2016 — Safety, Codes and Standards
Summary of Annual Merit Review of the Safety, Codes and Standards Program

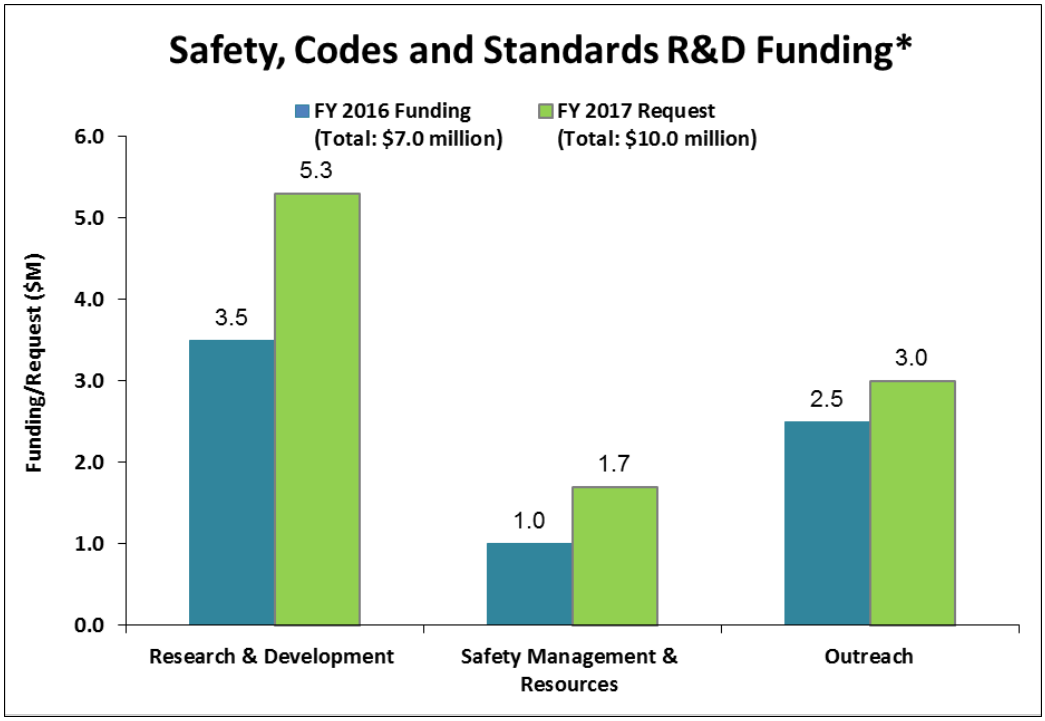
Summary of Reviewer Comments on the Safety, Codes and Standards Program:

The Safety, Codes and Standards (SCS) program supports research and development (R&D) that provides the critical information needed to define requirements and close gaps in safety, codes, and standards to enable the safe use and handling of hydrogen and fuel cell technologies. The program also conducts safety activities focused on promoting safety practices among U.S. Department of Energy (DOE) projects and the development of information resources and best practices.

Reviewers commended the progress made since the previous year and noted that the work of the SCS program enables the accomplishment of the broader goals of DOE and the Fuel Cell Technologies Office. They particularly applauded the balance of near-term and long-term activities in the program portfolio, mentioning progress in such areas as hydrogen behavior, separation distances, materials compatibility, and fuel quality. Reviewers were impressed with the science-based approach and the feedback provided to code development organizations (CDOs) and standard development organizations (SDOs). program engagement of relevant stakeholders such as CDOs and SDOs, both domestically and internationally, was praised. Reviewers felt that more progress could be shown in non-R&D activities. In particular, they stated that the outreach efforts have been “well-maintained” and that continued focus in that area is essential, and they recommended expansion beyond stakeholders to include outreach to the public. Key recommendations for R&D focus included medium- and heavy-duty fuel cell electric vehicles and fueling protocols.

Safety, Codes and Standards Funding:

The program’s fiscal year (FY) 2016 appropriation was $7 million. FY 2016 funding has allowed for continued support of codes-and-standards-related R&D and of the domestic and international collaboration and harmonization efforts for codes and standards that are needed to support the commercialization of hydrogen and fuel cell technologies. The FY 2017 request of $10 million will allow the program to broaden its existing R&D efforts and expand its focus on infrastructure-related activities.



* Subject to appropriations, project go/no-go decisions, and competitive selections. Exact amounts will be determined based on research and development progress in each area.

Majority of Reviewer Comments and Recommendations:

In FY 2016, 10 SCS program projects were reviewed, with a majority of the projects receiving positive feedback and strong scores. Reviewers' average scores ranged from 3.2 to 3.7, with an overall program average score of 3.4.

Research and Development: Seven R&D projects were reviewed, earning an average score of 3.45. The highest scoring project in this category received a score of 3.7 and was also the highest scoring project for the SCS program. The R&D category is divided into three sub-categories: Sensors and Component R&D; Hydrogen Behavior, Risk Assessment, and Materials Compatibility; and Hydrogen Quality. The summaries of reviewer comments for R&D are provided below for each sub-category.

Sensors and Component R&D: Reviewer comments for this category were generally positive. Reviewers were particularly supportive of the collaborative efforts and stakeholder engagement for projects relating to sensors and component R&D. The approach to component R&D was praised as being thorough, while the sensor effort was commended for its comprehensive validation plan, though some modifications were suggested. Reviewers recommended that the results of these projects be published to provide guidance on the application of the respective components.

Hydrogen Behavior, Risk Assessment, and Materials Compatibility: The science-based approach to codes and standards through hydrogen behavior and risk assessment related R&D was applauded by reviewers, who noted the value of these projects both domestically and internationally. The software and publication outputs of the risk assessment efforts were praised as being highly beneficial to stakeholders. Materials compatibility projects were praised for their relevance and for their efforts to enable stakeholders to utilize the data acquired during the course of the work. All of the projects received praise for collaboration and stakeholder engagement. Reviewer recommendations included adding clarification and focus to the future plans of the projects.

Hydrogen Quality: The expansion of scope from previous years was praised for efforts related to fuel quality. Reviewers also applauded the progress in developing a prototype hydrogen contaminant detector. They recommended that the standards-related portion of the work move forward at a more aggressive pace, but they felt that the pace of the R&D portion was commendable.

Safety Management and Resources: One safety management and resources project was reviewed, receiving an average score of 3.5. Reviewers applauded the expanded impact of the Hydrogen Safety Panel to include non-DOE work and noted the success of the panel in terms of the increased number of reviews from the previous year. They also praised the international collaboration for first responder training and the continued domestic outreach and training efforts. Reviewers raised concerns about having sufficient resources to update items developed elsewhere and hosted on H2Tools.org and whether the efforts to transfer external resources to the site might be duplicative.

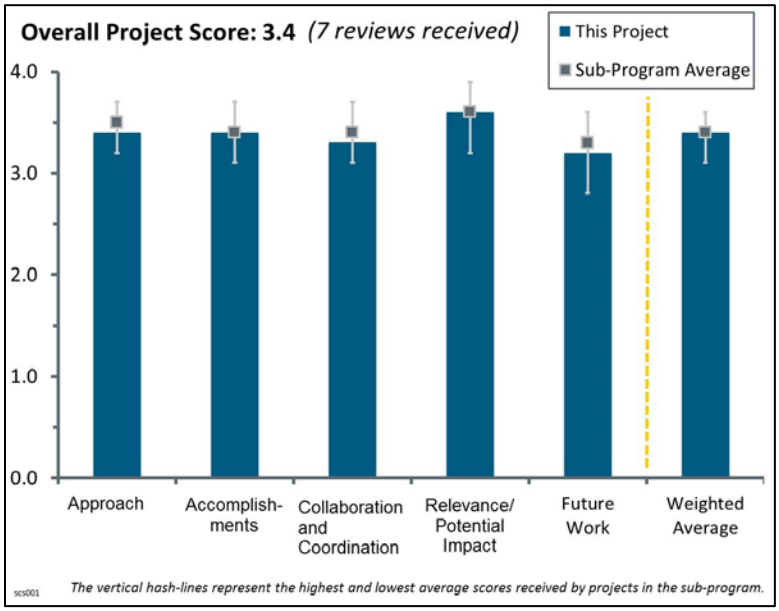
Outreach: Two outreach projects were reviewed and received an average score of 3.3. Reviewers praised the outreach activities for their engagement of a diverse set of relevant stakeholders. They commended both projects for their efforts to serve codes and standards activity coordination, which is a critical area of need. Reviewers encouraged even further development of outreach on a regional level and recommended that both projects seek clarification in areas in which there is perceived overlap.

Project #SCS-001: National Codes and Standards Deployment and Outreach

Carl Rivkin; National Renewable Energy Laboratory

Brief Summary of Project:

The objective of this project is to further the deployment of hydrogen fuel cell technologies with particular focus on the infrastructure required to support fuel cell electric vehicles. This outreach and training project supports technology deployment by providing codes and standards (C&S) information to project developers and code officials, making project permitting smoother and faster.



Question 1: Approach to performing the work

This project was rated **3.4** for its approach.

- This project consists of a multiannual effort aiming at continuous improvements and developments of C&S. It contributes to many overarching national activities and therefore integrates and aligns with the overarching goals. It is well designed and able to respond properly to new needs.
- The principal investigator does a good job at identifying the needs and doing the needed outreach. This project has really grown in collaborations and teaming compared to previous reviews. The Continuous Codes and Standards Improvement (CCSI) process is good, and having a national laboratory helps drive that positive process. Chairing the National Fire Protection Association (NFPA) 2 is appropriate as long as the national laboratory does not write code language. Code language is written by the technical committee, not by the chair, so there should not be an issue, but attention needs to be paid to make sure this stays "clean."
- The project is on track. The approach is sound, feasible, and integrated with other efforts.
- The approach is effective. It contributes to overcoming most barriers.
- This approach is working well; however, the team should keep improving the communication about the project, available resources, and potential activities. "Getting the word out" to all stakeholders is critical and should be done through multiple means. H2 Tools is excellent in the sense that it is a "one-stop shop" and fairly user-friendly, but even it is not well publicized. Additionally, social media outlets are useful tools. Many stakeholder groups, such as the International Association of Fire Chiefs and International Association of Fire Fighters, have Twitter handles and/or Facebook pages. This seems like something H_2USA should be working to promote because there are relevant topics for all audiences: those who are in the midst of commercialization (California), those who are preparing (the Northeast), and those who will begin preparing in the near future (the rest of the country).
- The outreach and training was a good approach, but it is not clear whether this is a role for a national laboratory. It may be better handled by an industry association. With CCSI, it is not clear if there is an overlap with the work with the Fuel Cell and Hydrogen Energy Association (FCHEA). If it is coordinating activities, FCHEA may be able to do additional work on continuous improvement. The National Renewable Energy Laboratory (NREL) connection to the FCHEA work was unclear, and the design is a bit amorphous. It is not clear whether it can be more focused year-to-year depending on needs. It is not clear whether anyone is looking across the U.S. Department of Energy (DOE) and national laboratories to push new science to technical C&S committees.
- It would be helpful to clearly state the needs and prioritize the specific barriers of concern with a little more detail at the beginning (i.e., examining what problems the project is trying to solve and why). While the

barriers can be understood from the context of the project, they might not be clear to an audience not closely involved in the topic. Also, a summary statement invites check-in and discussion from partners/collaborators to ensure that everyone remains on the same page regarding the work scope. That being said, the project does address the primary challenges in the topical area.

Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **3.4** for its accomplishments and progress.

- The completion of the video, the publication of the *Guide to Permitting Hydrogen Motor Vehicle Fuel Dispensing Facilities*, the availability of the H2 Tools portal, and the Northeast training sessions are major, noteworthy accomplishments in the outreach portion of the project. The formation of the Hydrogen Storage Task Group and its work is also noteworthy in that area. It would be good to have a greater understanding of the steps needed to drive the change into the NFPA 2 revision.
- The reviewer would give this a 3.25 if possible. The project is better than good, but it could still use some improvement. Outreach to the current and future users is essential to address all levels of concerns and questions, and to receive input. The project should ensure that messaging is consistent across the board with regard to properties of hydrogen, the reasons for this technology, the rollout of fuel cells, etc. There are some regional distinctions, but New York, for example, is a zero-emission-vehicle (ZEV) state (as is California), so much of the same dialogue/messaging can be used. Plenty of notice should be given on the *Stationary Fuel Cell Guides* document when it is published.
- The output for this project is very good, considering a $300,000 budget. There were six publications, some of which are NREL reports, but others are in proceedings of refereed conferences and are appropriate publications for this work. The important issue here is that this work is in the public domain, and there are places where it can be found and referenced.
- The project delivers a consistent high quality. The two important guides published this year are the result of previous years' efforts.
- The project is effective and contributes to overcoming most barriers.
- The degree to which progress has been made and measured against performance indicators is satisfactory, and the progress toward the goals is appropriate.
- There were some good accomplishments and progress noted. However, it is not clear whether national laboratories should be developing permitting tools and guidelines or whether this a role for industry associations or standards development organizations (SDOs)/code development organizations (CDOs)? It is also not clear whether a national laboratory should be working on state/regional regulatory issues. It is a good idea to link to the most recent version of C&S. The project should consider how this can be aligned with the Hydrogen Fuel Cell Standards website[1].

Question 3: Collaboration and coordination with other institutions

This project was rated **3.3** for its collaboration and coordination.

- The project appears to involve all of the right areas of expertise and stakeholders in producing and delivering consistent material to inform C&S development and streamlined permitting of hydrogen facilities. As discussed in the question and answer (Q&A) session, the area of removing restrictions (such as the Maryland tunnel restriction) remains challenging because of the different levels of authority and different authorities having jurisdiction (AHJs) at the state/local level. A future opportunity for the project may be to try to develop a framework for identifying such restrictions and providing a consistent approach to get restrictions removed.
- The collaborations/teaming with this project in the current year are better than it has been in the past. Particularly notable is the Hydrogen Code Improvement (HCI) Team activities collaborating/teaming with the FCHEA Transportation Working Group (TWG) Joint Task Force on Regulations, Codes, and Standards (RCS). That team is led by Jennifer Hamilton from the California Fuel Cell Partnership, which has two

[1] www.fuelcellstandards.com or http://www.hydrogenandfuelcellsafety.info/

special task forces: one for strategic thinking and one for writing code. The HCI is providing significant collaborative participation in that effort.
- The collaboration and coordination seem to be good and well managed with a high degree of involvement from different stakeholders.
- The number of coordinated interfaces is impressive.
- Collaboration exists, and partners are fairly well coordinated.
- The project should get the U.S. Department of Transportation (and its associated agencies: the National Highway Traffic Safety Administration and Pipeline and Hazardous Materials Safety Administration) more involved. The collaborations should not just be side conversations but should provide regular input so the work is not being done in silos and the different departments understand what the others are doing. This is critical to national rollout and coordinated efforts.
- It is not clear whether there is a better metric to show engagement with SDOs/CDOs, such as drafts reviewed, C&S proposals, accepted proposals, and leadership positions on committees/working groups. It is not clear whether there is enough engagement with industry associations. Much of this work should be coordinated by them.

Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.6** for its relevance/potential impact.

- Concise codes and broad AHJ understanding of applying codes are critical to the success of hydrogen infrastructure, and the project addresses both of those needs very well. Needed changes to codes (such as separation distances) will continue to evolve through the various standard-setting bodies, so work will need to continue both to educate the standard-setting bodies as new information informs changes to C&S and to inform/update those applying the C&S of the changes that have been made and why they are good.
- The relevance of this effort is very good. Without harmonized intelligent C&S, the deployment of safe hydrogen technologies would not happen. This project goes a long way to make sure the RCS domestic community is ahead of RCS needs.
- The project aligns well with the Hydrogen and Fuel Cells Program and DOE research, development, and demonstration (RD&D) objectives. It also has the potential to advance progress toward DOE RD&D goals and objectives.
- The project is certainly relevant. It may be difficult to gauge the immediate impact, but the project will certainly see the effects as stations are built/deployed in the coming years.
- The project has the potential of providing a high impact, but to maximize it, it is essential to keep the commitment of the different stakeholders.
- Part of the impact is evident as stand-alone products. Other impact is integrated or merged in a wider effort.
- This work aligns with DOE objectives. However, there may be some overlap with other activities (SCS-019 and SCS-022). It is unclear how this is truly coordinated.

Question 5: Proposed future work

This project was rated **3.2** for its proposed future work.

- The future work proposed is good and necessary. It continues in line with the previous efforts.
- The proposed future work grows from the existing effort, which is fine. It would be good to see increased effort in the collaboration/teaming area.
- On the topic of “codifying the mitigation measures to reduce setbacks,” codifying is already happening with stations being built (and opened), so it is crucial to get stakeholder input.
- There is some overlap with other projects. Some tasks did not fully describe how the project will drive results. There is no mention of the International Organization for Standardization. These documents will be published in future years. It is not clear how this project will support adoption/acceptance and improvement.

- With the exception of the engineering-based liquid hydrogen setback distances, the future work proposals have insufficient detail regarding who will do what and when. For a funding request to be made, a project plan with more detail about planned activities for the next year must exist. It would be helpful to see in particular what the measurable deliverables are and how they are prioritized.
- The project should continue to work on overcoming project barriers/challenges.

Project strengths:

- The project addresses a critical need in streamlining the safe deployment of fueling infrastructure for hydrogen vehicles and for other installations (e.g., stationary fuel cell applications). The emphasis on communication to stakeholders by developing and making available information that has been developed in the hydrogen industry is to be commended.
- There is a great deal of knowledge behind the work and many good and timely activities happening in parallel.
- The principal investigator is clearly very knowledgeable about code language, the code writing processes, and how AHJs work and think. The principal investigator is a very good asset.
- The project relies on highly qualified and broad competences.
- Continuous improvement of C&S is critical.
- The project is generally effective.

Project weaknesses:

- While not a weakness with this project, per se, communication to the "outside world" is a global challenge. Most of the time we are all talking to each other, but it is important to consider how to get the word out to the people who need to know it is there and use it. There is some of that through workshops, for example, but that is still very focused/targeted. Another challenge is dealing with commercialization in real time; stations are opening on a weekly basis, and there is lag with research and development (R&D), making it difficult to keep up with the pace. It is not clear that this can be fully resolved, but it should be recognized, and there should be efforts to stay "ahead of the curve." A good example of this is the reality of the code cycles, which lag behind the pace of industry but work closely with industry to get the most up-to-date information to help inform the code committees.
- While the teaming and collaboration is better, the project can still be improved. When presented, it looked like the HCI project was just at NREL, but when questioned, the principal investigator did articulate that it was part of the FCHEA TWG special RCS task force. It would have been good to have the principal investigator note that and embrace that activity during the presentation rather than clarify it during a Q&A.
- Because the area of interest is so large, there is a risk of tackling too many items with not enough resources for each one and of losing focus. It would be beneficial to see prioritization of the planned initiatives to justify/communicate a focus on the top five (or top three, six, or whatever is appropriate) with more specific deliverables for each one.
- From the presentation, it appeared that some of the achievements are based on a "one-man team." If they are the product of the team at NREL, it should be made clearer next year.
- It is not clear how this project has improved C&S or is driving clear movement.

Recommendations for additions/deletions to project scope:

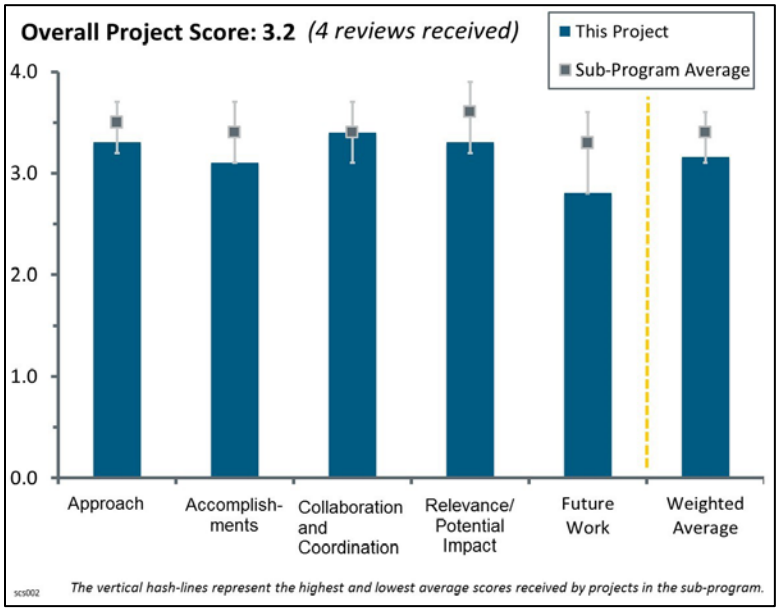
- It would be good to see a topic regarding development of a plan or template for how to tackle the issue of use restrictions that vary with location/authority (e.g., tunnel restrictions). This is a challenging topic, to be sure—the deliverable may not be a specific step-by-step list of actions to take, but rather a list of who to talk to and what questions to ask to establish the path of action for each individual situation.
- The project should maintain a balance between R&D (for future implementation) and the current activities and deployment.
- The project should consider reviewing overlap with other projects.

Project #SCS-002: Hydrogen Component Research and Development

Robert Burgess; National Renewable Energy Laboratory

Brief Summary of Project:

The objective of this project is to conduct research on pressure relief device (PRD) failures with the goal of gaining an improved basic understanding of high-pressure hydrogen operational safety and risk. Results are provided to manufacturers and system suppliers for enhanced design, operation, and quality control of PRDs for use on high-pressure hydrogen systems.



Question 1: Approach to performing the work

This project was rated **3.3** for its approach.

- The project provides learning that is potentially critical to many areas of hydrogen use and deployment—the work will inform design practices, component reliability research and development (R&D), materials assessment, risk analysis efforts, etc. It is good to see the literature search combined with the specific testing and test method development to help advance knowledge and raise awareness.
- The approach is good for the level of funding provided. The modeling of collaborations based on success with the sensor laboratory is an effective approach to managing reluctant participants from disclosing proprietary data. The main reservation with the approach is that the project analysis seems to be ending prematurely.
- It is unclear why this task was attempted. The approach, if it was to replicate a field failure, is appropriate.
- It is unclear how these results would be applied.

Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **3.1** for its accomplishments and progress.

- Progress so far is beginning to scratch the surface of creating knowledge that may have far-reaching impacts on the safety of hydrogen systems. Understanding PRD failure mechanisms is important to designing safe systems.
- The team has developed good root cause analysis and forensic review skills and tools.
- The project has laid good groundwork by uncovering/summarizing some specific problems/concerns. Data development is still needed; at this point the testing is not on a statistically significant sample size. Nonetheless, it can, one hopes, inform some of the work on risk analysis.
- The field failure was duplicated.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.4** for its collaboration and coordination.

- There is good work with the Compressed Gas Association (CGA) and gas suppliers. The industrial gas companies in their large installations have been able to apply engineering and administrative controls in

their installations/processes to mitigate risks associated with PRD valve reliability, but this may not work well with retail/public facilities—it is to be hoped that spreading awareness of this issue will elevate efforts to get systems to eliminate the hazard.
- CGA and the industrial gas suppliers in the hydrogen energy market are engaged.
- The collaborators appear to be suitable, but the lack of a valve manufacturer is notable.

Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.3** for its relevance/potential impact.

- This project likely will strongly influence codes and standards (C&S), in that it may provide sufficient rationale to determine whether PRDs enhance safety and should therefore be required or represent a failure mode and should therefore not be required.
- The project/results directly apply to key objectives/barriers in deploying hydrogen infrastructure and providing data to inform C&S development.
- It is difficult to see why a well-known failure mode was replicated.

Question 5: Proposed future work

This project was rated **2.8** for its proposed future work.

- Future work, at least as expressed in the slides, is somewhat broad/diffuse. It would be good to see more specifics on the development of statistically significant accelerated testing protocols to highlight maintenance interval needs and possibly materials selection issues.
- Much of the proposed future work is unrelated to this specific effort. Rather than using the limited data developed so far to support efforts to remove requirements for PRDs on hydrogen pressure vessels, it would be beneficial to see an expansion of the effort to better understand failure mechanisms of PRDs, thermal PRDs, etc. As the project could not replicate a key failure and identified some interesting information on some failure mechanisms, the objectives of this project as described on slide 6 have not yet been fully met. Some interesting information has been obtained that can readily lead to further investigation, which may result in better manufacturing techniques or designs of PRDs with improved reliability. The project results obtained so far do not convincingly demonstrate that removing the requirement for PRDs will result in a higher safety factor than exploring failure mechanisms sufficiently to facilitate more reliable PRDs.
- The project is complete.

Project strengths:

- The project deals with a very real problem and is working with real hardware samples. Also, the development of the test equipment and procedure are project strengths.
- This project provides useful information on failure mechanisms for PRDs.
- The expertise and resources of the National Renewable Energy Laboratory (NREL) are project strengths.

Project weaknesses:

- Recommendations for future work/direction need to be clearer.
- This was a short-duration project with a low level of funding. The effort does not explore leads identified from the project so far. It has not explored the subject sufficiently to conclude that PRDs should not be required in regulation, yet supporting the effort to loosen this requirement is one of the future work items.
- The applicability of the project is a weakness.

Recommendations for additions/deletions to project scope:

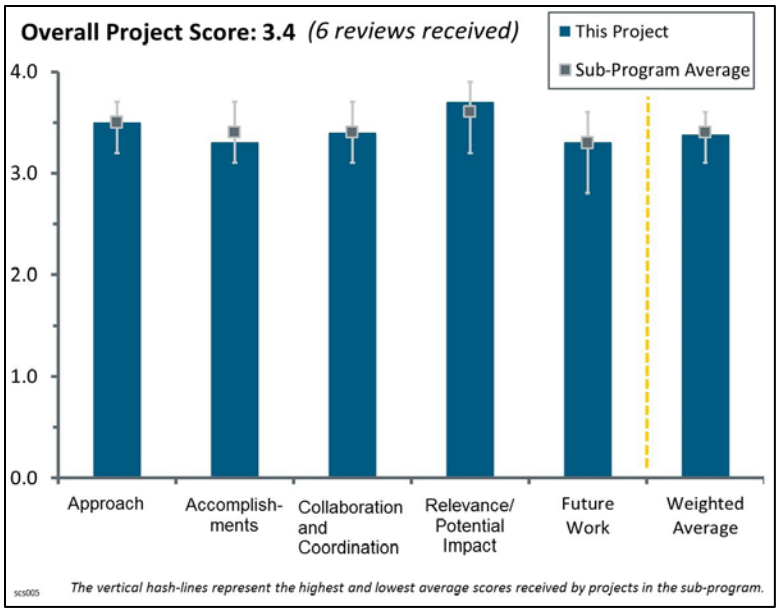
- While there is a need to start work on other components, this project has uncovered some interesting information that warrants further investigation. Recommendations for additions to the project include the following: (1) develop a plan for exploring more failure mechanisms, (2) expand the effort to various types of safety relief devices to make an informed recommendation on the feasibility of improving safety through use of such devices compared to a baseline of utilizing no such device, and (3) consider feeding lessons learned into safety models to help system developers make informed decisions regarding use of such devices.
- It is not clear whether additional samples (it appears that NREL has six valves in service) can be tested to develop at least preliminary statistics around valve failure modes.

Project #SCS-005: Research and Development for Safety, Codes and Standards: Material and Component Compatibility

Chris San Marchi; Sandia National Laboratories

Brief Summary of Project:

The main goal of this project is to enable technology deployment by providing science-based resources for standards and hydrogen component development and to participate directly in formulating standards. The project will (1) develop and maintain a materials property database and identify materials property data gaps, (2) develop more efficient and reliable materials test methods in standards, (3) develop design and safety qualification standards for components and materials testing standards, and (4) execute materials testing to address targeted data gaps in standards and critical technology development.



Question 1: Approach to performing the work

This project was rated **3.5** for its approach.

- The approach of this project aligns with the tasks required to overcome the barriers associated with developing a hydrogen embrittlement standard. The project has an excellent strategy to ensure the effort is valued and useful through coordination with expert organizations globally. The pursuit of a refined database is also a good approach to assist users in accessing and dissecting the various data.
- The project has clear deliverables/status for each barrier and is focused on a manageable number of topics (three). The topics selected provide key support for stakeholders working to develop performance-based standards.
- This is a sharply focused project. It has great graphics to depict the issue and accompany the data.
- The approach is sound and value-added. It is focusing on issues for higher-pressure hydrogen systems. More integration with the American Society of Mechanical Engineers (ASME) is warranted.

Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **3.3** for its accomplishments and progress.

- The project has excellent data that are clearly making it to codes and standards (C&S) committees and are usable by industry.
- Launching the database is a significant accomplishment, and it is commendable that the principal investigator resisted developing an in-house database program. The use of Granta not only should provide the maintainability and support benefits discussed in the session but also should make it familiar to outside stakeholders such as industrial users. The development of the low-temperature fatigue testing methods is also a significant contribution. It is not clear what will be required to move this methodology into the realm of performance-based standards and to ensure acceptance by stakeholders.
- The accomplishments to date are appropriate. Outreach through ASME, the American Society for Testing and Materials (ASTM), and SAE International is appropriate because they generate the general design codes and are where engineers have been trained to look for materials information. The CSA Group (CSA)

is a product safety standards organization. Outreach through CSA will have a limited effect as compared to ASME, ASTM, and SAE International.
- The materials property database is available for use. Low-temperature and fatigue crack propagation is ongoing.
- The technical progress of the project seems to be limited during the past year. The project established a database, which was useful, although additional testing data were not as prevalent in the project review. In addition, Sandia National Laboratories (SNL) has been developing the fundamentals for hydrogen embrittlement for a significant time. It would be helpful to highlight the previous progress and aspects that still need to be developed.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.4** for its collaboration and coordination.

- This project has a high level of collaboration with standards organizations, industry, and international organizations. It is excellent that the work associated with this project is directly linked to several hydrogen materials compatibility standards, including ASME, SAE International, and CSA. The collaboration of this project sets a good example for other projects to follow within the DOE C&S portfolio.
- The project has solid collaboration with standards development organizations, industry, and international entities. Data from international entities are clearly integrated and attributed. The project has great collaboration and outreach.
- The coordination and collaboration seem valid. The collaboration for documenting test methods is questionable. Test methods on this topic would most likely be published by ASTM. It is not clear why ASTM is not in the loop.
- The project is working with standards organizations, industry, and international research groups.
- The presentation gives limited information regarding collaboration in the database tools and low-temperature testing elements. It is important to articulate this for the low-temperature testing so that it is clear that there will be future broad buy-in and use of the methodology when standards are implemented based on the data created. In the advanced storage element, the collaboration with industry is discussed in terms of materials being provided by the partners. It is not clear how they have responded to the initial results and whether there is active dialogue with them regarding the methodology.

Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.7** for its relevance/potential impact.

- The project is highly supportive of the DOE research, development, and deployment goals to provide critical data and information needed to define requirements in developing C&S. The hydrogen embrittlement understanding and test method development is highly relevant for the industry.
- Continued migration to performance-based standards is critical to improving cost and timing of hydrogen-related product development. This project makes an important contribution to that migration by developing a methodology that should support and encourage standards that can reduce unnecessary conservatism in design.
- The project is highly relevant. Accelerating the pace of the research would not be inappropriate.
- The project is aligned with DOE goals and sharply focused.
- Developing standard test methods for materials testing would help develop harmonized standards.

Question 5: Proposed future work

This project was rated **3.3** for its proposed future work.

- The proposed future work makes sense. It would be good to publish the test methods at ASTM, generate a non-mandatory appendix for ASME (either Boiler and Pressure Vessel Code Section VIII Division 3 and/or

ASME B31.12) and create a technical information report through the SAE International Fuel Cell Standards Committee.
- Improving tools and database is a good path.
- The future work is appropriate for the project at a high level. Additional details and work plans would be useful to confirm the project has the needed focus and momentum to deliver results for the various standards organizations and collaboration efforts. It would be helpful to highlight the current gaps in the various hydrogen embrittlement standards and discuss the alignment to bridge the gaps.
- The project could benefit from a clearer statement of planned work. A summary of who does what when with specific deliverables would help make the project priorities clearer. It is likely that a project plan discussing resources and timing exists to support the future funding request. Perhaps that plan can serve as a starting point for a more concise plan for future work.
- Please coordinate results with Phase II of Global Technical Regulation (GTR) No. 13 on hydrogen and fuel cell vehicles. Phase II involves materials compatibility for hydrogen containers in vehicles.

Project strengths:

- The project provides significant support for the objective of simplifying materials selection and the designing/testing of hydrogen-related components, and highlights the need for specialized test capability and methodology (hydrogen at low temperatures and various pressures). These attributes coordinate well with SCS-026 regarding testing of polymeric materials and with the higher-level DOE objective of providing data to enable performance-based standards.
- The project strengths are its technical excellence and the value-added task in support of industry.
- The project is very focused and critical. Clear progress has been made.
- The researchers have the needed expertise, and their approach is good.
- The project serves a necessary role in developing and coordinating the technical data for hydrogen embrittlement test methods.

Project weaknesses:

- Most weaknesses from last year seem to be addressed. The need to continue to improve industry collaboration and conducting industry-led testing is the only “weakness.”
- A statement of specific areas in which future work can support standards development would be helpful and would support the need for more concise definition and prioritization of future deliverables.
- SNL has been involved with hydrogen embrittlement for a significant time, and the progress and remaining key actions should be explained because it is difficult to distinguish the relevance and new information from the project.
- There is room to improve on the end user aspect of the research.

Recommendations for additions/deletions to project scope:

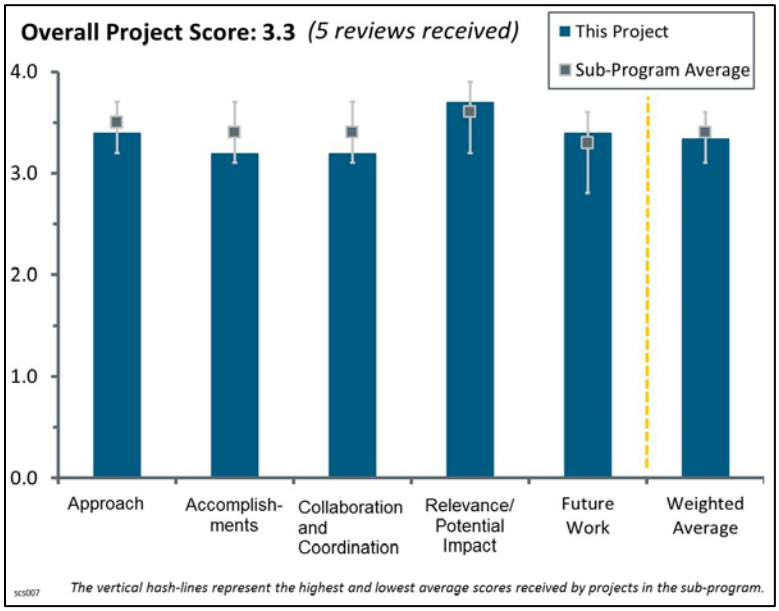
- More documentation through ASME, ASTM, and SAE International is recommended.
- The project should coordinate results with Phase II of GTR No. 13 on hydrogen and fuel cell vehicles. Phase II involves materials compatibility for hydrogen containers in vehicles.
- The recommendation for this project would be to ensure the database is accessible and helpful for users. The project should also include a roadmap of needed steps to complete the effort on hydrogen embrittlement. It would be beneficial to include in the scope a key next step for many initiatives being coordinated by this project.

Project #SCS-007: Hydrogen Fuel Quality

Tommy Rockward; Los Alamos National Laboratory

Brief Summary of Project:

The objectives of this project are to (1) focus on polymer electrolyte membrane fuel cell testing and collaborations and work with the American Society for Testing and Materials (ASTM) to develop standards and (2) develop an electrochemical analyzer to measure impurities in the fuel stream. The analyzer will be inexpensive, will be sensitive to the same impurities that would poison a fuel cell stack, and will support quick responses to contaminants.



Question 1: Approach to performing the work

This project was rated **3.4** for its approach.

- This is a broad project that covers three main objectives: ASTM work, an in-line analyzer, and the impact of a contaminant. The collaboration efforts with the VTT Technical Research Centre of Finland (VTT) and European Commission Joint Research Centre (JRC) on the impact of contaminants are valuable to this work. In addition, the approach taken to understand the effects and responses of CO and H_2S has been key in developing the analyzer prototype.
- The approach, which includes parametric studies of CO and H_2S tolerance coupled with single pass and hydrogen recirculation, seems very appropriate.
- The approach of evaluating the fuel quality under more realistic conditions, including recirculation, is a useful addition to the analysis. Other realistic conditions should be considered, such as the evaluation of the effects of complete stacks rather than cells. The international collaboration is a positive aspect of this project. The approach of using a fuel cell for the in-line gas analyzer appears to have significant risks because the noise factors within the fuel cell may cause difficulties with evaluating the impurity signal and the impurities may damage or alter the signal.
- Recirculation effects are significant. These were studied by the Japanese Automobile Research Institute (JARI) and presented to the International Standards Organization (ISO) Technical Committee (TC) 197 Working Group 12 in 2007. The approach could be improved to leverage existing data. JARI is listed as a collaborator in the overview slide, but the nature of that collaboration is not clear.
- The approach is very good. However, a more aggressive posture is needed with ASTM. The need for vetted test methods is moving from chronic to acute.

Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **3.2** for its accomplishments and progress.

- Accomplishments on this year's efforts have been outstanding. This has been demonstrated with the in-line analyzer results to include the instant response at 50 ppm CO plus the development of a prototype.
- Accomplishments are impressive.

- The project has made good progress in evaluating various impurities in a recirculation application and has attempted to validate the gas analyzer with a redesigned hydration scheme. The preliminary prototype results for the analyzer appear interesting, but further detail on the operation and validation is needed.
- Progress on hardware prototypes appears promising. Progress on ASTM standards cannot be evaluated from this presentation. Slide 6 states that eight standards are under consideration; however, the subject of these standards and their relevance to DOE goals is not clear. Progress on the development of standards since the 2015 DOE Hydrogen and Fuel Cells Program Annual Merit Review (AMR) is not clear.
- The progress at ASTM is slow, but this is probably beyond the ability of Los Alamos National Laboratory to influence. The progress on the sensor is excellent.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.2** for its collaboration and coordination.

- Collaborations seem to be appropriate and fruitful. With the recent work initiated under ISO/TC 197, this could be added to the list.
- The collaboration on this project is very good, especially with respect to ISO. It would be helpful to have additional information about the coordination with other organizations, such as SAE International. In addition, a status on the round robin testing would be useful.
- The collaboration on the ASTM work is appropriate. The work on the sensors is promising.
- The researcher has strong collaboration with international organizations that are leaders in the hydrogen fuel quality area. The team should explore further collaboration with scientists and engineers from the National Renewable Energy Laboratory who are working on fuel contaminant analyzers for hydrogen stations.
- The effort is focused on hydrogen quality; however, there is no mention of collaboration with ISO/TC 197, where international standards for hydrogen fuel quality have been developed and are undergoing revision. There is no mention of using the wealth of data already available on contamination testing and effects of recirculation. It is good that SAE International and ISO hydrogen-quality specification limits will be used in testing the in-line hydrogen analyzer. Further information on how the results may feed back into standards development would be useful.

Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.7** for its relevance/potential impact.

- The two project objectives related to hydrogen fuel quality and the in-line quality analyzer are highly relevant to the DOE research, development, and deployment goals and important for the fuel cell industry.
- Understanding the real impact of contaminants and continuous fuel quality monitoring are some of the main challenges that will need to be addressed not only in the United States but also globally to enable a successful rollout of safe and reliable hydrogen stations.
- Both topics are highly relevant. The work with ASTM is a critical path.
- Resolving fuel quality issues is one of the most critical objectives of the DOE Hydrogen and Fuel Cells Program.
- Development of the in-line analyzer will have a significant impact on deployment of fuel cell electric vehicles (FCEVs) and hydrogen dispensers. Impacts of the work with ASTM are less clear. The impact of the work is difficult to evaluate from the information provided in the presentation.

Question 5: Proposed future work

This project was rated **3.4** for its proposed future work.

- On the fuel quality part of the project, the team seems to be on the right path by continuing the collaboration with VTT, JRC, and CEA (CEA-Liten). For the in-line analyzer work, the focus has been on

CO and H_2S, and the path is clearly defined. It would be interesting to include in the future work some efforts on other potential contaminants, such as H_2O and NH_3, and have some preliminary analysis on the potential target cost for this device.
- The proposed future scope seems appropriate to meet the project objectives.
- The future work at a high level appears to be appropriate for the project scope. Additional details on the plans and timing would be useful to understand the expected timeframe for the deliverables.
- The proposed work is appropriate.
- Future work on ASTM standards needs better-defined milestones. The hydrogen fuel quality work appears reasonable; however, it would be useful to spell out in the presentation how this effort fits into existing efforts at SAE International and ISO beyond validating the in-line analyzer to the hydrogen quality specifications from those standards development organizations. Information, data, and idea exchanges should be described if they take place. A solution for the need for test sites and/or funding for testers needs to be determined.

Project strengths:

- Project strengths are the project's strong knowledge, experimental base, and international partnership.
- The strength of the project is the importance of the scope and focus that is underlying the effects of hydrogen quality and developing a gas analyzer.
- Development of an in-line analyzer for hydrogen fuel quality will facilitate deployment of FCEVs and hydrogen refueling dispensers.
- The expertise of the laboratory is a project strength.

Project weaknesses:

- Project weaknesses are the lack of time scale for publication of ASTM standards; lack of testing due to a shortage of suitable test sites or the need for funding testers; and lack of clear ties to available resources, such as previous studies. Decision points, milestones, risks, barriers, and challenges are not described. The final slide acknowledges a similar comment from the 2015 AMR; however, the response makes an erroneous assumption that reviewers have access to reports presented in other forums. Projects are reviewed based on materials provided for the reviewers in the presentation package. It is recommended that the principal investigator take advantage of the opportunity for reviewer-only slides to provide the details that were "presented to the Codes and Standards Tech Team."
- The weakness of the project is the under-appreciation of the noise factors that could change the gas analyzer signal.
- Dependence on test sites that may be lacking funding is a project weakness.
- The lack of urgency at ASTM is a project weakness.

Recommendations for additions/deletions to project scope:

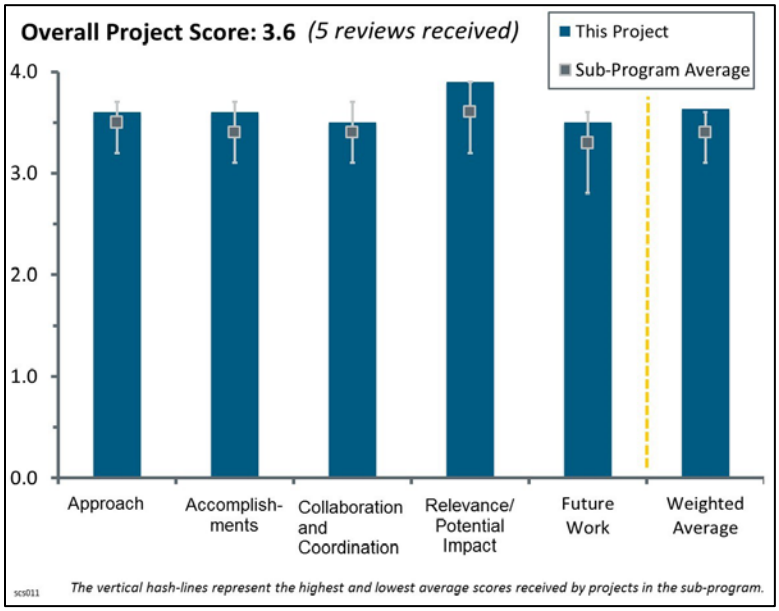
- Go/no-go decisions should be defined for this project, particularly for the ASTM activities. The project scope should include cohesive reporting to an audience that is broader than the Codes and Standards Tech Team. The project should consider publishing project progress and next steps in appropriate peer-reviewed journals or industry news articles to raise awareness of the activities and help inform interested parties.
- An addition to project scope would be to highlight the feedback of the desires from the hydrogen production industry to adjust certain impurities and develop a work plan to evaluate whether the purity standard can be relaxed to these values. The scope should also provide a better correlation of the effects of impurity on a cell level to a full stack level. For the gas analyzer, a disciplined study on the various noise factors needs to be conducted and evaluated to ensure viability of the approach.

Project #SCS-011: Hydrogen Quantitative Risk Assessment

Katrina Groth; Sandia National Laboratories

Brief Summary of Project:

The primary objective of this project is to provide a science and engineering basis for assessing the safety of hydrogen systems and facilitate the use of that information for revising regulations, codes, and standards (RCS) and permitting stations. Sandia National Laboratories will develop and validate hydrogen behavior physics models to address targeted gaps in knowledge, build tools to enable industry-led codes and standards revision and safety analyses, and develop hydrogen-specific quantitative risk assessment tools and methods to support RCS decisions and to enable a performance-based design code compliance option.



Question 1: Approach to performing the work

This project was rated **3.6** for its approach.

- The coordinated approach is well thought out. Targeted efforts to develop tools and put them into the hands of those needing them are directly relevant to U.S. Department of Energy (DOE) goals and the barriers and needs uncovered in recent years. As the software gets used, there may well be suggestions for further improvements.
- The project is effective and contributes to overcoming most barriers.
- This is really great work.
- The approach appears to be appropriate.

Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **3.6** for its accomplishments and progress.

- The project demonstrated excellent progress on adding the flexibility and improvements that stakeholders identified previously. Publication of reports and user guides is an excellent way to help meet objectives and make it easier for industry to be aware of and use the tools developed. Good efforts are being made to get the input and feedback required from users. This input is necessary to advance the project and is unfortunately not completely within the control of the project team.
- The progression from a beta version to a usable version of the Hydrogen Risk Assessment Model (HyRAM) has been impressive and will produce a great tool.
- The project has made substantial progress on HyRAM, its rollout, and its acceptance.
- The progress and accomplishments are impressive. However, it would be helpful to benchmark the hydrogen work against compressed natural gas (CNG).
- The project is effective and contributes to overcoming most barriers.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.5** for its collaboration and coordination.

- Agreements to work directly with key industry partners to validate efforts are excellent. There are very good international partnerships and a good approach that involves sharing ideas to build consensus in order to harmonize separation distance methodology.
- This team has coordinated with National Fire Protection Agency (NFPA) 2 Technical Committee (TC) and International Organization for Standardization (ISO) TC 917 and brought value to both committees.
- There is good collaboration; partners participate and are well coordinated.
- Although AVT Research, Inc., may be an exception, referencing one-man shops (Zero Carbon Energy Solutions, GWS Solutions) may not be as impressive as it sounds. Shell; Chevron; Air Products and Chemicals, Inc. (APCI); Praxair; etc., would carry more weight.

Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.9** for its relevance/potential impact.

- The combination of timely research, direct participation in codes and standards development activities, and interaction with stakeholders to validate and build upon the modeling work is outstanding and likely to result in harmonized, acceptable methodologies for science-informed separation distances.
- The project is critical to the Hydrogen and Fuel Cells Program and has potential to significantly advance progress toward DOE research, development, and demonstration goals and objectives.
- This is very useful for NFPA work.
- The work is highly relevant.

Question 5: Proposed future work

This project was rated **3.5** for its proposed future work.

- Adding suggested modules and developing a mechanism for user-supplied data as planned will make the tool even more useful.
- The work is effective and contributes to overcoming most barriers.
- Focusing on pushing a prototype program into the fire codes may not be well accepted. A benchmarked tool would be easier to get accepted. Continuing work on liquid hydrogen and the practical lower flammable limits and lower explosive limits would be helpful.
- The project needs more emphasis on adding liquid hydrogen capability. It would be helpful if the project could address releases in a container that did not trap hydrogen under a roof, thereby limiting the concentration.

Project strengths:

- HyRAM provides a visual representation of the underlying assumptions and physical phenomena, which is great.
- This project represents a science-based approach to address barriers directly relevant to DOE goals with significant interfaces for user input to ensure the tool meets stakeholder needs.
- The project will have excellent impact on hydrogen safety, codes and standards.
- Strengths include the skill set and value-added approach.
- There has been good progress on HyRAM release and rollout.

Project weaknesses:

- There may be additional recommendations from users as they begin to work with HyRAM, which may result in the need for development of additional modules, further data, etc. It would be good if this project were to continue with sufficient time and funding to accommodate such feedback.
- The proposed work to evaluate cold/liquid releases does not appear adequate to meet the needs of the project if the intent is to address large-scale releases.
- The project lacks benchmarking against other fuels.

Recommendations for additions/deletions to project scope:

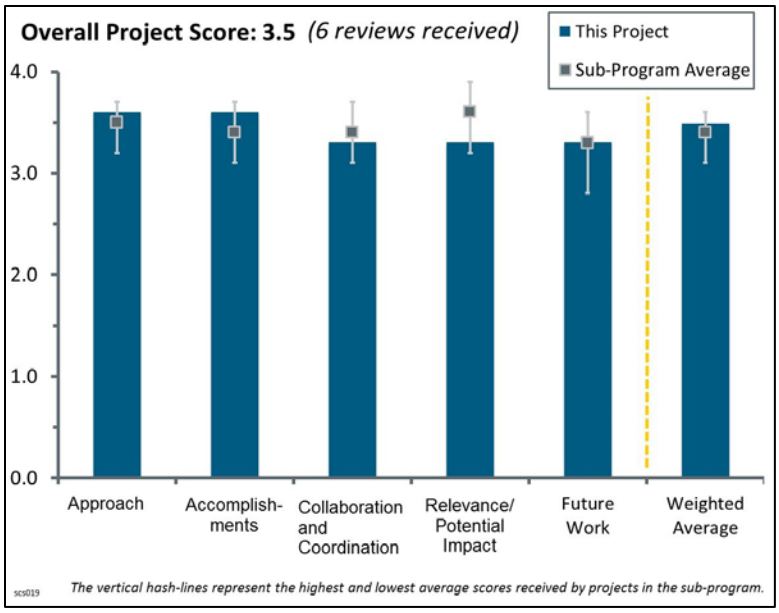
- The project should continue to promote the availability of the tool. The team might consider integrating it into future permitting workshops held by authorities having jurisdiction or other forums in which stakeholders can get hands-on experience using the tool and provide feedback. Experience and input is critical to improving the tools. While this model is focused on hydrogen fueling stations, it would be great to develop a tool (whether additional modules or a new modeling tool) that could help answer questions posed by regulators, such as what would happen if a hydrogen vehicle tank ruptured inside a parking garage, tunnel, etc.
- The project should continue to work on uncertainty analysis and sensitivity studies.
- The project needs to address roofless enclosures and evaluate the potential differences and/or advantages of such a design.
- The project should add benchmarking against other fuels.

Project #SCS-019: Hydrogen Safety Panel, Safety Knowledge Tools, and First Responder Training Resources

Nick Barilo; Pacific Northwest National Laboratory

Brief Summary of Project:

This project provides expertise and recommendations though the Hydrogen Safety Panel (HSP) to identify safety-related technical data gaps, best practices, and lessons learned, as well as helps integrate safety planning into funded projects. Data from hydrogen incidents and near misses are captured and added to the growing knowledge base of hydrogen experience to share with the hydrogen community, with the goal of preventing safety events from occurring in the future. The project also aims to implement a national hydrogen emergency response training resource program with adaptable, downloadable materials for first responders and training organizations.



Question 1: Approach to performing the work

This project was rated **3.6** for its approach.

- There are really three distinct tasks in this project. Each is important. The HSP, in particular, is an excellent way to help ensure projects include a quality safety review.
- This project (actually three projects) continues to perform very well, particularly given the limited budget. The approach and focus clearly enable project success.
- Focus on objectives is outstanding.
- The approach is generally effective but could be improved. The project contributes to overcoming some barriers.
- A panel, a website, and training/education, while critical, are obviously subject to scope creep without clear definition. It is not that these are not important but that clear definition/scope (and what is out of scope) around each activity was not fully clear.

Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **3.6** for its accomplishments and progress.

- Given the focus of these activities, the measurable output is excellent and well-focused on those who need it. The outreach from the HSP is exactly what was suggested in previous reviews, and the portal is clearly a used resource—indeed, people are finding it on their own and find it useful. The responder training remains a hallmark of this work. It is particularly good to see this effort collaborate as closely as it does with the California Fuel Cell Partnership. The book is really nice.
- Accomplishments are outstanding. The addition of new members to HSP helped to increase high-quality output. Recent work with the California Energy Commission indicates appreciation of HSP work and value for stakeholders other than those of the federal government. The release of a product (field) certification guide is a tremendous help to both industry and regulators.

- There has been demonstrated accomplishment in the HSP, safety webinars, equipment certification guide, engagement with states and the public, safety knowledge dissemination, the H-prize, and the H2Tools website. There has been a significant ramp-up in activity since 2015.
- The increase in number of projects reviewed by the HSP is indicative of this effort's success. Developing classroom training that is adaptable and accessible to emergency responders is progressing well, with great feedback from those who are taking part. The presentations on safety knowledge tools appear to be effective in generating interest. There are some concerns regarding the H2Tools portal part of the task. The first concern is in regard to the response of a 2015 reviewer comment pertaining to data maintenance. Although it makes sense to have the owners keep this information updated, this may not happen for a number of possible reasons. Such updating requires resources. There is no clear commitment or plans to provide such resources. There is a risk that the data will not be maintained or that such maintenance may end up needing to be performed by project participants. The second concern has to do with the home page of the H2Tools website, which looks like the Fuel Cell & Hydrogen Energy Association (FCHEA) Hydrogen and Fuel Cell Safety Report, with articles pertaining to codes, standards and regulations—several of which have recently been featured in the FCHEA publication. There are also several articles featured that are unrelated to safety. The home page has the look and feel of a trade association or advocacy group rather than a site to aggregate hydrogen tools focused on safety.
- All areas show good progress and accomplishments. Providing "approval" guidance does not solve the problem of lack of certified equipment. It is not clear how HSP supports codes and standards (C&S) directly or whether they can review/provide input on drafts. The project needs more metrics on training—retention of knowledge, etc.
- The project is effective and contributes to overcoming most barriers.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.3** for its collaboration and coordination.

- Domestic collaboration and outreach is truly outstanding. Indeed, this activity has recently opened collaboration with the HyResponse European Union program. The project has worked with HyResponse previously and recently visited France with firefighters to learn from the HyResponse project and for HyResponse to learn from U.S. firefighters to get feedback on the project. This is outstanding. This project should give serious consideration to what the United States can adopt from the HyResponse project in its domestic training.
- The project engages with many of the right partners and seeks to leverage resources with similar international efforts. Collaboration with H_2USA so far appears to be limited to a previous International Code Council (ICC) workshop. As H_2USA is also developing tools and information resources and conducting outreach with authorities having jurisdiction (AHJs) through presentations and web-based materials, closer collaboration is suggested, as well as cross-referencing to minimize duplication.
- Having HSP involved is outstanding. The collaboration with H2tools needs improvement (it seems to be mainly driven by national laboratories, leaving out industry associations and industry). Planned collaboration with first responders is good; it sounds like measures are in place to engage firefighters' associations.
- There is good collaboration; partners participate and are well coordinated.
- Collaborations seem to be appropriate and growing.
- More collaboration/outreach with states and local officials/public is needed to get quicker approvals for hydrogen stations.

Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.3** for its relevance/potential impact.

- These projects are spot on, and impact is high and fairly obvious. If the state of California is asked to name the rate-limiting step on deploying fueling stations, the answer is not permitting, codes, and standards.

Because of the outreach of this project and that of others, the AHJs are very receptive to hydrogen technologies. This comfort level is a direct result of the fine work this project has done over the years.

- The success of HSP and H2Tools is critical for the DOE Hydrogen and Fuel Cells Program (the Program) achieving its technology deployment objectives.
- The HSP, safety knowledge tools, and first responder training activities should be evaluated separately. The HSP is critical to ensuring early activities have expert safety review. The training activity has the potential to have significant impact if the training can be integrated into the curriculum of one or more organizations responsible for first responder training. The Safety Knowledge: Tools and Dissemination effort seems to be less relevant, as there are already organizations doing much of this work. The original concept was to pull together existing information, such as risk mitigation tools and hydrogen incidents, into formats to make them easier to access on the ground—for example, through applications (apps) on popular mobile phone platforms. The current direction appears more like a stand-alone website that uses information developed by others but which must be updated separately. At the moment, that appears to be duplicating effort. Maintenance of such information will require further duplication.
- Most project aspects align with the Program and DOE research, development, and demonstration objectives.
- There does not seem to be much specific tie-on to DOE relevance and impact.

Question 5: Proposed future work

This project was rated **3.3** for its proposed future work.

- HSP's proposed future work seems to be to continue doing what is being done, which is appropriate. Expansion to non-DOE projects, and in particular state-level projects, is also appropriate. Identification of a suitable entity or entities to take on the first responder training activity is critical to successfully getting this training into the hands of those who need it most. However, the H2Tools plans appear to have deviated from the reviewer's understanding of this aspect of the project. Adding more than 600 papers from the International Conference on Hydrogen Safety to the Hydrogen Tools Portal may not be the best use of resources. The kinds of tools that have a large impact on safety are tools for calculating or evaluating risks; data to prevent incidents such as those found in the Hydrogen Incident Database, which includes functionality to upload incidents; and the Hydrogen Risk Assessment Model (HyRAM). Loading hundreds of existing papers may not be as valuable an activity. If documents are needed in lieu of tools, perhaps the project could link to the resources rather than import them, as maintenance of imported information remains an issue. Regarding the plan to "Lead the development of the Safety, Codes and Standards outreach plan to establish a multiyear strategy for reaching code officials, relevant stakeholders and first responders through 2020," it is highly recommended that the project do this through or in partnership with H_2USA, as this group is already working in this space, having identified the target regions and markets, as well as with FCHEA, which has launched a significant targeted outreach plan. The plan to develop a C&S guide—a drill-down, question-based tool to provide an outline or checklist of code requirements for a specific application—could have value, particularly if this were to be a mobile phone app.
- The future plans are a natural growth of this project. The project did not receive a score of 4, only because there should be more effort to get the infrastructure development activities in the Northeast to make use of this project, specifically HSP. This will take more effort on behalf of HSP because the Northeast infrastructure developers are using private funds rather than using government funds as California is doing.
- There is a good plan for future activity. It is not clear why the certification guide was not included in future work for fiscal year 2017. This will need constant refinement as C&S and Nationally Recognized Testing Laboratory capabilities evolve. The HSP role in C&S development should be increased.
- The project is continuing ongoing activities and transferring some of the mature activities to a third party, which is good.
- Propose future work seems to be appropriate for meeting the project objectives.
- Proposed future work is generally effective but could be improved.

Project strengths:

- The project has an excellent principal investigator and excellent program/project execution. The project has achieved great results on a limited budget. The project is simply excellent.
- HSP is top-notch and critical. It is good to see this work expanded beyond DOE-funded projects.
- The project has a very strong knowledge and expertise base, which has significant potential for providing services to a broad spectrum of stakeholders.
- The project is well planned, and the project managers and participants have the needed expertise.
- It is important to have interface tools for the public. It is important to continue with HSP but push HSP into a broader role.
- Accomplishments relative to project barriers and challenges are good.

Project weaknesses:

- There are no significant weaknesses. The first responder training element is more of a transition element rather than a weakness.
- There is potential for loss of focus because each project has a different goal and different needs. Perhaps these can be better integrated and leveraged.
- The H2Tools part of the project no longer seems headed where it was when launched. Much of the effort duplicates existing efforts and requires extra maintenance.
- Funds are insufficient to really execute what could be done.

Recommendations for additions/deletions to project scope:

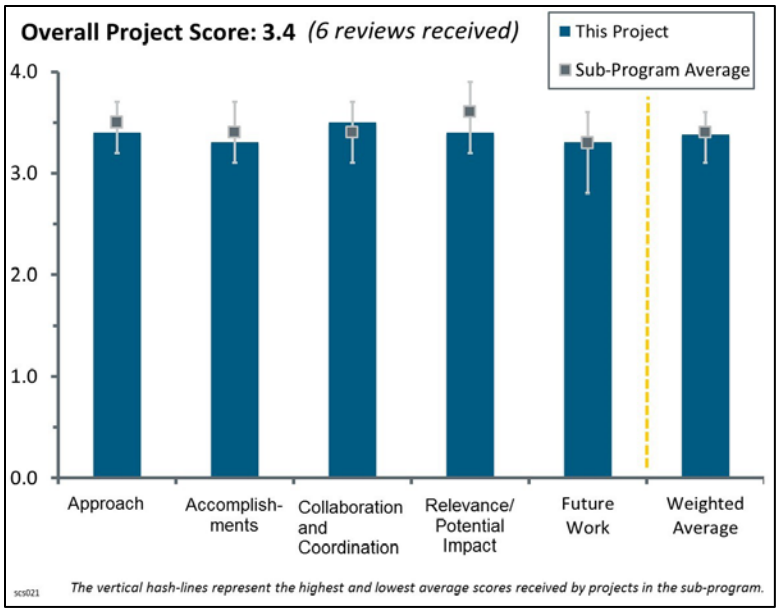
- The project should continue the outstanding effort in supporting/contributing to C&S development such as the published guides for enclosures and product field certification. This role could be extended in reviewing/vetting model code draft standards such as NFPA 2/55, NFPA 30A, etc. (potentially in partnership with the Sandia National Laboratories C&S team).
- H2Tools should be focused on the development of tools that project developers can use in the field rather than on a database of articles that exist elsewhere. The project should consider adding HyRAM to the H2Tools website, as this tool is now available for download by the public. The project should also consider announcing new features, workshops, tools, etc., through press releases shared with organizations that share such news to those most likely to utilize the tools. Examples include the National Association of State Fire Marshals, FCHEA, NFPA, ICC, and announcements at the National Hydrogen and Fuel Cells Codes and Standards Coordinating Committee monthly webinars.
- It is time for more attention to be given to the Northeast, with outreach and possibly more direct interaction with the HSP. To provide more resources for the outreach, training, and portal work, maybe a different funding model for the HSP should be considered. Possibly a user-funded model would help—for example, the financial burden of a safety review could be put on the project that is being reviewed, dividing up the financial responsibility among the projects that benefit from that review.
- More collaboration/engagement/outreach is needed with states and local officials/public to get quicker approval for hydrogen stations. Probably it would help to partner with environmental groups to advocate to the public on the safety of hydrogen fueling stations and other applications of hydrogen and fuel cell electric vehicles.
- The project should continue to address project barriers and challenges.

Project #SCS-021: National Renewable Energy Laboratory Hydrogen Sensor Testing Laboratory

Bill Buttner; National Renewable Energy Laboratory

Brief Summary of Project:

Sensors are a critical hydrogen safety element and will facilitate the safe implementation of the hydrogen infrastructure. The National Renewable Energy Laboratory (NREL) Sensor Laboratory tests and verifies sensor performance for manufacturers, developers, end users, and standards-developing organizations. The project also helps develop guidelines and protocols for the application of hydrogen safety sensors.



Question 1: Approach to performing the work

This project was rated **3.4** for its approach.

- The approach taken by this principal investigator (PI) and laboratory is generally excellent. The laboratory is well-thought-out; the collaborations are global, involving excellent laboratories and researchers. This provides an excellent opportunity for blind testing between the facilities to ensure the science and measurements are accurate. The interaction with the "community" involving the research community, equipment manufacturers, suppliers, users, and standards development organizations (SDOs) helps to ensure the project leads the state of the art and stays relevant to the needs of advancing the deployment of hydrogen technologies. The approach is excellent.
- There are many issues associated with development of hydrogen sensor technology, and the capability to evaluate the claims that manufacturers attribute to their products is key. Important aspects include measuring sensor performance at the sensing element level, as a sensing device and in analyzers; quantifying issues of sensor deployment in the application environment; translating overall findings into support of codes and standards (C&S) development; supporting safety and process applications; coordinating laboratory standards with other laboratories; and maintaining confidentiality of proprietary designs. The NREL Sensor Laboratory has worked to achieve all of these functions, which are critical for development and deployment of sensor systems.
- The approach of validating the accuracy of various sensor or sensor systems in a blind study is useful in and of itself to prove or disprove the myth that hydrogen sensors do not work. This is also probably the most extensive testing following the various sensor consumer product safety standard test methods. Feedback on the test methods to upgrade the SDO documents would be value added.
- The approach used is good because it is based on collaborating with organizations and helping them find appropriate sensors for a specific purpose.
- The project approach appears to fit in well with the overall NREL hydrogen safety structure and has provided model support for and interaction with industry in advancing the application of hydrogen sensors (the Service Bay project with Toyota/KPA). This project team has also acknowledged that there is much work to do in the area of appropriate application of sensors. There is evidence of a thorough study of and solid methods for empirical testing of sensors and the classification of sensors. It feels as if the project team is saying that one of the critical needs is documentation of guidance for application, but it is not clear that the work plan focuses on that priority. For example, the measurement of the venting profile does not clearly relate to the barrier reports or to the directions discussed in the relevance section.

- The approach is generally effective but could be improved. The project contributes to overcoming some barriers.

Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **3.3** for its accomplishments and progress.

- The sensor laboratory addresses a number of important needs of the hydrogen community that are DOE goals. Among these are providing a consistent and reliable methodology to evaluate sensors; coordinating sensor evaluation methodology with international partners; providing consistent and reliable evaluation of industry sensors, including the recent ones; evaluating the colorimetric indicator tape; and acting as a source of information on safety issues regarding sensor use, including recent CRC Press publications.
- The progress and accomplishments to date are excellent.
- Developing sensor function test facilities and methods is very important to the next step of developing better application information. It seems like many sensor problems are really application or misapplication problems, so having this foundation to start to address those issues is good. The tailpipe sensor selection/assessment work is also very valuable. Perhaps that work can now be coordinated with the component research and development to make sure the durability/reliability of a specific sensor in a specific application is well understood.
- It was a little difficult to score this review category, because all examples of accomplishments and progress, except one, were excellent. The sub-project "Support of Infrastructure Empirical Profiling of LH2 Releases during Routine Venting" could have been presented under Approach. However, what is being executed is an array of vertical pointwise measurements taken about 10 seconds apart. These are not simultaneous data points but separated in time because they are multiplexed into the data sampling system. There are 10 ports, 10 seconds apart, which means that each port is sampled every 100 seconds. Presumably this vertical probe will be moved spatially to try to get some spatial and temporal information on a highly transient, turbulent, three-dimensional (3D) spatially dynamic event. The purpose of this effort is to gain information on the cold plume behavior during a cryogenic fill operation from a cryogenic tank several feet high and presumably on the behavior of the hydrogen during the release. The physics of this event is a function of 3D and of time. The pointwise-in-time and space measurement of anything will yield useless information. If there are non-detects, it says nothing about the jet—for example, the plume could have been at the sensor location earlier than the sample and moved when the sample was taken. The reverse is also true. What is needed, ideally, is a 3D time-resolved movie of the release (hydrogen, water, ice, oxygen, nitrogen, etc.); the next-best option is a line-of-sight integrated volumetric time-resolved movie (such as schlieren or shadow graph). Point measurements in this situation are a waste of time and money because nothing of meaning can be expected from this effort. These pointwise measurements will be woefully inadequate to compare to any computational fluid dynamic calculation. Indeed, a FLACS software calculation would provide a much more trustworthy insight into the plume behavior than data from this proposed experiment. Except for the noted sub-project, this project continues to have an outstanding outreach/publication record. The project contributes to appropriate technical symposia, journals, reports, books, etc., which is excellent.
- The project has demonstrated application of different types of hydrogen sensors for different industry needs. The project could improve by providing a web-based data sheet on the types of sensors to use for different industry applications, as well as the method of verifying sensor performance to verify adequate operation with aging.
- The project is generally effective but could be improved. The project contributes to overcoming some barriers.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.5** for its collaboration and coordination.

- The technical breadth of collaborators, including industry, original equipment manufacturers, users, and developers, is excellent. This PI has truly developed a very good scope of collaborators, which makes this project relevant to needs, relevant to current state of the art, etc.
- The sensor laboratory works with a wide array of organizations, from manufacturers to C&S organizations to other government agencies—and with international entities charged with performing similar functions.
- The presenter did a good job of coordinating and collaborating with industry and research groups.
- The work with KPA and Element One to support the development of specific applications is good and also builds toward the reviewer's recommended long-term goal of improving application documentation and guidance.
- Collaboration exists, and partners are fairly well coordinated.
- It would have been nice to see sensor manufacturers listed: Det-Tronics, MSA Safety, Kidde Fenwal, etc.

Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.4** for its relevance/potential impact.

- The NREL Sensor Laboratory functions to help validate sensor performance, a key element in the development of a national hydrogen infrastructure. It is important to remember that hydrogen is invisible, has no smell or taste, and burns under many conditions with an invisible but extremely hot flame. Hydrogen systems, technicians, and the public must rely on sensors to regulate processes and inform of potentially hazardous conditions. It is critical that sensors be evaluated carefully and to consensus standards.
- The use of sensors in hydrogen applications is in the code structure; therefore, it is very relevant. From a use safety aspect, having confidence that one is using the correct sensor for the application at hand is critical. This project addresses that point. The project is missing one major aspect, and that is rigorous determination of sensor placement and a determination of characteristic time scales for a "leak" to find the sensor to trip an alarm. It is one thing to have a fast-acting sensor system (sensing and acting), but the convection time for the hazard to find the sensor (hydrogen in this case) needs to be considered. The PI does recognize that placement is an important issue—but it is done "informal[ly] and often by intuition." It is strongly recommended that this work be expanded to address this issue on a more technically rigorous basis.
- The work is highly relevant with the potential to have a high impact on increasing the reliability of such sensors. It is to be hoped that increases in the reliability also reduce the costs.
- The project aligns well with the Hydrogen and Fuel Cells Program and DOE research, development, and demonstration (RD&D) objectives and has the potential to advance progress toward DOE RD&D goals and objectives.
- Focus on robustness of sensors and documentation of applications are key to this project.

Question 5: Proposed future work

This project was rated **3.3** for its proposed future work.

- The future work plan is excellent. The project has identified critical areas to advance: validation, fuel quality, wide-area monitoring/distributed sensors, autocalibration, and placement. The rest of the future work is also excellent.
- The work is outstanding and was well outlined. Sensor placement, sensor response with aging, and faster-response sensors are key areas of future work.

- The sensor laboratory will prove to be an integral component in future national hydrogen programs. The laboratory should be adequately maintained to provide support to manufacturer development of sensors, end-user support and deployment, C&S development and maintenance, and the use of sensors for safety.
- The proposed future work is excellent.
- It would be good to see future work focus on the self-calibration project that was discussed and also understanding of sensor degradation due to contamination and aging. The benefit of the vent stack plume measurements, at least those related to hydrogen sensor testing per se, is difficult to see.
- The proposed future work is generally effective but could be improved. The work contributes to overcoming some barriers.

Project strengths:

- The NREL Sensor Laboratory is relevant to the national hydrogen community in that it has successfully provided and continues to provide sensor evaluation; assistance to manufacturers, developers, end users, and SDOs; collaborations with other laboratories; and continued investigation into relevant issues that involve sensor performance (safety, fuel quality, etc.).
- Collaboration with external organizations is a strength. Determining types of sensors to use for different industry/research applications is a strong objective.
- Strengths include the team's competence and the focused end goal to be value added to industry. This is not a science project.
- With the sub-project "Support of Infrastructure Empirical Profiling of LH2 Releases during Routine Venting" as an exception, this PI continues to produce very high-quality work, publishes well, and has earned international respect for the outstanding quality of work.
- There has been good progress and effort in addressing stated project barriers and challenges.
- There is good development of test facilities and methods.

Project weaknesses:

- The only weakness in this larger body of work is the sub-project on venting plume measurements. The proposed measurements will provide neither the insight nor the data needed for model validation. The experimental approach, data sought, and techniques to acquire the data need to be re-thought.
- The project may be a little unfocused, with some sub-projects outside the investigation of sensor technology. (However, some elements that involve real-world measuring are necessary to validate the approach.)
- The apparent lack of collaboration with major sensor manufacturers is a weakness.
- While there must be issues in providing the support needed from the NREL Sensor Laboratory, this reviewer is not aware of the specifics.

Recommendations for additions/deletions to project scope:

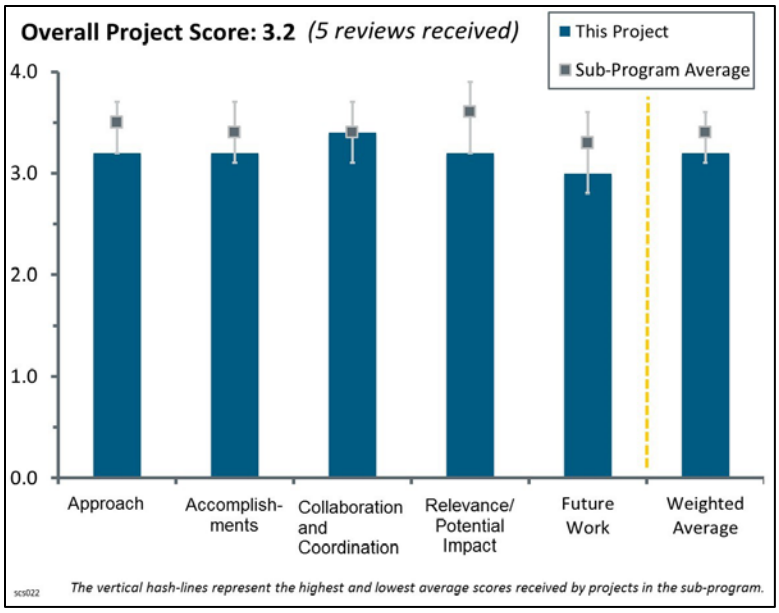
- The NREL Sensor Laboratory appears flexible in providing support to issues as they arise. Nothing specific is recommended, except that the laboratory continue.
- The project should continue to address project barriers and challenges.
- The hydrogen industry will really benefit from a better understanding of how to apply the various types of sensors. Also, sensor self-calibration and self-diagnostics have large potential cross-cutting benefits.
- Scope should include a web-based data sheet for sensor specifications for different applications. The project should also evaluate the life of hydrogen sensors and the effect of aging on response.
- The proposed measurements for the cold plume venting study will provide neither the insight nor the data needed for model validation. The experimental approach, data sought, and techniques to acquire the data need to be re-thought. The team really needs to embrace people who make this type of measurement. Combustion Research Facility (CRF) staff are well trained to make and study this type of behavior. It is strongly recommended that someone from CRF be made an integral part of this team and lead in the experimental design.
- The project should bring major sensor manufacturers on board.

Project #SCS-022: Fuel Cell & Hydrogen Energy Association Codes and Standards Support

Karen Quackenbush; Fuel Cell & Hydrogen Energy Association

Brief Summary of Project:

This project supports and facilitates development and promulgation of essential codes and standards (C&S) to enable widespread deployment and market entry of hydrogen and fuel cell technologies. The goals of the project are to ensure that best safety practices underlie research, technology development, and market deployment activities supported through projects funded by the U.S. Department of Energy (DOE); conduct research and development to provide critical data and information needed to define requirements in developing C&S; and develop and enable widespread sharing of safety-related information resources and lessons learned with first responders, authorities having jurisdiction, and other key stakeholders.



Question 1: Approach to performing the work

This project was rated **3.2** for its approach.

- The project has an outstanding approach. The established working group (WG) structure and flowchart of activities coupled with dissemination activities are hard to top.
- The WG approach is good, and it is to be hoped that the Fuel Cell & Hydrogen Energy Association (FCHEA) will provide plenty of input on *National Fire Protection Association (NFPA) 2: Hydrogen Technologies Code* this code cycle. FCHEA support for standards development programs at CSA Group, NFPA, and the International Organization of Standardization (ISO) is very important.
- The approach is generally effective but could be improved. The project contributes to overcoming some barriers.
- FCHEA coordinates a variety of national and international standards activities and for this effort receives what must be a contribution (roughly $200,000 per year) from DOE. The scope of what is performed seems very broad and extensive. Direct support of standards WGs is important. Reporting on perceived needs for C&S is valuable. Sharing of safety-related information, while important, is now done by many other organizations. It is not clear how DOE uses the matrix report. There are many collaborations. It is unclear how effective all these efforts are and whether they are all needed by DOE. Up until now, it seems the FCHEA support has been useful.
- The approach of this project is mainly a monthly call and bimonthly report to consolidate information from other organizations and activities that are performing the C&S development. The tracking of these C&S activities are useful, but it is uncertain whether this approach has resulted in any progress for the industry. The tracking matrix could be a good approach, but the method of gathering industry input is uncertain, and value to the industry is not clear.

Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **3.2** for its accomplishments and progress.

- FCHEA has been very helpful in the development of ISO standards and product certification standards at CSA. It is to be hoped that the FCHEA will develop and submit comments to NFPA 2.
- The progress of all WGs is impressive. The level of effort in coordinating monthly National Hydrogen and Fuel Cells Codes and Standards Coordinating Committee (NHFCCSCC) calls and publishing bimonthly Hydrogen Fuel Cell (HFC) Safety Reports is outstanding.
- The project is generally effective but could be improved, and it contributes to overcoming some barriers.
- The accomplishments of this project are uncertain since it is mainly tracking the efforts of other organizations. The WG effort of this project is highly confounded with the C&S activities occurring in the actual organizations.
- The presentation got lost attempting to explain accomplishments, perhaps because the project is too many initiatives. The priority given to each effort was not clear. The presumption is that the services described were accomplished.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.4** for its collaboration and coordination.

- FCHEA has been very good at coordination of C&S developments.
- The project has high collaboration with C&S organizations along with industry through the FCHEA membership.
- The established collaborations seem to be appropriate and well-coordinated. It is best to focus on established collaborations rather than spreading efforts too thin.
- FCHEA does collaborate and coordinate with many organizations.
- Collaboration exists; partners are fairly well-coordinated.

Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.2** for its relevance/potential impact.

- FCHEA's C&S support efforts are essential to development of comprehensive C&S. FCHEA's support for overcoming regional regulatory challenges is also relevant.
- Most project aspects align with the Hydrogen and Fuel Cells Program (the Program) and DOE research, development, and demonstration (RD&D) objectives.
- FCHEA activities have significant relevance to the Program's objectives.
- It is hard to evaluate the impact that the FHCEA activities achieve. The presentation attempted to detail myriad accomplishments, but it is not clear how they specifically benefit DOE. In general, they benefit DOE. Based on internet metrics, the FHCEA is still sought as a source of information. The FHCEA obviously drives three WGs, reports on standards activities, and provides reporting. In the past, the FHCEA ran the National Hydrogen Association (NHA) conferences, now discontinued. One reviewer lamented the absence of the NHA conferences, exhorting that they should be brought back. The presenter was overwhelmed in the attempt to describe all that the project performs and did not complete presentation of a number of slides.
- The relevance of this project is the intent to align with DOE RD&D goals and objectives, although the effort seems to be more of a monitoring and tracking activity rather than a contributing role. As indicated, the project supports other activities with participation, but the direct benefit of this project toward those activities is uncertain.

Question 5: Proposed future work

This project was rated **3.0** for its proposed future work.

- The proposed future scope seems to be appropriate. Doing more of the same and doing it well is a good thing in this case.
- The proposed future work is generally effective but could be improved. The work contributes to overcoming some barriers.
- C&S activities are not yet matured, and the need to support development of these efforts continues. It would be useful if the FHCEA could condense or summarize the nature of this support to DOE. As a level-of-effort activity, DOE would do well to continue to fund this effort and perhaps make clear what is expected from FHCEA.
- The future work appears to be more of the same monitoring activities without specific tasks.

Project strengths:

- The strength of the project is the coordination of various C&S activities and attempting to provide a summary of their status.
- FHCEA is involved in many efforts that support hydrogen C&S development and has been since FHCEA's inception. It would be hard to find an organization that could do as well.
- Strong knowledge and expertise base of very dedicated people are strengths of the project. Strong legacy and traditions of NHA are other strengths.
- Coordination is a strength.
- There has been satisfactory effort on addressing project barriers and challenges.

Project weaknesses:

- There are no significant weaknesses; however, the danger is always to spread project personnel too thin.
- Perhaps more focus is needed as to which FHCEA activities are vital and should be prioritized, at least as is reported to DOE.
- Beyond tracking and monitoring, the value of this project has not been communicated in a transparent manner. The effort seems to claim progress associated with C&S activities with which the project partners have been only indirectly involved.

Recommendations for additions/deletions to project scope:

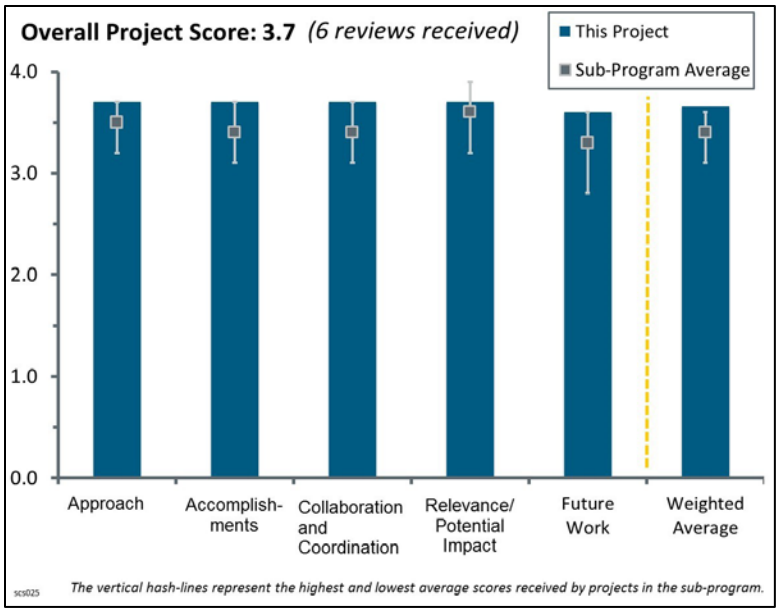
- The project should consider a revival (in some form) of NHA conferences. Those used to be marquee events. Revived events could be industry- or commercialization-focused under the banner of fulfilling the Paris Agreement. These events should be held in Washington, DC, exclusively (as opposed to, for example, a fuel cell seminar that may travel from place to place). It is critical to be in front of the politicians for the next three to five years.
- The recommendation for the project scope is to highlight the value of the project with specific examples of contribution and attempt to use the collaboration strength of the project to assist the industry in prioritizing technical tasks for the C&S development portfolio rather than simply monitoring.
- DOE management should consider what FHCEA products are vital. Alternatively, given the level of DOE investment, the product seems quite acceptable.
- Addressing project barriers and challenges should be continued.

Project #SCS-025: Enabling Hydrogen Infrastructure through Science-Based Codes and Standards

Chris LaFleur; Sandia National Laboratories

Brief Summary of Project:

The goal of this project is to enable the growth of hydrogen infrastructure through science-and-engineering-based codes and standards (C&S). Specific objectives include (1) streamlining cost and time for station permitting by demonstrating alternative approaches to code compliance and (2) revising and updating C&S that address critical limitations to station implementation.



Question 1: Approach to performing the work

This project was rated **3.7** for its approach.

- This work is extremely relevant to the implementation of hydrogen infrastructure. It has shown great value already with related projects that fed into the primary C&S for hydrogen and are being implemented. Much more can be done and potentially faster with increased funding from the U.S. Department of Energy (i.e., 100%).
- The approach taken by the project lead is very sound. Using science-based methods to improve codes and standards will be a key enabler to successfully implementing a hydrogen infrastructure. A great example of this is the work being supported on liquid hydrogen setback distances, which currently represent a significant barrier to the implementation of liquid hydrogen stations within existing gasoline retail sites.
- The approach followed by this project is excellent and is demonstrating value added.
- The approach is well conceived to address the critical barriers.
- The approach is sound, it is feasible, and it is integrated with other efforts.

Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **3.7** for its accomplishments and progress.

- Doing a real-world, actual, in-the-retail-fueling-environment application of alternate means will be of great value to various interested parties: station developers and authorities having jurisdiction, along with other city entities involved in the permitting process, and even the state of California (from the funders to the governor's office). The application is very valuable. A colleague says, "The gaseous separation distances are the most defensible and well defined anywhere in any code" (a project that this program worked on and is continuing to influence, along with other issues like liquid hydrogen [LH_2] separation and working directly with the task force). The Hydrogen Risk Assessment Model (HyRAM) is another tool that should prove extremely valuable in the station project planning process, although it needs more "advertisement" and certainly more support for the early users.
- The project has demonstrated significant accomplishments, including the report on the quantitative risk assessment analysis for the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) reference station, the science-based approach to update the gaseous hydrogen setback distances, and the initial results on the risk analysis of the liquid hydrogen storage systems, among others.

- Release of HyRAM and its use for updating and informing domestic and international C&S is an outstanding achievement by itself. The rest is icing on the cake.
- The progress and accomplishments are helping DOE meet its goals. The National Fire Protection Association (NFPA) has included a chapter in *NFPA 2: Hydrogen Technologies Code* to allow this type of modeling in lieu of the prescriptive separation distances.
- The degree to which progress has been made and measured against performance indicators is satisfactory, and the progress toward the goals is appropriate.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.7** for its collaboration and coordination.

- The project demonstrates excellent collaboration efforts that include industry leaders on liquid hydrogen station technology, significant engagements with the international community via the interaction with the International Organization for Standardization (ISO) as well as interfacing with world-class hydrogen safety researchers at the national laboratories.
- The collaboration and coordination seem to be appropriate and well managed with a good degree of involvement of different stakeholders.
- Developed collaborations are essential to this project's success. It is hard to add more to the list.
- The collaboration for outreach is very important and spans all projects, not just this one, but it is key to getting out the message that the knowledge, expertise, and resources are out there for those who need them.
- The collaboration appears suitable. It would be nice to include some state academic facilities to support the individual state fire marshals and to assist local industry on the use and interpretation of the results of this project.

Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.7** for its relevance/potential impact.

- The lack of general public exposure to and acceptance of results is a lack of information of risk acceptance that shows up as separation distances. In the real world, we either use the tool or the published excessive separation distances, which are often a guess because of lack of data. If this project helps reduce separation distances and reluctant acceptance, then this project will have been worth every penny expended.
- This project is extremely relevant to overcome one of the most critical barriers—footprint requirements—for the implementation of hydrogen refueling stations within existing retail sites.
- This project aligns not only with DOE's research and development (R&D) but also with some deployment, which still needs assistance. In general, DOE needs to maintain its focus on R&D for future advancements, but DOE also needs to continue to support demonstration and implementation as the commercial market is emerging and maturing. The market is not quite ready to expand on its own.
- The project has the potential to provide a high impact and is very relevant to the Hydrogen and Fuel Cells Program goals and objectives.
- Science-based contributions to regulations, codes, and standards development are critical to hydrogen infrastructure and hydrogen fuel cell technologies market deployment.

Question 5: Proposed future work

This project was rated **3.6** for its proposed future work.

- The proposed future work on the characterization of liquid hydrogen release via a science-based approach is probably the most critical activity in order to significantly improve the main issues with liquid hydrogen setback distances.
- The proposed future scope seems appropriate within the available budget and timing (i.e., personnel) constraints.

- The future work proposed is good and needed, and it continues in line with previous efforts.
- The proposed work is appropriate. The current model does not address the general public's acceptance of risk. Modeling similar applications, such as methane, and comparing the results with the current separation distances for methane would be useful in determining whether the computed separation distances are too conservative (or whether the methane rules are not adequately conservative).
- Perhaps the project should consider working with an authority having jurisdiction (AHJ) in another state on the Alternate Means/real-world component of the project. Another consideration would be to work on the metering issue(s) with the National Council on Weights and Measures, which again serves the effort to aid deployment across the country. The project needs to keep the pace with the setback work; it is unfortunate that a consensus agreement on a suitable means of quantifying hydrogen system mitigation features was not reached in time for this code cycle. There is much concern from industry, which should translate into support for the next fiscal year.

Project strengths:

- The project has superb talent and expertise on the C&S team. There are very strong domestic and international collaborations. HyRAM is a jewel.
- The project has extremely knowledgeable personnel, and the tasks are very relevant.
- The skill of the researchers and the perceived need for the product are strengths.

Project weaknesses:

- Restrictions (imposed by DOE policies) disallowing more in-depth participation in C&S committees, which are limited to providing scientific input, are a weakness. This restriction sometimes leads to misuse of the scientific input by those committees (e.g., NFPA 2/55 separation distance tables).
- The lack of financial support from headquarters puts strain on the projects and causes delay of very important results.
- Outreach and benchmarking are both weaknesses.

Recommendations for additions/deletions to project scope:

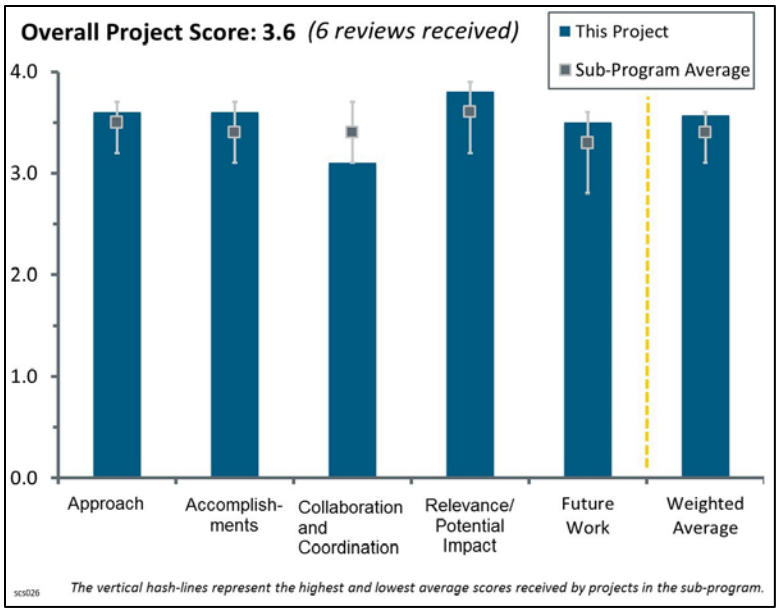
- Instead of just being science-based, it is important that C&S are evidence-based, which would include science, best practices, and lessons learned. A far-fetched suggestion is to partner with the Hydrogen Safety Panel to engage a review of codes such as NFPA 2/55, future 30A, etc. to ensure that the scientific input jives well with the best engineering practices and lessons learned. This partnering should help in avoiding situations such as NFPA 2/55 separation distance tables that in certain parts lack common sense and consistency.
- The project should work directly with AHJs in the upcoming states of deployment. The project should also work on metering, perhaps with the National Renewable Energy Laboratory.
- The project should model methane.

Project #SCS-026: Compatibility of Polymeric Materials Used in the Hydrogen Infrastructure

Kriston Brooks; Pacific Northwest National Laboratory

Brief Summary of Project:

The project objective is to fill a critical knowledge gap in polymer performance in hydrogen environments. Investigators will gather and assess stakeholder input about challenges and materials and conditions of interest for hydrogen compatibility, develop standard test protocols for evaluating polymer compatibility with high-pressure hydrogen, characterize polymers, and develop and implement an approach to disseminating information.



Question 1: Approach to performing the work

This project was rated **3.6** for its approach.

- The approach is perfect and hard to top.
- The approach is well-thought-out and realistic.
- This project is just starting. The approach taken to get this project going is very good; first, survey the stakeholders to understand problems and needs; next, define the operating domain; then expand laboratory capability to cover the domain; define the materials to be investigated; and develop the test method so repeatable, trusted data can be obtained. However, there was no reference to SAE International J2601 that will provide the temperature (T) and pressure (P) as functions of time for a J2601-compliant fill and hence define the P, T domain of interest.
- Three barriers are well addressed in terms of methodology. The approach, consisting of a consultation with stakeholders, is sound and helped in setting priorities. However, the presentation does not allow for assessing how much previous results have been taken into account (it is not the first time that a U.S. Department of Energy project is dedicated to hydrogen in polymers).
- There is too much focus on wear/abrasion, to the exclusion of other, more difficult issues to assess. The temperature bands should be widened to provide a safety factor to address the impact of excursions to a normal temperature range. For example, the lower range could be expanded to -60°C to see how close the materials are operating to the edge of problems.

Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **3.6** for its accomplishments and progress.

- This project is just getting started, with only seven months' progress at the time the presentation was produced; however, the team is moving quickly. The laboratories are up and running, and preliminary tests are already being performed.
- The start of the project is awesome. The information to date is value added.
- The project is still in its infancy (14% accomplished), and it is too early to evaluate whether results are able to overcome barriers. However, the progress so far is encouraging, and the first semi-quantitative results are convincing.
- It is too early in the project to fully assess this item. The project is off to a good start.

- The project could be rated as "outstanding." Insufficiently explained selection criteria for polymer testing is the reason for a lower rating.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.1** for its collaboration and coordination.

- The collaborations seem to be perfect and include very good coordination between the national laboratories and enthusiastic participation of an automotive original equipment manufacturer.
- The partners in this project all bring a lot to the table; they are experts with unique capabilities that together form a very powerful team to perform the needed investigations. The project has a really nice broad spectrum of "stakeholders" that will be used throughout the project and not only during the problem-definition stage. Neither a station provider nor a dispenser manufacture was included in the stakeholder list; the project team should include these additions.
- The collaborations to date are appropriate. Thought is needed on how to supply this information to the stakeholders.
- The project consists of a collaboration of three DOE laboratories. The activities are well distributed among the laboratories, and there is no reason to doubt smooth collaboration between them. One of the laboratories will provide the structural characterization to the other two to link macroscopic performance behavior with degradation phenomena and micro-level. A direct interface with industry is also present in the form of a sub-contractor. An international interface is not mentioned.
- It would be helpful to include more representation from fuel providers as well as feedback on areas experiencing particular problems.

Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.8** for its relevance/potential impact.

- This project, if successful, will book considerable technological progress by providing validated materials performance data and underlying degradation phenomenological models.
- Understanding hydrogen effects and the extreme pressure and temperature environments in this domain is critical to the safe, successful deployment of hydrogen technologies.
- Polymeric materials compatibility is one of the critical elements in successful market deployment of hydrogen technologies.
- These materials are very important to the hydrogen industry, and there is little information available for them.
- On a scale of 1 to 10, this project is a 12.

Question 5: Proposed future work

This project was rated **3.5** for its proposed future work.

- This work is just getting started, but the approach and direction this project is taking are exactly right. The project team needs to run tests under a J2601 protocol including removing the nozzle. J2601 will define the temperature–pressure time history, and removing the nozzle creates a sudden drop in pressure. As shown in some of the preliminary results, some of these materials take up large amounts of hydrogen when exposed to a hydrogen soak. A sudden drop in pressure will result in that hydrogen coming out of the material. Understanding that phenomenon is very important.
- The project is well on track, and the plan for the two future years is convincing and feasible.
- The proposed future work is well thought out.
- The proposed future scope appears to be appropriate for project objectives.

- The project should consider narrowing the scope to provide narrower but deeper understanding of materials for specific applications. In particular, hose materials are an issue and are exposed to extreme temperature and pressure cycles simultaneously. It would be helpful to see these conditions tested.

Project strengths:

- This is a very powerful team with excellent laboratory capability and thorough understanding of where the project needs to go. There is carefully constructed stakeholder outreach to learn what is needed.
- The project partners and collaborators have a very strong knowledge, expertise, and experimental base.
- The project strengths include interaction with stakeholders, the broad range of characterization, and the testing techniques.
- The project strengths include the topic, the collaborations, and the expertise of the laboratories.
- This project will provide useful information on these materials.

Project weaknesses:

- There are no significant weaknesses; however, the process for polymeric materials selection for testing could be improved.
- There are too many possible materials and too many potential applications, which creates too many combinations and permutations to adequately evaluate and address any of them fully. It would be better to narrow the focus. Numerous materials are subjected to simultaneous exposures, and the testing has to incorporate those exposures at the same time, as well as transient effects.
- It is not clear how the project has taken into account the results obtained in previous DOE activities. This project is not the first to investigate degradation of high-density polyethylene for liners.
- Outreach is a weakness.

Recommendations for additions/deletions to project scope:

- Engineers will go to one of three sources for this information: the American Society of Mechanical Engineers (ASME), SAE International, and the Parker O-Ring Handbook. Publishing the data through all three venues would be of value.
- The project should consider introducing purposeful flaws in the material to assess the impact of typical/potential manufacturing defects. This is similar to fracture mechanics for these polymeric materials. The temperature band of testing should be widened to better understand the impact of temperature excursions.
- As found in various risk assessments, many of the hydrogen technology chain components will experience operative conditions in their lifetimes beyond their design values (e.g., filling causing liners to exceed temperature limits). It would be extremely important to answer questions related to the behavior of plastic materials under these conditions and to quantify the degradation in terms of reduced lifetime. The project should also look into these aspects.