Appendix A: 2021 Hydrogen Program Review Summary

This appendix shows the results of the Hydrogen-Program-level peer review for the 2021 Annual Merit Review (AMR), including feedback from a subset of the reviewers attending the AMR. A total of 61 Program-level reviewers were invited to provide feedback, and 20 reviewers responded.

1. The Hydrogen Program has a mission and strategy that are clearly articulated and has appropriate goals and milestones, as well as quantitative metrics that are SMART (Specific, Measurable, Actionable, Relevant, and Timely).

Please comment on the overall Hydrogen Program (including activities in the U.S. Department of Energy [DOE] Hydrogen and Fuel Cell Technologies Office, Office of Fossil Energy, Office of Science, Office of Nuclear Energy, and ARPA-E), as well as each subprogram/activity area, as appropriate. (Note: The Hydrogen Technologies subprogram comprises three categories: Hydrogen Production (with HydroGEN Seedling as a sub-category), Hydrogen Infrastructure, and Hydrogen Storage.)

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. Please add any additional comments.

	Hydrogen Program Overall Rating	Hydrogen Technologies R&D Subprogram Rating	Fuel Cell Technologies R&D Subprogram Rating	Technology Acceleration Subprogram Rating	Safety, Codes and Standards Subprogram Rating	Systems Analysis Subprogram Rating
Average Score	9.2	9.1	9.3	8.9	9.1	9.1
Number of Responses	20	20	19	18	18	19

Comments:

- The Hydrogen Program is two things: “user friendly” and forward-looking. DOE is accessible to all, and the agency provides information on projects for all stakeholders. The Hydrogen Program is neutral and well-respected. The Program provides tools for analyzing hydrogen applications without actually investing in the applications. The ability to “test out ideas” without investing is invaluable to the goal of hydrogen available at $1/kg in one decade. The Program de-risks researchers from going ahead with their ideas. One is left with no doubt that the models are under continuous update, as are the technology validation programs. Stakeholders are under pressure to make decisions about their own projects, and the AMR provides the tools to make decisions on one’s own without divulging plans and products. I realize that an across-the-board rating of “strongly agree” may appear maniacal. In fact, the consideration took a long time, and I landed at a 10 for all. The plenary with the Energy Secretary was so impressive, I felt as though I was able to speak with her. The Program Manager’s presentation was equally remarkable, as it was full of details and data, and individuals’ names were mentioned. The agency leads’ session in the plenary was also very important for the AMR participants to hear through Zoom. Thank you for the thoughtful Program and AMR.
- The Hydrogen Program has a well-articulated mission and strategy with appropriate goals and metrics. This Program has some of the most talented researchers in the world; they should be considered an important asset for the program and the U.S. energy economy. This work provides early-stage research across several sectors, including hydrogen technology, hydrogen production, fuel cell development, technology validation, manufacturing, and market transformation. With support from the Secretary and President, the United States may continue to be in a position to increase efforts for international leadership, industry collaboration, and partnerships with resources from the national labs, academia, and state partners. With this leadership position, DOE may be in a position to increase efforts for collaboration, partnerships, and demonstrations with state and regional stakeholders. Such efforts will help to advance the research from the labs to commercial applications.

- I do not have any additional specific recommendations with respect to the mission, strategy, and goals. I feel that the goals are comprehensive and well-formulated. I have seen the goals respond to the needs of stakeholders, such as the addition of intermediate and near-term cost status and targets. The Program strategy appears to be well-designed to enable research and development (R&D) that has the potential to make progress toward the targets. The diversity of structures from individually funded projects to consortia and larger mainline efforts (such as H2@Scale) provides flexibility to the Program to address a wide variety of potential uses of Program outcomes and adjust to stakeholder needs.
- The Program is clearly a large and valued effort, judging from government spending across various offices. Efforts cover the full range, from fundamental science to loans and capital risk reduction for enabling scale-up of commercialization. There is an interesting increasing shift to hydrogen as a way to decarbonize CO_2-intensive industry (relative to the 2019 AMR). Dr. Satyapal had many special announcements; she certainly made the plenary must-see viewing.
- The overall Hydrogen Program goal among DOE offices will benefit from closer coordination among R&D activities. The Hydrogen Program plan will address collaboration among the DOE offices, and the Hydrogen Energy Earthshot initiative will drive the future targets.
- The Program is well-planned and well-managed, with each office having the appropriate focus. The Program and subprogram overviews were excellent. The increased focus on environmental justice is overdue and good to see. However, there are some gaps in the Program, and these will be discussed below.
- The use and development of metrics (goals and milestones and targets) in the Program is impressive, consistent, and forward-looking.
- The Program is very well-structured, with clear objectives and milestones. However, the Hydrogen Shot objective of $1/kg hydrogen in 1 decade will be extremely challenging.
- I am looking forward to the increased activity in all Program areas and the ability to deploy (moving past technology readiness levels [TRLs] 1–4) the goals set out by this administration, bolstering the U.S. visibility and overall activity in hydrogen.
- The Program is outstanding. It is the best R&D program worldwide.
- The Program's objectives are very clear. The synergy between the various offices is well-presented and helps focus efforts to achieve the Hydrogen and Fuel Cell Technologies Office (HFTO) objectives. The goals are consistent with the global community. However, I noticed, for instance, that work on hydrogen electrochemical compression was no longer part of the Program. It would be beneficial to indicate when an area is no longer active and the reasons why. I think it's important to learn from what works and what
- doesn't.
- I think the Program and subprograms could do a slightly better job in articulating strategy—for example, having more waterfall charts/total cost of ownership sensitivities explaining where the biggest gains can be made and then directly linking that to the portfolio of projects.
- The Hydrogen Program mission, strategy, and goals make sense. However, it is not fully clear whether the Program goals need further "revamping" to reflect the recently announced ambitions of the new administration, including the Hydrogen Earthshot.
- One of the most critical issues in the hydrogen economy scheme is large hydrogen storage. Unfortunately, from the work I have seen at the AMR, this issue has hardly been addressed, and there do not seem to be any new innovative ideas being developed. More emphasis should be given to this critical topic, including materials for hydrogen storage, with assessment of full cycle life, energy required to release hydrogen, and full thermodynamic study.
- Connections/synergies between various initiatives/consortia are not well-articulated.

2. The Hydrogen Program is well-focused and well-managed and is effectively fostering research, development, demonstration, and deployment (RDD&D) to enable innovation and advance the state of technology for hydrogen and fuel cell technologies to be competitive and achieve widespread commercialization and adoption by industry.

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. Please add any additional comments.

Average Score	9.0
Number of Responses	19

Comments:

- The Program is nicely arranged into the key areas needed to generate a hydrogen economy that functions, starting at hydrogen creation and ending with consumption, plus the steps in between and the facilitating functions such as codes. Each area can then be interrogated as to needs, and requests for proposals offered to address them. At the same time, the interfaces between areas are not ignored, and the relevant groups do discuss what it will take to be sure there is no problem going from, say, production to delivery; plus, the simulation and analysis teams also look at these issues. I am pleased to see long-term and near-term goals and planning. The individual managers seem committed personally to their areas, and Dr. Satyapal just about lives her work. This matters because it indicates the quality of effort they will put into making the Program succeed. Analysis is used to help isolate the key problems—not just as part of the R&D but as part of the management of the Program. This is another example of using a wide variety of inputs (scientists, industry, political considerations, simulation) to make well-informed and well-timed projects funded with a suitable distribution over the portfolio.
- As in prior years, I continue to find the Hydrogen Program to be well-managed and effectively operated. I do not see any faults in the work of the Program managers or DOE staff in running what is truly one of the most cutting-edge and reliable technology development programs in the world.
- The Hydrogen Program includes a vast portfolio of projects that address development of technologies from basic science to manufacturing and scale-up to demonstration of systems. The department is performing a commendable job managing the projects.
- My rating for the Program is actually 8.5, with 10 each in R&D, 8 in Demonstrations, and 6 in Deployment. The Program's R&D activities are outstanding, significantly advancing the state of the art. However, the Program has not done enough to enable deployment. Engaging more at the state and local levels and supporting education and outreach activities would help. There are still many people, including state policymakers, who are not aware of hydrogen and fuel cell technologies and their benefits. In addition, the ban of fuel cell electric vehicles (FCEVs) from the Northeast tunnels and double-deck bridges has delayed the deployment of FCEVs and hydrogen stations in the Northeast by 5–7 years. During that time, battery electric vehicles have gained in market share, and interest in light-duty FCEVs has waned. The tunnel safety studies conducted by Sandia National Laboratories were an excellent response to that issue; however, the ban should have been addressed much earlier—and those studies were completed two years ago, yet the ban is still in place.
- The Program is extremely well-focused and well-managed and has been very effective at fostering R&D. Some of the demonstration and deployment projects have been well-focused and well-managed. However, there may be value at this time to increasing demonstration and deployment to bring this technology into commercial applications with market acceptance, as are other clean energy technologies, such as solar, wind, and battery technologies.
- As it seems, the Hydrogen Program sets its targets on input from industry and the new results from the projects. In some cases, significant progress is presented by the principal investigators, and in my view, it has to be validated by at least one other lab (outside the same project) to avoid false positive outliers.
- The addition of Hydrogen from Next-generation Electrolyzers of Water (H2NEW) and Million Mile Fuel Cell Truck (M2FCT) is welcome and complementary to the other consortia. H2NEW's linkage with

HydroGEN 2 is clear as far as the line between the two. I expect H2NEW will grow to include a platform to host findings from HydroGEN that are maturing to that level in time.

- This is probably one of the best-managed office programs in DOE, with one of the best office teams.
- Excellent.
- Overall, the Program RDD&D portfolio is well-balanced and wide-reaching. However, considering the bulk of current domestic and global hydrogen supply comes from fossil fuel and is likely to stay that way for quite some time, there ought to be a more visible engagement in "greening" fossil sources of hydrogen. Because of the large scale, even incremental changes can translate into meaningful greenhouse gas reduction. Toward this goal, I suggest the Hydrogen Program more actively engage with the Office of Fossil Energy and Carbon Management to advance carbon capture, utilization, and sequestration (CCUS) and "blue hydrogen" production technologies from steam methane reformer plants or other fossil fuel sources.
- Some of the models could be updated to include new hydrogen/fuel cell applications. Also, what is needed are projects that integrate hydrogen applications, such as green steel with transportation at the hydrogen supply.
- Widespread commercialization and adoption by industry needs more effort.

3. The Hydrogen Program's portfolio of projects is appropriately balanced across research areas to help achieve the Program's mission and goals.

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. Please add any additional comments.

Average Score	8.6
Number of Responses	19

Comments:

- Appropriately balanced does not imply evenly balanced but, rather, employing people and funds where they are needed most in the order that makes sense. Using this definition, I feel the Program or office is in fact well-balanced. The funds seem in largest part devoted to those issues that prevent a hydrogen economy from taking hold; to science problems, such as how to force a very low-mass gas into a small enough volume to transport it; and to the accompanying engineering problems of getting said gas in and out in a reasonable time in a device that is modest in cost…but, at the same time, developing the codes and standards needed for societal acceptance and a legal framework that permits insurance that can be afforded for that storage system…and then also funding seemingly unrelated technology projects for use in what seem like niches but what are in fact the start of building the supply chain for the storage system we started considering. All these steps are needed—the science first, so you know what you are engineering, and that step is well in hand; the engineering next, in concert with the codes, which is also making good progress; and now an expanding Technology Acceleration subprogram that will bootstrap the supply chain. A good example here is that work to help implement technology to get through the valley of death, as it were, has been (appropriately) fairly low. Funds went to R&D, not to industry in the largest share. Now a great deal more is going to de-risking implementation and commercialization through facilities to validate and integrate and funds for lowering capital risk. This makes sense now, when it did not before, and the shift is an example of appropriate management response to the changing situation. All that said, I think to achieve the goals elucidated in this plenary, the funding needs to shift more toward technology acceleration.
- The Program has been well-balanced on development of polymer electrolyte membrane (PEM) fuel cells and electrolyzer technologies for a number of years. The focus has been shifted to other emerging technologies, such as solid oxide fuel cells (SOFCs) for electrolysis and energy storage. The reduction of hydrogen cost to the levels targeted by the Hydrogen Earthshot requires re-balancing the research,

development, and demonstration (RD&D) activities by prioritizing end-use demonstrations for hydrogen production.

- The portfolio is appropriately balanced across research areas and is recognized globally as world-class, with the United States in a leadership position. Increased efforts for demonstration and deployment, consistent with local and state and regional stakeholder engagement coupled with educational initiatives, may provide additional value for commercialization and market acceptance.
- The Program is very responsive to stakeholder recommendations.
- The balance of projects is excellent.
- I am concerned about the recent shift in focus in the Program toward medium-duty (MD) and heavy-duty (HD) applications. I do agree that this area needed to grow for the DOE's portfolio of projects, but I am concerned that the shift is looking to be too strong toward these focus areas and away from the light-duty applications. While there has been significant stakeholder interest in MD and HD applications in the last couple of years, my opinion is that this has been due to misunderstanding of technology capabilities and the current readiness of commercial products in these sectors. Several stakeholders are still looking to hydrogen and fuel cell technologies being an important part of the light-duty sector in addition to other sectors. What these stakeholders need help with is not only advancing the MD and HD market but also data, research, and demonstration that provide further insight and additional examples of how FCEVs continue to have a role to play in the future of light-duty transportation as well, especially for aggressive targets of full change-over to zero-emission options in the coming one to two decades. In addition, much of the HD fuel cell work appears to be considering the needs of HD as completely different from light-duty when, in reality, they are the same focus areas (cost, durability). Even if HD targets may be more aggressive, it doesn't seem logical that technologies to meet those targets have to be treated separately. It would seem that technology transfer would logically be immediate, just as it has been in the opposite direction so far (as we see examples today of light-duty fuel cell systems being applicable to HD vehicles.
- The Program should consider boosting projects aimed at "hard-to-decarbonize" industries such as iron, steel, concrete, etc., both in number and effort level. Given the growing desire and urgency to decarbonize these industries, as well as the inherent advantage in hydrogen quality and cost compared to fuel cell applications, this space could be an opportunity for early large-scale hydrogen market entry. The recently announced HyBlend project is one example that can potentially advance this approach.
- In the areas of "deployment," one of the more impressive portfolios of projects were presented by federal/ state agencies that were not from DOE, because the review of the applications showed successful use of hydrogen over a relatively long time. The emphasis on fuel cell research and hydrogen (vessels) stored on board vehicles is very much needed.
- There should be more funding for systems analysis, which can be essential in guiding where R&D efforts in other subprograms should be targeted.
- Given the lack of awareness of hydrogen and fuel cell technologies, the Program should increase education and outreach activities, particularly at the state and local levels.
- More emphasis should be given to hydrogen storage and hydrogen production.
- Having better defined priorities in various research areas is suggested.

4. The Hydrogen Program is collaborating with appropriate groups of stakeholders.

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. Please add any additional comments.

Average Score	8.4
Number of Responses	18

Comments:

- Working with Vehicle Technologies Office (VTO) truck groups is a good idea and very appropriate, given both groups' goals. Working with the Advanced Manufacturing Office is appropriate for getting new technologies in production. In addition, there is a great deal of work across offices and agencies in the hydrogen area, which seems to be counted as collaboration and, I suppose, is at the budget level. Within programs, there are many examples of significant collaboration at the project level. Where true collaboration occurs, it is a benefit to HFTO goals. I would like to see more U.S. Department of Defense collaboration, especially on implementation.
- The breadth and depth of collaboration with the various domestic entities are strong and encouraging.
- The key stakeholders are involved in every subprogram.
- The Office of Energy Efficiency and Renewable Energy (EERE) has been the de facto pioneer of the hydrogen economy and infrastructure over the years. The current trend is growing collaboration between DOE offices for implementing a coherent hydrogen plan. EERE can play a great role to re-focus the efforts in other offices, such as ARPA-E, on critical technology needs.
- The Program seems to have its own pull of research groups and stakeholders. To innovate and bring in new ideas, it has to refresh its ranks. In my personal view, each large consortium should include a certain percentage of newcomers with new ideas, tools, and perspectives. These need to be research groups from academia and companies that have not participated in the consortia before (or for several years). Also, there has been great advancement in the field outside the United States, especially on topics such as hydrogen production, which the U.S. consortia can leverage. Inviting international partners can contribute significantly to the advancement of the U.S. programs in areas where they are lagging.
- Overall, the involvement of the various stakeholders in the United States is quite good. It would be good to clearly see effort with other countries, especially on harmonization of codes and standards. Specifically, tight coordination with Canada, which shares a border, would be important when it comes to hydrogen blending in natural gas and infrastructure for cross-border transport, to name a few. As Canada has expressed clear intentions to promote the hydrogen sector through its new strategy, joint funding opportunities, at least coordinated, in areas of common interests would be a very good idea.
- Collaboration has always been a strength of the DOE Program and the projects it funds. I did not find any significant lack of necessary collaboration. The only area that could potentially be improved is for some individual projects related to hydrogen fueling infrastructure that provide analysis of needs in California from a carte blanche perspective. This is obviously not the case. I don't expect those projects to fundamentally alter their approach, but at the least they should address the ongoing development on the ground. They can engage with the California stakeholders and either look for opportunities to leverage ongoing development with respect to their own projects (either for tools in their projects or in terms of how their project outcomes can interface or build alongside current development).
- Collaboration with the public sector is excellent. Collaboration with industry needs to be increased.
- Stakeholder participation has been somewhat limited, with a focus on early-stage research. This is an area that at this time may be increased with collaboration from stakeholders, including state and regional authorities. With additional funding, demonstrations could be developed through state and regional stakeholder engagement with execution of planning documents that are now being developed in several states, including California and the Northeast states.
- Outside of DOE, perhaps more state governments can be included. Here, I mark off a "9." Perhaps, if there is no action in a zero-emission vehicle state, it would be possible for a status to be given, even as "no action." We need help with planning. As far as collaboration within the Program, the message of "we will work together" was conveyed, but given the newness of the administration, any accomplishments were premature.
- The Program should increase engagement with state and local decision-makers.
- Optically, the Program tends to rely more on national laboratories.

5. The Hydrogen Program's RDD&D aligns 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. Please add any additional comments.

	Hydrogen Program Overall Rating	Hydrogen Technologies R&D Subprogram Rating	Fuel Cell Technologies R&D Subprogram Rating	Technology Acceleration Subprogram Rating	Safety, Codes and Standards Subprogram Rating	Systems Analysis Subprogram Rating
Average Score	9.0	8.8	9.1	8.8	8.9	8.6
Number of Responses	18	18	18	17	17	17

Comments:

- The use of the "tech team" concept helps ensure a good alignment between industry needs and Program goals. My understanding is that offices with these teams do much better than those who do not use the concept, and certainly, here that seems true. The overall aim is, of course, a government value—a technically sophisticated clean energy system that creates valuable jobs and avoids pollution. But after that, the teams clearly have provided the needs seen by industry, and they also provide feedback to at least some of the researchers. In some of the projects, they are involved directly in the work and clearly will only propose work they value. The Program could improve by giving Technology Acceleration a tech team or perhaps a more useful equivalent, such as a consulting group of major industry reps.
- With industry, the alignment seems very good in terms of participation in DOE-funded projects or working with national labs on specific projects relying on competencies developed through DOE-funded projects. The alignment with states is dependent on the states themselves, and I'm not too familiar with that dimension. The increased collaboration between the labs seems to provide a much greater opportunity to align with stakeholders.
- The key to reducing hydrogen cost to below $1/kg by 2030 includes accelerated R&D, demonstration and deployment, and scale-up of mature technologies (PEMs and SOFCs). The less-developed and low-TRL technologies will need a longer horizon to achieve the Hydrogen Earthshot goals.
- There is good alignment with industry and stakeholder needs.
- Industry and stakeholder involvement has been achieved at every level.
- One of the reasons the overall Hydrogen Program and sub-areas are aligned well with industry and stakeholder needs is "we all are watching the costs." The competing technologies and systems are low-cost, by comparison, and the "cost drivers" and "focus areas" presented by Ned Stetson clearly explain the intent of researchers and projects to reduce the electrical energy costs and capital costs, along with the overall hydrogen refueling station costs. The stakeholder community, in general, has the same intent. Storage, as Ned Stetson explained, is another area (on land and on board)—again, another area where cost reduction is needed. All of that said, perhaps the presenters from the subprograms could be directed to address these cost drivers and focus areas for hydrogen. Perhaps, indirectly, they all work along these lines, but perhaps the presenters could directly speak to these imperatives at future AMRs. It may not have been possible because of the scope of work of the projects and the timing of when presentations are considered and due, but the Zoom platform showed how Ned Stetson's cost drivers could be threaded throughout the presentation and unambiguously described as such. Stakeholders are driven primarily by cost reductions (short- and long-term), and they are often required to articulate cost reductions. Perhaps the projects can be focused on economies of scale and also describe their cost metrics and how they will evaluate success from a cost-reduction point of view. Some of the models describe cost reduction, but maybe the output can be augmented with cost-reduction goals that support self-sufficiency (for some applications).
- Although the Program research aligns well with industry research, the Hydrogen Earthshot would be well-served with execution of plans for market commercialization and demonstration programs to accelerate state and regional deployment efforts.

- My main issue here is the hard shift to focus on MD and HD. It may have just been an issue of how the focus was presented or communicated and conveyed, but from the experience I had at the AMR and from speaking with other attendees, the change in focus was very strong and noticeable. I think, so far, the messaging does leave many with the impression that the light-duty effort is simply not moving forward through DOE's Program or is not considered a focus area anymore. This seemed most noticeable in the Fuel Cell Technologies and Systems Analysis subprograms, given the suite of projects. If this really is the intent, I strongly encourage reconsideration. If not, then perhaps the messaging simply needs an adjustment.
- The Program has good alignment with industry needs but is not aligned so well with other non-DOE investments.
- The Program should consider prioritizing advanced R&D effort for hydrogen sources from fossil fuels, including renewable natural gas. Given the sheer scale of current hydrogen supply, even incremental improvements to existing technologies can result in significant lower-carbon hydrogen volumes.
- The Program should do more to enable deployment in general of both mobile and stationary fuel cell systems and hydrogen infrastructure. Also, it is premature to abandon the light-duty vehicle application.

6. The Hydrogen Program is funding high-impact projects that have the potential to significantly advance the state of technology for the hydrogen and fuel cells industry.

	Hydrogen Program Overall Rating	Hydrogen Technologies R&D Subprogram Rating	Fuel Cell Technologies R&D Subprogram Rating	Technology Acceleration Subprogram Rating	Safety, Codes and Standards Subprogram Rating	Systems Analysis Subprogram Rating
Average Score	9.0	8.7	9.1	9.2	8.9	8.9
Number of Responses	18	18	17	16	17	17

Please respond for any subprogram/activity area as appropriate (e.g., hydrogen production, hydrogen storage, hydrogen infrastructure, fuel cells, technology acceleration, safety, codes and standards, solid oxide, ARPA-E, Basic Science, etc.).

Comments:

- First of all, if all the work were high-impact, then the Program portfolio does not have nearly the risk we should expect from government-sponsored research. Thus, a well-chosen portfolio will have projects with low impact. Secondly, in any R&D portfolio that has meaningful risk, there needs to be multiple paths forward at the same time so that when, inevitably, one route fails to bear fruit, the Program does not flounder. Inherently, this means some will be higher-impact than others. With that perspective, I would rate the Program well overall for picking projects that have the potential for high impact if successful, which I feel is the true "figure of merit" here. The outcomes highlighted in the afternoon (life of electrolyzer, >25,000-hour fuel cells, bringing up ARIES [Advanced Research on Integrated Energy Systems]) are good examples. Expanding the scope to non-transport uses offers many more opportunities for high impact, such as adding hydrogen to CH_4 for a fast increase in renewable content and to use in cement- and steel-making, which are big sources of stationary CO_2 production (and thus logical targets for abatement). Expanding fuel cell targets to HD trucks and rail and ship use likewise opens up many new high impacts, e.g., ship engines use the nastiest fuel imaginable and have huge engines running at below idle in port. With so much of world commerce moving by ship, this is a huge opportunity to decarbonize using hydrogen. The Energy Secretary's announcement of $1/kg hydrogen production within 10 years is an example of a potential high-impact area of work. If you want more impact, it makes sense to move funds out of highest-risk early TRLs and into technology acceleration.
- Given their high cost, the emphasis on electrolyzer and hydrogen storage technologies is appropriate. There has been excellent progress in reducing PEM fuel cell cost. At first glance, more stringent durability targets

for MD/HD vehicle fuel cells seems to be a major challenge, but perhaps not, when one considers that fuel cell electric buses (FCEBs) have demonstrated reasonable durability.

- The significant achievements of the Hydrogen Program include reduction in cost of PEM fuel cell stacks to <$80/kW and hydrogen production cost of $5–$6/kg. These achievements are significant milestones along the path to H2@Scale.
- The Program has an excellent selection of high-impact projects. It is the best way to advance the frontiers of hydrogen technology.
- The presenters at the plenary explained the deliberate coordination and collaboration with the national laboratories, private-sector companies, and universities. The presenters clearly explained the collaboration in hydrogen and fuel cells, technology validation, projects that explain the technical and economic impacts of MD and HD FCEVs, codes and standards, and overall systems analysis. The presentations clearly showed the accomplishments. In the future, perhaps an effort could be made to lengthen a few of the presentations so the topics can be presented in more detail. And finally, perhaps these presentations could be "linked" together by a high-level expert.
- The Program is indeed funding high-impact projects. However, there may be value in increasing the number of these projects consistent with state and regional stakeholder collaboration.
- In some cases, such as in the case of the Fuel Cell Technologies subprogram, most of the funds go to exploration of materials and technologies that are not fully developed. In the case of the Fuel Cell Technologies subprogram, this is the development of platinum-group-metal-free oxygen reduction reaction catalysts. It is wise and important to invest in the development of fuel cells based on earth-abundant materials, but one also needs to reassess the possible applications every once in a while. One application that has been on the rise in the past few years is anion exchange membrane fuel cells, which can use these materials as very efficient catalysts, but the Fuel Cell Technologies subprogram almost completely neglects this technology. It is not clear why. Another example is the growing need from industry for fuel cells for aviation. There are large companies such as Airbus and Plug Power that are in need of scientific support that the Hydrogen Program can supply. These emerging areas should be given the necessary attention.
- I did appreciate that the office has taken another look at the fuel cell systems' durability target that not only considers advances in material development but also looks more at the system-wide design possibilities. I think this will end up being an important piece of the strategy that fuel cell and vehicle providers choose to pursue in the future to meet the needed durability and cost targets. I also do appreciate the amount of effort that has gone into trying to develop more materials-based approaches. However, this area continues to appear to be elusive through the Program's efforts. It does leave the impression that there may be some opportunity for consolidation of efforts. Consortia approaches to advance the basic science knowledge and provide guidance for viable paths of further development seem to have been bearing fruit, but even that method appears slow. It appears that this is an area where perhaps DOE could benefit from a more critical view of funded projects and have stricter requirements for funded projects. Incremental improvements don't seem to be making enough headway, so perhaps the funded projects in this Program need more incentive to get beyond incremental development.
- The H2NEW and M2FCT consortia definitely provide a great platform for high-impact projects. The work on fuel cells is good, but I'm not too clear that materials R&D is a priority at the moment compared to industrialization R&D, like the work on high-volume manufacturing and quality control. International collaboration in those areas is also an opportunity to seize further.
- The Hydrogen Program could build a stronger engagement with the Office of Fossil Energy and Carbon Management to create some sort of a joint program effort around CCUS/hydrogen production from other fossil fuel sources. The refinery and petrochemical industry are likely to support such efforts.
- I believe that high-impact projects are being funded within the funding limitations.
- It is not clear whether all the funded projects are "high-impact."

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

Comments:

- I believe that the consortium approach is generally working to make necessary advances toward DOE's goals. I was happy to see the consolidation that occurred within the Hydrogen Materials Advanced Research Consortium (HyMARC) and its merging with the Hydrogen Storage Characterization Optimization Research Effort (HySCORE). I believe that one of the most valuable outcomes of a consortium approach is to start with many threads of research with potential for success so that they can be investigated and developed in parallel and in coordination with one another. However, that coordination should also enable easier narrowing down and focusing of efforts into the threads that have the highest potential as those projects progress. The consortium effort should enable this kind of re-focusing easier and faster than funding structures where every individual project has its own timeline and budget that must be carried through to completion. I was glad to see this kind of action take place as it was described with HyMARC, and I recommend that this philosophy be carried over to the other consortia whenever and as much as possible.
- The consortium approach has great potential. It focuses the human expertise spread across academia and the national labs and gets them to work together on solving groups of difficult and important problems. When this works, it is great—when it generates collaborations that are truly intertwined and could not succeed without such joint work. When it merely binds a bunch of individual projects under a loose leadership with monthly or quarterly Zoom calls, it really adds no further value. Certainly, the EERE consortia always promote cooperation; actual collaboration is harder and not always achieved. To be clear, this is nothing specific to DOE or EERE or the Hydrogen Program; this happens everywhere in government and industry and academia. The best way to get better collaboration is a line-item veto of projects at the solicitation phase so that only projects that require multiple groups working together are actually funded by this mechanism. It appears the consortia already do a good job of including only projects that make sense together in the same sub-portfolio.
- The research consortia approach appears to have increased collaboration among the national labs and created a synergistic work environment, resulting in significant progress toward technical targets. The devil is in the details, however. The Program might consider having this research model independently evaluated for effectiveness. I attended the following consortia overviews:
    - M2FCT, which had a well-organized and articulated presentation, outstanding leadership team, well-formulated projects goals, and excellent systems analysis to guide R&D. The accelerated stress test (AST) and investigation of degradation mechanisms are exactly the kind of work the national labs should be doing to inform industry development efforts, including vehicle operating and control strategies. Providing discretionary funding to support new concepts adds flexibility to the consortium approach.
    - H2NEW, which has an outstanding leadership team, excellent presentation, strong systems analysis guiding cell operating strategies, materials development, and AST.
- The research consortia approach seems to be valuable in leveraging and streamlining access to national laboratory capabilities and expertise. It seems that increased involvement from industries would be a better utilization of the consortia crosscutting research activities. The consortia agenda is well-defined, with focused technology area targets. The HydroGEN consortium can benefit from a focused program on limited specific technologies in lieu of scattered projects.
- The research consortia are very appropriate for guidance needed for early-stage research. Linkage of these consortia with state and regional stakeholders through market-based planning efforts could increase value and accelerate the pathway for development of policy and effective commercialization with market-based deployment.
- Separating HydroGEN 2.0 from H2NEW based on current TRL levels is a good idea. That way, HydroGEN 2.0 focuses on low-TRL R&D areas, given that low-temperature PEM electrolyzers are far more advanced than other advanced water-splitting routes. One benefit of the consortia approach is the

continuation of maintaining expertise and developing new talent around hydrogen science and technology through the core lab systems and academia.
- The materials science research in the consortia is excellent (the Hydrogen Materials Consortium [H-Mat] and HyMARC). Many use the outcomes of these groups.
- Consortia make remarkable use of people and labs, in particular national labs. Consortia make very powerful research teams.
- The HydroGEN network of nodes is an excellent example of cooperation between industry, national labs, and universities.
- The approach proposed appears excellent to enable the best experts to work together in a medium-term vision and to provide new results for further complementary R&D activities.
- Collaboration is going well. The avoidance of duplication of research effort at the national labs is being achieved.
- The approach is solid.
- The consortia approach is great for generating competencies and capabilities for industry to tap into for specific, more proprietary topics but also to tackle pre-competitive topics. A case in point would be quality control R&D, presenting a challenge to bring industry to a level of maturity to recognize where the pre-competitive aspects are and to exchange them more freely, both for fuel cells and electrolysis. The consortia should add more emphasis to bringing an even more dynamic dialogue between competitors on those topics and elevate their readiness to seriously compete globally where appropriate.
- The Electrocatalysis Consortium (ElectroCat) and M2FCT are well-developed and backed by well-experienced researchers and companies. HyMARC, HydroGEN, and H-Mat could benefit from better SMART goals, better collaboration, and more influence from industry to strengthen their management, ideas, and innovation.
- More focus on working with industry can be considered.
- An advisory board/committee may be needed to review consortia approaches/projects and progress.

8. H2@Scale: What are the strengths and weaknesses of the H2@Scale initiative? Do you have any recommendations for other H2@Scale analysis, research topics, or demonstrations to enable the scale-up and value proposition of hydrogen and fuel cell technologies (e.g., a region with low electricity prices, excess curtailment, and hydrogen supply opportunity along with a co-located demand for hydrogen, etc.)? Please provide any other recommendations on H2@Scale.

Comments:

- I whole-heartedly support the H2@Scale effort and believe this is the exact type of full-picture analysis and information-generating effort that we see is needed even in regions that are generally supportive of hydrogen industry development. The program's strength really is its ability to develop the types of information resources that policy makers and business decision makers need in order to develop a future hydrogen energy system. Some issues that I think H2@Scale could help address through research include the following:
    - Acknowledging the heavy interest and push toward electrification (specifically batteries) in many end uses; there is increasing need to have more nuanced understanding of the roles hydrogen can play. H2@Scale can help answer questions more fully about the specific applications and use cases in which hydrogen will be preferable and maybe even necessary. More detailed information than evaluation of general economic sectors is needed—for example, specifically about multi-unit dwelling residents or power needs in remote and protected locations. This may end up being a set of hyper-specific case studies, but that type of focused information is still needed by policy makers today.
    - There needs to be far more clarity about what it would take to build up a whole upstream supply chain to support the vision of H2@Scale. Even with all the development in hydrogen production, distribution, and dispensing going on today, it's still nothing compared to the volumes of a vision like H2@Scale, and there is not much good information available today about how that growth can practically occur, what its costs will be, what the potential societal impacts will be (again, with an eye toward localized analysis here), and what might become the bottlenecks. H2@Scale could help scope all this out and define the risks that should be avoided in this massive energy transition.

    - Climate change is a general and foundational motivating factor of H2@Scale. However, the effects are already being felt today and cause operational changes in our energy system today. For example, recent reporting has highlighted California's drought, leading to increased dependence on fossil fuels for the state's power needs, further exacerbating the issue. H2@Scale could also serve as a platform for studying hydrogen's potential role in short-circuiting this kind of feedback loop. This could be an immensely powerful piece of information.
- H2@Scale enables large-scale hydrogen production, storage, and utilization across different sectors of the economy. H2@Scale addresses many environmental and energy issues and provides for the transition to a net-zero-emissions economy.
- The Program should consider accelerating deployment by enabling approaches that have already been successful in one region to be pursued in other locations/regions. For example, what the Stark Area Regional Transit Authority did with FCEBs in Canton, Ohio, should easily work in many other cities.
- I don't have much to add on this, as I think the challenges along the hydrogen value chain are numerous already. The work done in this initiative is impressive already.
- Regarding the strengths and weaknesses of hydrogen at scale, a clear strength is that this expands the funding and technology readiness level (TRL) scope, which, of course, will drive progress. There seem to be many, many projects making progress. The leaders seem to have a high-level awareness of what the other offices are doing. It is very exciting to see expansion to uses such as agriculture (NH_3 generation for crops). All the projects sound exciting, though I am not in a position to appraise them from an economic viability perspective from what was discussed. While not a strength in the usual science or engineering sense, the emphasis the participants put on diversity, communities left behind, and environmental justice should help the end products to find societal acceptance, sustainability, and stability. A weakness I see is that collaboration seems to be defined as working on the same area, not working together. What I did not see is a clear method of making sure there is not duplication of effort and that the other offices are getting and valuing the guidance from industry that HFTO possesses. It may well be that there is sharing of this "intelligence" on what would matter if it were accomplished, and even what industry sees as industry-competitive areas that government should stay out of, but if so, it was not clear. It would be preferable if there were a clear leadership structure at a level above the offices involved that was driving this in a "peer-reviewed" direction, and that could be administrative peers as well as science peers. It is also critical that this effort not defund the existing work. At the very least, one might model this effort's organization on the counsel of battery research funding offices in VTO, EERE, ARPA-E, etc. that tried to make sure the massive efforts in the Obama administration on battery science, engineering, and commercialization were consistent, coordinated, and logical. Better yet, that model could be used as a base and improved upon based on where that effort succeeded and where it did not and where it was okay but might have been better.
- Since its inception, the H2@Scale initiative has generally been a success, both in terms of realizing actual projects and from the perspective of motivating the broader hydrogen community to think big, beyond transportation and the possibility of integration with broader industry sectors. However, maybe as a result of the understandable objective of simplifying a complex concept, H2@Scale appears to have sacrificed the critical parameters of technology readiness. It would be immensely helpful to incorporate the TRLs of the various components that make up the initiative. For example, a more meaningful representation of the petrochemical industry, transportation, and synthetic fuels can be added to the famous slide. Perhaps the Program can come up with a creative way to introduce current TRLs and hydrogen consumption volumes of the different opportunities. It might be useful to create different versions of the H2@Scale master slide, including one based on TRL, current and future market potential (energy or cost basis/year), greenhouse gas reduction potential, etc. That way, there are more realistic expectations and minimal room for misinterpretation by policy makers or non-technical stakeholders.
- The strengths are an excellent market-based approach to the research topics. The one aspect that is missing that I think could be improved is making a stronger connection to more fundamental research being supported by agencies such as the National Science Foundation and DOE's Basic Energy Sciences. I feel this could be a mutually beneficial link that is currently missing.
- H2@Scale is an important initiative to promote the application of hydrogen and fuel cell technologies. Better interaction between this initiative and the other consortia can result in more advanced solutions and technology assessments and overcoming scientific and engineering hurdles, which will help achieve the targets much faster.

- H2@Scale is a perfect example of a thoughtful approach to improving scale to reduce cost for market deployment. This approach could find additional value if coordinated with state and regional entities.
- It would be useful to add a "fourth dimension" that describes projects in just-in-time hydrogen production, i.e., a plant produces fuel based on the anticipated demand for the fuel.
- H2@Scale was focusing on mapping and modeling activities. It might be interesting to validate it through H2@Scale demonstrations.
- This is an important cornerstone that must form a stronger alliance with solar energy.
- H2@Scale is an excellent program to prepare massive deployment. It will not be sufficient to open the hydrogen market. The support of a strong U.S. policy, industry, and investors will be needed.
- The Hydrogen Program's analysis should be expanded to include additional emerging applications, such as mining and construction equipment as well as refuse trucks.

9. International Collaboration: The Hydrogen Program collaborates through a number of international partnerships. For example, the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) is an international partnership to coordinate activities on hydrogen and fuel cells across 20 countries and the European Commission. Additional international collaboration initiatives with U.S. participation addressing hydrogen include the Clean Energy and Hydrogen Ministerials, Mission Innovation, the International Energy Agency, and others. Please comment on actions DOE can undertake in conjunction with these international activities that can effectively accelerate progress in hydrogen and fuel cell technologies.

Comments:

- DOE international collaborations and partnerships in hydrogen R&D are important and successful. One expects a strong comeback of the United States at the end of the year in the 2021 United Nations Climate Change Conference (COP26).
- The extent of involvement in important international entities such as IPHE is paying off for all parties involved. Communication allows for peaceful, more rapid, coordinated efforts.
- International collaboration is key to accelerating hydrogen deployment. Any DOE action to foster international collaboration is thus fully supported. IPHE is the right partnership with which to exchange on regulations, codes, standards, and safety activities and may also facilitate some R&D collaborations. Direct connections to other R&D programs, such as the second generation of the European Fuel Cells and Hydrogen Joint Undertaking (FCH 2 JU) or the new upcoming Clean Hydrogen JU, could be used to continue international collaborations.
- These are great initiatives globally. I would recommend coordinating closely with Canada on topics related to codes and standards harmonization and cross-border issues such as vehicle infrastructure, hydrogen blends in natural gas, and so on. Coordinated funding for R&D with Natural Resources Canada would be very productive. There have been informal collaborations on the topics of quality control and membrane manufacturing, but it would be more productive and impactful if joint/coordinated funding were considered.
- One area of international collaboration that DOE could help with is standardization of reporting and progress methods. It is notoriously difficult to catalog, evaluate, and understand how different regions' hydrogen-specific plans, funding, targets, and progress compare to one another. An immediate example that comes to mind is comparing progress in terms of station network development. Countries, states, and regions count stations differently (based on type of access [private, public, behind-the-fence], permanent versus temporary/mobile locations, and other metrics). It has been very difficult to ascertain progress and competitiveness of the United States and its constituent states as compared to international efforts. At many times, this has led to the perception that no other country is making progress on hydrogen and that the United States or specific states "are going it alone." While this misconception can be corrected with available information, it is still very difficult to convey in a useful manner since all the regions' reporting is on different bases. The more that DOE can work with international partners to standardize the accounting and communication and make updating and publication a regular activity, the better.
- While there are many cited partners, the actual shared research or shared projects seem limited, and, given that U.S. tax dollars are being spent here, it is difficult to have true international collaboration that includes funding. Still, there is DOE representation on international boards and harmonization groups. It would be

nice if there were a more deeply international approach to all this, like R&D, but I understand that the U.S. economy depends on intellectual property, so that will not happen to the extent it could. The leadership certainly sees the need for a world approach, so the degree and kind of international joint projects are not from lack of interest. The EERE approach is certainly sufficient and about as good as one can hope for under the circumstances. I think the coordination internationally is good.

- The Hydrogen Program's international collaboration looks good. However, the collaboration level may need to constantly be updated to catch up with the fast-growing focus and funding in international hydrogen activities (especially the European Union, China, and Japan) and ensure that DOE-funded researchers are appropriately engaged.
- International collaboration is highly recommended. Higher levels of transparency and participation by U.S. industry in international collaborations are encouraged. U.S. industry involvement in European fuel cell and hydrogen collaborative projects needs to be facilitated.
- Collaboration with international partnerships is of value in raising global awareness and increasing opportunities for global development. Resource-sharing could improve research productivity and reduce cost; however, there will be a need for protection of intellectual property.
- The international collaboration is mission-critical for the stakeholder community, comprising global nationals and researchers with global viewpoints. There should be a way to garner information about the amount of past, present, and future (planned) investments in hydrogen refueling infrastructure from the IPHE members.
- So far, it seems the international collaboration is very limited to the different organizations stated above and to participation in their meetings. There is virtually no scientific cooperation such as joint research or work with international companies, although up until a few years ago, the U.S. hydrogen program was the world leader in its field. Since then, many countries have invested in facilities and experienced researchers who have made significant advancements that can contribute to the U.S. effort. Stronger research collaborations should be formed with international members. In addition, there are parallel research consortia, mainly in the European Union. The Hydrogen Program should try to formalize the collaboration between its consortia and the international ones.
- International workshops should be held periodically.

10. Prizes: Agencies have shown interest in implementing prizes and competitions as a mechanism to complement the conventional grant process. Examples include the H-Prize (H2Refuel) for a small-scale hydrogen fueling appliance that complements large retail stations. Please provide comments on the prize/competition approach and provide any suggestions for future prizes or competitions that would align with the goal of accelerating the widespread success of hydrogen and fuel cell technologies.

Comments:

- The prize and competitions do successfully complement the conventional grant process. The H2Refuel is a unique station, an architecture unlike any other. Had DOE not provided a competition for this unique plant, the company may not have been successful in competitive solicitations for larger refueling capacity requirements. The AMR presentation explained this correctly.
- Prizes and competitions have always been good motivators. I recommend continuing the existing programs.
- The right number of prizes is helping to hold interest and educate and grow stakeholders.
- This tends to be very single-goal-focused with little spillover. I would suggest the Defense Advanced Research Projects Agency/ARPA-E model would be better. The advantage of a prize is you do not need to pay out till someone "wins." However, you also do not get progress on really tough problems because the odds and timelines are too long. If DOE will use this, it should be used as part of the Program's implementation acceleration, and the Program should make absolutely sure this is a highly desired outcome and one the industry would not do without the prize. Finally, the prize should not be given out for good effort; that voids the value of the technique. As for ideas, DOE can just look at its tech team goal sets and pick one team's set of goals and make that the challenge—or make a meaningful subset of the goal set with limits on the other parameters that make the challenge target, if accomplished, sufficient to start some adoption on a wide enough scale to start up the development of a supply chain for a bigger hydrogen economy in time.

- I think prizes are a good idea but should be fairly limited in the size of the award and thus the scope. Prizes would be best for applications in which the technologies already exist and it's just the application or integration that is novel.
- Prizes and competitions may be an interesting and valuable mechanism for scholastic and academic competitions. However, acceleration of deployment to increase clean energy deployment might be best served with improved education and public demonstrations with state and regional partnerships.
- I'm not sure such prizes or competition would accelerate widespread success of hydrogen and fuel cell technologies.

11. Please comment on the overall strengths and weakness of the Hydrogen Program and its portfolio of projects. Please provide strengths and weaknesses for each subprogram as appropriate. On which technology areas should the Hydrogen Program put more or less focus for future activities?

Comments:

- I believe that the Hydrogen Program is generally well-balanced. The Program clearly delivers progress in technology development and key information to demonstrate the utility of hydrogen and fuel cell technology. The sheer volume of reliable and authoritative data and information that comes from the Program is its greatest strength. Especially in recent years, the Program has also demonstrated significant flexibility in the structure and goals of its funding program and projects, especially to provide timely information and results relevant to the evolving state of the hydrogen and fuel cell industry. It appears that Program activities looking forward could begin to add more focus to demonstration and perhaps even market development efforts that has been missing in recent years. I believe this has been a major lack in prior years of the Program and that, if it can actually be expanded going forward, it will prove to be a powerful engine of change and success for the hydrogen and fuel cell industry.
- Everything I might say is covered above. In summary, the management system, the involvement of industry, the breadth of effort across many TRLs and all aspects of a hydrogen economy, the expansion from a transportation focus to an economic focus, and the people's passion and expertise are strengths in what is no doubt the best hydrogen program on earth. The increasing emphasis on engaging industry past goal-setting to partners in technology implementation is appropriate at this point. The harmonization of standards internationally can only help. This is not a weakness but a place where improvement might occur: coordination and true collaboration on projects across the offices and agencies working in this area. The more understanding and coordination there is between funding units, the more efficiently everything will work. The same could be said internationally, especially if it is true research collaboration, working as if you were in the same lab, on the same project, talking all the time. It is clear there is economic risk that Congress would not accept in higher-TRL work, but perhaps the Office of Science and HFTO, for the lower-TRL work, could try to partner with the very best researchers in the world, with DOE funding our researchers in the partnership and the various European Union and national science agencies funding their top researchers in the partnership on a specific project.
- The Hydrogen Program is encouraged to address the most urgent and high-value uses of hydrogen, including fertilizer, steel industries, and refineries. Those are the industries that use energy and need hydrogen the most. The key to success for H2@Scale is the scale-up and demonstration of the technologies that are close to maturity by integrating different sectors and users that can benefit from hydrogen, leading to an increased role of the Technology Acceleration subprogram.
- The Hydrogen Program has clear objectives described in a very detailed manner, with associated quantitative key performance indicators. The projects appear well-structured and -monitored by the DOE team. The research consortia approach is a real strength of the Program, as it ensures a mid-term action enabling the best U.S. experts to work together on a specific critical item. Collaboration with other agencies has been improving, but it might be enhanced with more inter-agency projects. As the hydrogen technologies should significantly increase in the next decade, a stronger effort in considering sustainability, circular economy, recycling, and eco-design could be considered.
- The Program office is strong at all levels and should be used as a benchmark for other DOE offices.
- The Program has enabled outstanding R&D progress, significantly advancing the state of the art. That is the Program's strength. That progress stems from an outstanding leadership team and staff with significant

experience in program planning and execution, as well as scientists and engineers with in-depth technical expertise. The Program's weakness is enabling deployment and raising awareness of hydrogen and fuel cell technologies at the state and local levels.

- Overall, this is a strong program with a strong funding base. Building relationship with industries is needed to accelerate some of the key technology development.
- No doubt, the Program has made significant progress in technology RD&D and cost reduction of key performance indicators over the years, as clearly shown in Dr. Satyapal's presentation (slide 15). However, the same slide also appears to indicate an asymptotic plateauing of those key parameters in recent years and that they are still far from 2030 targets, namely costs for hydrogen production (PEM electrolyzers), auto PEM fuel cells, and onboard storage. This observation may suggest that those Program strategies with incremental changes may not be enough to achieve the ambitious DOE goals. Perhaps it is time for the Program to bet big on new ideas with potential for transformational changes.
- The biggest weakness the Program has is the lack of a formal route to validate results. This must be corrected. In some cases, the testing, parameters, and goals are not well-defined (H-Mat, HyMARC, HydroGEN). International collaboration has to be improved. The Program is the longest-lasting hydrogen and fuel cells program in the world. As such, it has the longest institutional memory, which must be cherished. Although it invests quite a bit in catalyst development, it has almost completely erased the Pt research programs. The Program has to maintain this research area, even at a low level, to keep the institutional memory and the top researchers in the field, which is now also becoming relevant for hydrogen production. In addition, not enough attention is given to development of advanced electrode materials (not catalysts) that can endure harsh conditions in fuel cell and electrolyzer operation. It is worth mentioning the M2FCT call for proposals, which is open to all U.S.-based universities (opening this to international participants as well should be considered). This program will allow bringing in new ideas that were not necessarily considered by the consortium or that can help the consortium mitigate some issue it faced.
- The Hydrogen Technologies subprogram and the Fuel Cell Technologies subprogram, which were the only subprograms I sat through and reviewed, are led by knowledgeable and goal-driven leaders within DOE. The programs they support at various companies and universities work very well in collaboration among themselves and the national labs. The weakness is the lack of a direct connection with basic science research being supported by the National Science Foundation and DOE Basic Energy Sciences program. While I understand that these programs have to be necessarily focused on applied research, a stronger connection with basic research being supported by other agencies will strengthen the programs.
- Overall, the Program strengths include the quality of its early-stage research; weaknesses include a need for more state and regional collaboration, with stakeholder engagement and cooperative partnerships; opportunities include advancement of hydrogen and fuel cell deployment with other initiatives, including offshore wind and energy storage, in support of climate protection and energy reliability; and threats include unproductive competition with other industries, such as battery technology that is better understood by the public and sometimes favored simply because of a better public understanding of the technology when compared with hydrogen fuel cell technology.
- The R&D program is outstanding, but it needs a strong link with U.S. energy policy to have an impact on climate change. DOE's announcement of the Hydrogen Energy Earthshot goal to achieve $1/kg hydrogen production in one decade could give the impression that one has to wait ten years to start deploying hydrogen. One has to start now to develop the hydrogen market to achieve net-zero goals.
- The international perspective is needed. The future or the planned exportation/importation of hydrogen is very important to global businesses, albeit just starting. A session should be added on the integration of hydrogen systems as expressed in H2@Scale: how the various processes and subprocesses work together.
- It is hard to tell where to drop focus. However, topics that are dropped, such as electrochemical hydrogen compression, should be identified in the overview of the Program and subprograms, with some justifications as to contribute to the collective learning.

12. Do you have any other comments or suggestions to improve the overall effectiveness of the Hydrogen Program or any of its specific subprograms?

Comments:

- This Program is well-planned, well-organized, and well-managed in every aspect listed above. All Program managers are very professional and dedicated. The virtual meeting agenda for this year of 2021 is organized nicely and moderated accurately. It is very convenient for the reviewers and principal investigators to attend the different presentations seamlessly. To further perfect this Program, the reviewer has the following suggestions for the Program to consider:
    - The deliverability of the large research projects, such as those led by the industry and national labs, could be monitored more closely, especially when they proposed to deliver the products to the market.
    - More investment in the smaller research projects led by universities (with much lower cost to this Program than those led by national labs) can be very beneficial in many aspects, including the training of the workforce and building the sustainable infrastructure for the hydrogen economy for the years to come.
    - The peer review process for the selected projects is very interesting. To make this review process more effective, a blind review is suggested. With the incorporation of the virtual activities, the blind review could be done by having the reviewer and panelist submit the questions/comments anonymously to the moderator. To ensure the success of the projects and to make the review more beneficial and constructive to the project that is being reviewed, the reviewer could have the option to provide both critiques and constructive suggestions/approaches to better the projects.
- Overall, the Program is technically effective, based on very high-quality, early-stage research and collaboration between academia and the national labs. Effectiveness may be improved with state and regional planning for demonstration and deployment to increase public education, public acceptance, and commercial market-based deployment. Other themes that were discussed during the plenary sessions that appear to be of high value and should be emphasized in program planning for the Earthshot include the need to move from the labs to the markets. There are collaboration gaps, and collaboration will be essential to reducing costs. National policy will be supportive of decarbonizing, providing energy storage, and increasing export opportunities. Interagency working groups will provide valuable federal coordination. Community engagement will be needed to get stakeholders comfortable. Stakeholder engagement will be needed to help determine which technology should be demonstrated, what the best end uses are, and what the best markets and applications are. System crosscutting to reduce costs is of value. Hydrogen opens up integrated pathways. These comments and themes are all consistent with an overall emphasis on increasing stakeholder engagement at the state and regional levels to accelerate application of R&D.
- Thank you for inviting me to comment on the Program. This is always a great event of which to be a part. I am looking forward to next year.
- It would be nice if reviewers could go over a copy of the plenary presentations for the Program beforehand, just as reviewers of the individual projects are able to go over a copy of the presentation and past presentations. I get that the Energy Secretary's announcement or Director Satyapal's announcements can't be released beforehand, as that would ruin the surprise. However, the subprograms are just the facts and could be available to reviewers to read and think about what we most need to focus on as the talk is given. I do appreciate the chance to see them afterward, at least. Standard DOE slides have several times more information than can be assimilated in the time typically given each one, and the fonts are concomitantly too small. And yet so many concepts or areas are covered per slide; there is seldom enough information to verify the results; listeners just have to trust the presenter. The result is a talk that is hard to listen to, and it is hard to focus on any particular take-away value. I know these slides get reused many times, and by covering everything possible, one avoids having to get more slide decks approved, but the Program is asked to consider focusing on what you really most need to tell this AMR audience and make clear simple slides for those issues, then provide electronic "handout slides" with all the expanded information (like the current slides) or even supporting proof. Finally, and definitely a comment on the AMR process rather than the Program, just as in an in-person AMR, there is much more time to interrogate the details of posters (30-minute question-and-answer [Q&A] window, plus you can stop and repeat the smooth, recorded presentation, if desired), which are generally regarded as the less critical project evaluations relative to the

oral presentations (10 minutes of Q&A and a live presentation with occasional small technical issues and often rushed endings as the speakers see they are over time). The Program is asked about reversing that.

- For the environmental/economic modeling projects, perhaps front matter can be added to the presentations and sites that conveys the level of expertise needed to run the models independently. Some stakeholders are interested in becoming self-sufficient in running the models, but without the knowledge of the required skill sets, they hesitate.
- Strong government support to the development of the hydrogen market is needed. The Program needs to develop links with industry, investors, and R&D programs of the European Union, Japan, etc. The AMR would need the input of these sectors to give a good vision of the hydrogen future.
- The awards ceremony is a great moment of the AMR. Awards are very useful for recognizing young people and significant progress.