2018 Hydrogen and Fuel Cells Program Review Summary

This Appendix shows the results of the Hydrogen and Fuel Cells Program-level peer review for the 2018 Annual Merit Review (AMR), including feedback from a sub-set of the reviewers attending the AMR. A total of 70 Program-level reviewers were invited to provide feedback, and 26 reviewers responded.

1. General: The Hydrogen and Fuel Cells 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 and Fuel Cells Program as well as each sub-program, as appropriate. (Note: The Technology Acceleration sub-program includes the prior-year sub-programs Technology Validation, Manufacturing R&D, and Market Transformation.)

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 and Fuel Cells Program Overall Rating	Hydrogen Production and Delivery R&D Sub-Program Rating	Fuel Cell R&D Sub-Program Rating	Hydrogen Storage R&D Sub-Program Rating	Technology Acceleration Sub-Program Rating	Safety, Codes and Standards Sub-Program Rating	Fossil Energy Solid Oxide Fuel Cell Sub-Program Rating
Average Score	8.8	8.6	8.3	8.6	8.4	8.7	8.1
Number of Responses	25	21	19	15	19	17	14

Comments:

- Congratulations are in order for the Fuel Cell Technologies Office (FCTO) director for bringing the Hydrogen and Fuel Cells Program (the Program) to its most exciting state, with the greatest potential in years. The involvement of the Hydrogen Council speakers in the plenary program was valuable. Congratulations to the DOE Office of Energy Efficiency and Renewable Energy (EERE) and Office of Fossil Energy (FE) for developing relevant and urgent programs.
- The Department of Energy's (DOE's) Program is excellent, since it clearly sets the cost target.
- The general focus of the various initiatives is in line with the long-term needs of the fuel cell industry.
- Overall, the work is excellent, with proper focus on reducing cost.
- With regard to the Safety, Codes and Standards (SCS) sub-program, the work is valuable, relevant, and timely. However, specificity and measurability within the goals is a bit lacking. Within the Fuel Cell R&D sub-program, there remains a bit of uncertainty as to the overall direction for finally achieving all of the technical sub-program targets simultaneously. This particular sub-program seems to have stalled in recent years, and it seems that the direction is not clear. Greater specificity is likely necessary within this sub-program to help it move closer toward its goals. Finally, the efforts regarding infrastructure and hydrogen production seem to be comprehensive and well formulated.
- The DOE Program mission and strategy are exemplary for the rest of the world. However, the Hydrogen Storage R&D sub-program was rated a bit lower than the others because the focus on hydrogen-in-materials solutions for applications is still too strong. This dimension is definitely a source of remarkable

scientific achievements, but it cannot continue to be labeled as a promising storage solution; the technological indicators have not improved in many years.
- The focus should be on renewable energy as much as possible.
- Increasing balance-of-plant (BOP) fundamental R&D is recommended. There is too much emphasis on platinum-group-metal-free (PGM-free) catalysts; over 20 years of R&D in this area has been unsuccessful. There is a question as to what percentage of the cost-per-kilowatt analysis (SA-James) is PGM compared to the total system cost, not just stack cost. Perhaps that should be the percentage of funds for alternative catalysts.
- The meaning of "early-stage research" in the context of the various sub-programs needs to be clarified, as does how "early-stage research" applies to hydrogen and fuel cells versus combustion and fossil fuels. It is not clear that the definition is applied consistently.

2. The Hydrogen and Fuel Cells Program is well focused and managed, and is effectively fostering research and development (R&D) to enable innovation and advance the state of technology for hydrogen and fuel cell technologies to be competitive and achieve widespread commercialization and deployment 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	8.5
Number of Responses	24

Comments:

- The recent direction to develop programs through consortia appears to be a particularly effective method of managing the Program's research directions and sharing findings and knowledge. The ability to leverage greater resources within stakeholder organizations that complement FCTO's capabilities is also effective. This appears to be a well-designed Program management development.
- The market would not be where it is without DOE R&D. Continued investment is needed.
- The technical/scientific knowledge and competence of the sub-program managers is admirable.
- Congratulations are in order on international involvement and collaboration at the highest levels.
- The Program team does a very effective job of managing the sub-programs.
- As a general cautionary comment, a robust modeling toolkit is certainly an asset. However, proposed analysis projects should be screened to avoid analysis overkill. It is important to determine whether every analysis objective in the proposed project addresses a rate-limiting knowledge need (given the time horizon considered). Furthermore, the modeling project workflow template should incorporate industry/adopter reviews as a standard element (this was not depicted on the relevant slide of poster SA02). An "in-flight" review from end-use adopters would likely add value to the projects.

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

Average Score	8.0
Number of Responses	24

Comments:

- The Program's portfolio of projects is balanced, and all aspects of hydrogen are covered. Polymer electrolyte membrane fuel cells (PEMFCs), solid oxide fuel cells (SOFCs), and others are covered for many applications.
- It is good to see how the Program has evolved over the years to maintain a strong impact on the market uptake of fuel cell and hydrogen technologies.
- It would be helpful to include in the plenary session of the AMR a presentation relating how projects are chosen, prioritized, and funded based on Administration input, FCTO strategy, review feedback from previous years, etc.
- The key areas of future development needs are HydroGEN; H2@Scale is effectively addressing key long-term needs. Also, manufacturing efforts and key component R&D are essential for future success.
- The balance is strong; however, the market could benefit from more focus on applying new technology to the market.
- The SOFC projects are focused either on core technology innovations or on large distributed power generation on the megawatt scale. Commercial application of fuel cell technology and its advancement into the mainstream requires special focus.
- Overall, the directions of the research Program are in line with the needs of stakeholders. However, the current restriction that deters projects geared toward implementation and late-stage R&D has the potential to significantly limit the relevance of the Program overall (acknowledging that this restriction is essentially imposed on FCTO by Congress). It does appear that even within this restriction, there may be opportunities to undertake more projects in line with implementation and growth in technology commercialization, given that these efforts within the fuel cell and hydrogen communities are firsts of their kind. Not much is known about consumers, market responses, and industry transformations that could provide key answers for large-scale fuel cell and hydrogen implementation. Therefore, it is suggested that the Program think creatively about justifications for projects that will be increasingly relevant as jurisdictions communicate first-of-their-kind information needs for making these technologies a reality.
- Manufacturing and BOP R&D are underfunded.

4. The Hydrogen and Fuel Cells Program's R&D aligns well with industry and stakeholder needs. Please comment on the overall Hydrogen and Fuel Cells Program as well as each sub-program, as appropriate.

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 and Fuel Cells Program Overall Rating	Hydrogen Production and Delivery R&D Sub-Program Rating	Fuel Cell R&D Sub-Program Rating	Hydrogen Storage R&D Sub-Program Rating	Technology Acceleration Sub-Program Rating	Safety, Codes and Standards Sub-Program Rating	Fossil Energy Solid Oxide Fuel Cell Sub-Program Rating
Average Score	8.2	8.3	7.8	8.6	7.9	8.2	7.7
Number of Responses	24	21	18	16	19	17	14

Comments:

- Program leadership is available to industry and stakeholders and is generally responsive to discussions about which projects will be helpful.
- Congratulations are in order to DOE EERE and FE for bringing important stakeholders into the Program. There should be cooperation in using the SOFC as a range extender in large hydrogen vehicles.
- An increased focus on deployment would be helpful. That said, the Program continues to provide tremendous benefit.
- The Program underemphasizes BOP and manufacturing R&D. The Program also ignores the cost of power conditioning; however, this will be important for commercialization.
- Some of the catalysis parallel projects seem to overlap in their objectives.

5. The Hydrogen and Fuel Cells Program is funding high-impact projects that have the potential to significantly advance the state of technology for the hydrogen and fuel cells industry. Please comment on the overall Hydrogen and Fuel Cells Program as well as each sub-program, as appropriate.

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 and Fuel Cells Program Overall Rating	Hydrogen Production and Delivery R&D Sub-Program Rating	Fuel Cell R&D Sub-Program Rating	Hydrogen Storage R&D Sub-Program Rating	Technology Acceleration Sub-Program Rating	Safety, Codes and Standards Sub-Program Rating	Fossil Energy Solid Oxide Fuel Cell Sub-Program Rating
Average Score	8.3	8.4	8.1	8.3	8.3	8.5	7.7
Number of Responses	24	20	17	14	18	16	16

Comments:

- The Hydrogen Production and Delivery sub-program, in particular, appears to present the opportunity to have a large, lasting impact on the development of hydrogen and fuel cell industries in the United States. The sub-program addresses several technical gaps simultaneously and is appropriately focused on the cost reduction of hydrogen for the ultimate consumer.
- The existing portfolio of pre-commercial approaches to cost reduction (particularly low-PGM systems) is a crucial component of the portfolio. The focus on reducing manufacturing process cost (roll-to-roll efforts) is also important.
- There are many high-impact projects within DOE FE and EERE, including projects concerning SOFCs, fuel cell electric vehicles (FCEVs), SOFC hybrids, EERE's H2@Scale, etc.
- The focus of the various sub-programs addresses primary issues/opportunities.
- The projects are relatively smaller than similar ones in other parts of the world. Perhaps some overarching projects with a strong (and guaranteed) multi-annual budget and a broader challenge portfolio could allow for intrinsically better coordination and stronger impact.

6. In your opinion, what were the most significant accomplishments within the Hydrogen and Fuel Cells Program during the past year? Please consider the entire AMR content and entire DOE portfolio, including poster sessions, rather than the plenary talks alone.

Please respond for any program area as appropriate (Hydrogen Production and Delivery, Storage, Fuel Cells, Technology Acceleration, Systems Analysis, Safety, Codes and Standards, Solid Oxide, ARPA-E, Basic Science, etc.).

Please state areas requiring more attention or improvement. If you do not have a response, please select "Not Applicable."

Comments:

- This is a hard question to answer, as the Program does many important things. From the perspective of establishing large-scale value proposition, some highlights are:
    - Systems analysis work (supply/demand curve)
    - Codes and standards work on nozzles and other station infrastructure, enabling hydrogen refueling station (HRS) rollout
    - Compatibility of pipeline materials and related codes and standards work to enable large-scale infrastructure
- These comments focus on the Safety, Codes and Standards sub-program, because this was the area allocated to the reviewer for this AMR. This sub-program has made small but important incremental progress. An example of this is H2Tools, built over many years but always up to date, providing much support and service, not only to the United States but also to the whole international community. An example of a one- to two-year accomplishment is the Sandia National Laboratories study of LH_2 behaviors and the new attention to public infrastructure.
- Different consortia (the Fuel Cell Consortium for Performance and Durability [FC-PAD], the Hydrogen Materials Advanced Research Consortium [HyMARC], etc.) were established a few years ago; this year, their relevance and effectiveness could be seen. Encouraging networks around a core team allows for concentration on a particular topic with a mid-term view and the capitalization of accomplishments; this is much more difficult when done only through projects.
- Accomplishments include the enhancement of the H2@Scale concept and the projects' collaboration with stakeholders, including Japan's Ministry of Economy, Trade and Industry (METI)/New Energy and Industrial Technology Development Organization (NEDO).

- It is critical to have a continued focus on electrolyzer technology improvement and reduced hydrogen delivery/station cost. An example is increasing the vehicle tank temperature to allow for an increase in the cooling temperature, ideally to 0°C, rather than the current -40°C.
- The highlights are accomplishments related to the Hydrogen Production and Delivery sub-program, the Safety, Codes and Standards sub-program, and the H2@Scale concept; these are driving hydrogen/fuel cell commercialization.
- The Program's key accomplishments were the progress in H2@Scale (hydrogen production and delivery), the volume manufacturing developments, and technology at scale.
- The most significant accomplishment is within the Safety, Codes and Standards sub-program; contributions to the codes development process are critical to the advancement of the hydrogen industry.
- Accomplishments include established collaborations with the Hydrogen Council members and many others.
- Some significant accomplishments include the Hydrogen Safety Panel's collaboration with internationally acclaimed organizations, as well as the plans moving forward.
- The reviewer works in the area of SOFCs and believes the plans for industry teams to demonstrate 200 kW prototypes are the most significant aspect of the Program.
- The adoption of H2@Scale has been crucial and will continue to be so through time.
- The Program has made progress in SOFCs and solid oxide electrolysis cells (SOECs).
- Projects particularly worth noting include (1) the characterization of electrolyzer performance in grid-tied operation to demonstrate the capability for grid balancing and grid services, (2) the characterization of liquid hydrogen vent plume fluid flow, (3) the evaluation of FCEV competitiveness compared to plug-in electric vehicles (PEVs) on various vehicle platforms, and (4) the characterization of hydrogen production potential across the United States. However, the Fuel Cell R&D sub-program has not exhibited significant advancement toward the ultimate technology targets for some time. It is acknowledged that the work in this sub-program requires perhaps a greater deal of basic research and, therefore, more time to achieve its goals than the other sub-programs. However, the Program does need to show more advances than it has recently.
- The FCTO's success in developing patents is commendable. Of the 255 patents developed by national laboratories, it would be helpful to know how many have been incorporated into fuel cell systems or the manufacture of fuel cell systems. This number could really show the value of national laboratory contributions and the importance of fundamental R&D. An emphasis on product water removal from thin-film catalyst layers could greatly enhance the value of ultralow-PGM catalyst layers. It would be good to address how transfer of product water to the anode can be improved, as well as look into new low-cost methods for corrosion protection of bipolar plates with high-rate deposition of protective coatings.

7. The R&D supported by the overall Hydrogen and Fuel Cells Program is appropriate in light of private-sector 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.

Average Score	8.0
Number of Responses	23

Comments:

- Based on the presentations and posters at the AMR:
  - FCTO's core R&D portfolio is entirely pre-commercial work—this is appropriate.
  - There is modest support for early-stage work in the private sector (e.g., the Small Business Innovation Research program)—this is also appropriate.
- At this time, the focus on the Hydrogen Production & Delivery sub-program and H2@Scale is most appropriate in terms of supporting commercialization.
- The stage and topics of R&D support the White House's early-stage applied research focus, which supports near-term economic growth.
- The supported R&D is based on industrial expectations and thus appears appropriate.
- Additional emphasis is recommended on high-rate manufacturing with reduction of stack conditioning times.
- It seems that private industry has recently been making several advancements in the areas covered by the Fuel Cell R&D sub-program. Moreover, the existing gaps appear to require developments that may be accomplished by continued engineering and science often within the bounds of industry efforts. This is the only Program area where future developments appear like they may be more industry-led, and the DOE Program may not be on as effective of a path.
- It is very difficult for this specific reviewer to have a clear and detailed enough picture of the various budget streams to answer this question. There is also a discrepancy between the figures resulting from the budget allocated to projects and the figures given in the plenary sessions, which focus exclusively on annual budget. In comparison to previous versions, this year's AMR has been less transparent.
- It is difficult these days to find private capital to fund longer-term developmental efforts, and the key enterprises in the fuel cell space simply do not have the capital to make these longer-term investments.
- The market would benefit from taking more DOE research and bringing it to market with seed funding. A number of great ideas are in need of help getting to scale.
- Until economics improve, it will be difficult for industry to commercialize these technologies.

8. The R&D supported by the Solid Oxide Fuel Cell sub-program is appropriate in light of private-sector 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.

Average Score	8.3
Number of Responses	12

Comments:

- The stage and topics of R&D support the White House's early-stage applied research focus, which supports near-term economic growth. There should be cooperation between SOFC efforts in natural gas and electric vehicle focus areas.
- While SOFC applications are further along from a commercial standpoint, it is important for the sub-program to have continued DOE support.
- SOFCs are an important technology option and should clearly be actively pursued.

9. Early-Stage Research and Development: The Hydrogen and Fuel Cells Program is focused on early-stage R&D as aligned with Administration objectives for federal research funding. Please provide suggestions for early-stage R&D that the Hydrogen and Fuel Cells Program should consider for promoting its goals and objectives.

Comments:

- It is recommended the Program continue research on hydrogen production methods with low lifecycle emission impacts (such as renewable or nuclear electrolysis), with the goal of making such production methods more cost-competitive.
- The early-stage R&D already in progress concerns key non-PGM catalysts and investigations of transitions to a higher rate of manufacturing of key stack components. Some activity into metallic plate and corrosion issues is suggested.
- The existing robust portfolio of early-stage research is appropriately aligned with this objective (e.g., low-PGM systems, alternative fuel systems [ammonia, dimethyl ether [DME], photoelectrochemical [PEC]).
- The Program covers almost all the topics to be investigated.
- There are several fundamental and basic questions about energy sector transitions and the successful implementation of those transitions that are currently unanswered. While not early-stage hard-science- or technology-based research, the questions are still early-stage because there does not appear to be a robust set of literature that points to definitive strategies for success, accounting for the technological, economic, and social behavior variables at play. It is recommended that these types of studies fall under the Technology Acceleration sub-program.
- An emphasis on product water removal from thin-film catalyst layers could greatly enhance the value of ultralow-PGM catalyst layers. The Program should address how transfer of product water to the anode could be improved, as well as new low-cost methods for corrosion protection of bipolar plates with high-rate deposition of protective coatings.
- The reviewer requests that FCTO and DOE consider the fact that some “bridging” effort in technology readiness levels (TRLs) 2–5 needs to remain to ensure that new research results reach the commercial pipeline.
- The Program should consider heavy-duty FCEV fueling and storage alternatives for H35 (in addition to cryogenic-compressed hydrogen, but not metal–organic frameworks [MOFs]).
- Focus may be directed to the industrial use of hydrogen, such as in steel manufacturing, refineries, and ammonia production.
- The Program should consider renewable hydrogen production, as well as medium- and heavy-duty applications.
- Early-stage R&D could include more collaboration with basic sciences in selected areas.
- The FE program should reestablish its focus on CO_2 reduction.
- Technology development efforts targeting the widespread usage of SOFCs, both in commercial and residential applications, require an impetus in order to create a pathway for lowering costs.
- Renewable hydrogen production is fundamental to success—and there is much research to be done.

10. Energy Materials Network (EMN) Consortia: Do you have any comments or recommendations on the Hydrogen and Fuel Cell Program's EMN consortia approach? Please state what is working effectively and areas that may benefit from further improvement. If you do not have a response, please select 'Not Applicable.'

Comments:

- The R&D consortia appear to be one of the more effective directions for Program management in recent years. In particular, the collaboration opportunities provided by these consortia seem effective and able to advance widespread commercial adoption in the future. So far, these consortia have been focused particularly on energy materials. However, it seems the general concept could be leveraged for other aspects of the FCTO Program. For example, questions of grid integration potential are largely information gaps for many stakeholders across the country that have similar questions but varying conditions, and likely varying solutions. Still, solutions and insights gained in individual applications of the concept and the surrounding research may inform other efforts. FCTO should consider how it can expand the consortia approach, especially the knowledge-sharing aspect, beyond materials research.
- The consortia approach is the best approach for long-term success and investment in R&D.
- This area is fully covered.
- The creation of the Energy Materials Network (EMN) is relevant and will allow cross-fertilization of materials knowledge. The main challenge might be effective coordination with the already existing consortia.

11. H2@Scale: What are the strengths and weaknesses of the H2@Scale initiative? Do you have any recommendations for other H2@Scale research topics or recommendations to enable the scale up and value proposition of H2@Scale (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. If you do not have a response, please select 'Not Applicable.'

Comments:

- The H2@Scale initiative is one of the most important government concepts in the area of energy. The initiative's strength is embedded in the range of applications it covers. To enable the scale-up and value proposition of H2@Scale, it is recommended the initiative coordinate with industries that use hydrogen.
- The H2@Scale initiative's strength is focusing DOE attention on scaling hydrogen. It is necessary to have a focus on connecting hydrogen to the grid in a way that enables renewable energy penetration at an economically attractive rate.
- The H2@Scale initiative is timely and appropriate. It is necessary to compare electric and hydrogen infrastructure as complete energy conversion networks.
- H2@Scale is key, as the industry tells us that one of the limiting factors to greater fuel cell adoption is fuel production distribution and cost.
- The strengths of the H2@Scale initiative are its timeliness, relevance, and comprehensiveness. H2@Scale is an absolute necessity at this moment, when jurisdictions in the United States are transitioning to fully commercial FCEV and hydrogen markets and are looking to provide examples and templates for development that other jurisdictions across the country can follow. The potential weakness is that the questions are so complex that, as an initiative, H2@Scale likely requires careful and constant attention in program management to ensure focus and continued drive toward the end goal, which should be the ubiquitous use of hydrogen as a transportation fuel, enabled by low production and delivery cost (which is also aided by the expansion of hydrogen usage in other markets and sectors). One potential area for

additional research that the initiative does not yet seem to cover concerns the technologies and/or strategies for the massive scale of hydrogen storage and transportation that will be necessary to meet the goals of H2@Scale. As noted by the initiative and other domestic analyses of the potential for hydrogen fuel demand in the future, the amount of hydrogen envisioned within H2@Scale is far greater than today's production capacities. Moreover, hydrogen will need to be more fungible and transportable than today's hydrogen typically is, given the large proportion that is captive on-site hydrogen in the petroleum industry. How this hydrogen will be stored and moved around, particularly at this scale, seems to be a largely unanswered question.

- Starting with the creation of an evidence base is a very good approach to supporting the role that hydrogen and fuel cells can have in energy and transport systems. The bottom-up approach followed for this early stage is positive and adequate. Further support could be allocated to the H2@Scale initiative, especially to support larger demonstration flagship projects that focus on how hydrogen solutions can support the decarbonization of energy and transport systems. It is suggested that the Technology Acceleration sub-program projects be framed with the H2@Scale initiative as examples to replicate to accelerate the market penetration of fuel cell and hydrogen solutions.
- An important enabler for H2@Scale will be the ability for commercial entities to have access to wholesale/very low-cost electricity. Currently, with the way utilities are regulated, this is not typically possible. Another enabler is the capital cost of electrolyzers; both cell-level research and system-level work similar to the dispensing infrastructure area could help.
- The initiative should demonstrate grid enhancement/support from colocation of hydrogen production, storage, and fuel cells with wind and solar so as to get hydrogen into the minds of organizations (such as non-government organizations) that push for other renewable technologies.
- The H2@Scale concept plays a very important role in creating networks with various stakeholders; however, it is weak in cooperation with basic research.
- H2@Scale is a nice approach that includes many usages of hydrogen. However, the reason for not including building heating and energy is not clear.
- Hydrogen should be evaluated in all aspects to maximize its role in the United States and the world: low-CO_2 energy.
- It is important to collaborate globally with stakeholders and strengthen the hydrogen supply chain.
- The H2@Scale market assessment effort is a critical underpinning to the rest of the Program. However, it is flawed in its present scope. It is critical that the H2@Scale market assessment effort incorporate broader sensitivity analysis across multiple input parameters. The credibility of the analysis (to this reviewer's dismay) is jeopardized by overly optimistic input assumptions for hydrogen generation, particularly regarding electrolyzer capital costs—$100/kW is likely not a reasonable baseline scenario. Capacity factor and electricity price are also key inputs, for which a range of values should be surveyed and prominently presented. Four scenarios (as briefly shown in the oral presentation) are not adequate. The project should be sufficiently resourced for more robust sensitivity analysis; otherwise, the results will lose credibility.
- Surprisingly, this year did not demonstrate a clear and strong strategic link between the initiative and decarbonization goals. This may be linked to the changed political landscape, but nevertheless, it is not clear how the hydrogen solution to the mentioned challenges is supposed to have a chance against existing/other energy storage solutions, if it is not strategically linked to the decarbonization of all energy systems.
- Grid connection requirements are set by power companies, and existing fuel cell manufacturers recognize that grid connect is in fractions of a second. An independent analysis of the grid connect potential for electrolysis is needed.
- Because of the potential for private industry research laboratory engagement, this initiative should include laboratories other than national laboratories.

12. Collaboration: The Hydrogen and Fuel Cells Program is collaborating with appropriate groups of stakeholders. Please add any additional comments particularly on which stakeholders (e.g. academia, companies, small businesses, types of industries, etc.) should be more engaged and in what manner.

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.

Please also provide recommendations for how the Hydrogen and Fuel Cells Program can better coordinate R&D with other offices in the U.S. Department of Energy (e.g., Office of Fossil Energy, Office of Nuclear Energy, Office of Science, ARPA-E, etc.), as well as with entities outside the U.S. Department of Energy (e.g. states, other agencies, industry, etc.).

Average Score	8.2
Number of Responses	24

Comments:

- Appropriate collaboration appears to be a Program-wide strength of FCTO. There has rarely been a project within the Program that appears not to have the appropriate group of collaborators.
- Engagement with key stakeholders for scale-up is substantive and a key Program element; therefore, collaboration (e.g., engagement with industrial gas companies, utility companies) should continue to be a proactive Program focus. Key industry stakeholder engagement (input and review) should be a standard and an explicitly scoped element of project development and execution. In particular, industry engagement should be a key element of the scope of fiscal year (FY) 2019 activities in infrastructure development and energy systems integration. The Program staff do quite a bit of this informally and through workshops, regular working calls with counterparts, etc.; this comment is to ensure that engagement is pursued fully and consistently.
- Coordination with other agencies in support of grid stability/reliability and H2@Scale seems to be most valuable. In particular, it is important to understand how to better integrate nuclear energy and perhaps work with state and regional utility regulators to enable integration of H2@Scale concepts.
- Increased collaboration is a key element of staying competitive in the longer term. Ideally, there would be more industry participation at the product, system, and application levels.
- The perspective of end users could have been more present in the AMR meetings for some of the Technology Acceleration sub-program projects (this comment is based on attended sessions). DOE may also want to consider having specific sessions in which projects (especially those that demonstrate a proof of concept) can directly address investors (e.g., by having a pitching session to potential investors). This could be done as part of the AMR.
- The H2@Scale presentation identifies hydrogen demand across the United States but does not make clear how much of that demand is presently satisfied by existing production or how much new production is necessary.
- The majority of focus seems to be with academia rather than the industry. Greater collaboration is suggested with FE and the DOE Office of Science.
- Coordination on SOFC R&D programs between ARPA-E, FE, and EERE is recommended.
- It would be helpful to have DOE as a full member of relevant associations.

13. International Collaboration: The Hydrogen and Fuel Cells 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 18 countries and the European Commission. The U.S. is assuming the chair role for IPHE in 2018. Please comment on actions DOE in conjunction with IPHE can undertake or activities that are effective/need improvement to accelerate progress in hydrogen and fuel cell technologies. If you do not have a response, please select 'Not Applicable.'

Comments:

- There are significant gaps in understanding the differences and similarities between approaches to fostering hydrogen and fuel cell advances and industry development across the globe. For example, the various countries that have initiated hydrogen fueling network development for FCEVs have, for the most part, adopted differing strategies. There is a lack of information and assessment regarding the effectiveness of these varying strategies, as well as opportunities for sharing insights between jurisdictions. International coordination on sharing information is necessary to help ensure continued success.
- It is necessary to be an "insider" to be able to detect the visible impact of work performed by IPHE. It is certainly a challenge for the United States, as the new chair, to increase impact and visibility, perhaps by modifying the modus operandi or even proposing new terms of reference and linking IPHE work to other international initiatives, such as Mission Innovation.
- The United States, specifically DOE, has been extremely forthcoming in presenting the results of its R&D investments and programs; it is not clear that other countries provide the general public with nearly the same level of information about results of their R&D investments.
- IPHE has definitely played key roles in promoting/implementing governmental policies. It is important to connect IPHE's activities with the Hydrogen Energy Ministerial Meeting in October.
- IPHE is too high level and limited because of political positioning during meetings. For example, in terms of the relationship between certain country interests, one will attempt with great difficulty to leave another out wherever possible. Thus, practical action items that can be committed to are necessary.
- Any work in the Safety, Codes and Standards sub-program, for example, that can contribute to harmonized regulations/standards is valuable.
- Regarding regulations, code and standards, safety aspects, and awareness-raising, the IPHE could support coordination among international actors and eventually support market acceleration and acceptance.
- DOE could ensure and facilitate an efficient exchange of global knowledge related to technology cost and performance, economically promising use cases, technical standards, and any other enablers.
- DOE's help is needed to communicate and translate success across different regions.
- International collaboration is of high importance. Nations are at difference stages in different areas, and all can help one another.
- Technology sharing in both directions—from and to the United States—should be emphasized.
- It is important to organize safety and regulation by international information exchange.

14. 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. If you do not have a response, please select 'Not Applicable.'

Comments:

- The prize approach is useful as one of a variety of strategies to encourage innovation in achieving Program goals. It is of high value to have a continued focus on driving down the cost of dispensing infrastructure.
- The prize for achievement is a good approach for recognizing key accomplishments and progress.
- It is recommended that the prize be focused on affordable renewable hydrogen production.
- A hydrogen prize for the application of PEMFCs in ocean-going ships is suggested.
- Prizes motivate many people.
- Perhaps there should be an H2@Scale Technology Transfer Award to recognize the successful commercialization of key technologies/use cases. Automakers have achieved this for FCEVs (with the introduction of production models), and big oil/station developers are on track with HRSs, yet other puzzle pieces remain (implementing economically favorable hydrogen feed-in to natural gas, grid integration, etc.).
- Hopefully, prizes help advance technology, although there is a bit of skepticism.
- Although this approach was good for spurring innovation in technologies that might have niche applications, industry was not entirely focused. The total market potential for the H2Refuel prize-winning technology is currently unclear; therefore, it is unclear whether the H-Prize program is an effective means of bringing technology to a market that was perhaps otherwise neglected. If further prize-based competitions are to be developed in the future, they should focus on solutions that (1) appear to need primarily engineering innovation rather than more basic science innovation and (2) meet a near-term gap in the available commercial products.
- This reviewer is against prizes, in particular if demonstrations have to be realized to earn a prize. Indeed, this means that project teams need a strong treasury to pay for the demonstration, and the funds may not be recovered if the team is not awarded. Such an approach is acceptable for industry but not for research entities. It may lead to favoring "rich" organizations, whereas good ideas can come from all.
- The concept of prizes is discouraged, as it has the ability to become too political.

15. Please comment on the overall strengths and weakness of the Hydrogen and Fuel Cells Program and its portfolio of projects. Please provide strengths and weaknesses for each sub-program as appropriate. On which technology areas should the Hydrogen and Fuel Cells Program put more or less focus for future activities? If you do not have a response, please select 'Not Applicable.'

Comments:

- The Program benefits from active review of progress being made, for example, at AMRs. There is a strong commitment to national laboratories, with many laboratories having projects that continue for decades. It is recommended that national laboratories have their projects competitively bid with other non-national-laboratory projects. Some of the most important technology, fuel cell, and electrochemical breakthroughs have come from industry, e.g., Nafion® and high-surface-area PGM catalysts, dimensionally stable electrodes, high-temperature electrochemistry, etc.

- For sub-program areas investing in R&D to explore liquefaction as a potential cost-reduction strategy for hydrogen production, delivery, and/or storage, it would be helpful also to analyze the energy and environmental impacts of liquefaction. If the process is energy-intensive, it could affect the well-to-wheels emissions of hydrogen and reduce the expected benefits relative to fossil fuels.
- FCTO's work has been great in terms of successfully establishing the best portfolio of projects with cost-targeting, including early-stage R&D and H2@Scale.
- The H2@Scale initiative is welcomed. The integration of market acceleration projects in this initiative could bring benefits.
- All areas within the Program are strong.
- The Program has been largely effective at advancing fuel cell and hydrogen technology toward the requirements identified in the Technology Roadmap, and the Program deserves great credit for this. However, within this success, the Fuel Cell R&D sub-program (specifically research on improving cell durability and other metrics) seems to need a new approach to continue providing meaningful advancements. The sub-program has recently adopted part of the consortium approach, and hopefully, this will usher in some progress that has not been present in that sub-program in recent years; however, if this, too, remains slow, a deeper restructuring may be needed. For future activities, H2@Scale and associated hydrogen production projects and activities should remain a priority for FCTO. In addition, safety, codes and standards work, especially work that helps address on-the-ground needs for improved science to inform standards and enable more widespread hydrogen fuel adoption, should remain a priority.
- Infrastructure R&D (identified as a FY 2019 priority) should be guided to some degree by the systems analysis work, in particular, the careful evaluation of regional markets and demand sectors in order to identify key stakeholders and region-specific infrastructure needs. Therefore, it is concerning to see the Systems Analysis line item reduced to $1 million for FY 2019 (from $3 million in FY 2018). Otherwise, the increased focus on infrastructure is potentially exciting, as long as it is scoped with substantial input from key private-sector enablers (e.g., oil majors, industrial gas handlers, potential demand sectors).
- In general, the sub-programs are addressing valuable topics. However, there are many subjects in total, so it might be worth prioritizing them to improve the overall focus (perhaps more resources on fewer high-priority projects). Also, a key strength of the overall Program is the test methods and test facilities that have been put into place. A focus is recommended on leveraging the use of those methods/facilities by other projects and by industry.
- The Program is well structured and coordinated. Its main strength is the evolution toward more basic research (TRL≤3). This is a real opportunity to prepare for the future through scientific and technological breakthroughs. However, this could also result in a weakness if having fewer demonstration projects decreases the connection with the industry (to which these findings are helpful).
- The reviewer's priority for adding faster adoption is to focus on hydrogen production delivery and distribution as a primary need. A secondary priority is continued investment in longer-term technology for stack components and higher-volume manufacturing strategies.
- Increased focus and budget are recommended on high-temperature electrolysis and energy storage using solid-oxide-based technologies.
- Fossil energy should have less focus. Instead, the focus needs to be on renewable and carbon-free energy that can help reduce climate-changing emissions.
- The research from the Fuel Cell R&D sub-program was fairly weak this year. The DOE laboratories were all in lockstep, pondering a single theory of oxygen resistance in electrodes. While the laboratories might feel that they are stronger united, it is not clear that they have latched onto the right theory and instead gave the appearance of groupthink, which is not conducive to cutting-edge research. The recognition that the accelerated stress tests mandated by DOE do not replicate the degradation of PtCo catalysts in the 2017 Toyota Mirai was quite a revelation. It is apparent (and noted by a speaker) that Toyota used the controls to meet performance goals. It might make more sense for the laboratories to report materials properties so that

all controls engineers can design around the materials properties. Instead, the laboratories are more focused on materials discovery. It seems that a focus on materials properties might be more productive overall.

16. Do you have any other comments or suggestions to improve the overall effectiveness of the Hydrogen and Fuel Cells Program or any of its specific sub-programs? If you do not have a response, please select 'Not Applicable.'

Comments:

- Overall, this is a very good program with excellent researchers and management.
- The work of FCTO and its sub-programs is extremely valuable and is helping to push hydrogen and fuel cells, especially in transportation, to successful commercial reality. Current Administration policy aside, the Program may need to start thinking about how to be most effective in a market and technology transition phase, rather than a market launch phase, within the next 5–10 years. Otherwise, the Program may risk having limited ability to remain as effective as it is today. Therefore, the current Administration's restrictions on the type of research conducted by the Program should also be reversed, such that the Program managers can most effectively tailor the projects to evolving stakeholder needs rather than an arbitrary limitation.
- There are no general suggestions. Instead, there is a comment regarding a detail of the AMR organization, which could improve the overall reviewing methodology: there was often not enough time available for reviewers to ask questions. It is recognized that a compromise is requested between many different boundary conditions, but often, the reviewers were not in the perfect position to assess a project because they could not ask some critical questions. It is proposed that those reviewers directly belonging to the FCTO team (thus having other occasions for understanding the projects) refrain from asking questions, or do so after the "external" reviewers (who have only a few minutes to understand a complex project) are finished.
- An increase in participation from the manufacturing industry as suppliers to the fuel cell industry is recommended. It is also important to balance funding between cell stack R&D and BOP R&D.
- There should be collaboration with FE on hydrogen production from coal and methane.
- The Program needs to have more focus on materials properties and less on materials discovery.