2015 — Safety, Codes and Standards
Summary of Annual Merit Review of the Safety, Codes and Standards Sub-Program

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

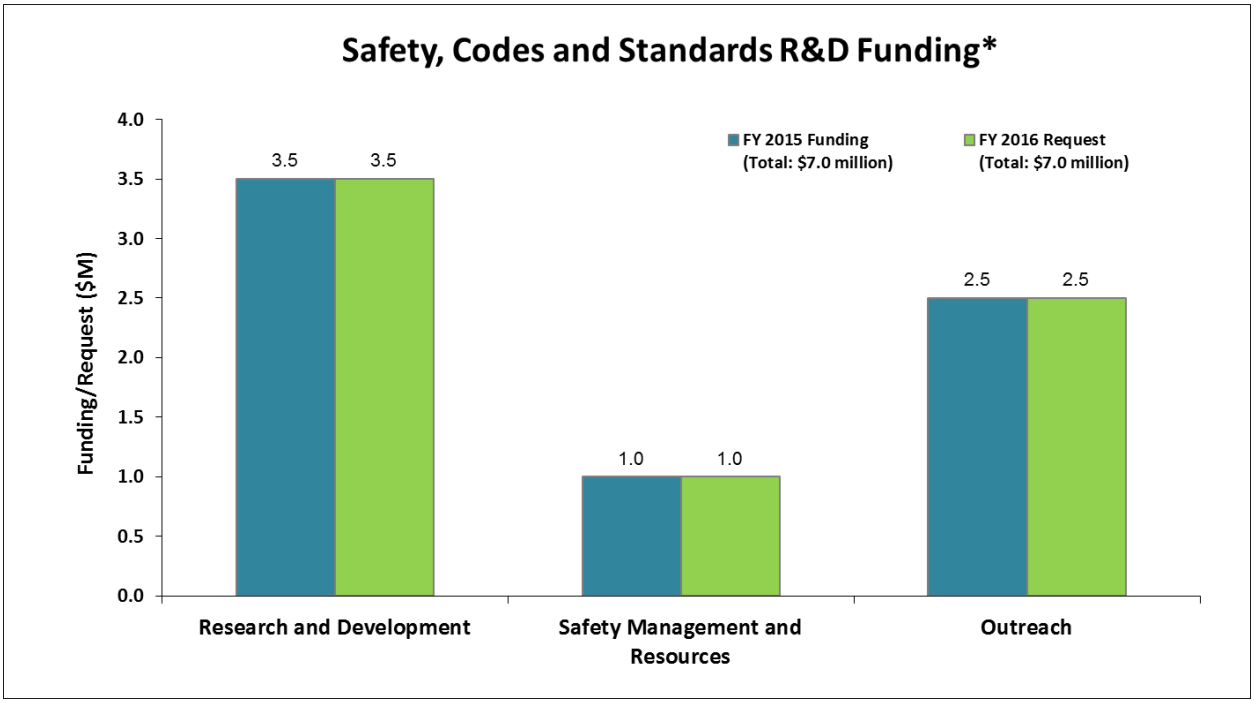
The Safety, Codes and Standards sub-program supports research and development (R&D) that provides the critical information needed to define requirements and close gaps in safety, codes, and standards to enable the safe use and handling of hydrogen and fuel cell technologies. The sub-program promotes safe practices among U.S. Department of Energy (DOE) projects and develops safety-related information resources and best practices. Reviewers stated that this sub-program is essential to the overall development of hydrogen and fuel cell technologies. Reviewers praised the sub-program's overall approach of starting with fundamental science, using that knowledge base to develop models and tools, and disseminating those resources to end users. They observed that the sub-program has transitioned to a more comprehensive and balanced approach from an R&D-focused effort.

As in prior years, reviewers praised the sub-program for its balanced and effective coordination with a wide variety of organizations, including national laboratories, standards development organizations (SDOs), and code development organizations (CDOs). Reviewers also commended the sub-program for its comprehensive approach to domestic and international issues, and especially for its international collaboration efforts. Reviewers agreed the sub-program appropriately prioritizes codes and standards and field validation, along with other critical issues. They commended the timeliness of the sub-program's efforts, especially with respect to outreach and information resources, and they credited this timeliness to the partnerships the sub-program has built with key stakeholders. Reviewers also applauded the sub-program's adaptability to the changing field, pointing out the Continuous Codes and Standards Improvement (CCSI) effort, as well as the long-term goals for alternative compliance methods. Several sub-program successes were also praised, including the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) project, a new DOE Hydrogen and Fuel Cells Program record demonstrating a 50% reduction in separation distances, and a commercially ready hydrogen sensor.

Although reviewers commended the sub-program for its balanced work with both national laboratories and the private sector, they recommended better defining the roles of partner entities with similar capabilities. Reviewers also recommended the sub-program place a greater emphasis on hydrogen metering and indicated this is a key area in need of significant improvement. Other focus areas recommended by reviewers include advanced refueling protocols, stationary applications, coordination with the U.S. Department of Transportation on standards for bridges and tunnels, and other applications such as medium-duty or heavy-duty vehicles. In terms of outreach, reviewers recommended the sub-program seek new ways to report training data to allow for better evaluation of the impact of projects. Finally, reviewers commended the sub-program's vast international collaboration efforts and encouraged the sub-program to seek further international engagement at the R&D level.

Summary of Safety, Codes and Standards Funding:

The sub-program's fiscal year (FY) 2015 appropriation was $7 million, as shown in the chart on the following page. FY 2015 funding has allowed for continued support of codes-and-standards-related R&D and of the domestic and international collaboration and harmonization efforts for codes and standards needed to support the commercialization of hydrogen and fuel cell technologies. The FY 2016 request of $7 million will continue these efforts.



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

Majority of Reviewer Comments and Recommendations:

In FY 2015, 12 Safety, Codes and Standards sub-program projects were reviewed, with a majority of the projects receiving positive feedback and strong scores. Reviewers' overall project scores ranged from 2.4 to 3.8, with an overall sub-program average score of 3.4.

R&D: Eight R&D projects were reviewed, earning an average score of 3.5. The highest-scoring project in this category received an average score of 3.8 and was the highest-scoring project for the entire Safety, Codes and Standards sub-program.

Sensors and Component R&D: Reviewers applauded the developments by sensor projects as well as the projects' collaboration efforts. They commented that sensor work is a critical issue and praised the focus on proper deployment. Reviewers commended the newly established component testing facilities, noting the potential for developing a hydrogen component knowledge base and the use of the facilities for work such as meter benchmarking. Reviewers recommended establishing a clear benchmark for operational wear of components and suggested further cooperation with industry and third-party testing laboratories. For sensor work, reviewers supported future plans for commercialization and recommended more focus on sensor installation guidance.

Hydrogen Behavior, Risk Assessment, and Materials Compatibility: Reviewers were impressed by the significant progress that has been made by all of the projects in this category and noted the critical importance of the work being done. They also commended the projects for their collaborations with the appropriate stakeholders. The reviewers praised the projects' efforts to close knowledge gaps in materials compatibility and recommended efforts to harmonize activities with work being done through the International Partnership for Hydrogen and Fuel Cells in the Economy. Reviewers praised the application of the developed modeling tools for validating alternative compliance methods and highlighted the potential for this use to contribute to further model development. They mentioned the potential difficulty in having performance-based designs accepted by authorities having jurisdiction (AHJs) and recommended demonstrating the results of a real case to encourage adoption. Reviewers also recommended continued efforts to expand models, such as for liquid hydrogen behavior.

Hydrogen Quality: Reviewers identified hydrogen quality work as a critical task that directly addresses needs expressed by the stakeholder community. Reviewers acknowledged these projects' efforts to consider consumer needs and to strive for a commercial application, as well as the demonstrated improvements over the previous year's work. Reviewers applauded projects' collaboration efforts, although they also encouraged further collaboration with CDOs and SDOs.

Safety Management and Resources: Two safety management and resources projects were reviewed, receiving an average score of 3.3. Reviewers commended the developed training resources and safety knowledge tools for their quality and innovation. Reviewers highlighted the value of the Hydrogen Safety Panel to the greater community and to DOE projects, noting that it leads to a general "safety culture." Reviewers praised the benefits of safety knowledge resources such as H2 Tools while also acknowledging the challenge of ensuring widespread deployment of these resources. Reviewers recommended that future work focus on expanding video resources.

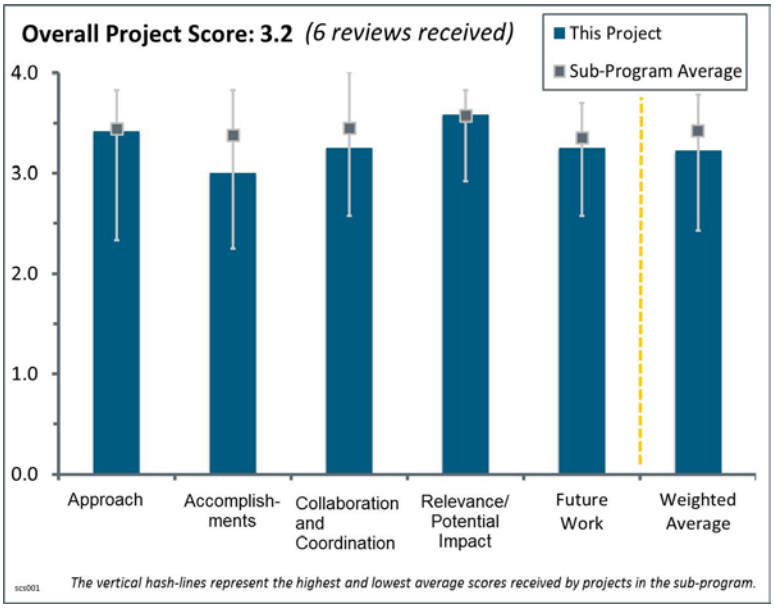
Outreach: Two outreach projects were reviewed, receiving an average score of 3.4. Reviewers agreed that the work to further codes and standards development and facilitate connectivity between stakeholders is critical. They described a forum for industry participation, such as that provided by the Fuel Cell and Hydrogen Energy Association, as relevant and providing valuable coordination. Reviewers applauded the projects' focus on domestic codes and standards, such as in the CCSI effort, as well as praised projects for acknowledging the importance of efforts beyond the completion of initial codes and standards. Reviewers encouraged further collaboration, including engagement of AHJs, to facilitate outreach and harmonization between similar code improvement projects to prevent redundancy and ensure success.

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 a 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 **3.4** for its approach.

- This project comprises two subprojects, with one focusing on development and deployment of national codes and standards and the second focusing on outreach and training for code officials and project developers. In both sub-projects, the approach is well chosen and effective— in particular the continuous codes and standards improvement (CCSI) approach as a structured mechanism for identifying and implementing needed improvements. The training approach also appears sound. For example, it is good to start from the point of view of end users in the development of the training video on hydrogen refueling station (HRS) permitting.
- The barriers are adequately addressed, and the project is well designed, feasible, and integrated with other efforts.
- The team also needs to pay attention to activities at ASME and American Society for Testing and Materials (ASTM) International. It is laudable that this team is more focused on the domestic codes, which are a critical path for the adoption of hydrogen, instead of the International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) standards, which as a rule are not adopted by state governments or the federal government.
- CCSI as a specific project activity produces mixed feelings. The code process is one of continuous development and improvement accomplished through periodic revisit, review, and code modifications. It is not clear what is new and novel about this concept. This project is connected closely with the relevant code development organizations (CDOs) and standards development organizations (SDOs), and with the research and development community, at least at the national level. The principal investigator (PI) of this project is very knowledgeable about the CDO/SDO community. However, the PI can be much more successful by more broadly embracing teaming across the community. The outreach is good.
- The approach could more explicitly link the barriers with the project objectives and efforts. The intent of the project is clearly articulated, closely aligns with the intent of the barriers, and represents feasible project objectives. This project offers leadership and information dissemination on critical areas. The approach of continuous improvement acknowledges the completion of the initial code and standards development while identifying that further efforts are equally as important as the effort to initially develop these documents.
- The team takes a good approach, but it is unclear how much engagement with project developers has been accomplished. It is also unclear what the pathways are for getting feedback from this group.

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

This project was rated **3.0** for its accomplishments and progress.

- The degree to which progress has been made and measured against performance indicators is satisfactory. The degree to which the project has demonstrated progress toward DOE goals is also satisfactory.
- CCSI is a continuous process and typically delivers incremental progress toward multi-annual objectives. In 2015, important results of the training and outreach effort become tangible in a series of important documents, including the ”Hydrogen Technologies Safety Guide,” the “Guide to Permitting Hydrogen Motor Fuel Dispensing Facilities” (which is expected to be published soon), and the HRS permitting video (which is expected later in the year).
- The permitting video and the animation are very helpful references for the community. These are outstanding accomplishments. The “Guide to Permitting Hydrogen Motor Fuel Dispensing Facilities” and “Hydrogen Technologies Safety Guide” documents seem poorly executed. This reviewer has interviewed several key contacts within the hydrogen community, and none were aware of or consulted on these documents. It is very problematic to have DOE or its representatives provide documentation for public use that is not sufficiently vetted by the industry that will be affected. It is counterproductive to the Fuel Cell Technologies Office (FCTO) mission and disables, rather than enables, national and international markets by providing inconsistent or potentially incorrect regulations, codes, and standards (RCS) information. This project is frustrating in that it does some things very well, with lots of creativity, but it does other things poorly, with aligning it to needs of the community. It is unclear whether there is a publication requirement within the laboratory that is driving the need to publish documents annually. It seems every year this group publishes 2–3 poorly vetted documents.
- The HRS permitting video appears to be comprehensive and will be very valuable. The plan for effective dissemination is unclear. The CCSI approach seems to be focused on one key finding (i.e., setbacks for liquid storage). It is unclear whether there is a comprehensive analysis that identifies all necessary codes and standards that might need to be addressed by CCSI. In general, it is a little difficult to evaluate progress from the presentation, especially with respect to the goals and project plan.
- The accomplishments to date are appropriate. Care and coordination is needed to avoid redundant work with other organizations (e.g., the Fuel Cell & Hydrogen Energy Association [FCHEA] and the California Fuel Cell Partnership [CaFCP]).
- This is a list of activities. The number of concrete accomplishments, as opposed to “work in progress” activities, is weak for this level of funding. This element of the project deserves a score of 2.5 because the concrete accomplishments were not clear. The video is being shot now—it is not complete. The script is complete; contracts were put in place in “early 2015” (fiscal year or calendar year 2015?). The video will be useful, but it is still a work in progress. The “Guide to Permitting Hydrogen Motor Fuel Dispensing Facilities” is in the review stage, so it is also a work in progress. The Telecommunications Industry Association document is “well on its way to completion,” so it is still a work in progress. Regarding codes and standards training, several in-person and web trainings have been completed, which is good. These trainings have received good feedback. The “Hydrogen Technologies Safety Guide” was published in January 2015, which is good. With regard to CCSI accomplishments on hydrogen component standards, meeting with CSA to discuss test plans, presenting the issue to the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) project for review (when H2FIRST itself is partially an National Renewable Energy Laboratory [NREL] project) , and prioritizing standards are not concrete accomplishments. However, the list of training activities on slide 13 does signify concrete accomplishments and represents good output from this work.

Question 3: Collaboration and coordination with other institutions

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

- The degree to which the project interacts with other entities and projects is excellent.

- The coordination and collaboration are very good. It might be time to engage the state fire marshal and building inspector trade organizations to facilitate outreach to the states' authorities having jurisdiction (AHJs).
- The project interacts with all required stakeholders, from AHJs to developers and operators. It is actively present in various standardization teams. It can also rely on the pool of competencies available in the coordinated approach to safety, codes, and standards at NREL. It is, however, not clear how the NREL supports the various improvement teams, supports the work of the HCI–H_2 Code Improvement team (HSI) team, and coordinates and prioritizes the huge number of collaborations.
- The list of domestic collaborators is impressive and relevant to this work. However, this project needs to strengthen the collaboration and coordination with international organizations such as ISO. The answer provided by the PI to the ISO question posed last year is unsatisfying. The international code development activities draw on work from other international efforts, and the U.S. efforts draw from the international code development work. Indeed, many of the same people sit on these committees (international and domestic). For harmonization, it is critical that the U.S. code efforts and this project remain well connected and contribute to these international code efforts. The comment from the FY 2014 review is still appropriate.
- NREL has a strong list of collaborators, making the lack of insight into documents much more difficult to understand. It is not clear why this project seems so resistant to collaboration with the H2FIRST and H2 Tools projects. Since they are all funded by FCTO, the program should try to resolve this. Lack of full cooperation seems to be a persistent issue within FCTO and the laboratories.

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

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

- The CCSI approach is very important and timely, now that a first (almost complete) safety and standardization framework is in place. The concept of continuous improvement of codes is something that cannot be left to the initiative of individual industry players, and in this respect, these NREL activities are exemplary.
- The degree to which the project supports and advances progress toward Hydrogen and Fuel Cells Program goals and objectives delineated in the FCTO Multi-Year Research, Development, and Demonstration Plan is satisfactory and on target.
- There is no doubt this topic and the work of this project are directly relevant to the needs of hydrogen technologies deployment.
- This is a very relevant project, given the state of the technology.
- This is a critical path activity.
- This project has had a notable impact, but it could be much more impactful if it were more aligned with the overall mission of the FCTO SCS sub-program. It seems there are disparate groups of individuals working on separate topics, while the industry needs support from a team. The potential impact is much greater than the current impact.

Question 5: Proposed future work

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

- The project will end by September 30, 2015. The degree to which the project has effectively planned its future in a logical manner by incorporating appropriate decision points; considering barriers to its goals; and, when sensible, mitigating risk by providing alternate pathways is satisfactory.
- The proposed work is very good. It might be time to engage the state fire marshal and building inspector trade organizations to facilitate outreach to the states' AHJs.
- The proposed future work is a logical continuation of the effort started in previous year(s).
- It is not clear whether the liquid hydrogen work is connected to other liquid hydrogen work performed at Sandia National Laboratories, or whether this is another example of independent and often competitive

laboratory activities. It was mentioned at the review that NREL should consider hosting on-site visitors for training rather than traveling to only a few key geographic areas. Sometimes the greatest influencers in the fire community are not necessarily located in the key area. The fire community is well connected and capable of relaying information, especially from internal experts and training officials. NREL could and should be an expert in networking to find those individuals, maintaining a close relationship and providing hands-on experience at a real station, rather than "death by PowerPoint" training sessions in the key areas.

- The planned future work is as expected. No really "out of the box"-type of thinking was presented, which would have been good. This project has so much potential—the team just needs to embrace a true teaming approach with others.

Project strengths:

- This PI is extremely knowledgeable in this area and brings years of experience to the table. With that, this project and the PI are very valuable in helping to navigate the code world and successfully executing necessary code language implementation.
- This is a good project that fills needed gaps for meeting barriers. It will be good to see the permitting video. Overall, NREL is well equipped to provide this important work and build on existing collaborations.
- The CCSI approach and results are very timely and an important support to reach the overarching goals of the SCS sub-program.
- The knowledge, determination, and dedication of the staff on this activity are areas of strength.
- The outreach content and outreach expertise are areas of strength.
- The project adequately addresses the states' three barriers, stated in the presentation as (1) Insufficient Technical Data to Revise Standards, (2) Enabling National and International Markets Requires Consistent RCS, and (3) Safety Data and Information: Limited Access and Availability.).

Project weaknesses:

- The concrete achievements made during this reporting period are weak. The slides list a 2002 start date. This is clearly an error. The PI is seasoned in this specific field and has years of experience. This specific program has been funded for at least two years (FY 2014 and FY 2015), for a total of $700,000. The amount of concrete accomplishments is weak; most of what was discussed here represents work in progress. One clearly would have expected some work in progress accompanied by considerable concrete accomplishments. Holding meetings to "finalize …" is not an accomplishment, but an activity.
- The ambition of the project (i.e., the CCSI concept) and the very wide field in which it moves (e.g., from codes development to field assessment) does not seem proportional to the amount of funding received.
- Weaknesses include the lack of cooperation and a cohesive team within FCTO, as well as the lack of industry vetting.
- It might be time to engage the state fire marshal and building inspector trade organizations to facilitate outreach to the states' AHJs.
- The project appears to need a more comprehensive/cohesive work plan.

Recommendations for additions/deletions to project scope:

- This project needs to develop a teaming collaborative structure with other programs and projects working in this space, both domestically and internationally. It is concerning that several projects are working in this space with little to no coordination/collaboration between them. The problem of liquid hydrogen separation distances is such an example. These activities need to be led by industry, not a national laboratory. FCHEA TWG/HCTF might be the perfect place to provide a center of activity to help coordinate efforts on this issue. NREL could team with the HCTF, providing the wealth and breadth of expertise this PI and NREL have to that industry-led activity. To be successful, this project will need to collaborate and team with a diverse set of talents.
- Slide 12 states that "NREL supports CS through active participation in technical committees..."—it is not clear what this "support" really entails. The project interfaces with many other projects in the SCS sub-program. From a 10-minute presentation, it was not completely clear how this interface is coordinated. It would certainly help the evaluation of the impact and the assessment of project efficiency if in the coming

years, some time would be dedicated to explain the relationships between the CCSI, which is an NREL specialty, and the development in the field of NFPA, the Hydrogen Safety Panel, and other related activities. It would also be good to see some examples to understand how the various improvement requirements are ranked and tackled in a prioritized manner.

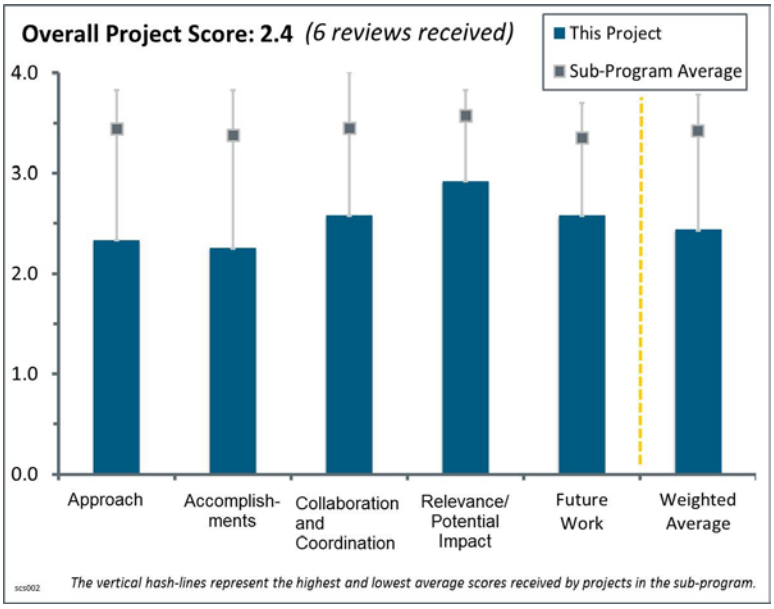
- It might be time to engage the state fire marshal and building inspector trade organizations to facilitate outreach to the states' AHJs.

Project # SCS-002: Component Standard Research and Development

Robert Burgess; National Renewable Energy Laboratory

Brief Summary of Project:

Safe deployment of hydrogen fuel cell technologies is dependent on components that are proven to perform safely and reliably as measured against new safety and performance standards. The goal of this project is to work with manufacturers, installers, and the National Renewable Energy Laboratory's (NREL's) Technology Validation program to prioritize gaps in safety and performance standards, and then work toward closing those gaps by conducting hydrogen component research and development and performance validation.



Question 1: Approach to performing the work

This project was rated **2.3** for its approach.

- The development of accelerated tests to evaluate material selection for the valve seat and seal may be useful.
- This review comments on two aspects of the project: dissemination of information to the community and methodology of obtaining failure data.
    - Iteration with the codes and standards community is important, but there was no concrete evidence where this actually has been done. It is critical to get this information out into the community; it is questionable whether technical reports are the most effective vehicle to disseminate results from this work. It would be good to also see this work published in refereed literature so it gets vetted by the community. The components workshop is very good as a communication vehicle. This work should be expanded.
    - As quantitative risk assessment (QRA) efforts are improved, data is needed on failure mechanisms and frequency (e.g., mean time between failures). This project should make sure it contributes to developing that database. The notion of "designing" components for failure in order to better understand failure mechanisms is a little curious. It is unclear how one designs for failure and still produces a component that represents the actual component used in service. In particular, one valve failure with which this reviewer is very familiar was a fatigue failure due to several factors, especially the hydrogen incompatible material. This failure is a materials issue, not a "component" issue. It is known that this was a mistake not intended by the original bill of materials. It is not clear how the components are being designed for failure in a realistic manner to provide new information, rather than simply doing so to create a failure in a domain that is already understood and/or putting the test specimen in a domain unrealistic for designed installations. Modifying a component for failure by changing the material to one that is susceptible to fatigue crack growth does not add to the understanding of failure mechanisms. However, the example given by the principal investigator (PI) of exposing a composite overwrapped pressure vessel (COPV) to a qualifying test when the COPV has been exposed to acid to see whether the qualifying test will fail the tank (as it should) is of value.
- The referenced report on pressure relief devices (PRDs) (*Pressure Relief Devices for High-Pressure Gaseous Storage Systems: Applicability to Hydrogen Technology*, http://www.nrel.gov/docs/fy14osti/60175.pdf) does not mention the current efforts at the Compressed Gas Association to remove PRDs from hydrogen and all other tube trailers. The "Unexpected Failure of

Rupture Disk on Liquid Hydrogen Tank" section on page 6 makes some confusing statements such as the "burst disk PRD ruptured prematurely when a cryogenic liquid hydrogen storage tank became slightly over-pressurized due to heating from ambient temperature. Investigation showed that the hydrogen piping was creating back pressure on the disk during manual venting, which caused the PRD to rupture below the set pressure." It is unclear how back pressure on the downstream side of the burst disk can create extra pressure on the process side. The laboratory testing of the PRD that was involved in the known valve failure is not being tested with pressure cycles and it is not clear why it is not being tested. This question was brought up, and the team seems to miss the point that these PRDs are on bank storage systems that experience daily pressure cycles.

- It is not clear why there is a need to replicate a known failure under laboratory conditions. The known failure involved improper part selection, not a misunderstanding of the underlying technical principles. The description of this project's approach is misleading. The project team attempted to fit testing of the failure into the broader suite of necessary evaluations (i.e., "Test Hierarchy" from slide 5)." It is not clear whether this effort is part of a larger hierarchy of improper part selection testing. For example, it is not clear whether the compressor check valves in the subcomponent laboratory testing use improper materials or improperly selected subcomponents, for the team just to see whether they will break.
- The test program does not appear to be vetted by the industry or correlate to real life. It would be advised that suppliers of hydrogen stations be contacted to update the plan.
- It is unclear whether the 70 MPa station was operational at the time of the presentation.

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

This project was rated **2.3** for its accomplishments and progress.

- It is nice to see the laboratory is up and running. The non-destructive inspection is good and will be valuable as this project continues. The PI also noted that destructive investigation/observation also needs to be performed to understand the failure mechanism. This project is funded at about 0.5 full-time equivalents (FTEs) for 2014 and about 0.3 FTEs for 2015. Even at this low level of funding, more concrete output is expected. However, the laboratory took a long time to get up and running, so the PI has not had a lot of time with a functioning laboratory to generate concrete output, which did not help. Regarding outreach, the component webinar is good.
- The accomplishments and progress may be appropriate; however, there is no clear goal or objective.
- It is not clear what the key performance indicators are for the project. It is also unclear how the team has reached the goals it previously set for itself. Besides some pictures of the test setup, it seems that no answers are provided. When questioned during the review, the PI had no answers or seemed too unfamiliar with the project to provide sufficient answers. This project, particularly by juxtaposition with tremendously beneficial projects such as the compressor durability work, casts a negative light on associated projects and should be considered for discontinuation. It is not clear why the metrology meeting only invited foreign private companies (e.g., Tatusuno and Iwatani), and why no U.S.-based or U.S.-operating companies participated. It is not clear how this benefits U.S. metrology efforts. The February webinar did not appear to add value. The open house seems to have provided little more than a networking opportunity. The proposed accomplishments have not achieved the stated objective (slide 3): "Successful deployment of hydrogen infrastructure will require components that are proven to meet existing safety standards."
- The purpose of slides 8–10 is unclear. The accomplishments stated in these slides seem to be that the test equipment is installed and the function and capabilities of the equipment. It appears this effort is more part of the approach for testing. It is good to see a CT scan is effective and non-destructive in identifying/inspecting/evaluating issues. When considering a relief valve nozzle, no indication or benchmark was provided for an acceptable level of operational and/or installation wear. It is unrealistic for the application environment (i.e., hydrogen fueling station) to expect no operational or installation wear for installed equipment. Regarding slide 13, the use of lower-pressure testing was attributed to the time needed to purge. However, for realistic accelerated test data, the project should consider using the pressures found in a 70 MPa station setting or explain how the resulting data correlates to 70 MPa station applications. The project team members should consider the relief valve failure reported in DOE's Safety Incident Database. The metrology collaboration event was good, but it was not clear why the California Department of Food

and Agriculture, Division of Measurement Standards was not involved. The team put forth good effort on the webinar and open house focused on hydrogen components.
- The testing of the known failed valve type spring-loaded safety relief valve needs to be conducted by pressure cycling. The thermal cycling approach currently used does not correctly simulate actual service conditions.
- Creation of a new CSA Group standard for pressure relief valves (PRVs) is advised, but this needs to be vetted with industry.

Question 3: Collaboration and coordination with other institutions

This project was rated **2.6** for its collaboration and coordination.

- Collaboration with the National Institute of Standards and Technology and international partners on meter accuracy is a good investment of time and money.
- The team made a good effort to reach out to the right entities. However, third-party testing laboratories should be more closely involved (e.g., through joint efforts or side-by-side in-laboratory collaboration) with NREL's efforts (instead of only talking). This will build capability at these laboratories to do actual third-party testing. It will take more time before this knowledge is gained, potentially effectively delaying the process of third-party certification of components.
- The list of collaborators is impressive; however, it is not clear how the interaction with these collaborators actually works. It would be nice to understand how the talent from these collaborators makes its way into this project. The project features a good suite of collaborators, including Sandia National Laboratories (SNL), which is necessary to study fundamental material behavior. The Energy Systems Integration Facility is a designated user facility, which should encourage additional collaborators and coordination.
- There are several remaining questions concerning the project's collaboration and coordination: (1) what other institutions are participating in the PRV test; (2) what other institution has advised this team on the scientific approach it is taking; and (3) what participating industry partner will take the findings and improve products, thus "successfully deploying the infrastructure components" through the lessons learned in this project. This project is likely to succeed in failing this valve and will also, apparently, investigate an unintended valve failure. One or many reports are expected to be generated from this project. However, without industry, academic, and other collaborators providing input, this project may fail to provide information useful to industry. The team should consider stopping or reorganizing the effort before further time and effort is lost.
- It is unclear who the industry partners are on this project. The project team should speak with members of the relief valve industry. It is doubtful that the members have facilities to test at 15,000 psi with hydrogen.
- More collaboration is needed.

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

This project was rated **2.9** for its relevance/potential impact.

- The project team has done well in setting up the laboratories for testing components, and this work could provide great benefits.
- Data for testing hydrogen components is important for future third-party component certification—it supports commercialization.
- This is a very relevant project.
- With appropriate guidance to make sure the work actually provides unique information on failure mechanisms, the data generated will improve understanding of the failure mechanisms and provide data for safety, codes, and standards QRA activities.
- It is unclear how this project, as explained, would directly benefit industry. A reconsideration of the goals of this testing may be in order. As an example, this testing could be used to (1) evaluate seat/seal materials; or (2) determine the thermal cycle life for valves in hydrogen service for incorporation in the National Boiler Inspection Code.

- There are no industry participants, and there is no technical plan beyond testing PRVs. If this project is truly addressing all infrastructure components, it is not clear why the plan is not more comprehensive.

Question 5: Proposed future work

This project was rated **2.6** for its proposed future work.

- Any successful work developing a master meter technology would be good; however, this seems like a challenging task.
- There is a short list of ideas, but there is no substance, collaboration, or basis. It appears that a similarly poorly planned test for nozzles and receptacles is under preparation. It is not clear (1) why this group did not publish a study that surveyed the most important components to evaluate and appropriate evaluation methodology(ies); (2) why this group did not consider various partners for testing the nozzle and receptacle; (3) who else might have done this work previously; (4) what nozzle modifications the stations and vehicle original equipment manufacturers (OEMs) are planning in the future; (5) what new nozzle designs are under consideration; or (6) why the researchers just assumed they could build a test fixture and take the Edisonian approach to getting some results—that is an irrelevant approach and is unfortunately consistent with this project.
- The focus of the future work needs to be on providing unique data to advance the understanding and to provide data relevant to QRA. This project has potential but attention must be given to performing test campaigns that will yield improved understanding of mechanisms, which would differentiate this effort from the fundamental materials science work that SNL performs.
- The proposed future nozzle/receptacle testing appears to be limited in scope, and it is not clear whether this is the best use of NREL's capabilities. More realistic wear-and-tear usage pattern testing or a method to do this instead may add more value for industry and commercialization in the long term.
- It is unclear where this activity might go. An end goal or interim objective is needed.
- The testing cycle needs to be representative of real-life events.

Project strengths:

- Strengths include the laboratory's testing ability and proper tooling to (1) develop and execute a thermal cycle test protocol to evaluate relief valves; and (2) test various combinations of set and seal materials for durability and functionality.
- Component reliability is important for the safe design of systems. This project has the potential to gather reliability data for use by the QRA community. It also has the potential to understand failure mechanisms to help component manufacturers improve their products.
- Component testing is important for commercialization. Other strengths include increasing hydrogen component understanding and improving the initial testing of components.

Project weaknesses:

- The approach of "designing" for failure will/could result in misleading conclusions or, worse yet, irrelevant data/conclusions. For example, replacing the material with a material that accelerates fatigue crack growth is a design change for failure, but it is irrelevant because a class of suitable materials for hydrogen use is known. In addition, this work will not yield fundamental information regarding the physics governing that phenomenon. SNL already performs that work. The project team needs to work closely with the teams already performing those investigations (SNL is a collaborator) rather than attempt to investigate that set of physics itself.
- There is limited in depth sharing of hands-on experience with testing. NREL is not using its capabilities to the full extent possible.
- The style of the known valve failure PRD should be tested with pressure cycles.
- The objective of the testing and the end use of the data are areas of weakness.

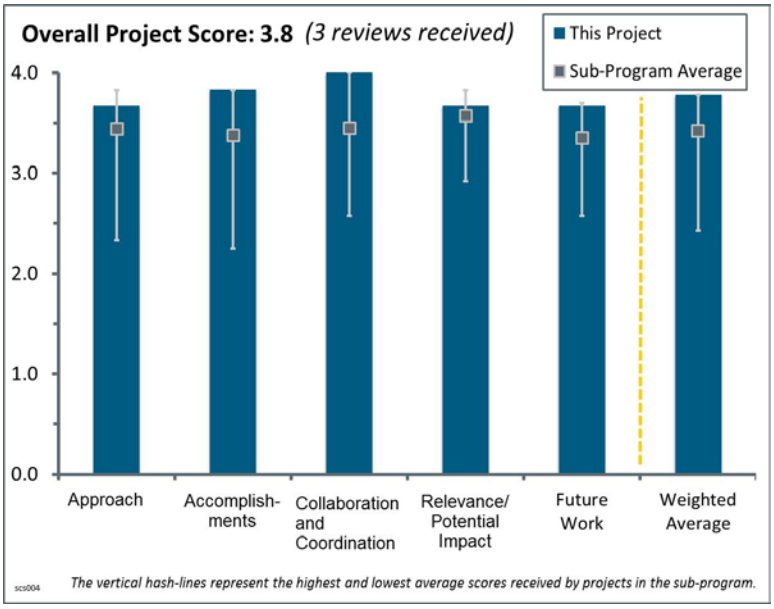
Recommendations for additions/deletions to project scope:

- The team should add an evaluation of nozzles/receptacles used in previous hydrogen station service (used at any pressure) to learn more about wear patterns in actual user environments. Examples of user environments from which to acquire nozzles/receptacles include forklift projects, fuel cell bus fueling projects, OEM vehicle testing grounds, etc. This could be a 1-to-1 exchange of equipment—one new piece of equipment for a used piece of equipment.
- It is suggested that NREL sit down with some industry members to develop a test program objective, determine specific data to collect, and identify an end-use location. The team should also include members from the relief valve industry, ASME, and possibly the National Board of Boiler Inspectors.
- FCTO should revisit the project's objectives and restart the project with a new direction.

Project # SCS-004: Hydrogen Safety, Codes and Standards: Sensors

Eric Brosha; Los Alamos National Laboratory

Brief Summary of Project:



The project objectives include the following: (1) development of a low-cost, durable, and reliable hydrogen safety sensor for stationary and infrastructure applications (extendable to vehicle protection) through material selection, sensor design, and electrochemical research and development; (2) demonstration of the working technology through performance evaluation in simulated laboratory and field test environments, rigorous life testing, and evaluation of sensor performance in relation to codes and standards with National Renewable Energy Laboratory (NREL) collaborators; (3) advancement toward commercialization by engaging appropriate industry partners, for activities such as long-term testing and development of manufacturing methods; and (4) pursuit of commercialization of the new sensor technology through industry partnerships.

Question 1: Approach to performing the work

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

- This project has been designed and executed well. During the last year, specifically, the approach to sensor packaging, field testing, and data analysis has been highly successful.
- The project has demonstrated significant improvements in terms of advancing the sensor technology and demonstrating reliability.
- This project is focused and directly applicable to hydrogen infrastructure.

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

This project was rated **3.8** for its accomplishments and progress.

- The field testing was a great success and allowed the team to identify a few deficiencies in the sensor system (mainly sensor communications). The sensor was found to be very sensitive to what was thought to be refueling leaks, which could be very valuable for new stations.
- The data supported the goal of developing hydrogen sensors with the appropriate response time, sensitivity, and accuracy for use in safety applications to reduce risk and help establish public confidence. The Safety, Codes and Standards (SCS) sub-program will develop hydrogen sensors with the appropriate response time, sensitivity, and accuracy for use in safety applications to reduce risk and help establish public confidence.
- The project team has conducted excellent work.

Question 3: Collaboration and coordination with other institutions

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

- The project had superb collaboration with government laboratories (i.e., NREL and Lawrence Livermore National Laboratory [LLNL], although LLNL is not funded in 2015) and the commercial sector, including with sensor packaging and field testing partners. The communication between the partners seemed excellent.
- The excellent collaboration between partners was demonstrated when an unanticipated need arose for additional data to support questions/concerns over sensing hydrogen and the partners were well suited to provide that data.
- The collaboration and coordination are appropriate for this point in the project.

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

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

- This system could provide a very low-cost, sensitive, and reliable hydrogen sensor for both stationary and vehicle applications, which is critical to the success of hydrogen fuel cell vehicles.
- Sensors are needed in many areas; this work shows good progress is being made to fill this industry need.
- This project is "spot on."

Question 5: Proposed future work

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

- The proposed future work is appropriate for the schedule of the project. The work involves continued data collection at the Burbank station to verify the excursions and incorporating lessons learned for sensor communications to increase data transmission reliability.
- The data gathering has shown/demonstrated the sensors are (1) responding as intended and (2) holding their calibration over a period of time.
- The next steps are toward commercialization, which makes sense.

Project strengths:

- There is good collaboration between partners. The team was able to gather and track data to identify and support sensor performance and provide confidence that the sensors placed in the field are performing well.
- The project's successes are an area of strength.

Project weaknesses:

- A concern not necessarily related to the project, but to the sensor manufacturing itself, is that an exceptionally high percentage of sensors failed right out of the box. A general consumer would not accept this rate of failure for other products. Granted these are not "consumer" products, but the quality control for production should be higher than it appears to be based on the report/discussion.
- One weakness is the lack of funding to expand environmental testing (e.g., altitude at NREL; temperature at the Las Vegas and Ann Arbor sites which are or were Air Products and Chemicals Inc. sites). The team should try to generate interest from major instrument makers (e.g., MSA Safety Incorporated, United Technologies Corporation/Det-Tronics, and Scott Safety) regarding collaboration. The team should show these potential collaborators the field data.

Recommendations for additions/deletions to project scope:

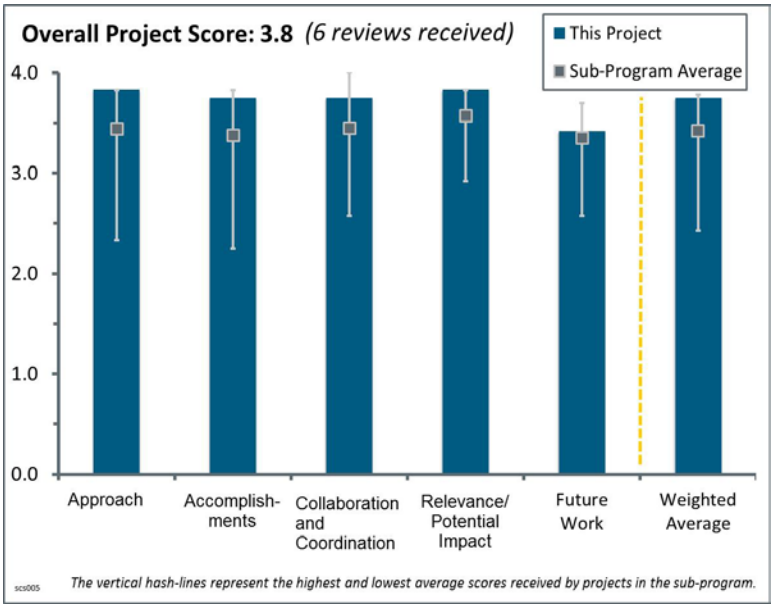
- Recommendations include adding environmental testing and discussions with major manufacturers to project scope.

Project # SCS-005: Research and Development for Safety, Codes and Standards: Materials and Components Compatibility

Brian Somerday; 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 develop and maintain a material property database, identify material property data gaps, develop more efficient and reliable materials test methods in standards, develop design and safety qualification standards for components and materials testing standards, and 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 **3.8** for its approach.

- The U.S. Department of Energy (DOE) has engaged the best and brightest material scientists on this project, and these scientists are leading the efforts to establish new standards for measuring the hydrogen effect on steels.
- The approach is industry-approved and actively supported by ASME. The data will eventually make it into the ASME pressure technology codes and possibly the ASTM International test methods, if support for the project is continued.
- The focus on relevant data and improved test procedures to evaluate hydrogen fueling station components is timely because industry focus is currently shifting from vehicle regulations, codes, and standards (RCS) to infrastructure.
- The approach to performing the work is very relevant to revise standards and good practices for designing materials. The international partnerships have to be maintained, and this prenormative work must be promoted to the international working group level.
- The team made good use of industry input to focus the work and identify the need for work, but it is not clear how industry participation and feedback was utilized during the project (other than through the provision of materials).

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

This project was rated **3.8** for its accomplishments and progress.

- This team continues to make significant contributions to the understanding at CSA Group and SAE International regarding hydrogen effects on steels.
- The accomplishments to date are impressive and assist in furthering understanding of the impact of hydrogen on alloyed steel, which are materials used for vessels and pipelines.
- It was impressive to see the summary slides of work in progress this year, combined with the publications list and collaborations with researchers and industry.

- Excellent progression was shown with respect to the project's accomplishments and progress. Limited information was presented on the progress toward DOE goals (perhaps the progress is implicit, but it should be explicitly stated/displayed). It is important to continue low-temperature testing for pressure vessels.
- Compared with the previous work, the experimental progress is excellent.

Question 3: Collaboration and coordination with other institutions

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

- This team has been collaborating with international partners, specialized technologists around the world, and key standards development organizations (SDOs).
- The collaborations are wide ranging, including SDOs, researchers, and industry.
- The project is very connected and very active.
- The collaboration is sufficient and appropriate. The lack of acknowledgement of the work and collaboration with the National Institute of Standards and Technology is assumed to be an oversight.
- The collaboration with other institutions in Japan and the European Union is very attractive, but insufficient details were provided on content and coordination with initial work.

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

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

- The relevance is high, and the potential impact is great. There is a potential for industry to reduce costs by properly selecting materials and thickness to ensure safety, while also reducing excessive conservative limits.
- The project is very relevant to improving good practices with materials for hydrogen technologies.
- This basic research on the susceptibility of metals to hydrogen attack is essential work.
- The stated goals (slide 3) are a comprehensive effort to provide data-driven development of international RCS for materials compatibility and components used in hydrogen systems.
- Although this is important work, the criticality of the work was not noted. The international impact was noted.

Question 5: Proposed future work

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

- The proposed work is essential to the success of the Hydrogen and Fuel Cells Program.
- This is critical, highly focused research. It deserves funding.
- Industry engagement and input remain evident in this work. Low-temperature and high-pressure testing is a good future approach. International round-robin testing will help move this project forward.
- The proposed work is a continuation of efforts to close gaps in material and component properties, develop test procedures for industry stakeholders, and facilitate safe and cost effective commercialization.
- This is excellent work thus far, but there needs to be clear collaboration with the SAE Safety Fuel Cell Group and an attempt to harmonize the efforts of this project and work being conducted under the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE). There should be a clear direction to develop plans that also include industry input, such as from the SAE Safety Fuel Cell Group. The work done by Sandia National Laboratories (SNL) at IPHE has not been well coordinated and needs to align with industry input. For example, room temperature testing of materials is not a valuable test for the automotive operating environment.
- Round-robin testing should be prioritized.

Project strengths:

- Strengths include the project's technical competence, history of tritium handling expertise, and funding for basic research on test methods.
- The project features strong collaboration and communication with knowledgeable industry members through ASME.
- The accomplishments are apparent and progressing. The team has identified logical follow-on work.
- The project's strengths include the experimental facility and team members' expertise and background.

Project weaknesses:

- There are no obvious weaknesses.
- Weaknesses include the lack of coordination to turn pre-normative work into harmonized standards at the international level.
- The industry input is apparent, but perhaps more direct engagement is warranted.

Recommendations for additions/deletions to project scope:

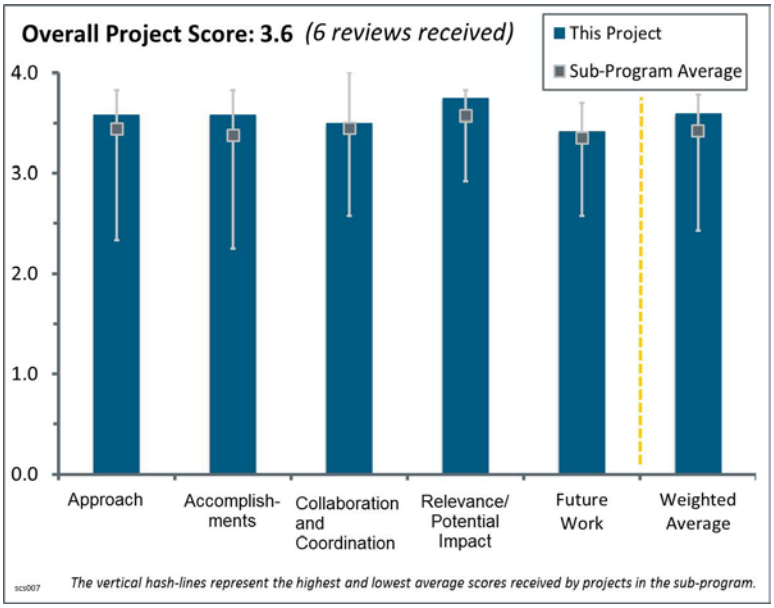
- The project should be continued. The team should consider evaluating other alloy steels and stainless steels (i.e., ferritic, martensitic, duplex, and/or series 200).
- The future work plans should align with the SAE Hydrogen Materials Round Robin, the sensitivity study, and the materials test campaign. Harmonization is needed with SAE Fuel Cell Safety Group input so that the plans for testing at SNL (and with IPHE) are aligned with the industry. There is a need to target and create an "open" materials database for automotive and stationary applications.
- The scope of the topic and the amount of gaps to be resolved are unknown, so it is not possible to make an assessment of what additional work might be warranted. There is no reason to delete anything from the existing scope.

Project # SCS-007: Hydrogen Fuel Quality

Tommy Rockward; Los Alamos National Laboratory

Brief Summary of Project:

The objectives of this project are to (1) contribute to the goals of ASTM International as subcommittee chair for D03.14 gaseous hydrogen fuel efforts, (2) develop an electrochemical analyzer to detect low levels of impurities in gaseous hydrogen fuel, (3) investigate the impacts of contaminants at the levels indicated in the SAE International J2719 and International Organization for Standardization (ISO) Technical Committee (TC)197 Working Group (WG)12 documents using 2015 U.S. Department of Energy (DOE) loadings, and (4) collaborate with international partners to harmonize testing protocols and fuel cell impurity testing.



Question 1: Approach to performing the work

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

- Exerting leadership at ASTM is not an easy task, and the principal investigator (PI) is doing an excellent job of stewarding a wide range of important work through the ASTM process. This is very important work for the progress of hydrogen fueling infrastructure. The efforts to reach out to international colleagues at the Japan Automobile Research Institute (JARI), French Alternative Energies and Atomic Energy Commission (CEA), and VTT Technical Research Centre of Finland is commendable and demonstrates true leadership in a confusing and challenging area, where not all stakeholders are on the same technical page and everyone is learning a lot.
- The ASTM work is spot on and the new activity with WG24 is perfect. Development of a sensitive, in-line analyzer for a polymer electrolyte membrane fuel cell (PEMFC) is a very good approach even without speciation; the fact that there is speciation on some contaminants (e.g., CO and H_2S) is a bonus. The PI is a principal player in the international effort to define fuel quality needs with a high degree of confidence and accuracy. This activity and the PI are clearly recognized internationally as the U.S. leader in this area, which is extremely valuable.
- This presentation covers three projects: (1) interfacing with ASTM on analytical test methods to detect impurities in hydrogen, (2) in-line fuel quality monitoring, and (3) testing of the effects of impurities in hydrogen on PEMFCs. All three activities are critical tasks.
- In-line fuel quality monitoring is one of the most relevant aspects of this project as well as one of the key enablers to a successful rollout of hydrogen fuel cell vehicles and hydrogen stations. For this aspect of the project, the researcher is taking a very effective approach in trying to validate the device with two of the most critical fuel cell contaminants, CO and H_2S, to the levels defined by established standards. The researcher is taking the right approach in first obtaining a response within hours and then decreasing that to levels of minutes. It would be good to see the team start to develop a future cost analysis for this device once it is ready to be deployed in hydrogen stations, because cost will carry a lot of weight when deploying these in a major rollout of stations.
- A great deal of work is being done, and the presentation covered a lot of information. It may be worth separating out the presentations so the presenter can give more information on each subject.
- It is not clear from the presentation how chairing the ASTM subcommittee contributes to the goals, objectives, barriers, and challenges in the Fuel Cell Technologies Office Multi-Year Research,

Development, and Demonstration Plan (MYRDDP). Perhaps chairing the ASTM subcommittee makes it possible to develop the needed test methods. It is not clear whether this can be accomplished by contributing to ASTM activities rather than chairing. The presentation is not clear on this aspect. Development of the in-line fuel quality analyzer and the hydrogen fuel quality testing work seem to directly contribute to meeting expressed needs.

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

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

- The project team is sharply focused on pushing the technology forward regarding a number of critical areas, including establishing international harmony on hydrogen impurity detection methods. The team has many areas of focus, and it is making nice progress on all of these areas, including the round-robin evaluation of laboratory test methods. The progress on the hydrogen fuel cell impurity detector is very good, considering the lack of official industry partners. Ford Motor Company deserves special recognition for supporting this very important work with some advanced technology.
- Given the level of funding (~30% full-time equivalents [FTEs] for laboratory work), the accomplishments are excellent, excellent in quality, and spot-on for the needs of the deployment of hydrogen technologies. The team made great improvement in sensitivity from last year. This is starting to look promising. The response times are getting small enough that when the response time for this technology is evaluated, the sample system must be considered. If care is not exercised, this device will measure the hydrogen from a previous fill, which could be an issue as the device is applied in the field. . Regarding the JARI comparison, the team worked to get the Ion Power cell to match the JARI cell on the JARI cycle. Ion Power redesigned the cell to match JARI—this is nice, but it is not clear why it was important to match PEMFC hardware between JARI and Los Alamos National Laboratory (LANL). This internationally designed hardware will form the basis of the international round-robin on fuel quality with respect to ISO 14687, SAE J2719. Regarding the new recirculation system, the collaboration with VTT-Finland is nice.
- The team conducted excellent work in reducing the response time from hours to minutes on traces for both CO and H_2S. The project is definitely moving in the right direction.
- While this work seems to be very well coordinated and moving along, there is some urgency for the in-line analyzer portion; perhaps more emphasis can be placed on this component of the project, and perhaps this component could be better aligned with the infrastructure that is being deployed now and in the near future. The presentation from the National Renewable Energy Laboratory (NREL) on the in-line analyzer work mentioned monthly calls with LANL. There is room for improvement in that collaboration—working together more closely could expedite a needed technology/product.
- The ASTM-related accomplishments are a disappointment. SAE J2719, the fuel quality standard, was republished in 2011. At that point, there was only one open item—an analytical test method for detection of halogenated compounds. This is still an open item, and it is critical path, especially for a hydrogen vehicle rollout in the Northeast. Regarding the fuel quality monitoring work, the accomplishments on detecting CO and sulfur compounds are encouraging. Regarding the work on the effects of impurities, the data collected on the effects of CO on lower catalyst loading electrodes is needed and useful as the industry moves to new electrode designs.
- The presentation does a very good job of demonstrating progress toward the overall project goals. Improvements can be made on how the presentation describes the degree to which the project has demonstrated progress toward DOE goals.

Question 3: Collaboration and coordination with other institutions

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

- The outreach to international partners is outstanding and groundbreaking. The possibility of international round-robin testing and validation of test methods is about to come true, thanks to the diligent efforts of this team and funding from DOE. The collaborations with international partners are outstanding, and projects such as the VTT-Finland/LANL collaboration and the LANL-JARI-CEA baseline evaluation of membrane

electrode assemblies (MEAs) are breaking new ground by developing international round-robin testing capabilities. Support for the International Electrotechnical Commission WG11 PEFC document on testing, which is under development, is another example of this team leading international standards development.

- This project features the right mix of collaborators—including ISO WG24 in this effort is excellent. The PI should pay attention to evolving efforts in the international standards community. The issue of fuel quality assurance is being reconsidered (including a revisit of contaminants identification and tolerance levels). This fuel quality assurance capability is critical to ensuring those new activities are successful. WG24 is important, but this effort will be superseded by a new work item proposal on fuel quality (previous WG12).
- The coordination and collaboration on the hydrogen fuel quality activity were described well. Further expansion of the relationships with the partners/collaborators shown on the Overview slide would be helpful. For example, the presentation shows the "National Hydrogen and Fuel Cell Codes and Standards Coordinating Committee Call" on the list, but there is no further description of this collaboration or coordination. While there has been sporadic, brief reporting on the project activities by the project lead on the monthly National Hydrogen and Fuel Cell Codes and Standards Coordinating Committee calls, this represents participation, rather than collaboration and coordination.
- Regarding the ASTM work, the collaboration is appropriate for this task. Regarding the fuel quality monitoring work, the collaboration is also appropriate for this task. Regarding the work on the effects of impurities, it is disappointing that collaboration was limited to national laboratories in several countries while the academic laboratories that generated the data used in the fuel quality standard were not included.
- The current collaboration is very good; however, more interaction with any industry partners and other laboratories working on similar/related topics seems warranted.
- The team is collaborating with key partners in this area, including ASTM, SAE, and JARI. The project team would also benefit if progress is also presented to ISO.

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

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

- There cannot be enough said about the relevance of this team and the work it is doing to establish new hydrogen impurity test methods and bring these methods through the ASTM process. There is no one else to do this work, which is critical for the success of the Hydrogen and Fuel Cells Program and DOE research, development, and demonstration goals and objectives.
- All activities this PI contributes to are spot-on regarding relevance and impact. This work is critical to understanding and ensuring that the fuel delivered has the purity needed to protect the fuel cell. The PI contributes to ASTM as a chair. The in-line analyzer is critical to the assurance of fuel quality delivered. The continued work on tolerance levels is excellent. The work related to harmonizing safety, codes, and standards is excellent. Regarding the ASTM work, the PI chairs the sub-committee work with WG24, which is excellent.
- The relevance and potential impact of the ASTM task is critical path. The relevance and potential impact of the fuel quality monitoring task is relatively high. The relevance and potential impact of the effects of impurities task is high.
- This work is critical to current hydrogen stations and even more so to future stations and those in development (all will ultimately see more vehicles). It is imperative that the fuel quality is, to the fullest extent possible, guaranteed to meet SAE J2719 and to not disrupt vehicles' performance, and hence the consumer experience.
- In-line fuel quality monitoring and the assurance of the appropriate fuel quality are essential for the development of the hydrogen fuel market.
- The relevance-related text stated on slide 4 seems to describe an approach—a means to an (unstated) end. For example, the first stated objective is "Contribute to the goals of ASTM as sub-committee chair for D03.14 gaseous hydrogen fuel efforts." This does not reflect the direct relevance to the DOE barriers, goals, and objectives. Instead, this seems to be an approach to addressing the DOE barrier ("G. Insufficient technical data to revise standards"), and to support the objective "Support and facilitate development and promulgation of essential codes and standards by 2015 to enable widespread deployment and market entry

of hydrogen and fuel cell technologies and completion of all essential domestic and international [regulations, codes, and standards] by 2020." This barrier is not shown on the Overview slide. The project contributes directly to the following Technical Challenge expressed in the current MYRDDP:

- Test Measurement Protocols and Methods: "The key technical challenge is to perform the first principles work to develop internationally harmonized robust, validated test measurement protocols so that a system qualified for service in one country will be accepted by other countries. Test measurement protocols must be developed for all relevant pressure and temperature environments that materials are subjected to during hydrogen service and must account for relevant manufacturing variables such as welds and other process effects. In addition, measurement protocols and test methods must be optimized to minimize the time and cost of qualification and enhance the timely development and deployment of new materials, components, and systems. The cost of qualifying hydrogen components and systems can be prohibitive, and if test methods are too time consuming, new technology deployment can be delayed. Accelerated testing methodologies must be developed for materials, components, and system qualification that resolve the relevant physics and adequately emulate operational conditions. These test measurement protocols and methodologies must be documented rigorously such that they can be implemented by standards development and testing organizations."
- The presentation would be more effective and the work would be better understood if the project team focused on the higher-level DOE goals, objectives, barriers, and challenges to address objectives and relevance, and then showed the means to achieve these (e.g., chairing an ASTM subcommittee) in the Approach section.
- In summary, the project is relevant to the DOE goals, objectives, barriers, and challenges; however, it is difficult to determine this from the presentation as written and presented.

Question 5: Proposed future work

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

- While the presenter did not have time to talk about this slide, and left it up during questions, he did mention that other tests are in development (e.g., the current work on a [new] protocol with JP Hsu). It is not clear that a new protocol is appropriate, given the amount of future work and the ongoing work. Perhaps that protocol development is organic with the current work. The fact that the in-line analyzer will be validated at NREL is excellent; NREL gave a presentation on the in-line analyzer work being done there. The workshop mentioned on the slide is a valuable item for pulling in industry participants.
- The proposed future work is perfect and needed for the deployment of fuel cell technologies. One expects that this PI will continue to provide global leadership in this field.
- The future work is very well defined. It is good to see that the moisture effect will also be evaluated because electrolysis could be a main pathway for on-site hydrogen generation. The researcher could also consider other contaminants such as hydrocarbons, ammonia, and others on the current SAE and ISO standard. Tests at higher pressures could also be included in the future work. Once a prototype is developed, the team should conduct a cost analysis for a future commercial device.
- This team is carrying a huge load and is pursuing a wide range of active work efforts. The challenges of developing a low-cost, highly sensitive, and accurate analyzer with rapid response are significant. This subproject alone is a daunting task and includes numerous technical hurdles. The task of managing the movement of new fuel cell impurity test methods through the ASTM process is a major subproject that is very challenging due to the limited number of independent laboratories with the ability or interest in investing in the capability of performing comprehensive analytics of hydrogen at the required fuel cell quality levels of detection.
- For the ASTM work, there is no mention of the critical path test methods. For the fuel quality monitoring, the proposed work is appropriate. For the work related to the effects of impurities, the proposed work is appropriate.
- The future work may be reasonable and worthwhile; however, little detail is provided in the presentation. The decision points are not described. Risks, barriers, and challenges are not described.

Project strengths:

- The PI has some of the best personal knowledge of the relevant analytical techniques of anyone in the world, and his experience with MEA resistance to contamination has been an outstanding foundation for the work on the contaminant detector, the in-line hydrogen quality analyzer.
- The project features a world-class PI who is doing world-class research. This work is among the best in the world, and it is recognized as such.
- This project has great importance and significance to what is happening in infrastructure (and vehicle) rollout.
- The technical aspects of the project are areas of strength.
- The hydrogen in-line analyzer activity and hydrogen fuel quality efforts are making good progress.

Project weaknesses:

- While there has been progress, there is still so much to answer and more to do (e.g., the topic of performing the work at pressure) before getting the in-line analyzer out to the "real world." This is not a true project weakness; it is more of an observation on the amount of work to be done.
- The project's weaknesses are the apparent lack of urgency with ASTM and the apparent lack of collaboration with the academic laboratories that developed the initial data.
- Perhaps the project team could do more with more funding.
- The main weakness is communication, both within the presentation and through collaborations.

Recommendations for additions/deletions to project scope:

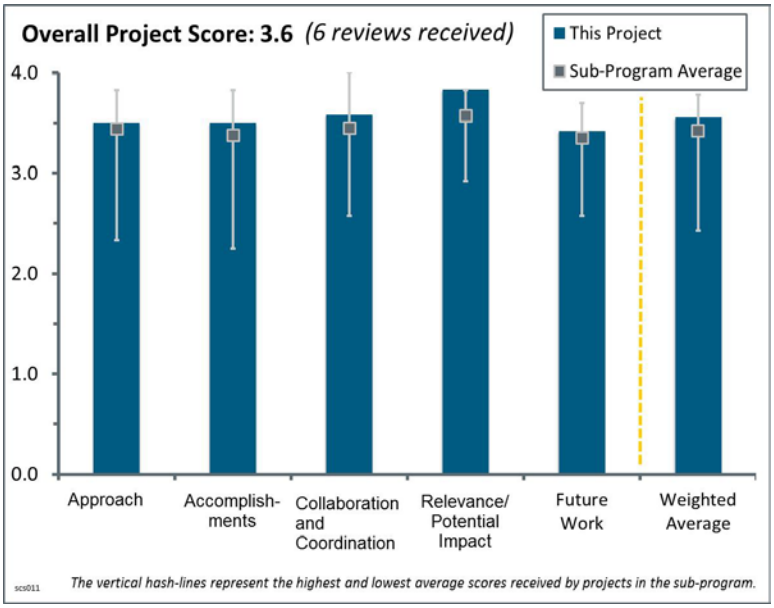
- It seems that more interaction and load sharing (of the work) is needed. Not to take away from the presenter's responsibilities, but there is so much happening simultaneously, along with parallel/similar work happening elsewhere, that all involved parties should consider how to pull all of that together to get more done, faster.
- The PI should pay attention to the emerging activities to revisit fuel quality, which would also involve embracing fuel quality assurance. The work with ASTM is also critically important, and it needs to be continued, with attention given to determining how to cost effectively get testing methods to the testing laboratories in the field.
- Completing the needed ASTM test method and more activity with the domestic academic laboratories would be appropriate. The domestic academic laboratories are where the next generation of researchers are being trained.
- The research team should evaluate the effectiveness of chairing the ASTM subcommittee.

Project # SCS-011: Hydrogen Behavior and Quantitative Risk Assessment

Katrina Groth; Sandia National Laboratories

Brief Summary of Project:

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



Question 1: Approach to performing the work

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

- The team is bringing the science behind the NFPA 2 (Hydrogen Technologies Code) setback distances into a layered risk management analysis platform and offering this to risk mitigation system developers around the world. This is a long-term project, and the team is making good progress as it reaches out to establish international partners. The mission of this project team is a critical one, and the team is doing a stellar job.
- This is an extremely timely and important approach; efforts are finally aiming at bridging stand-alone results from academia and the engineering solution needed for the deployment of hydrogen infrastructure. In addition, the integrated approach, including the probabilistic methodology, is novel and well placed. The choice of an integrated tool for the safety evaluation is also an important step toward increasing the accessibility of data for end users.
- The approach seems well thought-out, with effective use of partners and development of hardware for validation of models. The forward-looking inclusion of liquid hydrogen release modeling is commendable because this is an expressed need from industry for future RCS activities. The approach regarding the development of data and models seems sound. The implementation of the work is the subject of another presentation (SCS-025), and there must be an effective interface between the modeling work and implementation of this work into RCS.
- The approach follows from all the work performed by SNL in support of NFPA. The model should prove very useful to system designers.
- Regarding the degree to which barriers are addressed, the project is well designed, feasible, and integrated with other efforts. Barriers A, F, G, and L are satisfactorily addressed in this project.
- The approach appears sound. It is not clear how the model was validated. It is also unclear whether the model has been applied to compressed natural gas.

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

This project was rated **3.5** for its accomplishments and progress.

- This work clearly contributes toward the stated DOE goals. The effort is a long-term effort, and it has some iterative characteristics in that user/industry feedback is used to develop improvements to the models and leads to further investigation. Stakeholder validation/testing is in early stages. This, along with successful implementation of the work into appropriate RCS, will be critical for determining the effectiveness in meeting project and DOE goals.
- Excellent progress has been made and measured against performance indicators, and excellent progress has been demonstrated toward DOE goals. Also, the three SNL goals listed on slide 5 are meaningful and meet DOE goals and expectations.
- This past year, the work of this team on the International Organization for Standardization (ISO) technical committee (TC) 197 working group (WG) 24 risk mitigation task force has been outstanding, with significant acceptance and support from international colleagues from Linde, TÜV SÜD, and Air Liquide.
- The project addresses important aspects of the DOE Hydrogen and Fuel Cells Program (the Program) and will contribute considerably, when finalized, to DOE goals, specifically by enabling a science-based, validated, and harmonized approach to the design and acceptance of hydrogen infrastructure. To achieve this, however, the level of funding must remain as before for at least an additional two years.
- The accomplishments and progress are appropriate. The use in support of code changes in NFPA 2 and NFPA 55 is excellent.
- The release of the model for alpha testing is an important milestone.

Question 3: Collaboration and coordination with other institutions

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

- The SNL delegation to the ISO TC 197 WG 24 task force on risk management has been very successful in reaching out to Europeans colleagues and has been able to bridge the chasm created during the previous efforts at ISO to create an international standard for hydrogen vehicle fueling stations.
- Regarding the degree to which the project interacts with other entities and projects, there is outstanding collaboration and coordination with other institutions such as the International Energy Agency Hydrogen Implementing Agreement Task 37 (Hydrogen Safety).
- The international cast is important for gaining acceptance (and review) of the model.
- The project has a reasonable plan for engaging partners and is establishing cooperative research and development agreements (CRADAs) and other appropriate mechanisms to engage stakeholder groups. While it is recognized that not all stakeholders are created equally, it seems curious that a CRADA is in place with one hydrogen supplier directly, and that the team is pursuing a CRADA with other hydrogen suppliers through a third-party organization. It will be good to see future updates on this topic. H_2USA is a potential stakeholder group that is currently evaluating models for usefulness in planning hydrogen fueling infrastructure deployment. The presentation notes organization memberships in the H_2USA Locations Working Group and the H_2USA Stations Working Group. Consideration should be given to developing a more direct collaboration with H_2USA on this project specifically—particularly with the H_2USA Stations Working Group to collaborate on design insight activities and aid this key industry group in resolving open issues.
- The interfaces with all the players are well coordinated, extremely well developed, and guarantee the required level of input and assessment. One essential interface is the one with industry for the information on component performance and realistic failure frequencies. To this respect, CRADA or similar activities are an enabling mechanism; however, the project should pursue CRADAs with more than one major player.
- The industry collaboration is appropriate. It is unclear whether there was any direct outreach to NFPA (a research foundation).

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

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

- The project has greatly supported and advanced progress toward the Program goals and objectives delineated in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan (MYRDDP). The team has done an excellent job in terms of the relevance and potential impact of the project on these goals and objectives.
- The project will have a great impact, both in relation to the DOE goals and for the international communities. It will have an impact not only in terms of the one-step integrated tool, but also as an innovative incubator of new approaches and methodologies.
- This project is focused on developing the data and tools necessary to advance progress toward DOE goals and objectives. This work facilitates opportunities to improve RCS using science-based data and tools. This project fills significant gaps to enable performance-based compliance.
- The efforts by the project team to reach out to the international community and be an active participant in the ISO TC 197 WG 24 development team will have a significant impact on the ability to deploy hydrogen fueling stations in downtown environments. The changes in codes and standards will not happen overnight, and the ISO process will be a 3–4 year sojourn just to get the first editions of standards published. The full impact of the efforts of this team will not be complete for at least two, and maybe three, code cycles of NFPA 2.
- This activity could be highly relevant. Slight reductions in separation distances can save industry millions of dollars. Separation distances are often a major impact on the capital cost of a fueling station.
- There is a definite need for tools that can describe hydrogen behavior and predict risk.

Question 5: Proposed future work

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

- The liquid hydrogen behavior work being done this year is essential and is providing key input into the NFPA 2 task force on hydrogen storage setback distances. All of the members of this team are doing extremely important work today.
- The following aspects of the planned future work are particularly interesting:
    - Design insight: the safety impact of different designs, and which components drive risk/reliability.
    - H_2USA should be considered as a potential partner for this stage of the project.
    - The proposed work to validate liquid hydrogen releases is also very important to industry.
    - The nature of the project requires flexibility for future work. This project recognizes this need. Out-years plans are highly commendable, as there will undoubtedly be value in future validation.
- The project supports and advances progress toward the Program goals and objectives delineated in the MYRDDP by providing a good roadmap and milestones for future work.
- The proposed future work appears to be a sound path forward.
- It is absolutely important that the underlying physics and the frequencies are validated and that data is updated regularly. Regarding validations, it is not clear whether there are plans for an (international) effort—for example, in the form of round-robin tests. Regarding data updates, the use of the tool to describe real situations will deliver a source of lessons learned and reliable failure data that need to be fed back into a continuous improvement action. It is unclear whether there are plans for such continuous improvement. Some long-term funding has to be planned by DOE to guarantee continuous development—for example, synchronization with the continuous codes and standards improvement activities mentioned in other Safety, Codes and Standards sub-program projects.
- It is important that “modules” to allow similar assessments with cold gas releases are designed and tested.

Project strengths:

- The project team's engagement with industry, as well as with codes and standards activities, facilitates a well-rounded understanding of the needs to be addressed by the project output, as well as a real-time feedback loop for continued improvement of quantitative risk assessment tools. The project is well focused on resolving the noted barriers from the 2013 MYRDDP.
- The cold release laboratory is an important facility that will bring key information to the NFPA 2 and ISO TC 197 WG 24 committees.
- The strength of this project is SNL's testing ability to support this development. The experience of the specialty gas companies with field incidents could be interesting.
- This is a well-coordinated project. Also, the project is progressing very well and is focused on addressing the four key barriers: A, F, G, and L.
- This project is a novel way to link basic science, pre-normative research, and RCS efforts. It deserves great applause.
- The application is based on scientific risk modeling and data.

Project weaknesses:

- Overall, the project is very strong. The effectiveness of the work, however, will be determined based on adoption of the tools and data into RCS activities. It is not clear from this presentation how the results of the project will be fed into the RCS processes. The presentation does note this will be covered by a separate presentation (SCS-025). Therefore, it is difficult to evaluate the overall effectiveness of the project without taking this separate presentation into account. Looking at the SCS-025 materials does not actually provide insight into this issue. The adoption of the work into RCS seems to be dependent on how the tools are ultimately adopted and used. SNL is pursuing multiple avenues to engage with authorities having jurisdiction (AHJs), targeted code officials, and targeted fire protection officials directly. It would be better to see the outreach taking place with appropriate industry organizations to facilitate development of code change proposals by industry. Messaging to AHJs should be clear and coordinated to avoid mixed messaging, and it should be led by industry needs.
- The development of the cold release laboratory has been hampered by the inability to source small liquid hydrogen containers—a commodity available in Japan and Germany but not in the United States. The laboratory is not able to do release and ignition testing because of the urban site and the lack of portable liquid hydrogen containers to carry into more remote sites.
- The only weakness in this project lies in its high ambitions. If not heavily tested and validated, the tool risks remaining a toy for first-stage designers. The presentation stated that all the phenomena already considered in Hydrogen Risk Assessment Models (HyRAM) have been validated. It is highly probable that 10 minutes was not enough time to give full demonstration of this fact, but that should occur in the future.
- The weakness of this project is that ultimately the model needs acceptance by local AHJs. It is not clear how this outreach is envisioned.
- Weaknesses are not known at present; they will be revealed through testing by users.

Recommendations for additions/deletions to project scope:

- Establishing CRADAs with major industries is an essential step toward realistic values, and perhaps also toward validation exercises. CRADAs are, however, only enablers. It is difficult for reviewers to evaluate the real efficacy of this mechanism to reach the desired results. Next year, the presenter should disclose additional details on how data on real component performance is gathered and elaborated in HyRAM.
    - The international collaborations are unquestionably a means of dissemination and consensus achievement, but it is not clear how effective the collaborations are with respect to the development of the project. The presenter said, for example, that selected ISO TC 197 WG 24 partners are acting as alpha testers. Entities are required to agree to so many legal conditions before receiving permission to access HyRAM that not many international players will be able to do so. For HyRAM to have a chance to become the reference tool for design, it would be better to follow a much more public distribution to allow independent verification and validation.

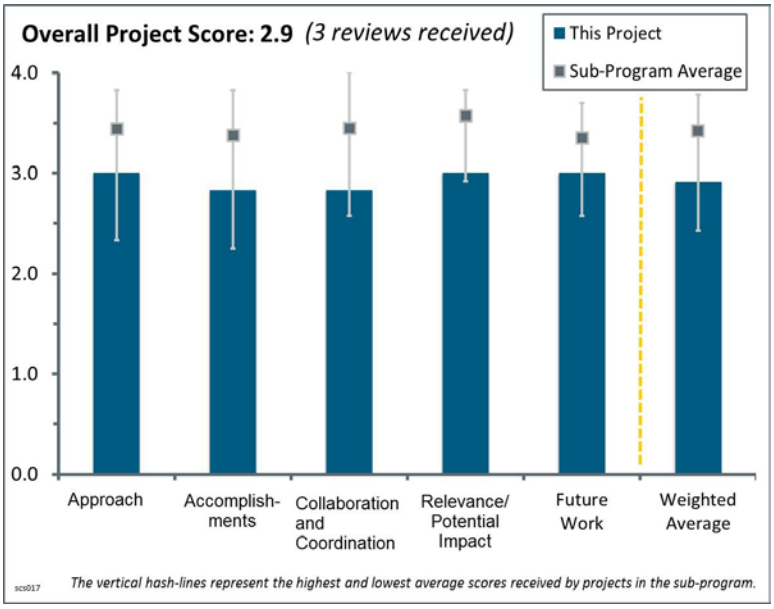
  - Failure or success will depend mainly on the development and dissemination strategy. The decision on whether to make the application available as freeware will be functional to this strategy. The project has not yet made a decision on the boundary conditions for the further development and utilization of the tool. It would be good to know the pros and cons underlying the decision. To really help the deployment of the infrastructure, this tool should be as open and transparent as possible.
- More effort should be made to bring portable liquid hydrogen tanks into use in the United States because that would enable release and ignition testing to support model validation and revision of liquid hydrogen setback distances. A facility should be developed to test hydrogen equipment enclosures to validate the sizing models that determine deflagration venting.
- It is recommended that this project include AHJ outreach and modeling of previously documented incidents to validate the model. The team should consider working on mitigation of liquid hydrogen releases. For example, it is not clear whether a deluge system, intended to heat the hydrogen to facilitate the evaporation of the release, would reduce or increase the risk of a fire or explosion.
- It would be good to see more direct collaboration with appropriate industry groups to utilize the tools and data to develop risk-informed decisions in codes change proposals and standards provisions, in lieu of direct engagement between research activities and AHJs.
- The project should include uncertainty analysis in the HyRAM's calculated risks: Potential Loss of Life, Fatal Accident Rate, and Average Individual Risk.
- It is recommended that this application be extended to include effects from liquid spills and overpressures due to confinements.

Project # SCS-017: Hands-On Hydrogen Safety Training

Salvador Aceves; Lawrence Livermore National Laboratory

Brief Summary of Project:

Appropriate hydrogen safety training is key to avoiding accidents. The overall objective of this project is to develop a hydrogen safety training program for laboratory researchers and technical personnel. The 2015 objective is to develop classroom materials for a hands-on training course that includes comprehensive instruction on components, system design, assembly, and leak testing.



Question 1: Approach to performing the work

This project was rated **3.0** for its approach.

- There is a good approach to performing the work and addressing the specified U.S. Department of Energy (DOE) barriers.
- The project has progressed well in working to incorporate training and lessons learned and having more people/individuals view the work/training.
- Overall, the approach is good. The project could benefit from additional focus on feedback mechanisms to improve developing training beyond the Hydrogen Safety Panel (HSP).

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

This project was rated **2.8** for its accomplishments and progress.

- The project has done good work based on the degree to which progress has been made and measured against performance indicators and the degree to which the project has demonstrated progress toward DOE goals.
- The project has progressed well in working to incorporate training and lessons learned and having more people/individuals view the work/training. The project seems to have addressed last year's comments that additional exposure is needed to get the information more into the mainstream.
- This project has accomplished very little since the last peer review. It is operating on a small budget. Funding disruptions are likely to have a significant impact on progress. In order to evaluate the effectiveness of the online training class, a chart showing scores achieved on the end-of-module quizzes with respect to class completion would be useful. A similar metric for hands-on training modules would also be useful in the future.

Question 3: Collaboration and coordination with other institutions

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

- The project seems to have addressed last year's comments that (1) additional effort is needed to get the training information into more mainstream forums and to more individuals and (2) the training needs to include more hydrogen-specific information. It would be interesting to understand whether there is a level of "certification" that would be valuable for individuals to have. Delivering the training is only one aspect

of understanding whether the individual has "received" the knowledge being transferred and can successfully apply it.
- The partnership with the HSP is very good. The title of slide 7 indicates the training is being used as regular training for various organizations. The presentation does not cover partnerships with organizations that provide similar generalized training, such as industrial gas companies. Such partnerships could be useful to validate the training and potentially provide additional avenues to incorporate the results of this project into the mainstream. This is an important feedback mechanism for the project, and further project focus and information should be provided.
- There is good collaboration and coordination with other institutions, such as the HSP.

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

This project was rated **3.0** for its relevance/potential impact.

- Hardware training is an important aspect of safety that has not received much attention. This project does a good job of starting to address this need.
- The project's relevance and potential impact on hydrogen safety awareness are good.

Question 5: Proposed future work

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

- The proposed work to complete the modules is very important. Additional focus on industry validation would improve the project. Further focus on outreach to increase awareness and uptake of the training is identified as a remaining challenge. Close coordination with the Fuel Cell and Hydrogen Energy Association (FCHEA) and Pacific Northwest National Laboratory (PNNL) could aid this effort.
- This project will probably not continue beyond 2015.

Project strengths:

- The project is developing tools to educate about hydrogen and how to handle/use it.
- Hands-on training is a valuable activity that had not previously been addressed.
- The project offers extensive hands-on training in hydrogen safety.

Project weaknesses:

- The project is weak in terms of understanding whether the tools are effective in delivering the information by evaluating whether the individual has "received" the knowledge being transferred and can successfully apply it.
- Progress is slow.

Recommendations for additions/deletions to project scope:

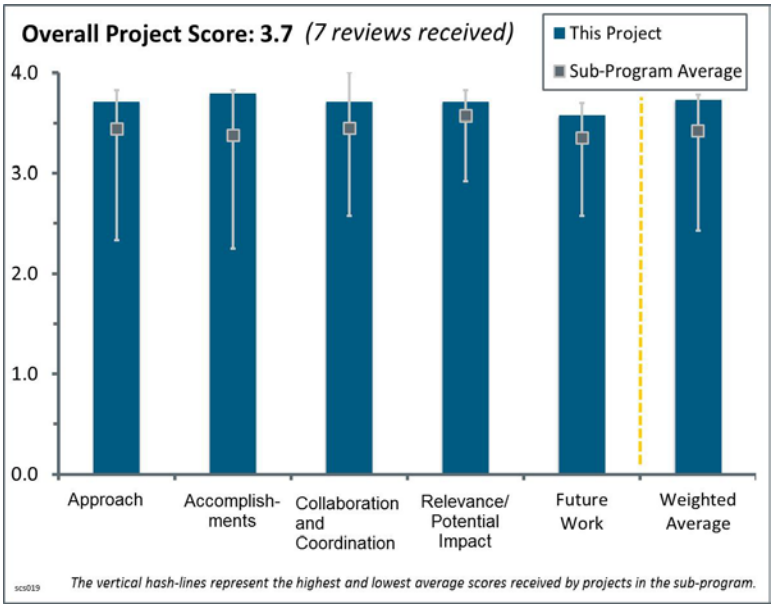
- It would be good to see some analysis of the potential for this work to be used for other audiences. These include technical colleges, industrial gas company training programs, gas utilities, etc. Future validation by such audiences could help improve the overall training and fill training gaps to accommodate hydrogen-specific information in mainstream gas safety training programs. Inclusion of the project in PNNL's Hydrogen Safety Toolkit and FCHEA's Hydrogen and Fuel Cell Safety Report is recommended to improve uptake of the training and facilitate feedback for continued improvement.

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

Nick Barilo; Pacific Northwest National Laboratory

Brief Summary of Project:

The objectives of this project affect three main areas: the Hydrogen Safety Panel (HSP), safety knowledge tools and dissemination, and first responder training. This project provides expertise and recommendations through the HSP to identify safety-related technical data gaps, best practices, and lessons learned and help integrate safety planning into funded projects. To further safety knowledge tools, 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. The team has developed 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 its approach.

- The presenter's approach to ensuring hydrogen safety is right on point. A centralized database for authorities having jurisdiction (AHJs) is needed. H2tools.org is the resource California has been awaiting because it simplifies information flow and provides a reliable, neutral source to recommend to AHJs. With ongoing attention and funding, the tool will continue to grow in both relevance and importance. Component listing is critical as well. The plan to level the playing field by showing AHJs and station developers how to establish comfort with station system performance is incredibly timely and important. This is a big unanswered question in California. First responder training is crucial, and more is needed. Going to videos on H2tools.org to supplement in-person training is a great way to expand the all-important reach.
- The approach is excellent. The HSP safety plan reviews bring much value to project safety. The proposed involvement at post-award kickoff is a particularly strong point. The site visits are also a great enhancement to safety. Nothing complements understanding and problem identification like having experts on site. Sometimes projects are managed from beginning to end entirely without site visits, and site visits, on the rare instances when they are possible, are extremely valuable. The other two segments of the program—first responder training and instant, easy access to learnings and best practices—extend U.S. Department of Energy (DOE)-funded project learnings out to the field. The plans for housing the tools with the National Fire Academy/Federal Emergency Management Agency are an excellent long-term solution for managing and updating the information and providing it to the broadest audience.
- The HSP component is excellent; this talent still needs to be used more broadly. Moving the knowledge tools to the portal is a very powerful move. The first responder training component remains excellent—the saying, "if it ain't broke don't fix it," applies. However, with that said, there is value in moving this activity to a more mainstream activity, possibly with the National Fire Association.
- This project is made up of three considerably different areas: the HSP, the training tools for first responders, and the safety knowledge tools. However, because these areas interface with each other, it makes a lot of sense that they are clustered in one single project. The advantage is that the competencies

developed in each of the three areas are generated in the same team and can be efficiently mutually profitable.
- The H2tools site appears to be a great improvement/advancement and is needed by industry. It is concerning that one of the initiatives is to address the lack of certified equipment, but there do not appear to be any certification agencies involved in the activities. In addition, the statement "Safety is not treated as a continuous process" is listed as a barrier. The "safety standards" have this as their primary focus, yet there is no support for standards development organizations (SDOs) or their process.
- It is difficult to remove all barriers because the scope of work is very broad. There is too much focus on AHJ approval; there should also be focus on increasing listed components and systems.

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

This project was rated **3.8** for its accomplishments and progress.

- Given the funding level, this project has achieved much very high-quality work on all three aspects. Having the notion of safety planning in the funding opportunity announcement (FOA) is a great idea. It sets the posture for a safety culture and allows the HSP to engage early in the project. Regarding listed equipment, development of a guide to assist AHJs in "approving" installations that are not "listed" will be a great asset in the early stages of development until the community gets hardware listed. Moving safety knowledge tools to a portal is outstanding! The number of "hits" is quite impressive.
- As stated in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan, it is not possible to evaluate the progress according to quantitative indicators for these types of activities. Nevertheless, the progress booked this year is evident and of high quality. The new H2 Tools website is an example of a successful communication effort; it is well structured and of utility for users with different goals and levels of competence.
- Safety is paramount—it is the first question that is asked in California in local communities. If anything, stakeholders need to figure out how to expand the HSP's reach. The reviews from the HSP, a crucial, trusted third-party resource, have already shown the HSP's benefit to the state. Education and outreach is the undercurrent that appears to feed this work. This is the state of the market in California—the more influencers are comfortable with the technology, the better. H2 Tools gets at this issue.
- There has been significant progress on numerous objectives; the project achieved many key deliverables over the year. The primary question now is ensuring widespread deployment and use of the tools that have been developed.
- The DOE Hydrogen and Fuel Cells Program seeks to increase the "safe" use of hydrogen and fuel cell technologies. The tools being developed will support industry. The review of plans for stations provides good support for the nascent industry, but it does not appear to be a sustainable solution. In addition, it needs to be stressed that the data from the incidents need to be routinely fed to the SDOs/code development organizations (CDOs) so the information can be reviewed by the technical experts to understand whether revisions to the standards/codes are needed.
- Overall, project accomplishments include broadened outreach activities and continued expansion of knowledge of safe hydrogen handling, as documented in the slide deck.

Question 3: Collaboration and coordination with other institutions

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

- Pacific Northwest National Laboratory (PNNL) has worked very well with the California Fuel Cell Partnership and state agencies (e.g., the California Air Resources Board, California Energy Commission, and California Governor's Office of Business and Economic Development [GO-Biz]). The coordination and collaboration is fundamental to overall project success.
- The approach is excellent. The project should consider working with other federal departments (particularly the U.S. Department of Transportation) and state agencies (particularly in California) that are funding hydrogen infrastructure/fuel cell vehicle deployment projects to also include language in solicitations that

"encourages coordination with the HSP for development of Safety Plans" similar to the DOE FOAs. This has been very effective for early project involvement for DOE projects.
- National and international collaborations are excellent. Getting from the federal level to SDOs and local AHJs shows great coordination.
- The collaborators and collaborations for this work are good. While Sandia National Laboratories (SNL) is mentioned as a collaborator, during the presentation, following up on a question from the audience, it was noted that the principal investigator (PI) should work to interface with the SNL Hydrogen Risk Assessment Model (HyRAM) activity more strongly.
- There is widespread, direct engagement with many key stakeholders.
- In general, collaboration is good. However, the activity should not happen without SDO/CDO and Nationally Recognized Testing Laboratory (NRTL) involvement.
- The HSP is per se a collaborative exercise, in terms of both (1) teamwork that includes different competencies and (2) engaging many players and stakeholders.

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

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

- The relevance of all three of these activities is perfect. The HSP has proven valuable to the community beyond the collaboration on the DOE projects as originally intended. The outreach activities such as the Tools Portal will continue to grow and increase in impact on the AHJs as more and more AHJs seek to understand how to get hydrogen in their communities. The first responders training remains a powerful activity. This activity must continue; however, maybe it is time to move this to a more mainstream activity, such as with the National Fire Association. This was noted in the presentation.
- Safe operation of hydrogen resources, coupled with well-designed education and outreach, is fundamental to market success. Technological advancements mean very little if communities do not welcome the technology into their areas. Hydrogen solutions need to be safe, and they need to be perceived as safe. The HSP can help ensure the former; education and outreach (and exposure) help the latter.
- It is difficult to assess the impact of the many activities related to the deployment of the technology. This is the only reason why this assessment was given a ranking of "good" instead of a higher ranking. It is probable the impact is visible in an incremental way—in the improvements achieved in the projects that received the HSP's assistance and in the use that website visitors have made of the lessons learned from safety events. All items are difficult to assess quantitatively.
- Safety is always relevant, and a safety incident resulting in death or injury could paralyze the industry.
- The tools are ready; implementation and use are key.
- This is important to help the industry grow and move forward safely.

Question 5: Proposed future work

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

- Building out the H2 Tools portal and leveraging HSP resources are key. Both help push the collective understanding and knowledge of both the safety and community reaction. The key is for stakeholders to help PNNL ensure these tools are widely acknowledged and used. Building out video resources has the potential for broad impact. City officials do not have much time to digest new technology; if simple and short videos can be produced to create a baseline understanding of safety, they will be used.
- Part of the future plans consists of continuing and making incremental progress in the already running activities. This is perfectly fine and deserves further funding of the same level. The draft certification guide planned in 2016 is ambitious, very useful, and extremely timely.
- Continued safety performance data collection and outreach are desirable. Engaging the insurance industry with the AHJs is a necessity for safe commercialization, so it would be good to see more involvement of insurers.

- The proposed future plans are spot on in each of the three areas. However, attempting to bring other databases into the portal could rapidly become unwieldy from a maintenance perspective. Serious thought should be given to understanding how the databases can be referenced rather than actually incorporating them into this portal. This would put the burden of maintenance on the "owner" of the database.
- There are good initial plans for reaching first responders, but there do not appear to be plans for non-fire personnel or certifying personnel (e.g., second responders and maintenance professionals).

Project strengths:

- This project yields a fantastic bang for the buck! For the level of funding, the output quality, innovation, and quantity are excellent. The HSP is doing its job and has developed an outstanding resource that is quite frankly the envy of the world. The hydrogen safety tools component has grown and will continue to grow and become an outstanding resource to the AHJs and permitting communities. The first responder training has matured but continues to provide enormous value to the community as the hydrogen fueling infrastructure is rolled out. It is time this activity move to something more mainstream, such as the National Fire Association—a move recognized by the PI and in the future plans.
- Strengths include coordination, collaboration, and doing what is necessary to support a budding network. Getting the emergency responder training package into existing courses will help amplify the project benefits. The fact that the HSP exists is extremely comforting—AHJs are likely to trust the collective wisdom of the panel.
- Strong tools with strong content have been developed. There are good early adoption pathways. Partnerships and communication are strong.
- This project involves many important activities that will ensure safe deployment of hydrogen. There are many tools for industry, regulators, and the public to utilize.
- This project profits from the integrated gathering of experiences and the elaboration of them into a permanent pool of first-class experts.

Project weaknesses:

- H2 Tools is a great resource. The challenges will be getting people to use it and setting it up to capture useable lessons through time so that all stakeholders can benefit from multiple learnings. It is tough to do the appropriate level of training with limited resources. PNNL is taking a great approach in trying to integrate resources into existing training—this needs to be successful for the project to have the reach that is needed.
- No weaknesses were identified.
- It is difficult to implement all of these key initiatives under the banner of one project.
- There needs to be additional SDO/CDO and NRTL involvement.
- There is not much presented here on automotive applications.

Recommendations for additions/deletions to project scope:

- Nothing should be deleted. From the California perspective, it would be good to see all of this project's activities augmented and amplified. The more people who can be reached/trained, the better. The market is coming, and this effort is exactly what is needed. It is suggested that the project do the following:
    - Figure out how to best maximize the use of the HSP. Perhaps funding can be increased to support more reviews. Perhaps California and other active states should help establish priority reviews (as opposed to first come, first served).
    - Focus on the video expansion. A general video explaining hydrogen stations and their safety systems would be very helpful for communities.
    - Work to make sure H2 Tools collects collective lessons that can be easily accessed.
    - Explain incidents in the headings of search results on H2 Tools. Some search results can be scary for a city official new to hydrogen, so this step may be worthwhile. A search on incidents brings up a page of potential scariness; some sort of reassuring explanation could be helpful.
- The project should consider development of a simple tool/video that could be referenced on public stations either by URL link or quick response (QR) code that would provide information to public users on

hydrogen basics and safety. Most of this information has already been developed and would just need to be distilled into quick, basic, educational information that would be easy to access at point of use. This link could go to or through the Portal as well, but perhaps there could be a quick refresher for users while fueling.

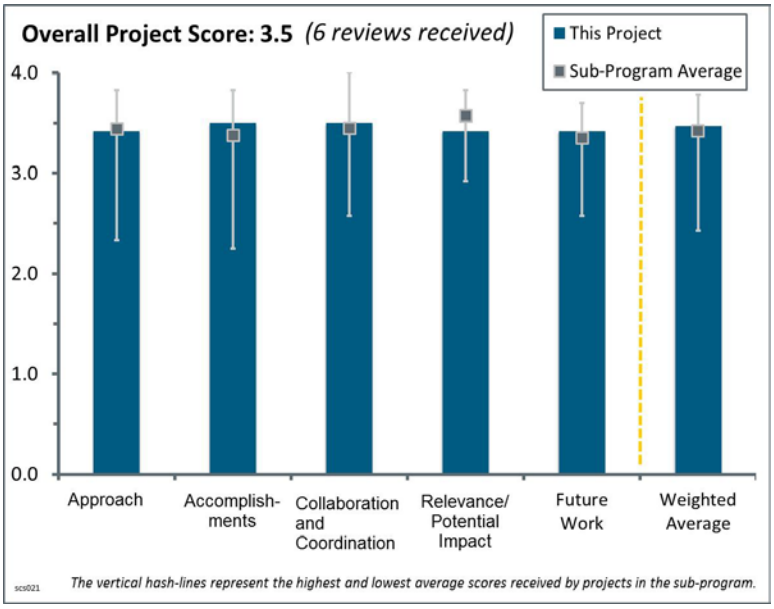
- The first responder projects should involve vehicle original equipment manufacturers. Also, the project should get involved with the SAE J2990/1 Gaseous Hydrogen and Fuel Cell Vehicle First and Second Responder Recommended Practice committee, which is working on a document that provides recommendations to vehicle manufacturers from the first responder perspective and includes recommendations for emergency response guides. Also suggested is involvement in the SAE committee to develop Hydrogen Fuel Cell Vehicle Crash Testing Safety Guidelines, which is associated with SAE J3040 and the SAE Impact and Rollover Test Procedure Committee.
- This suggestion is challenging and not easily implemented. Progress in this area cannot be evaluated simply on the basis of progress toward a few quantitative targets. However, some qualitative indicators are available, such as the numbers of downloads of a training package, the availability of guidelines where none had existed to date, or the number of DOE projects for which safety planning is a reality. However, it is not clear how to evaluate the impact of these achievements. Perhaps the project is planning some kind of "users' satisfaction survey." It is not clear the project has a way to assess how the impressive mass of lessons learned have contributed to the overarching goals.
- The project should break some of these tasks out into their own projects/speakers. There is much information that should be explored further.

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

Bill Buttner; National Renewable Energy Laboratory

Brief Summary of Project:

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



Question 1: Approach to performing the work

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

- This project is of a very special nature; it specifically addresses one of the most critical hydrogen safety components in a holistic and integrated way. The project interfaces with all players (i.e., industry, permitting bodies, developers, and manufacturers) and with all other parts of the U.S. Department of Energy (DOE) Hydrogen and Fuel Cells Program (the Program). It is well aligned with the evolution of the overall Program area. In recent years, the project has developed from activities aiming to produce a fundamental assessment of sensor performance toward activities aiming to understand the complexity of sensor deployments in the various stationary and transport applications.
- The team did a very good job of keeping the approach "neutral." While the presenter is clearly very knowledgeable and committed to the work, he did not have bias in the presentation and gave the facts, positive or negative. The statement at the bottom of slide 6 is right on.
- The project features good background investigation and cooperation with the Joint Research Centre (JRC).
- The sensor laboratory work is very timely and a very much needed capability.
- The project and work on sensors is important for the industry—it is recognized that additional information is needed and welcomed. In that sense, the project is fulfilling DOE goals and objectives. However, a confusing part of this presentation (and the others from NREL) was how this activity addresses the three barrier statements (listed below), since the project is neither a code nor a standard activity.
    - C. Safety is not always treated as a continuous process
    - F. Enabling national and international markets requires consistent regulations, codes, and standards
    - G. Insufficient technical data to revise standards
- Overall, the approach to meeting the barriers to implementation of safety sensors is fine because this effort should support industry partnerships, safety working groups, and code development. However, it seems that the tailpipe emissions work might be straying somewhat from the intent of this project. Also, it is not clear how this project interacts with the H2FIRST (Hydrogen Fueling Infrastructure Research and Station Technology) sensor project that was implemented; there was no mention of supporting or interacting with that particular project, although they were both led by NREL.

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

This project was rated **3.5** for its accomplishments and progress.

- The project delivers important short-term support to meet DOE objectives, but it is also helpful in identifying and achieving long-term goals. Examples of this latter aspect are the book on sensors technologies and the gap analysis and recommendations at the service of standards and regulations. An example of the former aspect is the collaboration with sensor developers to meet the requirements of specific applications.
- The KPA Inc. work and the SAE International document work seem extremely relevant and important to the commercialization of hydrogen and all types of fuel cell electric vehicles. The technical report may be very valuable to station developers in their project submissions for funding.
- The team is making good progress in setting up the laboratory and developing sensor test methods.
- The research testing was on point. Technical areas of concern were identified and improved.
- The accomplishments were adequate and meet the needs of the Safety, Codes and Standards sub-program.
- The publication of information is good; however, the quality of production/manufacturing of sensors needs to improve.

Question 3: Collaboration and coordination with other institutions

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

- The project has developed excellent working relationships with industrial partners, (international) governmental bodies, and codes and standards developers. It is thus in the best position to play a reference role for this part of the safety galaxy.
- The collaboration with various agencies on different kinds of projects demonstrates the flexibility and knowledge base of the team.
- The project seems to work with codes and standards, testing, and commercial entities on a regular basis, and it should be part of any further H2FIRST sensor projects going forward.
- The project features excellent communication with other technical laboratories, especially JRC.
- The collaboration with outside partners is excellent.
- The project features good collaboration. Presenters should refrain from making comments that imply collaborating organizations do not have routine interactions and do not have good working relationships. This indicated that NREL was the reason the collaborators were able to interact/work together, which is not true.

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

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

- This research is very much in line with and advances progress toward Hydrogen and Fuel Cells Program goals and the objectives delineated in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan. The sensor technology is much needed for compliance testing.
- There is so much work needed for sensors, and this team is providing leadership and relevant research and development of test methods.
- This is an important aspect of facilitating the implementation of hydrogen fuel cell vehicles because maintaining a safe environment is key for success.
- A lot of good information is being developed. The next step is to have it applied in the field/real life.
- The impact of the project is mainly incremental and in many different directions: from the recommendations for Phase II of the Global Technical Regulation (GTR) to the SAE group addressing onboard sensors, and from the international collaborations within a European project and the International

Energy Agency/Hydrogen Implementing Agreement to the support to end users related to sensor field deployment.
- It was good to accentuate the point that this is about educating the community on the usefulness of sensors. The presenter did a good job of "validating" the relevance of this work. There could be more potential impact and relevance if the project worked with suppliers on refining guidance on sensor application, use, and installation.

Question 5: Proposed future work

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

- The proposed future work is in line with the previous project goals, but it is more focused on strategic, present priorities related to the practical installations (e.g., the use of sensors in tunnels and in confined spaces). It also further explores detection methods to meet additional detection aspects, such as those related to fuel quality. In this sense, the project is continuously adapting to the evolution of overarching safety goals.
- The proposed future work is very well focused on the key issues.
- The project needs to work more closely with the automotive industry to ensure the knowledge is shared, and to identify possible weaknesses (e.g., non-compliance) of sensors being used in compliance testing.
- The project basically proposes to continue its interactions very similarly to how it operates currently. It would be good to see some emphasis on identifying inexpensive sensors for hydrogen production, delivery, and onboard monitoring—following up on the report generated by the H2FIRST project.
- There seems to be uncertainty on the next steps and the impact on real-life acceptance of hydrogen, and on how this will improve the reliability of sensor technology. Addressing the reliability of sensors—when taken out of the box, or reducing the number of "failures" when new—would be a key initiative.

Project strengths:

- The overall approach of the laboratory and the types of projects it is involved with has evolved, demonstrating the team's flexibility and openness to various options/uses for sensors and to improvement of sensors and their uses. The work with GTR and KPA Inc. (i.e., private industry) is excellent. The investigation of Wide Area Monitoring (a potential future application for outdoor use at stations) is good.
- The project tackles all aspects of hydrogen sensors and constitutes an internationally recognized competence center for this technology. Considering the limited amount of funds, it shows a very high level of efficiency.
- The principal investigator has a good background in sensors and is involved in the sensor and safety community.
- Bill Buttner is the expert in the field of sensors, and he has done outstanding work on this project.
- Project strengths include identifying information and defining key terms/information for industry.
- The project features a very capable team that is focused on key issues.

Project weaknesses:

- There are no observed project weaknesses.
- There were not any apparent weaknesses.
- Based on the presentation, there is a need to communicate with industry, either through an SAE committee or directly. Sensors in this application are not well known, and this type of research should be shared widely.

Recommendations for additions/deletions to project scope:

- While this work is good, there is a need for more guidance on the installation of sensors—where to place them, how many are needed, maintenance recommendations, etc. Current codes and standards say to follow manufacturer instructions, but those need improvement. Because this project already works with industry, it should be an "easy" next step. The team could take the KPA Inc. work further and do some case studies at

actual facilities (which could also feed into codes and standards revisions on sensor use). This would require collaboration—for example, with other projects/laboratories that work closely with authorities having jurisdiction. The project team could use California as the testbed.

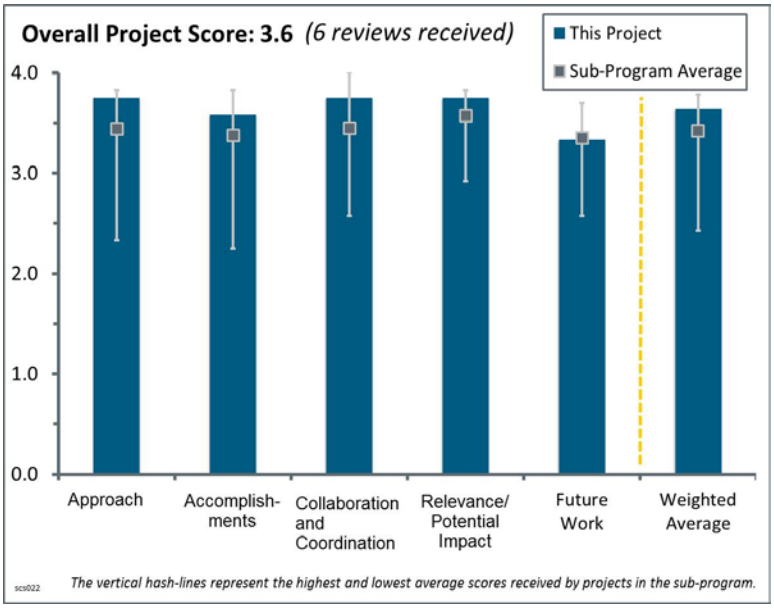
- Perhaps it is possible to couple sensor performance indicators with risk assessment tools to be able to answer the question of where to more effectively install safety sensors to ensure capture of all possible hazards related to hydrogen accidental releases.

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

Morry Markowitz; Fuel Cell & Hydrogen Energy Association

Brief Summary of Project:

This project supports and facilitates development and promulgation of essential codes and standards to enable widespread deployment and market entry of hydrogen and fuel cell technologies. The goals of the project are to (1) ensure that best safety practices underlie research, technology development, and market deployment activities supported through U.S. Department of Energy (DOE)-funded projects; (2) conduct research and development to provide critical data and information to define requirements in developing codes and standards; and (3) develop and enable widespread sharing of safety-related information resources and lessons learned with first responders, authorities having jurisdiction, and other key stakeholders.



Question 1: Approach to performing the work

This project was rated **3.8** for its approach.

- Code harmonization and information dissemination will play such a huge role in the overall market success within and beyond California. Exposure is one thing, but playing from similar playbooks is another. The more codes and standards can be harmonized, the easier it will be on everybody. Establishing a clear picture of discrepancies and establishing pathways to fix them is the right first step.
- Regarding the degree to which barriers are addressed, the project is well designed, feasible, and integrated with other efforts. The project provides good insights to addressing the stated barriers (on slide 2)—namely, F, H, and J.
- The approach is good; it involves facilitating and coordinating the participation of members in the working groups of the normative bodies. The team made a strong effort to identify critical items and prioritize work. The website is becoming a reference resource for stakeholders.
- The approach provides a forum for interested parties to participate, for education and outreach to occur, and for the identification of standards requirements, just to mention a few attributes of this effort.
- There certainly is no lack of entities and activities to coordinate. The structure and amount of working groups are appropriate.

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

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

- This work is critical and needs to continue. Relationship building is crucial, and the project is focusing on it. Ideally, the information developed by this effort will be integrated into existing systems/organizations.
- The accomplishments and progress indicate that the project is doing good work, and the national and international interfacing efforts are valuable.

- The degree to which progress has been made and measured against performance indicators is good, as is the degree to which the project has demonstrated progress toward DOE goals.
- The results over the years have included the development of international standards for hydrogen infrastructure and the promotion of U.S. interests in this area.
- The meetings and connectivity are clearly happening. There appears to be a lack of direct impact, apart from coordination, which is important but a soft goal. More emphasis should be put on other direct impacts.

Question 3: Collaboration and coordination with other institutions

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

- The project interacts well with other entities and projects, such as the Fuel Cell and Hydrogen Energy Association (FCHEA), code development organizations (CDOs), standards development organizations (SDOs), and the National Hydrogen and Fuel Cell Codes and Standards Coordinating Committee.
- The project team is connected and collaborating with all of the appropriate groups.
- This is a truly international effort.
- The tent continues to grow, which is all for the better.
- Coordination with multiple SDOs/CDOs is a strength of the project, but interfacing with pre-normative activities could be improved.

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

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

- The project does a good job of supporting and advancing progress toward the Hydrogen and Fuel Cells Program (the Program) goals and objectives delineated in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.
- The project is very relevant to Program goals and seems to work well with industry members to support trade interests. The website and coordination effort illustrate the strong, positive impact of the project.
- This effort is a necessary component for the development of a globalized industry.
- All of this work helps to establish this trust.
- The increase in coordinated efforts is apparent.

Question 5: Proposed future work

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

- The project will end by November 2015. The project has effectively planned its future in a logical manner by incorporating appropriate decision points; considering barriers to its goals; and, when sensible, mitigating risk by providing alternate pathways.
- Continuity in this effort is needed now more than ever, as the first “real” infrastructure and automobiles are put in service.
- The challenge is balancing the long-term timeframe of the codes and standards environment with the need for short-term results in some respects.
- The Special Task Force for Strategic Planning is a relevant proposition to anticipate critical items. The future work is mainly carrying on the present activities.
- The future work seems to be more of the same. It is not clear whether alternative approaches have been fully explored, and whether there is a way to better anticipate looming hurdles for the industry.

Project strengths:

- The project features excellent communication. The teleconferences provide an excellent opportunity for stakeholders to exchange information and discuss important milestones.
- This project provides a multiyear, continuous experience in promoting and coordinating normative efforts at the national and international levels.
- The project features well-coordinated efforts with other partners and provides meaningful support to FCHEA codes and standards.
- The strength is in the collective participation.

Project weaknesses:

- The lack of interface with a research activity is a weakness.
- Progress may be delayed by standards bureaucracy.

Recommendations for additions/deletions to project scope:

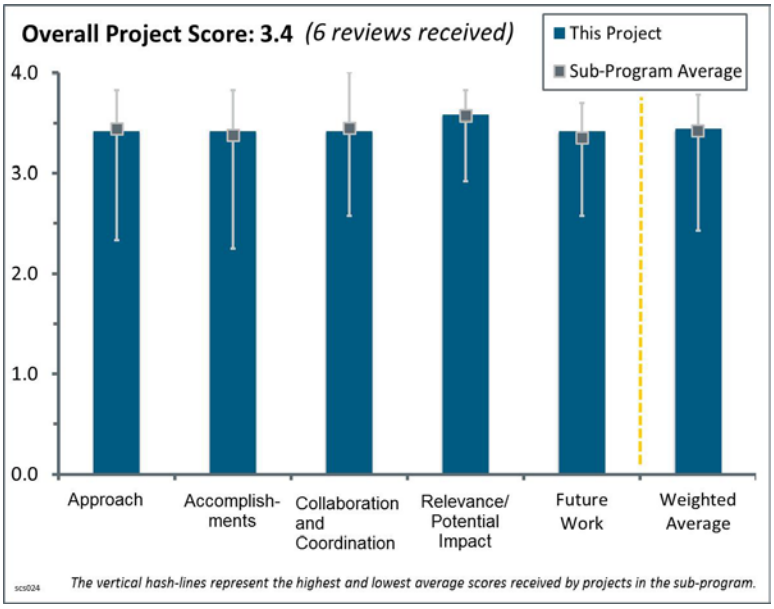
- To the maximum extent possible, this effort should be integrated with the H2tools.org and Hydrogen Safety Panel efforts so that lessons learned are centralized and accessible to all.
- No change is needed, but FCHEA could play the role of interfacing normative activities with research or pre-normative activities (e.g., round-robin testing).
- This effort must continue to be supported.

Project # SCS-024: Hydrogen Contaminant Detector

Daniel Terlip; National Renewable Energy Laboratory

Brief Summary of Project:

The goals of this project are to (1) reduce the installation cost of a hydrogen fueling station to be competitive with conventional liquid fuel stations; (2) improve the availability, reliability, and cost while ensuring the safety of high-pressure components; (3) focus a flexible and responsive set of technical experts and facilities to help solve today's urgent challenges and unpredicted future needs; and (4) enable distributed generation of renewable hydrogen in a broader energy ecosystem.



Question 1: Approach to performing the work

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

- Protection against contaminants arising in hydrogen fuel is a complex problem. This effort has been systematic in identifying the important factors that must be accounted for and how that might be accomplished.
- This was a $30,000 study to understand the state of the art for hydrogen contaminant detection suitable for hydrogen fueling stations with an SAE J2601 fill. This work has been completed and is reported in a National Renewable Energy Laboratory (NREL) report.
- A market study as described is appropriate. The data needed were included in the earliest edition of SAE J2719. It is suggested that NREL speak with Mike Steele, the SAE International chair of the Fuel Cell Standards Committee (FCSC). He has the supporting documents and presentations for this activity. The generation of engineering requirements is appropriate. It is not clear whether the requirements were vetted by industry. Again, Mike Steele would be a sound resource.
- This approach seems much better aligned with and geared to the commercial application. Working more closely with Los Alamos National Laboratory (LANL) may speed up the process even further. It is good to see the collaboration with California Air Resources Board (CARB) on station configuration, SAE International on contaminants, and original equipment manufacturers (OEMs) on levels indicating process upset. In addition, please note it is helpful to include links to reports in the slides.
- Near-term solutions are not likely "one size fits all." It is not clear why it needs to be that way. Lower-cost alternatives may work better in some situations, while other station configurations may require higher-cost alternatives for hydrogen contamination detectors (HCDs). On slide 8, the statement was made that "not all contaminants are probable in stations," which appears to support this contention.
- The first barrier described in the presentation, "A. Safety Data and Information: Limited Access and Availability," has not been addressed well. However, the following barrier from the U.S. Department of Energy (DOE) Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan (MYRDDP) is being addressed well: "G. Insufficient Technical Data to Revise Standards – Research and operational data collection activities are underway to develop science-based codes and standards. New approaches for data generation, collection, and analysis will also be needed to close safety knowledge gaps." The results of this project will facilitate publication of revised SAE International and International Organization for Standardization (ISO) technical committee (TC) 197 standards relating to fuel quality and cleanliness, as well as the promulgation of these requirements.

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

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

- The project is 100% complete. The report was published (for this project), and the Phase II proposal was submitted. Funding Phase II is strongly suggested, as is working more closely with LANL in that phase.
- The researchers are finished. The report was published by NREL under the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) project.
- The project accomplishments are comprehensive. The project has identified customer and functional requirements, integration of detection into a station system, contaminant levels of interest, measurement techniques and existing equipment through a survey, and technology gaps. The team has proposed the next steps that are needed.
- The data summary is very interesting. It should be noted that "OpCost" is usually presented in dollars per hour or dollars per year.
- This project has accomplished a good deal, considering it was started so recently (during the fourth quarter of fiscal year 2014) and is funded at the level indicated ($30,000 total with 50% expended). The presentation did not describe the following applicable DOE goal: "Develop and implement practices and procedures for the safe conduct of DOE-funded hydrogen and fuel cell projects. Provide the scientific and technical basis for requirements in critical [regulation, codes, and standards] to enable full deployment of hydrogen and fuel cell technologies in all market sectors." The project should consider more clearly articulating how this important work aligns with the overall DOE goals and objectives, as well as the technical challenges and barriers the project is addressing in outreach and communications to make it clearer to the audience how this project fits in to current research and development (R&D) needs.
- The cost impact of the inline hydrogen contaminant analyzer is not clear. It is also unclear whether there is a path toward cost reduction. "Manufacturers that submitted information about available sensors have not expressed strong interest to develop sensors that meet [the] list of requirements developed by H2FIRST HCD project team." The team needs to discuss what can be done to change this or how this can be addressed.

Question 3: Collaboration and coordination with other institutions

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

- The collaboration appears excellent. It is not clear what collaborations are occurring with sensor manufacturers, aside from requesting input/information through survey. The project should consider international collaboration for this. It is not clear that international collaboration is currently part of the project.
- This was a survey of the state of the art in contaminant detection technologies. This team consulted with the appropriate experts in the code development world and in the technology space.
- Again, it is great to see collaboration with all of the key players (e.g., CARB, OEMs, and SAE International). The presenters should be sure to also indicate (in the slides) that there is communication with LANL, other laboratories, and internationally because this was not apparent. The use of the SAE J2719-1 table (and communication with the chair) should also be indicated. It would be wise to carry out the market survey.
- It appears the right project partners are involved. Further work collaborating with related efforts could improve uptake of the project results and reduce the potential for duplication of effort. This project is fairly new and is funded at a very low level. Closer integration of the activity with SAE International activities and enhanced outreach of the project goals and progress within H_2USA and SAE International would be useful; however, it is recognized that these take time and effort, which may not presently be accommodated in the project's level of effort.
- Collaboration was performed by both research organizations and parties responsible for initial infrastructure deployments.
- The collaboration list is somewhat limited. The engineers with the data may be found at SAE International FCSC (M. Steele), CSA HGV (S. Marxen), ISO 19880 (J. Schneider), and ASTM Committee D03 on

Gaseous Fuels (R. Dominguez). ASTM is especially important. It is where the instrument manufacturers are interfacing with this endeavor.

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

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

- This work is extremely important for stations currently rolling out and those that will be in the immediate and near future.
- This work is likely too difficult for industry to accomplish by itself. This effort will accelerate efforts to standardize quality control and maintenance issues for delivery of a quality product.
- The OEMs are currently insistent about inline sensing. Therefore, the project is highly relevant.
- HCD is critically important for fuel quality assurance. This survey report pulls this information into one place, which is very valuable.
- Although not noted in the presentation, this project seems to be relevant to the following DOE goal in the MYRDDP: "Develop and implement practices and procedures for the safe conduct of DOE-funded hydrogen and fuel cell projects. Provide the scientific and technical basis for requirements in critical [regulations, codes, and standards] to enable full deployment of hydrogen and fuel cell technologies in all market sectors." Specifically, the project relates to the following objective: "Conduct R&D to provide critical data and information needed to define requirements in developing codes and standards." The presentation could be improved by clearly linking project goals back to appropriate published DOE goals and objectives.
- The overview of targets and available sensor equipment with resulting gaps (compared to targets) do not indicate how many gaps there are exactly because of the bandwidth of sensor capabilities.

Question 5: Proposed future work

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

- Phase II is essential/needed.
- The next step in the process, the development of deployable test systems, will be more difficult. The plan calls for engaging industry, which is a necessary first step.
- The proposed follow-on is interesting. It would be nice to evaluate sensor systems. It is not clear at which step the sensor systems are designed and fabricated.
- Some proposed next steps seem logical; however, it is not clear what impact technology gaps have on the team's ability to develop a suitable system or conduct suitable testing. Describing go/no-go decisions and validation partners more fully could improve the proposed future work. There is some potential for this work to lead to a development project that addresses unacceptable gaps in technology, which might be useful.
- Future work for this particular effort is irrelevant—the work is done. However, it will be important to keep this information current as the technologies change and as the tolerance toward the contaminants changes.
- The project is missing efforts to analyze the cost of sensors (in dollars per kilogram dispensed)—especially because all sensors available are at least two times more expensive than the target installed cost of $5,000.

Project strengths:

- This project directly addresses a need defined by industry for effective use of hydrogen quality standards (i.e., SAE J2719 and ISO 14687-2), as well as develops requirements for cleanliness and testing. Integration into H_2USA's Hydrogen Fueling Station Working Group allows for close collaboration with many of the key stakeholders and opportunities for real-time refinement.
- The project has demonstrated a comprehensive approach.
- The expertise of the laboratory at NREL and the desires of the OEMs are project strengths.
- The gaps are identified.

- The project did an okay job in understanding the current state of the art. The project is done, and the results are published.

Project weaknesses:

- The project weaknesses are not known at present, but they will become known with the effort to place equipment in the field.
- Articulation of alignment to DOE goals and objectives, as well as how the project addresses barriers and technical challenges, could use improvement. The project's level of effort may not be adequate to facilitate coordination with key stakeholders at a sufficient level. An increase in technical interchange meetings with SAE International and H_2USA, along with information dissemination through broader channels, could increase understanding about the project and increase stakeholder input to guide future efforts.
- A project weakness is the lack of relevant collaborations.
- It does not appear that the identified gaps will be filled any time soon because manufacturers that submitted information about available sensors have not expressed strong interest in developing sensors that meet the list of requirements developed by the H2FIRST HCD project team.

Recommendations for additions/deletions to project scope:

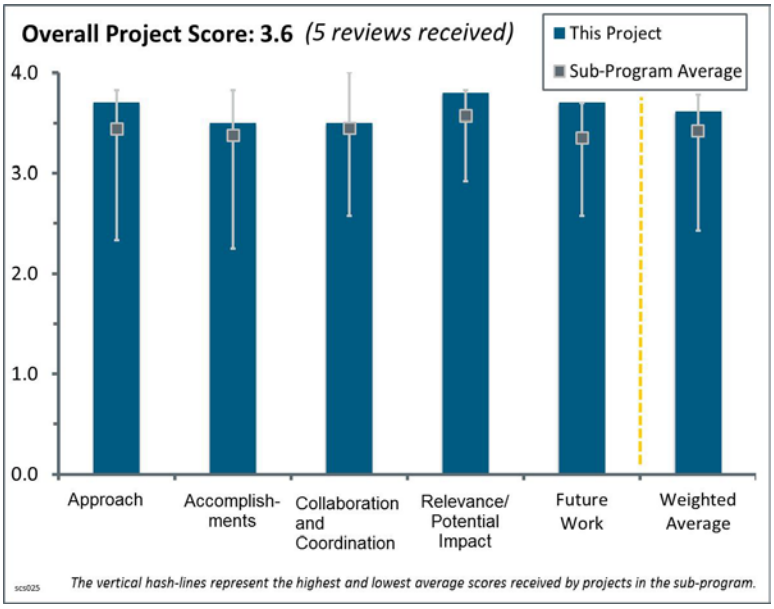
- In the cases of some station configurations, three HCD locations are possible, but it is not clear which location is most essential and challenging. The project should do the following: (1) consider variations and focus first on an HCD location that is related to a contaminant that does irreversible damage to fuel cells in fuel cell electric vehicles; (2) focus on the least damage-related contaminant HCD location last; and (3) consider what it would take to have the third HCD potential location removed from the list of potential HCD locations.
- The project should interface with SAE International, CSA, and ISO 19880 committees for data requirements, as well as with ASTM Committee D03 for instrument manufacturer outreach.
- The project should work with the ISO WG 24 Draft Technical Report 19880-1 document committee, CSA HGV TC, and SAE International. The technology should be implemented at "real" commercial stations for field testing.
- Interface with stakeholders should be increased. The ability for the results of the gap analysis and testing to lead to new work (whether a part of this project or not) would be useful in launching an effort that improves upon the available technologies.
- The state of the art for HCD devices really needs to remain current. This technology space will change in the coming years. This will be a result of improving technology, as well as changing requirements.

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

Chris LaFleur; Sandia National Laboratories

Brief Summary of Project:

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



Question 1: Approach to performing the work

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

- The approach of developing performance-based safety methodologies is sound and worthwhile. The project lead is a fire safety engineer. This adds significant credibility and increases confidence when working directly with authorities having jurisdiction (AHJs). However, it is critical to avoid potentially sending mixed messages to the AHJs. Collaboration with industry stakeholders on messaging is recommended. Use of developing modeling tools had the double benefit of validating the project results and contributing to the further development of the models. Direct involvement in the International Organization for Standardization (ISO) working group (WG) that is developing general requirements for gaseous hydrogen fueling stations is an effective way to coordinate with key national and international stakeholders and keep the project focused on the most significant concerns.
- The approach is very comprehensive and timely.
- The approach is multidisciplinary and multi-methodology. It integrates all aspects and all players to reach the objectives (obtaining industrial input for frequencies data, achieving excellent scientific competences required for a science-informed tool, and engaging with stakeholders, such as code developers and AHJs).
- The approach is two-pronged. The first approach is to allow alternative methods to show compliance with the model codes. The second approach is to generate the research to relax the existing prescriptive requirements.

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

This project was rated **3.5** for its accomplishments and progress.

- This project will certainly contribute, once finalized, to the overarching goals of the DOE Hydrogen and Fuel Cells Program (the Program). Thanks to the integrated approach, it even has the potential to accelerate the achievement of those goals. It appears that the project's degree of accomplishment is also aligned with the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan. The only uncertainty is related to possibly failing to reach consensus among the stakeholders. As already mentioned by previous reviewers (in 2014), there is some suspicion about probabilistic methods among end users and AHJs.

- This project has been ongoing for many years and is always focused on the highest-priority needs. Significant progress has been achieved in the gaseous hydrogen risk analysis. The project's current focus on liquid hydrogen storage issues is timely.
- The accomplishments and progress to date are impressive.
- Working both domestically and internationally is consistent with the recent efforts across the board in codes and standards harmonization. While the rest of world may not use the National Fire Protection Agency (NFPA) work, the efforts with ISO are critical to getting other countries on board with the quantitative risk assessment (QRA).

Question 3: Collaboration and coordination with other institutions

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

- Collaboration and coordination levels are appropriate for this point in the project.
- The collaboration section shows collaboration with the key laboratory activities, but it is not clear whether this collaboration extends to messaging. A more clearly articulated and coordinated approach with related industry and laboratory efforts regarding messaging with AHJs would improve the project. To avoid perception issues, the presentation would benefit from a sentence or two relating to the openness and fairness in developing project partnerships.
- The project has developed strategic collaboration with key industry players, is well integrated in the national codes and standards frame, and reaches out to end users. Regarding the international dimension, the project also strives for worldwide consensus achievement in the frame of the ISO and makes use of the International Energy Agency's Hydrogen Implementing Agreement research and development collaboration for further tuning its science-informed tool.

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

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

- This is a high-value project with clear alignment to the Program's goals and objectives, as well as with the technical challenges and barriers the project addresses.
- This activity is highly relevant and has the potential to reduce capital costs.
- The impact of this project can be very big, but the impact depends on (1) the team's ability to develop an integrated tool that is well validated and accepted by the scientific community, and (2) the adoption and use of the tool to produce performance-based designs. While the first condition is more related to SCS-011, the second condition is specific to this project and, if fulfilled, could have positive consequences on other fields and trigger wider adoption of the performance-based design and probabilistic approach.

Question 5: Proposed future work

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

- The proposed future work is very good, but outreach needs to be addressed. Just because the NFPA book committee agrees does not mean that AHJs will accept the methods. Working with state authorities who have jurisdiction over their states (plus New York City) is suggested. States such as Massachusetts, Connecticut, New York, New Jersey, and Florida are recommended. If those officials get on board, getting the county or municipal official to accept the methods will be easier.
- The proposed future work is very relevant and important. Information on technology transfer, however, is limited. For this critical technical work to be useful in achieving the desired adoption of risk-informed alternative compliance methodologies, a well-thought-out plan for vetting, educating, resolving concerns, etc. should be included. To avoid potentially sending mixed messages to AHJs, this activity should be performed with other key groups that are involved in related efforts. These groups include the California Fuel Cell Partnership, the Fuel Cell and Hydrogen Energy Association's Hydrogen Codes Task Force,

H_2USA's Joint Regulations, Codes, and Standards (RCS) Task Team, the National Renewable Energy Laboratory, Pacific Northwest National Laboratory and, at the appropriate time, the NFPA Hydrogen Technologies Technical Committee.

- It would be beneficial to include an educational portion in California permitting workshops. In addition, the project should work with NFPA staff (perhaps as an H_2USA project) to offer a NFPA course on the implementation of NFPA 2 across the country. The educational element could/should educate workshop attendees on the history of the setbacks and explain the rationale for the alternate methods/performance-based option (risk equivalency) so that the AHJs might be more apt to approve/accept it through the permitting process. (To clarify, this is not to show the AHJ how to use the QRA but to show how to apply Chapter 5 of NFPA 2 when a project proponent submits a plan using this method.)
- The project management has a clear vision of the pending milestones and critical deadlines. The time to achieve the important goal of inclusion in the updates of the NFPA 55 and NFPA 2 is limited, but the plan to achieve this is realistic.
- This is an excellent plan for future work; however, it does not appear to be realistically funded to meet the code revision needs in 2020. Separation distances and mitigations for liquid hydrogen are one of the key barriers for the large-scale success of the hydrogen fueling infrastructure. Coupled with Hydrogen Risk Assessment Models (HyRAM) and the liquid hydrogen release studies also being done at Sandia National Laboratories (SNL), this alternative compliance effort may make an impact on U.S. code and also have a worldwide impact through the collaborative work with ISO TC 197 WG 24. However, there should be a near-term funding mechanism within DOE to assist in accelerating this important gap. This is basic science and should be assisted as soon as possible.

Project strengths:

- The project relies on a very competent team and capable management. Strategic interfaces with stakeholders have also been put in place. Project goals are very ambitious because of the novelty of the methods adopted and the short time frame available for reaching them.
- This project responds directly to industry needs in developing RCS and is well aligned with DOE goals and objectives.
- The project strengths are the needs of the industry and the abilities of the laboratories.

Project weaknesses:

- The project weakness is the idea of public outreach to the local AHJ.
- An adoption strategy closely coordinated with key stakeholders is described in comments under "Proposed Future Work" but is currently lacking.
- The only apparent weakness is the high risk of the project due to the lack of acceptance of the approach among stakeholders and the very tight schedule for acceptance. The probabilistic approach is not widely accepted by AHJ or design engineers.

Recommendations for additions/deletions to project scope:

- This project has an excellent plan for future work; however, it does not appear to be realistically funded to meet the code revision needs in 2020. Separation distances and mitigations for liquid hydrogen are some of the key barriers to the large-scale success of the hydrogen fueling infrastructure. Coupled with HyRAM and the liquid hydrogen release studies also being done at SNL, this alternative compliance effort may make an impact on U.S. code and also have a worldwide impact through the collaborative work with ISO TC 197 WG 24. However, there should be a near-term funding mechanism within DOE to assist in accelerating the liquid hydrogen releases and the HyRAM tool. This is basic science and should be assisted as soon as possible.
- It is recommended that the outreach focus on the states (and New York City) that have central jurisdiction to accept the methodology. If they accept and endorse the methodology, then the states with distributed jurisdiction are most likely to accept and adopt the methodology. The first step might be state fire marshal and state building inspector trade organizations.

- The team should develop a coordinated plan for promoting acceptance of the resulting risk-informed methodologies into the codes and standards.
- Abandoning a traditional, deterministic methodology and prescriptive approach to design is difficult. Demonstrating the results and the advantage of using the new approach in real cases is critical for project success. In addition, hands-on sessions with a wide group of stakeholders would lower the "psychological" barrier represented by a new "unknown" system. The creation of an area on H2Tools dedicated to practical cases and the hosting of question and answer sessions would help. Finally, it is not clear if the project has a backup plan. The impact of the project results could still be important even if the adoption of its approach in the next code updates does not take place.