2018 – Safety, Codes and Standards
Summary of Annual Merit Review of the Safety, Codes and Standards Sub-Program

Summary of Safety, Codes and Standards Sub-Program and Reviewer Comments:

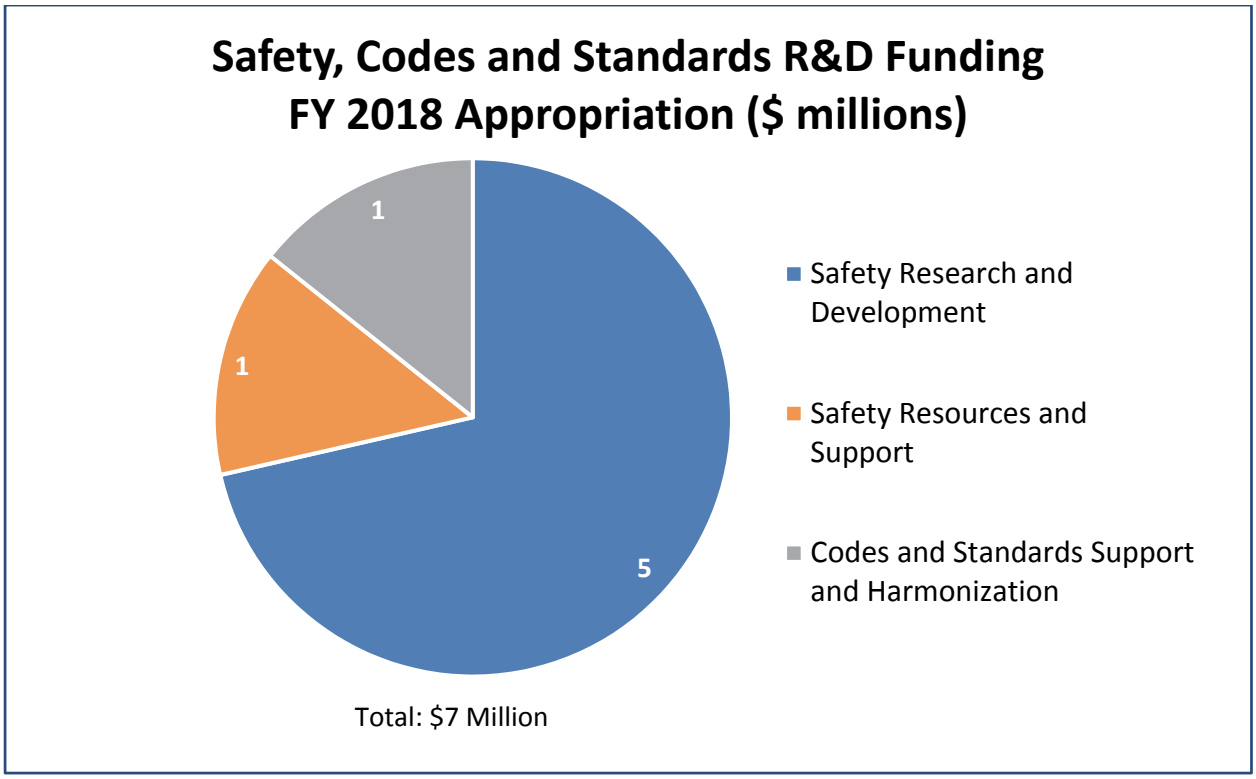
The Safety, Codes and Standards (SCS) sub-program supports research and development (R&D) that provides critical information needed to define requirements and close gaps in safety, codes and standards to enable the safe use and handling of hydrogen and fuel cell technologies. The sub-program also conducts safety activities focused on promoting safety practices among U.S. Department of Energy (DOE) projects and the development of information resources and best practices. The SCS sub-program includes research on liquefied and cryogenic hydrogen release physics, contaminant detection and sensor technology, and quantitative risk assessments and consequence analysis. The sub-program also focuses on domestic and global codes and standards harmonization to enable large- and small-scale hydrogen applications.

Hydrogen and Fuel Cells Program reviewers were highly supportive of the SCS projects and noted that the work of the SCS sub-program enables accomplishment of the broader goals of DOE and the Fuel Cell Technologies Office. The collaborations in many of the projects were seen as much improved, as was the progress made since the previous year in projects related to hydrogen behavior, national codes engagement, materials compatibility, and fuel quality. Reviewers continued to praise the science-based approach and the provision of feedback to code development organizations and standards development organizations. However, reviewers recommended that the H2@Scale concept be broken out into specific activities with better-defined scope and resources to incorporate it into this sub-program. Reviewers indicated support for outreach projects, including H2Tools.org, and encouraged the direction of additional resources for this critical work in educating regulators and responders. Key recommendations for SCS R&D included development of fueling protocols for medium- and heavy-duty fuel cell electric vehicles and continued emphasis on hydrogen contaminant detection, incuding preventative maintenance of the devices and validation of the prototype devices.

Safety, Codes and Standards Funding:

The FY 2018 appropriation for the SCS sub-program totaled $7 million. The funding was focused on safety R&D and is depicted in the following figure. The funding is expected to provide continued support of SCS R&D and efforts on domestic and international collaboration and harmonization of codes and standards. Future work in the sub-program is expected to focus on facilitating reduced regulatory barriers, such as by providing scientific anlaysis for revised bulk liquid hydrogen separation distances.

Nine projects were reviewed, receiving scores ranging from 3.4 to 3.75, with an average score of 3.53. Each of the following project reports contains a project summary, the project's overall score and average scores for each question, and the project-level reviewer comments.

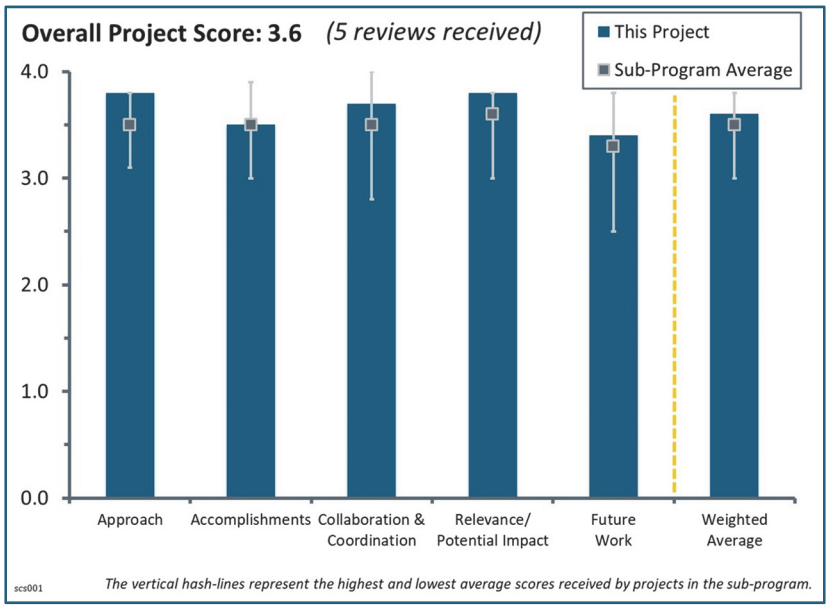

Safety, Codes and Standards R&D Funding
FY 2018 Appropriation ($ millions)
1
1
5
Safety Research and Development
Safety Resources and Support
Codes and Standards Support and Harmonization
Total: $7 Million

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 information to project developers and code officials, making project permitting smoother and faster.



Question 1: Approach to performing the work

This project was rated **3.8** for identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- The approach to this work is excellent and ever-evolving. This principal investigator (PI) is getting better at working with others (Inter-Laboratory Research Integration Group [IRIG]) and dissemination of the work into places where authorities having jurisdiction (AHJs) and others are most likely to find it. The Continuous Codes & Standards Improvement (CCSI) process aggressively seeks to integrate scientific research into the code process, which is excellent. In addition, the active outreach to first responders and AHJs is very good.
- The project addresses identified barriers very well. The project is effective and well integrated with National Fire Protection Agency (NFPA) 2 to a great extent, and to other relevant codes and standards activities to some extent. The approach allows for a holistic approach to identifying safety concerns, conducting research, and feeding that work into developing codes and standards, with an appropriate emphasis on NFPA 2.
- The approach is excellent: integrating research into the codes and making the information available to all kinds of users in a form that matches their needs in a location that they expect to find it.
- The project is clearly defined and extracts actionable tasks that make significant progress against overarching objectives.
- This project has done a much better job of aligning with appropriate and necessary activities.

Question 2: Accomplishments and progress

This project was rated **3.5** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The development of a "standard" permitting guide should dramatically help reduce time and cost for permitting hydrogen fueling station deployment. When asked about how to reach the 44,000 AHJs, the answer was to put this as an appendix on NFPA 2, which has already been adopted (in one way or another) in every state in the nation. It was an excellent answer. The PI identified unexpected hydrogen behavior associated with venting from the National Renewable Energy Laboratory's (NREL's) fueling station and hydrogen vented from test bays. While hydrogen properties are widely understood, in many scenarios, hydrogen behavior is not understood. NREL will likely work with others in the hydrogen community to dispel the well-published myth that just because hydrogen is 14.4 times lighter than air, and its molecular

diffusivity is ~3.8 times that of methane, it does not necessarily go up and diffuse rapidly. This is a myth that can be dangerous if applied when indeed hydrogen does not behave in that manner, as in the two examples presented during this presentation.

- Significant and impressive progress has been made with regard to hydrogen safety outreach and increasing accessibility for useful hydrogen safety information. Additionally, significant progress has been made on closing the loop on the codes and standards revision process that addresses barriers with regard to hydrogen safety. One suggestion is also to include barriers for hydrogen fuel cell deployment that are not safety-related, such as public and community benefits, and information that can be made available to localities (in the context of permitting and within the scope of the project) that increase support for hydrogen fuel cell technologies from an environmental or economic benefit perspective. Safety-related barriers are only one of many categories of barriers to increased deployment.
- Accomplishments made in the past year are overall much better than in previous years. There are still concerns with the precedent of equating success with leading task groups and standards efforts, which should be led by commercial participants, and adding research to fire codes and standards, as this could lead to efforts that are counter-productive to industry needs or that over-complicate the regulations. The more appropriate efforts of publications, particularly in non-scientific periodicals, code summaries, code training, videos, etc., are excellent accomplishments and examples of a very useful precedent that will be needed for years to come. While some of the leadership of task groups and research added to fire codes has been very helpful, this should not be the ongoing measure of success for this project. The project ambitions should identify very specific areas where leadership or research is needed and direct more efforts to the outreach efforts.
- The project is making excellent progress toward the DOE goals. While many would like to see the work move even faster, the project is moving steadily forward at a pace supported by the availability of data and resources, as well as code development schedules.
- Some referenced resources are quickly becoming outdated (e.g., the Certification Guide by the Hydrogen Safety Panel, the AHJ video). The Standard Permit Task Group and its deliverable are very positive. The paper for the American Society of Safety Engineers Journal needs some discussion, or at least the findings do. This is potentially critical to outreach and messaging of hydrogen to AHJs and first responders.

Question 3: Collaboration and coordination

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

- The project utilizes excellent collaboration and coordination with other institutions and relevant stakeholders. Use of IRIG ensures related research efforts throughout DOE laboratories are well coordinated. Leadership of NFPA 2 development, as well as task forces to address specific issues, ensures industry and other stakeholders are engaged to help solve issues as they arise and learnings are shared.
- A clear strength of this project is that the team has been very effective in collaboration and coordination with other institutions.
- This project does an excellent job of coordinating many stakeholders.
- This project has been criticized in the past for not being better connected (in collaboration) with other DOE resources (i.e., national laboratories). With the creation of the IRIG, much of this criticism has been removed. The PI has also developed an impressive, well-balanced set of collaborators, mostly through his work with NFPA. It is anticipated that this new collaborative posture will continue and grow as the community understands what needs to be done with regulations, codes, and standards (RCS) as we transition to H2@Scale. It would still be good to see this project be more assertive in finding collaborators and coordination with others. In answer to a reviewer comment, "NREL would welcome any opportunities for additional collaboration and identification of special programs that should be connected to this work," it would be good to see NREL be assertive in identifying these opportunities rather than waiting for them to avail themselves to NREL.
- Collaboration could be more transparent, and there could be better communication about the opportunities to collaborate. For example, the NFPA task groups are not always transparent/known about initially. It is unclear whether the code gap analysis is done and available.

Question 4: Relevance/potential impact

This project was rated **3.8** for its relevance to/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.

- The CCSI project enables the safe deployment of hydrogen fuel cell technologies by informing the development of required codes with science-based data, and appropriately engages industry experts and other stakeholders to target critical issues and disseminate learnings. The Codes and Standards Outreach and Training project supports technology deployment by engaging and providing needed information directly to project developers and code officials, making project permitting smoother and faster.
- This project is highly relevant and has had a significant impact with regards to hydrogen safety, awareness, outreach, and education. Focus on other, non-safety-related barriers may make an even larger impact toward deployment cost objectives of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan (MYRDDP). H2@Scale focus is critical to increasing public awareness and acceptance of hydrogen technologies.
- Like the Sandia National Laboratories project, "Enabling Hydrogen Infrastructure through Science-Based Codes and Standards," this work is also imperative to the advancement of the hydrogen economy and to the safety, codes and standards community.
- This project is key to deploying and improving critical RCS to deploy hydrogen technologies in a safe and expedient manner.
- This project is having a real and lasting impact in hydrogen energy. The project should consider a panel of stakeholders to provide guidance on future efforts.

Question 5: Proposed future work

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

- The PI should continue the open collaboration with all others in the community to ensure the best results. Communication is key.
- With the foundation developed for cooperation/collaborations, mechanisms to incorporate science into the code development, taking this to H_2@Scale is very good and should greatly help accelerate and remove critical barriers to the deployment of hydrogen technologies at scale.
- Future work proposed on H2@Scale is a plus. Larger, not-yet-seen hydrogen projects are on the horizon, and this project promises to stay ahead of that curve.
- This project struggles with soliciting and listening to input from stakeholders. A standing panel of stakeholders that review and advise this project's direction would be much more efficient. While this project has great success and impact, a great deal of effort is expended trying to corral this project, as it tends to initiate projects that must be significantly changed to result in that success.
- In addition to continuing to make progress on NFPA 2 issues and educating permitting officials, the project will expand the focus to encompass the larger scope of H2@Scale. While this is necessary, the scale of the effort will need to ramp up to avoid a significant slowing of results on the current efforts.

Project strengths:

- This project does an excellent job at holistically addressing barriers in codes and standards with a focus on NFPA 2: The Hydrogen Technologies Code. The effort also serves a critical role of providing necessary information to code officials and other stakeholders to help accelerate the safe deployment of hydrogen technologies. The project also ties codes and standards development needs with science-based research and dissemination of learnings.
- The overall project strengths include collaboration/cooperation with a wide variety of stakeholders and beneficiaries, project management and project focus, and future work with a focus on H2@Scale (much-needed and valued work to ensure success in the marketplace and toward MYRDDP targets).

- This project is at the core of identifying and generating RCS to remove barriers to the safe deployment of hydrogen technologies. This project has significantly improved its collaboration and coordination with other RCS groups inside and outside the Hydrogen and Fuel Cells Program.
- This project has timely and pointed goals and deliverables to enable the hydrogen community.

Project weaknesses:

- While it is not necessarily a weakness, transparency, communication, and collaboration are imperative to success for all.
- The project objective is to further enable the safe deployment of hydrogen fuel cell technologies. While hydrogen safety and safety-related outreach and education are clear priorities to meeting this objective, non-safety-related work can have a significant impact on the project objective. For example, experience permitting hydrogen fueling stations has shown that fire safety is a contributing barrier to deployment. However, a general lack of understanding of the benefits of hydrogen technologies to communities, the workforce, and the energy economy are also contributing factors to the technologies' lack of priority in the community project roster. This will be increasingly important with an H2@Scale focus.
- The planned increase in scope to cover potential gaps in H2@Scale opportunities is a large order. It would be useful to understand the impact of such efforts on the project duration and funding requirements for the future, as well as the ability of the project to meet the timeliness needs for NFPA 2 activities. It would also be good to see plans for disseminating learnings that currently have no specific code or standard focus. For example, slide 13 of the presentation found that hydrogen venting from experiments involving multiple fuelings has migrated into nearby work areas where it was not expected to accumulate, and hydrogen vented from indoor test bays into stacks serving multiple sources has been driven back into work spaces. The presentation noted that such findings will be documented. The project should consider publication in safety-related articles so that the safety community can learn about these situations quickly and begin to better understand the mechanisms noted.
- The project can still improve its reach internationally.

Recommendations for additions/deletions to project scope:

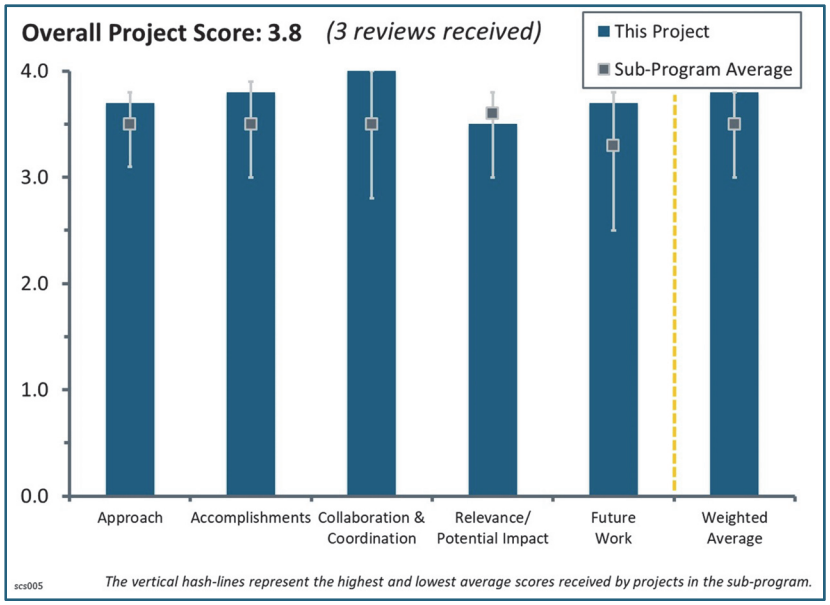
- Expanding the scope to H2@Scale is already a huge addition. It would be good to see that concept broken out into specific activities with a better idea of the scope and necessary funding. An expansion of the project team will likely be necessary.
- This project needs to start embracing an international component to its overall scope; the project would benefit greatly.
- The addition of community, workforce, and energy economy benefits of the technologies will improve progress toward the project objective.

Project #SCS-005: Research and Development for Safety, Codes and Standards: Materials 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 **3.7** for identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- The project approach has an excellent focus on the key parameters associated with hydrogen compatibility for metallic materials. The project researchers have the appropriate balance of experimental evaluation and practical application guidance.
- A set of austenitic stainless steels with varying strengths and nickel content is investigated under uniaxial cyclic loading to calculate the fatigue life dependence on hydrogen pressure and temperature. The conservative assessment of life through notched specimens is also addressed. Next, the resistance of the steels to fatigue crack growth is assessed by using the acceleration technique through the load parameter C. Because it is well known that hydrogen degradation is more pronounced at low frequencies, the acceleration approach needs to be carefully ascertained. Given the capabilities of the Sandia National Laboratories (SNL), the need for an accelerated testing approach is unclear.
- This project activity directly addresses present industry needs.

Question 2: Accomplishments and progress

This project was rated **3.8** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The project successfully completed the testing of notched tension–tension specimens (conservative approach) and demonstrated small variability of life among the steels tested. In the case of resistance to fatigue crack growth, the project successfully demonstrated that steels with tensile strength less than 950 MPa also behave similarly and came with a fitting curve for fatigue crack growth rate (da/dN) vs. the change in stress intensity factor (dK). In particular, for steels with strength greater than 950 MPa, the project established that the fatigue resistance becomes uncomfortably low.

- The project had a significant accomplishment this year by establishing a generic fatigue crack growth curve and providing this to the ASME committee. The project continues to make excellent progress in evaluating materials and distributing results to various stakeholders.
- As conveyed by the principal investigator (PI), fiscal year 2018 milestones are being met.

Question 3: Collaboration and coordination

This project was rated **4.0** for its collaboration and coordination with other institutions.

- The project is an example for other projects in the Safety, Codes and Standards portfolio to follow. The project verifies results through round robin testing, collaborates with experts both domestic and international, and disseminates the results to relevant codes and standards. In particular, the project provided results to the Global Technical Regulation Phase 2 effort, which is a global collaboration with industry.
- Collaboration with Kyushu is most excellent. Kyushu has tremendous testing capabilities, among the world's best.
- Collaboration was well considered and included excellent partners.

Question 4: Relevance/potential impact

This project was rated **3.5** for its relevance to/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.

- The project is highly relevant for the fundamental determination of metal compatibility in hydrogen applications. The potential impact of the project is unknown for on-board storage systems, as there is limited stainless steel used and aluminum is a material that is often used for valves and other components. In addition, the other materials being evaluated may not result in a cost savings owing to other factors. Regardless, the effort provides the necessary data for the codes and standards.
- The project is extremely relevant and meets all requirements of the Hydrogen and Fuel Cells Program. The project provides a wealth of required data for the design of high-pressure hydrogen fuel systems (performance-based) and stationary pressure vessels (design-based).
- Research was conceived to target industries with information they considered valuable. The findings are coordinated with standards organizations and published through an online database.

Question 5: Proposed future work

This project was rated **3.7** for its proposed future work.

- Low-temperature response, ratio of minimum peak stress to maximum peak stress (R-ratio) effects on crack growth, understanding the mechanics of notched specimens, and the probing of microstructural length scales are all outstanding issues that need investigation.
- The future work appears to build on the past effort effectively, although the PI should consider a specific plan to assess aluminum alloys. Reducing the test effort with lower R-ratios and reducing the complexity of lower-temperature testing—these goals are worthwhile.
- The project's proposed future work is in line with goals.

Project strengths:

- The strengths of this project include the following: the project targets information needed by industry stakeholders, research elaborates important relationships in data to promote future prediction, findings are coordinated with standards organizations, partners and collaborations are strong, and data are made available to the public.

- The project strength is the fundamental approach of the experimental designs and the effort to challenge the historical test methodologies. The project also does an excellent job in communicating and participating in codes and standards development.
- The strengths of this project include the experimental capabilities of SNL; collaborations with Kyushu University; and the capabilities, knowledge, and general expertise of Chris San Marchi.

Project weaknesses:

- The project lacks mechanics modeling to account for and assess the influence of the microstructure of austenitics on fatigue life and crack growth. This wealth of experimentally obtained results is not assessed and explained from a mechanistic perspective.
- The weakness of the project is the uncertain impact of the results. The verification of new materials may be costly using these methods and may fail to result in significant improvements in cost or function over the current material (i.e., low-carbon stainless steel 316L). It would be helpful to expand the project scope to include aluminum.
- The reviewer is not a metals expert and is not aware of gaps, so weaknesses in the work are not apparent. More could be said about the data management plan.

Recommendations for additions/deletions to project scope:

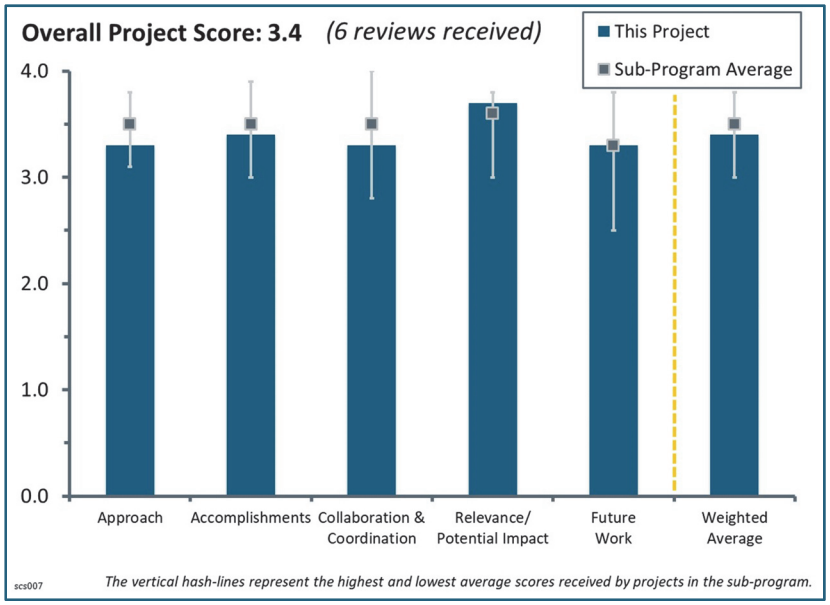
- The project scope is good, although aluminum should be considered in the near term. In addition, it would be helpful to work with a component supplier to develop a component using an alternative stainless steel material to quantify the benefit. Any effort to simplify the test method and ensure laboratories other than a national or specialized laboratory can conduct the test would be helpful.
- Modeling and simulation should be incorporated into the project scope. The accelerated testing approach needs to be carefully validated in a systematic way in terms of the response in low frequencies and high-load ratio. There is no obvious rationale for such an approach.

Project #SCS-007: Fuel Quality Assurance Research and Development and Impurity Testing in Support of Codes and Standards

Tommy Rockward; Los Alamos National Laboratory

Brief Summary of Project:

The objectives of this project are to (1) focus on polymer electrolyte membrane (PEM) fuel cell testing and collaborations and work with the American Society for Testing and Materials 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 **3.3** for identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- The notion of using PEM hardware to detect contaminants that will poison PEM fuel cells is excellent. Support for this approach to develop a fuel quality sensor has existed from the beginning. The methodical, systematic approach to the development of this sensor is spot-on.
- The ability to monitor, in real time, the quality of hydrogen fuel at the station is important. Most impurities will be introduced to the fuel because of poor hose cleaning and/or equipment failures. This makes measurements "at the nozzle" important.
- The project approach combines development of the fuel quality analyzer with field testing activities to support meeting SAE International J2719 fuel quality limits. The approach is appropriate for this type of work. The use of a fuel cell as an in-line sensor is worthy of investigation. The main shortcoming in the approach is the lack of clear targets to evaluate success of the device in terms of cost, effectiveness, response time, sensitivity, reliability, etc. There is also a need for benchmarking device performance.
- The approach seems appropriate. Analysis of the fuel to ensure that it meets the purity standard is important. The only concern is that a small amount of fuel (sidestream) flows through the analyzer, which may not give a true picture or a timely assessment of the fuel.
- The approach reflects a progression to a more refined design, patent, and field trial. Making sure there is a clear plan to move to practical deployment at scale would be beneficial.
- The approach to install an in-line fuel quality analyzer to improve reliability of the infrastructure is important. However, it does not seem certain that the analyzer is sufficiently in-line with the fueling for field trials.

Question 2: Accomplishments and progress

This project was rated **3.4** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The patent, a culmination of a multiyear development effort, indicates a notable accomplishment. The demonstration of necessary response time specifications and field experiment implementation in Burbank are noted as accomplishments.

- Timely progress toward the goal has been achieved. The deployment of an in-field analyzer shows good progress toward the goal. The next step of determining how the device works in the field should provide a better assessment of whether the goals will be met.
- A response to 200 ppb CO was demonstrated. It was noted that a provisional patent was applied for in November 2016. Provisional patents are good for only one year, so a question remains as to whether the patent was filed and awarded yet. Progress in field trials is excellent. However, the principal investigator should consider rethinking the application of this technology. The response time of ~1.5 to 6 minutes, depending on the threshold level, is too long to detect an upset during any one fill, especially considering the flow times associated with actually delivering the sample to the detector. In addition, this detector, in its current configuration, will not be able to handle a -40°C and 70 MPa fill environment. This does not mean that the sensor does not have enormous value. It just means that the target application/location and response timescales dictate a re-thinking of the sensor's exact optimal value application/installation. This is particularly true given that different species are to be considered, such as H_2S, which could be introduced into the fuel as late in the system as the nozzle if a recent cleaning or repair occurs. This technology and its application to fueling stations is good; it is just that its optimal application may not be attempting to detect a fueling contamination during a single fueling event and catch the contamination on that fill. The timescales are just not good enough to catch such an event in a three-minute fill.
- The membrane hydration challenge was solved with the wicking scheme system, and the electrode performance with larger baseline currents is making great progress. Optimizing downtime for cleanup voltage will help with throughput.
- The biggest accomplishments are the installation of the prototype analyzer in the field at the H2 Frontier site and the establishment of remote monitoring capabilities at Los Alamos National Laboratory (LANL). This is a big step forward. The patent filing is also an important step. The rest of the progress is less clear. Several of the slides differ minimally from what was presented last year. Slide 8 discusses a milestone to identify and address the cause of baseline current drift, but it was not clear where the result of this was presented. Some drift is attributed to humidification, but there are no plots showing the effect of humidification on drift. The drift is still visible in plots on slides 8–10. It is questionable whether the clean-up strategy is appropriate, given that contaminated hydrogen supply would not reset between vehicle fuelings.
- Several questions came to mind. It is unclear if the plan for the 15-minute recovery time, as indicated on Slide 8, is part of the station powering up in the morning or something else. Slide 9 was (seemingly) showing the loss rate contamination or tortuosity (water balance). Given that the response time is around 90 seconds for 20 ppm CO and 230 seconds for 500 ppb, it is unclear how far back into the system one has to be to prevent vehicle contamination.

Question 3: Collaboration and coordination

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

- The collaboration partnership with H2 Frontier should yield excellent data and provide the analyzer with a path for future improvements and experiments. The involvement with the International Hydrogen Delivery Risk Assessment and Impurity Tolerance Evaluation (HYDRAITE) meeting was successful.
- There is good coordination between the developer of the test apparatus and the end user, which allows field testing of the test apparatus.
- The collaborators and cooperation are appropriate for this project. The only reason the project did not received a 4.0 score was its lack of international cooperation, specifically the International Organization for Standardization (ISO) Technical Committee 197 with 14687 fuel quality. Admittedly, ISO 14687 and SAE J2719 are well harmonized, but ISO 14687 is undergoing revision, and to contribute to and stay on top of that work would benefit this project greatly.
- Collaboration between LANL and the station partners is excellent. The main shortcoming is the lack of communication with similar efforts internationally.
- Collaboration with Lawrence Livermore National Laboratory and H2 Frontier on field studies has been coordinated. The initial connection with the HYDRAITE community in Germany is noted, but the tangible outcomes of the outreach are not clear. Additional collaboration might help facilitate and address practical deployment.

- It was surprising to not see MSA Safety, Inc., or Detronics involved, both of which are major combustible gas sensor suppliers.

Question 4: Relevance/potential impact

This project was rated **3.7** for its relevance to/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.

- Ensuring fuel quality is important to ensure that vehicles do not have problems. Poor fuel quality will cause consumers to question vehicle viability. The analysis of the fuel quality will help to promote vehicle deployment.
- This project is extremely relevant and urgent for ensuring the reliability of hydrogen infrastructure and vehicles during early commercialization.
- This project has a very important relevance to the industry, as contaminated fuel has the potential to bring on problems for a vehicle's fuel system.
- The effective mitigation of degradation from contaminants is relevant and aligns with Hydrogen and Fuel Cells Program objectives. The project is showing progress toward a field-tested solution to address CO.
- Fuel quality control and monitoring at the station is critical to ensure the safe deployment of hydrogen technologies such as those found in fuel cell electric vehicles. Smooth deployment and success of the technology, particularly in these early deployment times, is critical.
- The potential impact is to protect the PEM fleet. The cost estimates, though, are unclear.

Question 5: Proposed future work

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

- The future work is neatly divided into both field experiments and continued research and development (R&D) in the laboratory. Having remote access to the analyzer should help the effort understand analyzer needs, such as maintenance. The R&D laboratory work will provide the team with an opportunity to study the effects of other contaminants, such as H_2S, in the fuel supply.
- Plans to address operating improvements and other contaminants are relevant and practical extensions.
- This seems reasonable.
- Field deployment of the analyzer is the next step in the process. Determining where to draw the stream to be analyzed is something that must be determined, and it is critical to ensure that the fuel sample to be analyzed be representative of the fuel as a whole. The small amount of fuel that is analyzed may not be representative of the bulk source.
- Future work on the field experiments is consistent with what is expected from a recently installed prototype device, although the presentation lacks specifics about test design. The future R&D work is vague. Many ideas are presented, but there is no timeline or priority given. It is unclear how feasible any of these ideas are.
- It is strongly suggested that the team rethink how to best use this technology to ensure adherence to the fuel quality standards. The notion that this detector can actually detect a fuel quality upset during any one fill is not realistic because of characteristic times to deliver the sample to the detector, the characteristic time for the detector to respond, the environment in which the detector can and needs to respond, and the time over which a fill actually takes place (three to five minutes). The suggestion is to recast the application into a more realistic scenario or application.

Project strengths:

- In-field, real-time analysis of fuel is something that could provide critical information to ensure that vehicle fuel cells are not poisoned by poor-quality fuel. Field deployment of the device and future data collection should provide a level of comfort that high-quality fuel is being produced.

- The field testing of the fuel quality analyzer adds significant value to establishing the effectiveness of the prototype in a real-world environment. The project includes good partnerships between national laboratories and industry.
- The project team has the technical knowledge and planning capability to develop an impurity detector. The partnership with the H2 Frontier station in Burbank is allowing for real-time data collection.
- Project strengths include a relevant focus on mitigating damage, sustained refinement of the design, and a practical version being actively field-tested.
- This is a very intriguing technology, and it is showing very impressive results.
- The expertise of the laboratory is a project strength.

Project weaknesses:

- The principal investigator and DOE need to recast the specific application with respect to fueling stations to redirect some of the goals and targets to more closely align with realistic timescales and sensitivities. A previous reviewer remarked on not having enough time and money to work at a faster pace, noting that fuel quality assurance technologies are needed in place now, because hydrogen fueling stations are being deployed in California now and in the Northeast soon.
- Having the analyzer function with a response time of under five minutes is critical. It is a bit misleading that the analyzer is installed at the Burbank station, but it is not in-line, and it does not analyze fuel at 700 bar. The placement of the analyzer is a problem for detecting CO and H_2S; the location could be moved, but then there may be a temperature or pressure problem.
- The project might benefit from more active and expanded collaborations around specific, scaled, and practical deployment plans.
- There is a lack of clear metrics to define the analyzer's success. There is an unclear timeline for moving beyond the prototype, as well.
- Ensuring that the obtained fuel sample is representative of the bulk fuel is a concern, as is any potential ongoing maintenance activities that are required to ensure that the device remains viable.
- A question remains about who will develop this prototype into a commercial piece of equipment.

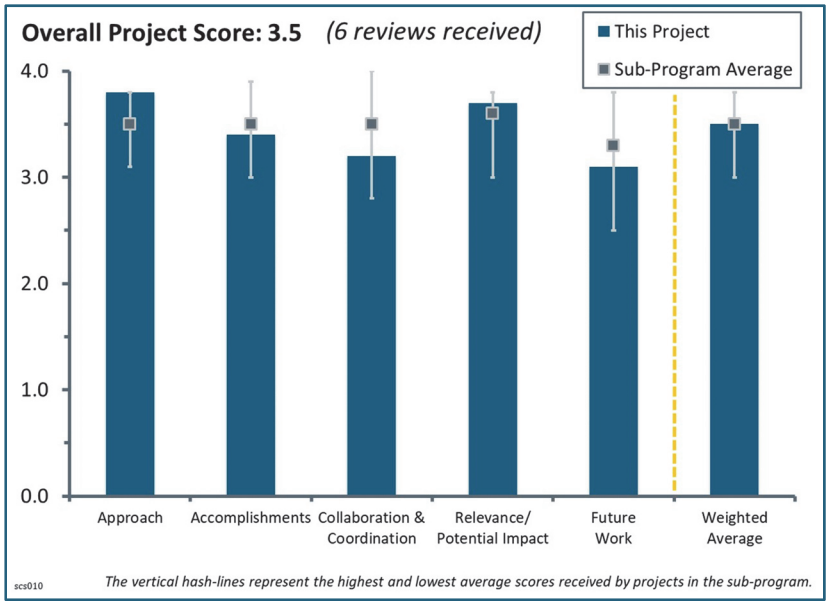
Recommendations for additions/deletions to project scope:

- The project should make a determination as to whether there is any required preventative maintenance on the device that must be investigated. The enclosure must be assessed to ensure it is intrinsically safe. If there are ignition sources within the enclosure and a hydrogen leak were to occur, the results could be detrimental.
- A plan should be added to validate the prototype measurements. The non-dispersive infrared CO analyzer at the H2 Frontier site provides an opportunity here.
- The project should rethink the precise application's location in the station and how it can be used to maximum benefit.
- Additional clarity on the operating costs, durability, and similar aspects would be important to moving forward.
- The project should continue to study the Burbank location installation to determine whether results are reliable and repeatable.
- The project should find a partner who can commercialize the prototype.

Project #SCS-010: Research and Development for Safety, Codes and Standards: Hydrogen Behavior

Ethan Hecht; Sandia National Laboratories

Brief Summary of Project:



The project's purpose is to perform research and development to provide the science and engineering basis for the release, ignition, and combustion behavior of hydrogen across its range of use (including high-pressure and cryogenic). The research includes model and tool development to facilitate the assessment of the safety (i.e., risk) of hydrogen systems and enable use of that information for revising regulations, codes, and standards and for permitting stations. Sandia National Laboratories (SNL) is working to address the lack of safety data and technical information relevant to the development of safety codes and standards by (1) providing a science and engineering basis for understanding the release, ignition, and combustion behavior of hydrogen across its range of use (i.e., high-pressure, cryogenic), (2) generating data to address targeted gaps in the understanding of hydrogen behavior physics (and modeling), and (3) developing and validating scientific models to facilitate quantitative risk assessment (QRA) of hydrogen systems and enable revision of regulations, codes, and standards to accelerate permitting of hydrogen refueling. The project began in 2003.

Question 1: Approach to performing the work

This project was rated **3.8** for identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- The issue is providing science-based data for separation distances to support development of liquid hydrogen (LH2) storage and dispensing centers and related standards. This effort gets good marks for a careful and systematic approach to understanding hydrogen release behaviors.
    - That said, the project should approach one step at a time by looking first at cold gas dispersion and pursuing liquid spill behaviors later. However, it is important that the liquid spill behaviors be addressed in the future because of known possible behaviors that are very hazardous and because of the large quantities of LH2 that will be needed to service future hydrogen infrastructure. The concern is the limited budget provided for this effort.
    - Careful process of elimination on measurement techniques was considered. From experience, past measurement techniques are difficult to deploy and have only crudely addressed measurement of hydrogen dispersion. The proposed Raman approach holds the best promise for providing sufficient detail, but adapting that approach from a laboratory setting to a medium-scale environment will still be difficult. The SNL Thermal Test Facility is a good choice for a medium-scale environment with controls.
    - Incorporating findings into models made available to the public addresses the data management plan.
- The project's goals and objectives are simple and clearly stated. Therefore, the approach is very well laid out. Gaps in the data for the release, ignition, and combustion behavior of both high-pressure and cryogenic

hydrogen will be addressed by developing scientific models to predict hazards and methods of QRA, and then applying those models to real-world situations.
- The project team has an excellent approach to this work of developing the methods and models and including the implementation of experimental work to validate the modeling work.
- The scientific problem tackled is critical to the whole success of hydrogen technology. Knowledge of LH2 behavior is still in its infancy, including the methodology to study it.
- The approach is carefully thought out, designed, and implemented.
- The approach is questionable. It is unclear why the project team did not use both sensors and optical diagnostics if neither technique is entirely suitable for the application. It is unclear why a thermal map was not generated as part of the "sensors."

Question 2: Accomplishments and progress

This project was rated **3.4** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The project has made a significant advancement in the scientific understanding of the behavior of hydrogen plumes and flames at very low temperature. The project shows great promise with regard to informing the national fire codes on revised separation distances, which has the potential to reduce station footprint and siting and thereby decrease the cost of fuel by allowing more distribution of LH2 to fueling stations, in line with DOE goals. Large-scale testing may be a challenge in terms of schedule and scope.
- The project has made excellent progress in 2018 to develop and validate a ColdPLUME model for cryogenic hydrogen leaks in a laboratory-type situation. This progress includes evaluating various techniques to measure the dispersion.
- This project has shown excellent progress, mainly around the Raman imaging results and on the validation of the ColdPLUME model for laboratory-scale hydrogen release.
- This effort faces many difficulties, but the project team has overcome them and continues to make progress. However, the progress is confined to cryogenic gas dispersion. The concern is that funding may dry up before other significant experiments on liquid behaviors can be addressed. These future activities are addressed only as remaining challenges.
- The project has set very ambitious targets and shows visible progress. The targets may be too ambitious. It does not seem credible that it will be possible to characterize scaled-up release, including pooling and realistic environmental conditions, with the given funding and the still-existing challenges of the chosen diagnostics tool.
- The "accomplishments" contradict the "approach." The accomplishments to date show progress. It is not clear whether the experience with instrumentation can be applied to low-cost leakage sensors.

Question 3: Collaboration and coordination

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

- The sound design of realistic LH2 release experiments is very challenging and will benefit from an international effort. The fact that an interface is now in place with the European Project, Prenormative Research for Safe Use of Liquid Hydrogen, and with Chinese experts is extremely good, and these connections should be developed further.
- The project has very good collaboration with external stakeholders. The constant interaction with the National Fire Protection Agency 2 Technical Committee is essential for the success of this project.
- Collaboration and coordination with industry, academia, and code-setting organizations are good. Several cooperative research and development agreements (CRADAs) are in place.
- Collaboration and coordination with other institutions has been good, especially among experts. It is recommended that the project increase collaboration with members of industry associations, such as the American Petroleum Institute and the Compressed Gas Association.
- The presentation did not make clear how, or if, the partners had contributed to the present progress. Air Liquide was mentioned as participating in an H2@Scale CRADA that will accelerate progress, but how this would occur was not elaborated. In the past, Germany's Federal Institute for Materials Research and

Testing has performed spill experiments, and various Japanese research efforts have sought to model spill behaviors, but it is not known whether these organizations are still involved in this research. In the more distant past (1980), NASA performed moderate-scale (1500-gallon) LH2 spills, but at present NASA is not investing resources in further study (i.e., no shuttle or space launch systems are in development).
- The partners (slide 2) and collaborators (slide 15) do not agree. It is not clear how Shandong and the Fuel Cells and Hydrogen Joint Undertaking add value. Air Products and Chemicals, Inc., and NASA White Sands might be of more technical value.

Question 4: Relevance/potential impact

This project was rated **3.7** for its relevance to/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 work is of extreme importance to the hydrogen and fuel cell community, mainly in the transportation sector. As more hydrogen stations are coming online and the ramp-up in the deployment of hydrogen fuel cell vehicles keeps moving forward, the transition to liquid hydrogen stations will soon be approaching. Having a clear understanding of the safety aspects of liquid hydrogen is key for moving forward with these technologies.
- The LH2 topic is of relevance in many nodes of the hydrogen technology chain, from bulk storage to hydrogen transportation to on-board storage for specific mobility and transport modes. This project is making an incremental step in fundamental knowledge of the problem by designing an advanced diagnostic tool and contributing considerably to expansion of the experimental dataset.
- The information sought is critical to the deployment of LH2 infrastructure for public use. Without it, hydrogen dispensing stations will be both uneconomical and unsafe. It is appropriate and perhaps critical that an organization such as SNL (unbiased) conduct the research.
- Cryogenic hydrogen is likely to be used in larger fueling stations, so the development of this information is critical. The relevance is very high for the Hydrogen and Fuel Cells Program goals and objectives.
- The project has strong relevance and potential impact toward Multi-Year Research, Development, and Demonstration Plan targets. LH2 system designs and features that can reduce the overall risk, in addition to the primary task of characterizing/modeling cold plumes and flames, should be kept in mind.
- The relevance of determining the characteristics of a plume from a liquid release might be of use in determining the appropriate setback distances. It would also be interesting to determine the lower flammability limit and lower explosive limit levels at cooler temperatures (maybe -40°C, -100°C, -150°C). Ignition energy requirements might also be of interest.

Question 5: Proposed future work

This project was rated **3.1** for its proposed future work.

- The proposed future work has been clearly defined by the project team, and the team has clearly articulated how this future work will address the remaining challenges. It is great to see that experiments and models to characterize pooling and evaporation are planned for next year.
- The proposed work is absolutely necessary, but it is still a bit general as described and needs more development/elaboration before review can determine its adequacy.
- In general, the proposed future work is appropriate and pertinent. However, the plans to address the many variables in real-world situations are not well defined.
- The proposed future work is perhaps over-ambitious when claiming to tackle real liquid spilling, including pooling and evaporation. So far, the project has focused on small-scale experiments in the laboratory.
- The proposed future work to model large-scale releases will be a significant challenge. The project team should evaluate the need and cost of large-scale releases. The team should coordinate and collaborate with others in industry to ensure success. The project should include a backup plan for model validation if large-scale releases with Raman scattering prove difficult.
- The proposed future work is limited. The team proposes to figure out the instrumentation grid, predict the extent of the plume on a release, and validate the model with data from the release. This reads as an ending

point. It should be a starting point. It would be good to know the local temperature and mole fractions in the plume, at the mole fraction at which an ignition is likely, and the pressure/thermal map of the plume at ignition, deflagration, and detonation. It is not clear how this project matches up to Chris LaFleur's work. The models should merge seamlessly.

Project strengths:

- The project pursues a good technical approach to measuring cold hydrogen gas behaviors. It is an approach that has risk, but a risk worth taking, given that previous measurement strategies have significant drawbacks. The project approach is straightforward and will directly address the needs of both equipment and standards developers.
- This project already has and will further reduce a critical knowledge gap in the field of LH2 behavior. The whole hydrogen technology chain will benefit. The project also provides advancement on basic physics as well as improvement of advanced diagnostic tools. Because of the considerable challenge ahead, including the cost of validating experiments, joining international forces is paramount. Because the project has a working interface with a parallel European project, it scores high in this dimension as well.
- One project strength is the identification of an important gap in hydrogen data, particularly cryogenic hydrogen, related to safety. Another strength is the assessment of currently available dispersion measurement techniques and laboratory use of simultaneous particle image velocimetry and Raman spectroscopy.
- Project strengths include the science-based merit, the approach and model validation strategy, the impact the project has had on national codes, and the downstream effects on the built environment.
- The project has very strong modeling and technical capabilities for LH2.
- The expertise of the laboratory is a strength.

Project weaknesses:

- There are no project weaknesses.
- The work is absolutely needed, and the results could be applied to today's development efforts. Perhaps the work could be pursued faster. Certain spill hazards could be investigated without the cold gas dispersion knowledge and therefore might be done in parallel. DOE would need to make more resources available to accelerate work.
- A milestone has already been achieved in the project regarding the diagnostic to be adopted in the following phase of the project. The choice has fallen on an advanced optical diagnostic, which is the only one promising to capture the complex processes of cryo-releases in their entirety. Nevertheless, the project also has the ambition to study scaled-up field releases (closer to real-world situations). It may be the case that the advanced diagnostic (still partially to be developed) does not perform well in a much more complex experimental set-up or that a high number of very expensive experiments will be necessary for validation. The project seems to have focused on only one diagnostic strategy, and it is not clear why the possibility to make use of standard, much less accurate but cheaper and already well-tested sensors has been excluded.
- Large-scale validation of the model will be a challenge. The project team should consider including a backup plan for model validation if full-scale LH2 system-level releases are not practicable/feasible.
- The approach of the laboratories and the lack of accessing data from other industry and government entities are weaknesses.
- The project will need to address a wide range of leak/spill situations. This should include environmental effects.

Recommendations for additions/deletions to project scope:

- There are no recommendations for additions/deletions to the project scope.
- Scope expansion recommendations would suggest accelerating work by describing in more detail what spill testing should be conducted. Experimental efforts that do not require the cold gas dispersion techniques could be pursued on a more aggressive schedule. Possible initiatives might include developing the following:

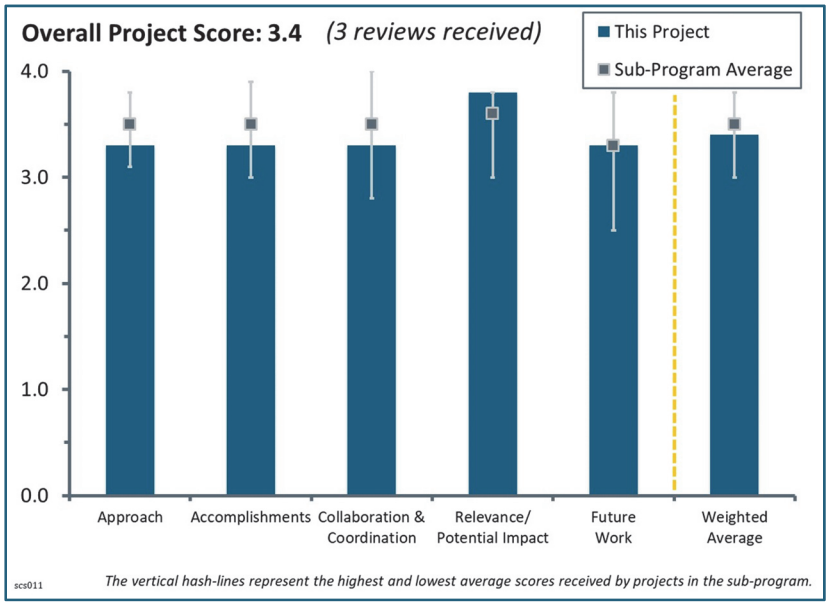
  - Interactions with ambient gases.
  - Data on pool formation and modeling how large pools can become, how long they persist, and what factors influence outcomes. This should include steady leaks that will chill the ground until a pool can persist and, under certain weather conditions, will promote advance of a ground-level cold plume that can extend some distance from the leak point.
  - Identification of circumstances that lead to shock-sensitive mixture formation and experiments to bound the likelihood of their formation.
- One recommendation is to further deepen and expand the international collaboration, in particular when going for full-scale field experiments. Another recommendation is to reconsider the diagnostic strategy to add more standard (i.e., off-the-shelf) sensing methods, as well as a benchmarking exercise.
- The team should continue to stay abreast of similar efforts in other countries, for example, in the European Union and Japan. The project has had success in modeling in a laboratory situation. Perhaps this could be relevant to potential cryogenic hydrogen use indoors, such as forklift operation in a warehouse.
- It is unclear whether NASA White Sands is a better test site. Perhaps the project could ask NASA or the Jet Propulsion Laboratory for suggestions on instrumentation.
- The project team is strongly encouraged to keep engaging with industry stakeholders that handle large volumes of LH2.

Project #SCS-011: Hydrogen Quantitative Risk Assessment

Alice Muna; 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 (QRA) 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 **3.3** for identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- The project approach is good to ensure that safety analysis is based on validated scientific models and that such analysis is incorporated into models for usage by industry and codes organizations. The content of the approach for this year appeared to be on maintenance and support, rather than on new contributions.
- There is good coordination with other projects feeding data into this project to support this project's efforts.
- The approach is tried and true. However, some verification may be in order. It was previously suggested that the model be used to predict the requirements for a liquefied natural gas release and then compare the model's predicted separation distances with the separation distances required by National Fire Protection Agency codes. This would give an indication as to the degree of conservatism in the requirements and possibly be the ammunition to relax the distances for hydrogen.

Question 2: Accomplishments and progress

This project was rated **3.3** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- Input into model codes makes it possible to reduce separation distances for storage at fueling stations. This is an excellent accomplishment that will make it easier to site these stations. There is progress in terms of liquid release modeling, but it must be validated with diagnostic tests.
- The overall progress is appropriate to that which is expected from a professional engineering organization. Expanding the flexibility of the model is a big plus. As an aside, the table on slide 9 needs a little work. The precision on the distances does not match the accuracy of the model. A tolerance equivalent to 1% of full scale on the appropriate gauge is sufficient.
- The accomplishments for this project were good, as depicted by the publication of the tunnel safety study, although other progress metrics needed to be further clarified. It is good that the Hydrogen Risk

Assessment Model (HyRAM) is being expanded to other applications, but examples of the other applications would have been useful. The further reduction in separation distances is excellent. Examples of HyRAM being used by hydrogen infrastructure providers in the field would be a good addition to identify the progress.

Question 3: Collaboration and coordination

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

- The project appears to have an excellent collaboration list including both national laboratories and industry. The project clearly is involved with codes and standards organizations and the distribution of the tools.
- There is good coordination with other national laboratories and fuel station providers; however, the project should attempt to coordinate with authorities having jurisdiction (AHJs) to find a jurisdiction that will allow the use of the risk assessment model.
- The lack of major players and of AHJs is disappointing. Having a state or major east coast city fire marshal's office (such as the New York City Fire Department [FDNY]), a utility (possibly Pacific Gas and Electric), and an energy provider (such as Exxon Mobil) would help with credibility and advertising.

Question 4: Relevance/potential impact

This project was rated **3.8** for its relevance to/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.

- The rigorous science basis of safety analysis is of high relevance and very impactful to the fuel cell electric vehicle market and commercialization. Without this and similar DOE projects, the codes and standards would not have the data and analysis for making informed decisions.
- If used properly, this tool should be useful in reducing setback distances. Buy-in from FDNY would cement the acceptance.
- The use of the risk assessment model could enable the location of fueling stations and other applications to be more easily sited. The prescriptive setback distances required by the model codes may be overly conservative, and the use of HyRAM could help overcome this burden.

Question 5: Proposed future work

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

- The plans to expand the model for use in other applications are relevant, specifically the plans for use with liquid hydrogen applications.
- The proposed future work is good, although it could be further developed to acknowledge the remaining barriers associated with hydrogen QRA, along with identifying opportunities to validate the results and strengthening the effort with codes and standards development.
- Outreach needs to be considered to get acceptance and usage of project results.

Project strengths:

- The project strength is the coordinated effort among various DOE projects to evaluate behavior, develop methods to assess risk, and apply these procedures using models that are released to the public. The individuals on this project are also a strength in their ability to predict hydrogen behaviors to influence practical applications.
- This project's strength includes its coordination and collaboration with other projects, as well as opportunities to reduce storage and equipment setback distances. The use of the model to justify code changes is also a strength.
- The expertise of the laboratory is a strength of this project.

Project weaknesses:

- The project weakness is that the scope of the tools in the past has been focused on infrastructure. It was encouraging that there is an effort to expand the application of HyRAM.
- To utilize the model, the project proponent must find a jurisdiction that will allow the use of the model, which may be difficult. Outreach to the prospective jurisdictions where stations are to be built should be a priority in order to find a good fit.
- The limited access to the novice is a weakness of this project.

Recommendations for additions/deletions to project scope:

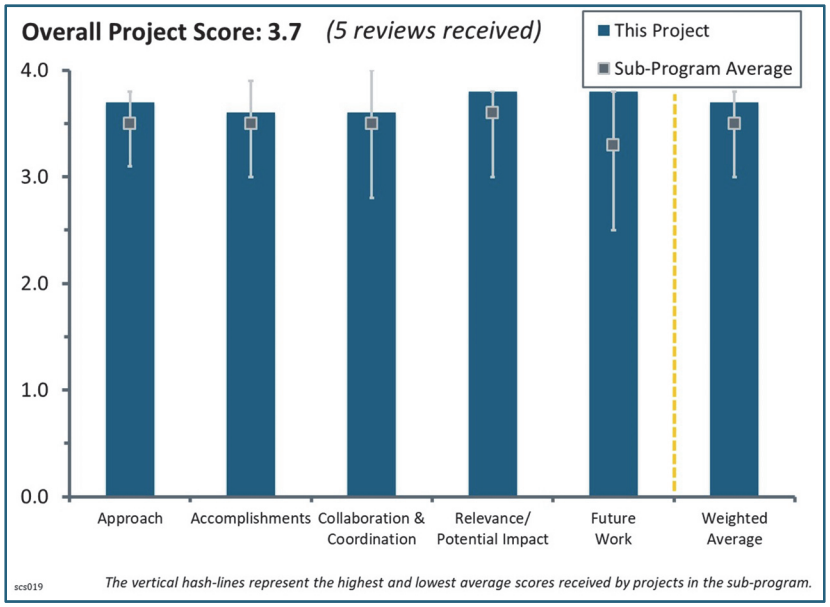
- It is recommended that the project continue to expand the use of HyRAM beyond infrastructure. For example, the HyRAM tool could be used for releases on a vehicle related to the thermally activated pressure relief device, especially in providing scientific guidance regarding the preferred location and orientation of the release. In addition, the emissions from the vehicle tailpipe could be further evaluated to understand the actual safety hazards.
- It is recommended that the project team focus more on federal and state collaboration. It is important to get buy-in from fire marshals and thus, general access of the general public through the marshals.

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 through the Hydrogen Safety Panel (HSP) to identify safety-related technical data gaps, best practices, and lessons learned, as well as help 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 **3.7** for identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- This project is really twofold—the HSP and safety outreach. The approach to both is excellent. The Hydrogen Tools (H_2Tools) portal is becoming an ever-increasingly valuable tool nationally and internationally. Indeed, the international community is turning to the portal as a single point for dissemination of lessons learned, archived papers from the International Conference on Hydrogen Safety (ICHS), etc. The H_2Tools portal is an incredibly valuable resource. The HSP needs to grow and change its focus to be in line with the maturing and changing hydrogen landscape. The emerging collaboration/ partnership/cooperation with the American Institute of Chemical Engineers (AIChE) at this point is perfect. That expanded platform very well could be exactly what is needed for continued and expanded value added for the HSP.
- This project is making excellent use of unique and specialized expertise available in the U.S. Department of Energy (DOE) and the national laboratories to ensure that markets are ready with critical safety and emergency information for expanding hydrogen use into their jurisdictions. The approach has a keen eye to ensuring that the work is not one-time-use and instead provides a growing library of insights and lessons learned as more experience is gained. This aspect of the approach is critical and exemplary.
- Three projects are in the report. The first is the activities of the HSP. The second is the safety knowledge tools. The third is first responder training resources. The approach, as described in the presentation, is appropriate to the funding. Identifying that input into the design, and to a lesser extent construction, is the most technically appropriate and cost-effective approach—in retrospect, an obvious finding. Companies have found that using a tool called a hazard analysis, a top-down discussion to identify and quantify the issues, at the start of a project is helpful. Annex A in American National Standards Institute/Canadian Standards Association (ANSI/CSA) FC 1-2014, "Fuel cell technologies – Part 3-100: Stationary fuel cell power systems – Safety" has a fairly extensive, but not exclusive, list of potential hazards that might be used to populate a hazard analysis. At the end of the design phase, a bottom-up assessment is made, which

often results in changes before construction. The tool often used on a product is a failure mode and effects analysis. The tool often used on a process is a hazard and operability study. Both tools evaluate the effects of a single point of failure (cascade failures are considered single point). This analysis method is used to identify where multiple levels of safety are needed to avoid serious incidents.
- The approach is excellent. Now the project needs extra funding to increase availability for safety reviews of a large number of projects.
- The project objectives are clearly matched with DOE goals. The project has three distinct tasks, all of which are integrated well into other relevant efforts.

Question 2: Accomplishments and progress

This project was rated **3.6** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- This project is really the collection of three different activities: (1) HSP, (2) first responder training, and (3) outreach. This principal investigator and this project have excelled in each of these areas in the following ways.
    - The HSP has gained international recognition to the point that the European Union has emulated this and started its own HSP activity. The HSP has grown beyond its historical activities focusing on providing reviews and safety assistance to the DOE projects. Engaging with California and providing safety reviews and assistance to HSP rollout in California is an excellent example of a very successful extension of the HSP traditional engagements. The engagement with the AIChE should prove to be an excellent move forward for the HSP.
    - First responder training remains a hallmark of this overall activity. Collaborating/coordinating with the California Fuel Cell Partnership has been and remains excellent leveraging of activities. A lack of understanding that training must go beyond the bounds of just those that have hydrogen projects in the local jurisdiction is starting to become an issue. Several examples exist in which first responder training in the jurisdiction with the hydrogen project was performed appropriately, but upper management changed, the new management did not get trained, and an incident occurred. The untrained individual had authority, resulting in over-reaction. The potential new relationship with AIChE in this space and the creation of a "Center for Hydrogen Safety" is probably perfectly suited to expand the hydrogen first responder training to a much broader audience and not just those with hydrogen projects in their jurisdictions, which is outstanding.
    - The H_2Tools portal continues to grow and prove itself as an international resource. Other safety and regulations, codes, and standards organizations not only use the portal but are now contributing to its content. Examples include the International Association for Hydrogen Safety, ICHS (paper portal), and the Japanese. The International Partnership for Hydrogen and Fuel Cells in the Economy just agreed to use the portal as a central dissemination point for "lessons learned" and information with a safety focus to disseminate to the public, which is outstanding.
- The Center for Hydrogen Safety effort represents excellent progress. Significant accomplishments and progress may lead to understaffing due to the need for availability.
- The project appears to be addressing the safety and emergency response needs in a significant number of markets and areas and appears to be focusing relative amounts of effort appropriately with the pace of development of hydrogen initiatives in each respective region. It is good to see the focus expanding to the Northeast states as their network efforts grow alongside California's. The project identified a need to expand its reach beyond just the particular jurisdictions that contain hydrogen fueling locations, to all jurisdictions where hydrogen customers may travel with that hydrogen. This is a very well-identified need and should be a priority. At the moment, the question of how to accomplish this has not been answered, but it should be a priority for the coming year(s).
- The accomplishments still appear to be California-centered. The limited expansion into Connecticut, another progressive yet different environment (distributed jurisdiction versus central, professional jurisdiction) is wise. Expanding this to include New York City (Fire Department of New York City) should be a goal. Expanding into South Africa may not be a wise move based on the instability of the region. Focusing on areas of high fuel costs and high pollution issues may be more cost-effective. Examples for consideration include Italy, Poland, India, and Mexico. Outreach through the transit agencies and trade

organization(s) might be useful. Perhaps discussions with the U.S. Department of Transportation (DOT) Federal Railroad Administration (FRA), Amtrak, Metro-North Railroad, New Jersey Transit, etc. would be useful, if discussions are not already ongoing. Permission to transport hydrogen through rail tunnels by FRA might help deal with the Port Authority of New York & New Jersey (the Port Authority). Additionally, these authorities may be interested in clean electric locomotives that can run on non-electrified tracks. In the Amtrak Northeast Corridor, trains from Boston to Washington, DC, are electrified (and have been so for over 100 years). However, most of the feeder lines are not. The use of hydrogen fuel cell locomotives can "electrify" the rails to at least Roanoke and Newport News, as well as the inland route (Hartford, Springfield, Boston), Philadelphia, Maryland Area Regional Commuter (MARC), Virginia Railway Express (VRE), etc. The white papers written sound interesting, but it is not clear how to obtain them.

- There is a backlog of HSP reviews to complete and still much work to ensure that first responders are ready to appropriately handle an incident at a hydrogen fueling station, other hydrogen facility, on a highway, etc. The project is well designed to work toward these ends; however, progress was slowed because of funding constraints during the first half of the fiscal year.

Question 3: Collaboration and coordination

This project was rated **3.6** for its collaboration and coordination with other institutions.

- The new collaboration with AIChE to establish a Center for Hydrogen Safety is a notable development. This will help ensure hydrogen safety information and tools are readily available to chemical engineering professionals. It is a significant step toward rolling out the hydrogen safety work beyond the hydrogen community. Many of the key organizations are engaged in the work. The support of HSP members is critical. Building upon the new effort with AIChE, future collaboration with well-known entities that supply training to a wider variety of professionals will further the effort to roll out the knowledge beyond the hydrogen community.
- The aggressive outreach by Pacific Northwest National Laboratory (PNNL) clearly shows in the impressive list of collaborators: national laboratories, industry, standards development organizations, code development organizations, other special interest organizations, etc. All contribute to the success of this project.
- The list of project partners involved is comprehensive and has the right mix of collaborators. Their collective work appears to be effective and leverages their respective strengths well.
- The collaboration and coordination is excellent, including the global institutions.
- The collaboration with different organizations should be evolving with time. PNNL should be ultimately supporting public safety agencies such as DOT FRA, Amtrak, DOT Pipeline and Hazardous Materials Safety Administration (PHMSA), and the Coast Guard. PNNL projects should be moving toward that goal with focus on all alternative fuels. The project should work toward being the testing and training support for PHMSA, the Coast Guard, and the various state agencies.

Question 4: Relevance/potential impact

This project was rated **3.8** for its relevance to/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.

- All three elements of this project are critically important to help ensure the safe deployment of hydrogen technologies, with the accompanying first responder training to help ensure that when events occur, they are handled in the safest manner possible.
- Put simply, this work is absolutely necessary and mission-critical.
- All three topics are highly relevant. The project should be careful to avoid overreach. PNNL should support testing and training support at PHMSA, the Coast Guard, and the various state agencies. PNNL should not usurp the code authorities or the Nationally Recognized Testing Laboratories (NRTLs). Outreach to DOT FRA, Amtrak, and the Northeast commuter railroads might help with the Port Authority.

- The project has high impact owing to progress around the world and the steep learning curve for new entrants in the market.
- All three aspects of this project are directly relevant to multiple DOE objectives.

Question 5: Proposed future work

This project was rated **3.8** for its proposed future work.

- All three efforts have worthwhile plans for future activities. Continuation of the HSP and discussions in the Northeast are excellent endeavors. The advancement of collaboration with AIChE to establish a Center for Hydrogen Safety is a notable activity. It is a significant step toward rolling out the hydrogen safety work beyond the hydrogen community. Further, future collaboration with well-known entities that supply training to a wider variety of professionals will further the effort to roll out the knowledge beyond the hydrogen community. Putting props in the hands of the Massachusetts Fire Academy is good. The plans are very promising. It is to be hoped that resources are sufficient to get it all done.
- The value to the safe deployment of hydrogen technologies into the commercial environment has been clearly demonstrated. The articulated future plans are on track to continue and improve on this excellent track record. The collaboration with AIChE should prove to be a powerful step in the right direction for this work.
- The proposed work is appropriate. Outreach to other NRTLs versed in products in this field (FM Approvals LLC and Intertek Testing Services NA, Inc.) may be of benefit to all. Outreach to supply research and training support to federal, state, and local officials who have authority in this area is a must. However, the offer should not be limited to hydrogen but rather should extend to all transportation and transported fuels. Comparisons of hydrogen properties to methane, propane, pentane, and acetylene (i.e., fuels to which the authorities having jurisdiction [AHJ] are well accustomed), using data from Perry's and National Fire Protection Association 497 (i.e., references the AHJs use and trust), have worked very well with AHJs in Connecticut in the past.
- The presentation noted the wide reach of the tools that are available online and the continuing effort to keep information up to date. As more information continues to be developed through this effort and available to stakeholders across the world, there may need to be increasing focus placed on organization of the information for those visiting the online data websites. There may also need to be a "customer-focused" approach adopted for guiding visitors with varying degrees of familiarity with hydrogen to the appropriate information.
- The project team should consider growing/expanding collaboration with different departments within DOT that touch on safety aspects of hydrogen and fuel cell vehicles (all applications) to provide reliable resources and education in this topic area.

Project strengths:

- This project does an outstanding job at providing (1) a safety tools portal for the international community, (2) much-needed first responder training (and an expanded audience of those exposed to this training, thanks to the new relationship with AIChE), and 3) the HSP, which has proven to be a well-recognized, internationally valuable activity that is being replicated elsewhere internationally. The partnership with AIChE should enhance this capability, which is outstanding.
- The three activities strongly support DOE goals and are well coordinated with each other and other projects funded by DOE. The project is beginning to address legacy issues by establishing relationships with others to expand the effectiveness of this effort.
- The project is essential in the effort to provide a balanced view of all safety aspects involved in hydrogen and fuel cell vehicle technology. First responders and stakeholders need reliable and consistent information to be able to provide an acceptable level of safety.
- The project's strengths are its relevance and its necessity. In addition, it is well organized and is particularly effective at disseminating highly valuable information to a wide audience.
- The expertise of the laboratory is a project strength.

Project weaknesses:

- The HSP has expanded its role beyond its historical activities of reviewing the DOE projects, which has been an area for comments and encouragement from the Hydrogen and Fuel Cells Program Annual Merit Review over the past few years. Funding continues to be a challenge for this important and well-respected activity. The H_2Tools portal is, and has proven itself to be, an international resource, both as a resource and as a depository for international communication (e.g., ICHS papers, international incidents, etc.). Again, this project is financially challenged.
- The project's limited budget is probably its biggest weakness. There is much more work to be done than is budgeted.
- This work is very important, and there is still so much more to do faster. It is not clear that resources are sufficient.
- The parochial approach of the national laboratories is a weakness that, it is to be hoped, will change.
- The lack of a secured funding stream for the Center for Hydrogen Safety is a weakness.

Recommendations for additions/deletions to project scope:

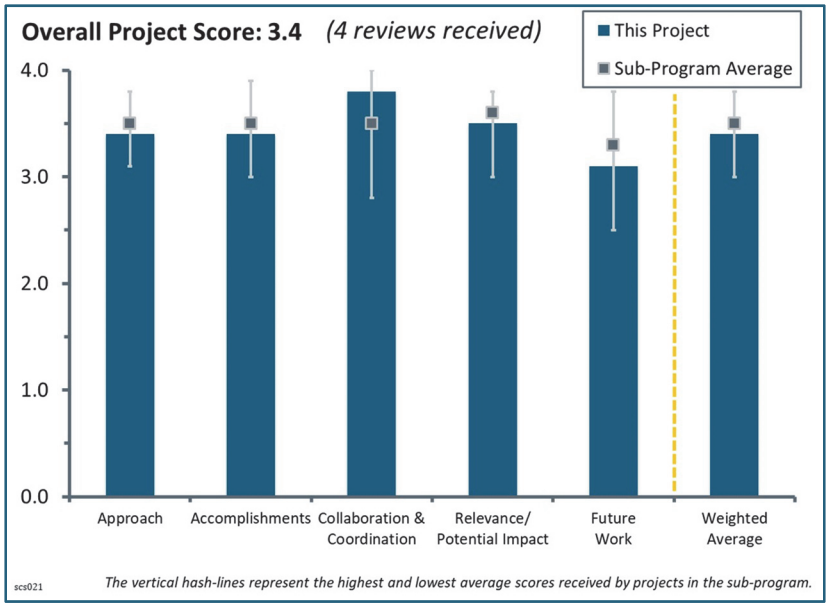
- There are no recommendations for additions/deletions. The project is on the right path.
- The issue of resources for planned future work should be addressed. Rolling out the learnings to others is a necessary step to maximize impact of the work and to train professionals to perform project safety reviews, particularly as the number of deployments grows beyond the ability of the HSP to review them all in a timely fashion. There may be others, particularly entities who train emergency responders, engineers, and other professionals, that can be identified to build upon the AIChE idea.
- There is a need to expand the project's reach beyond just the particular jurisdictions that contain hydrogen fueling locations to all jurisdictions where hydrogen customers may travel with that hydrogen. This is a very well-identified need and should be a priority. At the moment, the question of how to accomplish this has not been answered, but it should be a priority for the coming year(s). In addition, the upcoming partnership with AIChE likely will go a long way toward this, but the project seems like it needs to develop a clearer path for transfer of the work and effort (or simply the funding support) to another body, given the limited DOE funds that are allocated.
- The project should focus more on federal and state collaboration and less on being seen as the model code experts. The AHJs are the decision makers, even when they are not hydrogen experts.

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

William 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 Sensor Testing 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 identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- The approach is thorough and well developed. There is a progression of the technological aspects of hydrogen sensors from assessment toward practical deployment. A strong collaborative network has added to both the richness of the findings and the use of the work produced.
- This is an ongoing activity with clearly articulated motivations, goals, and objectives. The project continues to be well executed and well integrated into other efforts, including those done internationally.
- The most effective portion of this effort relates to the team's determination of which sensor was best for a given application and how to locate it.
- The approach is basically for the project to act as a resource for the hydrogen community through the use of laboratory assessments, field deployments, and partnerships. While this is good and very useful to the hydrogen community, the presentation did not really address how the project accomplished the objectives. The project appears to be mainly reactive to needs as they arise.

Question 2: Accomplishments and progress

This project was rated **3.4** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- This principal investigator (PI) maintains a fairly high level of excellent quality publications, presentations, and reports detailing the results of this project. This guarantees timely dissemination of this effort to the community to ensure the safe deployment of hydrogen systems. This project received special recognition from the DOE Office of Energy Efficiency and Renewable Energy as a success story for the involvement with KPA Services, LLC (KPA) and Toyota Motors in permitting fuel cell electric vehicle repair facilities—this is outstanding. The outdoor cold hydrogen plume used sensors multiplexed together into an array that was simplistic and criticized as a result. Nonetheless, it did answer some critical questions, such as whether hydrogen reached the ground under these conditions—the answer proved to be yes. This was a question in need of answering by the National Fire Protection Agency (NFPA) code committee. This system has been greatly improved by the implementation of many sensors that can be operated in parallel,

rather than in series. Also, the development of validation system optical techniques, such as light detection and ranging (LiDAR), is in progress. This is outstanding.

- Significant progress has been made, but work to improve the clarity of the project's objectives and performance indicators would result in a higher score here; the accomplishments contribute to overcoming some barriers. As an example, the project mentions SAE standard J3089: Characterization of On-Board Vehicular Hydrogen Sensors. It is worth noting that the PI led this effort to develop the technical information report (TIR) at SAE. This TIR is undergoing ballot, and it appears to be very well received by industry. This activity directly supports the project's approach of developing strategic partnerships to support the deployment of hydrogen sensors. This seems to specifically contribute to DOE Objective G, which states that there is "Insufficient technical data to revise standards."
- The project has produced accomplishments. Practical limitations in the efficacy of available products in the market have been assessed and analyzed. Both laboratory and field efforts have been productive in assessing the use of sensor technology. The publication of a reference book on hydrogen sensors and the 2017 workshop report are positive tangible outcomes for the community. Frequent citing of papers reinforces the relevance of the findings. Work with the European Commission Joint Research Centre (JRC) and the activities supporting the development of the global technical requirements in GTR-13 also reinforce global reach. The present work to identify how sensors may be used to effectively change the NFPA 2 standard for the Hydrogen Technologies Code and reduce clearances is promising in advancing practical siting of hydrogen stations. However, there is a need for additional clarity and alignment with the findings of the work by Ethan Hecht et al. from Sandia National Laboratories (SNL) (R&D for Safety, Codes and Standards: Hydrogen Behavior), which concludes that sensors will not be effective because of their limitations and that optical technologies are more practical. More clarity going forward as it relates to the sensor laboratory, coordination for gaseous and liquid applications, and co-optimizing the work on each project being applied practically would be beneficial.
- The sensor evaluation provided results that indicated that some sensors were not performing as required. It is unclear whether feedback was supplied to the sensor manufacturer, but if not, this information should be provided.

Question 3: Collaboration and coordination

This project was rated **3.8** for its collaboration and coordination with other institutions.

- This project has a history of mentoring young scientists and engineers, providing a unique learning experience. The collection of collaborators is impressive. More important is the long-standing collaboration/cooperation with a parallel facility at the JRC in Petten (the Netherlands); also upcoming are collaborations with the Health & Safety Laboratory and others on the development of a hydrogen wide-area monitor (HyWAM) system, which is critically needed to understand leak origins and dispersion.
- Collaboration has taken many forms and is robust and rich. The relationship with JRC has leveraged strengths from each institution and expanded global relevance. The sensor workshop engaged the broader technical community effectively, and the report captured relevant information on gaps to be addressed. Field work with KPA and Toyota has addressed practical market uses of sensor technology and leveraged field experience. Work with the U.S. Department of Transportation has helped address both vehicular and infrastructure applications of sensor technology. Work with SNL needs to be better coordinated for a clearer message to the community about the relative merits and limitations of different technologies in particular applications.
- The project team seems to be collaborating with all the right stakeholders and appears to be readily available to expand collaborations as needed.
- This project has some excellent collaborations with industry and other government entities.

Question 4: Relevance/potential impact

This project was rated **3.5** for its relevance to/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.

- The project aligns well with the Hydrogen and Fuel Cell Program's (the Program's) priorities on safe deployment, and the project has helped advance knowledge on the use of sensors to promote the safe use of hydrogen technologies. Relevance across vehicular and infrastructure applications has been considered and addressed. Advancing the understanding of the efficacy of available sensors has reinforced both the confidence in the project's potential and the need for a better systemic validation of efficacy. Future impacts for H2@Scale (through HyWAM) and NFPA 2 siting requirements might be promising potential impacts, but both would need to be better aligned.
- Sensors are required by the codes. Understanding sensor behavior, being able to select the correct sensor, and determining its appropriate placement is critical to (1) being able to detect hazardous leak events and (2) understanding hydrogen release behavior. These techniques are applied in very expensive laboratory environments, but application in the field is critical.
- The project is relevant because it applies science to help solve safety needs through improved sensor performance and application. The development of a TIR at SAE will improve the impact of the work in vehicles; meanwhile, work on the HyWAM system has the potential to improve the impact for hydrogen fueling stations and other facilities.
- While the sensor location and type of sensor to be used is relevant, there are existing sensors available that can meet necessary requirements.

Question 5: Proposed future work

This project was rated **3.1** for its proposed future work.

- Future work on using findings to address sensor placement and optimize hydrogen station specifications is relevant. Considering applying the findings for H2@Scale is also relevant. Field testing of exhaust gas analyzers is a logical progression. More details around the execution of these aspects would be helpful in promoting success.
- The proposed future direction is appropriate for this work. The focus on the development of a cost-effective radially deployable HyWAM is encouraging. Point measurements are necessary at times (strategically located to indicate a hazardous condition resulting from a leak); however, they are flawed in that one cannot be assured that they are indeed providing the appropriate information. The leak and dispersion of a hazardous cloud may never reach the sensor geographically or temporally to mitigate the hazard. A HyWAM does not have this limitation. The HyWAM will be very valuable in identifying a leak and the resulting plume location.
- HyWAM, sensor placement, and process control activities are good next steps.
- While the work on the wide-area network is interesting, there are no existing sensors of this type, and it may not be practical to initiate work on this. More emphasis on sensor location would be preferable.

Project strengths:

- This project continues to produce high-quality, relevant results in evaluating sensors and developing new capabilities to answer challenging questions posed by those who need answers, such as the code committees, global technical regulation working groups, etc. It is particularly encouraging that this PI has engaged with the SNL Combustion Research Facility (CRF) regarding their detailed plume modeling of cold releases from hydrogen. This will prove to be very valuable in validating the plume release single-point measurements.
- Project strengths include relevant accomplishments, a strong collaborative network, sustained engagement of the technical community, and a good progression of findings to practical scale, even with funding reductions in fiscal year 2017.

- The PI is clearly a national leader in sensor technologies—leading the effort to publish a TIR for SAE is a major achievement. The HyWAM work looks very promising.
- The project's strengths lie in its evaluation of the sensor's location and the type of sensor used for a given application.

Project weaknesses:

- Reaching out to engage the talents of others (such as the CRF) removed the only concern, which was expressed in previous Program Annual Merit Reviews. There are no weaknesses.
- The main weakness is the need for improved clarity with the SNL findings for stations, which should be addressed. There will be an opportunity for a more holistic and consistent approach to be articulated. The next (2020) edition of NFPA 2 is in the Annual 2019 Revision Cycle, which is in progress. Since revised setback distance is an important practical outcome of the project, and "Insufficient technical data to revise standards" is one of the identified barriers the work has intended to address, clearer articulation of the specific outcome(s) would be beneficial. As more start to rely on sensors based in part on this project, additional work to understand and characterize sensor degradation and ongoing efficacy will be important in maintaining the safety of the systems over their useful lives. It would be helpful to refresh the applicability of the data management plan to the details of the project.
- Some of the sensor evaluation work seems to be something that an entity such as Underwriters Laboratories (UL) could perform and, therefore, seems not to require DOE funding. Sensor manufacturers should seek a listing for their products to a published standard.
- There was no data management plan. There is no information provided to facilitate access to the research.

Recommendations for additions/deletions to project scope:

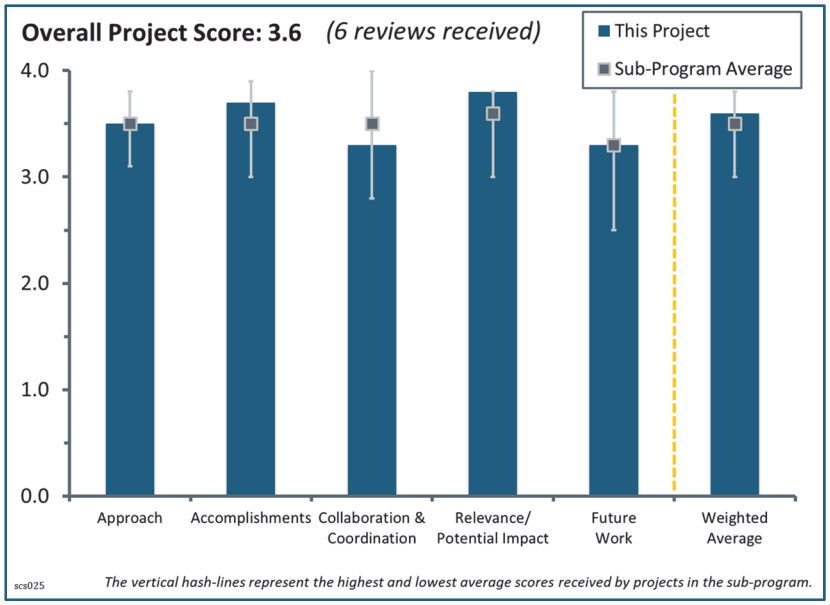
- The clarification of sensor uses versus optical detector uses will be important. Work to address sensor degradation/poisoning modes and to characterize efficacy over the lifetime will be important for effective and ongoing safety of the systems in use that rely on sensors.
- The engagement of detailed cold plume modeling is supported, as is the continuation of powerful collaborations (particularly with the JRC) and the development of the HyWAM.
- It is recommended that the team consider adding a method for accessing the project data, reports, presentations, draft plans, etc. The team should ensure these can be readily accessed by stakeholders.
- If sensor testing could be done by UL or a similar entity, it could be removed from the project scope.

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 **3.5** for identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- The project team is doing a good job of using analysis to select/develop experimental methods for the liquid hydrogen (LH2) separation distance modeling. Likewise, for the tunnel behavior modeling, the project has executed a couple of specific scenarios for specific Boston tunnels and is now looking at a holistic approach that could be applied more generally.
- This is one of the most productive and important projects that the U.S. Department of Energy (DOE) funds, as it is greatly helping code development. It also is an integral support to the safety community.
- This effort is imperative to the successful deployment of hydrogen infrastructure.
- The project appears to build on its successful approach from past years.
- The approach on some barriers is very strong, for example, the technical data attempts to revise C&S and create a synchronization between codes and standards. The approach could be improved by undertaking alternate methods to address code compliance and usage/access restrictions in tunnel parking structures.
- The work being performed is critical, but it may not be sufficient to achieve end goals. The work's focus was on the effects of the hydrogen flame to the tunnel structures. While this is critical, something should be said about the hazards to other vehicles and drivers, as well as the effect of other fuel fires upon the hydrogen vehicle. This may be an expanded scope. The effort does identify the need to communicate with tunnel authorities, but no such specific authorities are listed as part of the collaboration. A separate comment is that the presentation seemed to have a dual focus—partially to review the total coordinated activities and partially to review the technical advances in tunnel hazard research. With regard to the other Sandia National Laboratories presentations that referenced their role in the total coordinated activity, there seemed to be an inconsistent approach. Perhaps a separate project presentation should cover how C&S research was addressed overall and present specific technical investigations separately.

Question 2: Accomplishments and progress

This project was rated **3.7** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The tunnel project has delivered outstanding results and demonstrated that it can satisfy the requirements of the engineers in the authorities having jurisdiction (AHJs), if not the bureaucrats. The LH2/cold leak project is doing a good job of working through significant technical challenges in measuring the cold plume and is making good progress.
- The project has made progress in working with code officials/regulators to understand and address regulatory barriers.
- In general, the C&S effort has identified primary barriers and is systematically addressing them (which is excellent). Regarding the tunnel research, the work is vital, but it will need to focus on other aspects (i.e., a "good" rating), such as collaborating with tunnel AHJs.
- Significant progress has been made in all areas. However, more progress should be made in demonstrating alternate methods/approaches to code compliance. It is recognized that this is strongly limited by support from industry partners; however, the approach itself does affect progress.
- Excellent progress was reported, with many important milestones being met in 2017 and 2018. However, performance-based design for a real-world station seems to be progressing a little more slowly.
- The work thus far is excellent. However, it needs more support to meet some of the timelines for the code development.

Question 3: Collaboration and coordination

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

- In general, this project's collaboration and coordination with institutions is strong, especially in the area of C&S synchronization and technical, science-based data for the purposes of revising C&S. Quantitative risk assessment (QRA) methods and tools have not been widely adopted by industry or recognized/understood by local authorities. The tools are available and generally easy to use, but there is a reluctance to use them as alternate methods of demonstrating code compliance in industry. The proposed future work with QRA, alongside an industry partner (FirstElement Fuel, Inc.), is a promising addition to the project and may have a significant impact on this barrier to deployment.
- The project exhibits excellent collaboration and coordination with industry partners, international organizations, national laboratories, U.S. government organizations (such as the DOE Hydrogen Safety Panel and the U.S. Department of Transportation [DOT]), and C&S organizations.
- The project has involved multiple collaborations with industry, other national laboratories, and AHJs and has also coordinated with other projects.
- The collaboration is *key* to this project's success; it is recommended the team be open to new opportunities for collaboration as they arise.
- The project is collaborating with industry partners (FirstElement Fuel, Inc., the Linde Group, and HySafe), C&S developers (National Fire Protection Association 2/55 and state transportation departments), and international collaborators (HySafe and the Prenormative Research for Safe Use of Liquid Hydrogen activity); this collaboration is important. The project team should consider whether additional collaboration is necessary, as having other station/fuel providers could help.
- Collaboration with AHJs is recognized as important, but this should not be left for later. A separate comment is in regard to the phrase "alternate means." According to the presenter, this does not refer to use of performance specifications, but the description of what was intended is not clear. The alternate means approach would require endorsement by AHJs and should be presented to them. The team should clarify whether more involvement with DOT is necessary.

Question 4: Relevance/potential impact

This project was rated **3.8** for its relevance to/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.

- The project is highly relevant and has a made a significant impact on the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan targets, specifically the reduction of gaseous storage separation distances through science-based code development. The project could also potentially have future effects on fuel cost reduction targets by enabling the wider adoption of liquefied hydrogen delivery to fueling stations.
- The project is absolutely relevant. The key to successful deployment of fuel cell electric vehicles (FCEVs) is in reliable and appropriate infrastructure. Meeting code requirements with alternative and safe infrastructure is necessary. Science can be used to predict and demonstrate safety parameters for tunnels and stations.
- The project has extremely high relevance and potential impact on the speed/cost of permitting the installation of hydrogen stations and facilities. This work also has relevance in "normalizing" the use of facilities such as tunnels, bridges, service facilities, and parking garages by hydrogen-fueled vehicles.
- This effort is crucial to the use and adoption of hydrogen for vehicles and to avoiding the unnecessarily conservative quantity–distance (Q-D) guidelines of the past.
- The work on both storage code improvements and modeling and tunnel research is critical and must be supported.
- This work is imperative to the progress of the hydrogen economy.

Question 5: Proposed future work

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

- The proposed future work is promising and clearly defined. If QRA is not widely adopted by industry or accepted by local authorities, it is suggested that the team investigate alternate or backup approaches toward achieving targets.
- The plans for the remainder of fiscal year (FY) 2018, FY 2019, and beyond are concrete, well-thought-out, and aligned with the overall objectives.
- The proposed future work is defined adequately. The tunnel results of the "risk and modeling" should include a comparison of FCEVs to internal combustion engine vehicles. Sadly, the biggest obstacle may be a stubborn AHJ.
- The project has clear challenges to work on. Some invention is required for the LH2 release measurements, so it is not 100% clear whether there are alternate approaches already identified if the current approaches do not work. The work plan for the alternative methods part of the project could be clearer.
- Bringing in AHJs for tunnel jurisdictions is important. More interaction with the DOT is missing. The team needs to elaborate on an alternate means for LH2 station permits.

Project strengths:

- The project team used an effective, science-based approach to C&S development that has made a significant impact toward the deployment of hydrogen fueling stations and hydrogen-fuel-cell-powered vehicles. The project is clearly defined, with a concise objective and barriers to address.
- The project's main strengths lie in its systematic identification of barriers to hydrogen use, research to provide information to overcome the barriers, and coordination of the use of the data in C&S. These are all accomplishments, especially in today's funding environment.
- The project team's past record of accomplishments is excellent, including the first part of FY 2018. The approach builds on previous years and is still very appropriate. The project is key to DOE's goals and objectives for fuel cells and hydrogen use.
- The project's strength is that science can be used to support the data gaps. The team possesses strong technical knowledge of C&S related to separation distances and the tunnel work.

- The project team has clearly communicated the goals and results (and needs) widely within the hydrogen community and has involved key collaborators throughout the project.
- This project provides excellent data to the code development process, and experts are available for outreach and education to AHJs. This project contains valuable input for code committees.

Project weaknesses:

- In the case of the tunnel research and modeling, the risk analysis shows that the probability of immediate ignition is not that significantly different from delayed ignition (i.e., both have low probability), while the detailed heat transfer model really addresses only the effects of heat on the structure, not overpressure or impulse from a delayed ignition or deflagration flame front. Delayed ignition and pressure are noteworthy hazards of hydrogen that are not as critical with diesel fuel, for example. These effects are important to understand for tunnels and parking structures. More justification should be provided on the decision to focus only on a heat transfer model.
- There are many excellent technical efforts being undertaken, but the framework or overarching strategy needs to be clearer so that the milestones can be more clearly tied to specific identified gaps in C&S and be prioritized to fill the most critical of those gaps.
- The tunnel work requires more technical work surrounding the effects on drivers and the interactions between different fuel hazards. As an example of a possible recent issue, NASA work shows that small combustions of hydrogen at close range can present an acoustic hazard (hearing). Perhaps the team could look into what occurs when larger quantities of hydrogen combust in the confined space of a tunnel. More explanation is necessary to make clear what the "alternate means" are.
- To continue implementing FCEV deployment, educating the AHJs on the safety of hydrogen vehicle technology is imperative to overcoming some obstacles. The team should use resources such as the Hydrogen Safety Panel to help communicate the message. It is also recommended that the team publish the tunnel risk modeling, along with a comparison of today's gasoline/diesel vehicles.
- It may be difficult and/or expensive to validate the proposed models with real-world experiments and data. Funding may not be available in the out-years. This is not necessarily a project weakness, but having to deal with multiple AHJs for tunnel safety may be difficult.

Recommendations for additions/deletions to project scope:

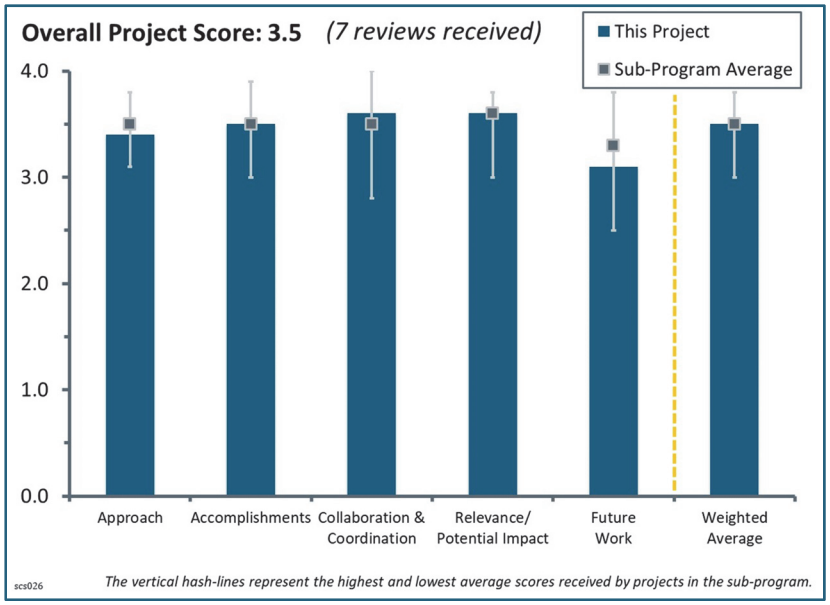
- It is recommended that the team create a matrix of specific C&S that are key enablers for hydrogen fueling infrastructure and then fill in the specific gaps for each, prioritizing the gaps so that the projects and work can be specifically targeted at the highest priorities. The principal investigator may be able to articulate this, but it is not entirely clear in the presentation, and since this is such an important area of work, it would be helpful to have a one-page format to support the Safety, Codes and Standards sub-program education and outreach process.
- It is suggested that the team consider or review the value of a performance-based design approach to alternate methods of code compliance using QRA versus other approaches or methods of demonstrating code compliance, such as alternate materials and methods justifications.
- It is recommended that the team accelerate work on bringing tunnel AHJs into the discussion of tunnel safety. The project team should also further elaborate how alternative means analysis would work.
- The team should address, in more detail, the need to develop/obtain sufficient technical data to revise standards.
- The project should model the comparison of other fuels and their reaction in tunnels.

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

Kevin Simmons; 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 are gathering and assessing stakeholder input about the challenges, materials, and conditions of interest for hydrogen compatibility. Findings inform the project's development of standard test protocols for evaluating polymer compatibility with high-pressure hydrogen, characterization of polymers, and development and implementation of an approach for disseminating the information.



Question 1: Approach to performing the work

This project was rated **3.4** for identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- The approach is good: gather industry stakeholder input, followed by failure mode and effects analysis, to prioritize the concerns needing more work. The translation of these priorities into fundamental tests represents an excellent approach—those tests can be used to build the database or as a launching pad for other organizations/companies to do comparative testing of other materials. It would be useful to do some vetting of test methods to make sure they encompass real-world geometries (such as O-rings) and applications (such as air on one side and hydrogen on the other).
- The approach to the work is appropriate; the team employs performance-based methods and utilizes codes and standards development organizations as a mechanism for the ultimate delivery of outcomes. As this is potentially the last year of this project, it is appropriate that the gas pedal has been hit with the standards organization. It is good to hear that progress on the development of the CSA's Compressed Hydrogen Material Compatibility 2 (CHMC 2) document is moving forward nicely.
- The approach constitutes a disciplined development of characterizing material compatibility for polymers used in hydrogen systems. The use of test environments and characterization methods has resulted in practical tools that have been and will be disseminated to the technical community to guide optimal designs and selection of materials for safety and performance.
- The approach to this work is well focused and clearly outlines well-defined opportunities.
- The approach is excellent. The compounds selected are relevant and in current use. The involvement of the Parker O-ring division would have been preferred. UTC Fuel Cells used Parker O-rings for the Apollo and Space Shuttle programs.
- There is a significant lack of clarity in the objective and purpose of the work. The specific stated objectives and overall presentation raise the question of whether the project is developing test methods, investigating industry component failures, or characterizing polymers for the proposed database. There seems to be a huge disconnect between the scientific motivations for this work and the industry need for test methods and component failure data. The approach for the test method development was not discussed. The approach for the basic research on polymer characterization did not explain what scientific gaps were being addressed by this research. The approach for disseminating relevant information was not discussed. The project also does not appear to address Barrier J in any meaningful way.

- The project is all about experimental observations and data collection. There is no underlying science; hence, the project contains only material- and design-specific results. The testing protocols that were developed and will be developed have no underlying science to make them universal. In fact, because of this lack of underlying science, there is no transferability between laboratory results and real-world conditions/applications.

Question 2: Accomplishments and progress

This project was rated **3.5** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The technical assessment of understanding the effects of hydrogen exposure and system use on polymer fillers and plasticizers, and permeation and diffusion of hydrogen in exposed materials, follows best practices used in assessing materials used in other fuel systems. Developing this work for the hydrogen domain is very relevant in mitigating cascading risks through more informed design. Sharing information with the community through the Hydrogen Tools portal (H2Tools) is an accomplishment, as is the ongoing standards work.
- The accomplishments and progress toward project goals have been significant, and they appear to be yielding more consistent results with the transition from purchased commercial materials to controlled material compounds for research. Although much of the data matched previous work, it was interesting to see the new findings that were focused on controlled materials and conditions related to hydrogen storage. The project's collaborations (with Sandia National Laboratories [SNL], Ford Motor Company [Ford], H2Tools, CSA Group, etc.) show leadership in the area.
- The development and verification of the test methodologies are the major accomplishments of this project. It is important to have the database, but the existence of the catalog of test methods has tremendous value for other organizations to test other materials and increase the database—so there is much opportunity to leverage this work.
- The project team has exceeded expectations for accomplishments, both in the research efforts and the communication of results for significant impact. This suggests the science of this project and its alignment with industry needs are both strong.
- The data presented were interesting but, in retrospect, not surprising. Elastomers without fillers released the absorbed hydrogen relatively quickly. Elastomers with fillers released the absorbed hydrogen relatively slowly and retained several percent of the initial absorbed amount. Fillers increased durometer readings, etc.
- The project team has developed much new data about basic material behavior in hydrogen environments. For scientific work, the main performance indicator is publication; however, there have been no publications and only three presentations about this work this year.
- If a metric of success for the project is to have a large number of results, then the project does have a series of accomplishments to present. However, one wonders about the value of these accomplishments because of the lack of underlying scientific understanding. For instance, the results reported on slides 9 and 17 are not supported by explanations. As a consequence, if tribology features are sought for another reinforced polymer for which there has not been any testing, these data will need to be taken, and it is not certain whether the developed protocol of the project will apply. Also, there is no explanation whatsoever of the coefficients of friction values reported on slide 13.

Question 3: Collaboration and coordination

This project was rated **3.6** for its collaboration and coordination with other institutions.

- The collaboration is rich and productive. Project partners bring relevant contributions both within the project and through connections in the outside technical community to promote practical impacts. Connections with H2Tools and standards development reinforce these types of tangible extensions of the scientific findings into revised practice.
- The project includes collaboration with a wide and varied population of standards organizations, industry, and research laboratories around the world.

- The project has a good selection of partners. Perhaps Parker and NASA may be helpful; space flight has a good deal of low-temperature exposure.
- This project has very good collaboration and coordination.
- This project would easily achieve a score of outstanding if it were an applied research effort. It is an outstanding example of effective collaboration and coordination between national laboratories, and the Ford partnership adds strength. There is evidence of engagement with other industry stakeholders at an appropriate level for a scientific project. However, there is a critical shortcoming which motivates a lower score: there is no evidence of engagement with the scientific community, universities, or non-national laboratory researchers. These are the most important stakeholders in basic materials research.
- The presentation listed Ford, Pacific Northwest National Laboratory (PNNL), SNL, and Oak Ridge National Laboratory (ORNL) as collaborators. The project team did not clarify whether the group of industry stakeholders who were canvassed to identify issues was larger than the listed names. If so, that would strengthen the work, so it would be good if the presentation could list the stakeholders and the level of response to the canvassing.
- There is a large number of collaborations within this project, but no collaboration results were listed with Dr. Shin Nishimura of Kyushu University. This question was raised at the last DOE Hydrogen and Fuel Cells Program (the Program) Annual Merit Review, but no action has been taken despite the fact that a year has passed. No collaborative results could be found with Dr. Nishimura. This is unfortunate because Dr. Nishimura could have contributed to mitigating the weakness of the project, which is a lack of underlying scientific understanding of the tests.

Question 4: Relevance/potential impact

This project was rated **3.6** for its relevance to/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.

- The project is relevant to achieving a sustainable hydrogen and fuel cells industry. Having research that helps with understanding how to quantify compatible materials will ensure the long-term viability of materials used with hydrogen.
- The practical relevance of the work for advancing hydrogen technology through more robust systems is clearly aligned with the Program.
- This research will have an immediate and lasting impact on a global scale on hydrogen energy applications.
- This project is dead on target. It addresses stationary and vehicular concerns.
- The data obtained by the project team are of value to the Program.
- This is a very relevant project, and it has a good deal of impact, for example, on the safe application of materials. The statement was made that testing was shifting from commercially available materials to "specific controlled material compounds." These compounds were described, but it was not clear why these specific materials were chosen or why the focus changed from commercial materials (which might now be likely chosen for commercial applications as the technology accelerates).
- This project provides critical scientific information about hydrogen materials. The connection of the materials data (rather than test methods) to Barrier A or G needs to be articulated. The project does not address Barrier J in any meaningful way.

Question 5: Proposed future work

This project was rated **3.1** for its proposed future work.

- The investigators appear to have a solid plan to continue the test development and testing. Continued refinement of the test protocols is a very important piece of the work, and to that extent, testing relies on some custom test rigs (such as the pressure cycling manifold setup). It is suggested that the project team consider how to make those facilities/rigs accessible to industry and materials suppliers to test materials and components.
- The project's future work for fiscal year (FY) 2018 seems well planned and appropriate to meet the stated objectives to address the stated barriers.

- The completion of the standards work is relevant, although the need for that to be funded in this project merits consideration, as the private sector typically has mechanisms to address that separately with minimal cost. Similarly, the generation of data for particular materials is a topic that is generally best addressed by the private sector, once the methods have been developed and the context for use provided by standards. Future work envisioned to further characterize degradation mechanisms, such as effects of pressure and thermal cycling and long-term degradation profiles, is relevant.
- Polytetrafluoroethylene (PTFE) should be lower on the proposed future work list. As a gasket, it will need to be "trapped." It cold creeps at room temperature, and this creep effect accelerates with temperature. The UTC experience is that an ASME B16.21 (flat ring) style gasket can be an issue in many applications for this material. An ASME B16.20 (spiral wound) gasket that traps the PTFE is often acceptable.
- The future work on slide 31 describes many possible directions for FY 2019–FY 2022. The directions are broad and vague ("build up material properties database"). The presentation does not articulate priorities or a plan for making progress. This demonstrates additional lack of clarity about the objectives and the goal of the work. The project should define next steps more clearly.
- The proposed future work is good, but given the prior progress of the project, it is not clear how the project will come up with a polymeric material damage model. The project has not focused on identifying failure modes and, hence, has not focused future testing on the understanding and modeling of the specific failures pertaining to specific microstructures.
- The proposed future work is a bit broad and undirected. It appears to be more of a plan to maintain a database. Perhaps the team could focus on closing the task and developing a new project or determining an "exit strategy" for the maintenance of the database and information.

Project strengths:

- The project team has strong technical knowledge. The broad range of testing capabilities, as well as the domestic and international partnerships, is a strength. The partnership/involvement with the CSA CHMC 2 standard is strong; combined with populating the H2Tools webpage, the partnerships should produce resources that are helpful to the industry.
- The project is very well structured in terms of the series of steps aimed to "Identify issues" and "Populate [the] database," and it provides an excellent mechanism for developing and prioritizing tests and test methods and disseminating results.
- There is outstanding collaboration between national laboratories. This project should be the model for national laboratory collaborations. Another strength of this work is its use of each laboratory's unique experimental capabilities for multidimensional materials characterization.
- The project's strengths include very effective collaboration and the advancement of relevant scientific protocols based on sound materials science to improve hydrogen system safety.
- This project's strength lies in the development of research methods and a database of materials performance that are critical to hydrogen energy.
- The strengths of this project include testing capabilities at PNNL, ORNL, and SNL.
- The expertise of the team is this project's strength.

Project weaknesses:

- The presentation does not really clarify how the candidate materials were chosen (perhaps this came from the stakeholder canvassing). It would be good for the team to clearly state that process, since the database will presumably be used by industry in selecting durable, safe materials for various applications.
- The work on publishing the standard is promising, but it is not yet complete; this will be a milestone for moving from best practices to repeatable approaches. The need for DOE project funding to accomplish future work in standards and materials data generation should be reviewed.
- The project team needs to involve some fundamental science components to help explain the data obtained and their relevant magnitudes. In fact, testing protocols can be established only when the very nature of data and their magnitudes is understood.
- There is a lack of clarity in the objectives and approach, as well as a lack of appropriate collaborations with scientific stakeholders beyond the national laboratories. There is no plan for the preservation and dissemination of scientific data.

- It is recommended that the project team rethink how the data is made available to the engineering community.
- The project lacks a long-term strategy for database maintenance and improvement.
- The project cannot evaluate every material.

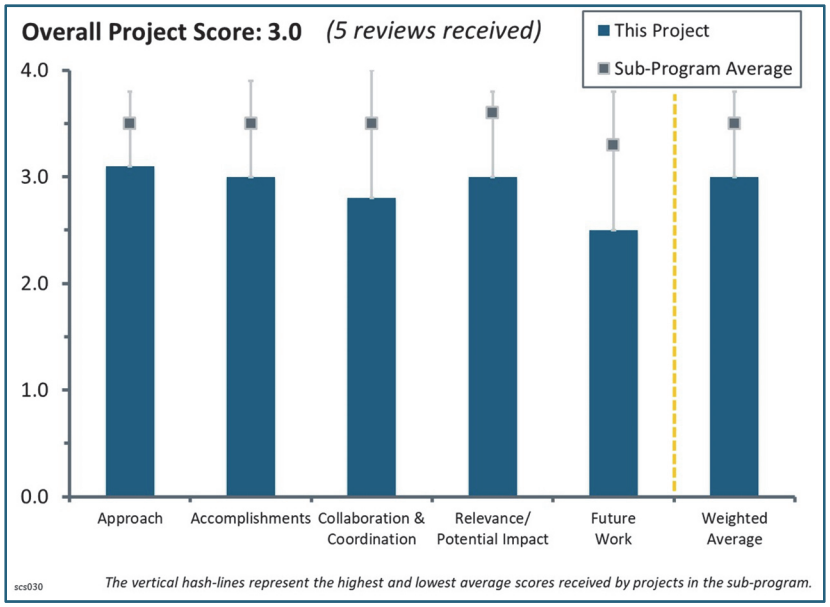
Recommendations for additions/deletions to project scope:

- Polymeric materials for hydrogen infrastructure have been the focus and goal of a number of projects in the Program since 2005. In assessing the progress made so far, it seems that the understanding of the behavior of these materials in the presence of hydrogen has not advanced significantly. More data have been obtained, but a lack of understanding precludes the rational development of codes and standards.
- It would be good to see the intent of the custom material formulations clarified. Also, the team should consider the behavior of key materials in geometries that are likely to be found in typical applications and in applications where there might be hydrogen on one side and air on the other.
- Standards work and the generation of data on particular materials should be deleted from the project scope, as these steps should be fulfilled within the private sector.
- There should be scientific engagement beyond the national laboratories. The project should also publish the results in scientific papers and develop a plan for disseminating raw data to the scientific community.
- The project team should continue to maintain dialogue with the stakeholders.
- More data, at a faster rate, is necessary.

Project #SCS-030: Advancing Fuel Cell Electric Vehicles in San Francisco and Beyond

Jessie Denver; City and County of San Francisco

Brief Summary of Project:



One barrier to increased use of fuel cell electric vehicles (FCEVs) is the complexity of permitting and inspection processes among multiple jurisdictions. This project aims to address this challenge by updating and harmonizing best practices in permitting and inspecting hydrogen fueling stations among the San Francisco Bay Area authorities having jurisdiction (AHJs). Additional project activities include (1) delivering hydrogen safety and best practice education planning, building inspection, and public safety officials and to elected officials in the area; (2) increasing community awareness of the availability and value of hydrogen and FCEVs; and (3) driving market demand for FCEVs through an established group procurement program.

Question 1: Approach to performing the work

This project was rated **3.1** for identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- This is basically an educational outreach project for the public, AHJs, and others, focused on the San Francisco Bay Area. The project engaged in several "events" (e.g., Earth Day, National Drive Electric Week, Electric Vehicle [EV] Week). Of particular interest is the partnering with SunShares, a proven group with established outreach experience and a stakeholder community. This project was able to use EV activities to keep FCEVs in front of stakeholders who were otherwise ignorant of FCEVs and were probably focused only on battery electric vehicles (BEVs). The principal investigator (PI) also collaborated with Tim Lipman (University of California, Berkeley) and Nick Barilo (Hydrogen Safety Panel) to present a tag team presentation at the Fifth Annual Bay Area AltCar Expo and the Green Transportation Summit and Expo, respectively. The PI provided an introductory presentation (titled Hydrogen 101) to prime the audience at those events for Mr. Lipman and Mr. Barilo. This proved to be a particularly powerful and successful approach.
- The approach is sound. It is good to have the team both document and facilitate best practices and do community outreach, education, and training.
- The approach is in agreement with the project objectives.
- The approach should capture "lessons learned" from the interaction with AHJ officials to identify information gaps that could be addressed in areas that are common to all jurisdictions. Also, it is recommended that the team put together a central website dedicated to this project that provides a resource to easily capture and disseminate information (such as webinars, webinar slides, presentation slide decks, etc.). Currently, the project is leveraging other websites, such as the Clean Cities website, that are not as obvious and/or easy to navigate to and find information specific to this project.
- This project focuses on community awareness and outreach in the San Francisco Bay Area only, with no real mechanism to share the lessons learned with other regions.

Question 2: Accomplishments and progress

This project was rated **3.0** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- This project has a very aggressive outreach engagement, and the team partnered with SunShares. Together, they produced a monthly education and training newsletter (with 350 subscribers), maintained a website, worked with the San Francisco Clean Cities coalition, presented webinars for code officials, and gave briefings on FCEV and hydrogen fueling station (HFS) development. The project has a very impressive and expansive list of outreach activities.
- The work with AHJs seems to have been successful; strategically, this is an important group to target because they are very important to the establishment of infrastructure. It is much more difficult to target the general public because it is a large group, and it is difficult to find an effective way of addressing the largest possible group with limited communications and financial resources. A good website would be a good start, but there also needs to be a means of attracting people to the website. There should be a requirement to count the number of hits to the website to measure effectiveness. From the data presented on the review slides, it appears that the number of members of the general public contacted is small. One could argue that that is the job of the auto industry, but the general public still needs independent third-party information.
- The project makes good progress toward its own goals; however, the focused area of the project limits its impact on the DOE objectives. This could be improved through integrating aspects of this project with other funded activities so that lessons learned in other regions could be applied here, and lessons learned here could be better applied in other regions.
- Several activities have been reported for the different points mentioned in the approach. The team conducted many meetings, webinars, and training sessions and met with various people. Nevertheless, quantified data, feedback, and impact are missing. Thus, it would be interesting to provide the number of meetings and people met (industry, regulators, funders, public, etc.), as well as feedback pertaining to any difficulties or questions raised by the attendees. The impact of this project regarding hydrogen perception (positive and negative) after these actions would also be interesting to note. Links to the different meeting materials should be provided for the reviewers. The Hydrogen Station Permitting Guidebook mentioned was published in November 2015. Following these meetings (and as the technology is evolving quickly), perhaps it would be worthwhile or necessary to update the document. It would be good to know how many orders were received after SunShares 2017.
- The community outreach accomplishments are reasonable. The team could have done a bit more in this area. The connection to the SunShares Group Procurement Program is strange—it is not clear why this is part of the project.

Question 3: Collaboration and coordination

This project was rated **2.8** for its collaboration and coordination with other institutions.

- This project has an excellent list of collaborators and coordination activities. This activity is similar to the activities of others, such as the California Fuel Cell Partnership, which is a collaborator on this project. However, the obvious missing partner is H_2USA. Because of this, a score of 4.0 could not be given, particularly since this was noted in the reviewers' comments for the last review. However, it is important to specifically highlight the partnership with Tim Lipman and Nick Barilo and the tag team presentations that resulted from this cooperation—these were really nice.
- The collaborations noted in the project presentation were excellent. There remain key collaborators missing who could help maximize the usefulness of this project. It would have been good to see collaborations with entities that could help ensure project learnings can be used in future projects. It seems as though reviewer comments from the previous year were not adequately addressed. The broader national and international collaborations suggested last year could have helped ensure a more coordinated approach between this project and similar activities that have already taken place elsewhere, or will take place in the future.
- It was good to see collaboration with Tim Lipman—however, it is uncertain how significant that interaction and collaboration was.

- The collaboration level regarding Californian entities was very good. Increased collaboration, or at least a reference to national and international bodies, would be appreciated.
- The level of "outreach" potential is not clear, nor is the size of the respective networks that the collaborating organizations have and the methodology for achieving an ongoing collaboration project. Webinars and conventions tend to be "one-shot" opportunities, but they are also highly specialized to a small community that, in many cases, are already "converts." The larger challenge is to reach outside of the "true believers" group to the general public at large, and it is not clear this project has done that. The lack of the project's own dedicated website is a major problem in achieving this objective. Having a monthly newsletter is a good attempt, but the number of subscribers is still very low (possibly less than 400); perhaps this is because it is buried within the Clean Cities website.

Question 4: Relevance/potential impact

This project was rated **3.0** for its relevance to/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.

- As FCEVs and HFSs are increasingly deployed, the role of and necessity for public outreach and education becomes increasingly obvious. While the vehicles are being deployed at rates that exceed expectations, there are still huge elements of society that simply do not have a clue what this is about, what hydrogen is, or what an FCEV is. For example, according to a story once relayed to this reviewer, a man went to a Toyota dealership in Los Angeles and requested the most environmentally sensitive vehicle on the lot. He was sold a Mirai, which was good. However, when filling up at an HFS, the man expressed that he thought hydrogen was simply an additive for gasoline to decrease emissions. Clearly, there is a lot of educating to do.
- The effort coordinating the AHJs is strategic and appears to have been effective. The team needs to compile a "lessons learned" list so that others can leverage the investment made by the project.
- The project does contribute toward the two DOE goals described in the presentation, albeit in a very limited geographical region. The specific DOE goals are the complexity of permitting and inspection processes among multiple AHJs, and a lack of consumer awareness of hydrogen and FCEVs.
- There is a very significant need to get the word out and to convince the general public and policy makers that fuel cell technology is necessary and complements battery electric drivetrain vehicles well (i.e., they have different features and applications). It is not certain that the team has contributed substantially to informing the San Francisco area of these facts.
- This project may have a very high impact in the acceptance of HFS deployment and, thus, FCEVs in California. This may then also impact other U.S. states and bring instructive inputs for international discussions. However, regarding the information provided for review, there was only a presentation of the numerous actions undertaken, with no real impact assessment.

Question 5: Proposed future work

This project was rated **2.5** for its proposed future work.

- It is good that the team is planning to continue this project for a third year past the planned two-year completion date, with a focus on consumer outreach. The team should look at the potential of coordinating with the automotive industry. Also, it is necessary to build up the mailing list. Those from the Governor's Office of Business Development probably have a large mailing list that could be leveraged.
- The DOE portion of this project is finishing this year. However, the PI will be continuing the effort.
- This project is wrapping up. The presentation notes that the PI will support a third year of the Bay Area SunShares project with outreach to FCEV manufacturers and participation in community workshops. Reporting and dissemination activities appear to be merely turning in a final report to DOE. There is nothing in the presentation that suggests that results will be available in any other form or disseminated more widely.
- The future work and, in particular, the reporting should focus on the lessons learned during this project from all the meetings, webinars, and training sessions that took place. Positive and negative

feedback should be provided to the community, with a list of recommendations to solve the remaining issues both locally in California and also more broadly.
- The project has a very short and weak description of future work planned (even though it is self-funded).

Project strengths:

- This project organized and participated in many conferences, meetings, and webinars aimed at policy makers, safety authorities, trainers, and the general public. These actions are very important in order to facilitate the installation of hydrogen stations and to increase the knowledge and social acceptance of hydrogen technologies.
- There was a significant number of stations planned in the Bay Area. This project helped facilitate community awareness and outreach to permitting officials that could facilitate adoption and more timely approvals for these deployments.
- The project focused on the strategic imperative, which was to work with AHJs to progress permitting. The newsletter is useful and is worth maintaining going forward.
- The idea is good. Outreach to promote fuel cell vehicles as a necessary zero-emissions vehicle option is important.
- This is/was a very aggressive, well-focused, and successful public and permitting outreach activity.

Project weaknesses:

- The degree to which the project accomplished the required outreach to change the perceptions of San Francisco's general public and policy makers regarding fuel cell vehicles is unclear—it does not appear that the outreach was significantly successful. The poster presentation itself was very poor and consisted of printed sheets with thumbtacks. The reviewer visited the poster three separate times and never found the PI present to discuss the project.
- The project lacks its own dedicated website and needs to compile a list of "lessons learned." Furthermore, there was no access to presentation materials, and data on the outreach level achieved (i.e., the number of people attending each event) was lacking.
- The main project weakness is the lack of quantified metrics of all the work performed during these two years, as is the lack of an impact assessment with a list of concrete recommendations for follow-up.
- It would have been good to see collaboration with H_2USA and/or the Fuel Cell & Hydrogen Energy Association (FCHEA) to leverage their more national activities and to feed back to H_2USA and FCHEA this activity's learnings and experiences.
- The project was narrowly focused on a particular geographic region. It was a disappointment to see the lack of robust plans or collaborations to facilitate the sharing of lessons learned.

Recommendations for additions/deletions to project scope:

- The DOE-funded part of this activity is finishing up in fiscal year 2018, so recommendations are not applicable.
- This project is ending. The project learnings should be published and made available for others engaged in future efforts in other regions.
- The main recommendation would be for the project team to perform a real impact assessment, leading to a list of concrete recommendations of actions to further facilitate HFS deployment.
- Given the small budget and limited resources, the focus should be on working with AHJs, political officials, and developers, not on public outreach.
- The project team should do more significant outreach to change public perception.