrogen energy system will benefit from or be hindered by a private overseer, as with the electric interconnects, and some or no regulation. All this needs to be understood well before the hubs start to grow toward each other and connect up. • As a new technology and product, clean energy may a have higher cost than traditional energy for a longer time after its introduction to the market. The federal government may design a variety of tax credit programs at different times to encourage companies and consumers to accept clean energy sooner rather than later. The mass production may help to further reduce the cost.
Other (specify)	• I am happy to see increased funding to support the R&D in new materials and concepts. The innovation in new materials and concepts eventually will benefit the broader application and cost reduction of clean energy in the long run.	• Just as DOE took on the challenge of heavy-duty transport several years ago to be ready when needed, there is a similar gap or opportunity out there. Railroads demand even faster and larger amounts of hydrogen fill and storage for long-haul applications (a very hard-to-decarbonize area). Thousands of kilograms of cryo or liquid hydrogen in under 30 minutes will require new equipment and standards. Trains have the pleasant property of staying on tracks, so the required fueling network can be pretty much deduced, but it *must* go into Canada and Mexico, so there is a need to estimate the size of the lift to do the science/engineering to make the fueling and storage possible, as well as to get the price of hydrogen down to where railroads will accept it, estimate the network of fueling needed (which may not logically be putting hydrogen where diesel is now), estimate whether the safety checks done at refueling are an opportunity or challenge for

		hydrogen, and estimate the cost of the North American fueling network implied by the foregoing and figure out what loans or de-risking (think hubs) projects are needed to make it happen. It would need to be done with the U.S. Department of Transportation. Argonne National Laboratory's methods of looking at delivery might well be a start.

4. The Hydrogen Program is effectively collaborating in RDD&D across the DOE offices and with other agencies.

Please rate your response on a scale of 1 through 10, with 1 indicating that you strongly disagree and 10 indicating that you strongly agree, or N/A if you have no opinion.

	Hydrogen Program Effective Collaborations
Average Score	**8.5**
Number of Responses	18

General Comments:

Please comment generally on offices or agencies that should be more engaged or leveraged and in what manner.

- Speakers from the U.S. Departments of State, Transportation, and Labor all showed clear desire to work with DOE, plus indications of support and work on the clean hydrogen economy support and development. The panels and keynotes demonstrated a cooperative intersection between DOE research on making, moving, and using hydrogen and the U.S. Department of Transportation (DOT) in regulating and supporting broad-scale transport of hydrogen safely and effectively. There also seem to be plans to increase interaction in the future. Plus, there are projects with NASA, the U.S. Department of Defense, etc. There is an interagency work group to ensure the many agencies are working in a way that they are informed by one another's work and to help maintain a state of working in complementary work streams. More fundamentally, there is a joint office between DOE and DOT. Also, less obvious areas, such as the Maritime Administration, are working to bring hydrogen to the very hard-to-change ship industry.
- The Hydrogen Program is likely the best-organized, -managed, and -executed program in DOE. Drs. Satyapal and Miller, as well as the other managers, provide excellent and the highest-quality leadership for the program throughout DOE. They masterfully integrate the entire government-wide effort to ensure attaining 2026, 2031, and 2050 goals.
- There is large-scale funding, and this seems to be getting buy in from different departments. There is focus on competitiveness of industry, good jobs, and equitable pathways (with a laser focus on human capital). The goal is 100,000 jobs by 2030.
- This was clear from the participation and program presentations from other DOE and government agencies, e.g., the U.S. Navy, NASA, U.S. Geological Survey, and National Oceanic and Atmospheric Administration.
- Collaboration across DOE offices has improved significantly in recent years—great job!
- General question: Is the Hydrogen Program collaborating with the National Institute of Standards and Technology, for example, in the area of reference standards for hydrogen station refueling? Perhaps this is not needed if the majority of the projects take place in SAE International.
- While there seems to be a growing emphasis on collaboration, the execution to date seems questionable. From personal experience, the SC, ARPA-E, EERE continuum for hydrogen was built on separation of technology rather than TRL.

- There are some areas, particularly for hydrogen, where EERE may need to work more closely with other agencies. For example, hydrogen for aviation or space applications may need a collaborative effort with the Federal Aviation Administration, DOT, NASA, etc.
- Other agencies could have been highlighted more. In addition to the U.S. Departments of Commerce, Labor, and Transportation (including the Pipeline and Hazardous Materials Safety Administration), there are various regulatory agencies that can partner. Initial conversations began on research coordination with the U.S. Nuclear Regulatory Commission, for example, but I am not sure how that played out.
- International work cooperation with DOE could be strengthened further.
- This theme was clearly front-of-mind for most DOE presenters.

Office-Specific Comments:

Please comment on particular strengths and/or improvement opportunities relative to specific DOE Hydrogen Program offices in the table below:

DOE Office	Collaboration Strengths	Improvement Opportunities
EERE	• International collaborations, e.g., the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), help to maintain contact with current happenings around the world. Staying abreast of these international developments—which vary country by country, with their varying requirements and priorities—helps to keep U.S. R&D activities and perspectives up to date. • HFTO has organized and is executing an outstanding Hydrogen Program across all agencies.	• Strengthening the interactions between national labs and academia will further advance the goals and objectives of the offices. Strengthening metrics such as numbers of joint publications, lab internships, job placements, etc. need to be developed.
FECM		
NE		• The Nuclear Energy University Program can be used to further advance the intersection between nuclear energy and hydrogen production.
SC		
ARPA-E		
OCED		
Other (specify)	• International cooperation on safety and codes is a great collaboration, and this just has to be done cooperatively, or we end up with a mess of conflicting regulations worldwide.	

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

Please rate your response on a scale of 1 through 10, with 1 indicating that you strongly disagree and 10 indicating that you strongly agree, or N/A if you have no opinion.

	Hydrogen Program EEJ and DEIA
Average Score	**8.4**
Number of Responses	18

General Comments:

Please comment on which stakeholders, external groups, or resources (e.g., academia, companies, small businesses, types of industries, states, other agencies) should be more engaged with or leveraged and in what manner.

- Most speakers emphasized that every project supported will have extensive community consultation and desire to build in EEJ. The U.S. Department of Labor is gearing up to provide training for underrepresented groups to be sure they share in the well-paying jobs expected via the various recent funding initiatives, using proven methods such as apprenticeships aimed at DEI communities. Community benefits agreements in contracts and up-front labor (e.g., construction) discussions to prepare potential workers to prepare a workforce in DEI communities can help with construction and advance disadvantaged communities. There are programs to include minority students and listening sessions with communities and tribes. HFTO has greatly increased its DEI staffing in a show of the Office's commitment. HFTO is working with the Office of Energy Justice and Equity to better educate and take in the inputs of communities impacted by new hydrogen-based companies and transport.
- It is great to see EEJ become an essential aspect of the Hydrogen Program. Please continue and expand the effort.
- This has been one of the greatest areas of growth, and I support and encourage these. In my personal experience, I have and will continue to interact with and support these programs.
- The Hydrogen Program is a model for DEIA in DOE.
- HFTO did have a policy and guidance to increase the clean energy funding in disadvantaged communities.
- There is a strong focus on EEJ and community engagement, especially through requiring community impact plans. In future years, will need to see the outcomes of this effort to demonstrate that it was not just a goal. The Office of Energy Justice and Equity presentation could have been better connected to specific projects on which that office is partnering.
- Time will tell. There are a number of exemplary activities, such as Mr. Rockward's at Los Alamos National Laboratory, that engage students from historically black colleges and universities in the area of fuel cell R&D. With time, we will see if these students transition into the technology companies, national labs, and academia and take on leadership responsibilities.
- It is really cool to see so much focus on equity. However, I am very uncomfortable with any research that encourages the ongoing use of fossil fuels. We need to find technologies that minimize consumption rather than new pathways to exploit fossil energy—this is a very dangerous thing to promote when the world is teetering on the brink of a climate catastrophe. Fundamentally, we need to reduce our footprints, and I am a little worried that the Hydrogen Program is based on the belief that we can just switch fuels without a more holistic assessment of environmental and social impacts.
- These EEJ goals make projects harder to deliver. They often are outside the core skillsets of participants. We all understand the goal of trying to fix EEJ issues while also rebuilding a fossil-free energy infrastructure, but it is humanity's hardest problems, squared. This suggests that far more support

specifically in EEJ skills needs to be provided to Hydrogen Program participants. Simply put, the best hydrogen technologist is not likely also the best community outreach organizer.

- DOE needs to educate business leaders (hydrogen producers, infrastructure developers, and hydrogen end users) on how to approach, engage, and interact with tribal communities. DOE should develop awareness and education programs for leaders in environmentally distressed communities on the importance of hydrogen in decarbonizing local communities.
- I did not hear a lot on this topic during the review meeting. I know it is in the design, with the 40% in structurally weak areas, but the conceptual part could be strengthened.
- General comment: Have the definitions for DEIA (each term) been codified as national standards? Do they have "staying power" and stability as national standards?

Targeted Comments:

Please comment on particular strengths and/or improvement opportunities in EEJ and DEIA relative to the overall DOE Hydrogen Program and/or to specific offices:

- The Hydrogen Program director tirelessly advocates for all, especially for women and minorities, as it should be.
- It seems like the pieces are there to make this change. The key will be whether they are used. To be fair, it is too early to see much change, other than the inclusion of DEIA in FOA requirements and staffing up to handle this new management aspect. So the Program gets high marks for doing that, saying the right things at the AMR, and even making some DEI efforts in pre-existing programs (e.g., HyMARC) and giving an award of excellence to a person who has been walking this road already. But going forward, the proof will be in what is actually achieved. Will meaningful DEI efforts start showing up regularly in proposals, or will it be a cut-and-paste of the university or company public relations on DEI issues? The score I gave (7) reflects this uncertainty of what the current efforts will yield. DOE gets a 9 for effort in setting up a new paradigm, but I prorate it down for the uncertainty of success at this moment.
- Clean energy is another revolution in human history. HFTO may want to collaborate with other DOE offices to take immediate actions to come up with feasible plans for increasing the funding and investment in disadvantaged communities and rural areas to ensure these communities/areas can benefit from clean energy, as other large cities do, and not be left behind.
- These are hard to judge and implement. Perhaps focusing on pilot projects designed to determine and scout the best way to implement these is a good approach.
- Here is one idea: initiate a DOE EERE technical fellowship or post-doc program for researchers to be available to be embedded into awarded projects.

6. Please comment on whether the Hydrogen Program is doing enough to advance goals for workforce development and science, technology, engineering, and mathematics (STEM) education.

General Comments:

Please comment on how the Program could build on and/or adjust its current portfolio to accomplish goals in workforce development and STEM.

- There are great initial efforts thus far, yet this is a growing need—as the market appears to be growing faster than the qualified workforce—and thus this needs to continue and be expanded.
- It is good to see some centrally coordinated focus on education. This work clearly needs to continue and engage with the fledgling industry to identify what specific skills are needed.
- Yes, in general the STEM area is addressed very well. Is there a way that the community college program can be "elevated" in terms of available courses? I read the community college catalogs and find no references to the DOE funding. Would it be possible to add references to DOE funding?
- It is hard to know; the efforts are really just starting. It sounds like this might be part of the huge hubs funding, but until those are contracted, we cannot know. Perhaps DOE should pair with the other DOE (the

U.S. Department of Education) to develop and drive a clean energy curriculum at the high school and junior college/technical college levels.

- DOE can institute scholarships and fellowships for graduate education in all areas of hydrogen. In particular, the area of life cycle analysis for hydrogen technologies and decarbonization is urgently needed, as this space is not covered in universities. This will also enrich and expand the graduate programs in academia, or even bring them up to speed on the rapidly developing hydrogen economy.
- H_2EDGE is a great start in developing a sustainable pathway to meet the needs for workforce development. I hope the lessons learned from H_2EDGE are used to expand efforts in this area.
- It seems to me a larger impact could be to start earlier—K-12—and prime the pump long before these kids enter into a science and engineering, etc., education.
- This did not appear to be highlighted in the plenaries, other than noting that there were GEM fellow recipients to support underrepresented groups. Greater workforce development and STEM education for these groups, especially Native Americans, would be welcome.
- More is needed. As a technology manager who has hired 30+ folks in hydrogen in the last 10 years and has 6 open positions now, I can say that we need better education and training at all levels.
- I have not seen the practical and solid plans to advance achieve goals for workforce development, especially in the disadvantaged communities and rural areas.

Targeted Comments:

Please comment on particular highlights and/or improvement opportunities in workforce development and STEM relative to the overall DOE Hydrogen Program and/or to specific offices.

- I am happy to see more funding to support internship and R&D programs for college students and graduates in STEM to promote their interests. Technology innovation is the foundation to keep U.S. leadership in the world.
- Basic outreach and education at lower levels of the educational system—education that is reaching elementary and high school children to inspire them early—could be expanded, along with more traditional higher education workforce development.
- Helping professional associations convert the fossil-fuel-heavy curriculum would be of great benefit—at high schools, technical high schools, colleges, and trade schools and in the re-education of our existing workforce. Perhaps example curricula could be developed for dissemination.
- DOE might consider partnering with the American Indian Science and Engineering Society to develop scholarships, fellowships, and internships.
- DOE could reach out and make the states aware of opportunities for workforce development programs in hydrogen technologies.

7. The Hydrogen Program also collaborates with other countries through several international partnerships, such as the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), Clean Energy and Hydrogen Ministerials, Mission Innovation, the International Energy Agency, and others. Please comment on actions DOE can undertake in conjunction with these or other international activities that can effectively accelerate U.S. progress in hydrogen and fuel cell technologies.

Comments:

- It would be very hard, but if the approach to the hydrogen economy was done on an international basis (rather than through countries competing against each other), we would do so much better with a world plan, rather than a national plan. Once you do that, world peace will be easy. To the extent the U.S. plan can collaborate with, rather than compete with, the European Union's and China's and Australia's plans, that will be more efficient. International cooperation on safety and on codes is a good model in an easier area in which to accomplish global cooperation.

- This is an area for focus and growth, as the United States is too inwardly focused. Targeted collaboration is essential. My own experiences with the International Energy Agency's Hydrogen Technology Collaboration Programme suggest this is a particularly useful avenue of fostering collaboration at the research level.
- Integrated energy systems with nuclear may warrant partnership with the International Atomic Energy Agency (on both the promotional and safety sides) and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development.
- This is a very important opportunity to observe how other international entities are approaching their specific regional requirements. This can inform many aspects of U.S. hydrogen R&D policy.
- DOE may already do this, but this person is not aware of it: It is suggested that we have a small group of experts to monitor progress and advancements in international activities and report information/data regularly to stakeholders.
- Our world is integrated, from supply chain, to workforce, to products, to national defense. Clean energy is a national defense matter, and we should support it as we do our allies. Perhaps organizations such as the North Atlantic Treaty Organization (NATO) could be a template for energy.
- I recommend that the Hydrogen Program administer a working group to develop a technical report on DEIA used in the EERE FOAs so the concept can be promulgated worldwide.
- Data production and sharing is an important subject. Perhaps this is an area where we can collaborate, for example, with Japan.
- It is important to follow and leverage any international hydrogen efforts to inform the DOE strategy.
- More frequent and more open (shared) activities are recommended.

8. Please provide any additional suggestions you may have for improvement of the overall DOE Hydrogen Program (e.g., in areas such as technology development, demonstration, and scale-up; technoeconomic and environmental impact assessments; safety, codes, and standards; soft costs; commercial liftoff; outreach and education; etc.).

Comments:

- In my opinion, this Hydrogen Program is one of the very best programs among all the different federal agencies. I was able to attend, in person, all key presentations from Monday's plenary talks to the very last excellent talk delivered by the National Renewable Energy Laboratory on Thursday in the late afternoon. I am very impressed with the technical quality of the projects and the different programs presented throughout AMR 2023. Apparently, higher-TRL technologies would help DOE to achieve the DOE 1-1-1 goals. If the Hydrogen Program stays focused on investment and continuously promotes the high-TRL directions (such as oxide-conducting SOECs), it will help the hydrogen technology and help DOE to achieve its goals.
- DOE and, in particular, the current "moon shot" approaches are inspiring. I urge DOE to enact real change and persist. Perhaps creating "pilot" programs designed for quick understanding of the issues involved in in new thrusts would be helpful. For example, what is needed to convert a lab-level novel ammonia synthesis catalyst to a field trial? How does one map other such technologies onto a lab-to-field trajectory?
- The increased focus on safety, codes, and standards is encouraging.
- The $1 target is encouraging distorted and unrealistic techno-economic analyses. I would like to see at least some framing of the narrative in a way that hydrogen is truly a critical part of transitioning society to more sustainable and equitable practices. It is no silver bullet, though, but is the only foreseeable option for some applications. It is great that significant funding is now available, but we need to be careful to avoid a boom–bust cycle and be very mindful of what the longer-term strategy for the overall energy system is.
- I have a comment about my rating in the question about reaching 1-1-1 goals. My rating is not purely technical. It includes other factors such as loss of funding due to a change in who holds the White House, geopolitical turmoil rearranging priorities, and inflation (seeing as there is no year for the dollar listed).

- Recommendations include more market-based (implementation) efforts; more workforce development to meet the rapidly expanding market; and more education and outreach, including early education years and the general public.
- Suggestions include (1) a national program to educate local (county) governments on the benefits of the hydrogen economy and (2) an initiative that will incentivize universities and community colleges to introduce courses and certificates in the areas of hydrogen energy, codes and standards and safety, etc.
- Standards, safety, and codes require additional efforts and funding, as well as collaboration with other countries.

9. Based on DOE's hydrogen activities, and given the Bipartisan Infrastructure Law (BIL) funding across the RDD&D spectrum, how likely do you think:

a) The BIL target of $2/kg clean H_2 be achieved by 2026?*

	10 – very likely 1 – not likely
Average Score	**7.1**
Number of Responses	20

b) Hydrogen Shot will be achieved ($1/kg clean H_2 by 2031)?*

	10 – very likely 1 – not likely
Average Score	**6.5**
Number of Responses	20

** Note: these are modeled levelized costs of production only, at high volumes (e.g., GW scale)*