
Sub-Program Comments Provided by Reviewers

Hydrogen Production and Delivery Program Comments

1. Was the sub-program, including overall strategy, adequately covered?
 - The overview review does an excellent job of giving a highly structured presentation of the overall strategy.
 - Yes, the presentation covered the program clearly.
 - Yes.
2. Is there an appropriate balance between near-, mid-, and long-term research and development?
 - Yes, this comes out clearly in the overview presentation.
 - The goal of the DOE Hydrogen and Fuel Cell Program is to achieve less than \$4/kg of hydrogen in the next six years. It was hard to tell from this presentation how realistic this is—if it is realistic, then the emphasis on near- and mid-term (five years) research is appropriate. If the near-term research is successful and infrastructure is in place to deliver hydrogen using near-term sources, the longer-term work on developing sustainable sources will have an eventual home. Under this scenario, longer-term work can be funded at a lower level, and the investments in U.S. Department of Energy Basic Energy Sciences (BES) can be leveraged to build commercially viable new technologies. If it is not realistic that the cost target can be reached, then an analysis of feasibility and areas for focus will help develop new funding priorities. It is essential that the near-term infrastructure for hydrogen delivery and production is in place using current sources of hydrogen in order for the new technologies to have a chance to succeed.
 - No, the sub-program is failing to address the mid-term research and development (R&D) needs.
3. Were important issues and challenges identified?
 - Slide 4 is an excellent summary of the important issues and challenges.
 - The issues and challenges were discussed.
 - Some of the important issues and challenges were identified.
4. Are plans identified for addressing issues and challenges?
 - Yes, plans are identified for each issue/challenge.
 - Yes, plans were identified. However, plan development with industry representing the stakeholders will be short-term focused. Perhaps it would be useful to have another layer of plan development to assess the balance between long-term and short-term investments.
 - Some plans were identified.
5. Was progress clearly benchmarked against the previous year?
 - Yes, the overview slides clearly indicate progress versus 2013.
 - Yes, cost trends were presented and discussed.
 - 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 overview presentation shows a very-well-structured roadmap of problems that need to be addressed.
 - To some degree, the projects are addressing the relevant problems and barriers.
 - Yes.

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

- The overview presentation shows strong focus in addressing the identified barriers.
- Yes, this sub-program appears to satisfy FCTO's needs. There is a need for some examination regarding whether the resources available are up to the scope defined. Opportunities for leveraging related work could be evaluated as a means for extending the value of the Office of Energy Efficiency and Renewable Energy's (EERE's) investments.
- Yes, with the exception of focusing on mid-term needs.

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

- There is lots of good-quality R&D on long-term needs, such as novel hydrogen pipelines and concrete/steel composite tanks. A weakness is failing to address the mid-term needs of the hydrogen and fuel cell space; in the near-term, most hydrogen will be produced on-site by electrolysis or steam methane reformers or with truck-delivered gaseous hydrogen. Very soon, however the industry will be shifting to liquid hydrogen delivery. This is already happening with the five Linde liquid hydrogen stations in California. In addition, most of the hydrogen used at warehouses for the growing fuel cell material handling equipment (MHE) market is trucked-in liquid hydrogen, and Praxair has announced a 50% expansion of its liquid hydrogen production capacity at Niagara Falls. Other industrial gas companies (IGCs) have excess liquid hydrogen capacity in the East. The sub-program should be focused more on reducing the cost of liquid hydrogen stations. There is a need to develop lower-cost and more reliable liquid hydrogen pumps; for example, to replace or reduce the need for hydrogen gaseous compressors. (It seems that Linde's use of its proprietary ionic compressors at its liquid hydrogen stations may drive up the cost and lower the reliability of these stations.) In addition, there is too much emphasis on electrolysis. Strategic Analysis, Inc. (PD-102) has shown that the likely cost of electrolytic hydrogen will range between \$7.58/kg today and \$5.79/kg in the future, indicating that there is little hope of reaching the U.S. Department of Energy (DOE) target of less than \$4/kg with electrolysis. Another weakness is the absence of projects (with the exception of PD-091) to develop hydrogen from landfill gas or anaerobic digester gas, both of which can lead to zero-carbon hydrogen production.
- The key strength of the sub-program is the comprehensive view of the opportunity and the scope of the work that needs to be done to bring widespread use of carbon-neutral fuels to reality. The strength of the sub-program lies in the short-term projects, and the focus on forecourt and other needs to deliver fuels to consumers. The longer-term portfolio includes top talent, but it seems to be underfunded. It seems like resources were only available to support one of each kind of approach, rather than a best-of-breed approach. This is high risk in my experience. The working groups are a great way to benefit from broad experience, but they are more focused on knowledge aggregation than innovation. An examination of strategies to meet long-term needs given the resources available could be valuable at this point.
- It is sometimes difficult to assess the progress of some of the more long-term projects.

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

- The long-term projects in particular are very novel approaches to the identified barriers.
- The projects are more on the safe side. The need for short-term progress (in short-term and long-term portfolios) works against taking risks and being innovative.
- In some cases, the projects represent novel and/or innovative ways to approach the barriers.

10. Has the sub-program engaged appropriate partners?

- The sub-program is impressive in its engagement activities with industry. The partnerships with science programs could be stronger, both inside and outside of DOE. Hopefully a partnership with BES would be in place before a partnership with the National Science Foundation (NSF) is developed, because the missions are more naturally aligned.

- Yes, the sub-program has engaged appropriate partners for the topics chosen. If the sub-program were to focus on delivered liquid hydrogen, then there would have to be more collaboration with the IGCs and/or their liquid hydrogen component suppliers (such as liquid hydrogen pumps).
- It appears that the sub-program has engaged appropriate partners, given the progress that is shown.

11. Is the sub-program collaborating with them effectively?

- Yes, the collaborations described seem to be effective. What could be considered is the balance of voices to ensure that input on long-term as well as short-term research priorities is available for decision making.
- Yes, this appears to be the case.
- For the most part, the sub-program is collaborating with them effectively.

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

- There do not seem to be gaps, but there are too-hard boundaries at the edges. In particular, where hard science is needed to overcome technological obstacles, there seems to be little means to do what is needed.
- Perhaps there are gaps in some of the long-term approaches, but this is a difficult call to make because there are some highly immature technologies that are probably outside the scope of the technology area and should belong more in BES.
- Yes. The sub-program needs the following:
 - A project to reduce the cost of liquid hydrogen stations (trucked in liquid hydrogen with 700 bar gaseous dispensing).
 - More of an emphasis on landfill gas and anaerobic digester gas sources of hydrogen to generate zero-carbon hydrogen.

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

- Broadly, the balance is thoughtful. There are details that can be improved, which is normal.
- It would be useful to see the infrastructure financial analysis that is needed to attract investors as part of this technology area.

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

- The areas selected are appropriate.

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

- The materials work described in the reports could be augmented. DOE does not have as strong of an applied materials program as it needs.
- It might be useful to benchmark the rollout of infrastructure in other areas, such as compressed natural gas and liquid natural gas.

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

- The sincere dedication of the program managers in this area is to be commended. The only way to improve the sub-program's effectiveness is to increase outreach to external scientific communities. Awareness of the challenges will increase research (funded by other sources) that will benefit the sub-program and the nation over the long term.
- The sub-program should routinely compare the delivered cost of hydrogen by various avenues (e.g., on-site production, trucked-in gaseous hydrogen, and trucked-in liquid hydrogen), review what the IGCs are using at warehouses and at fueling stations, and focus projects to minimize the costs of those pathways.

Hydrogen Storage Sub-Program Comments

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

- As usual, the description of the sub-program was quite clear, as evidenced by the lack of any substantive questions following the presentation. The goals, current status, and future trajectories and strategies of the sub-program were described in the level of detail appropriate for the overview.
- The sub-program was described well, and the long- and short-term strategies were presented.
- The overall strategy was clearly communicated.

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

- With the completion of the three materials centers and the engineering center wrapping up, it would appear that the balance in the sub-program is shifting to more near-term development projects at the expense of performing on the more difficult, riskier, but potentially higher-payoff mid- to long-term research projects where DOE is expected to excel. Shortening up the time horizon to two-year projects that are largely development projects begs the question of how near is near for the Hydrogen Storage sub-program, and where the low-risk, low or moderate benefit line crosses over. The newer projects directed at improving high-pressure tanks are, albeit interesting, perhaps too close to where industry is playing now that 700 bar tanks are on the horizon for commercial deployment. It is unclear if industry really needs DOE assistance and motivation to make incremental changes in resins, or resin additives, for example, to make incremental improvements in performance and/or cost. Perhaps the pendulum has swung too far. Perhaps this is also somewhat driven by DOE's new rules on procurements, which has substantially slowed funding opportunity announcements (FOAs) over the last couple of years. Perhaps this trend will be reversed with more FOA opportunities.
- Unfortunately the sub-program has too much emphasis on short-term R&D; for example, on high-pressure gas tanks and engineering material-based systems, as opposed to long-term innovative research approaches to overcome existing limitations with the gas tanks.
- This was difficult to assess without seeing the budget breakdown between these areas.

3. Were important issues and challenges identified?

- Issues that remain were nicely identified by the now common practice of placing progress on easy-to-understand spider charts, where the "white space" clearly identifies the technical barriers that still remain to achieve the target(s). The sub-program has worked nicely to provide this information all on a fairly common set of parameters, so that each system approach, or material approach, may be quickly evaluated and compared as far as progress is concerned. One example where the sub-program has done a very good job in identifying future opportunities is in the chemical hydrogen storage area, where the sub-program has "reverse engineered" a basis set of minimum materials requirements that will be of substantial help in guiding future R&D in chemical hydrogen storage materials and approaches. This does not seem to be available (yet) for the metal hydrides, but does seem to be "in progress" for the sorbents. These "reverse engineered" materials properties will all hopefully be made available for the various materials approaches as part of the Engineering Center's final report, or associated publications.
- Short-term issues of cost were addressed. For the long term, it is obvious that breakthroughs are needed, but it is not clear how the materials being targeted will address the gaps.
- Issues and hurdles were identified and explained.

4. Are plans identified for addressing issues and challenges?

- Plans were explained.
- The spider charts do a nice job of describing where there are still unmet technical challenges to overcome in either the materials or systems. There was some discussion of where the remaining challenges are (e.g., carbon fiber costs, off-board inefficiencies), but plans to address the challenges were largely not made available. Clearly there are ongoing plans and actions to address the carbon fiber cost issue, but plans for addressing many of the materials or systems deficiencies were not explicit.

- Short-term strategies to lower carbon fiber costs were clear, but it was not clear that relevant targets and metrics exist to assess the success of new materials-based storage systems.

5. Was progress clearly benchmarked against the previous year?

- The spider charts provide a very clear representation of progress as a function of time. Presentation of this information gives a readily interpretable snapshot in time of where things were over the last several years, and even a glimmer of evidence as to where they might get to in the future. They are a very nice addition to how the overall Hydrogen Storage sub-program displays a large volume of data in a readily interpretable format, and one that surely drove the Engineering Center toward.
- Progress was communicated and benchmarked.
- Short-term carbon fiber accomplishments for polyacrylonitrile (PAN) precursors were clear. For other areas, 2014 progress was not as obvious.

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?

- Storage of hydrogen for either vehicular or niche applications is crucial for the successful deployment of fuel cell technologies, and the sub-program is providing significant strides forward in anticipating future hydrogen storage needs. Thus, the sub-program is crucial to overall FCTO success. With high-pressure tanks in commercially available fuel cell cars coming onto the market, the sub-program has the opportunity to reassess barriers for advanced hydrogen storage concepts (e.g., materials for onboard applications).
- The projects are partially addressing the challenges. It would be beneficial to have more emphasis on material-based approaches.

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

- The sub-program is very well managed. The sub-program lead is a technical expert in hydrogen storage, and the rest of the team contributes substantially to maintaining the focus of each and every project within its portfolio. The project management team is obviously very valuable to FCTO in that it is highly engaged on a day-to-day basis with its entire portfolio. The team responds well to change, makes decisions, and communicates easily with all of its principal investigators (PIs) and Engineering Center members. This sub-program must be considered exemplary in addressing the nation's needs in storage to achieve the broader FCTO goals.
- It is well focused.

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

- The sub-program's strong technoeconomic analysis is a strength.
- One weakness is that there is some overlap in the Argonne National Laboratory system analysis activities and the Engineering Center activities, and likewise between the cost analysis portion of the sub-program and some of the Engineering Center activities. Perhaps some overlap or repetition is good as a crosscheck, but one must not allow it to go too far for too long. An additional weakness is that the portfolio has become quite near-term in focus. Perhaps that will be remedied in the next several rounds of potential FOAs. Also, another weakness is that there is a sorption project (ST-103) that is still operating a lot like a BES project, and it has not really responded to input on what it takes to succeed in an applied research program. A strength of the sub-program is the excellent communication among the stakeholders, the PIs, and DOE to drive the projects forward more effectively. The Engineering Center has become a very strong example of this.
- A weakness is the focus on short-term activities.

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

- As the Centers ended, and the Engineering Center winds down, the number of novel approaches or degree of innovation in the overall sub-program has declined. Perhaps this is to be expected because these previous projects have provided many more technical constraints and boundaries as to how to meet all of the targets simultaneously. The “phase space” for successfully meeting all the targets simultaneously with one material and one system has certainly been dramatically shrunk, which may be wringing much of the potential for a high frequency of innovation out of the field. It is a very hard problem to address in innovative ways within the constraints of dollars and time that DOE places on researchers.

10. Has the sub-program engaged appropriate partners?

- Absolutely—it is hard to imagine the sub-program doing this any better.
- It did engage appropriate partners.

11. Is the sub-program collaborating with them effectively?

- Yes. The sub-program is internationally recognized for being a collaborative, innovative focal point.
- The sub-program is collaborating effectively.

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

- The sub-program needs to lengthen out the time horizon to attract more innovative approaches that may be quite risky, but with high payoffs if successful. The sub-program has transitioned to a time horizon that is too short, which makes it difficult to propose highly innovative, albeit risky, R&D. The periodic table is not getting any bigger (for stable elements). The sub-program may want to go back and revisit “nitrogen trihydride” and update its view on onboard ammonia. There are recent advances that may indicate that some R&D in this area of nitrogen-hydrogen compounds is appropriate. While off-board efficiency has been identified as a significant barrier for some materials classes, there is no current plan to address those barriers. This may be a very-high-risk program element, but if successful, it can enable some high volumetric and gravimetric systems sometime in the future.

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

- *[No responses provided.]*

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

- *[No responses provided.]*

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

- Losing the Centers could be expected to substantially reduce collaboration, creativity, and innovation, and the ability for DOE to rapidly move ahead in chosen areas where the Center concept might work. DOE might want to rethink how to structure future solicitation or opportunities around some variant of the Center concept.

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

- The sub-program is spread too thin in the medium- to long-term research that FCTO is good at. There needs to be a rebalancing of the portfolio, and DOE needs to take a closer look at how near term they want to be. DOE appears to currently be encroaching in areas that are best suited to industry, and where DOE teams are less effective.
- The sub-program should include more projects for long-term R&D.

Fuel Cells Sub-Program Comments

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

- Yes, the sub-program has been well covered. The overview presentation is clear and describes very well the expectations, the barriers to overcome, the main accomplishments, and the future activities. However, having information about the targeted and current system density (kW/l and kW/kg) would have been appreciated.
- The sub-program presented an excellent summary of strategy and goals that are measurable and correctable. The focus areas look good. The use of automotive fuel cells in grid-support-related R&D focus/needs will be helpful.
- The strategy was adequately covered. The focus is on R&D of materials, components, and the balance-of-plant (BOP) system to address the cost and durability barriers, which are clearly the key barriers for commercialization.
- The sub-program covers the necessary technical focus for the pre-competitive phase of research for automotive fuel cells. The area of advanced analytical methodology to support fuel cell R&D is an opportunity to further efforts. This area may be beyond what FCTO covers. Perhaps collaboration with other DOE offices could be pursued to develop an FOA in this area. The current projects on microscopic analysis at ORNL and neutron imaging at the National Institute of Standards and Technology (NIST) are good models for this area.
- Yes, the sub-program presented a good overview of its overall strategy, progress, and accomplishments.
- The overview presentation provided a good overview of the sub-program. However, it feels like the overall strategy is a bit weak on specifics and too broad in scope.

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

- Yes. The development of advanced materials to cell, stack, and system testing, as well as validation testing, are important parts of balancing. The use of market-driven parameters in planning is excellent. The high-volume projections are good but not sufficient. A transition strategy is needed from low volume to moderate volume.
- Resources are appropriately allocated for long-term and mid-term R&D.
- The balance is appropriate.
- The near-, mid-, and long-term R&D is balanced; however, more emphasis is needed on fundamental understanding of the different stack component degradation mechanisms and their coupling, component interfaces, and changes in materials properties.
- The sub-program is balancing the near and long terms fairly well. However, the strategy for the mid term is unclear. Most fuel cell original equipment manufacturers (OEMs) are concerned about the commercial “valley of death.” It is unclear whether FCTO is responsible for and mandated to think about the mid-term commercial challenges.
- Yes.

3. Were important issues and challenges identified?

- Yes. Cost, life, and reliability are important barriers. The sub-program has a good strategy to handle them. The use of national laboratory resources and feedback from industry to guide decisions and planning is very productive.
- Cost and durability have been well identified as the main challenges to overcome. Another big challenge for commercialization will be the quality control of the component manufacturing; in particular, the membrane electrode assembly (MEA) and bipolar plates.
- The research focus area is consistent with the views of OEM partners in the U.S. Council for Automotive Research (USCAR), and important issues and challenges are identified.
- The challenges/issues were highlighted and appropriately addressed as much as possible in the limited number of slides.
- Yes. Cost targets are well outlined and current cost components for fuel cells have been identified.

- Important issues and challenges have been identified and have remained the same over the past three or so years. The remaining challenge of the cost of fuel cell systems is beginning to asymptote at around \$55/kW, while the target for 2020 is \$40/kW. The cost reduction trend is not encouraging; it is unclear whether the sub-program is concerned about this trend and, if so, whether there is a focus on funding the key enabling technologies.

4. Are plans identified for addressing issues and challenges?

- The sub-program features good plans to address major issues. The use of analytical tools and input from stakeholders is very well done.
- Yes, in general. Among them, one would notice the better understanding of the degradation mechanisms, the development of new materials such as catalysts or critical BOP components such as compressors, the improvement of the MEA, and system modeling.
- Yes, they are.
- Plans for cost reduction in automotive fuel cells are unclear; while the focus area has been identified, the specifics are not clear. Pt reduction has been identified as a key focus area; however, it is not clear what more could be done. The high-activity catalyst (>10x compared to Pt/C) has been reported since 2009. However, these are not being used on the MEA scale to collect data or improve the cost model. The strategy seems to be stuck in neutral (i.e., the focus area is not resulting in additional cost reduction).
- Many projects that cover important challenges are ending or ended in this fiscal year. Therefore, the research project portfolio needs to be fixed. The new FOA currently planned is imperative to fix the research project portfolio. Also, it is important to track fuel cell R&D funding by other countries' governments and keep DOE R&D portfolio updated and competitive.
- Yes.

5. Was progress clearly benchmarked against the previous year?

- Yes. Good progress is being made. There is a nice list of parametric achievements.
- The progress is clearly highlighted by key new research findings. The highlighted results are very exciting; however, in some cases, the technology is by far too immature for one to understand its true impact on fuel cell commercialization (e.g., no MEA performance results exist).
- The sub-program was benchmarked against the previous year for automotive fuel cells. There was no clear benchmarking for other areas such as combined heat and power (CHP) or materials handling applications.
- Yes; however, for the budget section, it would be nice to show bar charts for budget amounts for at least the last five years to give a perspective of whether the budget is increasing, staying same level, or decreasing.
- In general, all the presentations explained the new achievements from this year.
- Further analysis on fuel cell system cost trends might be necessary. The trend of estimated cost shows a plateau for the last four years despite significant R&D efforts. Going forward, it will be important to maintain priorities and focus for additional funding and further R&D efforts to succeed.

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. There is a good portfolio of solution options and progress trackers. Additional opportunities are identified that can ensure better performance results.
- Yes. Nevertheless, there are no more projects dealing with bipolar plates even though it is not clear if the announced cost targets have been achieved or if the durability of the metallic plates will be as high as needed, in particular for stationary applications.
- The projects in this technology area are partially addressing the barriers that FCTO is trying to solve. However, they do not address the broad problems in the area.
- Generally, the projects do address the barriers of fuel cell commercialization. However, many projects did end this year, and there will be a gap until the new funding is in place.
- FCTO is trying to solve problems properly. Most of the projects that focus on addressing key challenges are ending this fiscal year. The currently planned FOA should be pursued in appropriate timing to address this issue.

- Yes.
7. Does the sub-program appear to be focused, well-managed, and effective in addressing FCTO's needs?
- Yes. OEMs' input is seriously considered, which is a very positive thing.
 - The sub-program is well managed. The focus area still needs to be further refined to address the most challenging issues.
 - Yes. Coordinating with other EERE offices such as Wind and Solar on energy storage challenges would enhance the value further. The workshop on multi-fuel flexibility and gas clean-up, including biogas and shale gas applications, would lead to expanding the market base and further cost reductions.
 - The sub-program seems generally focused; however, there seems to be an imbalance between catalyst and MEA/cell R&D.
 - Yes. (2 responses)
8. What are the key strengths and weaknesses of the projects in this sub-program? Do any of the projects stand out on either end of the spectrum?
- Strengths of the sub-program include that almost all of the funded projects are focused on issues identified by FCTO, and that the projects have very strong teams with excellent cross-collaboration between academia, laboratories, and industry. One weakness is that, although rotating disk electrode (RDE) testing should be used as a catalyst screening tool, many projects highlight RDE results as their achievements in catalyst development and these results in most cases do not correlate with MEA results. FCTO should not encourage National Science Foundation-type activities. Non-platinum-group-metal (PGM) projects are showing type iV performances under air, which is very promising, but many ultra-low-PGM projects keep focusing on RDE, which is very disappointing.
 - The sub-program's strengths include the quality of the researchers involved in the projects, and the well-structured project organization with "SMART" (specific, measurable, attainable, realistic and timely) objectives. Weaknesses include the possible gap in collaboration between the researchers and industry, leading to a lack of real system understanding from the researchers.
 - Strengths include the sub-program's world-class talent pool, excellent transparency, and merit review. A weakness is the sub-program's inability or lack of emphasis to move cutting-edge technologies from the laboratory to the real world by developing an adequate supply base.
 - The sub-program has made good progress toward its goals. However, it also needs to focus on multipurpose solutions; as crosscutting solutions can increase near-term cost reduction. For example, development of fuel cell use for grid-support working with the DOE Office of Electricity Delivery and Energy Reliability (OE), and fuel-flexible cleanup systems for DOE Bioenergy Technologies Office and Office of Fossil Energy (FE) applications.
 - The key strength is the continual reassessment of the fuel cell system cost for the different fuel cell applications to understand progress toward the 2020 targets. Another strength is the novel approach to the development of new catalysts. A weakness is that some of the project approaches are not systematic and do not generate fundamental understanding.
 - The sub-program is well organized and communicates with U.S.-based automotive OEMs. It also leverages the advantages of the technical resources of national laboratories. However, the project portfolio needs to be extended; the planned upcoming FOA will be able to fix this,
9. Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?
- There are some excellent outcomes with novel and innovative approaches; for example, the nanoframe catalyst.
 - Yes. The use of nanomaterials, non-Pt modeling tools, and high-temperature fuel cells is good. Higher-temperature membrane work will help both automotive and grid-applications as well.
 - There is a correct balance between novel and/or innovative projects and more conventional projects.
 - Many of the projects are trying novel ways to address these barriers.
 - No.

10. Has the sub-program engaged appropriate partners?

- The sub-program has strong engagement with U.S.-based automotive OEMs through the U.S. DRIVE Partnership.
- Yes. There is room to leverage resources with the U.S. Department of Agriculture, the U.S. Environmental Protection Agency, and OE-grid support applications—that would be beneficial. Multipurpose demonstrations with crosscutting support from other partners will increase the value being created by the current efforts.
- Yes; however, it is unclear how FCTO is leveraging similar work from other countries such as Germany and Japan. DOE conducts the Hydrogen and Fuel Cells Program Annual Merit Review (AMR); however, there is no similar-scale review for the projects funded by the New Energy and Industrial Technology Development Organization and the Fuel Cell and Hydrogen Joint Undertaking.
- The national, international, and industry collaborations are all captured.
- Yes. (2 responses)

11. Is the sub-program collaborating with them effectively?

- Yes. Having the collaborating partners at future peer reviews to talk about the synergistic values will be great.
- It is unclear. A strong collaboration needs to exist between the various international codes and standards activities.
- Yes. (3 responses)
- No.

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

- FCTO is doing a great job in this area to address issues based on feedback from stakeholders and balancing the funding respectively.
- The main gap observed is the stack level. National laboratories and universities are working only on single cells to develop new materials or new models (even system models). Stack and systems are only developed and tested by industry. The impact of the laboratory developments might be more efficient and faster if the researchers could validate their findings in an early stage at the stack level.
- The project portfolio is an issue because most projects for the important technical focus area are ending in this fiscal year. It should be fixed. The upcoming FOA is an opportunity to fix it. The next funding opportunity should consider an updated technology focus and priority.
- The key gap is understanding how state-of-the-art materials (e.g., catalysts and ionomers) can be integrated into a robust state-of-the-art MEA. There seems to be a lack of leadership in trying to move technology from Technology Readiness Level (TRL) 3 to TRLs 4 and 5.
- No. Value can be added by future multipurpose validations/demonstrations.
- There are no high-level gaps.

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

- System control strategies are not addressed at all; the research community (also outside the current fuel cell community) has a lot of competence in that field.
- Topics for projects to be funded can follow the same breakdown as fuel cell cost breakdown; for example, more funded projects for higher-cost component (catalyst).
- Fuel and air contamination is key to long-life fuel cell operation. Thus, some research should focus on contamination-tolerant catalysts.
- The development of markets for already proved technologies and a supply base is not being adequately addressed.
- No.

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

- Under this portfolio, most of the areas are already covered.
- The sub-program should continue building on the high-temperature membrane working group achievements. It should also support multi-use, crosscutting technology strategies to produce a greater value proposition. In addition, it should validate advanced, higher-reliability, lower-capital and operating cost technology options that simplify hydrogen refueling and reduce parasitic power for higher-pressure hydrogen.
- There are more opportunities to develop novel analytical methodology areas to support focused R&D. The ORNL microscopic analysis is a good example.
- Yes, FCTO needs to lay out a clear roadmap on how it is planning to improve the stack robustness and simplify system design.

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

- Because the stack is a key element of the fuel cell system, stack development involving parallel MEA and bipolar plate development should be promoted. At the least, stack testing by national laboratories should be performed to speed up the validation of new solutions. Durability and cost barriers may be addressed by non-material constraints such as better system control strategies. Even if it is very sensitive for industry, academic researchers may also propose breakthroughs.
- There is little-to-no established supply base for key components in the United States. The United States currently does not have any world-leading supply base for catalysts, ionomers, gas diffusion layers, or bipolar plates. These four components account for more than 80% of the projected long-term stack cost. DOE and other U.S. government organizations need to be paying attention to this lack of competency. Perhaps FCTO can leverage its size and leadership to get the other organizations to open up their reviews (e.g., post proceedings online), or perhaps it can fund a project to monitor and convert these proceedings into English for a U.S. audience.
- The sub-program should pursue multipurpose technology development and validation. It should consider an R&D model similar to the one used by the Solid State Energy Conversion Alliance (SECA) program's DOE- industrial team.
- There should be more feedback from stakeholders and more focus on MEA results. MEA results should be required in the second year of the project.
- The upcoming FOA is key to fixing the project portfolio.

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

- The sub-program should continue using the same strategy—workshops are a great way to get guidance from stakeholders!
- Webinars have been great so far to share the results, but they should be advertised well, not only on the website. Maybe an email subscription would work better. Publications and patents filed under funded projects can be included as accomplishments in every presentation.
- The projects are annually reviewed by the U.S. DRIVE partnership's Fuel Cell Technical Team, which provides recommendations entirely focused on automotive applications. Including industry with a focus on stationary fuel cell applications would yield a balanced view.

Manufacturing R&D Sub-Program Comments

1. Was the sub-program, including overall strategy, adequately covered?
 - Yes, the sub-program's needs, intent, and strategy to generate a solution were well developed with industry collaboration and thoughtful consideration.
 - Yes, it was covered in sufficient detail.
2. Is there an appropriate balance between near-, mid-, and long-term research and development?
 - The appropriate balance between mid- and short-term development is difficult to identify at this time due to some potential overlap between evolving research and vetted products that are ready for increased efforts for lower-cost manufacturing and production. Nonetheless, the strategy to move from research to production with scale up of laboratory processes, quality control (QC) diagnostics, and quantification of defects is appropriate.
 - It would be helpful to classify initiatives into immediate through long-term categories.
3. Were important issues and challenges identified?
 - Yes, but determining the defining line on what products and components are ready for increased efforts for lower-cost manufacturing and production may be difficult. The approach to collaborate with industry is appropriate, but the task to vet which efforts are ready for advanced manufacturing and production should not be underestimated.
 - Yes.
4. Are plans identified for addressing issues and challenges?
 - Yes, identification of cost drivers, elimination of steps, use of process control tools, increased automation, reduction of scrap, and increase of yields are all appropriate to reduce production costs. Controls including scale up of laboratory processes, QC diagnostics, and quantification of defects are appropriate to maintain proper attention on the technologies and components that are ripe for commercialization and manufacturing.
 - Yes.
5. Was progress clearly benchmarked against the previous year?
 - This appears to be a relatively new area, but in the previous year collaboration with industry and open workshops provided a reasonable benchmark of industry concerns from which to move forward.
 - The comparison with last year was a bit vague.
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 very much addressing the problems and barriers with DOE's Clean Energy Manufacturing Initiative to increase production and manufacturing with reduced costs, consistent with the overall U.S. strategy.
 - The projects discussed are consistent with FCTO goals. Rather than focusing on only one aspect, several components are addressed.
7. Does the sub-program appear to be focused, well-managed, and effective in addressing FCTO's needs?
 - Yes. While it is just beginning, the sub-program appears to be well justified by industry, thoughtful to avoid waste of resources, well managed in an open and transparent manner, and consistent with U.S. policy.

- More emphasis could be placed on real-world manufacturing and technical component requirements.
8. What are the key strengths and weaknesses of the projects in this sub-program? Do any of the projects stand out on either end of the spectrum?
- The strategy to identify barriers and solutions is a key strength. One weakness may be the inability to project the potential for evolution of technology through advanced research, rendering the product unready for large-scale manufacturing. Nonetheless, controls have been taken to largely avoid this weakness with QC diagnostics and quantification of defects.
 - One project detects online component defects, but required detection limits are not clearly quantified.
9. Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?
- Yes, the approach appears well justified as an effort to move R&D to a commercial level. This may be one of the first innovative attempts to standardize the manufacturing processes for the hydrogen fuel cell industry to promote appropriate commercialization as an effort to increase competitive production.
 - Yes, they represent novel and innovative ways, and some have been down-selected.
10. Has the sub-program engaged appropriate partners?
- Key industry partners were approached and engaged at the previous workshop. Perhaps an annual commercialization workshop would be appropriate to help gauge progress with the technology targets. This approach might be considered on a regional basis to directly address industry clusters.
 - Yes.
11. Is the sub-program collaborating with them effectively?
- Yes, but continued collaboration with regions and clusters would be helpful. Continued collaboration with other sub-programs (Systems Analysis; Safety, Codes and Standards; Technology Validation; and Market Transformation) would also be of long-term value.
 - Yes.
12. Are there any gaps in the portfolio for this technology area?
- The sub-program should make sure technologies are consistent with fuel cell requirements.
 - Continued collaboration with industry and stakeholders would be helpful.
13. Are there topics that are not being adequately addressed?
- Stationary fuel cells with other MEA stack configurations would be appropriate next steps.
 - No.
14. Are there other areas that this sub-program should consider funding to meet overall programmatic goals?
- Other MEA technologies, continued collaboration, and QC processes should be considered. Also, tracking of performance metrics would be helpful to justify sub-program funding.
 - No.
15. Can you recommend new ways to approach the barriers addressed by this sub-program?
- There has been much work on increasing manufacturing efficiency and competitive production within the manufacturing industry. Much of this work has been adopted by large OEMs, including in the automotive industry. Coordination with these non-fuel-cell industries to identify generic manufacturing, advanced production models, “lessons learned,” and efficiency solutions would be of value.

- No.

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

- Coordination with the U.S. Department of Commerce and the U.S. Small Business Administration may be helpful and of value to better understand their efforts for increased manufacturing efficiency and competitive production.
- The sub-program should make sure defect detection can see defects of importance to component performance and durability.

Technology Validation Sub-Program Comments

1. Was the sub-program, including overall strategy, adequately covered?
 - The validation strategy is quite straightforward and is described appropriately. No further discussion is required.
 - Yes. (2 responses)
2. Is there an appropriate balance between near-, mid-, and long-term research and development?
 - For the technology validation topic, all of the areas are going to be near term or at most mid term. It seems to be a waste of effort to validate a very immature, long-term R&D concept. Those long-term projects may need some form of investigation, but it would not be under the Technology Validation sub-program. The areas validated (e.g., buses, fuel cell electric vehicles [FCEVs], compressors, and stations) are all appropriate.
 - Not applicable; this is technology validation, which, by definition is evaluating existing technology in the field, so these are all near-term projects.
 - Yes.
3. Were important issues and challenges identified?
 - Yes, they were identified, but not explicitly. In the future, the presentation could explicitly list the top challenges in each validation area.
 - Yes.
4. Are plans identified for addressing issues and challenges?
 - In some cases they are identified. In others, the goal seems to be merely testing the systems to show that they meet goals. That is a worthy effort, but it would be better to more clearly state exactly what key parameter is being tested (and why).
 - Yes. (2 responses)
5. Was progress clearly benchmarked against the previous year?
 - No, there was no clear benchmarking against the previous year.
 - Yes.
 - 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?
 - In a sense they are addressing the problems and barriers, because providing operational data helps to validate the technology and pave the way for increased market acceptance.
 - Yes. (2 responses)
7. Does the sub-program appear to be focused, well-managed, and effective in addressing FCTO's needs?
 - Yes; it seems to be well organized and well run.
 - Yes. (2 responses)

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8. What are the key strengths and weaknesses of the projects in this sub-program? Do any of the projects stand out on either end of the spectrum?
- The projects examine a breadth of technology validation approaches. There are (relatively) large-scale automotive demonstrations involving the major FCEV manufacturers, specific device/system developments such as high-pressure tube trailers, testing of small-scale equipment such as compressors, and a consortium approach to catch all intangible aspects of the “fueling station experience” (H2FIRST).
 - The project to test the PDC Machines compressor (TV-019) is a key strength because compressors are the weak link in hydrogen fueling stations. One weakness might be the lack of a similar project to test high-pressure liquid hydrogen pumps, because trucked-in liquid hydrogen is the primary method of delivering hydrogen to MHE sites, and trucked-in liquid hydrogen will become more prevalent for FCEV fueling stations, too.
 - The newer projects—those closer to their start—did not seem like they had much to report, and maybe they should have been kept out of the review.
9. Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?
- H2FIRST is the most novel and innovative.
 - Some projects did not represent novel and/or innovative ways.
10. Has the sub-program engaged appropriate partners?
- Some did not engage appropriate partners; some listed partners because they thought they should.
 - Yes. (2 responses)
11. Is the sub-program collaborating with them effectively?
- It appears to be.
 - It is unclear.
12. Are there any gaps in the portfolio for this technology area?
- It is unclear.
 - Testing and evaluation of liquid hydrogen high-pressure pumps is a gap.
 - No.
13. Are there topics that are not being adequately addressed?
- No.
14. Are there other areas that this sub-program should consider funding to meet overall programmatic goals?
- No.
15. Can you recommend new ways to approach the barriers addressed by this sub-program?
- Presenters from the same organizations should benchmark against each other; for example, at least one NREL presentation was phenomenal, other NREL presentations, with similar aims, were not.
 - No.
16. Are there any other suggestions to improve the effectiveness of this sub-program?
- The sub-program should coach the laboratories as the difference between the quality of the presentations was great.
-

Safety, Codes and Standards Sub-Program Comments

1. Was the sub-program, including overall strategy, adequately covered?
 - The sub-program's objectives and strategy are well defined. There is a very strong focus on key areas around safety, codes, and standards (SCS), which will enable the early deployment of hydrogen and fuel cell technologies.
 - The sub-program's scope and activities, including its strategy, are definitely adequately covered. The presentation could have benefited from some more information on the necessary (and intended) interaction with H₂USA, both in content and in process.
 - Yes. The sub-program has done good work considering its time constraints and breadth.
2. Is there an appropriate balance between near-, mid-, and long-term research and development?
 - There are appropriate topics, given the working area and challenges for the commercialization of fuel cell technology.
 - There is good balance in the overall portfolio of the sub-program.
 - Emphasis is currently concentrated on tackling outstanding issues related to the deployment of hydrogen refueling systems. This is understandable, but a longer-term view on other applications did not emerge from the presentation.
3. Were important issues and challenges identified?
 - Yes, the main issues are clearly stated and the sub-program is really focused on addressing these.
 - Yes. (2 responses)
4. Are plans identified for addressing issues and challenges?
 - The plan that the sub-program has established looks very well thought out and well managed. The strong integration with the domestic and international communities is the key for the success of this sub-program.
 - Such plans are mostly provided in the presentations of the individual projects covered by the Safety, Codes and Standards sub-program.
 - While a comprehensive plan was put forth, it would have been good to see the foreseen challenges and the path to avoid or address them.
5. Was progress clearly benchmarked against the previous year?
 - New accomplishments and their importance were clearly defined.
 - This was not directly apparent from the 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?
 - Absolutely, yes! The projects in this group are generally important for the adoption of the technology related to meeting existing codes and standards or appropriately modifying codes and standards.
 - Yes they are, especially the recent developments in the materials compatibility area, the in-line analyzer work at LANL, the Quantitative Risk Assessment toolkit, and the strong focus on safety education and training.
 - Without any doubt, they are addressing the problems and barriers.
7. Does the sub-program appear to be focused, well-managed, and effective in addressing FCTO's needs?
 - The sub-program is well managed and clearly focused on the main objectives and challenges.

- Generally, yes. The budget should be reevaluated. While the overall budget is fine, if not on the small side, the \$625,000 dedicated to the hydrogen safety panel relative to the other topics is questionable.
 - Yes.
8. What are the key strengths and weaknesses of the projects in this sub-program area? Do any of the projects stand out on either end of the spectrum?
- One of the key strengths of the sub-program is the very close collaboration with the key domestic and international stakeholders and organizations.
 - Each project is addressing a critical need for fuel cell technology adoption. The only project that has questionable execution and adoption is the “hands-on safety training.”
 - This reviewer has reviewed six projects in the SCS sub-program. Among these, the weakest score has been obtained by SCS-015, and the highest by SCS-007. All reviewed projects (not the total number of the SCS sub-program) hence fall in a rather narrow score band, indicating the generally relevant and high-quality work in the projects.
9. Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?
- Very innovative approaches are taken, such as the work at LANL on fuel quality analysis and the hydrogen safety sensors projects.
 - In this year’s review, the most novel/innovative items are the integrated HyRAM toolbox and the progress in the in-line fuel quality analyzer. Other projects that this reviewer has reviewed mostly build further on their already well-established past achievements.
 - Yes.
10. Has the sub-program engaged appropriate partners?
- This is the key and the strongest aspect of this sub-program.
 - For the SCS sub-program, U.S. standard development organizations and code development organizations are logical and indeed necessary partners. However, with the global deployment of hydrogen and fuel cell technologies, even more active involvement of the sub-program in international standardization and regulatory activities would be useful. It is not clear how findings from the Technology Validation sub-program are fed into (updating) the SCS sub-program.
 - In general, all relevant working partners were identified.
11. Is the sub-program collaborating with them effectively?
- Collaboration is very effective and very well managed.
 - Yes. (2 responses)
12. Are there any gaps in the portfolio for this technology area?
- Two identifiable gaps across most of the technology areas are outreach and adoption. Many of the tools and programs have high value but could be hidden within industry.
 - Given the current focus on enabling the deployment of hydrogen refueling stations, SCS for stationary fuel cell applications and non-road transport could fall behind.
 - No.
13. Are there topics that are not being adequately addressed?
- The topics included in the sub-program are adequately addressed.
 - No.

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

- There are no other technical areas to consider for funding, but periodic international workshops to take stock of global SCS activities and share SCS-relevant experiences should possibly be funded.
- The proposed upcoming activities should provide additional value to the overall success of this sub-program.
- No.

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

- While difficult, deepening the working relationships with the collaboration partners is recommended. This is a time issue with all parties.
- No.

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

- A periodic international workshop to take stock of global SCS activities (United States, Canada, Japan, China, Korea, European Union [EU]) and to share SCS-relevant experiences from ongoing and imminent deployments of hydrogen and fuel cell technologies can definitely add value. Such an activity has recently been launched for tackling issues related to the implementation of hydrogen infrastructure (Berlin and Los Angeles workshops sponsored by DOE, Germany's National Organization for Hydrogen, Japan Automobile Research Institute, Scandinavia, and the EU) with the active involvement of appropriate industries. A similar effort is ongoing on identifying R&D priorities for hydrogen safety within Hysafe, with active involvement from DOE, the European Commission – Joint Research Centre, and relevant industries. In view of the absence of industrial partners, the International Partnership for Hydrogen and Fuel Cells in the Economy's Regulations, Codes and Standards Working Group does not seem to be the appropriate forum for housing such a workshop.
- The sub-program should ensure pathways exist to market any products of this sub-program, whether they are physical (hydrogen quality) or related to training (hydrogen safety).
- The sub-program should keep the close collaboration with the international community because this is a key area, especially with the upcoming international developments in the hydrogen and fuel cells space.

Market Transformation Sub-Program Comments

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

- Yes. The objective of the Market Transformation sub-program was evident and focused.
- Yes, the general area of the Market Transformation sub-program was adequately addressed, with a presentation on demonstration work for stationary, mobile, refueling, and hybrid applications.
- The sub-program and strategy were adequately and thoroughly covered.
- The sub-program was covered during the overview presentation. The slides could be improved by providing a framework or context that explains why the specific niche markets were chosen (and others were not). Otherwise, the slides give the impression that the applications were chosen opportunistically as opposed to being driven by a DOE market transformation strategy that focused on “low-hanging fruit” to make the most efficient use of taxpayer money.

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

- Yes, the work appears to be tied to near-term demonstration activities; however, this approach is appropriately balanced because it is coordinated with other DOE initiatives for systems analysis, codes and standards, and technology validation. With such coordination, there is an appropriate balance for near-, mid-and long-term development.
- With the limited funding, concentration on near-term opportunities that can be leveraged for longer-term benefits seems appropriate.
- The balance does not come out from the presentation, but perhaps it is difficult to show without an overall market transformation strategy that clearly maps niche markets versus their maturity/attractiveness.
- Yes.

3. Were important issues and challenges identified?

- Yes, important issues and challenges were clearly identified for the given target applications that are being funded.
- Yes, the sub-program manager painted a complete picture.
- Yes, they were identified—principally, as technology and market adoption due to price.
- Cost and budget were identified as critical issues; however, market drivers, technology validation, and compliance with codes and standards were also addressed.

4. Are plans identified for addressing issues and challenges?

- Yes, coordination with private companies, state and federal government, and other stakeholders was presented. This coordination was shown to be critical in identifying appropriate projects for demonstration and validation with the best probability for long-term development.
- Yes, for each issue/challenge, an action plan is identified on the individual project level.
- Yes. (2 responses)

5. Was progress clearly benchmarked against the previous year?

- Yes, progress was clearly benchmarked against the previous year, but once again it was mainly on the individual project level.
- Yes, past progress and future work were addressed and benchmarked, but future plans may be constrained by budgets and funding.
- This is unclear. Although good information was presented about ongoing initiatives and projects, one could not determine how the “needle” had been moved from 2013 to the 2014 review.
- Yes.

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 presentation addressed demonstration work for stationary, mobile, refueling, and hybrid applications; all represented important breakthroughs in market transformation.
 - Once again, given its very limited resources, FCTO is doing a very credible job of trying to advance the technology through partnering and leveraging investments from multiple parties.
 - Each individual project is contributing. A gap analysis is missing that might identify a key application market that is not being currently funded, and that should be solicited. The upcoming request for information (RFI) on fuel cell range extenders is a step in the right direction, but it seems like this has been chosen opportunistically.
 - Yes.
7. Does the sub-program appear to be focused, well-managed, and effective in addressing FCTO's needs?
- Yes, the sub-program was well focused and justified on a sub-program basis and a project-by-project basis. Management was excellent, and the project results will be helpful for increased market acceptance in opportunistic market areas.
 - Overall, yes, the sub-program appears to be addressing FCTO's needs; it would be useful to look at market transformation more strategically to see if there are niche markets that should be more aggressively pursued by DOE.
 - Yes, this is a complete effort.
 - Yes.
8. What are the key strengths and weaknesses of the projects in this sub-program? Do any of the projects stand out on either end of the spectrum?
- The breadth of projects being funded is a strength of this sub-program. The projects that appear to be the best use of taxpayer funding are those that are on track to show results, such as: (a) small commercial building fuel cell CHP, and (b) ground system equipment.
 - The effort to focus on Hawaii presents the best opportunity to create a situation that helps move the market forward on several of these project fronts. The sub-program should put a "full court press" on getting this as the springboard for the technology.
 - The sub-program is consistently high performing.
 - The project demonstration with performance tracking for key emerging technologies in emerging markets was clearly a strength. Weaknesses are related to the decision-making process of which projects get selected for demonstration and which ones are not selected, consistent with budget limitations. Projects that are selected clearly stand out as superior, but there was not presentation of information on rejected projects and the reasons why such projects were not selected for demonstration. Such a vetting process may exist but may be tedious to present, and thus it was not presented. Perhaps some type of a decision matrix with criteria and topics could identify the general decision-making process with accepted and rejected topics.
9. Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?
- Yes, all the projects appeared to be well selected as innovative to address goals, market drivers, and removal of barriers.
 - The novel aspect of all these projects is that they are very business-case focused; this is unusual for government-funded projects and is to be applauded.
 - These are tried and true pathways to address and solve some of the challenges—they are not necessarily novel or innovative.
 - Yes.

10. Has the sub-program engaged appropriate partners?

- Yes, the Market Transformation sub-program's coordination with agencies is commendable and allows the sub-program and the other agencies to leverage funding to achieve mutual and individual goals.
- The list of participants and partners is very robust; it is perhaps one of the strengths of the program.
- Yes; for example, having BMW in the landfill-to-gas project is an excellent idea.
- Yes; such collaboration was well justified, but there may be opportunities for increased collaboration and identification of additional partners. Such partnerships may be difficult with competitive private companies, but they may help to increase awareness among additional stakeholders and market participants.

11. Is the sub-program collaborating with them effectively?

- Yes. There is good communication and sharing, and collaboration is evident.
- Yes, this seems to be the case.
- Yes. Collaboration was well justified and effective, but there may be opportunities for increased collaboration and identification of additional partners. Such partnerships may be awkward and difficult with competitive private companies and a larger number of project participants, but such expanded partnerships may help to increase awareness among additional stakeholders and market participants.
- Yes.

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

- There are no significant gaps in the sub-program, but some areas that could be addressed include the following:
 - Continue collaboration with other DOE teams (e.g., Systems Analysis; Safety, Codes and Standards; and Technology Validation).
 - Continue efforts to increase partnership building for project demonstration.
 - Provide a summary presentation and justification of all demonstration projects selected and rejected.
- The only thing that is crosscutting and needs to be attacked aggressively is the cost of the technology and helping to bring that down while improving the value proposition in the market.
- The upcoming RFI on fuel cell range extenders fills in an existing gap.
- Yes, there are gaps that additional funding could help.

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

- All topics appear to be relevant and well justified. Another topic that appears ripe for demonstration is fuel cell microgrid applications. This topic is receiving national and international attention with the need for standardized, ultra-clean, quiet, and efficient stationary generation resources for use with mission-critical end users, and for nodal grid reliability.
- Lowering costs will bring stronger market adoption. It is unclear what exactly could address that, but that might be a topic for consideration.
- The upcoming RFI on fuel cell range extenders addresses a topic that was not covered.
- No.

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

- The Market Transformation sub-program is already leveraging other agencies.
- One particular area that may be ripe for consideration is the diversification of zero emission vehicle (ZEV) refueling infrastructure. This topic is receiving attention as a result of potential overreliance on electric grid resources for plug-in battery electric vehicles (EVs). This overreliance is tied to local grid interconnection with home and commercial recharging stations that may threaten grid capacity, and it is further complicated with the tie between centralized electricity systems and the transportation sector. Solutions include the use

of islandable stationary fuel cell generation facilities at EV recharging stations and diversification of the ZEV refueling market with increased efforts to deploy hydrogen refueling at mission-critical fleets.

- A gap analysis is missing that might identify a key application market that is not being currently funded, and that should be solicited.
- Cost-cutting or other measures to improve the value proposition should be considered.

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

- Recommendations include the following: (a) continue collaboration with other DOE sub-programs (Systems Analysis; Safety, Codes and Standards; and Technology Validation), (b) increase partnership-building for project demonstration, (c) summarize reasons to select and reject all demonstration projects considered, and (d) expand the scope to consider fuel cells and hydrogen refueling as a reliability asset on the electric grid.
- No. (2 responses)

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

- The sub-program should (a) investigate fuel cells for microgrid applications at mission-critical facilities, (b) investigate stationary fuel cells at EV recharging stations as a reliability asset on the electric grid, and (c) investigate hydrogen refueling for FCEVs at mission-critical fleets as a reliability asset on the electric grid.
- A gap analysis is missing that might identify a key application market that is not being currently funded, and that should be solicited.
- Increased funding might help to identify a stronger role in the value proposition.
- No.

Systems Analysis Sub-Program Comments

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

- The sub-program features a very broad and diverse analysis portfolio that really focuses on the main goal of supporting the infrastructure development. It is a very-well-managed sub-program. It features an excellent combination of industry, academia, and laboratory work.
- Yes, the strategy was adequately covered. Fred Joseck presented a comprehensive description of how the strategy will help address the challenges and meet the objectives of the Systems Analysis sub-program area. Models and tools were well described and seemed adequate to address some of the barriers outlined in the FCTO Multi-Year Research, Development, and Demonstration Plan.
- The sub-program was described well and all areas were covered.
- Yes. All major areas were mentioned.
- Yes.

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

- Yes; however, greater emphasis is now needed on issues related to the early deployment of hydrogen fuel cell vehicles and infrastructure. Greater emphasis is also needed on the dynamics and costs of the transition. Great work has been done on the current situation and on the long-run, post-transition costs and benefits; however, the transition itself is critical and needs to be better understood. Good work is being done on non-automotive fuel cell applications and on hydrogen delivery and station economics. Life cycle analysis and market penetration models are generally addressing long-run conditions. The workshop on infrastructure financing was a step in the right direction, but much more is needed in this area given that Hyundai is leasing vehicles now and Toyota and Honda will soon follow.
- The Systems Analysis sub-program seems to be tackling near-, mid-, and long-term challenges. The models and tools, as well as the financial analyses, are helping stakeholders understand the current status of the technology and its near-term challenges. Further, the investor workshop is creating awareness among the investing community; this is paving the way for the future while keeping stakeholders engaged now. For the mid and long terms, the projects sponsored by this sub-program are helping to do the following:
 - Identify potential investment gaps.
 - Analyze cost implications for different refueling pressures from the points of view of the consumer and the station owner.
 - Understand the environmental implications of different transportation modes, including greenhouse gas emissions and water.
 - Model the future impact on employment.
 - Understand which components need additional R&D to get the technology to compete in future markets.
- Yes, but as presented, the difference between near term and long term was not always clearly marked. Thus, a practice of explicitly noting the term might benefit the sub-program balance and illuminate asymmetries.
- The sub-program has a well-balanced portfolio in terms of the different time frames.
- The analysis portfolio is broad based and attempts to cover the most pressing analysis needs.

3. Were important issues and challenges identified?

- Yes, slide 3 describes in detail the challenges being tackled by the sub-program: future market behavior; data availability, accuracy, and consistency; and coordination of analytical capability.
- The main challenges were clearly stated by the sub-program, and the sub-program is clearly focused on addressing these issues.
- Yes, with one exception that was noted by the sub-program manager. That is, models and planning tools are needed that incorporate the interdependence of hydrogen supply and demand. There is a need to have transferable planning models that municipal, state, and federal decision makers can use in collaboration with industry to plan the deployment of early hydrogen infrastructure and test policies for supporting that deployment. This applies not only to the first few stations (such as the STREETS model), but also to the

next 100 and so and beyond. These models must represent the interdependence of vehicle demand and infrastructure supply. They must deal with transition costs such as majority risk aversion, value of fuel availability, etc. These are very difficult topics and no one has yet produced a model or models that adequately represent all the issues. Indeed, basic research is needed to understand many of the issues. Given the magnitude and difficulty of the challenge, the Systems Analysis sub-program budget is probably not adequate at the present time.

- The challenge of describing future markets stands out as a major challenge.
- Generally, yes, they were identified.

4. Are plans identified for addressing issues and challenges?

- The various methodologies employed by the overall Systems Analysis portfolio provide great value to DOE's efforts in achieving its technical targets.
- Yes, with one exception: models and planning tools are needed that incorporate the interdependence of hydrogen supply and demand. Outstanding work has been done on life cycle analysis, hydrogen station financial analysis, employment impacts, the economics of hydrogen delivery pressure, trigeneration, interaction with the grid, and more. Data development and validation efforts are very strong. A powerful suite of models and analytical tools has been developed. Unfortunately, more is needed to address the challenges of the transition. A large-scale energy transition to address social concerns (e.g., climate change, energy security, and energy sustainability) is a new problem for DOE and public policy in general. A well-focused and well-funded effort is needed to adequately address the research needs and model development to support such a transition.
- Yes, the projects described tackle all the challenges described in slide 3.

5. Was progress clearly benchmarked against the previous year?

- The cash flow and financing work is a valuable addition to the sub-program.
- Yes, this was clearly shown in a slide.
- No, the presenter did not mention how much progress was made compared to last year. However, it seemed that many of the projects described were initiated within the last year.
- Progress was generally not clearly benchmarked.

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 analyses supported by this sub-program are painting a very clear picture of the pathways that can be taken to help accelerate the introduction of hydrogen FCEVs and their supporting refueling infrastructure.
- The analytical work in this sub-program definitely provides a lot of value in addressing the main challenges of FCTO.
- Analysis efforts are well suited to addressing the pressing issues. The cradle-to-grave study has been a valuable addition to the Systems Analysis portfolio.
- Yes, with one exception: models and planning tools are needed that incorporate the interdependence of hydrogen supply and demand.
- Yes.

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

- Yes, none of the projects seem to overlap, the data is accurate, models are validated, the right stakeholders have been engaged, and future activities are in alignment with FCTO's goals.
- This is a very focused and excellently managed sub-program.
- The sub-program appears comprehensive. A large number of models have been developed for system analysis and are available for future study.

- The analysis efforts are focused on key areas and the available resources seem to be allocated appropriately.
- Yes, with one exception: models and planning tools are needed that incorporate the interdependence of hydrogen supply and demand.

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

- The projects are generally rigorous and state-of-the-art. For example, the hydrogen fueling station operation and cost analyses, the life cycle impact analyses, and the grid integration analysis stand out as especially strong examples. More needs to be done on transition analysis. The *Transitions to Alternative Vehicles and Fuel¹s* study is a good resource for illustrating the kind of knowledge that needs to be developed and the kind of modeling that will be needed. However, even that study does not go far enough with respect to the need for planning tools at a high level of spatial resolution.
- Key strengths include the following: (a) the strong support from national laboratories and U.S. DRIVE partners, (b) the PIs have strong analytical capability and experience in advanced fuels and vehicle technologies, and (c) the portfolio of activities is diverse and targeted. Weaknesses are that (a) the industry data is not always available and (b) the budget will remain flat for 2015.
- The sub-program is doing a great job of modeling the technoeconomics associated with FCEVs. There may be a need to involve stakeholders more to look at financial and investment strategies.
- The main strengths are the very strong collaboration with some of the top experts in these areas and that the analysis work is based on very-well-established modeling tools. Weaknesses include the limited resources and budget, especially for a key area such as this one.
- Some of the assumptions used in the individual analyses are optimistic. For example, DOE Program Record #14003² is shown as documenting 7–9 cents/kW for stationary fuel cell systems, yet it is predicated on \$1,500/kW installed capital cost. Thus, the levelized cost of energy may be true, but the capital cost is not achievable in the near term. The analysis is useful, but critical assumptions (and the time frame in which performance levels are likely to be achieved) must be (repeatedly) stated.

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

- Some of the projects are innovative, while others have not been around for a long time. The latter is not necessarily a bad thing; useful models such as the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model and the Hydrogen Analysis (H2A) model need to be continuously updated and refreshed.
- The projects reflect many innovative ideas for finding new markets or new ways to use hydrogen and fuel cells. However, the economics remain difficult.
- Yes.

10. Has the sub-program engaged appropriate partners?

- Yes, there is strong stakeholder support on the technical side; the models are built by PIs with very strong technical skills (e.g., ANL and NREL) and vetted by the appropriate industry partners. Further, the AMR provides a great venue for other stakeholders to comment and help direct the sub-program.
- The very strong and broad collaboration is probably one of the key aspects for the high success and value of this sub-program.
- The collaboration with industry is strong. The appropriate partners are involved. The collaboration among national laboratories is strong. The sponsorship of university research is not so strong.

¹ National Research Council. *Transitions to Alternative Vehicles and Fuels*. Washington, DC: The National Academies Press, 2013.

² U.S. Department of Energy, Offices of Solar Energy Technologies and Fuel Cell Technologies. Program Record 14003: Levelized Costs of Electricity from CHP and PV. http://www.hydrogen.energy.gov/pdfs/14003_lcoe_from_chp_and_pv.pdf. March 14, 2014.

- Industrial secrecy and business concerns often make it difficult to vet models and supporting data, but the sub-program is making a good effort to work with industry and other stakeholders to develop and validate models.
- Yes.

11. Is the sub-program collaborating with them effectively?

- Yes—through U.S. DRIVE meetings and presentations, informal discussions with industry and government laboratories, and the AMR, the sub-program has received invaluable feedback and information.
- The collaboration among the laboratories is good. The sub-program needs to continue to work with H₂USA and international groups. More direct involvement with universities would be good, but the budget would probably need to be increased.
- Yes.

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

- Many of the models assume a certain level of market penetration to determine cost. It would be good to see those models focus on current and near-term (i.e., 5–10 years into the future) scenarios as well to understand how the transition may happen.
- Demand modeling is perhaps the greatest gap and is one area where the required expertise may not reside within DOE or national laboratories.
- Yes—transition modeling, research, and planning tools.
- Limited resources and budget are gaps for the sub-program.

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

- The previous Secretary of Energy overemphasized nonautomotive fuel cells and hydrogen use relative to automotive use. That imbalance has not yet been fully corrected. At the same time, the challenges of achieving a transition to hydrogen FCEVs are great. There are many important aspects of market behavior, for example, that are poorly understood at present, but that are very important to the transition. Although great progress has been made in modeling, there is still no model that adequately represents the interdependence of infrastructure supply and vehicle demand. This is an important area that needs to be addressed.
- The following topics are not adequately being addressed: (a) market transition; (b) integration of natural gas systems with renewable energy technologies; (c) impact of international introduction of advanced vehicle technologies on the U.S. market; (d) large-scale electrolyzers >1 MW; and (e) comparing the cost, emissions, and performance of tri-generation systems with other advanced technologies (e.g., cogeneration and integrated gasification combined cycle [IGCC]).

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

- The current portfolio is very complete.
- Regarding market transition, it is unclear how current technology needs will evolve in terms of cost, efficiency, and rate of deployment to achieve the penetration levels in H2A. Regarding the integration of natural gas systems with renewable energy technologies, natural gas is a low-cost, low-carbon fuel that can be combined with renewable energy technologies, including wind, photovoltaics (PV), fuel cells, batteries, and others, to provide stable power and heat in the most environmental manner. In terms of the impact of the international introduction of advanced vehicle technologies, it is unclear how the introduction of hydrogen production, delivery, and dispensing infrastructure abroad will impact the market in the United States. Regarding large-scale electrolyzers (>1 MW), no data is available, even though the central-production scenarios of DOE models assume that the technology will be available. The sub-program should compare the cost, emissions, and performance of tri-generation systems with other advanced technologies (e.g., cogeneration and IGCC). The sub-program should also pursue financing options for fueling infrastructure, such as leasing, purchasing, and hydrogen production and delivery agreements.

- In order to predict consumer behavior, the sub-program should seek to partner with OEMs (possibly through third parties to make OEM data anonymous).
- Yes.

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

- An interesting approach would be to help developing countries that are in the process of developing their vehicle and fuel infrastructure. Because greenhouse gas emissions are global and affect everyone equally, a reduction in emissions abroad has the same effect as a reduction in emissions domestically. Technology deployment abroad could be cheaper and help prove technologies. Further, domestic production and exports of alternative vehicles, components, and fuels could be boosted. It would be interesting to model and analyze this approach. There should be more engagement with policy makers to explain the results of the models. In addition, this reviewer recommends projects to explore the following issues:
 - The dynamics of the market transition, and how current technology will evolve in terms of cost, efficiency, and rate of deployment to achieve the penetration levels in H2A.
 - The integration of natural gas systems with renewable energy technologies.
 - The impact of the international introduction of advanced vehicle technologies and hydrogen production, delivery, and dispensing infrastructure abroad will impact the market in the United States.
 - Data gathering on large-scale electrolyzers (>1 MW), which the central-production scenarios of DOE's models assume will be available.
 - Comparison of the cost, emissions, and performance of tri-generation systems with other advanced technologies (e.g., cogen and IGCC).
 - Alternative financing options for fueling infrastructure, such as leasing, purchasing, and hydrogen production and delivery agreements.
- It is not likely that the markets for fuel cells and hydrogen could develop without public policy support. Policies are considered in the Systems Analysis sub-program, but there could be a stronger connection with DOE policy and a stronger emphasis on modeling and analyzing how policies affect business models and what policies are needed for market development.

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

- The sub-program should take a step back and rethink the modeling portfolio. The Systems Analysis sub-program has an impressive array of sophisticated models (shown on the models slide). In many areas, the models work together well to address needs for analysis. However, it is not clear how they all fit together to address the modeling needs. Perhaps a workshop on this subject, supported by an initial white paper, could lead to an improved understanding of how the models relate to the range of analytical needs and possibly to more effective use of the modeling resources.
- The sub-program should involve more automotive manufacturers.