Program Comments Provided by Reviewers

Hydrogen Production & Delivery Program Comments

1. Was the program, including overall strategy, adequately covered?

- The program was covered thoroughly, including hydrogen cost status and targets; and the research, development, and development (RD&D) strategies and framework, which addressed the leveraging of resources among stakeholders. The production of renewable hydrogen and delivery of hydrogen was shown to have been analyzed from a techno-economic perspective. Lastly, several advances in research and development (R&D) were presented, e.g., on platinum-group-metal (PGM)-free anion-exchange membrane (AEM) electrolysis, magnetocalorics in hydrogen liquefaction, low-carbon hydrogen production, and joint efforts between the U.S. Department of Energy (DOE) and National Science Foundation (NSF) on photoelectrochemical (PEC) and solar thermochemical (STCH) production.
- This program was very well described by the presenter. The technical challenges, the barriers to implementation, the very broad range of technical approaches that are involved, etc. were very clearly and concisely presented. This appears to be an excellent program, well managed and well executed.
- The strategy of the Hydrogen Production and Delivery program was clearly presented and very well defined. It has a very clear focus on what the near- and long-term challenges are and a very strong and balanced portfolio and excellent resources to address these challenges.
- Yes, the roadmap provided a good overview, and it indicated how far technologies are from commercialization based on technology readiness levels (TRLs).
- Relevant topics seem to be covered.
- Yes.

2. Is there an appropriate balance between near-, mid-, and long-term research and development?

- One of the strongest attributes of the Hydrogen Production and Delivery program is its clearly defined portfolio to address the near- and long-term challenges. For the production projects, there is an excellent portfolio to cover the durability and efficiency challenges to enable hydrogen production from renewable sources. For the delivery projects, there is a very strong portfolio to address the near-term challenges on the infrastructure needs, which includes reliability improvements and cost reduction of hydrogen refueling station components. For the long-term challenges, the program is strongly focused on key areas: liquid hydrogen technologies, advanced compression options, and issues on pipeline transport.
- The many short-term R&D needs in areas such as fueling stations, delivery hoses, codes and standards, sensors, and systems analysis were well balanced against a longer-term portfolio of hydrogen production approaches and more medium-term issues, such as renewables integration and reforming. This area by its nature must contain a very broad array of timeframes and technical approaches, but it remains a well-balanced portfolio.
- The program has a balanced R&D portfolio, both on hydrogen production and hydrogen delivery vis-à-vis near- and long-term objectives. This balance can be seen clearly on slide 9. In fact, the program should be commended for the thoughtful distribution of resources, e.g., on electrolysis, PEC, and STCH.
- Yes, there is reasonable balance within the Hydrogen Production and Delivery program, although it is clear most of the hydrogen production effort is long-term since renewable hydrogen approaches are still at an early TRL of development; hydrogen delivery and dispensing technologies are relatively near-term.
    - That said, given that renewable and affordable hydrogen is a cornerstone to the ultimate success for fuel cell electric vehicle (FCEV) commercialization, there seems to be a big and clear gap in effort level and budget allocated to hydrogen production research compared to other sub-programs, including those in the Vehicle Technologies Office. In light of this, the 16% budget reduction requested for 2017 for the program is even more puzzling.
    - The program ought to advocate for proportionally bigger effort for renewable hydrogen production R&D, either for accelerating incremental improvements or for advancing breakthrough developments. Short of that, the sub-program's stated goals of developing renewable hydrogen will seem shallow.

- Yes. However, it is not clear how the FCEV original equipment manufacturer 700 bar path chosen at a global level affects choices made for R&D in different timeframes.
- There are more projects on mid- and long-term R&D. Although two of the high-priority items are reducing costs of FCEV refueling stations and renewable production pathways, there do not appear to be any industry-driven projects to do so, e.g., industrialization of polymer electrolyte membrane (PEM)-electrolysis or refueling station technology development.

3. Were important issues and challenges identified?

- The program management clearly addressed the main issues and challenges, and evidence of this is the broad portfolio for both the production and delivery areas to address the key areas to enable low-cost clean hydrogen production and delivery to meet Fuel Cell Technologies Office (FCTO) cost targets.
- Issues related to renewable hydrogen production and hydrogen delivery and dispensing costs were clearly delineated. The various steps from analysis to stakeholder input to R&D portfolio and related priorities and targets were all presented in a lucid way.
- Yes, in addition to cost, the many diverse technical challenges across this broad portfolio were addressed.
- Yes, meeting the cost targets was an important challenge.
- The nationwide rollout in the United States in an important issue. It is not clear what the achievements of H_2USA are so far.
- Yes, only it is not clear how the 700 bar path affects R&D (i.e., creates issues and challenges).

4. Are plans identified for addressing issues and challenges?

- Yes, both near- and long-term issues and strategies are identified. The near-term plans are primarily focused on hydrogen delivery, while the long-term plans are focused on renewable hydrogen production. However, although not explicitly stated, fossil-based hydrogen sources are assumed for near-term plans.
- A techno-economic analysis of delivery and production costs was presented, and the various cost-influencing parameters were assessed and accounted for. Plans for RD&D were stated on the strategy slide (slide 8) along with the national laboratory support framework.
- The plans were clearly identified as presented on the Applied RD&D Portfolio Development slide.
- In general, the program and its projects are well focused on addressing the key technical challenges.
- Yes, by focusing on funding in different areas, the plans address the issues and challenges.
- Although two of the high-priority items are reducing cost of FCEV refueling stations and renewable production pathways, there do not appear to be any industry-driven projects to do so, e.g., industrialization of PEM electrolysis or refueling station technology development. Slide 7 does not show any industry RD&D.

5. Was progress clearly benchmarked against the previous year?

- There is excellent progress and accomplishments in both production and delivery areas. Some of the main highlights include the Hydrogen Station Equipment Performance (HySTEP) device, the world's first demonstration of gas liquefaction using magnetocaloric materials, the demonstration of PGM-free AEM electrolysis, and the significant progress on PEC and STCH pathways, which are key enablers for renewable hydrogen production.
- A number of advances were presented, such as hydrogen production for bio-gas and fuel cells operating in electrolysis mode. For instance, in the case of fermentation and microbial electrolysis cell (MEC) production, a rate of increase greater than 85% was reported in comparison to 2015. A similar percentage increase was reported in the case of liquefaction through magnetocalorics. Most important, there was the example of the cascading pressure receiver by Sandia National Laboratories (SNL) reactor (CPR2) whereby the concept was moved to demonstration in one year.
- All FCTO sub-programs are very well benchmarked against prior years. This program is no different.
- Yes, hydrogen cost per kilogram and accomplishments of different projects (liquefaction, non-PGM electrolyzer stable operation, H2 Refuel H-Prize, HyStEP, etc.) were clearly benchmarked.
- Although implied, the benchmarking of accomplishment timing was not clear. It was hard to tell what was done this year or last year.

- No, the presentation does not give a benchmark to last year.

6. Are the projects in this technology area addressing the broad problems and barriers that the Fuel Cell Technologies Office (FCTO) is trying to solve?

- Yes, they are, and the projects are addressing the problems in a balanced way among the alternative technologies. An example is the ultra-high-current, high-temperature solid oxide electrolysis cells and stack. The operation moved from the cell stage to the stack stage.
- The program is dedicating significant efforts and resources to overcome some of the main barriers of the FCTO, which include the cost reduction of hydrogen refueling station components and advancing renewable hydrogen production.
- Yes, the broad problems and barriers are definitely being addressed.
- Yes, they are, especially considering the overall limited funding.
- Yes, this is clear from the projects and the program overview.
- There do not appear to be industry R&D projects that address the high-priority items.

7. Does the program appear to be focused, well-managed, and effective in addressing FCTO's needs?

- This program is very well managed and has quite a large management team that is commensurate with the breadth and diversity of the project areas. This appears to result in uniformly good projects that are addressing the key specific challenges they are resolved to solve.
- The key to the success of this program is mainly attributed to the outstanding management and the team around it.
- Yes, and the program should eventually focus on two or three renewable paths for further RD&D activities. The available analysis results should enable this.
- Given the resources, the program is well managed. However, the allocated budget for hydrogen production projects is insufficient to meet the long-term objectives of securing large-scale renewable hydrogen for less than $2/kg.
- Yes (two responses).

8. What are the key strengths and weaknesses of the projects in this program? Do any of the projects stand out on either end of the spectrum?

- The projects on the positive end of the spectrum are the magnetocaloric liquefaction project (Pacific Northwest National Laboratory), non-PGM stable operation project (Proton Onsite), and the reformer/electrolyzer/purifier project (Fuel Cell Energy). No projects are on the negative end of spectrum.
- A key strength is the balanced portfolio on production and delivery involving short- and long-term efforts. The SNL STCH and hydrogen materials compatibility efforts do stand out and constitute assets for the program. Lack of fundamental science seems to be a weakness. Good engineering sets the device parameters in concert, but fundamental science, such as surface chemistry and catalysis, is the way to achieve order-of-magnitude increases in efficiency.
- The strengths of the program are the management and supporting team, clear focus on the main challenges, approach to address these challenges, and excellent interaction with external stakeholders, both domestic and international.
- A key strength is the diversity of approaches being actively managed and rebalanced.
- A very in-depth analysis is being performed as a strong basis for deriving RD&D priorities, but it is not clear that these results are appropriately shared with industry.
  The program has its strength in the quality of its short-term projects, while its long-term projects are generally weak and less focused.

9. Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?

- The program is definitely taking an innovative approach on some of the projects to include significant efforts on materials research for renewable hydrogen production, advanced compression technologies, advanced hydrogen liquefaction technologies, and the ongoing efforts on the HydroGEN initiative.
- Renewable hydrogen is key to the hydrogen-powered society, and the program addresses this challenge through both mid-term (electrolysis, biomass pathways) and long-term solutions (PEC, STCH). The program is similarly well balanced in its strategies for overcoming the delivery barriers.
- Yes, there appear to be innovative approaches in the solar thermal area as far as reactor design. It is too soon to determine whether these innovations will pan out, but there are multiple examples of newly innovative R&D ongoing across the program.
- Yes, for the most part the projects represent novel and/or innovative approaches.
- Yes.

10. Has the program engaged appropriate partners?

- Yes, the program has a wide range of collaboration among academia, national laboratories, and industry. Both the hydrogen production and hydrogen delivery technical teams in the U.S. DRIVE Partnership have decent representation from industry. In addition, the program has regular collaboration and workshops with other U.S. DRIVE technical teams, such as the Fuel Pathways Integration Tech Team and the Hydrogen Storage Tech Team.
- The program has impressive collaborative projects among national laboratories and interagency interactions, e.g., a joint funding approach with NSF.
- The program is receiving significant feedback from industry partners and international stakeholders in addition to excellent intra- and inter-agency collaborations.
- Without a doubt, the hallmark of all FCTO programs is collaboration and teaming with the right partners. This program is no different.
- It is questionable whether the industry link is appropriate. It is not clear whether all relevant players are present in H_2USA and U.S. DRIVE. It is not clear whether industry is really doing its job or whether it relies on laboratories.
- Yes.

11. Is the program collaborating with them effectively?

- Collaboration is outstanding.
- Yes, especially with the other hydrogen technology teams.
- Yes, it appears so from the overview of collaborations.
- This could not be determined from the presentation. Apparently, collaboration details could not be given because of time limitations.

12. Are there any gaps in the portfolio for this technology area?

- If there are gaps, they are gaps in how the portfolio is balanced, but this is a moving target, and funding opportunity announcements tend to make the "right balance," whatever that is, ebb and flow. Hence, the gaps in the portfolio are being adequately managed.
- It is not clear how fundamental science is integrated in the program. Apart from the reference to joint funding with NSF on slide 18, the university community's contributions to the program were not referenced.
- The cost trajectories for renewable hydrogen for the last few years appear to be flat and stalled. Perhaps this is a sign to look for breakthrough technologies.
- There is a gap regarding the effects of global choice for 700 bar for light-duty FCEVs.

13. Are there topics that are not being adequately addressed?

- The effect of hydrogen quality requirements on production cost per kilogram of hydrogen is not being adequately addressed. Inclusion of the right-of-way cost for hydrogen pipeline implementation in urban areas is also not addressed.
- Perhaps the program should address fundamental science to support engineering.
- The program is very robust and well managed, and it is extremely focused on addressing the main challenges and barriers.

14. Are there other areas that this program should consider funding to meet overall programmatic goals?

- Larger-capacity renewable hydrogen production projects (beyond 100–200 kg/day) at 500–1,000 kg/day with inclusion of delivery method (not large-scale, such as the capacity of conventional centralized steam methane reforming) should be considered.
- Perhaps the program should consider compressors. It is not clear what the state is of this important component of refueling stations.

15. Can you recommend new ways to approach the barriers addressed by this program?

- A key issue in the area of hydrogen delivery and infrastructure (e.g., materials for compressor technology) is hydrogen-accelerated fatigue of metals and alloys. SNL is successfully driving the codes and standards efforts, but fatigue is an issue that is still unresolved. Further, there are no mitigation strategies, and fatigue could be responsible for potential failure scenarios in the future. A joint program with NSF or DOE/Basic Energy Sciences is indicated.
- The program should expand the H2 Refuel H-Prize award funding to stimulate market players to think out of the box and do something when funded—also because Advanced Research Projects Agency–Energy (ARPA-E) does not cover hydrogen production very well. The project should more closely explore and assess companies and projects that are funded internationally in the European Union and Japan in topical areas of production and delivery.
- The program should have more industry-driven RD&D projects.
- The program should explicitly declare that it will be impossible to meet the DOE production targets with renewable hydrogen for many years. That way, policymakers will be well informed about the dependence on fossil hydrogen for the near term and the need for more investment to make renewable hydrogen affordable.

16. Are there any other suggestions to improve the effectiveness of this program?

- The program should include the university community on fundamental science issues, e.g., in the area of fatigue or the areas of surface science and catalysis for hydrogen production. In summary, the program manager has done an excellent job in shaping the program into one that steadily advances toward the targets with an optimum allocation of resources serving short- and long-term goals.
- The program should provide clearer definitions for “short term,” “medium term,” and “long term.” Approximating timeframe helps with perspective, e.g., short term is 2020, medium term is 2030, and long term is 2050 (with the understanding that uncertainty increases in the longer term). The program should improve the productivity of international collaborations by exchanging information or setting up shared projects at a lower level (actual RD&D level), not only at a high overview level.
- This program needs to make a strong case that the upstream challenges associated with renewable hydrogen production are very significant and that much more upfront investment will be needed to meet the desired cost and other targets.

Hydrogen Storage Program Comments

1. Was the program, including overall strategy, adequately covered?

- In 2016, this program continues to focus on achieving improvements in the storage of hydrogen for onboard automotive applications. The overall strategy is to address a range of short-to-long-term technical strategies to achieve improvements in cost, capacity, balance-of-plant issues (mass, weight, and cost), and overall energy efficiency, among others. The short-term strategy to reduce costs for physical storage of hydrogen at high pressure within tanks focuses on reducing the cost and mass of the carbon fiber structural reinforcements, whereas the longer-term strategy continues to focus on materials-based research and development (R&D) to develop lower-pressure, higher-capacity systems relative to storage in tanks. The sub-program's R&D portfolio adequately reflected the various emphases on storage approaches and short-to-longer-term strategies for achieving U.S. Department of Energy (DOE) storage system targets. A new piece of the overall strategy was introduced this year, that being the Hydrogen Materials–Advanced Research Consortium (HyMARC), which takes advantage of all the prior learning from the three previous materials centers and the engineering center, and asks the appropriate questions about how to solve the extremely difficult materials storage problem. This approach has some risk associated with it, but the benefits could be large.
- The program has addressed the shortcomings in existing storage solutions and has devised strategies for attacking them. The slide showing the current status of technology was clear and concise. The program has addressed the shortcomings in existing storage solutions and has devised strategies for attacking them.
- Yes, a spectrum of activities is well covered in the program: compressed gas, materials-based hydrides and sorbents, and fundamental research and analysis. They include near-to-long-term activities. Support organizations include national laboratories, universities, industry, and other government agencies.
- Yes, the Hydrogen Storage program was explained very well in terms of overall strategy and highlights from the portfolio.
- The program was well covered.

2. Is there an appropriate balance between near-, mid-, and long-term research and development?

- The balance between shorter-term R&D that addresses physical storage of hydrogen in tanks and approaches to achieving overall cost and mass reductions of physical storage is well balanced with other medium-to-longer-term strategies that are addressing the very difficult problem of materials-based hydrogen storage.
- Yes, compressed gas is near-term, storage materials are mid-to-long-term, and fundamental research efforts (HyMARC) are aimed at improving the progress in long-term materials development.
- Yes, the hydrogen storage portfolio appears to have a good mix of near-, mid-, and long-term research.
- There still seems to be more emphasis on short-term developments; however, compared to previous years, there are improvements regarding increasing emphasis on long-term research (i.e., the HyMARC launch).
- The long-term approach seems to be focused on materials-based storage. Perhaps there should be more long-term efforts addressing physical storage. It is not clear whether cryo-compressed is mid-term or long-term. Materials-based storage research continues to disappoint, yet it is receiving the lion's share of funding. Given the lack of promising results, it is not clear whether the emphasis on materials storage needs to be scaled back. It seems like the research is being driven more by the talents and capabilities of the national laboratories than by the experimental results.

3. Were important issues and challenges identified?

- This program continues to be very focused on addressing all of the key barriers to successful implementation of viable onboard hydrogen storage systems.
- Yes, the program has clear numerical targets for weight, volume, temperature, cost, etc. Most important, there are different targets for onboard light vehicle storage, materials-handling equipment, portable power, and stationary storage.
- Yes, the critical barriers were explained along with the strategy.

- Challenges were identified and briefly explained.
- Yes, continued focus on carbon fiber costs is an example.

4. Are plans identified for addressing issues and challenges?

- Plans for addressing the challenges for hydrogen storage going forward were well described. The new HyMARC approach to materials-based storage is relatively new and in its formative stages. Challenges there are numerous, both organizationally and technically, to develop this very computational-centric approach into a productive enterprise.
- The program has put in place several plans to tackle the challenges associated with short- and long-term R&D.
- Most of the barriers are being addressed, although it would be helpful to provide a clear linkage or matrix that identifies the projects in the portfolio and their focus on a certain barrier. This matrix may identify some challenges that are not currently being addressed in the current portfolio.
- Yes.

5. Was progress clearly benchmarked against the previous year?

- This program continues to do an excellent job of benchmarking progress among its various R&D efforts and also indicating technical areas where more progress needs to occur.
- There was clear benchmarking for appropriate projects. Yes, PAN/MA and glass fiber accomplishments were clearly described, but it would have been nice to have seen the potential impact of those developments on tank costs. More information on prototype systems would have been useful. It is not clear whether the systems met the predicted performance.
- Yes, selected advances made during the last year were listed.
- The progress of each project was highlighted, although the progression of reducing the gaps was not specifically identified from the previous year. It would be useful to identify the progression of some key targets (e.g., cost) or indicate the theoretical potential for advancement with the progress of projects in the portfolio.
- Developments have been explained for this year; however, the progresses were not clearly benchmarked compared to the previous year.

6. Are the projects in this technology area addressing the broad problems and barriers that the Fuel Cell Technologies Office (FCTO) is trying to solve?

- Yes, the projects address the barriers quite closely in most cases. The creation of extensive basic science activities under the new national-laboratory-based HyMARC is especially welcome to provide future ammunition to attack the formidable FCTO storage barriers.
- Yes, the Hydrogen Storage program is an important enabler for addressing the broad problems and barriers that the FCTO is trying to solve.
- The projects appropriately addressed the barriers of the FCTO.
- This program of the FCTO continues to select and fund projects that have promise to address the technical challenges of hydrogen storage for onboard automotive applications. There are a few projects that are in need of some direction either because of technical challenges or because they are very new to working in this particularly target-focused R&D environment.

7. Does the program appear to be focused, well-managed, and effective in addressing FCTO's needs?

- Yes, the Hydrogen Storage program is very well managed. The program managers provide exceptional leadership for a broad portfolio of projects in the pursuit of advancing hydrogen storage for fuel cell electric vehicles. They ensure the research is relevant and focused on the needs of industry.
- The program is well focused, well managed, and continues to be viewed as a world-leading force in hydrogen storage technology.

- Over the years, the program has zeroed in on the critical issues for physical storage and has developed projects to address them.
- The program is well managed and effective.
- Yes.

8. What are the key strengths and weaknesses of the projects in this program? Do any of the projects stand out on either end of the spectrum?

- The sub-program's real strength is the way it has built on its previous experience and identified critical issues, and then developed clearly targeted projects to address them.
- Key strengths of the projects are that most are well focused on the key barriers and largely have logical approaches to addressing the challenges. The "analysis" projects are always very informative and help the R&D community as well as DOE to better focus its resources. The Lawrence Livermore National Laboratory project in magnesium borohydride is quite well focused. Areas that are lagging include the laboratory-led effort in alane and two relatively new projects at Ames and Caltech. Otherwise, projects are uniformly moving forward with approaches that are reasonable in achieving their technical goals.
- The strengths of this program are the diverse spectrum of technologies that would be difficult for industry to develop in a comprehensive manner. The weakness of the projects in this program is the lack of commercialization. There should be a greater emphasis on developing technologies that have partners with the intent of implementing the technology in products.
- The key strength is the variety of storage approaches being taken, from conceptually simple compressed gas to more esoteric chemical, hydride, and physisorption materials. The key weakness is the present state of the art in storage materials that makes meeting quantitative storage goals very difficult, if not impossible.
- No projects stand out on either end of the spectrum.

9. Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?

- There is novelty in the conformable tanks project; the new computational focus in HyMARC, while difficult, would be considered very innovative if successful. Time will tell. There is new and innovative work in the characterization efforts, and the newer results from Lawrence Berkeley National Laboratory on adsorbing greater than one hydrogen per metal site is very innovative chemistry; its impact on storage is to be determined.
- Yes, most of the projects are novel ideas with a good balance between risk and rewards.
- Yes, in general the projects represent novel approaches. Some seem practically very complex and unlikely to succeed commercially.
- It was difficult to discern how innovative the approaches are, since there was not a lot of detail on the project approaches in the overview presentation.

10. Has the program engaged appropriate partners?

- There are an extraordinary number of good partners within national laboratories, universities, industry, consultancies, and other government agencies.
- This program continues to demonstrate the value of cross-project collaboration to move the field of hydrogen storage forward; this is what makes the DOE Hydrogen and Fuel Cells Program (the Program) recognized as the world-leading program. This is largely because the management of the Program has always rewarded excellent collaboration, and the participants have risen to the challenge.
- The program has encouraged and enabled collaboration among national laboratories.
- Yes, the program has engaged the key researchers and industry partners to advance the technology. A recommendation is to develop further partners with a focus on commercialization. The program has recently increased the involvement of national laboratories without a strong engagement of implementation partners.
- Appropriate partners are engaged.

11. Is the program collaborating with them effectively?

- There appears to be a continuing high level of communication and collaboration with the program management and the technical community involved in storage.
- Yes, the program is effectively collaborating with partners in the development of hydrogen storage systems. The program managers encourage and facilitate collaboration within the program.
- The program is collaborating effectively with the partners.
- Yes, program collaboration clearly is effective.
- The number of consortia in the program may be growing too fast.

12. Are there any gaps in the portfolio for this technology area?

- No, there are no gaps now that HyMARC has been established to address some critical fundamental science in storage materials.
- There are no gaps in the portfolio of the program.
- Most of the work seems focused on short- or long-range. More mid-term work might be appropriate.
- Yes, there are some gaps in the portfolio for this technology area. This could be apparent with a cross-comparison of the technology barriers and the project portfolio. An example is the fact that the materials cost for the materials-based storage is not being considered in the efforts.

13. Are there topics that are not being adequately addressed?

- While some topics may be underrepresented or overrepresented from time to time, this is a function of how often and how large funding opportunity announcements (FOAs) are that allow technical gaps to be smoothed over time. The program now appears to have a good long-term trajectory to be able to respond to new opportunity areas and to rebalance if necessary.
- There appear to be none.
- Much of the work in production and delivery points to liquid delivery as a more viable option than gaseous delivery. Strategies such as cold-compressed or cryo-compressed need more emphasis.
- Yes, there should be a greater emphasis on the strategic approach of these various storage technologies in terms of system cost analysis and the value proposition to the customer along with the infrastructure modifications required to support the various technologies.
- The new materials effort, HyMARC, was not adequately addressed. It was unclear how the consortium would leverage the R&D of hydrogen storage materials beyond what has been already done before, i.e., a materials center of excellence and independent projects.

14. Are there other areas that this program should consider funding to meet overall programmatic goals?

- This is a good, comprehensive program to address the key challenges in onboard hydrogen storage.
- The program should consider novel materials systems for hydrogen storage.
  There should perhaps be more work on low-cost, large-scale stationary storage that will be needed for the newly proposed “Hydrogen at Scale” project.
- The program should consider funding strategic studies regarding the value equations for certain technologies to consider the viability in order to focus resources on the potential options with the probability of achieving a commercial product.

15. Can you recommend new ways to approach the barriers addressed by this program?

- The approach of studying all of the hydrogen storage technologies may need to be reconsidered based on an understanding of the quantified gaps and key enablers for certain storage approaches and then a focus on the technologies with the viable path to reduce the gaps. The program should start developing a set of filters based on the reverse engineering results from the Hydrogen Storage Engineering Center of Excellence (HSECoE) and Argonne National Laboratory (ANL).
- There should be more funding for physical storage because it seems to be the default option at this point. Reduce efforts on materials-based storage until a promising approach emerges.
- No.

16. Are there any other suggestions to improve the effectiveness of this program?

- One suggestion would be to include/attract more new materials concepts leveraged by the HyMARC analytical and computational abilities.
- One characteristic of the overall effort that has changed is that there are far fewer R&D members who come from chemical sciences backgrounds, and so the community that used to bring a good deal of chemical expertise and intuition has eroded over the last several years. For the materials-based approaches, bond-forming and bond-breaking events are required in the final analysis, and this being the domain of chemical scientists, there could be a net benefit to the enduring program to re-engage with more reaction chemists to bring some of that expertise and intuition in reacting materials back into the program.
- Coordination among the many HyMARC partners and associates is very important for the effort to succeed without significant overlap and duplications of effort. Congress and many other stakeholders will be critically watching this expensive new consortium, much like the observations made of the recently ended HSECoE. Dissemination of the results of HyMARC to the next generation of scientists and engineers who must reach the goals and targets of the FCTO Multi-Year Research, Development, and Demonstration Plan is of primary importance.
- The HyMARC and Characterization and Validation Team initiatives to study the fundamentals are useful, although their effort is not very well aligned with the barriers. Also, the fundamentals have been studied in the past, and the HyMARC team should emphasize the novel aspects of its approach. The results from the HSECoE and ANL regarding the reverse engineering for the required materials properties to meet the system targets should be utilized and highlighted in all of the projects related to materials-based storage. This work was important and does not seem to be acknowledged within the program for directing the future work of HyMARC and the Characterization and Validation Team along with other projects in the portfolio.

Fuel Cells Program Comments

1. Was the program, including overall strategy, adequately covered?

- The program was defined clearly, and the overall strategy for the objectives was covered in sufficient detail.
- Yes, the strategy was well covered, and the use of other sub-programs' analyses to guide priorities for this program is a notable highlight.
- The program and overall research strategy were adequately covered. The research approach to address the barriers of cost, durability, and performance has been adequately discussed.
- Yes, it was adequately covered in combination with the FCTO Office Director's talk that filled in the broader context.
- The overview covered all salient aspects.
- The program presentation described the overall strategy. However, the strategy is currently unclear. The efforts should focus on solving known problems. It looks like the broad vision and corresponding strategy are not well established or thought through.

2. Is there an appropriate balance between near-, mid-, and long-term research and development?

- Yes, particularly when additional fuel-cell-related programs under the Office of Basic Energy Sciences (BES), Advanced Research Projects Agency–Energy (ARPA-E), and the Vehicle Technologies Office are taken into account. The Office of Energy Efficiency and Renewable Energy (EERE) covers a very useful range of pre-competitive research and development, from early-stage catalyst development at the milligram scale to demonstrations with complete fuel cells. Even the most fundamental of EERE projects has a tighter focus on the requirements of practical fuel cell technologies than do fuel cell-related projects funded by other agencies. BES projects pursue fundamental knowledge that could advance the field but are unlikely to affect the next generation of technology development. ARPA-E pursues fringe ideas that have a low probability of working in a practical context but that arguably could cause a major disruption of the field if successful. Taken as a whole, the U.S. Department of Energy (DOE) properly covers a broad spectrum of fuel-cell-related activities. EERE occupies the sweet spot in the center, with enough innovations to stimulate change and enough attention to technical realities that developments within the EERE have a good probability of being adopted by fuel cell developers, thereby stimulating the U.S. economy.
- There is appropriate balance between near- and mid-term goals discussed in the Fuel Cell Technologies Office (FCTO) Multi-Year Research, Development, and Demonstration Plan. Long-term development may ultimately be fleet-vehicle, or consumer-vehicle, driven. It is not clear at this stage how fuel cell electric vehicles (FCEVs) will transition from test markets to broader use once cost and durability have been addressed.
- The full gamut was addressed.
- Yes.
- The funded projects seem to be oscillating from immediate (e.g., low-cost compressor) to long-term (non-platinum-group-metal [non-PGM] catalysts) every few years. The stability of approach and clarity of vision is critical for long-term success of fuel cell development in the United States. Further, the area of focus between ARPA-E and FCTO is unclear (both are funding anion-exchange membrane research).
- There seems to be a large focus on the long term. It does not appear that current solutions being investigated will materialize into cost savings (even incremental ones) in the near term. There does seem to be a good deal of movement in getting infrastructure together to potentially result in more near-term benefits (such as the many consortia), but it was not clear what near-term gains were expected.

3. Were important issues and challenges identified?

- Yes, cost and durability are well known in industry to be the main issues, and the program has significant focus in these areas.
- Yes, the primary remaining challenges of cost and durability were properly identified and set into context.
- The challenges and issues regarding the stack cost and durability were identified, and the key focus areas were addressed clearly.
- The issues with the development of fuel cell power systems for transportation have been clearly identified. Durability and cost to address distributed generation/combined heat and power fuel cell systems have been identified to a lesser degree. Issues for fuel cell development in the transportation area may be more difficult to address. Cost and durability have been identified as the issues for fuel cell development, and PGM catalysts are still the issue.
- Important issues and challenges are partly identified. Some of the DOE-highlighted issues (e.g., stability of cathode catalyst support) have been solved by the industry. However, DOE may be unaware of these developments.

4. Are plans identified for addressing issues and challenges?

- The program addressed well-organized plans with collective and effective approaches for the challenges.
- Yes, plans have been identified to address cost and durability. The Fuel Cell Consortium for Performance and Durability (FC-PAD) is a strong collaboration that will meet these goals.
- Reasonable plans have been put forward. The new consortium-based method of funding activities of the national laboratories and drawing connections between outside projects and the laboratories should prove superior to the previous procedure of having the laboratories and outside organizations compete for funding within the same call, with only outside organizations able to provide the required cost share. However, it will take a while for the consortia and their interactions with outside projects to settle in. Great care and effort will be required to maximize the productivity of the new arrangement, and trying to implement a number of new consortia in the same year increases the danger that only pro forma, rather than truly effective, interactions will develop between the laboratories and between the laboratories and the outside partners. The deliverables for the laboratory-call projects should include accounting of activities with the consortia and outside partners, lest the outside work be neglected in comparison to the activities within the individual laboratory-call projects.
- On the cost side, yes. Multiple avenues for addressing cost were presented (although the focus is weak). However, plans to address durability were not as clear, especially for polymer electrolyte membrane fuel cells (PEMFCs). Accomplishments and projects in durability for other fuel cell types were presented, but PEMFCs still seemed relatively unaddressed.
- Yes.
- Plans are only partially complete. It looks like some of the projects were kicked off without much thought into how a single new technology (e.g., nanostructured thin film [NSTF]) will fit into the overall picture and how this will address the primary issues and challenges hindering the commercialization of fuel cells.

5. Was progress clearly benchmarked against the previous year?

- Yes, the progress was clear and comprehensively covered.
- Progress was clearly benchmarked to a great extent.
- Progress in the area of cost has been adequately benchmarked over several years. It is a bit difficult to assess whether catalysts, membranes, gas diffusion media, membrane electrode assembly (MEA) fabrication techniques, or testing are responsible for the cost reductions shown. FC-PAD may address this issue by providing a common evaluation methodology.
- Progress against past performance was properly benchmarked, albeit not generally against the previous year. The field is now sufficiently mature that one should not expect large numerical changes in metrics over one year, but progress is evident over spans of approximately five years. However, examples of individual advancements within the past year were properly highlighted.
- On cost, progress seemed to be benchmarked, but not on durability.

- The cost progress has stalled for the last five years (~$55/kW), and the durability has not progressed much since the 2014 review. Therefore, it is not clear what has been accomplished by the projects funded through this initiative. While many new catalysts are being invented and tested, none of these has made any significant impact on the power density (cost) or improved the durability of the overall fuel cell system.

6. Are the projects in this technology area addressing the broad problems and barriers that the Fuel Cell Technologies Office (FCTO) is trying to solve?

- The projects in this technology area are addressing the problems and barriers that the FCTO is trying to solve. The projects are focused, correctly, on cost and durability. However, catalyst supports other than NSTF require more research.
- Yes, the work is going to be necessary to support the widespread adoption of FCEVs.
- The current portfolio of projects seems to be a mixture of long-term objectives and many Small Business Innovation Research initiatives and development initiatives focused on addressing key challenges. On paper, it looks like there are too many initiatives and not enough focus on solving the biggest challenge.
- Yes (three responses).

7. Does the program appear to be focused, well-managed, and effective in addressing FCTO's needs?

- The Fuel Cells program is focused, well managed, and effective in identifying and addressing the FCTO's needs (2 responses).
- The program was well managed, and meaningful progress was achieved. The program effectively addressed the important needs of the FCTO.
- The program is well orchestrated.
- This appears to be the major weakness of the program. There seems to be a lack of focus. Given that this is the closest of the sub-programs to basic science, a certain degree of broad research base can be reasonably expected. However, it seems that the overall program lacks focus even with this consideration. Projects seem to overlap in their overall goals and do not sufficiently explain why they may all be necessary together as a suite of initiatives. One clear example from this year's Annual Merit Review was alkaline. In the overview, it was mentioned that long-term targets likely require elimination of platinum and that alkaline was being pursued in this regard. However, neither the program nor the individual alkaline presentations discussed why alkaline in particular was pursued or why certain technologies within the program were pursued. Clearer expression of the promise of alkaline toward both achieving the long-term target (the primary goal) and removing platinum (the secondary goal, which is really only one possible means of achieving the primary goal) needs to be provided. Otherwise, the program does seem well managed and effective. Many important improvements have come out of the program, but as mentioned by a commenter in the audience, it does appear that a new program structure may be necessary to increase focus on technologies that will really help build on past progress and break the stagnation that seems apparent (e.g., reductions in cost that are now flatlining).

8. What are the key strengths and weaknesses of the projects in this program? Do any of the projects stand out on either end of the spectrum?

- The strength of this program includes nicely organized and managed projects with excellent collaboration efforts among the leading national laboratories.
- The work that has begun to look into consistent evaluation of the durability of fuel cells in various applications is a particularly valuable effort. This project bridges some of the more exploratory work that must be done in the laboratories with the eventual market concerns. Evaluations like these may be expanded to help bring focus to the program. Additionally, the consortia efforts stand out as having potential for powerful transformation of the technology. The opportunity in these projects simply needs to be capitalized and perhaps more thoroughly discussed in the future.
- The key strength in the Fuel Cells program is in starting collaborations such as FC-PAD. It would be good if a program such as ElectroCat (the Electrocatalysis Consortium) could be similarly developed with

the suggestion of collaborative work being focused to single-year awards with a possibility of a second-year follow-on.

- There were three major strengths: (1) the strong pursuit of and progress toward well-chosen targets developed in consultation with DOE strategists and industry experts; (2) new relationships between laboratory consortia and outside projects that could significantly improve productivity of all projects if enthusiastically pursued by all parties; and (3) EERE projects that often include synergistic collaborations among fuel cell developers, established suppliers, academia, and national laboratories. Such vertical integration limits myopia and fosters eventual commercialization of developments based on DOE funding. There were three major weaknesses: (1) some fuel cell developers are still overly reluctant to share true state-of-the-art data and details of specific technical challenges with DOE; (2) the recent increase in emphasis on alkaline membrane fuel cells may be misguided; and (3) non-PMG catalyst projects still place too much emphasis on oxygen reduction reaction kinetic activity and not enough on improving transport properties through the much thicker catalyst layers needed for non-Pt systems.
- The focus of the program needs to be improved. Also, regarding achievement of targets/goals, every year the achievement of fuel cell performance targets comes with the caveat that these achievements are not all met by the same technology all at once. This method of counting accomplishments is not ultimately of high value. For practical application, all of the targets will need to be met at the same time by an individual technology. Perhaps focus can be gained not only by presenting the separated target achievements but also by evaluating technology potential by looking at performance versus the full suite of targets for a given technology.

9. Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?

- The projects represent a wisely chosen spectrum between innovative projects still far from application (e.g., non-carbon supports or fancy structured catalysts) and incremental improvements to previously studied systems.
- Yes, the projects do investigate novel ideas, especially for catalyst development. However, the program overall perhaps needs to think differently about its approach and use new principles to guide its focus.
- Yes, within the funding available (2 responses).
- Many novel ideas seem to be stuck in technology readiness level three (ex situ testing). There is no clear path for moving these ideas to an in situ fuel cell environment and solving the high current density performance issues to meet 2020 cost and durability targets simultaneously.
- The projects discussed do not represent novel/innovative ways to approach the technology barriers of cost and durability. The projects discussed are evolutionary in nature. This issue may be addressed in the ElectroCat program.

10. Has the program engaged appropriate partners?

- The Fuel Cells program has engaged the appropriate partners to address the various issues identified for the broad commercialization of fuel cell technologies.
- The program engages in extensive, worldwide collaboration.
- Yes, there is significant coordination among many of the stakeholders in the area.
- Yes, although fuel cell developers and materials suppliers need to be more open in sharing details with DOE to make progress more efficient. More should be done to foster precious-metal-catalyst development and manufacturing by U.S.-based companies. Foreign ownership of all major suppliers of precious metal catalysts should be investigated as a possible national security issue.
- Yes (two responses).

11. Is the program collaborating with them effectively?

- Yes, it appears the collaborations are well suited to the individual projects.
- A good example of effective collaboration is FC-PAD. FC-PAD is a good platform for collaboration between many stakeholders and investigators.
- Yes (two responses).

- Yes, though the fuel cell developers need to be more open with DOE, particularly about technology status. Catalyst suppliers need to be more open to unrestricted analysis of their materials. Because process, not composition, is usually the basis for competition in the catalyst world, open analysis should not generally compromise any company's competitive position.
- Partially.

12. Are there any gaps in the portfolio for this technology area?

- None within the funding allowed.
- There do not appear to be significant gaps in the research.
- Not particularly.
- There are few gaps in the Fuel Cells program portfolio.
- Experienced catalyst manufacturers should be recruited to attempt development and scale-up of advanced catalyst types out of the national laboratories. Scale-up efforts at the national laboratories have proceeded slowly. For non-Pt catalysts, insufficient attention has been given to engineering thick (~100 micron) electrode layers with adequate transport properties. This needs to be looked at, perhaps initially using very low-loaded Pt on derivatized carbon supports that are structurally similar to pyrolyzed non-Pt catalysts. If effective thick electrodes turn out to be an engineering impossibility, then the substantial effort in improving activity and durability in non-Pt catalysts is wasted.

13. Are there topics that are not being adequately addressed?

- No (two responses).
- This may be more appropriate in another program area, but it seems that there needs to be a risk/cost assessment performed for research ideas being pursued that would require significant change in direction for industry. For example, in moving from PEMFC on vehicles to alkaline, it is not clear whether stranded assets (or other economic risks) could result from such a large shift in technology onboard the vehicles. It is also not clear whether such a risk could affect the market; some automobile manufacturers may see current technology as too unsettled and therefore are waiting for more optimal/proven/viable technologies to become apparent and avoid the possibility of being stuck with stranded assets.
- There are two topics that may not be adequately addressed. The first is MEA fabrication with catalyst supports other than NSTF. There have been durability questions with NSTF-based catalysts for many years; the pathway for these being addressed is not clear. Perhaps more work that addresses membrane degradation directly or additives that address membrane degradation can be future topics. There is funding for the membrane work; it was included in the package, but it was not adequately addressed.
- Greater attention should be given in all of the projects to the implications of the local oxygen transport effects that limit the performance of low-Pt-loaded fuel cells at high current density. These limit the utility of catalysts with very high Pt-area-specific oxygen reduction activities unless the Pt-mass-specific Pt surface areas are reasonably high (above about 30 m^2/g). This issue, unless it can be solved by something like a new ionomer for use within catalyst layers, forces a reprioritization between approaches to lowering Pt loadings on fuel cell cathodes from those that give high area-specific activities to those that give high Pt-mass-specific surface areas. Certain specific projects are addressing local oxygen transport, but awareness of the implications of the effect does not seem to have permeated through to the planning within all of the projects.

14. Are there other areas that this program should consider funding to meet overall programmatic goals?

- There is an increasing focus on contaminants in the hydrogen supply from infrastructure currently being installed. Industry response has been to focus on quickly detecting and addressing impurities at the supply side. Another approach is to look into fuel cell impurity tolerance. There has been some focus on this in the past, and it may be worth considering adding more focus on this area again. In particular, this would be most helpful if it resulted in near-term developments.
- The recent requirement that all multiyear projects be completely funded upfront within the budget year in which they are initiated has led to the frequent issuing of more tightly focused funding opportunity

announcements (FOAs), with very few projects being funded from each FOA. For example, catalyst projects have been funded one year, and MEA integration projects have been funded another year. Unfortunately, making substantial progress on the status of fuel cell development requires coordination between catalyst development and MEA integration. Good proposals can be rejected because they do not fit the topic restrictions of the current FOA. Therefore, the current funding procedures, while likely making the accounting more transparent, distort the technical projects from what would be planned for optimal technical effectiveness. Extreme care must go into the long-term planning of a multiyear series of FOAs if significant distortion of the program is to be avoided, and some activities that are unrelated to a given year's FOA topic should be tolerated.

- No.

15. Can you recommend new ways to approach the barriers addressed by this program?

- This program needs a clear vision of what the step-out ideas need to be and a well-balanced portfolio that works toward the long-term vision while supporting the industry and developers to achieve near-term cost and durability goals.
- A program like FC-PAD that allows for one-year contracts with a one-year follow-on based on performance review could help address technology development barriers in the Fuel Cells program. In this (1+1) model, research would be evaluated at a program review, and continuation (funding for the second year) will be assessed. If a project does not make it to the second year, others would be given an opportunity to contribute.
- Reconsider the assignment of so many resources to alkaline membrane fuel cells. Yes, they make it easier to replace Pt on the cathode, but then one faces significant challenges in getting adequate hydrogen oxidation activity on the anode without significant use of precious metals. The performance of OH-conducting membranes still falls short of requirements for transportation applications. An explicit effort to engineer thick (100-micron) electrode layers with adequate transport properties is necessary to see whether continued non-Pt-catalyst development is warranted. One could start with a very low-loaded Pt catalyst.

16. Are there any other suggestions to improve the effectiveness of this program?

- Establish clear go/no-go criteria based on state-of-the-art MEAs; if any project is unable to meet the majority of the performance benchmarks of state-of-the-art MEAs, there is not much value in trying to make progress on this one focus area if other objectives are being moved negatively (e.g., metal oxide support for cathode catalyst improves stability at the cost of high Pt loading).
- Do not waste effort on high-throughput synthesis of non-Pt catalysts, whose success or failure is a matter of proper processing, not of a particular composition. Instead, focus on the engineering of transport-effective thick electrodes. As with most funding agencies, it seems difficult for new applicants to break in and get a project approved. Many of the new projects are essentially extensions of previous projects, recast to fit the requirements of the current FOA. Some of this is good, as one does not want to throw away experience and demonstrated project performance. However, two changes might be productive:
    - Push for ambitious go/no-go criteria and shut down projects that do not fulfill the criteria. It is difficult administratively to shut down a project, but doing so occasionally should stimulate the remaining projects to higher performance and would clear the way for new applicants.
    - Consider setting aside a portion of each year's appropriation to support smaller projects (likely in a separate call), with particular encouragement given to new applicants. This could help get more academic activity back into the EERE mix, thereby fulfilling the goal of training the future technical workforce. Perhaps BES already fulfills this role, and EERE should just get involved in the evaluation of fuel-cell-related BES projects (if it is not already).

Manufacturing R&D Program Comments

1. Was the program, including overall strategy, adequately covered?

- Yes, the strategy was clear on how to address identified barriers within the broader framework of goals and objectives.
- Yes, the presentation comprehensively presented the problems, strategies for work, and outcomes.
- Having a single manufacturing program for very different technologies, ranging from fuel cell membranes to pipelines, makes gaining a clear focus difficult. The small budget also hampers progress.
- Yes (two responses).

2. Is there an appropriate balance between near-, mid-, and long-term research and development?

- Yes. In particular, it was encouraging to hear about the exchanges with industry for some of the defect-detection technologies. The engagement with manufacturers and eye toward technology transfer is important and was well addressed to keep the near-term focus that is necessary in this program.
- Because of the nature of manufacturing, the program has a short-term focus, which is appropriate for this program.
- The main focus appears to be on near-term research and development (R&D) to serve long-term manufacturing goals (production at the scale of 500,000 units).
- Yes (two responses).

3. Were important issues and challenges identified?

- The program has identified several critical issues for manufacturing and is addressing them appropriately, given the funding available. If more funds were available for the area, the work could be expanded, but the program has chosen appropriate challenges.
- Yes. However, if there is more significant demand from original equipment manufacturers (OEMs) and/or polymer electrolyte membrane (PEM) fuel cell manufacturers for fuel cell material/component products, the areas of “quality control in production” and “supply chain maturity and U.S. opportunities” can be expected to improved rather rapidly—unless this has been established outside of the United States (but this was not made clear).
- Yes. However, some of these projects have been focusing on similar challenges in manufacturing during the past couple of years. The program likely needs to start expanding to tackle other issues. As a prime example, compressor manufacturing should be investigated (especially the highest-pressure compressors at fueling stations) to determine what role, if any, manufacturing may have in the high rate of downtime as demonstrated by the National Fuel Cell Technology Evaluation Center (NFCTEC) project.
- Yes (two responses).

4. Are plans identified for addressing issues and challenges?

- Yes, the translation of program goals to actionable projects and efforts was well presented.
- Yes (four responses).

5. Was progress clearly benchmarked against the previous year?

- This was briefly presented in some of the project presentations, but in general, the program overviews do not address this question well, as was the case here.
- Comparison to the previous year could have been better.
- No. However, this could be understood from reviewing the 2015 presentation and comparing it to the 2016 accomplishments.
- Yes (two responses).

6. Are the projects in this technology area addressing the broad problems and barriers that the Fuel Cell Technologies Office (FCTO) is trying to solve?

- Yes, the potentials for cost reduction and growing scale of deployment of fuel cells address key barriers. Also, the supply chain technical exchange project will be valuable not only for developers but also for other stakeholders who may be looking to assess the technology from a regulatory or economic analysis perspective.
- Largely, yes. Some of the efforts represent benefits that will likely not materialize in the near term but could materially reduce costs.
- The broad problems and barriers were mostly addressed. However, pipeline material manufacturing research is challenging to justify because it is not clear whether there is a good understanding of the barriers and challenges of implementing more hydrogen pipelines in the United States (this includes the cost of pipeline right of way).
- Yes (two responses).

7. Does the program appear to be focused, well-managed, and effective in addressing FCTO's needs?

- Yes. Given funding limits, the program is well directed and focused.
- Yes (four responses).

8. What are the key strengths and weaknesses of the projects in this program? Do any of the projects stand out on either end of the spectrum?

- The program strengths seem to lie in the innovative developments that come out of the program as products/ deliverables. The weakness is the limited scope in some sense (increasing the number of fuel cell components and station components will need to be introduced into the program). The really strong projects seem to be the technical exchange centers and the quality control (QC) diagnostics. None of the particular projects is weak.
- The National Renewable Energy Laboratory's efforts related to QC methodologies have been a strong project for some years. The other current projects are higher-level assessments and development of supply chains that have the potential to lead to measureable improvements.
- A strength is the use of appropriate funding instruments, e.g., Small Business Innovation Research (SBIR) and funding opportunity announcements, to address relevant issues.
- A weakness is possibly that major membrane electrode assembly (MEA) manufacturers, such as Johnson Matthey, do not appear to be directly involved with the MEA QC project.

9. Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?

- Yes, there are examples of first-of-their-kind efforts among the sub-program's projects.
- Yes, the Mainstream SBIR Technology Transfer Opportunity project represents a novel approach. Others, such as assessments and facilitated networking of industry suppliers, are not novel, but they are necessary and good for addressing barriers.
- It does not seem that they are highly novel or innovative.
- Yes.

10. Has the program engaged appropriate partners?

- It appears to have engaged appropriate partners. However, involvement of larger industry players may be beneficial.
- Yes, the program has engaged partners quite extensively. This should continue, especially for the technical exchange.
- There is good work with OEMs and Tier 1 suppliers. The regional technical exchange center collaboration work is yielding valuable information.
- Yes, the projects generally have good collaborators from industry to academia.

11. Is the program collaborating with them effectively?

- Yes, cross-cutting activities provide good leverage for existing funding.
- Yes (three responses).

12. Are there any gaps in the portfolio for this technology area?

- With the available funding budget for this topic area, it appears properly addressed.
- There are not any significant gaps at this time. The program is in a bit of a transition, and current higher-level projects should identify more discrete future efforts.
- Type 3 and Type 4 fully overwrapped storage tubes need to be used in ground storage applications for hydrogen fueling station use.
- QC of manufacturing is generally a focus of the program, but the projects so far are limited to a single component of fuel cells. This focus needs to be expanded to other fuel cell components and station components. On the station side in particular, there may be an opportunity to help identify issues that are affecting stations today.
- Yes, but insufficient funds are available to address them.

13. Are there topics that are not being adequately addressed?

- Gaps are being addressed adequately with available funds.
- There may be opportunities in QC inspection methods of steel vessels for stationary hydrogen storage.
- Type 3 and Type 4 fully overwrapped storage tubes need to be used in ground storage applications for HFS use.
- This is potentially a cross-cutting effort, but it seems that there should be some risk/economic analysis on the manufacturing side for situations in which equipment providers "switch" to a new or future technology. For example, if alkaline becomes predominant instead of PEM in vehicles, or cryocompressed or solid-phase hydrogen storage becomes predominant, it is not clear what potential manufacturing equipment, lessons, and other investments could be leveraged in the transition to these proposed future technologies. It is not clear what the potential for stranded assets is, especially because the market may scale significantly before some of these future options become commercially viable.
- No.

14. Are there other areas that this program should consider funding to meet overall programmatic goals?

- The program should consider investigating composite hydrogen tank wrapping methods (manufacturing) to determine whether this can be sped up while delivering the same quality. The current manufacturing speed (tank/unit of time) does not align with mass volume production of cars (10,000 fuel cell electric vehicles [FCEVs]/year is about 30 FCEVs/day, requiring ~60 composite tanks/day, and 100,000 FCEVs/year is about 300 FCEVs/day, requiring ~600 composite tanks/day).
- Type 3 and Type 4 fully overwrapped storage tubes need to be used in ground storage applications for HFS use.
- Yes, assuming that they are not addressed in other sub-programs.
- No, no other areas should be considered at the moment.
- No.

15. Can you recommend new ways to approach the barriers addressed by this program?

- It is recommended that the program assess state-of-the-art manufacturing capabilities and quality assurance methods in Europe, Japan, and China and assess (in addition to specific methods) what other quality assurance processes play an important role to warrant product quality of supplied product over the years.
- For reducing costs, it may be worthwhile to have not just a supply chain exchange but also a lessons learned or best practices exchange, at least to the extent that manufacturers are willing to participate.

Development of something like “best practice guides” for manufacturing various components may catalyze expansion and new entries into the component and equipment supplier markets, which could bring costs down through competition.

- No.

16. Are there any other suggestions to improve the effectiveness of this program?

- Given its funding, the program is functioning effectively.
- It is recommended that the program assess FCTO projects in other sub-programs (such as the Hydrogen Production and Delivery program) in which manufacturing is part of the project and finding solutions for manufacturing issues is part of the project scope. Some of the solutions found or paths taken to find solutions could be beneficial for Manufacturing R&D program projects (cross-pollination of expertise).
- No (two responses).

Technology Validation Program Comments

1. Was the program, including overall strategy, adequately covered?

- Yes, the program was adequately covered with identification of the project areas, emphasis, verification, and risk mitigation.
- Yes, there was a clear discussion and slide for the strategy of the Technology Validation Program.
- Yes, the program was well covered.
- Yes (two responses).
- The objectives are reasonable but should be more inclusive of the technologies being tested. For instance, it is not clear what the objectives of testing cryogenic vessels and high-pressure liquid hydrogen (LH2) pumps are. It is not clear what the goals are. The strategy overall is adequate, but the program was not adequately covered during the presentation. During the poster session, it was observed that there are more projects under this program than were presented during the program overview.

2. Is there an appropriate balance between near-, mid-, and long-term research and development?

- The presentation provided a clear set of objectives (targets) for the near-, mid-, and long-term goals and objectives. The balance was demonstrated by comparing several of the slides that identified accomplishments and new projects.
- Yes, there seems to be good communication with the laboratories to ensure that after technology is verified at the laboratory scale, it evolves into the technology validation area before moving to market transformation. The projects adequately cover technologies that range from near- to long-term.
- Yes, the program seems to have a major focus on near-to-mid-term projects. The longer-term electrolyzer grid integration project provided a good balance for the portfolio of projects.
- Generally yes, the program is balanced with identification of laboratory analysis and measures for risk management.
- Yes (two responses).

3. Were important issues and challenges identified?

- Yes.
- Generally yes, the important issues/challenges were identified with project selection, metering/ measurement, and reporting. Many of the other presentations supported the overview.
- Important issues and challenges were identified, though the specifications for some areas seem like they need to be updated. In particular, the hydrogen station goals appear to address too narrow of a subset of the specifications that are being established or determined right now by stations being put in place in the United States and around the world. Necessary specifications such as back-to-back-fill sequencing and timing and simultaneous fueling capability are all issues that need to be addressed, and this program could help validate these more advanced capabilities of station equipment. Additionally, the targets that are set (capacity and fueling rate) need to be updated. The target for 2019 is already met or nearly already met by stations being built today. The targets for the program need to look to the next generation of stations and be set appropriately.
- The presentation focused on accomplishments and failed to mention issues for each of the projects. The individual project presentations did mention challenges. It would be informative to list challenges on the slides of the program assessment.
- There did not appear to be a chart identifying specific challenges; however, under the accomplishment charts, there were targets given that were assumed to be challenges for the projects.
- No, the issues/challenges were not identified in the presentation.

4. Are plans identified for addressing issues and challenges?

- Yes, the Request for Information issued by the Fuel Cell Technologies Office for truck targets is a particular example of a necessary and well-designed step for addressing an upcoming and urgent challenge.
- Range, efficiency, and operation were all appropriately identified for refueling. The connection with grid modernization, grid simulation, and energy storage is of value, but the connection was not fully assessed for actions and remedies.
- Data collection appears to be the approach for addressing the issues and challenges, combined with working closely with industry.
- Challenges were not identified in the main presentation, but individual project presentations did mention challenges in most cases and how they are being addressed.
- Some issues/challenges need help.
- No.

5. Was progress clearly benchmarked against the previous year?

- Yes.
- Yes, sufficient detail was available for the light-duty fuel cell electric vehicles (FCEVs), fuel cell electric buses (FCEBs), and fuel cell electric trucks (FCETs).
- Data collection and analysis for both FCEVs and FCEBs were presented for 2015 and 2016. While it was clear which parameters improved, it would have been informative to get additional information about the challenges that resulted in lower-than-expected performance and the plan to bridge the gaps between the current number and the target. The differences between 2015 and 2016 were explained during the project presentation (FCEV Data Collecting and Analysis slide), as was the cost difference between fuel cell vehicles, compressed natural gas, and diesel vehicles. This cost comparison slide should also have been included in the main presentation to provide a more complete picture of the status of the technologies. For the United Parcel Service (UPS) vans project, it is unclear what the progress was between 2015 and 2016. For the performance validation and contaminant detection project, it was unclear when the project started and whether any data have been collected from compressor manufacturers. The progress of other projects not presented during the program overview was explained during other sessions.
- Progress was not fully benchmarked, but the goals were adequate to show the intent and intended progress. Other presentations supported the U.S. Department of Energy (DOE) directive to benchmark progress.
- This was not very clear from the program overview presentation, but it was included in some of the individual project presentations.
- No.

6. Are the projects in this technology area addressing the broad problems and barriers that the Fuel Cell Technologies Office (FCTO) is trying to solve?

- Yes.
- Yes, this program is critical to evolving technologies from the laboratory to the field and to demonstrating their feasibility at scale.
- The projects are collecting real-world data that will provide guidance for future developments to move FCEVs to commercialization.
- Yes, the project to address the ability of hydrogen to enable more renewable electricity was particularly good.
- Generally, yes, they are. There was one particular project that seemed like its applicability could be limited, though. The station equipment power and energy demand project appears to be built around a single station. There seems to be significant potential that any conclusions or lessons learned from that project will be highly specific to that station design or possibly even just that particular station. This project should keep an eye toward how its findings can be applied broadly once the project is complete.
- Yes, but an improved connection between the vehicle refueling and grid modernization with energy storage would have been helpful.

7. Does the program appear to be focused, well-managed, and effective in addressing FCTO's needs?

- Yes (two responses).
- Yes, this program is addressing needs that are particularly well timed to ongoing developments, even outside of FCTO.
- Yes, both areas of the presentation were focused and well managed, but next steps should increase the connection between the refueling and grid storage topics.
- The focus is a little unclear, given that some of the technologies being tested do not fall within the objectives listed for 2019, 2021, and 2023. The projects do fall within the strategy, though. It is also unclear how some of the projects transition from the Technology Validation Program to the Market Transformation program; for instance, the UPS (Technology Validation program) and the FedEx (Market Transformation program) projects are very similar. The data analysis and reporting project is particularly strong and well underway to providing useful data.
- Yes, the program is focused on the very important transportation applications. The infrastructure development of a hydrogen station needs to be emphasized. It did not appear that DOE had access to the data developed by industry for the hydrogen stations used for forklift and backup power applications, although the reviewer believes DOE has this information.

8. What are the key strengths and weaknesses of the projects in this program? Do any of the projects stand out on either end of the spectrum?

- The data collection, management, and reporting projects of the program are a particular strength. Going forward, it would be helpful for the program to coordinate with its stakeholder "customers" for composite data products to ensure that the information being provided through the program is relevant to the stakeholders' needs. Some data presented have at times seemed like they would be more useful if expressed or provided in a different metric, visualization, etc. Gaining this feedback directly from stakeholders will maximize the impact of a program that is already highly effective and very necessary during today's rapid acceleration of fuel cell deployment. Hydrogen Station Equipment Performance (HyStEP) is another strength, especially for its collaborative nature and ability to help stakeholders solve problems right now. The generalizability of the power and energy use project is a little suspect. A similar concern exists for the Washington, D.C. station, as it is not clear how lessons learned from what may be a highly local set of circumstances (permitting agencies, etc.) could be easily translated for other stations in other regions. However, this is not as mission-critical as it is for the power and energy use project.
- Two good topics (FCEV hydrogen refueling and grid modernization with energy storage) with opportunity for coordination is an obvious strength. A weakness would be the lack of strategic coordination to connect these two strengths.
- Key strengths are large-scale grid storage and FCETs (to open up new markets such as the forklift truck market). A weakness is the continued development of onboard LH2 storage in passenger vehicles. (LH2 will continue to be a valuable pathway to transport hydrogen to the station, but as long as no original equipment manufacturer [OEM] is developing FCEVs that store LH2, it seems to be a poor use of taxpayer money to continue automotive onboard LH2 storage, since all OEMs have settled on 700 bar storage.)
- The strongest project right now is data collection and analysis for both FCEVs and FCEBs. The hydrogen-at-scale project is also very important, but not at its current scale; it is necessary to partner with a utility to scale up the project and produce hydrogen off-peak. There is great potential value in this application if integration challenges can be addressed, although the applications may be limited by geographical location (sources next to customers); ability to provide hydrogen to ensure availability in, for instance, hydrocracking units; long-term hydrogen contracts; and others. Developing targets for medium- and heavy-duty trucks is important, but it is unclear why that responsibility falls under this program.
- The key strength is the close collaboration with industry. The weakness is the long timeline for the development of FCEVs and FCEBs. Validation of the technology without a reduction in cost of the technology may not be beneficial.
- The National Renewable Energy Laboratory's project on hydrogen station data collection and analysis needs attention.

9. Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?

- Yes.
- Yes, HyStEP and the National Fuel Cell Technology Evaluation Center are examples of projects within this program that generated tools that simply did not exist and are proving their value to stakeholders.
- Yes, the notion to bring energy storage into grid operations with vehicles and vehicle fueling is not well accepted but would be of high value.
- They are not necessarily novel, but this is not the program where novelties are expected. New technologies are generated in the research and development (R&D) side and then tested in Technology Validation program. The approach is appropriate.
- Novel and innovative are not descriptors for this effort. Hard work, incremental improvements, and close collaboration with industry better describe these projects.
- Nothing particularly novel stands out.

10. Has the program engaged appropriate partners?

- Yes (three responses).
- Yes, the partners were identified in the presentation.
- For the most part, yes, but it would be good if the program brought in more international partners for data gathering and analysis and also for cryogenic hydrogen testing— BMW and Shell are doing a lot of work in this area. It was good to see during the poster session that there is a collaboration with Air Products and Chemicals, Inc. to test dispensing from tube trailers.
- Partners appear adequate, but additional feedback from utility partners, regulators, and transportation planners would be of value.

11. Is the program collaborating with them effectively?

- Yes (two responses).
- There appears to be good collaboration.
- Collaboration appears adequate, but additional collaboration between automakers, fuel providers, utility regulators, state transportation planners, and grid managers would be of value.
- Yes, collaboration is adequate.
- Mostly yes, although some need improvement.

12. Are there any gaps in the portfolio for this technology area?

- It is unclear why the Technology Validation program and Safety, Codes and Standards program are not working together on a cross-cutting project to address inline fuel quality testing at hydrogen stations. Combined with the work presented last year by Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST), it seems that such a cooperation could help accelerate the development and validation of sensor technology that is needed now but does not exist in a plug-and-play component.
- Correction or normalization of performance data from the buses as they age is a gap. This was, however, addressed in one of the project presentations.
- None are apparent (2 responses).
- There are no projects addressing stationary fuel cells. It is not clear whether there is any new R&D in this area that needs validation. Although a tube trailer refueling project is underway, that was not mentioned during the overall program presentation. Also, the hydrogen-at-scale project needs to be scaled up and tested at large scale in partnership with a utility.
- It is not clear how the cost of the fuel cell systems and the hydrogen stations fits in with Technology Validation.

13. Are there topics that are not being adequately addressed?

- No (three responses).

- More integration of cost numbers with the projects is needed.
- More precise goals are needed to coordinate topics for energy storage with both transportation and grid management.
- Several topics were not adequately addressed: (1) scaling up renewable energy power to hydrogen with added storage, (2) partnering with international stakeholders (e.g., Shell, BMW) to gather additional data on cryogenic hydrogen dispensing, and (3) comparing data gathered from domestic stations against data from Germany and Japan (aggregated).

14. Are there other areas that this program should consider funding to meet overall programmatic goals?

- No.
- The program addresses the important applications.
- The program may be able to help investigate the viability of co-locating medium-/heavy- and light-duty fueling at the same location. While there are a couple of examples existing, their designs were more one-offs, and lessons may not be generally applicable. It would helpful for the program to discern the special considerations of combining purposes and help determine whether there are sufficient gains to be had for either application and the extent to which similar components/designs/etc. could actually be used in one station to meet two needs. The benefit or penalty of increasing system complexity is also uncertain.
- Increased coordination with utility regulators for grid management and transportation planners that control transportation budgets should be considered.

15. Can you recommend new ways to approach the barriers addressed by this program?

- No (two responses).
- Better management review by some is recommended.
- The approach should address how technology validation and cost reduction interact.
- The program should increase coordination with state transportation officials and utility regulators, and with vehicle refueling, vehicle OEMs, and utilities.
- It would be good to remind the program manager of the importance of providing cost information on all of the projects.

16. Are there any other suggestions to improve the effectiveness of this program?

- Overall, the program is thoughtful and well managed. Increased coordination and collaboration among transportation fueling and grid stakeholders may produce valuable partnerships that connect transportation with energy storage and grid performance.
- It is not clear whether the program addresses distributed generation using solid oxide fuel cells. If it does not, it is not clear why.

Safety, Codes and Standards Program Comments

1. Was the program, including overall strategy, adequately covered?

- Yes, there was a good overview of the overall strategy with goals and objectives. It is clear that safety, codes and standards (SCS) enable introduction of hydrogen infrastructure and adoption of fuel cell electric vehicles (FCEVs).
- Yes, the strategy was presented well and made logical sense. The explicit inclusion of feedback to regulations, codes, and standards (RCS) is key and a highlight of the program.
- The program was clearly presented with a clear strategy of defining near-term and long-term objectives and efforts, and of how the research and development (R&D) approach will be an enabler to achieve the main goals of the U.S. Department of Energy (DOE) Hydrogen and Fuel Cells Program (the Program).
- Yes, there are many projects targeted at key areas and the broad barrier of "lack of data to inform development of performance-based codes and standards" to support vehicle/infrastructure deployment.
- The strategy is clear, well set, and thorough.
- Yes, thanks to the initial presentation that provided a general overview—although it had strong emphasis on only three out of five areas of activity, followed by several presentations devoted to the specific activities performed by projects—the SCS program seems to perform as planned, adequately covering the different activity areas proposed in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan: (1) safety management, (2) R&D, (3) test measurement protocols and methods, (4) development and harmonization of RCS, and (5) dissemination of data, safety knowledge, and information.

2. Is there an appropriate balance between near-, mid-, and long-term research and development?

- Yes, the near-to-mid-term focus of many of the projects in the program is appropriate. The needs in this area are very "boots-on-the-ground," and the program does a good job of developing projects that focus on this characteristic.
- The near- and long-term balance seems appropriate for this program. This can be can be seen through the fact that there are significant efforts on near-term activities, such as fuel quality and gaseous separation distances, and at the same time, the program is allocating significant resources to longer-term efforts, such as the ongoing efforts on liquid hydrogen activities.
- Yes, there is a combination of near-term testing with actual hardware (hydrogen sensors and pressure relief devices [PRDs]) and longer-term (materials compatibility) projects. All of these can provide good data for current specific code development and outreach/education work.
- Yes, the SCS program shows a balanced portfolio of activities with goals in the near, mid, and long terms.
- There was no unbalance between the different time spans of the program. The activities are multiannual, and the projects are integrated in the overarching strategy.
- It is not completely clear whether balance is needed, given the limited budget. There is sufficient balance as is.

3. Were important issues and challenges identified?

- Yes, many of the major challenges facing stations and fuel cell applications today are being addressed by the program.
- The program manager has clearly identified the main issues and challenges associated with hydrogen station rollout. This can be documented with the emphasis on some of the critical areas, such as fuel quality and station footprint, and by using a science-based approach to solve these.
- Yes, very good examples in PRD testing and material compatibly testing show potential problem areas with current industry approaches. The project will need to keep an eye on opportunities to get new/additional data and identify emerging risks/opportunities because both vehicle and infrastructure deployment are ramping up fast, so the project should get plenty of data.
- Yes, the activities within the program are inherently challenging by their own nature, but in the main, the challenges appear known and seem to be under control. Nevertheless, there are no references within the

information provided to potential new challenges that may appear or have already appeared during the course of the activities and the associated plans to address them.
- Yes.
- No.

4. Are plans identified for addressing issues and challenges?

- The program portfolio is very well-rounded with very clear objectives and a clear strategy for addressing the main challenges being identified. The science-based approach is definitely key to the success of this program.
- Most have identified plans. Several of the projects need to make sure that plans for future work are well/better focused on the mission of generating clear data to inform standards to support deployment.
- Yes (two responses).

5. Was progress clearly benchmarked against the previous year?

- Yes, this was well documented by the program manager on slide 12. The reviewer really wants to highlight the significant progress being made on the liquid hydrogen activities, such as the liquid hydrogen release behavior experiments. Other activities that demonstrate significant progress include the development of a prototype for in-line fuel quality monitoring, the release of the Hydrogen Risk Assessment Model (HyRAM), and the materials compatibility efforts.
- Yes, this was one program in which this was clearly covered in the program overview, and it was appreciated. A good deal has clearly been accomplished since the previous review.
- Yes, the progress is clearly shown in the R&D activities, but this could be extended to the rest of the activity areas.
- The progress shown, obviously incremental, was very convincing.
- Yes, this was done very clearly on slide 12.
- Generally yes, but the reviewer has not personally reviewed these projects before and therefore cannot make a direct comparison. However, in most cases, there is a clear account of deliverables/ accomplishments in the past year. It is not always as clear for multiyear projects whether the project is on track with the original plan in the long run, so some summary of the projects over their full lives might be helpful for ongoing projects.

6. Are the projects in this technology area addressing the broad problems and barriers that the Fuel Cell Technologies Office (FCTO) is trying to solve?

- Yes, without any doubt, the projects within the program are complementing the activities of the rest of the sub-programs within the FCTO, providing valuable information and knowledge to facilitate the deployment and commercialization of fuel cells and hydrogen technologies. The efforts to promote international collaboration, which strengthen the excellence of the Program while avoiding addressing issues that may already be addressed in other places in the international landscape, are commendable.
- Yes, the program is definitely addressing some of the main issues associated with initial rollout (fuel quality and footprint issues) as well as addressing the main long-term issues (mainly footprint) associated with liquid hydrogen stations.
- Yes, SCS program projects are clearly tied in to the need for enabling deployment in terms of generating data to inform code/standard work, education, and outreach.
- Yes, these projects are helping to ensure uptake of hydrogen and fuel cell technologies.
- This technology area is an enabler for the deployment of hydrogen technologies.
- Overall yes, but it is very focused on light-duty FCEVs. Expansion into medium- and heavy-duty FCEV technology application areas may be beneficial for newly supported FCTO areas of interest.

7. Does the program appear to be focused, well-managed, and effective in addressing FCTO's needs?

- One of the key aspects for the success of the program is the fact that the program manager and his team are very engaged with the scientific community, the main standardization bodies, and relevant hydrogen stakeholders, both domestic and international.
- Yes, the SCS program management shows professionalism and a high degree of competence.
- It is clear that there is a strong interface with the other technology areas, aiming at identifying and prioritizing all cross-cutting issues.
- Yes, the projects taken as a whole present some very good work on developing test facilities, test rigs, and testing procedures that will, in the future, support ongoing research and data gathering. The program should make sure each project has clearly focused goals/deliverables for future work.
- Yes (two responses).

8. What are the key strengths and weaknesses of the projects in this program? Do any of the projects stand out on either end of the spectrum?

- The strength of this program lies in its focus on addressing real-world barriers that need solutions today. Additionally, many of the outreach and safety efforts have been well maintained and continued over many years. It is essential to keep doing this, as the need for outreach and education across all the states is immense, and building the scalability of the market will require building very widespread acceptance of the technologies. The program should be encouraged to keep these efforts in place.
- In general, the projects have a very integrated approach, and projects are complementary and comprehensive. It is, however, difficult to understand the very complex national standardization system, and therefore a simplification of it is desired.
- The following work stands out at the positive end of the spectrum:
  - Polymer and materials compatibility work
  - Setback distances work
  - International collaboration
- The strengths include the nature of activities, balanced portfolio of activities, international collaboration, comprehensive coverage of safety-related issues, and multidisciplinary and competent partnerships. The weakness is that industry participation could be widened.
- The strengths are the program management, very strong scientific resources, and international collaboration. A weakness is that the program could benefit more with an increased budget.
- The key strength is that the projects mostly have key practical applications in advancing performance-based standards. A weakness is that the future work for some of the projects is not always clearly focused—it would help to try to define/prioritize future key work items with deliverables whenever possible.

9. Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?

- Yes, they do. New tools and devices have come out of the program that are not available anywhere else and that required innovative design and application of existing technology on a very limited timescale.
- This program is thinking out of the box compared to other sub-programs with regard to the extent of international collaboration.
- The science-based approach clearly demonstrates novel/innovative ways to approach the main barriers.
- Yes, the projects are of high quality and seem to address efficiently the identified barriers.
- Most of the projects are narrowly targeted (which is good in this case) on specific needed data, so it is not clear how much "novel and innovative" applies. The development of specific test apparatus and test methods was a strong point of these projects and could be classified as innovative in that perhaps similar tools/methods did not exist previously.
- Yes.

10. Has the program engaged appropriate partners?

- Yes, the program involves a variety of partners, which provides the perception that the challenges are being covered by an appropriate and well-balanced number of stakeholders from the private and public sector.
- This program is very integrated and complete, involving all national stakeholders and players. Also, internationally, it plays on all the tables deserving attention.
- The program manager and his team are very engaged with the scientific community, the main standardization bodies, and relevant hydrogen stakeholders, both domestic and international.
- The projects have generally engaged the national laboratories, industry partners, and codes and standards (C&S) groups in both the United States and internationally and received good support. It might be helpful to consider opportunities for more collaboration with academic institutions. There was not much reference to such partners, and it seems that the projects might be missing significant potential expertise and resources.
- Yes (two responses).

11. Is the program collaborating with them effectively?

- Yes, the program appears to be engaged effectively with the partners noted.
- There is no evidence that the program is not collaborating with them in an efficient and timely manner.
- Yes (four responses).

12. Are there any gaps in the portfolio for this technology area?

- There is no evidence of gaps or areas that are not being addressed appropriately. Perhaps additional initiatives focused on safety training devoted to the general public or at least to first consumers could reinforce the program.
- Perhaps, with an increased budget, more work could be done on refueling protocols.
- There are a few gaps: understanding of C&S adoption cycles and patterns in California and the Northeast, underground hydrogen storage assessment and footprint benefits, and safety standards for medium- and heavy-duty vehicles.
- No (three responses).

13. Are there topics that are not being adequately addressed?

- The projects the reviewer reviewed covered the subject topics well.
- Fueling protocols could be an area in which the program could allocate some resources.
- Non-proprietary medium- and heavy-duty hydrogen vehicle fueling protocol development is not being addressed.
- No (two responses).

14. Are there other areas that this program should consider funding to meet overall programmatic goals?

- The program should consider funding the assessment and development of safety standards for medium-and heavy-duty FCEVs and the transfer of lessons learned from natural gas.
- Perhaps initiatives focused on increasing the general public's acceptance and awareness of fuel cell and hydrogen technologies could be considered as a reinforcement of the outreach activities.
- International collaboration on standards development appears to be an area that is missing from the program. It is only recently developing, but as the conversation shifts to increasing volume, the need to capitalize on the potential worldwide nature of the market (especially on the fueling technology) is becoming even greater. There will likely soon be a need to evaluate and even attempt to reconcile various standards and best practices being developed by different organizations around the world. This is an area that seems like it would fit well with the sub-program's goals.

- In view of the increased interest in another part of the FCTO dedicated to power-to-gas issues, it is suggested that the possibly related safety aspects are taken into account.
- Work on hydrogen storage system materials/designs that can either allow original equipment manufacturers to package 5 kg in a vehicle at lower pressure than 700 bar or that would relax the Type IV tank constraints (temperature) that drive the refrigeration requirements of J2601 could provide major cost benefits in hydrogen fueling infrastructure. As an example, obtaining real-world data on tank temperature during/after fueling events (thousands of them, one hopes) would help understand how often -40°C precooling is really needed to complete a fast (<5-minute) fill.

15. Can you recommend new ways to approach the barriers addressed by this program?

- The project should support underground burial of a liquid hydrogen storage tank project to assess challenges of applying "business as usual" (of conventional fuel industry burying fuel tanks underground at gas stations) on hydrogen fuel.
- The lack of harmonized standards at an international level is still considered one of the main barriers for the commercialization of fuel cell and hydrogen technologies, and therefore, new ways to collaborate at an international level could be analyzed in order to avoid overlaps; to detect synergies and gaps; and to distribute, in an efficient and strategic manner, the efforts among the international actors, maximizing the overall progress in this area. The International Partnership for Hydrogen and Fuel Cells in the Economy Working Group on RCS is a good example, but perhaps there are other stakeholders that could contribute in this field. In line with the previous comment, a specific forum devoted to safety-related issues, such as the International Conference on Hydrogen Safety, could promote the safety culture among the diversity of stakeholders and provide guidance on next steps to be taken in this sense.

16. Are there any other suggestions to improve the effectiveness of this program?

- The program should call out specific areas that could be sped up to make progress toward goals/objectives faster and get results swifter with more funding. Some areas are bound by code adoption cycles, while others may not be. If R&D results are achieved faster, this may result in swifter adoption of revised/created C&S. The program should also hand off the "Hydrogen Tools App" to a volunteer entity that thinks it can benefit from using the application and continuing its use/availability in the market for business purposes.
- The international collaboration shall be a keystone for maximizing the impact of this program by finding synergies and gaps on the different activity areas.
- Given the highly localized nature of permitting projects such as hydrogen fueling stations, it is a little unclear just how widely applicable the permitting guidebook and video will turn out to be. The program should make an effort to reach out to those who have accessed the material and evaluate how effective the material was for their specific applications and needs. If gaps are identified, then there should be consideration of whether they can be addressed through further development of the guiding materials.
- The program should have an increased budget.
- It is not clear whether there are government agency/department counterparts to DOE in other countries that are/could be effectively engaged as collaborators and to compare work and results. In addition to possibly supporting harmonization of standards, it would be beneficial to avoid duplicate efforts.

Market Transformation Program Comments

1. Was the program, including overall strategy, adequately covered?

- Generally, yes, with a good summary of objectives, partnerships, and projects. Other reviews followed the theme(s) presented here with consistency.
- Yes, given the broad range of possible projects/topical areas, the projects covered a good sample. Participation in education/outreach support is an excellent tactic in support of the strategy of the Market Transformation program.
- Yes, the program and overall strategy were covered in detail and easily understood. The strategy was outlined with a statement of the objectives. New strategies were identified, but it was unclear how these strategies would be funded or implemented by the U.S. Department of Energy (DOE).
- Demonstrations and deployments were sufficiently covered. There did appear to be a good deal of analysis work that was not covered as well in the overview presentation.

2. Is there an appropriate balance between near-, mid-, and long-term research and development?

- There is a good balance of near-, mid-, and long-term research and development (R&D). The demonstrations of the airport cargo tractor fleet results were given (near term). The demonstration of maritime pier-side power was completed (near term). The FedEx project is under development. Analysis of the business case scenario for idle fuel cell lift trucks provides a mid-term peak shaving project. Business cases for a renewable hydrogen station in Hawaii and the site-specific technical economic analyses for Hawaii, Connecticut, Massachusetts, and New York look to the future for the long-term case. Educational seminars are a needed addition.
- Yes, the focus for the program seems to be appropriately weighted toward the near-to-mid-term. This should be maintained.
- Yes, this balance was generally described through the projects and challenges. Other presentations were consistent with the program overview and themes.
- Generally, yes, although at this point all of the auxiliary power unit, range extender, truck, aerospace, backup power, etc. applications seem to be near-term R&D. It is hoped that the H2-at-Scale focus will inform us of additional high-priority mid- and long-term opportunities.

3. Were important issues and challenges identified?

- Yes, important issues were discussed. In particular, the work shown on developing business cases for early market adoption will likely become increasingly important in the coming years. There should likely be some anticipation of developing the necessary programmatic infrastructure to continue to meet this growing need.
- Yes, particularly in the area of increasing/ensuring demand for fueling infrastructure by the addition of multiple applications, such as range extenders and airport equipment.
- The use of technology readiness levels (TRLs) provides a measurement of the status of the technology and identifies entry points for the technology. It is recommended that manufacturing readiness levels be included in the challenges.
- Yes. However, some of the challenges to identify targets and clusters with the existing and proposed budgets will be difficult to resolve. Other presentations generally followed the issues and challenges.

4. Are plans identified for addressing issues and challenges?

- Yes, in particular, the extensive collaboration with stakeholder working groups seems like it has been, and will continue to be, a valuable resource for the program to continue working on pertinent projects.
- Generally yes, but it would be good to see more detail for deliverables for the projects and any thoughts on future projects that support high-usage infrastructure and H2-at-Scale strategies.
- Yes, but the work will continue to be stretched thin because of budget constraints. Oversight, management, and measurement of individual projects by DOE will continue to be necessary.

- Testing of new technologies at user operating conditions provides a methodology for addressing the issues and challenges, but it was not clear how the testing referenced back to the TRLs.

5. Was progress clearly benchmarked against the previous year?

- Yes, although the key successes (materials handling and backup power), while certainly successful, happened a while ago now. It is good to see the progress/benefits of the Northeast outreach. It would be good to see more detail on what was learned and what might be recommended from the Federal FCEV Fleet Analysis.
- Targets, impacts, and analyses were identified. Explicit benchmarking from previous year(s) was not highlighted; however, such highlighting would have provided limited value. Other presentations provided appropriate benchmarking, indicating appropriate oversight by DOE with a goal for progress.
- The Market Transformation Deployments referenced the previous year's results and identified the increase in deployments for both lift trucks and backup power. The 2015–2016 deployments were done without DOE funding, although the bar charts contained DOE appropriations and combined DOE/industry data. The bar charts could be confusing, and it could be interpreted that funding was supplied by DOE during the current reporting period. Dates on the bar charts would have made the data clearer.
- This did not seem to be addressed in the overview presentation.

6. Are the projects in this technology area addressing the broad problems and barriers that the Fuel Cell Technologies Office (FCTO) is trying to solve?

- Yes, in particular, it is hoped that the range of applications that are being explored by the program will help to develop potential for deployment of fuel cells at large scale, bringing costs down.
- Yes, the projects are of high value and consistent with market needs and trends. Overall, the program successfully accomplishes its goals for market transformation. Other presentations generally followed the theme with consistency.
- Yes, in terms of increasing the number of commercial applications of fuel cells and in demonstrating examples of increased usage of infrastructure. It would be helpful to come up with ideas, maybe through a request for information, on how some of these projects could support gathering real-world data to inform codes and standards.
- Hydrogen stations are critical to implementing the current deployments and the future strategies. The cost of the hydrogen stations and the distribution of the hydrogen stations were not discussed in the charts.

7. Does the program appear to be focused, well-managed, and effective in addressing FCTO's needs?

- Yes, there is clear focus, but at the same time, the program is still innovative. This combination appears to make the program particularly effective.
- Generally, yes, the program appears focused with well-selected targets, intended partnerships, and analysis. Additional reporting regarding the outcomes for market penetration would have been helpful. Overall, the program, with consideration of other relevant presentations, was focused, well managed, and effective in addressing market and industry issues.
- Generally, yes, although it would be helpful to categorize the various projects under some major subheadings (such as Mobility and Renewable Hydrogen) and prioritize them to clarify how projects are chosen. In this area, there are several subheadings and hundreds of possible projects, so it would be good to tie projects back to higher-level enablers.
- The program appears to be well organized, and successful market transformation activities were identified.

8. What are the key strengths and weaknesses of the projects in this program? Do any of the projects stand out on either end of the spectrum?

- The great strength of the Market Transformation program projects is the partnerships with private industry. Technology validation under DOE guidance has established a high level of confidence in the future success of industry, which provides a basis for the Market Transformation program. The development of safety, codes and standards is a significant benefit that is necessary for the transition to industry of the fuel cell applications.
- Selection of appropriate topics and projects for analysis to test market transformation is of high value and should continue. Some of the ancillary areas, including state training for codes and standards, cash flow, and fleet identification, were good areas of interest. The direct impact and relationship with the targets was not clearly proven during the presentation but was shown through other presentations that are under the guidance of DOE. Overall, the presentation provided a good overview of program direction.
- A key strength is the gaining of real-world experience in the various projects and the "stretching" of potential fuel cell and infrastructure applications. An example of this "stretch" is how the FedEx trucks are going to get hydrogen (which did not seem very well defined).
- Strengths are in the real-world applicability of the sub-program's projects. A weakness of the program may be the limited number of projects it can take on with its given budget. There are many developing issues as fuel cell deployments accelerate now, and many more will likely appear. While this program addresses a good number, there are already some issues that could benefit from more work, so the future potential for work in this program could be even greater. For example, there is a clear need for business cases or alternative business models not only for fleet operators but also for fueling network operators.

9. Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?

- Yes, the projects were well selected. Additional work to promote the findings for increased market transformation would be of value. This work was described during many of the other related presentations under the guidance of DOE.
- Yes. The reviewer would like to reiterate the benefit of supporting the Northeast outreach efforts as an innovation compared to funding hardware demonstrations.
- Novel and innovative are not necessarily terms for market transformation. Well organized and dedicated to hard work better describe this program.
- Yes.

10. Has the program engaged appropriate partners?

- Collaboration with partners was discussed and is expected to be pursued. Other presentations also provided strong intent to collaborate with stakeholders.
- Yes, collaborations are listed and demonstrated in the presentation.
- Yes. It is suggested that the program consider some additional industries to include because the H2-at-Scale opportunities (utilities, wind, solar, etc.) are meant to build on the current infrastructure projects.
- Yes.

11. Is the program collaborating with them effectively?

- It is expected that the partnerships will continue for effective collaboration. Other presentations also provided information on intent for effective collaboration.
- Yes, based on the success of the deployments, collaborations are effective.
- Yes, the program might consider focusing work with infrastructure providers on how core high-usage fueling infrastructure can support multiple types of vehicles/applications from single sites (consider how one airport site would support cars, trucks, tugs, buses, etc.).
- Yes.

12. Are there any gaps in the portfolio for this technology area?

- No, but the program should consider how to "put together" the various applications so that they support high-usage infrastructure such as at an airport or port. For example, the future look at car-sharing might consider this aspect and examine whether a high percentage of Uber/Lyft trips originate or end at an airport.
- It is perhaps a little bit early, but there did not appear to be any discussion of anticipated work for following and reporting on the light-duty vehicle (LDV) market transformation. Given that the vehicles are starting to come onto the roads, it seems like there will soon be plenty of information that will need to be tracked, assessed, and reported similar to the information presented in the overview for the materials handling and backup power markets.
- Increased focus on transformation targets with stronger reporting on results would be of value. Many of the other presentations provided information to fill gaps consistent with comprehensive program management.
- A discussion of the availability of hydrogen fuel was missing. A discussion of the cost of hydrogen delivery is necessary.

13. Are there topics that are not being adequately addressed?

- No, to the extent that the Market Transformation program is focused (as it should be) on markets that utilize compressed hydrogen gas at the infrastructure-to-product interface.
- The topic of identifying a cluster strategy was identified, but specifics were not provided. Other presentations provided a great amount of information demonstrating the diversity and connection of topics being addressed.
- This may be a cross-cutting project with the Hydrogen Storage program, but it appears that there may be a need for a risk/cost assessment of a potential future shift in the hydrogen storage medium used for vehicles. Public and private entities are currently investing significant amounts of money in compressed hydrogen storage. The Hydrogen Storage program has identified this as only a short-term solution, and none of the mid-to-long-term solutions seem to have much in common with compressed gas. An analysis may be necessary to determine the risk of increased costs or even stranded assets in a hypothetical future shift to one of the other storage media.

14. Are there other areas that this program should consider funding to meet overall programmatic goals?

- The analysis of car-sharing/ride-sharing opportunities is good. It is not clear whether there are any other emerging LDV usages or fleet opportunities that might lend themselves to supporting high utilization of infrastructure.
- Market entry and potential growth for electrolyzers seem to be accelerating at the current moment. This may be a technology area that the program should consider adding to its portfolio. In particular, economic and business analyses seem to be a key area for potential research in the technology.
- A reproducible strategy to identify clusters with a focus on market transformation may be helpful for the targeted promotion of the results to stakeholders, including partners. Many other presentations provided substantial information on the vast array of topics being managed by DOE. Overall, the topics are appropriate, connected, and effective in addressing market and industry issues.
- It is not clear when the commercial fuel cell markets will no longer need the tax credit and will be self-sufficient.

15. Can you recommend new ways to approach the barriers addressed by this program?

- The current methods are appropriate.
- Overall, the program is doing a good job of keeping a broad view of opportunities in the space. The program should keep a close eye on the H2-at-Scale initiative, because that may open up some new project areas with potential.

- Increased promotion of findings to stakeholders for reproduction of successful projects is suggested. The sub-program overview was very helpful to identify barriers, but a full understanding of all barriers was only possible after review of several other presentations.
- No.

16. Are there any other suggestions to improve the effectiveness of this program?

- The program should continue its close collaboration with the other FCTO sub-programs and with industry and look at whether there are similar agencies/investigations going on internationally that could inform or support U.S. strategies and projects so that the United States is not duplicating efforts.
- As somewhat of an aside, it seems like there may be an important opportunity for DOE to coordinate with the U.S. Department of Transportation regarding the Fixing America's Surface Transportation Act. It seems like the Market Transformation program would be the appropriate program to accomplish this.
- An increased budget would seem to be appropriate to move some of the R&D to commercialization. While difficult, the program overview might have been used to highlight some additional success stories presented by others.
- The program should provide a cost analysis demonstrating that the cost of the fuel cell power plants is meeting commercial, non-subsidized targets.

Systems Analysis Program Comments

1. Was the program, including overall strategy, adequately covered?

- The program manager did an excellent job defining and presenting the overall strategy of the Systems Analysis program and how it fits in addressing the main targets and challenges of the U.S. Department of Energy (DOE) Hydrogen and Fuel Cells Program (the Program).
- The projects within the program covered a wide range of modeling and analyses required to evaluate hydrogen and fuel cells. Models for customer preference, cost, and greenhouse gas (GHG) emissions cover hydrogen production, hydrogen infrastructure, and vehicles. Models elucidate the benefits of the DOE investments in terms of employment, deployments, and GHG emissions. One area that was lacking was the analysis of criteria emissions or petroleum reduction. It may be useful to develop a graphic showing what space each of the models works in, how they differ, and where there are still gaps. The team's purpose and assumptions should be mapped out as well. There appears to be some overlap between the various models. The work of Melaina, Levinson, and Vijayagopal, although different in some respects, does some of the same analysis. One advantage of the overlapping analysis is that the conclusions of these models can be compared. In many cases, the results are consistent. This is encouraging.
- Yes, it was adequately covered in slide 3 by listing each segment of the strategy and the projects that fall within each category. The only omission was the water life-cycle analysis (LCA) work that is being conducted by Argonne National Laboratory, which is a very important area of study. Fuel Cell Technologies Office (FCTO) barriers being addressed by this program were not presented.
- Yes, maintenance and development of modeling tools were covered well.
- Yes (two responses).

2. Is there an appropriate balance between near-, mid-, and long-term research and development?

- The sub-program's portfolio has an excellent mix of near-, mid-, and long-term analyses. Some examples include the following: for the near term, the low-volume hydrogen production and delivery analysis; for the midterm, the GHG emissions analysis for the emerging hydrogen production pathways; and for the long term, the fuel cell electric vehicle (FCEV) cost-of-driving analysis, comparing it with conventional vehicles up to the 2030 timeframe.
- Yes, one of the key issues is understanding how to build out the hydrogen infrastructure. The analyses consider near-term issues such as effective policies for its growth, mid-term evaluation of the costs with models like the Hydrogen Financial Analysis Scenario Tool (H2FAST), and long-term projections with the work of Rosner.
- By mentioning the 2020 cost target, it is obvious how all the near- and mid-term projects are geared toward reaching that target. It is not clear where technologies need to be in terms of GHG reductions in the long term, so perhaps a cost-per-gram GHG target would be appropriate to gauge the effectiveness of technologies and what needs to be done to attain that target. Alternatively, a longer-term target (beyond 2020) would be helpful to compare status vs. target and guide the development of new projects. In the longer term, it is obvious that the more exotic hydrogen production alternatives are in scope to try to reduce the cost.
- Yes, each timeframe is clearly defined.
- Yes, analysis of fueling at multiple station capacities is an example of projecting long-term costs.
- This is not an appropriate evaluation measure for the Systems Analysis program.

3. Were important issues and challenges identified?

- The work carried out under this program has enabled the FCTO to identify targeted areas for reducing costs, GHG emissions, and petroleum use.
- The program manager clearly identified the main challenges, which are understanding the future market behavior and the very limited availability of data for these type of analysis work.
- Yes, they were accurately reflected on slide 4.

- The primary issues of hydrogen and FCEVs are being addressed with the projects in this program. One area that could use more work is that of hydrogen distribution. The issue that FCEVs will reach a premature saturation due to limitations in gaseous hydrogen delivery to refilling stations should be addressed.
- The issues were mostly identified. Results were well presented, but the volume of data partially obscures highlighting of the key issues and challenges.
- Yes.

4. Are plans identified for addressing issues and challenges?

- Yes, these include significant engagement with relevant stakeholders as well as the utilization of excellent modeling capabilities and leveraging resources from the top experts at the national laboratories, which support these analysis efforts.
- It is good to see that the barrier of inconsistent data, assumptions, and guidelines is being addressed by multiple projects using the same models to develop their analyses. Even more integration of existing software within new models is encouraged so that the assumptions used throughout the program are the same, or if not, the differences are starkly highlighted. For example, it is not clear whether the information from Autonomie is being used in H2FAST.
- Yes, but the plans could have been more directly linked to the challenges.
- It appeared that none of the projects address consumer choice/behavior. Perhaps this is being addressed under a different program to later be integrated into the Systems Analysis program. The program is doing a good job at consolidating data from different models under, for instance, the Macro-System Model and the cradle-to-grave (C2G) models. There is good collaboration with national laboratories to ensure that high-quality data are sourced or generated.
- Plans are not explicitly identified.

5. Was progress clearly benchmarked against the previous year?

- Yes, very significant accomplishments in this year for this program were clearly presented, such as the C2G analysis and its recently published report, the update to H2FAST, the GHG emissions analysis on emerging hydrogen production pathways, the employment study, and the sustainability workshop with relevant stakeholders.
- It was an improvement from last year to see actual selling prices of hydrogen at the station, which was a gap from last year. Looking at the 2015 slides and comparing them against the 2016 slides, it is notable how much progress has been made in terms of patents and jobs creation. It is also interesting to see that there are new projects and new results from ongoing projects (e.g., C2G).
- Yes, obtaining consensus and publishing a C2G study is a significant accomplishment.
- The information shared in the Systems Analysis program presentation appears to be new and does not repeat what was done in previous years. As a result, it is hard to know what capabilities already exist in the models. It may be helpful to provide a short description of the purpose of the models rather than just describing the delta from one year to the next.
- No, analysis results are shown for the current year with updated projections for future years. This is reasonable and in keeping with the analysis theme of the entire effort, but year-to-year progress or change was not tracked.
- No.

6. Are the projects in this technology area addressing the broad problems and barriers that the Fuel Cell Technologies Office (FCTO) is trying to solve?

- The program manager has done an excellent job in balancing the project portfolio to address the main FCTO barriers. All of the projects have significant interactions with the industry, academia, national laboratories, and relevant stakeholders, which will be a key enabler to providing very robust analysis work. In addition, the analysis projects are leveraging the use of very well-established modeling tools and top researchers, which will provide clear direction and results for this program.

- Yes, analysis is critical to ensure that the FCTO is working on relevant issues that will enable cost-effective implementation of hydrogen vehicles in a way that addresses national needs. The H2FAST model, which addresses critical issues for investors, is a great addition to the program.
- Yes, the program is assessing the right benefits and evaluating current performance against targets. Systems analysis is needed to assess the potential of new technologies (e.g., solid oxide electrolyzer cell, BDL) on a techno-economic and environmental basis to guide DOE funding on research and development of new hydrogen production technologies.
- Yes, although sometimes the models are not pushed to address the really big questions of the FCTO and instead just provide additional data.
- Yes, in general, the projects are addressing the broad problems/barriers.
- Yes.

7. Does the program appear to be focused, well-managed, and effective in addressing FCTO's needs?

- Yes, the program is focused on assessing the right technologies and fuel/vehicle pathways. Yes, the program is well managed and effective.
- Yes, the program is working well with DOE, original equipment manufacturers (OEMs), and fuel providers to provide relevant, accurate analyses.
- During the presentation, the program manager and his team demonstrated that they are clearly focused on addressing the main barriers and targets of the FCTO.
- With FCEVs now coming into the market, the analysis should focus on the issues of hydrogen infrastructure and back off on the vehicle analyses. Low-cost hydrogen production will continue to be a major issue and should continue to be addressed.
- Yes (two responses).

8. What are the key strengths and weaknesses of the projects in this program? Do any of the projects stand out on either end of the spectrum?

- Strengths are the management, modeling tools, and the researchers/leads from the national laboratories, external stakeholder engagement, and balance of near- and long-term activities. Perhaps the limited budget is a weakness.
- It is great to see that many of the models are trying to validate their results by using available data from California infrastructure, hybrid electric vehicle sales, and the like. It is not clear what work will be done to evaluate sustainability and the utility of this project. It would be beneficial to provide concrete details of what information will be gathered and how it will support the overall program.
- A weakness is that the cost of battery electric vehicle (BEV) charging equipment per BEV is much higher than the cost of hydrogen infrastructure per FCEV by a factor of at least three, but slide 10 shows that charging equipment costs are similar to or even less than hydrogen station costs per vehicle; this needs to be corrected. A strength is showing GHG reductions due to fuel cell technology deployments (slide 18); this is very useful.
- The electric vehicle and hydrogen infrastructure cost analysis results are misleading. Using dollars and miles to compare gasoline vs. electric vehicle charging stations is very misleading. A different metric is needed. The impact of FCTO targets on the vehicle cost project is very weak and not very material. Given that targets for FCEVs are set to be competitive with hybrids, modeling the competitiveness of gasoline internal combustion engines (ICEs) against FCEVs is not particularly relevant. It would be more useful to assess when FCEVs will become competitive with gasoline ICEs on their own merits without assuming that a particular target is met, but rather, using technology assessment as a way to gauge progress to the target. It is hard to make a case for the sustainability framework projects. There are very few cases in which sustainability metrics are required to commercialize a product.
- Job estimates and return on investment calculations are difficult to make. The reviewer is suspicious of the values and thus generally considers them "weak."

9. Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?

- Yes, researchers involved in the Systems Analysis program are well informed of cutting-edge technology and innovations, which they integrate in their analysis when/if the technology shows promise, at least at the laboratory scale.
- The program is fortunate to have a very capable group of analysts who are knowledgeable in the economics and science of hydrogen fueling.
- None of the analysis work seems particularly novel and/or innovative. However, the analysis appears to be focused, on-target, needed, and professionally conducted.
- The projects do not appear particularly novel.

10. Has the program engaged appropriate partners?

- Yes, and this is probably one of the strongest areas of the program; it has extensive interactions and engagement with a broad set of key stakeholders.
- The Systems Analysis program relies on collaborations with third parties to acquire data and targets and to validate models. Collaboration with external stakeholders has been adequate, and the right people have been involved.
- The program has worked well with OEMs and fuel providers to ensure credibility and relevance.
- It may be beneficial to analyze the niche markets that are being evaluated by the Market Transformation program and Technology Validation program. Most of the work done so far has been on mid-size vehicles. Work should be done to evaluate these other markets.
- Yes.
- It appears that it has, but it is difficult to tell from the presentation.

11. Is the program collaborating with them effectively?

- Yes, it appears that collaboration has been effective with external parties and even across offices within DOE (e.g., the Bioenergy Technologies Office). Further, the Annual Merit Review is a good opportunity for researchers working on similar projects to communicate results and share best practices. It is good practice to run preliminary results of the projects by the Fuel Pathway Integration Technical Team and other U.S. DRIVE Partnership technical teams.
- The evaluation of the DOE targets and their long-term impact on the market is very beneficial. This information helps to justify these targets and demonstrate a pathway to successful fuel cell implementation.
- A great example of this is the C2G analysis, which resulted in a publication with significant collaboration between the government, industry, and national laboratories.
- Yes, the program manager has been an effective coordinator.
- It appears so.
- It appears so, but it is difficult to tell.

12. Are there any gaps in the portfolio for this technology area?

- None were detected.
- There is a limited budget.
- It would be good to see Systems Analysis program tools be expanded and used for the H2@Scale Big Idea.
- The Systems Analysis program should use a new metric, for instance, cost per GHG emissions abated. The program should also add low-volume and near-term assessments to the models, including Hydrogen Analysis (H2A). It is useful to assess the future potential cost and technology advancement of technologies, but it is more useful to know where those technologies are now in terms of cost and how the gap between today and the future will be bridged, particularly when future values for parameters such as cost and efficiency are based on DOE target goals. The program should add short-term climate forcers to the technology LCA assessment.
- DOE should be taking a longer and wider analytical view of GHG reduction by broadening the scope of the analyses. In order for the nation to achieve its GHG reduction goals, GHGs must be reduced in both

transportation and electricity generation. While the FCTO is focused on transportation, hydrogen as an energy carrier is uniquely qualified to provide a major contribution to GHG reductions in both electricity generation and transportation. For example, consider the impact of the introduction of coal gasification with carbon capture and sequestration (CCS) to produce hydrogen. Coal reserves are much greater than oil or natural gas reserves in most parts of the world. The United States could, in theory, replace all gasoline and diesel fuel used in transportation with hydrogen made from coal by coal gasification, thereby dramatically improving our national security (a Toyota executive, for example, has suggested that Toyota may stop producing ICEs by 2050, presumably relying entirely on FCEVs). An integrated gasification combined cycle (IGCC) and CCS would significantly cut GHGs in the electricity generation sector compared even to natural gas combined cycle (NGCC) plants. Taking a holistic, societal view of hydrogen use in both transportation and electricity generation could dramatically reduce GHGs while simultaneously decreasing threats to national security. The Office of Energy Efficiency and Renewable Energy should take the lead in conjunction with fossil fuels in analyzing and promoting the use of coal in IGCC+CCS plants to provide both low-carbon electricity and low-carbon transportation via FCEVs, with hydrogen as the main energy carrier.

- Predicting consumer demand for hydrogen FCEVs remains a challenge. Predicting consumer behavior does not appear to be part of the DOE skill set.

13. Are there topics that are not being adequately addressed?

- No.
- Perhaps one of the areas that was not being addressed was related to the sustainability analysis, but the program has taken the right steps to move forward with this (by organizing the sustainability workshop), and it was clearly presented as one of the efforts for upcoming activities.
- While GHG emissions and water usage are being calculated by the models, how this information can be integrated with cost needs to be evaluated. Several different scenarios (carbon taxes, credits, etc.) may need to be looked at. It is hard to couple these less tangible areas with cost.
- Using infrastructure cost in dollars per mile to compare gasoline refueling stations vs. electric vehicle chargers is misleading. This metric does not provide a fair representation of reality. It is difficult to understand the value of some models, such as H2FAST. It would be helpful to present a report of who is using these models and whether they have resulted in investment considerations.

14. Are there other areas that this program should consider funding to meet overall programmatic goals?

- No.
- The Systems Analysis program should use a new metric, for instance, cost per GHG emissions abated. The program should also add low-volume and near-term assessments to the models, including H2A. It is useful to assess the future potential cost and technology advancement of technologies, but it is more useful to know where those technologies are now in terms of cost and how the gap between today and the future will be bridged, particularly when future values for parameters such as cost and efficiency are based on DOE target goals. The program should add short-term climate forcers to the technology LCA assessment.

15. Can you recommend new ways to approach the barriers addressed by this program?

- The program could also benefit by engaging with international stakeholders and their efforts on this space.
- The FCTO should consider the use of agent-based models for looking at consumer behavior, using hybrids, BEVs, and plug-in hybrid electric vehicles to calibrate.
- The program should continue to assess the readiness level and potential of hydrogen technologies throughout the value chain of hydrogen production, transportation, and delivery. The program should continue to engage with national laboratories and academia to integrate results from laboratory tests into models to help provide early guidance to FCTO on funding alternatives. The program should continue

to partner with industry to vet model assumptions and results and to help transition technologies that show promise to commercialization.

16. Are there any other suggestions to improve the effectiveness of this program?

- The funding level for this subject area is low. Additional analysis would be beneficial. Further/more coordination among analysis, vehicles, storage, and production sub-topics would enhance effectiveness of the analysis.
- No, it is a very robust and well-managed program.
- No.