Appendix A: 2022 Hydrogen Program Review Summary

This appendix shows the results of the Hydrogen Program (the Program)-level peer review for the 2022 Annual Merit Review (AMR). A total of 71 Program-level reviewers were invited to provide feedback, and 38 reviewers responded. 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	Nel Hydrogen US
ACS Industries Inc.	New Energy and Industrial Technology Development Organization, Japan
Air Products and Chemicals, Inc.	New Jersey Fuel Cell Coalition
Ballard Power Systems	Pajarito Powder LLC
Bar-Ilan University	Patturns
Boston University	Plug Power Inc.
California Air Resources Board	SLR Consulting
California Fuel Cell Partnership	Stottler Development LLC
French Alternative Energies and Atomic Energy Commission (CEA)	Strategic Analysis, Inc.
Connecticut Center for Advanced Technology	Toyota Motor Corporation
DJW Technology, LLC	University of California San Diego
Fuel Cell and Hydrogen Energy Association	University of Connecticut
General Motors Company	University of Maryland
Hyrax Intercontinental	University of South Carolina
KeyLogic	U.S. Department of Energy
NASA	U.S. Nuclear Regulatory Commission
NASA, White Sands Test Facility	West Virginia University

1a. The Hydrogen Program and strategy was clearly articulated and well-aligned with mission and goals of the National Clean Hydrogen Strategy 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.

Average Score	**9.0**
Number of Responses	38

Comments:

- The U.S. Department of Energy (DOE) Program and strategy were easy to understand and are indeed very well-aligned with the goals of the National Clean Hydrogen Strategy and the Hydrogen Shot. You can see a clear connectivity and logic in the Program's many parts and a consistent focus on $1/kg hydrogen and development of markets to use it. The goals are supported all the way from fairly early technology readiness level (TRL) research and development (R&D) seeking big changes in cost and efficiency to market de-risking of technologies just entering the marketplace. Safety and diversity and environmental justice were clearly part of the plan for reaching these ambitious goals.

- The Program is well-aligned with the mission and goals of the National Clean Hydrogen Strategy and Hydrogen Shot. Moreover, the strategy was clearly articulated and well-aligned with U.S. energy policy through work that includes extensive research, modeling, analysis, and assessment of energy alternatives. The work is of very high caliber and recognized worldwide for leadership with development of clean energy technology.
- A comprehensive strategy that includes R&D, demonstration, deployment, education, and outreach—on a national scale—is required to achieve the ambitious Hydrogen Shot goals. The Program has done an excellent job developing that comprehensive strategy. To date, the Program has executed the R&D strategy extremely well and designed an ambitious pathway for the other elements, which are critical to demonstrating and deploying hydrogen at scale and reducing the cost of hydrogen infrastructure.
- Goals are exceptionally well-aligned. The increased integration across multiple projects over the past few years is really impressive. Also, the nearer-term goals in the strategy ($2/kg by 2026, for example) make the longer-term "shot" feel more manageable.
- Overall, this is a really well-organized and well-run program—great on vision, strategy, and execution.
- Goals were well-defined. The reviewer particularly liked the balanced portfolio of companies, consortia, direct projects with the laboratories, and Small Business Innovation Research (SBIR) projects.
- The goal is clear ("1 1 1"), and the focus on scale-up is appropriate.
- The presentation made it clear that there is a well-coordinated national effort.
- The hydrogen plan does an excellent job of covering the entire gamut of hydrogen management from production to consumption.
- The Hydrogen and Fuel Cell Technologies Office (HFTO) has done a nice job in 2021–2022 to quickly develop the Program's strategies and plans toward realizing the big Hydrogen Shot challenge. When the Hydrogen Shot vision was announced at last year's AMR meeting, this reviewer was honestly concerned that it might be just a slogan without a possible action plan. However, with the strong funding support from the infrastructure bill and quick actions from the Office of Efficiency and Renewable Energy (EERE), we will have a chance to fight. Thanks for the great effort.
- The Program and strategy were clearly articulated and well-aligned with the mission and goals of the National Clean Hydrogen Strategy and the Hydrogen Shot. The focus supports the mission, and the goals of using clean hydrogen to decarbonize industry, fuel heavy-duty (HD) transportation applications, and enable energy storage are unambiguous. Thank you for providing an explanation of the sector-based CO_2 emissions. People need this reference. The snapshot of "where we are presently" is important, i.e., hydrogen production, pipeline, polymer electrolyte membrane (PEM) electrolysis, fuel cell buses, retail stations, and light-duty (LD) passenger cars. The only "adds" would be that the production is in many cases "already spoken for" by paying customers and the primary feedstock is natural gas.
- The strategy supports the Hydrogen Shot goals, and the existing program has done as well as it can to address these goals with the very small amount of funding allocated versus the investment made to date in fuel cells and batteries. The Program will take some time to catch up based on the new funding; there was no funding for new low-temperature electrolyzer projects last year, other than within the national laboratories. It is extremely important to "catch up" to the strategy through industry engagement with Hydrogen from Next-generation Electrolyzers of Water (H2NEW) and the HydroGEN Advanced Water Splitting Materials Consortium (HydroGEN) and use of the new funding through the Infrastructure Investment and Jobs Act/Bipartisan Infrastructure Law (BIL), to kick-start new, applied R&D projects in key electrolyzer components and system concepts.
- It is strongly agreed that the Program and strategy are clearly articulated and well-aligned.
- The Program has done a very good job of communicating overall goals and targets and how each of the subprograms fits into the larger picture.
- The U.S. policy of leading the world was clearly stated and easy for participants to understand.
- The vision articulated was uniformly delivered by all speakers during the plenary.
- It was clear that coordination had occurred among the presenters.
- The Program is addressing the daunting challenges and obstacles facing full implementation and consumer acceptance of hydrogen infrastructure and fuel cell technologies in a comprehensive and impressive way. A well-coordinated research, development, demonstration, and deployment (RDD&D) strategy comprising input from multiple national laboratories, private companies, and DOE offices is ensuring that critical issues are being thoroughly evaluated and addressed. Successful and complete integration of hydrogen-based technologies into our overall renewable energy portfolio is clearly challenging. The Program strategy

has been formulated to meet those challenges in a timely, cost-effective, and impactful way. The Hydrogen Shot initiative is an aspirational "reach" that provides well-formulated, concise, and challenging goals and focus for the Program. Achieving those goals is imperative for the Program to be established as a major element of the renewable energy portfolio. Minor note: One issue that would have been helpful in the AMR Program strategy discussion is a candid and honest comparison with incumbent and other emerging technologies (especially batteries). Such a comparison would provide a useful context for reviewers to fully appreciate and assess the future impact and advantages/disadvantages of the Program in relation to all other renewable energy options.

- This question is a bit difficult to gauge, as the final National Clean Hydrogen Strategy has not been published yet. The reviewer evaluated this based more on the general concepts and draft thoughts presented during the plenary and with respect to the known information about the Hydrogen Shot.
- The reviewer requested more on a metric-driven, investment-inspiring national strategy.
- There is good overall Program strategy targeting high-impact end uses and bringing in other DOE offices like the Bioenergy Technologies Office and Office of Fossil Energy and Carbon Management (FECM). The only overarching concern is that five years of BIL funding may not be enough to move the cost curves sufficiently. One would hope there are milestones and gates built into the funding allocation that can apply the brakes if necessary. Scaling up expensive technologies too early would be a costly mistake, given the unique nature of this opportunity.
- The presentation provided a clear and comprehensive document identifying the group of hydrogen projects and their objectives, with high-level discussion of how to meet those objectives. This included the identification of H2@Scale, H2NEW, Electrocatalysis Consortium (ElectroCat), Million Mile Fuel Cell Truck (M2FCT), Hydrogen Shot, hydrogen demonstrations, etc. The 92 charts identifying these activities was somewhat overwhelming. With the expansion of the Program, it may be necessary to modify the structure of the AMR to address the large number of project recipients and subrecipients, consortia, etc. With over 400 projects spanning from basic research to demonstrations and deployment, the audience for the Program overview has many diverse interests, and there are areas where the audience has little interest.
- The three charts that discussed the Justice40 Initiative did not provide a clear pathway to execute the objectives. A definition of the acronym DEI (diversity, equity, and inclusion) was not found.
  The Hydrogen Education for a Decarbonized Global Economy (H2EDGE) discussion did not identify "industry-led" activities but discussed academic accomplishment; it was unclear what the industry did. Chart 76 necessitated going to Google to find out what IPHE was (International Partnership for Hydrogen and Fuel Cells in the Economy). It was unclear if technical transitions were planned and why they were being reported, as they appear to be getting only 0.024% of the budget. Budgets were clearly identified for the HFTO.
- Chart 23 identifies a minimum of four hydrogen hubs, while chart 46 suggests there could be tens of hydrogen hubs; it was unclear how the number of hydrogen hubs would be resolved.
  It was not clear if "National Clean Hydrogen Strategy" and "National Hydrogen Strategy and Roadmap" were the same thing.
- Yes, the Program was well-articulated. What was not clear was whether there would be expenditure issues with the present pace of the Program rollout. In other parts of the government, the funds would be swept up. With other pressures on the government (pandemic, inflation, war in Ukraine), it was not clear if DOE would be able to protect the funds or if they would be targeted for changing priorities.
- There are numerous positive aspects to the overall Program. However, it appears that politics have started to overcome the technical aspects of the Program. This is a longer-term risk to the Program, as has been seen in the past.

1b. Were the important challenges to meeting goals identified, and were plans to address the challenges articulated?

Comments:

- From 3 respondents: Yes.
- Important challenges, including cost reduction, durability improvement, and technology provision to meet market demands for clean energy production, were well-articulated. These challenges have been heightened

and may continue to grow with the recent global cost increases for energy. Plans to accelerate progress, given these global changes in energy pricing, may be welcomed.

- The goals were listed at both a high level and in specific within subprograms, and the goals are very aggressive. Each speaker was clearly aware of the challenge that lay before them. Indeed, without this level of funding, it is unlikely the goals could be met.
- The Program is well-structured, with precise objectives (through clear key performance indicators) identifying the important challenges.
- The meeting's goals were well-identified, and the plans, to a large extent, were well-articulated.
- Yes, they were, along with opportunities to engage to help overcome the challenges.
- Yes. The goals and objectives were clearly stated, with plenty of references to the plans to achieve them.
- Yes, the plan and approach seem fairly comprehensive.
- In most cases, yes.
- The Program did an excellent job outlining the goals and their alignment with the challenges. Hydrogen production cost was clearly identified as a key challenge, and some time was spent outlining the pathways at a high level. Current projects are a good balance between high and low TRLs. Transport is also a key area and significant source of cost. There seemed to be fewer projects in this space overall.
- Yes, they were, to the extent that they can be in a public meeting. The proof of plans to address the challenges will be in the upcoming funding opportunity announcements (FOAs) and awarded projects, which DOE obviously cannot comment on before projects are actually selected.
- Yes, the BIL provisions seem to have given DOE much-needed tools to develop a more holistic strategy than ever before, one that addresses the needs of scaling up, market development, analysis and evaluation, and basic and applied research. There seems to be a good mix of research into the production, conversion, and end uses of hydrogen fuel. There is appropriate focus in the technical areas of the Program to address ways that costs (one of the most prevalent hurdles now) can be reduced over time. The Program also continues to keep its focus on overall energy efficiency and environmental protection. This needs to continue to be emphasized in order for hydrogen and fuel cell technologies to actually have a meaningful impact in transportation electrification and the broader energy transition to cleaner and more sustainable options. Within the environmental impact, there is a strong focus on greenhouse gases (GHGs); it would be good to see this GHG effort maintained while also diving deeper into air pollutants. The GHG effort is well-justified and aligned with today's challenges across the globe. But the local air pollutants are also an important factor in addressing individual communities' concerns about environmental health hazards. Extending this to other hazards, like the emission of air toxics species, would also help fill a large gap in data, science, and understanding. DOE should consider adding this to the scope of analysis for evaluating hydrogen's environmental impacts. This will require basic science analysis, as well as engineering and modeling work. Finally, the reviewer deeply encourages DOE to bring back some of the overall focus on the light-duty vehicle (LDV) sector. It is well understood why medium-duty (MD) and HD sectors are receiving significant focus, and those sectors do need more effort to get them ready for broad deployment. However, the work on LDVs is not yet finished, and that market is currently at a more advanced stage. In spite of that advancement, improvements are still desperately needed in durability and cost. It does not yet seem like scaling up manufacture will be the solution. It would be highly unfortunate if that market were to falter now after so much work has been put into it simply because the focus shifted at the wrong time.
- Oral presentations were focused on the reduction of carbon fiber, which is critical for reaching near-term goals for hydrogen storage. In addition, more focus has been shifted to HD applications, which has become much of the focus of industry. The Hydrogen Materials Advanced Research Consortium (HyMARC) continues to focus on material evaluation to meet long-term goals for low-cost, high-volumetric, and high-gravimetric efficiencies.
- Coordinating across DOE is an important challenge. Sharing information from the recipients of grants and contracts, the work of the consortia, national laboratories, and small businesses is also an important challenge. More information is needed as to the practicality of how the efforts will be coordinated and how the shared information will be provided to the public. Real-time information is needed, from all of the parts of DOE, including for the failed projects and go/no-go decisions for projects that border on failure. The presenters brought up, in general terms, the need for a trained workforce, but they did not provide quantitative or qualitative analyses about the jobs that are needed, nor did they provide information as to how the jobs will be created. It is advisable to include the potential for incremental changes and course correction if the goals for projects and workforce development are missed.

- Cost status and goals were clearly articulated, but more analysis is needed to dig into the entire value chain. For example, it would be good to know what the buffering costs are when hydrogen is made from intermittent wind/solar power yet downstream users require an uninterrupted feed for continuous operation. In the ammonia space, it would be good to know what discount is required to move urea users to neat ammonia. A good start has been made on the viability analysis—it just needs to continue and go one or two layers deeper.
- Although the goals have been clarified, the detailed issues to achieve them are a subject for future study.
- There was a lot of strategy and activity to address the strategies outlined, but the presentations could have been more upfront about the challenges and barriers in the plenary sessions (as was done in the detailed technical presentations). For example, it would be interesting to show the predictions in these presentations over the past 5 to 10 years, what has actually played out, and what was learned from that in terms of what the biggest challenges are and how to tackle them. Learning from missteps can be very instructive.
- Yes, because of its strong collaboration with industry, the Program has always had a good grasp of the important challenges. Plans to address those challenges have also been developed in collaboration with industry. However, the Program has not always had the budget to address all of the important challenges, particularly for demonstration, deployment, education, and outreach. Now DOE has ample budget through the BIL funds. Also, the regional-hydrogen-hub approach will provide DOE with increased opportunity to engage with states, which was not well-supported in the Program in the past. However, with the significantly increased budget and opportunities will come the challenge of managing many more projects to ensure optimal results. Currently, it appears that DOE does not have the staff to manage the increased effort effectively. It is critical that DOE increase staff and identify management tools and approaches to provide effective oversight of the hydrogen hubs, mitigate risk, and achieve steady progress toward goals.
- Overall, yes. However, the staffing challenge to administer and manage/provide oversight was not addressed on the timeline(s) laid out, while simultaneously there is an initiative under way to grow DOE staff with several hundreds of positions.
- The key challenges around hydrogen cost, scale, and timeline are clearly articulated and hard to miss. However, other equally important technical challenges in achieving the "clean" or "net-zero" goals are less obvious and ought to be more visible in the Program, especially in the early TRL projects. Given that hydrogen is an energy carrier and not a primary energy source, the challenges in overcoming the inherent but significant energies/GHGs involved in producing large-scale hydrogen should be highlighted and addressed sooner rather than later.
- The technical goals and solutions were clearly articulated. However, what is not clear is how technologies at different TRLs will be treated in the Program. For instance, integration with nuclear plants may take 5 to 10 years for permitting, testing, and training. It was not clear whether there would be different rating systems for high-TRL technologies (such as alkaline with solar) versus low-TRL/manufacturing-readiness-level (MRL) technologies (such as solid oxide electrolysis cell [SOEC] with nuclear).
- There were not always clearly defined R&D pathways to reduce the costs of various components or approaches, for example. It would be more useful to present some idea as to what the R&D pathways might be, as well as a probability of achieving the goals, or the remaining risks or barriers involved in meeting the various goals (be they cost, durability, etc.).
- The DOE targets were clearly identified on chart 16 for clean hydrogen, electrolysis, and fuel cells for HD trucks. There was a clear statement of guiding principles for DOE's National Clean Hydrogen Strategy development, and targets were clearly defined. The reviewer did not find a discussion or details about the establishment of a roadmap and its goals, unless this was included in the National Clean Hydrogen Strategy development. It was unclear what the deliverable is, who is doing the roadmap, and whether this was the existing U.S. hydrogen industry roadmap. Further, it was not apparent whether the clean hydrogen use scenarios suggest industry (ammonia and refineries) will change its hydrogen production processes to a new and cleaner hydrogen production process or whether this includes an evaluation of potential cost increases.
- The important challenges have been clearly identified. However, connecting the challenges to meeting the goals could use some work. It has been discussed that the Program will focus on decreasing the stack cost by 80% and determining which components it will be necessary to improve to meet this goal; however, it has not been articulated how much cost reduction is really possible with each component.
- Generally, yes. Discussion of the ability of the electric grid to move clean power to the point of hydrogen production was lacking and needs consideration.

- To the extent that hydrogen is an energy carrier, its cost will be heavily dependent upon the input energy. As events over this past year show, there is not a clear pathway to unsubsidized renewable energy to produce hydrogen at the indicated $1/kg, even if there are large-scale breakthroughs in technology. There is virtually no mention of the significant materials-related infrastructure that is needed to support these goals.
- Goals were clearly identified; however, they are aggressive, and the plans to mitigate challenges as they are now presented may not be enough to meet the goals outlined.
- The important challenges need to be prioritized and better articulated.

2. The Hydrogen Program is aligned well with industry and stakeholder needs and is appropriate given complementary private-sector, state, and other non-DOE investments.

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.

Average Score	**8.1**
Number of Responses	38

Comments:

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

- Clearly, there has been a massive effort to obtain industry and community input in many locations. There were multiple instances in which the work was integrated with state and local efforts and, in some cases, international programs like IPHE. The private sector is a bit harder to be sure of because much of that work is secret, but obtaining input from industry technical teams is probably as good a strategy as one can imagine for avoiding duplication with industry work. Of course, much funded work is with industry partners and recipients, and in this case, proper collaboration is assured. While not a part of this question specifically, there is clear cooperation and avoidance of duplication between offices in DOE and with non-DOE U.S. government programs in other departments.
- The Program appears to be tackling all sectors at once, so industry needs are likely being met. Making these programs self-sustaining (eventually with less federal support) will be the proof. The many public–private partnerships, hubs, etc. are impressive.
- The Program is well-aligned. There is very little “clean” hydrogen produced today, and the Program is well-designed to address that gap.
- The Program is well-structured, with strong involvement of the industry. There is no specific missed area, keeping in mind the TRL range covered.
- For the budget it has had, the Program is as aligned as it can be with stakeholder needs. Additional testing infrastructure and increased investment in component development will be critical in the next two to four years.
- The active and pending activities address the non-DOE needs as well as a government agency can.
- The Program works very well with industry.
- The AMR rightly focused primarily on DOE investments. There was not much information on private-sector, state, and other non-DOE investments. Perhaps it would have been helpful to have a roundtable of state officials or investors to explain their views regarding hydrogen. Input from Europe’s point of view could also be helpful. However, it is not clear that non-DOE input was appropriate for this Program review. Perhaps it would be appropriate for another venue.
- The stated aspiration and scope of the Program are well-aligned with what is needed to move related initiatives by the private sector and other non-DOE stakeholders. The proposed significant investment in hydrogen hubs is especially meaningful and, if successful, could build confidence in private-sector and other investments and propel the envisioned hydrogen economy. Overall, the Program has a much broader scope that intersects with multiple hydrogen stakeholders. Two notable examples this year are as follows:

  - The introduction of hydrogen activities in FECM. This is important since almost all current domestic and global hydrogen supplies come from fossil fuel sources, and it may stay that way beyond the next decade. For the goals of the Hydrogen Shot to be realized, significant advances in large-scale, low-carbon hydrogen production from fossil fuel will be necessary. As such, higher federal funding will be needed for FECM to demonstrate technical feasibility and meet the ambitious cost and timeline.
  - The proposed material recycle and end-of-life effort. This is also necessary and significant progress toward achieving the big goal. One area of activity that could use more funding and expertise is the development of a robust standard of life cycle analyses around GHGs and other environmental impacts (air quality, water, energy, land use, etc.) across all hydrogen production and delivery systems. That way, researchers and stakeholders could use this as an additional screening tool beyond just cost and scale.
- The appropriations for Fiscal Year (FY) 2022 and the request for FY 2023 appropriations are "heavy" in the areas of workforce development; validation of one-of-a-kind technologies; de-risking technologies; and safety, codes and standards. Perhaps the data and information gained from the work in one-of-a-kind and de-risking of technologies could be fed into the workforce training systems. That way, the infrastructure and the people who will build it have a better chance of progressing together. E-learning systems, based on artificial intelligence and machine learning, can be used to train the workforce and document the infrastructure. Eventually, e-learning systems will reside in the metaverse, and they will facilitate three-dimensional (3D) virtual learning—i.e., site visits and testing. Funding support is needed to integrate these e-learning systems with hydrogen and fuel cells and allow "learning for all," including for individuals living in rural areas and disadvantaged communities (DACs). This would differ from and be more effective than providing static, non-interactive pages. Funding is needed to capture and mine the project information, in situ. This "natural fit" of materials for the future workforce should be addressed immediately.
- The Program is well-aligned with industry and stakeholder needs. Extensive collaborations and industry engagement are evident. Multiple consortia (HydroGEN, HyBlend, H2NEW, ElectroCat, M2FCT, HyMARC, Hydrogen Materials Compatibility Consortium [H-Mat], etc.) that address critical Program challenges have been established. Although those consortia seem to be functioning well, the Program Office must be cognizant of the potential difficulties with coordinating those activities in closely related areas and avoiding redundancies across so many parallel efforts. Particularly confusing is the perceived overlap of technical efforts within the H2NEW and HydroGEN consortia. It would possibly be helpful in future reviews to clarify the differences in related consortia objectives and directions. In addition, it seemed that no mention was made concerning the role of "Tech Teams" in future reviews and planning going forward, and it was unclear if those relationships with industry stakeholders were continuing.
- The Program is well-aligned with the hydrogen and fuel cell industry and energy stakeholders. However, additional efforts to provide education for local officials, state agencies, and community groups would be welcomed to enhance opportunities for effective technology deployment, community acceptance, and market transformation.
- The large number of industrial participants confirms the Program is well-aligned with industry. It was not clear how large the contributions from the states were.
- State-level investments and policy support were not as visible in the previous Program projects. It would be great if the hydrogen hubs could motivate more support from regional governments. One important aspect that DOE may need to consider is how to provide stability and continuity assurance for these hubs. Basically, developing a sustainability plan/strategy beyond the five-year period would be very important and helpful to ensure that these hubs will continue to serve their local communities, not just be short-term experimental trials.
- Although the BIL calls for continued work on fossil fuel implementation for hydrogen production, this is one area where the work that is called for may not be in line with stakeholder needs. It is not immediately clear what fossil-fuel-production pathways will have to offer in the future that other, renewable-based pathways will not be able to provide. Especially when we are looking significantly into the future, between the resources available from solar, wind, biomass, and other renewable feedstocks, it is unclear how much fossil production will still be necessary. DOE should work to clarify this and very carefully consider how much fossil fuel production will really be necessary, for how long, at what cost, and for what benefit. Absent a more thorough evaluation, it seems that continued development (if any is even really needed) of fossil-fuel-based pathways is simply too at odds with the worldwide movement away from these limited resources and the desires of stakeholders at large for a clean energy transition.

- One area that might need different focus is the area of reducing the cost of carbon fiber for fiber-reinforced tanks. Much of the DOE effort is focused on polyacrylonitrile (PAN) precursors; presumably, the industry is well-invested in processes for PAN to try to reduce costs. Perhaps DOE efforts should focus on wholly new approaches. Perhaps there are biopolymers that could be investigated, conversion chemistries and mechanisms detailed, and wholly new processes discovered for the production and upscaling of aerospace-grade carbon fiber.
- While the industry needs for a hydrogen society are still unclear, the reviewer liked that the policies necessary to actually use hydrogen were clearly outlined.
- Although there was discussion of codes and standards, that is an area where more support is needed—particularly in new and emerging applications for hydrogen.
- Emissions from hydrogen combustion (turbines) will be a continued area of discussion, and clarification is needed regarding the methods for reducing nitrogen oxide (NO_x) emissions.
- In the area of freight trucks and maritime, it should not be assumed that hydrogen will succeed as a direct-use fuel. Zero-emission vehicles (ZEVs) may not be required in trucking freight long distances in certain parts of the country, so a thorough assessment of hydrogen versus hydrogen-derived, non-fossil liquid fuels is in order. On the electrolyzer front, there did not seem to be any mention of Chinese competitors. Major Chinese players should at the very least be thoroughly benchmarked. The solar industry is in an awkward position at present with respect to supply from China (wanting domestic but needing Chinese supplies). Policymakers need to be informed to avoid this same situation with electrolyzers. Reports out of China (per BloombergNEF) suggest a cost level of $300–$500/kW already with alkaline units.
- This year saw a substantial reduction in the emphasis of solid oxide fuel cells (SOFCs) compared to polymer electrolyte fuel cells. The industry appears to be still focused on commercializing the technology, and yet DOE seems to be de-emphasizing this area. The reasons for this were not clearly spelled out, and it would have been helpful to hear a little more about why this is so. High-temperature fuel cells have a vital role to play in stationary power generation applications and do not require the use of precious metals. These fuel cells have to be part of the mix of our energy future going forward. There are many important basic and industry challenges that need to be solved, and more federal funding is necessary to address these continuing challenges. There ideally could have been more emphasis on the current state of SOFC technology and its remaining challenges.
- It is unclear to what extent hydrogen end-user/demand-market stakeholders are engaged in assessing the needs and whether these needs are being addressed.
- The decrease in the Program's 2023 fuel cell budget request, when the overall Program budget is increasing, is a concern. Though the Program has made outstanding progress in improving fuel cell performance and reducing cost, the shift in focus from LDVs to MD vehicles and HD vehicles (HDVs) has increased durability requirements, which also makes cost goals more challenging to achieve. The fuel cell budget should be increased to achieve these goals, not decreased. The apparent move away from LDVs is also a concern. LD fuel cell electric vehicles (FCEVs) should remain a ZEV option for fleets and for drivers whose vehicle range and refueling needs are not met by battery electric vehicles.
- There is a difference between cost and price. Private suppliers will require a return on investment and operating costs, which will drive the price of hydrogen to a higher level. It is not clear that this is addressed in the targets. Adequate materials, at a reasonable price and from reliable sources, are required to meet future alternative energy needs. There is a lack of involvement and support for a smooth transition of energy technologies without significant disruption (note today's energy prices and supply chain challenges), as well as for economic and secure supply chains that benefit all stakeholders.
- One of the challenges in this Program is aligning existing national laboratory resources and expertise with industrial needs, including the industrial need for secrecy. Unfortunately, it is unclear how this can be addressed. Yes, there are agreements that can be signed in place; however, the tendency of national laboratories to then publicize similar work makes reliability challenging.
- The alignment is not very clear from the Program presentations.

3. The Hydrogen Program is collaborating with and gathering feedback from appropriate groups of stakeholders, including those with a focus on workforce development and justice, equity, diversity, and inclusion.

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.

Average Score	**8.1**
Number of Responses	33

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.

- Multiple speakers, both at the high-level plenaries and discussing specific projects, pointed to progress in environmental justice (EJ), creating opportunities for minorities and traditionally disadvantaged groups, and the inclusion of community/Tribal concerns and knowledge. It is indeed quite remarkable and commendable to see this level of response to these issues so quickly, by far the most this reviewer has ever seen in 35 years of watching and doing cooperative and industry–government research.
- The Program has done a solid job of engaging external stakeholders and enabling collaborations. No additional participation or involvement appears to be needed. A solid plan (based largely on DOE's Justice40 Initiative) is in place to address DOE policy priorities for underserved and disadvantaged communities. An impressive array of DEI- and EJ-related activities are in place. Although the impact of those activities remains to be seen, they provide an excellent framework for addressing critical issues associated with workforce development in DACs and collaboration with minority-serving institutions (MSIs). The engagement with Tribal communities is especially noteworthy and important.
- The Program is collaborating with a very broad variety of stakeholders, both at the Program level and within the different projects. Inclusion of justice, equity, diversity, and inclusion has been particularly stressed during the whole AMR.
- DEI is included in the guiding principles for DOE's National Clean Hydrogen Strategy and Roadmap development. There is emphasis on benefits in underserved and disadvantaged communities, as well as emphasis on engaging the American Indian Tribes, Native Hawaiian communities, and others. Funding opportunities have been established for Historically Black Colleges and Universities (HBCUs) and MSIs. The funding for HBCUs/MSIs is very important for developing the next generation of engineers and scientists.
- Overall, the Program has good external engagements on these points.
- DOE has done a good job of gathering feedback through requests for information (RFIs).
- There does appear to be a clear direction or intent to incorporate DEI, but it seems a bit too early to fully judge DOE's effectiveness. It has only recently become such an explicit part of the strategy. It does seem well-structured and similar to other efforts around the United States, but whether the strategy works well at the national level is not yet discernable. It was also not clear what stakeholders have been invited into DOE's efforts to address workforce concerns. There would likely need to be significant outreach to non-governmental organizations (NGOs), community-based organizations, nonprofit organizations, and/or their representatives, and not much discussion has been seen in terms of the groups that have been engaged in that regard. So far, it seems this is part of the planning for future work. That is, their importance is recognized in things like the planned requirements for the hydrogen hub solicitation, but then that means it is left up to funding applicants, instead of direct work by DOE, to research this area. In-depth discussion was not seen regarding the metrics and expectations when this effort is relegated to funded parties instead of DOE. This may be an area that could provide fertile ground for research from an organization with such a high-level view and extensive reach as DOE. Understanding the strategies, approaches, analyses, and metrics that actually effect community change and are successful at meeting workforce and community

member needs could help inform state and local governments across the country about how to better implement their programs toward equity goals. DOE is encouraged to take a more active role in helping to establish equity program principles that translate into improved community and workforce outcomes.

- The advances in EJ and outreach to DACs and Tribes is really admirable and a big step forward for the Program. The discussion of Tribal views took up one slide out of 92 in Sunita Satyapal's presentation. This could be expanded, especially if hydrogen could benefit these remote communities.
- This has been a relatively new focus, and it is therefore difficult to quantify whether the engagement has been sufficient or has made an impact. However, the "listening sessions" and engagement with distressed communities are a good first step and are highlighting needs such as hydrogen education and dispelling myths about clean energy.
- It was apparent that the Program team made significant efforts in collaborating with and gathering feedback from a variety of stakeholders. A little more transparency or communication about how these collaborations and feedback might have affected the Program's strategy would be helpful in future AMRs.
- DOE has done an excellent job stating the importance and the goal of justice/DEI, and it is commendable. It is important to determine clear goals and actionable pathways.
- It is strongly agreed that the Program is very good at gathering feedback from and responding to stakeholders across the portfolio of efforts. The reviewer was not able to speak directly to whether these stakeholders have a focus on diversity, inclusion, etc.
- The structure to collaborate and gather stakeholder feedback is well-organized and well-intended. However, direct feedback from community groups, distressed-community leaders, municipalities, workforce development organizations, and EJ organizations may be of value for effective technology deployment, community acceptance, and timely market transformation.
- H2EDGE is a great start. While this effort is focused on training for electric power engineers, and the Center for Hydrogen Safety offers courses in general hydrogen safety, progress is needed in existing workforce development to include repair and maintenance of FCEVs and other hydrogen equipment. Collaboration with original equipment manufacturers (OEMs) and institutions providing auto mechanic training is needed.
- It seems that most people understand the needs and importance of diversity and inclusion. Ms. Shalanda Baker talked about the toxic legacy of fossil fuels and how the Program was supposed to help fix that problem. As most of the people involved in hydrogen research are not involved with the fossil fuel industry, it would have been helpful if DOE could have provided quantitative illustrations of the toxic legacy that she was talking about and perhaps map out a more desirable outcome. As described, this discussion was very qualitative relative to the other clear technical metrics laid out by DOE. DOE could also provide some clear references, and perhaps a model (like the National Renewable Energy Laboratory's [NREL's] Hydrogen Analysis model or Argonne National Laboratory's Greenhouse gases, Regulated Emissions, and Energy use in Technologies [GREET] model).
- The IPHE Early Career Network is important. It is recommended that the participants provide input to e-learning systems. Perhaps business partnerships could be established for education and outreach, as is done by the Center on Hydrogen Safety to reach future experts who work in hydrogen and fuel cells and/or live in rural areas and DACs. Business groups could potentially be set up to collect and curate the data and information from DOE projects for training in DACs. ("All tools in the toolbox.") Also, perhaps individuals in DACs with expertise in the extraction and management of fossil fuels could be helped so they can understand how to transfer their skills to non-fossil industries. It is recommended that business partnerships coach those individuals on new uses for fossil fuel expertise and that training systems augmenting formal education be developed to accelerate the workforce development.
- The Program should be more engaged with states and with education and outreach organizations, such as Clean Cities and other coalitions. However, the Program has had insufficient budget and staff to pursue those engagements adequately in the past. The regional hydrogen hubs should enable the Program to increase those engagements.
- Manufacturing and supply chain stakeholders should be engaged more—it is unclear what challenges are ahead for this sector's capability to ramp up production or transition from manufacturing other products. The supply chain for hydrogen-related technologies is challenged as is with increased demand and geopolitical changes. Environmental–NGO–stakeholder concerns should be assessed on validity and "apples-to-apples" comparisons before adopted/confirmed as an actual concern affecting decision-making.

- It is important to interact with small businesses, labor unions, and technical training schools regarding workforce development in order to reduce job loss fears caused by the transition to clean energy from fossil fuel. It was not necessarily clear how jobs would be plentiful and cleaner, safer, etc., nor what the impact on pay would be for employees who have to learn new skills. It is worth considering how the geographic dislocation of employees could be minimized.
- It is agreed that the current Program is collaborating and gathering feedback. However, it was not clear if this has been identified as an issue with previous DOE technology efforts. Decisions should be based on technical and economic merit and, as always, appropriately within the existing law. Otherwise, this runs the risk of being a distraction from the core goals.
- It is recognized that an effort is being made, but diversity seems to be lacking.

4. 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 R&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.

Average Score	**8.2**
Number of Responses	37

Comments:

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

- The new budget planning and breadth of the Program, with the addition of the BIL funds and goals, is definitely enabling DOE to accelerate some research areas that previously needed more attention for a major hydrogen transition in the United States. The overall structure looks to really be attempting to accelerate technology potential and is appropriately focused on identifying R&D needs that were possibly languishing or simply not being advanced quickly enough with private enterprise alone. The current Program plan has the potential to address many areas of need and really translate mid- and long-term issues into more near-term solutions. Given the urgency, scale of the desired eventual hydrogen industry, and desire for solutions to come quicker than ever before, this is entirely appropriate.
- Program research, without question, has been of very high caliber, directed to achieving mission goals, and well-balanced between near-, mid-, and long-term goals. Next steps may be directed to focus on the transition of research to commercialization and then to widespread deployment through community engagement, technology deployment strategies, and advancement of domestic manufacturing (balanced with demand).
- The Program's portfolio covers all of the hydrogen value chain. Budgets allocated for the different projects reflect the prioritization to be given to achieve the near-, mid-, and long-term objectives. Early-stage (low-TRL) research aiming at preparing the mid- to long-term solutions is very well considered. It can be seen as a general strength of the Program.
- The way national laboratory research expertise is made available for state and regional projects, as well as industry, is particularly impressive.
- The reviewer has advocated the importance of scale-up projects and demonstrations for many years and, as such, is happy to see things like the Advanced Research on Integrated Energy Systems facility in Boulder being included in the portfolio.
- The portfolio seems to be appropriately balanced across RDD&D areas. DOE consortia and related seedling projects have become important technology incubators and especially useful for organizing disparate activities in a collaborative and effective way.

- The portfolio is well-balanced. In particular, the incorporation of difficult issues such as alkaline-type PEM water electrolysis as a long-term issue is commendable.
- It is good to see low-NO_x hydrogen turbines as a priority. This seems like a good opportunity to utilize existing assets as part of the transition.
- Clearly, the portfolio of projects in electrolysis will be expanding greatly over the next few years. DOE currently does a good job of supporting U.S.-based electrolyzer manufacturers. In the future, there will need to be a significant focus on supply chain development.
- It is impossible to know what the "appropriate" balance of short-, mid-, and long-term R&D should be; there are too many unknowns, and even if we did know right now, it would change rapidly. Rather, there is a significant effort at all TRL levels appropriate for this office and its peers to fund. There are more early projects and more money in higher-TRL projects, as there should be. Effort and funding are appropriately distributed, but we will not know until the results are in if this was the best distribution of projects possible given the challenge.
- This is well-designed overall. Arguably, there is a critical need to do large projects, and this is something that the Loan Programs Office is starting to support now.
- It is not possible to comment on funding appropriateness, but the strategy clearly addresses near- and long-term challenges across many sectors.
- The funding levels in each area appear appropriate.
- There is definitely a mix of near-, mid-, and long-term projects, although sometimes it is not explicitly stated in those terms.
- The Program has generally been doing a good job in balancing near-, mid-, and long-term R&D. With the infrastructure bill and ambitious Hydrogen Shot goal, it is recommended that the Program management team consider "breaking" such a balance for the next three to five years, concentrating manpower and resources on addressing critical barriers on hydrogen production, storage, transportation, and refueling infrastructure. As this is a once-in-a-lifetime opportunity for the hydrogen community, a typical balanced approach that covers everything may not serve the best purpose under such a situation. Time is limited to achieve the significant milestone by 2026.
- As shown, the funding level in each area is appropriate to reach the planned cost reduction thresholds for hydrogen to be cost-competitive across markets: today, $7/kg for forklift applications, and the long-term goals of $1/kg for chemical industries, seasonal storage, synthetic fuels, industrial heat—and then, the longer-term export markets. This, however, is for today's known conditions. There are some gaps—namely, contingencies. Perhaps contingencies could be developed and the funding plans modified to include encumbrance and liquidation dates. For example, if electrolysis optimization falls, ever so slightly, out of sync with deadlines because of a parts shortage or supply chain difficulties, it is possible the encumbrance and liquidation dates become important, such that those projects would have to undergo course correction. The plenary presentations, which include the portfolio, could become public dashboards to show the progress in meeting the thresholds: $7/kg today, $6.50/kg in two years, etc. A dashboard could remain stationary such that comparisons can be made from year to year, and go/no-go decisions about continued funding could be made publicly available. It was unclear if funding has encumbrance requirements such that it could be reallocated if a project were to fail.
- Overall, the Program has a broader scope and well-balanced portfolio of research, development, and demonstration (RD&D) projects that aim to address the long-term goals. It is understandable that the near- and mid-term targets/objectives would vary by R&D areas, with some more challenging than others. Most near- and mid-term expectations involve incremental improvements to the hydrogen process. And often these incremental improvements result in performance trade-offs that may not be readily recognized or recorded. For example, a hydrogen production system may achieve some improvement in $/kg hydrogen cost but at the expense of increased emissions per kilogram of hydrogen, which may not be a line item in the near- or mid-term performance goals. Therefore, it is recommended that near- and mid-term improvements also identify and, if possible, quantify any performance trade-offs caused by the improvement that may have an impact on the ultimate long-term goals.
- In a relative sense, it appears that production overall is appropriately represented in the portfolio because of its importance to meeting Hydrogen Shot goals. Distribution seems to be relatively under-represented, and fuel cells are somewhat over-represented since they are not critical to achieving low-cost hydrogen. Platinum-group-metal-free (PGM-free) catalysts for water electrolyzers and fuel cells are perhaps over-represented, considering the very large durability challenges that remain. Notably, the above are assessed

on a relative scale, based on current funding levels. It is likely that with the BIL funding, projects in all areas will be raised. One key gap that may have a strong impact on the ability to achieve near- and long-term goals is that the size of the technical R&D workforce in the United States may not be sufficient. That is how it seems. It is based on a wide-scale departure and shrinking of the field in the mid-2010s as automotive fuel cells were diminishing in relative importance and hydrogen/water electrolyzers were not yet gaining steam. The talent pipeline partly depends, of course, on the number of graduate programs in the hydrogen economy. This should be assessed, and if truly insufficient, some efforts may be needed there.

- As previously stated, the decrease in fuel cell R&D funding for FY 2023 is a concern, especially when the overall Program budget is increasing. There are still many technical challenges to overcome to improve fuel cell performance and lower costs. In fact, the Program's focus on HDVs has made the durability target much more stringent, and although the cost target is higher than it was for LDVs, higher durability is difficult to achieve at low-precious-metal loadings. Developing non-PGM catalysts is a significant challenge, as will be developing alternatives to fluorinated membranes, which the industry will likely have to move away from because of environmental concerns. On the positive side, it is good to see an increase in the Basic Energy Sciences (BES) program's hydrogen R&D budget request. Given the plans for regional hydrogen hubs, the Program should consider increasing the Systems Analysis budget to increase analysis efforts for specific states and regions. For example, updating the Northeast Electrochemical Energy Storage Cluster's techno-economic analyses that were conducted in 2017–2018 for the Northeast states and expanding to other states could be useful. Finally, the Program should continue to apply sufficient resources to manufacturing R&D to lower technology costs.
- Yes, the 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 R&D. A major challenge with hydrogen fuel cell technology is that it is "bottom-heavy," with many researchers and has few opportunities for profitable successes. As set up now (by U.S. law), the universities and national laboratories develop intellectual property that then needs to be licensed by a company to be put into practice. However, the hydrogen company is presently unlikely to have enough profits or resources to be licensing technology. Perhaps this will change as new companies try to get into the hydrogen field. DOE should track how business practices and licensing progress over the next few years, and DOE hopefully helps businesses to be profitable with a robust hydrogen economy.
- The current portfolio is under-represented in near-term R&D, especially TRL 7 and above. The recent demonstration projects within H2@Scale are very good additions to the portfolio, and the plan as described to use BIL funds to expand more in these higher-TRL/nearer-term technologies will help correct this imbalance. This should not be at the expense of mid- and long-term research, which is also critical to maintain technical leadership in the United States.
- From a deployed-system-capital-expenditure perspective, some of the sub-cell- and cell-level electrolysis and fuel cell research should reassess the trade-offs between near-term high performance and long-term stability. The techniques that achieve highly performing electrochemical cells often do not persist and may require replacing the expensive electrochemical hardware more frequently.
- The reviewer hopes DOE continues to provide strong support for early-stage R&D work in the areas that may take a long time to mature, such as proton-conducting SOECs.
- The impact on industry if the Hydrogen Shot is achieved should be analyzed. It is unclear how Hydrogen Shot success would impact the agricultural community (ammonia cost).
- It appears that the time horizon for several of the R&D areas seen during this AMR has shortened significantly. This is appropriate for some (where the technology is at or on the cusp of being handed off to industrial concerns), but there are other areas where there is still much need for out-of-the-box thinking—storage, liquid carriers, and materials for high-pressure tanks, to name a few.
- The near- and mid-term goals are well-represented. Longer-term goals appear somewhat out of balance. SOFCs seem to have been largely de-emphasized. Also, the rationale for the 75%/25% funding split between low- and high-temperature electrolysis was not made clear. Clearly, high-temperature electrolysis has many thermodynamic advantages, even if it is behind on TRL levels relative to low-temperature systems, but the longer-term funding picture should recognize the advantages offered by high-temperature systems. Going forward, a more equitable distribution of funding between low- and high-temperature systems is more desirable.

- University support is lacking compared to national laboratories. There are still some fundamental issues to be solved for the PEM- and solid-oxide-based (SO-based) electrolyzers. In tackling these problems, universities have advantages.
- The projects seem to be more focused on the mid-term goals, whereas not enough emphasis is put on more basic science to allow the development of solutions for the long-term goals.
- Additional attention is needed regarding safe, secure, economical, and reliable sources of materials within the industry. More work is needed on how to maintain reliable energy supplies during the transition and the longer-term dependence on fewer sources of energy (e.g., common mode failure).
- Underrepresented topics include pipelines, small (up to 10,000 kg) engineered underground hydrogen storage (versus salt domes), liquid hydrogen storage, liquefaction technology R&D, fueling interfaces for liquid hydrogen, and off-road FCEVs.
- There are several interesting projects with industry that seem either not to have done any work or to not be well-developed and implemented for a domestic supply chain. If a domestic supply chain is supposed to be developed, it should be developed using domestic materials.

5a. The Subprograms of the Hydrogen and Fuel Cell Technologies Office (HFTO) have clearly articulated their mission and strategy and have appropriate goals, milestones, and quantitative metrics.

For the HFTO subprogram(s) you are evaluating, 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 Technologies Sub-Program Rating	Fuel Cell Technologies Sub-Program Rating	Technology Acceleration Sub-Program Rating	Safety, Codes and Standards Sub-Program Rating	Systems Analysis Sub-Program Rating
Average Score	**8.7**	**8.7**	**8.6**	**8.7**	**8.5**
Number of Responses	34	33	27	24	28

Comments:

- The subprograms indeed have clear and appropriate goals across all those that presented. Milestones along the way were provided, and goals/milestones were quantitative, time-bound, and generally very challenging.
- The subprogram organization is logical and effective. It provides a rational framework for coordinating complementary RDD&D activities. As currently configured, the framework is structured to mitigate unwanted “stovepiping” of priorities and reduce organizational redundancies.
- Technology Acceleration has been a particularly excellent addition to the subprograms.
- These subprograms are focused and based on metrics that are well-thought-out and well-modeled.
- The subprograms are considered to be very proactive in promoting the Program.
- The subprograms all have a clear mission and strategy. The level of detail in the metrics varies, and it is difficult to define these for some areas, such as Systems Analysis, where metrics may relate only to achieving certain dates for important analyses, for example. The Fuel Cell Technologies subprogram has by far the most detailed metrics, and it would help if the Hydrogen Technologies subprogram had similar metrics and targets. For example, the targets are defined by component (membrane, catalyst, bipolar plate, etc.) and through multiple parameters (conductivity, durability, activity, etc.), while Hydrogen Production is defined only by $/kg and $/kW. The latter, while easy to compare, should really be changed since $/kW is better for lower-efficiency electrolyzers but actually increases $/kg.
- The Fuel Cell Technologies plan is well-articulated, with specific achievement metrics for each subcomponent. The Hydrogen Technologies plan needs to be developed further to this level of subcomponent analysis.
- All of these subprograms appeared to be extremely well-managed and well-articulated to achieve goals, milestones, and quantitative metrics. The next steps may be to emphasize Systems Analysis and Technology Acceleration to hasten the transition of research to commercialization, with community engagement and advanced domestic manufacturing to meet demand.

- The subprogram presentations (specifically the Program/subprogram plenary and Hydrogen Technologies oral presentations) were uniformly solid in describing the pathways and goals with appropriate metrics needed to "move the R&D needle." If an improvement could be made, a more semi-quantitative assessment of the risks remaining to overcome barriers could be useful.
- HFTO clearly conveyed the current mission with appropriate goals, milestones, and metrics. It appears to be challenging to incorporate the rapidly evolving commercial space and Congressional directives.
- The Hydrogen Technologies and Technology Acceleration goals make sense for the current level of technology—it is time to get this technology commercialized. Not a lot of new goals/projects were seen for the Safety, Codes and Standards (SCS) subprogram, and it was not clear if any new projects have begun or are envisioned. It seems that new or ongoing data from a "technology validation" project on fueling (both LDV and forklift) is a large enough body of data at this point that it can inform practical, statistics-based standards going forward.
- There was no SCS subprogram overview presentation. The SCS presentations from Tuesday morning have appropriate goals, milestones, and metrics. It may be time to establish the current SCS mission, strategy, and goals. The 2020 Program Plan also lists no specific SCS goals. With so many emerging applications, consideration should be given to determining goals, milestones, and metrics.
- Regarding the mission and strategy, it is suggested that MD/HD targets, goals, and research should be in addition to, and not in place of, parallel LD efforts. This is especially the case in the Fuel Cell Technologies subprogram where, as presented, all the LD targets and evaluation were not mentioned and were replaced with their MD/HD counterparts. The Program is asked to maintain the focus on LD and communicate clearly where the advances in one application may or may not be transferrable to the other. This will be especially important to keep stakeholders properly informed as these industries and technologies develop. For instance, as cost targets may be achieved for MD and HD, they might depend on technology advances that are particular to or only really achievable in that application. If so, it will be important to clearly communicate that so stakeholders have properly set expectations and an understanding of the overall market and the technology interactions between end uses.
- For Hydrogen Technologies, more information is needed on how the cost of electricity will be reduced. It was not apparent if natural gas would be a primary fuel for electrical power production, nor how the issues of spinning reserve would be addressed to reduce the cost of electrical power. For Fuel Cell Technologies, it would be good to know what cost breakthroughs are needed to achieve a cost-effective HDV fuel cell system, and if the cost-reduction program for fuel cells depends only on the benefits of high-rate production. It was not clear how projects that would reduce the cost of fuel cell systems are chosen, nor where manufacturing comes into the Fuel Cell Technologies, Hydrogen Technologies, and Technology Acceleration subprograms. It is possible that we would develop technology and manufacturing processes, only to have the products of this technology manufactured outside of the United States; "manufactured in America" should be a goal included in all of these subprograms.
- More work is needed on the demand and quantity of the projected use of hydrogen for various applications. It seems we are past the point of "Can we make hydrogen?" and are now at the point of asking who is out there to use hydrogen and at what quantity. An inventory of the age of existing facilities, along with their replacement/upgrade cost potentials (i.e., quantitative metrics), is needed. It is unclear what is out there, what can actually be transitioned into decarbonized approaches, and whether the industry is willing to go along with it. It is recommended that metrics be added to explain go/no-go decisions made at certain milestones that include the encumbrance and liquidation dates.
- There is an unfortunate mismatch between industrial- and national-laboratory-stated materials and performance goals. This is an ongoing issue that is partially caused by different manufacturers using different approaches with differentiators. It is also partially due to reliance on a set of experts who do not choose to engage with the difficult task of monitoring industrial goals and instead base their analyses on academic models and goals.
- Metrics could have been emphasized more in individual subprogram presentations—they are clear at the high level, but alignment down to the individual project level is important.
- It is difficult to apply quantitative measures to several of the subprograms. Systems Analysis needs to look at macro-economic and system-wide economics and reliability during transition.
- Systems Analysis needs to look deeper into the entire cost chain.

5b. Were the important challenges to meeting these goals identified, and were plans to address the challenges articulated?

Comments:

- From four respondents: Yes.
- Yes, the subprogram challenges are well-identified, and the plans to overcome those challenges have been well-communicated. In addition to the AMR, the subprograms' topic-focused webinars and workshops are an excellent approach to providing more detailed information on challenges, activities, and plans, as well as getting input from industry and other stakeholders. The goals, milestones, and quantitative metrics are ambitious, and appropriately so.
- Yes, for the Program goals, end uses, and applications as presented, the major challenges were properly identified, and DOE clearly has a strategy for addressing them.
- The ground that needed to be covered and the barriers to meeting the goals were correctly identified, along with plans (typically multi-path plans) to surmount the barriers. In general, there was an overarching plan to fund several approaches and then subsequently focus funding on those that work, helping those approaches progress up the TRL chain.
- Yes, well done.
- Mostly yes.
- Largely yes.
- Yes, in general. Please continue to update the understanding of challenges and revise plans accordingly at future AMRs.
- The communicated challenges include end-user cost, insufficient existing infrastructure, poor public awareness, limited business cases, poorly aligned annual demand of hydrogen relative to existing production capability, required technical innovations, and a limited skilled labor pool. Discussed solutions focus on outreach with academic and commercial partners to improve situational awareness and education while funding training/educational opportunities and research to close technology gaps.
- For each subprogram, and in particular Hydrogen Technologies and Fuel Cell Technologies, there is a clear and well-defined description of the qualitative and quantitative objectives, the articulation between the topics, and the timeframes. The Program is mainly focused on technology and economic aspects. Hydrogen is considered a powerful pathway for global decarbonization, as required by our society. This means the hydrogen community has to ensure that society can trust in the positive environmental impact of the hydrogen developed. Investigating in more detail all the environmental impacts (carbon footprint, land use, materials needs, etc.) could contribute to building that trust.
- Some challenges were clearly articulated—e.g., the case for integrating hydrogen production with nuclear. A near-term opportunity that was not covered is capturing the status and information from Technology Acceleration projects for training systems. For example, with the integration of hydrogen production with nuclear energy (again, this was well-presented), the learnings could be placed into training systems as they occur. It is recommended that future grants and contracts stipulate this data collection and reuse of the data.
- Mostly, yes. It would be good to see efforts to identify and address the challenges that will remain even after the technology and cost goals are achieved. Deploying the technologies will require acceptance by regulators, industry, and the public.
- While cost and technology performance may be a substantial challenge, community acceptance for market transition may be the greatest challenge to increasing market pull for a clean hydrogen economy.
- Challenges were well-identified; general plans were articulated, but this will take some time, given the large task ahead of HFTO. The FOAs would be expected to have more detailed information on how to address these challenges.
- Challenges were well-articulated and plans to address the barriers were also thoroughly discussed. One area of improvement might be to address the specifics of the R&D steps to achieving the goals, or at least there was little discussion as to the risks involved in how successful the R&D pathways might be. This comment comes from the impression that, for example, when waterfall charts are shown for reductions in cost, specifics were often absent as to how the reduction would be achieved and how much risk it would entail.
- For the most part, the challenges and obstacles were articulated satisfactorily, and plans to address the barriers were adequately formulated. In the 2022 AMR overview of the Hydrogen Technologies subprogram, there was a significant emphasis placed on approaches for efficient and cost-effective

hydrogen production. It is assumed that was done to set the stage for hydrogen production R&D that will be devoted to addressing the challenging goals of the Hydrogen Shot initiative. That said, it was surprising that hydrogen storage technologies were relegated to second- or third-tier importance in the presentation. An approach that meets the volumetric and gravimetric capacity targets as well as reversible thermodynamic and kinetics targets has not yet been developed. This seems to remain a critical issue, and it should be highlighted in a more direct and active way. For example, work within the HyMARC advanced storage material consortium received very limited attention. It begs the question about the R&D directions in this important technology area. The HyMARC activity should have at least been granted an oral presentation slot in the review; it seems like that work is being marginalized.

- If one searches the Hydrogen Technologies subprogram for "challenges," nothing shows up. However, targets are identified and extensively discussed. Importantly, "focus areas" are identified. The planned progression through the TRLs is discussed, but no detailed pathway for achieving the progression was identified, and breakthrough technology needs were also not clearly identified.
    - The Fuel Cell Technologies subprogram identified four challenges: cost, efficiency, durability, and power density. Each of these challenges had approaches identified. Cost is a critical driving force for the HDV market. RD&D cost reduction areas identified for HDVs with high-level goals were presented (e.g., increased power density, although what would be done to increase the power density was not directly stated). (Perhaps Pt-to-Pt spacing would be modified to improve oxygen reduction catalysis, or ternary alloys of PGM would be considered to increase durability.) When considering plans to address challenges, discussion was at a high level—not what one would consider a "plan." The Los Alamos National Laboratory and Brookhaven National Laboratory catalysts look promising; however, it was not clear that the data after 90,000-hour-equivalent accelerated stress test (AST) cycles, as shown for these catalysts, are in the baseline. It is assumed they are, but a better label on the chart would help. The discussions of General Motors (chart 18) and Carnegie Mellon University (chart 19) provide greater insights into how the challenges would be addressed. The importance of a 25,000-hour-equivalent AST is a good addition to the Program. It may be difficult to separate out the different degradations if they interact; catalysts degrade, and there is higher current density at constant power, which may affect supports and vice versa. Migration of degraded catalyst into the membrane may suggest membrane weakness. There were a number of unclear points: whether there was the capability to sort out the potential mixing of degradative effects; whether the decrease in performance of a PGM-free catalyst compared to a PGM catalyst suggests a larger fuel cell stack, more bipolar plates, and more membrane; and how these are rationalized in the design for the fuel cell system.
    - Diversity, inclusion, equity, and accountability efforts would benefit from industry internships since RD&D drivers may be different in industry compared to national laboratories or universities.
    - Technology Acceleration is an important stepping stone to higher TRLs that will lead to manufacturing. It was not clear how HFTO rationalizes doing some of industry's important development activities. SCS programs by national laboratories are very important aspects of the Program and benefit all industry. For demonstrating hydrogen and fuel cell integration, it was not clear if a pilot facility needs to be developed and if this effort involves national laboratories/universities, nor what industries' participation is. It would be helpful to know whether industry results (patents/trade secrets) are shared with other industry on a non-competitive basis and whether the results of Technology Acceleration are only for U.S. industry. Ammonia production is a well-defined and mature industry. Further questions include what level of improvement (as a percentage of current cost) is needed for the ammonia industry to expend new capital based on Technology Acceleration results, if there is a study that states what cost improvement is necessary to undertake capital expenditures, and whether H2@Scale cooperative research and development agreement (CRADA) results from General Electric (GE) and Nel Hydrogen would be available to manufacturers not selected for the CRADA. There are similar questions for GKN Powder Metallurgy hydride storage.
    - Regarding grid energy storage and minimizing hydrogen cost through multiple generation sources, it was not clear why multiple generations were not just made using the lowest-cost system. The nuclear hydrogen production should be emphasized. It was not clear why there was more wind-to-hydrogen-electrolyzer modeling (this has been repeatedly done for the last 10+ years), whether transportation results would be available for all U.S. companies, and how the support of non-U.S. companies (e.g., Daimler) is justified. Hydrogen dispenser nozzles are currently in use, and it is unclear why new designs, etc. are needed and whether this is a cost or safety issue. Total cost of ownership analysis is

very beneficial and should be done in close cooperation with industry. It would be helpful to know how many hydrogen hubs there would be.

- The goals are clear; however, all subprograms and accomplishments are treated as equal. It would be helpful for DOE to illustrate the relative TRL and MRL of accomplishments. That is, if the current density of a small SOEC is increased, it is unclear how this will directly feed into the Program goals—for instance, whether it will increase the TRL at all, or just help toward the "1 1 1" goal if it could somehow be commercialized.
- The individual subprogram presentations included slightly more detail, but the challenges and past experiences were emphasized less than the future.
- DOE will need to address the larger industrial uses of hydrogen, which to date are generally handled by independent producers and users. For example, existing codes and standards generally do not cover larger industrial hydrogen processes and are handled independently through risk analysis by producers and users (e.g., not within the scale of such documents as NFPA [National Fire Protection Agency] 2).
- Real emissions from hydrogen projects (carbon emissions, constituent emissions like NO_x, and hydrogen in the atmosphere) were alluded to, but detailed discussion or projects directly related to quantifying/controlling emissions were not seen.
- The challenges to meet the HFTO subprogram goals need to be prioritized and better articulated.
- HyMARC has been in process now for seven years; it is difficult to see if we have a clear path to a material that will meet the goals and is practical for the automotive environment.

6. HFTO Subprograms are effectively fostering innovation and advancing the state of technology for hydrogen and fuel cell technologies to be competitive and achieve widespread commercialization and adoption by industry.

For the HFTO subprogram(s) you are evaluating, 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 Technologies Sub-Program Rating	Fuel Cell Technologies Sub-Program Rating	Technology Acceleration Sub-Program Rating	Safety, Codes and Standards Sub-Program Rating	Systems Analysis Sub-Program Rating
Average Score	**8.4**	**8.4**	**8.4**	**8.5**	**8.3**
Number of Responses	34	33	27	24	28

Comments:

Please include recommendations on any novel or innovative ways to address the challenges and achieve the Program goals, including the challenge to meet the Hydrogen Shot production cost goal of $1 per kg of hydrogen in 1 decade.

- There are small projects to support scientific concepts, SBIRs to support nascent industrial innovations, and a variety of efforts with many players to progress the best ideas and work them toward commercialization. As they approach that point, there are then the hubs and Technology Acceleration to help bring up regional markets and supply chains, helping industry accept initial risks so that a demand-pull market results. Of course, this is easier in some areas than others; Systems Analysis cannot as easily foster innovation, but it does allow one to see how the innovations might fare if they succeed—so there is value. Likewise, Technology Acceleration is more about fostering market insertion and supply chain development, so innovation is less that subprogram's responsibility. But it does create a place where innovations, once developed, can thrive.
- The subprograms cover the novel and innovative ways of which this reviewer is aware.
- It is recommended that the Program look at the integration of renewable power, grid capacity, and hydrogen production at the point of use to understand how we can minimize the need to transport hydrogen other than via pipeline by developing production infrastructure at/near the point of use. It would also be helpful to accelerate both SCS and materials testing work to support easier and less costly deployment of hydrogen pipelines.
- DOE has done a first-rate job of structuring the overall Hydrogen Technologies and Fuel Cell Technologies subprograms to nurture innovation and to foster advanced technology development. Collaborations with the

Office of Science and Advanced Research Projects Agency–Energy (ARPA-E) are important. However, a continuing challenge remains to show stakeholders how those linkages are leading to meaningful advancements and impact in the core Program. The goals of the high-profile Hydrogen Shot initiative are clearly challenging. A focused effort is planned and being executed. However, other critical areas (e.g., storage and carriers) must not be de-emphasized at the expense of progress on the Hydrogen Shot activity.

- To achieve the Hydrogen Shot production cost goal of $1 per 1 kilogram of hydrogen in 1 decade, the addition of alkaline and anion exchange membrane (AEM) electrolyzers into the Program was a very good decision. With the cost of PGMs continuing to increase, AEM water electrolyzers seem to be the most promising candidate to reach the target. Acceleration of AEM water electrolysis R&D would be critical for future success.
- Achieving the Hydrogen Shot production cost goal of $1/kg of hydrogen in a decade, and considering only "clean" hydrogen, will depend mainly on the electricity cost, which is outside the influence of the Program. The technology impact is well integrated in the current Program.
- The thermodynamic advantages of high-temperature systems offer a clear path to achieving lower cost.
- Thinking a bit outside of the box: perhaps there should be a competition for which the prize would be the award of a federal fleet (or other hydrogen offtake) contract for the first organization to demonstrate production at $1/kg while also selling the hydrogen for the contracted use at a competitive rate (at or below conventional fuel cost equivalent).
- The number of neighborhood-level microgrid demonstrations should be increased. This simultaneously reduces the load on the high-voltage power grid and illustrates integrating the multiple renewable and hydrogen-based power sources needed to reduce the carbon footprint at a local level. With a properly selected site, this can demonstrate a reduced electricity cost, thereby increasing the demand for hydrogen. This added demand could create a business case for the commercial sector to participate. Unfortunately, this would likely result in a near-term increase in hydrogen costs before industry could develop enough to satisfy the demand. If combined with an educational institution (such as high school, vocational school, or community college), this can incorporate outreach and educational elements while potentially serving a DAC.
- The subprograms are working very well on innovation and technology. The concern is with "be competitive." It is very hard to compete with fossil fuels, especially in transportation, so shooting for cost parity within five years or a decade is probably setting the bar too high. It should be reasonable to assume that good progress and a line of sight on ultimate goals will be enough to spur policy support.
- The Program has been very effective at fostering innovation and advancing the technology through R&D. The regional hydrogen hubs should enable innovation in demonstrations, deployments, education and outreach, and approaches to working with states. However, it is not clear that the HDV market alone will generate the demand needed in the transportation sector to reduce the cost of hydrogen to the Hydrogen Shot goal or enable widespread commercialization. The Program should do more to support LD FCEVs in applications where they make sense. In the Systems Analysis area, the Program should consider doing more state- and region-specific analysis to assist states/regions in planning hydrogen and fuel cell demonstrations and deployments.
- The $1/kg target is indeed very aggressive and aspirational. That is good, and a "failure" of achieving only $1.25/kg or $1.5/kg hydrogen would still be a major win. However, there is still a deficiency of specific articulated pathways to achieve the $1/kg goal. DOE would be better served with more analysis discussing what it will take to achieve the targets so as to relate the goal to what is achievable in the timeframe.
- HFTO has traditionally fostered significant innovation in electrolysis and fuel cells. However, the electrolysis area has had much less investment and very little funding past TRL 6–7, which leaves a lot of investment for small companies to actually transition R&D advancements to process development and scale-up. With the upcoming FOAs, hydrogen/electrolysis should start to catch up to fuel cells on being world-leading at the commercial level. On safety, the Center for Hydrogen Safety is a great resource and can help drive consistency and learnings. The one area where HFTO could play a stronger role is in clearly communicating and pushing to resolve obstacles in existing codes and standards that are hindering implementation. Similarly, NREL in particular is very strong on systems analysis, but some deeper dives across the community on what can be done to improve cost at the systems level would be a good next step with the added resources in hydrogen.
- A goal of $1/kg production cost by 2030 is a tremendous challenge. DOE should take a somewhat balanced approach. Higher-TRL technologies (PEM, alkaline) for production must be emphasized overall, as they

are the most likely to achieve the substantial improvements needed. While the operating efficiency can only be increased somewhat, capital costs can be dramatically improved through scale-up, but this can get us only part of the way down the cost curve. Balance of plant efficiencies needs to be improved as well, but it is unclear how much is possible. The remaining path is a reduced stack capital cost at the material level, meaning increased operating rate while maintaining/improving efficiency. For alkaline, thinner separators are critical. For polymer electrolyte membrane water electrolysis (PEMWE), thinner PEMs with lower hydrogen crossover and mechanical strength are needed—research is needed to define targets and measurement methods to know what is truly needed from a materials property perspective in the PEMWE environment. For PEMWE catalysts, it seems that only Ir-based catalysts will be impactful by 2030. Significant materials development is needed to develop truly stable Ir-based catalysts at the low loadings needed for PEMWE at the multiple-gigawatt-per-year scales needed to achieve the vision. In-depth understanding of degradation mechanisms are needed, and new materials science is needed to stabilize—i.e., through optimization of Ir structure and composition (oxide level, grain/particle size), support–catalyst interactions, and surface modification. This needs to be done with both strong computational theory guidance, as well as advanced fabrication and characterization methods. Toward the reduced capital cost, DOE should consider projects that directly address higher-current-density operation in the near term—5 A/cm^2 or higher. The key barriers (material stability, reaction uniformity, heat and mass transfer) should be determined through advanced characterization, modeling, and baselining, and then focused materials development efforts should be initiated to address these barriers. Along with the high-TRL emphasis, DOE should also fund lower-TRL efforts at appropriate levels. AEM technologies have incredible promise but are still far away from the goals—no supporting electrolyte, durable ionomers for membranes and electrodes, and PGM-free catalysts. Focus needs to be on developing truly durable ionomers. HFTO should also have seed programs for innovative high-risk–high-reward-type projects, akin to the ARPA-E model.

- To foster innovation and advance the state of the technology for competitive applications and widespread commercialization, an inventory of the expended life and life expectancy of carbon-based energy systems is needed. This may not be novel. The data and information in the inventory "review" can be imported into e-learning systems that use artificial intelligence and machine learning to train the workforce. These can be served as free-of-charge apps that provide a dynamic learning environment. These systems help the workforce and instructors realize their progress and also design personal pathways to broaden and strengthen their knowledge. Project developers also need assurance that training systems meet their needs and that these systems will help attract and retain a skilled workforce, so the developers must be included as partners. The developers will gain confidence as they experience how the e-learning systems expand with use and interaction. Somehow, the impact of the war in Ukraine and the drought conditions and precious nature of water should be added to analyses.
- The HFTO programs are clearly technically sound and advancing technology. However, the innovations as described were not explained as part of a total cost of ownership/techno-economic analysis model, so it was hard to understand how they have an impact on DOE's "1 1 1" goals. Quantifying progress toward "1 1 1" goals should be included in all future programs if DOE can provide a model for reference. It probably makes the most sense for the DOE laboratories to model the projected impact of the university/corporate innovations, as the labs can be impartial. There are so many issues related to "adoption by industry" that it seems like an unrealistic metric. Perhaps it is better to think about "accelerating the hydrogen industry."
- The Program should not penalize lower-cost "gray" sources of hydrogen waiting for more cost-effective green hydrogen. Inexpensive gray hydrogen can help nascent hydrogen applications gain traction earlier and still result in emissions reduction. With a lower barrier to hydrogen use, efficiency increases and long-term carbon goals will be obtained as a natural optimization process. Too high of a hurdle upfront will slow the technology. "The perfect should not be the enemy of the good."
- Unfortunately, it is unclear how there is going to be a clear path to implementing the necessary groundbreaking technology in the market. This requires both refinement of existing technologies and significant breakthroughs. While the refinement is likely and can likely achieve $4/kg or even less, $1/kg really does seem to require significant technological breakthroughs. And the current frameworks do not seem to encourage a smooth transition from laboratory-scale innovation to benchtop to prototype to pilot to mass production. Encouraging national laboratory scientists to become innovators and entrepreneurs will not achieve this in the timeframe desired. It is critical that DOE actively engage with demonstrated technology disruptors and innovators at the incubator level, and the A- through C-round start-up.
- Unfortunately, it is difficult to believe $1/kg of hydrogen will be achieved in a decade. HFTO and FECM and their predecessors have been working at this for over 10 years. Improvements have been evolutionary,

not breakthrough. This does not suggest that the subprograms should be eliminated; they are definitely of value. Recognizing that progress would be evolutionary and setting goals with that approach in mind for some of the subprograms and establishing breakthrough projects (the reviewer avoided using ARPA-E) with recognized high risk would be beneficial.

- The Hydrogen Shot production cost goal of $1/kg of hydrogen in 1 decade is ambitious, as it should be, but the work being done is less ambitious and relies solely on U.S. progress, whereas—in contrast to the development of fuel cell technologies, where the United States kept the lead for several decades—hydrogen production using electrolyzers is much more developed in the European Union (EU). More international collaboration is required to leverage the knowledge and progress outside this country. As it seems, the work done in the United States is still at a very early stage compared to many other countries.
- Increased education to local communities may be an effective pathway to gain market acceptance, commercialization, and transformation. Direct communications with community leaders may be needed and welcomed to create an effective pathway for market transformation. Generally speaking, DOE needs to move the research to community markets for commercialization, domestic manufacturing, and workforce development.
- There was no SCS subprogram overview presentation. It may be time to establish the current SCS mission, strategy, and goals. Widespread commercialization will require regulatory changes at the national, state, and regional level.
- From the reviewer's experience, work on porous transport layers is necessary for PEM electrolysis. It will also be valuable to expand the portfolio in alkaline electrolyzers.
- The challenges to meet the Hydrogen Shot goals need to be more clearly defined.

7. The HFTO Subprogram'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 R&D.

For the HFTO subprogram(s) you are evaluating, 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 Technologies Sub-Program Rating	Fuel Cell Technologies Sub-Program Rating	Technology Acceleration Sub-Program Rating	Safety, Codes and Standards Sub-Program Rating	Systems Analysis Sub-Program Rating
Average Score	**8.4**	**8.4**	**8.5**	**8.5**	**8.4**
Number of Responses	34	32	26	23	29

Comments:

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

- As with the overall Program, each of the subprograms has early- and mid-term R&D and some near-term projects. The only exception is Technology Acceleration, which is designed to be focused on helping high-TRL products make it through the valley of death to a functioning capitalist market. But even Technology Acceleration has commitments at different timescales befitting the goal of demonstration, de-risking, or transition to demand-pull.
- Given all the moving pieces, the staff has done an excellent job overall in balancing priorities and investments.
- No particular area seems inappropriate.
- GREET training is needed for integrating non-carbon energy facilities or upgrades with those facilities that use or produce fossil fuels. This would support a gradual and reasonable transition. Additionally, an analysis of the workforce is needed to support the transition. The analysis needs to be specific, determining who works now, what training is needed for the future workforce, where they live so that we can reach them, and whether those who live and work in rural areas have high-speed internet access (broadband) so that announcements and training in energy systems can be sent to them. The distribution of information

about new energy systems or modifications of existing energy systems can assist with the permitting process and public acceptance.

- Other than Hydrogen Technologies, the reviewer's scores/comments are from the Program/subprogram plenary presentations. One impression received over the years is how extremely important it is to transportation applications to obtain high-strength materials for high-pressure tanks. Toray has been in the carbon fiber R&D business for roughly four or five decades, and carbon fiber is still far short of its theoretical properties, with just incremental progress still occurring. Perhaps a joint BES–EERE program in materials discovery is in order to make a big leap forward in properties, which would hopefully go to tackling the cost barriers that have been identified.
- With the focus on "1 1 1" and hydrogen hubs, several of the legacy programs are somewhat orphaned and not related to new DOE goals. The long-term research is inappropriate for the "1 1 1" programs but, overall, is important to hydrogen research. For instance, the HydroGEN programs seem somewhat unrelated to "1 1 1," but they do important research and should not be cut. Solid-state hydrogen storage does not work despite ample investment, but the payoff of a success would warrant the investment. The Technology Acceleration projects seem very successful. DOE might study which projects were most successful and which were their most critical elements, and consider what mix of high and low technical/industry goals have led to commercialization.
- For Hydrogen Technologies, it does seem that while the biomass/waste pathways are included in the scope of the goals, they are certainly taking a back seat in focus and funding in that subprogram. This should perhaps be reconsidered or adjusted, especially as waste and waste emissions will continue to be an issue that needs to be addressed in the future and could be a positive opportunity for hydrogen to abate these emissions. In addition, LD fuel cell development should not be left behind in favor of MD/HD; rather, development for these end uses should be pursued side by side.
- The Fuel Cell Technologies work has been changing its focus over the past couple of years and to some extent putting aside previous achievements related to AEM fuel cells, SOFCs, and PGM-free catalyst development. The subprogram has completely removed the development of PGM catalysts, losing capabilities that could benefit both PEM fuel cells and PEM electrolysis. It is important to maintain these projects in order to avoid the loss of capabilities after such a long and costly investment.
- Overall, the subprograms' R&D seems to be geared toward the long-term goals, but the mid-term R&D activities seem to be lacking. It is a long road to achieving certain goals, and working toward intermediate steps will provide important milestones and opportunities to re-evaluate whether the goal previously set is still the right one.
- R&D needs must be determined to facilitate the regulatory frameworks necessary for deployment of technologies across a range of new applications, such as grid resilience, heavy-duty trucks, maritime, aviation, and railway.
- Near-term R&D for hydrogen production has been under-represented because of funding availability, other than some H2@Scale demonstrations, which are very valuable in showing real-world integration. This can be re-balanced as BIL funds start to be allocated.
- As a skilled workforce may become the main barrier of hydrogen deployment, increased investments on this topic are recommended to ensure inclusion of hydrogen specifications in general courses starting at undergraduate levels. Training activities for teachers and trainers might also be more strongly considered.
- As an evolutionary process, more emphasis on balance of plant is recommended. For breakthrough projects, more industry participation is suggested, with industry accepting some financial risk but receiving greater rewards (with exclusive patent awards).
- With pre-BIL funding levels, non-PGM catalysts for fuel cells and water electrolyzers seem over-represented. While they hold great long-term promise for addressing cost, they remain far from commercial viability.
- A balance of short-term ways to ease the economic transition to cleaner fuels with longer-term benefits is needed. A realistic self-evaluation of the scales of effort and timeline will pay off with a more achievable approach.
- SCS seems under-represented this year, with only five projects reviewed. There needs to be a focus on codes and standards for local/lower-pressure hydrogen distribution networks.
- It is premature to reduce funding for fuel cell R&D when significant performance and cost challenges remain for HDV applications.

- The split between low-temperature systems seen to have a higher TRL and high-temperature systems with a lower TRL seems out of balance. Future funding should be more balanced.
- Direct communications with community leaders, workforce development organizations, municipalities, and EJ groups should be a priority for market transformation.
- While a longer-term issue, recycling fuel cell stacks, systems, and vehicles could use additional support.
- Technology comparative analysis should be conducted to evaluate whether funding levels in each area are appropriate.
- Alkaline electrolysis is under-represented.

8. 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:

- International partnerships appear to be of high quality, balanced, well-organized, and effective for international cooperation and global progress.
- The international collaborations that developed over the last two years are very impressive, and an increase in acceleration of these collaborations is highly encouraged. This is especially relevant in ally nations in Europe, the United Kingdom, Japan, and Korea, who are well-integrated into our economic system, educational system, and market.
- There is significant coordination between DOE and other government and policy groups internationally, including joint activities, workshops, webinars, etc.
- Numerous global and bilateral collaborative partnerships are in place. They are contributing to solid progress, as well as international awareness of the Program. Well done.
- One of the most important issues will be to achieve alignment and standardization of clean hydrogen production and distribution evaluation methods, metrics, targets, and implementation. Right now, there are inconsistent standards across the globe that are beginning to be established. This will likely cause confusion in the market if not addressed, especially as companies and governments work toward implementing low-carbon and low-emission energy solutions. Verifiable, trusted, certified, and consistent hydrogen life cycle performance is required to make sure this is not a speedbump that is later an impediment. There should also be an international alignment of strategies and use cases for support of or preference for certain hydrogen distribution and use life cycles, especially as concerns the method of transport, distribution, and delivery of hydrogen. There simply does not appear to be common understanding of the multiple options, their requirements, and the potential impacts. The reviewer has been witness to this lack of consistency being a cause of confusion and at times even being exploited by organizations to mischaracterize their product offerings. It seems that more standard methods and terminology is sorely needed when it comes to the environmental performance and the engineering and technology language used. One thing DOE should be commended for in this regard is the focus on terminology of "clean" hydrogen rather than "green" hydrogen. The use of the term "green" is rapidly being tightly associated with only renewable-powered electrolysis and risks leaving out other production methods than can still be carbon-neutral or -negative while producing low or no emissions.
- Clearly, monitoring what is happening around the world in hydrogen technologies is a benefit to DOE and to U.S. industry. Partnering, collaborating, and meeting with international peers has always been an excellent window into ascertaining progress, and sometimes an early window into important developments can accelerate progress.
- It is very encouraging to see the international collaborations. Although global hydrogen communities have witnessed significant growth in recent years, they are still weak and in the early stages overall. DOE may further enhance collaboration with internal organizations on safety, codes and standards development, which is going to be very helpful. Another aspect is related to design and parts standardization. Currently, each company has its own design, which increases the cost of suppliers. If DOE can collaborate with

organizations from other countries to encourage OEMs to communicate and somehow standardize certain parts and design, it will be very beneficial to supply chain development.

- The new BIL-driven effort will be much greater than most countries can contemplate, and it is appropriate that U.S. taxes pay for work in the United States. Nonetheless, these goals are sufficiently aggressive that coordinating work with existing foreign efforts would make the odds of timely success greater. Such an outcome would help other countries as well, as a robust supply chain serves all. Thus, as projects are considered, it would be good for proposers to both (1) show that they are aware of international efforts in their area while demonstrating that they are not duplicating work, and (2) preferably, wherever possible, show international partnership with accompanying international funding (wherein there is one goal and the tasks are allocated between teams, allowing the overall team to accomplish more than either could alone).
- These partnerships help establish agreements that can then be deployed in participating countries. Perhaps there is a strategy or roadmap for ensuring the agreements are reflected in the myriad U.S. regulatory frameworks. There is the Global Technical Regulation for FCEVs and the U.S. Department of Transportation engagement. Aside from those and other environmental goals, this reviewer would like to better understand how these international partnerships can effectively accelerate U.S. adoption and deployment of hydrogen and fuel cell technologies.
- DOE is engaged in extensive collaboration. Co-funding of joint research projects would further accelerate U.S. progress through increasing leverage of global activities.
- Collaborations and exchanges with international partnerships/efforts are very welcome and should be continued. Opening calls to non-U.S. partners (as partner but not as subcontractor)—as it is, for instance, at the EU levels for non-EU partners—may contribute to supporting international collaborations.
- The United States has the potential to be an exporter of hydrogen-based energy and materials to other regions. International partnerships, and the connections formed therein, are a good opportunity to explore this potential.
- This is another area where there should be many SCS opportunities for projects that support harmonization of hydrogen standards globally.
- International coordination and collaboration should be encouraged and facilitated.
- The definition of renewable hydrogen, globally, needs technical development. For example, the Asia-Pacific Economic Cooperation (APEC) is reviewing the existing standards that are relevant to low-carbon hydrogen, the value of developing a low-carbon hydrogen international standard that reflects the APEC region's views, and ways that a low-carbon hydrogen international standard could be implemented, particularly from the perspective of certification, accreditation, and assurance. It is recommended that U.S. experts participate through the IPHE. Another potential study topic is how to accelerate the deployment of renewable hydrogen in the United States and Europe to decrease dependence on fossil fuels.
- Coordination of these efforts usually involves senior researchers and program managers going to many meetings. Perhaps DOE could consider another model, such as international postdoctoral fellow exchanges or rotations/details to the different committees. This is a long-term process, but it is worth the investment to keep DOE involved. DOE might look at successful programs from the U.S. Department of Defense—for instance, the U.S. Navy has science advisors through the U.S. Office of Naval Research Global. This is a very successful and long-term program.
- DOE should establish a team of experts whose only responsibility is to evaluate the results of other countries and international partnerships, with the goal of identifying the technology innovations that will accelerate U.S. progress. This team of experts should report back to senior management of DOE (HFTO, Office of Science, FECM, etc.) on a quarterly basis. To avoid bias and dilution of a researcher's RD&D focus, the team of experts should not have their own RD&D responsibility.
- These associations are nice to maintain the dialogue with the rest of the world, but they are not enough. The global effort in realizing the full potential of the hydrogen economy is much larger than just the U.S. effort, and DOE should leverage the work being done elsewhere. It needs to extend its international collaboration significantly in order to maintain its leadership. To do this, it needs to facilitate joint international research programs.
- Advertising DOE's activities in this area through Electrochemical Society meetings on fuel cells and hydrogen generation symposia is recommended. The Program managers can seek to participate more actively in symposia organized by the Electrochemical Society.
- In order to promote R&D, it may be worth considering, for example, a program that would require applicants to collaborate with overseas research institutions.

- This is not the reviewer's area of expertise. IPHE's focus is very practical and most likely to lead to sustained change across the international space. Perhaps regional hubs at the Canadian and Mexican borders could be considered, especially given the large amount of trucking across these borders.
- Market and techno-economic analyses are important.
- It would be helpful if the Program shared lessons learned from its international engagements or what it considers best practices from overseas efforts.
- How international collaboration can effectively accelerate the Program is not clearly articulated.

9. Do you have any comments or recommendations on the Hydrogen Program's research consortia approach for conducting laboratory-supported research (e.g., H2NEW, M2FCT, HydroGEN, HyMARC, ElectroCat, and H-Mat)? Please state what is working effectively and areas that may benefit from further improvement.

Comments:

- The Program's research consortia approach has been working very efficiently for many years. This approach enables focusing on specific items with a highly skilled core team. Giving the possibility to add further complementary "classical" projects emphasizes this positive effect and should ensure a smooth transition to the industry. This approach should be spread in other countries with the creation of bridges between them.
- The consortia approach has been shown time and time again to be a valuable catalyst to innovation and progress. DOE should stay the course. Bringing multiple laboratories together with appropriate industrial and academic participation supercharges the ideation and knowledge creation that is necessary to support the applications at hand.
- The research consortia approach appears to be very well organized for the production of high-quality research directed toward specific technology development for safe and effective operations.
- The consortia model has been very successful. It allows for a sustained effort with national laboratory experts focusing on key issues.
- Support of the FOA projects through laboratory facilities and other research support is an effective way to accelerate learning in those projects and therefore accelerate the progress overall.
- These consortia are vitally important, and DOE has done a good job of advertising them to university researchers and participants. The work should continue.
- The laboratory consortia model has worked very well.
- The extensive collaboration is admirable.
- This reviewer is involved in infrastructure projects at commercial scale and so did not sit in on many research presentations. Conceptually, it seems like an effective approach, and it is apparent many capable people/organizations are involved.
- It has been especially impressive how "seedling" and "push" projects have been fully and effectively integrated into subprogram consortia (led primarily by national laboratories). The seedling and push projects have energized and expanded the technology purview of the consortia, and they are leading to important new technology developments. The Program administrators are commended for creating such an effective model for integrating those activities into the larger consortium framework. It would be useful to know whether any lessons learned concerning organizational approaches and consortium logistics have been shared across consortia. There are undoubtedly some approaches to addressing common concerns and issues that could be important to share. It is unclear from the 2022 AMR whether changes (perhaps due to mid-course corrections) in the priorities and DOE recommendations for the HyMARC hydrogen storage consortium are occurring or being planned. It is understandable that the compressed gas (incumbent) storage approach is being adopted for the near term. It was not apparent if decisions have been made concerning continuing work on advanced technologies (metal–organic frameworks, covalent organic frameworks, complex metal hydrides, advanced carrier systems, etc.). Specifically, it would be good to know whether there are plans in place to "sunset" any technology areas in which insufficient progress might warrant diminishing support and, if so, how those decisions are being made.
- HydroGEN in particular was an extremely effective consortia model, at least for research groups that were familiar with the laboratories' capabilities and collaborative project structures. Having an FOA model where winning teams could then work with the laboratories worked very well. H2NEW should get to that

point as the electrolyzer FOAs are released, and the current capabilities being developed within H2NEW should set up the laboratories well for this effort.
- The consortia are working well to distill and collate the disparate ranges of information. A mechanism needs to be found to better advertise these consortia to academic entities and U.S. businesses (particularly SBIRs), which would increase the rate of innovations progressing from ideation to commercial implementation. The consortia links could be posted to the SBIR sites.
- The consortia approach seems to be working well. The laboratories appear to be collaborating more, and that increased collaboration should lead to accelerated progress. It would be interesting to know whether the Program surveyed the laboratories and other participants to get their feedback on how well the model is working. An anonymous survey of laboratory personnel, along with industry and university partners, would likely identify best practices and areas for improvement.
- Areas of improvement may not be in the scope of work of these groups but rather in information sharing in the metaverse (3D and virtual learning). This will save time and open up the work to all stakeholders. It is recommended that the learnings from these groups be continually posted for public review and input and that the future workforce shadow these groups to learn from them. Mentoring from these groups to members of the future workforce is also recommended.
- These projects appear to be doing well. There are some management challenges for projects involving more than five or so key principal investigators.
- The emphasis in these larger subprograms has to be more than simply funding the projects that comprise them. Some consortia have been more successful than others at spurring new ideas, shifting resources to help one or another project when it needs them, and building together—as a portfolio of independent research funding and a complex project integrate several work streams differently. Simply holding a seminar where everyone presents their work is not enough, and just having monthly or weekly manager meetings is not enough; the best of these start with an integrated plan and manage it. The best of these have managers who *actively* look for opportunities for projects that support each other and amplify outcomes. Likewise, when teams come together and every person is looking to advance to a goal (and not get their idea or work the most funding), these consortia do wonders. When they are funding mechanisms for academics to publish papers and industrial researchers to augment funding, then they serve no purpose other than to help DOE spread the load of project review.
- As direct water splitting is unlikely to contribute to the 2030 Hydrogen Shot goal, it is suggested that HydroGEN reconsider its position and research focuses. For ElectroCat, switching direction toward developing PGM-free catalysts for AEM electrolyzers would be a good strategy for the next three to five years. For HyMARC, with many new applications beyond passenger vehicles, the consortium may consider developing specific hydrogen storage materials that can be less challenging to some applications, including one-way storage materials for hydrogen cartridges.
- Although all of these subprograms try to accommodate the needs of industrial stakeholders, they must keep one foot in basic research to allow development on groundbreaking technologies. It seems the steps these subprograms are making are more low-risk–low-gain, which is good for meeting the near- and mid-term goals, but they must also have some high-risk–high-gain projects to allow for meeting the long-term goals.
- The emphasis on meeting performance goals for the Program is useful as a general guideline; however, there are many examples in which the targets have shifted over the lifetime of a specific funded project while the state of the art has shifted. For example, PGM loadings have gone both higher and lower than expected, but the subprograms do not adjust the targets. Similarly, other projects have continued even though fundamental flaws in applicability of the material set have been identified.
- Based on the presentations, the Program's research consortia approach should be beneficial. However, it is not clear whether RD&D participants participate in multiple consortia; if they do, whether this dilutes their RD&D focus; and whether the lead researchers spend too much time at meetings and not on RD&D.
- The consortia involve many meetings and are typically organized by top scientists. Perhaps DOE headquarters might use technical program managers to handle the administrative burdens for the scientists so that they can focus on work.
- The laboratory nodes program in HydroGEN needs a clear set of metrics for evaluation and feedback from the performing teams. Some of the laboratory node collaborations are not very effective.
- It is recommended that the Program's research consortia be reviewed periodically by "outside review committees" to assess operation and effectiveness.

10. Is the Hydrogen Program sufficiently incorporating a diversity of approaches for improving justice, equity, diversity, and inclusion in the execution and impacts of its RDD&D activities (e.g., multi-disciplinary approaches to project/research design, demographic diversity in project input and execution, diversity in geographic applications/impact of research efforts)? Please provide any recommendations for additional approaches or strategies the Program can employ.

Comments:

- From two respondents: Yes.
- There has been a drastically improved approach to this in the last year. The reviewer works for a small company with internal resources devoted to equity, and they have been very impressed in what is becoming available and will continue to support and try to address this greatly. This respondent happens to be based in one of the poorest states and one of the few states with a predominant majority of underrepresented groups. Company staff strongly believe that energy independence and security are critical for all groups and that, in this particular instance, the modularity have clean energy and availability of clean energy to underrepresented groups as a very well-aligned goal. As a small company, they would welcome any resources developed by DOE to augment their own internal resources and efforts.
- A broad-based, inclusive approach has been formulated. There are no suggestions for additional programs or strategies. Collaborations and engagement with the Tribes are especially compelling. Outreach to Tribal colleges is a useful way to increase engagement and to recruit participants into the Program.
- A diverse group of participants are conducting research. In addition, they are able to exchange opinions at places like the AMR provided by DOE.
- HFTO has done an excellent job highlighting the importance of justice/DEI and has made very good efforts to address these issues. It will be important to have key measurable indicators to determine the success of the effort and to determine a means for making these efforts sustainable through changes in administration.
- The goal of 40% in EJ communities, as well as the increased outreach to these communities, is notable and a big change. Continued outreach to understand (not assume) the needs of these communities is important. Current issues with gas prices may make these conversations easier to start. To the extent that demographic diversity can be increased in projects and employment, that would also be great to ensure the views of all groups are well-represented. Increasing Tribal engagement and direct participation would be very helpful, especially given negative Tribal experience with other forms of energy production.
- While the structure for improving EJ and DEI is well-designed, direct communications with community groups, municipalities, workforce development organizations, and EJ groups could be prioritized for effective Program execution and market transformation.
- There is a good focus on diversity and a good start with some diversity supported. Increasing the trajectory of some of the efforts initiated (e.g., scholarships, fellowships, and projects with appropriate institutions) will be beneficial.
- Participation and collaboration must be more diverse. Reaching out to underprivileged communities and providing knowledge and sparking interest in hydrogen would be greatly beneficial.
- The increased focus on EJ and DEI is encouraging. It would be helpful to hear more from local officials and residents who live in DACs about their needs related to energy, the environment, and education and outreach.
- The efforts from the Program to address diversity have been very visible at the AMR. The Program is encouraged to continue. However, the Program should not compromise technical purpose and goals for apparent diversity.
- It is not clear that the diversity of the presenters in the AMR is really representative of that of the general population. However, some of the education/internship initiatives are promising in regard to more diversity in the future of science and engineering. There was a map of underserved communities across the United States, suggesting that DOE is tracking/aligning projects and spending, so that is a positive sign.
- This has historically not been a major emphasis, but it is clearly an increasing priority, and the activities are appropriate.
- Yes. The reviewer did not see internships in industry, which would be beneficial, but may have missed it.
- As part of the Justice40 Initiative, an interactive strategy could be deployed. The approach could use computer software that is based on artificial intelligence. The software can support instructors and serve information to individuals in DACs who are interested in learning. There is great potential in serving 3D

imagery of energy systems so that the individuals who live or live/work in DACs become familiar with the technologies and the benefits of using them prior to the permit application. The systems can serve to inform previous detractors so that they better understand the benefits and the creation of good jobs. The systems can also address past opposition to the installation of new energy systems as part of the determination of how to educate. Perhaps it would help if universities in poverty-stricken cities (e.g., Rochester [New York], Detroit [Michigan], and Buffalo [New York]) were included in the introduction of apprentice programs for energy systems. It is not clear whether the universities themselves understand the potential for cleaner air, more sustainable energy systems, and the development potential for new jobs. The Program should establish business partnerships to conduct outreach to determine the degree to which the installations will be embraced by the communities. Perhaps local jobs can be created to operate energy systems ("learn while earn") and partnerships can be established to create the training for in-demand skills in the "real world" to meet the needs of jobs (e.g., safety crews, construction, manufacturing, surveying and land use, and supply chain logistics). The Program might consider requiring "community benefits plans" and readiness plans. The principles of "good jobs" should be required of the recipients of DOE funding: benefits, diversity–equity–accessibility, the right to organize (representation), job security/working conditions, pay (prevailing wage), "proof" that the funded organization exemplifies leadership and respects employees, fair recruitment and hiring skills, and career advancement (to the next career).

- One of the major needs in the areas of justice, equity, diversity, and inclusion is developing best practices and methodologies for sound evaluation of investment benefits to advance the goals. For example, there is still much uncertainty about how to measure and evaluate the benefits of ZEV infrastructure built in or near DACs. So far, the most common metric has simply been proximity of the infrastructure to these communities, but this is an incomplete picture. It does not address the actual use of the infrastructure by the community members or how the infrastructure use by those traveling from outside the community may or may not benefit the community where the infrastructure is located. There are a number of questions: whether there is actually an air quality improvement that can be tracked/measured/estimated; whether there are additional secondary considerations, such as traffic and congestion, that can actually work counter to advancing equity, justice, etc.; and whether these are additional impacts (e.g., jobs and the local labor market) that can be quantified. An organization like DOE is well-positioned to investigate, test, and validate different thoughts on appropriate methodologies, bring together key stakeholders to develop consensus, and help refine the finalized methods.
- It seems that these goals are being considered at the early stages; of course, it remains to be seen what amount of progress will actually be enduring. It would help if DOE further encouraged projects (especially high-dollar projects) to make permanent hires from lesbian–gay–bisexual–transexual–queer-and/or-questioning (LGBTQ+) and minority communities rather than funding interns. It is also critical to see that the DACs targeted are indeed disadvantaged. The money going into Opportunity Zones is a cautionary tale; almost all of that money poured into a very small percentage of these zones, and of course, they were either not very distressed or were adjacent to wealthy communities—the money mostly went to make large firms wealthier, rather than to the people in those DACs. This must be avoided. Proposers must show they are not cherry-picking but actually helping the disadvantaged. Secondly, while it is true that hydrogen will reduce greenhouse and criteria pollutants and that this is preferentially good for DACs, it is also inherent in the concept, so it is not appropriate that proposers use reduction of diesel exhaust or reduction in potential warming as what they are doing to help DACs. It is DOE who is helping them by causing such work to occur; the proposer must show more.
- The Program should be consistent with applicable U.S. laws and regulations. Disproportional impacts on blue collar jobs (manufacturing, mining, transportation, etc.) are being insufficiently understood for this energy transition. This is true for both jobs and cost of living and will have an impact on lower-/middle-income groups more than higher-income groups. Effective programs are needed to ensure that long-term benefits of key technologies are not offshored for design, manufacturing, or production. The United States is effectively energy-sufficient today with fossil fuels, so the transition has to maintain that balance to remain neutral. This will require activities that might otherwise be considered "dirty" (metals production and refining, manufacturing, etc.) but are an important aspect of a stable blue collar workforce. This has to be more than political "window dressing". It is an interesting balance to provide benefits in certain areas without also being perceived as "dumping" less attractive aspects into those same areas.
- The listening sessions are a start but should be turned into actions. For example, it should be clear how teams should incorporate research impact and diversity into proposals to help improve equity and justice efforts across the hydrogen landscape.

- The goals for diversity and inclusion are very vague and should be better articulated by DOE. There is also confusion about diversity and inclusion versus EJ. The scientists and engineers do well when a technology roadmap is presented, and DOE might think of creating something similar for their social goals.
- This reviewer cannot speak to that. While it was a focus of the DOE Program directors' (and others') discussions, it may not yet have drifted down into the wide variety of R&D cultures represented in the technical portfolio.

11. Is the Hydrogen Program doing enough to advance goals for workforce development and science, technology, engineering, and mathematics (STEM) education? How can we build on and/or adjust our current portfolio to accomplish our goals in workforce development and STEM?

Comments:

- Yes. The work done at Los Alamos National Laboratory and the number of undergraduate students involved in the work are impressive. It is extremely important to engage more students to be able to meet the increasing need for qualified researchers in the field.
- The reviewer has limited knowledge about this area and no suggestions for improvement. However, based on the information presented at the AMR, there is confidence that Program administrators are well aware of the underlying issues and are crafting a program that is responsive to workforce development and STEM needs.
- The Program has done enough to advance the goals of workforce development and STEM education.
- Yes.
- The advanced research is of very high quality. However, additional emphasis for workforce development (with or without advanced educational research degrees) may be of value to increase domestic manufacturing, commercialization, and market transformation.
- This area needs support, and there are already a number of DOE activities researching this topic.
- University collaborations, particularly with MSIs, are welcome. Because of how many disciplines can be involved in the Program, it could be challenging to focus these efforts in a way that is accessible to high schools and colleges. "Train the trainer" methods, such as workshops for high school teachers, have been successful in other areas, even fields with historically low visibility (space weather, materials engineering, etc.). These efforts serve as a force multiplier rather than reaching individual students or programs.
- Generally yes, as the Program has played an important role in STEM education through funding projects at universities and national laboratories. As there will be many new projects under the incoming BIL funding, one way to further enhance STEM education would be to mandate cooperative education programs into the projects in which companies serve as the lead principal investigator.
- Developed resources that would seek to incorporate clean energy, and in particular hydrogen, into standard curricula would be greatly appreciated. For example, this reviewer was not made aware of the technology until university, whereas in current discussions with university and high school educators, multiple instances have been found in which these new technologies can be used instead of the traditional demonstrations coming from the petrochemical world. Developing resources to aid in education across kindergarten through 12th grade (K–12) and university, as well as perhaps outreach to state educational groups, might be helpful here. Any support possible in this effort would be very appreciated.
- The Program has good ideas about funding different universities for workforce development; it is not yet clear how much these universities are practically implementing these goals. They should be working with industry to make sure workforce development actually results in skills that are valued by industry.
- It seems as though the modules on the DOE website are mostly static pages and do not necessarily interact and change with the progress of the online learner/instructor communities. Nor do they help the users to develop their individual learning paths to advance throughout their careers. Some discuss career paths, but these should be updated through discussions with actual hiring managers. Some training on the DOE webpage is out of date when compared with recent (2020) publications from DOE laboratories and presentations at the AMR (2022). Others seem to require DOE employees to deliver the modules, which in some cases may be impracticable. Perhaps the workforce training could address energy efficiency, durability/lifetime of systems (20–30 years), capital expenditures evaluation that leads to lower capital expenditures, and ways to decrease the cost of electricity. Much of the training presently addresses

individual energy technologies—i.e., a page for each renewable, instead of energy systems integration, which can be addressed in STEM. Learners could benefit from training in how the energy systems work together with various renewables, rather than basic STEM (which is available from many sources).
- Consideration should also be given to workforce development for blue collar workers, such as maintenance personnel. Auto mechanics and utility workers will need some training to work with the hydrogen and fuel cell technologies those workers will see in their work.
- Projects at universities could include some funding dedicated to STEM instruction, either for university students or for K–12 students in summer or school year programs. Most universities already have a big infrastructure for this type of work.
- There are more opportunities in this area, particularly getting a diverse cross section of students interested in STEM at the middle school and high school levels. One opportunity is to figure out how to facilitate local companies providing shadowing/internships for students less than 18 years old.
- To promote STEM, it is important to develop an interest in science from a very young age. Therefore, it would be better if outreach activities introducing research could also target elementary school students before they decide on their future life plans.
- More workforce development efforts at the state/regional level are needed. It seems the hubs will enable that. More industry internships would be helpful as well.
- Establishment of two-year training courses focusing on hydrogen and fuel cell technology at community colleges is suggested to develop a large number of technicians and support personnel for industry and national laboratories.
- The most direct and important way to build the workforce seems to be through targeted grants/scholarships for undergraduate/graduate programs.
- There should be more funding for summer fellowships for graduate students at national laboratories.
- Additional activities on training teachers and trainers might be considered.
- There should be a larger focus on non-PhD-level technician development.
- Inclusion of STEM activities in the research proposals is encouraged.
- It is not clear that the researchers in the Program should be directly responsible for workforce development, and DOE might involve other agencies with specific expertise to help in this area. Scientists at national laboratories and companies are trained in science/technology and often do not have specific training in workforce development. Professors can also help, but (as if at a research university) professors will be limited to the pool of students that applied to the program years earlier. Given all the pressures of carrying out successful research (safety, equipment maintenance, professional society responsibilities), DOE might make available specific resources to help scientists with workforce development and STEM. At present, the workforce development is largely ad hoc and left to individual passions—much more could be done with professionals helping. The researchers are under a good deal of pressure to deliver on technical targets, and it would be great to give them some support for the social goals of DOE. Some ideas include assistance with job finding and linking community colleges to research universities. DOE should also rethink their definition of a path to success—it might not mean working at a national laboratory. Owning a company that supplies high-pressure equipment to the industry is equally, if not more, important.
- This did not seem to be particularly highlighted in this year's AMR proceedings, other than perhaps the Hydrogen Business Case prize. So perhaps some additional refocusing on this area in the future would be reasonable. One possibility for future DOE work that would be well-suited to the organizational structure is perhaps the development of a hydrogen parallel to the Electric Vehicle Infrastructure Training Program, which sits on top of standard electrician certification and provides additional training and certification for topics specifically important for electric vehicle infrastructure development. DOE could potentially help with outlining the types of additional training and education that would be beneficial in the promulgation of such a certification.
- To date, this has not been a well-rewarded activity for R&D staff (based on the reviewer's years at a national laboratory). Finding ways to recognize and reward such outreach efforts should continue to be a focus. As for the laboratories, ensuring that any recognition gets to senior management is perhaps something to work on. In this reviewer's experience, the recognition has only been fairly "local" in character—i.e., it has not reached the upper echelons of the laboratories.
- There was not much discussion on this point in relation to the technical and EJ areas. While there will be benefits caused by many graduate students and even undergraduates being pulled into the fields needed to support the eventual hydrogen economy—and at least the hope of more disadvantaged students being given

a chance at good jobs—there is not much specifically directed at improving curricula and ensuring it supports what is needed. Promoting the teaching of life cycle analysis and the enhancement of communication skills are two areas that academia does not handle well enough, and DOE might try to nudge them along the right path.
- It is not clear what is being done in this area. If this is desired, then an effective, honest, and balanced approach is needed that highlights both the advantages of cleaner fuels as well as the practical challenges that need to be overcome.

12. Please comment on the overall effectiveness, strengths, or weaknesses of the Hydrogen Program or the individual subprograms and provide any additional suggestions you may have for improvement. Do any of the projects, subprograms, or activities stand out as particularly strong or weak (and if so, why?)

Comments:

Please include comments or recommendations on how the Hydrogen Program can better coordinate RDD&D among DOE offices (Office of Energy Efficiency and Renewable Energy, Office of Fossil Energy and Carbon Management, Office of Nuclear Energy, Office of Science, ARPA-E, Office of Electricity, Office of Clean Energy Demonstrations).

- The increased coordination across offices is a dramatic growth area for the Program and very impressive. Just about three years ago, the highest-profile collaboration was with the Office of Fossil Energy on solid-state fuel cells, and other collaborations were growing but not at the point to be showcased in the plenary sessions. The chart showing the huge investment across offices ($400 million total in the FY 2023 request) is very impressive. Continuing this collaboration to reduce duplication, break down barriers between groups, and find solutions that help all is very important. The growing Office of Nuclear Energy collaboration is a good example of this; although it is unfortunate Jason Marcinkoski moved from HFTO to the Office of Nuclear Energy, his position there almost ensures good integration will continue.
- For many years now, the Program has been structured and managed very well. Exchanges with other offices is more recent and very welcomed in order to ensure an energy systemic approach (hydrogen, gas, electricity, heat) and to favor technology couplings (e.g., hydrogen–nuclear).
- Overall, the Program is directly focused on addressing the key gaps that need to be overcome to achieve the "1 1 1" goals. H2NEW is excellent overall—the technical understanding and capabilities are unparalleled.
- The Program has traditionally been excellent in TRL 3–5 or 6. Continuing to expand to more TRL 6 and 7–8 activities will be essential in the near term to make the hydrogen hubs and the United States a success story in hydrogen production. Coordination and co-funding with the Advanced Manufacturing Office, such as on the Roll-to-Roll Advanced Materials Manufacturing consortium, is also a strength that should be continued.
- The Program is one of the best overall programs in DOE. It is managed, coordinated, and directed exceedingly well. It is an excellent model for all government agencies and offices.
- Overall, the Program is comprehensive and managed and coordinated well. It is producing an impressive response to the daunting challenges of fully integrating hydrogen production, delivery, storage, and fuel cell technology/manufacturing into the DOE renewable energy portfolio. The consortium model is innovative and is enabling important progress on challenging problems to be made in an efficient and timely way. The Hydrogen Shot initiative provides a meaningful focus going forward. However, it will be important not to marginalize or de-emphasize other notable challenges (especially high-capacity, reversible hydrogen storage and hydrogen carriers) in pursuit of focused progress on the Hydrogen Shot initiative. Minor note: in future reviews, it might be helpful to provide a succinct and candid comparison with incumbent and other emerging technologies (especially batteries). Such a comparison would provide a useful context for reviewers to fully appreciate and assess the future impact and advantages/disadvantages of the Program in relation to all other renewable energy options.
- A strong and broad Program was presented. No evidence was seen of a lack of cooperation between the DOE offices. It is suggested that a branch of the effort focus on breakthrough technologies and that this branch have the charter to explore any technology that would benefit hydrogen and fuel cell technologies, while a larger effort addresses the evolutionary development of hydrogen and fuel cell technologies (very similar to the ongoing efforts).

- The overall effectiveness of the Program is very good. However, DOE should remain flexible to accelerate development and to increase community engagement to meet the recent challenges for the production of technology and clean, cost-effective, and sustainable energy.
- The Fuel Cells subprogram has always been strong; the couple of technical presentations seen on the nuclear hydrogen side were good, but the project management seemed uninspired. Also, there was a bit of discussion as to how important grid modernization was going to be in order to maximize the impact roles hydrogen and/or electrolysis may play on the grid. It was not clear whether DOE had been engaged in this discussion; if this is a major barrier to implementation of hydrogen technologies, perhaps this is an area that could be highlighted in the future.
- The Program is well-planned and has been very effective in driving hydrogen and fuel cell technology performance and cost improvements through R&D. It is encouraging to see that the Program now has the funding, through the BIL, to move those technologies through the typical post-R&D valley of death and into the market, with increased focus on nationwide demonstration, deployment, education, and outreach. While the Program usually does an excellent job communicating to its stakeholders, the Program's communications on the multi-billion-dollar hydrogen hub FOA were not timely. Industry, academia, small businesses, and state/regional NGOs were scrambling to pull together agreements, plans, and proposals for a legislated May FOA release, only to learn in June that the FOA's release is now planned for August/ September or September/October. While stakeholders are relieved that they have more time to plan these very large regional projects—and the work they did for a May FOA release certainly is not wasted—the uncertainties and rumors around the FOA release created difficulties for many organizations. The Program should improve its communications relative to FOA release dates.
- The increasing collaboration and coordination between the offices is promising and helpful. One area that remains weak is a credible, commercial-scale carbon capture and storage (CCS) technology. Many approaches are predicated on this, but it is not clear that we have anything yet that really works and is cost-effective at scale. It is also concerning that if you use CO_2 obtained from CCS to make a liquid hydrocarbon and then you burn that, you are still releasing that CO_2 into the atmosphere—at best you get a 50% reduction.
- Overall, the communications between the offices appears to be effective, but the websites appear to be weak. What would be helpful is a collaborative system to collect information on how projects are shared and a dashboard on the status of the projects. Additionally, perhaps the Program could embark on an inventory assessment of the carbon-based energy installations in use today, their life expectancy, scalability, and upgradability. This information may be difficult to obtain, should it be proprietary. If the information is proprietary, maybe a condition of applying for funding could include disclosure of the life expectancy of systems (under a nondisclosure agreement) and their potential for upgrade or future-proofing.
- The technical programs are especially adept at identifying fundamental technological aspects—for example, materials degradation development of analytical techniques and accelerating standardized testing. Development of materials, modeling systems, and commercialization efforts have been less successful. While these are worthwhile efforts in the long term, the time needed to develop effective methods in these preclude them from being useful in the Hydrogen Shot timeframe. Therefore, it is recommended that efforts be focused on developing the tools both to support existing stakeholders and to enable industrial partners who are interested in becoming involved in this field to come up to speed more rapidly.
- Overall, the Program has handled promoting low-TRL efforts well. The conversion of these technical progresses to products or commercialization were not as fruitful. There is a big gap in high-speed–low-cost manufacturing technologies in the United States. DOE should not expect companies to be able to develop such on their own. The clean hydrogen manufacturing funding is too little to address the issue. If possible, the Program is asked to help carefully consider priorities and additional support in this area.
- The biggest strength of the Program is its institutional memory. To maintain it, the Program must keep the specialized workforce that was developed over decades. One good example is the PGM work, which could be leveraged now for electrolyzers but has been turned down significantly during the past five years, with risk of losing capabilities.
- The main strength of the Program is the various initiatives and consortia to address the complexity of hydrogen technology development. The main weakness is the lack of prioritization and the need for improvements in interaction and coordination between the different subprograms.

- The basic research programs at the Office of Science are always important because they develop students and take on high-risk initiatives. It is not clear that ARPA-E is contributing to, or even wants to contribute to, the Hydrogen Shot goals.
- It might be good to know whether any of these offices have stakeholders with safety, codes and standards or R&D needs for hydrogen and fuel cell technologies, and to include these needs in developing plans.
- The reviewer did not see a really strong or weak subprogram but does see a train wreck approaching. Everyone knows what it is. The Program budget increased by roughly two orders of magnitude. It is astonishingly hard to spend that much more wisely for several reasons. First, the intellectual and physical infrastructure is not there to accommodate a 100-fold increase in funding; there just are not enough good ideas and good people to do the work. By increasing high-TRL work and loan programs, you decrease the pressure because they require massive funding relative to laboratory projects, but it is still going to be an issue. That makes the second issue worse: namely, you cannot do a sufficient job of choosing, much less monitoring, a 100-fold increase in funds with roughly the same number of people. It is doubtful the program is at liberty to increase its staff by even a factor of three, much less the roughly tenfold increase needed to really monitor all the new work closely. The Program should strongly consider taking on proven program monitors as contractors with full authority to monitor and coach projects—and take them on very clearly only for the term of the BIL funding so no one feels cheated. Otherwise, these major programs will reach suboptimal performance.
- One question is the use of 3¢/kWh in some of the cost models. While a standalone solar facility may achieve a value like that, unless the hydrogen production was "behind the meter" (and therefore either accepted power whenever it was produced, with a capacity factor matching the solar, or also relied on storage, in which case 3¢/kWh is too low), 3¢/kWh is too low. There are also costs for transmission and distribution, which are typically several cents per kilowatt-hour. The lowest industrial electricity prices in the United States now are near 6¢/kWh; again, excluding transmission and distribution from the electricity cost requires behind-the-meter solar or wind.
- The consortia need more visibility. Many of the small businesses that are tangentially related to this industry are unaware of these consortia and the potential benefits of participating. These tangential businesses are more likely to change their business model to support the hydrogen economy if they can leverage the consortia to modify their products.
- There is very little focus on the stable transition to alternative fuels—for example, how to maintain a reliable supply of fuel and electricity when entire industries will be eliminated. The risk is that no one will invest in or be committed to older technologies before new technologies are ready. This should not be underestimated since it is already becoming an issue in the electricity, refining, and automotive industries.

13. Do you have any specific comments on the Program's plans for the funding provided under the Bipartisan Infrastructure Law for (1) Regional Clean Hydrogen Hubs, (2) Clean Hydrogen Electrolysis Program, or (3) Clean Hydrogen Manufacturing and Recycling?

Comments:

- Goals appear to be well-aligned with efforts already under way.
- It is going to be awesome.
- There are exciting times ahead.
- The plans are very promising. Continuity is key to success.
- The level of support has been positively impressive and is appreciated. As always, administering these types of efforts is challenging, and hopefully the need for improving a domestic supply chain is not overemphasized in these days of integrated economies with allies such as the EU, United Kingdom, Japan, and South Korea—which both manufacture systems and components in the United States and are great consumers of our products.
- The Clean Hydrogen Electrolysis Program was well-detailed; it is well-planned, but it might be worth favoring advanced concepts a bit more to increase the odds of making the "1 1 1" goal on time. The manufacture and recycling program is less well-defined but is also much broader, so this is not too concerning. There could be more emphasis on refurbishing fuel cells rather than recycling them, since much of the value is in the structure of the materials (other than the PGMs, obviously), especially advanced catalysts with no PGMs, which will be much more dependent on structure than metal value (likewise

bipolar plates, etc.). The hydrogen hub structure still seems notional; if there are specific administrative, technical, or regional goals, they probably need to be made clearer prior to floating the FOA. It may be clear to DOE what is wanted, but truth be told, the Hydrogen Shot structure and goals were substantially clearer than the hydrogen hubs expectations.

- The Program's plans for hubs, electrolysis, manufacturing, and recycling are well-placed, well-thought-out, and articulated. One more concern to those mentioned earlier is the planned 50% cost share required at a time when inflation is causing businesses to curb spending—and within a small industry that will be spread very thinly among the regional hubs. Additionally, not all states will be in a position to provide substantial cost share.
- The Regional Clean Hydrogen Hubs shows great program strategy to solicitate multiple seeds and select to fund in later phases. This would definitely help spread out the infrastructures into different regions. If possible, the Program is encouraged to consider the sustainability plan for those hubs after the BIL funding period. Regarding Clean Hydrogen Manufacturing and Recycling, the funding for clean manufacturing may be too little to address all the technical barriers. Prioritization to a few critical items would be more effective.
- Efforts for the Regional Clean Hydrogen Hubs focus on various aspects (commercial/product) of hydrogen technologies (including production, storage, delivery, and usage), technology infrastructure, impacts on regional workforce development/employment, climate, and regional economy. Efforts on the Clean Hydrogen Electrolysis Program and Clean Hydrogen Manufacturing and Recycling focus on technology demonstrations, innovations, and R&D activities (since the technologies are not fully mature) to reduce cost and improve efficiency and reliability to meet the "1 1 1" goal.
- Having notices of intent for the electrolysis and manufacturing and recycling efforts will be very helpful in understanding the Program plans for these areas and allowing teams to prepare.
- Specific areas that could be enhanced include direct communications with community leaders, municipalities, and workforce development organizations, with guidance for siting and deployment to enable integration into the community. Guidance could include education and coordination to identify market opportunities for market transition of the following:
    - Stationary markets including combined heat and power, mission-critical facilities, microgrids, and siting for reversible fuel cells.
    - Transportation motive markets for LDV fleets, HDVs, materials handling, and aircraft.
    - Utility natural gas and electric utility markets to help decarbonize electric and natural gas infrastructure.
    - Refueling markets with renewable (offshore wind and solar) feedstocks and fueling with volume and pressures to meet application and market demands.

  In addition, DOE may seek to accelerate transformation by providing the following:

    - Guidance for hydrogen production to identify and coordinate with renewable feedstock producers, including offshore wind and solar developers. The guidance could help coordinate natural gas and electric grids for decarbonization with new opportunities to produce hydrogen during off-peak surplus periods, connection with natural gas distribution companies for blending and separation, and connection with energy markets for the storage, transport, and dispatch of hydrogen.
    - Guidance to facilitate community siting and investment to help identify and address concerns of distressed communities, underserved cities, and opportunity zones consistent with state policies and goals, community investment goals, and BIL requirements.
    - Guidance to encourage alliance-building with local industry, supply chains, and community resources. Participants may include direct coordination of OEMs, supply chain companies, renewable energy developers, and utilities with municipalities and community organizations. Such guidance could encourage coordination for community investment, clean energy market expansion, coordination with the supply chain, workforce training and placement, STEM education, and advanced domestic manufacturing to meet market demand and community needs, and to deliver the investment in jobs and economic development back to the local economy.
    - Guidance to local community stakeholders on environmental performance to identify carbon offsets, greenhouse-gas-equivalent reductions, air quality improvements, community siting impacts, and potential impacts from hydrogen production and leakage; safety, including assessment of leakage and materials embrittlement for integrity management and safe operations; and economic projection of the

impact to consumer energy costs and the utility rate base. This engagement may be helpful to ensure non-technical community stakeholders that hydrogen can, with direct community input, provide a positive impact on the economy, environmental resources and climate, energy reliability, domestic production and manufacturing, EJ, and safety.

  - Coordination with non-hydrogen stakeholders on overall integration with other technologies, including battery storage, battery electric vehicles, gas blending and decarbonization, production of hydrogen with renewable energy project developers (biomass, wind, and solar energy), utility-based energy storage and dispatch, and direct consumer use. Results could provide confidence to local stakeholders that hydrogen can be part of an integrated and diverse clean energy ecology.

- Since some in the private sector state that hydrogen supply projects can be funded privately, the question becomes how to quantify the demand for hydrogen and what can have an impact on the quantification. It is not clear if the demand side of the anchor tenant of the hydrogen hubs would be able to keep up, nor (if the technology for the hydrogen hubs is available) that the private-sector user community would "pull" the hydrogen produced. In addition to the H2 Matchmaker, another dimension of this problem/question relates to today's geopolitics; regardless of companies' interest in explaining the demand, it remains to be seen how that explanation could change if the war in Europe continues or drought conditions in the United States worsen. The Matchmaker tool should help. Perhaps the results of the Matchmaker could be made public prior to the hub solicitation, and it is recommended that the comments on the hydrogen hub RFI be made public. For the Clean Hydrogen Electrolysis Program and Clean Hydrogen Manufacturing and Recycling, it would be good to know how any hesitancy of returning equipment to the equipment supplier after it is spent would have an impact on the adoption. It is recommended that the equipment supplier industry perhaps be "required" to receive, dispose of, and learn from used equipment as a condition of receiving DOE funding.
- There is a need to really think critically about the scale of hydrogen production/distribution/use that can/will be supported by the BIL provisions and funds. The goal should not be simply to help fund what sounds or seems like a large investment project today but to fund what will actually be a large investment project a bit further in the future. The whole goal is jump-starting industry development and helping to accelerate the industry's approach to large-scale projects, given the short timeline for the potential need and the large amount of growth potential for hydrogen in the country's energy system.
- The nature and complexity of the hydrogen hubs are such that it will be difficult and time-consuming to award, contract, permit, and build in the stated timeframe. Despite their nominal large size, the relative scale of these hubs compared to the overall energy market needs to be recognized. Inadequate attention is being placed on the materials infrastructure regarding what will be needed for a successful energy transition, particularly with regard to indigenous supply of raw materials. This will be important for cost-effectiveness, long-term jobs, and energy security. The BIL notice of intent lacks emphasis on technical attributes in lieu of political attributes. The concern is that it will not be effective in its stated goal to advance technology. It is important for the implementation of the BIL to also be bipartisan, or it has significant political risk to long-term acceptance and success.
- There are two concerns. First, low-TRL technologies will be considered and not be able to meet Program goals in 2026 or even 2031. The funding required for true hydrogen hubs across the United States, even with existing high-TRL technology (PEM and alkaline), will take $100–$500 billion (see Princeton's Net-Zero America report). DOE needs to be realistic that this $9 billion will not go far if it is not focused. The second concern is that the funding is not being obligated quickly enough and will be swept up.
- As presented during the AMR, it was sometimes hard to see if the HFTO funding was increasing or decreasing because the money went to other sections of DOE. A more comprehensive summation would be useful. While it is understood that this is because of Congress' direction, the majority of the BIL goes to the national laboratories (via the $8 billion for four regional hubs). While the national laboratories do good and groundbreaking work, a more even split of the money with industry might spur innovation (as well as the development side of R&D).
- Creating hydrogen hubs will allow the hydrogen technologies to really go at scale, but this will consider "only" a few locations. Strategies ensuring spillover effects of these hubs should be considered from the beginning.
- It is recommended that there be a laser focus on the long-term viability of the hydrogen hubs beyond DOE funding (as it is not known how long that will last beyond the current legislation). Projects and locations really need to provide clear evidence of plans for commercial sustainability.

- There is a large amount of funding for the Regional Clean Hydrogen Hubs. It was not clear whether they will be focused on state-of-the-art hydrogen and fuel cell technologies or how new technology would be introduced to the hubs.
- Regarding the Regional Clean Hydrogen Hubs, this is an extremely difficult task that will require many technical reviewers and experienced project managers to put it in place. For the Clean Hydrogen Electrolysis Program, the Program is encouraged to put more emphasis on hydrogen compression to improve system-level reliability. The Clean Hydrogen Manufacturing and Recycling effort is early in the process, such that there are no particular recommendations at this time.
- For the Clean Hydrogen Electrolysis Program, inclusion of basic research is needed to address several fundamental issues in developing PEM and SO electrolyzers.
- The Program FOAs and subsequent management should be as streamlined and simple as possible.
- The administrative burden of reporting and data-collection requirements should be reduced.

14. Based on DOE's hydrogen activities, and given the BIL funding across the RDD&D spectrum, how likely do you think:

(a) Hydrogen Shot will be achieved ($1/kg clean H2 by 2031)?*

Note: these are modeled levelized costs of production only, at high volumes (e.g., GW scale). Rate your response on a scale of 1 through 10, with 1 indicating not likely and 10 indicating very likely.

Average Score	**6.4**
Number of Responses	37

(b) The BIL target of $2/kg clean H2 be achieved by 2026?*

Note: these are modeled levelized costs of production only, at high volumes (e.g., GW scale). Rate your response on a scale of 1 through 10, with 1 indicating not likely and 10 indicating very likely.

Average Score	**6.5**
Number of Responses	37

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