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## 2014 — Safety, Codes and Standards

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

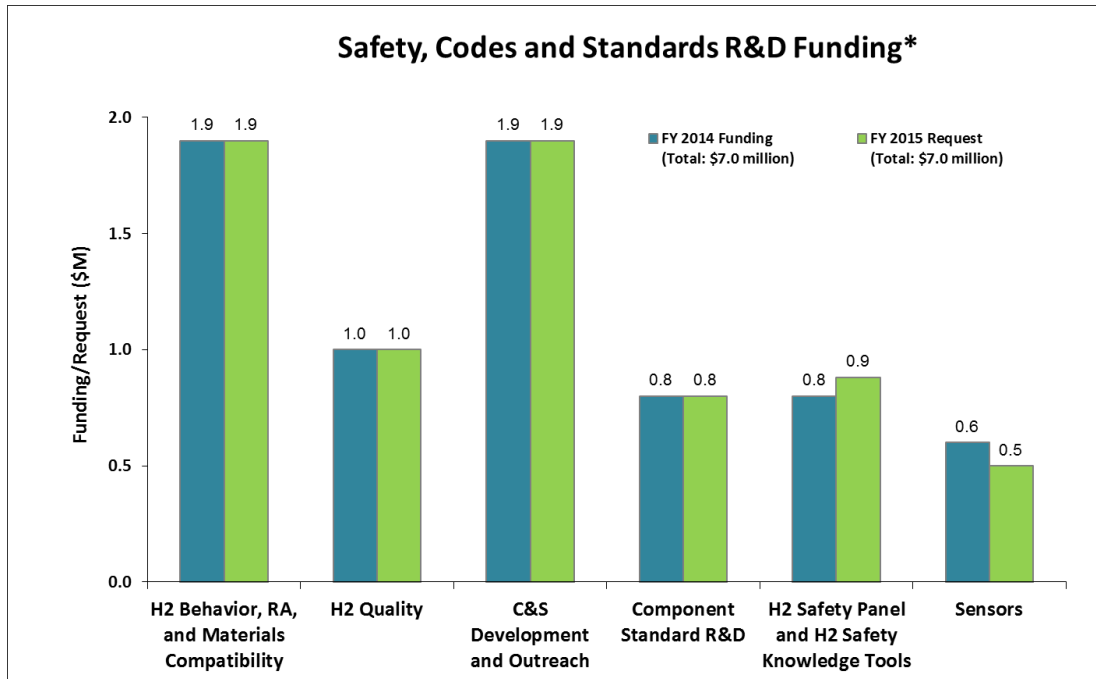
#### Summary of Reviewer Comments on the Safety, Codes and Standards Sub-Program:

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 also conducts safety activities focused on promoting safety practices among U.S. Department of Energy (DOE) projects and the development of information resources and best practices. Reviewers recognized that the sub-program's objectives and strategy are well defined and continue to provide strong support to enable early deployment of hydrogen and fuel cell technologies. The sub-program's portfolio was commended for its balance of activities in the following critical areas: hydrogen and fuel cell codes and standards, including domestic and international harmonization; permitting outreach; hydrogen sensor technology; hydrogen components and material compatibility; hydrogen behavior and fuel quality; hydrogen infrastructure risk assessment; hydrogen safety and related tools; and safety training for first responders and researchers. Reviewers made similar observations as they have in prior years, such as that projects in this sub-program have effectively leveraged the resources of academic institutions, standards development organizations (SDOs), code development organizations (CDOs), national laboratories, government agencies, industry, and other offices within DOE. Overall, the sub-program was acknowledged for its comprehensive approach for addressing challenges related to codes and standards.

In addition, although reviewers commended the sub-program for the strong international participation through existing engagements with the international standardization and regulatory communities, they noted that more active involvement would be beneficial. Reviewers also felt that the sub-program was well focused and well managed, but they stated that it could increase its effectiveness in reaching its goals and impacting the marketplace with improved outreach and technology adoption efforts to better market sub-program outputs. Finally, while reviewers recognized the sub-program's sound approach, they recommended shifting the current emphasis of activities from the deployment of hydrogen refueling stations to a more long-term perspective that also supports other applications.

#### Summary of Safety, Codes and Standards Funding:

The sub-program's fiscal year (FY) 2014 appropriation was \$7 million. FY 2014 funding has allowed for continued support of codes-and-standards-related R&D and of the domestic and international collaboration and harmonization efforts for codes and standards that are needed to support the commercialization of hydrogen and fuel cell technologies. The FY 2015 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 2014, 12 Safety, Codes and Standards sub-program projects were reviewed, with a majority of the projects receiving positive feedback and strong scores. Reviewers' overall scores ranged from 2.5 to 3.8, with an overall sub-program average score of 3.3.

**Hydrogen Behavior, Risk Assessment, and Materials Compatibility:** Two hydrogen behavior and risk assessment projects were reviewed, earning an average score of 3.5. Reviewers commended the performance-based approach to risk assessment and sound scientific approach to addressing technical gaps. The reviewers suggested adding efforts to communicate findings regarding lower-cost steels and the benefits of automated welding to station builders and design engineers because these efforts relate to real-world service conditions. According to reviewers, the hydrogen behavior and risk assessment work should more closely engage industry and end users (i.e., code officials) of the Hydrogen Risk Assessment Models (HyRAM) tool and expand collaborations with international entities, hydrogen suppliers, and car manufacturers.

**Hydrogen Quality:** One hydrogen quality project was reviewed, receiving a score of 3.6. Reviewers commended this project for its progress and strong contributions to the international harmonization of fuel quality standards due to participation from international and domestic CDOs and SDOs. Reviewers suggested reexamining the project focus to ensure support of SAE J2719 (i.e., via compliance testing), bolstering national outreach and feedback activities, and extending testing from the membrane electrode assembly to the stack level.

**Codes and Standards Development and Outreach:** Two codes and standards development and outreach projects were reviewed, receiving an average score of 3.1. The reviewers praised these projects for their potential impact, their extensive lists of collaborators, and the Fuel Cell & Hydrogen Energy Association's (FCHEA) focus on multiple technology applications. The scope and breadth of this work and the depth of expertise and experience of the project teams were noted as clear strengths. However, the reviewers commented that the projects' approach and strategy for codes and standards deployment and outreach should be improved. They noted that the projects' approach and strategy should include more substantive and proactive engagements and input from industry stakeholders, with increased collaboration between national laboratories and trade associations (i.e., FCHEA) to gather critical input and better leverage resources and expertise to optimize the projects' impact.

**Component Standard R&D:** One component testing project was reviewed, receiving a score of 2.5. The reviewers commended the project's collaborations with manufacturers, system installers, CDOs, SDOs, and other stakeholders to ensure appropriate standards development efforts are undertaken to provide certified products to commercial markets. Reviewers strongly recommended (1) teaming with national laboratories to better leverage existing, relevant expertise and (2) focusing component standard development on system-level components of infrastructure hardware rather than a single component.

**Hydrogen Safety Panel and Hydrogen Safety Knowledge Tools:** One project in this area was reviewed, receiving a score of 3.8. Reviewers noted the project team's flexibility in developing tools and resources to keep pace with the changing stages of technology commercialization. The project was also acknowledged for its outreach efforts to insurance groups and authorities having jurisdiction to better understand user needs. Reviewers recommended that the project team collaborate more closely with FCHEA and the National Renewable Energy Laboratory (NREL) to avoid duplication of effort and provide more robust products.

**Hydrogen Emergency Response and Safety Training:** Two training projects were reviewed, achieving an average score of 3.2. Reviewers praised these projects for their continued training activities, both online and in person, and for filling an important knowledge gap. They recommended that the project teams examine long-term strategies to better engage targeted stakeholders (i.e., local fire and police departments) and broader audiences, with the potential to "train the trainer" and hand off training course activities for industry to continue.

**Sensors:** Three sensor projects were reviewed, receiving an average score of 3.0. Reviewers applauded the overall approaches and notable progress made in developing a hydrogen-specific sensor and addressing technical barriers such as reliability, durability, and cost. However, reviewers recommended expanding the focus of project work to cover stationary applications instead of just vehicles, and ensuring the alignment of sensor development activities with related work in the Safety, Codes and Standards and Hydrogen Production and Delivery sub-programs. Reviewers also suggested identification of a mainline manufacturer to partner with and more rigorous estimation of real-world life cycle cost, market price, and overall operations and maintenance cost savings from new sensors compared to commercially available products. The Small Business Innovation Research project was commended for its progress and high accuracy over a wide temperature range, but reviewers recommended continuing the project only if NREL testing shows promise for the technology and at least one partner (e.g., fueling station builder or original equipment manufacturer) is added to the project.

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

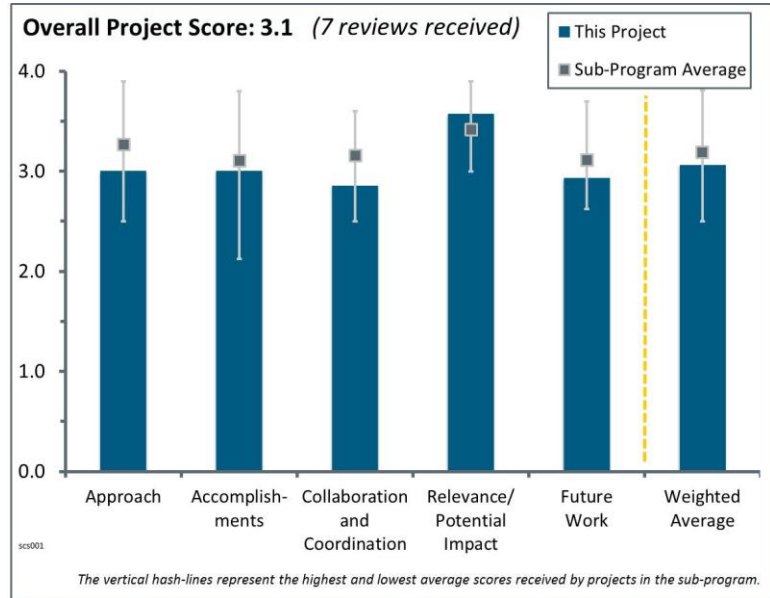
Carl Rivkin; National Renewable Energy Laboratory

### Brief Summary of Project:

The main objective of this project is to develop and support the codes and standards required to safely deploy hydrogen technologies. Current year objectives are to develop outreach tools, conduct training, and address key codes and standards to support the safe deployment of hydrogen technologies. Long-term goals are to support the development of integrated codes and standards and to provide the outreach required to have these codes and standards used effectively.

### Question 1: Approach to performing the work

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



- Continuous codes and standards improvement (CCSI) is a very good approach. Having a video with the Orange County Fire Authority is excellent; the reviewer is looking forward to it. Continued support of the permitting workshops is needed, critical, and extremely valuable!
- The overall approach for CCSI—continuous monitoring of the code development organization/standards development organization (CDO/SDO) community and user community—is critical to the success of regulations, codes, and standards (RCS) development. The other half of this is deployment—targeting the regional areas that are deploying hydrogen technologies and creating tools to be utilized regionally (the California permitting guide, for example) and extended to the national level—is very good. However, teaming with other entities working in the same space (e.g., Pacific Northwest National Laboratory [PNNL], Fuel Cell and Hydrogen Energy Association [FCHEA], Sandia National Laboratories [SNL]) was absent. FCHEA, H2USA, SNL, and the international community (through the European Infrastructure Project H<sub>2</sub>FC, which includes members such as the Karlsruhe Institute of Technology, the University of Ulster, etc.) are all working to provide tools to help with the local authorities having jurisdiction (AHJs), with codes and standards (C&S), and with the needs of the permitting, design, and construction process. The partnering with appropriate groups—such as the local fire departments, programs that support deployment (such as the California Fuel Cell Partnership [CaFCP]), and now H2USA—is spot on. However, the project also needs to embrace fuel suppliers and original equipment manufacturers (OEMs). This was pointed out during the question and answer (Q&A) period. The presenter responded that the training sessions are open to the public and that these groups are free to attend. That was the wrong answer; these groups need to be included in the program, design, and execution of the product, not just be the recipient of the product. Attention and focus on the deployment product to make sure the intended audience can use it easily is very good; for example, putting this information in a form that is easy and effective to use and suitable for AHJs that need to have state-of-the-art knowledge. This was an issue correctly identified by the principal investigator (PI); however, no mention of the PNNL resource tool web portal was mentioned. Both activities would benefit greatly by a strong collaboration, which is clearly absent. Not including other efforts as 100% collaborators results in duplication of effort and a product that is less impactful than it could be. The approach to this work has a serious shortcoming centered on the notion of collaboration and teaming.
- The approach discussed is appropriate for this type of activity. Elaboration of the CCSI process by explaining “code cycles” would help the uninitiated.

- This is a never-ending task since C&S are always evolving. The best approach is to focus on the codes—not the component standards at this point, which seems to be the plan. Effective “training” for AHJs is likely to be a low-return investment unless timing/personnel work out perfectly. The permitting guide might have merit but requires actual use/verification to gauge impact.
- The approach consists of two activities, CCSI and deployment. This is a valid concept. However, the targets of these two activities are exclusively U.S. actors and entities (as indicated in the project title). Deployment of hydrogen technologies, in particular for transport applications, however, is a global issue. Hence it is recommended that the project include international activities, in particular those related to the hydrogen refueling infrastructure in the work.
- The approach for this work lacks a sense of direction. It appears that the PI does not have a coherent vision for the project. Also, there are insufficient industry feedback loops built into the project. It is not clear whether the project lead anticipates a transition to industry C&S improvement and, if so, where in the approach and plan there is this transition to the industry. There is not a clear building of consensus. The approach illustrated a myopic view of the development process with very little sense for the valuable work of building consensus and helping stakeholders through technical communication, barriers, and concerns.
- It is not clear when partnerships will be realized, nor whether there is a plan to engage even more code officials. Granted that only a few code officials now have to deal with hydrogen siting and certification now, but still, there is no clear strategic plan to roll this out to a larger audience because there are more and more hydrogen systems being deployed.

## 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.

- There has been good progress harmonizing the International Building and Fire Codes and the National Fire Protection Association (NFPA). There is much work yet to do on liquid hydrogen, but the project has a realistic timeframe.
- The updating of the permitting guide with a focus on California’s needs is very timely. What makes this particularly nice is that the PI is keeping national needs in sight. This will make it easier to create a “national” permitting guide. The PI should be careful to clearly delineate accomplishments (for example, “4 FY 2014 [training] sessions May 19 and 27” or “Draft 2014/final 2015”) versus the activity: “active participation on C&S technical committees including identifying...” (slide 12). On slide 20 in the summary table, the reviewer credits as accomplishments: the formation of the NFPA Liquid Hydrogen Task Group (albeit a weak accomplishment) and the C&S workshops held. The reviewer considers activities such as the National Permit Guide/tools and the Stationary Fuel Cell Permitting Guide to be works in progress, not accomplishments with 2014 publication dates. There are only two items listed on slide 23 (for reviewers only), and these are for “inside audiences.” One is for DOE, and the other is an internal National Renewable Energy Laboratory (NREL) technical report, and is not in the refereed literature. This is weak. While the workshops are an appropriate and important outreach activity, there should be a more aggressive effort to put the accomplishments of this work in the open literature for larger distribution—for example, the *NFPA Journal*, the *International Journal of Hydrogen Energy*, or in DOE records—whatever is appropriate, given the article. The PI for this project is perfectly able to identify suitable open public domain outlets of this work. Paying attention to this, the number and impact of the accomplishments this reporting period listed are weak, particularly considering the average funding for this work is two full-time equivalents. Largely, this could improve substantially if this project would aggressively embrace the collaboration/teaming of others in this topical field.
- The accomplishments and progress are uneven. There are a number of reasons for this that are mainly outside the National Renewable Energy Laboratory’s (NREL’s) control. The progress seems to be predicated on the CDO/SDO committee makeup, which actually reflects industry interest. When there is a lack of interest or urgency expressed by industry, the void is often filled by individuals with good intent but lack of hands-on experience.
- It is unclear where the results are in the accomplishments. The example cited that this project provided a bridge in NFPA 2. It is not clear how this project is coordinated with other national training efforts. This project seems to exist as a reporting service for DOE on the outcomes of codes and standards meetings. The

project should reevaluate its direction. It is not clear how CCSI—an acronym, a PowerPoint slide, and a process—is considered an accomplishment. It would be good to have a relevant example of how this was implemented or how the process has been used and how it directly benefited standards development efforts. The National Permit Guide had no collaboration; the reviewer was concerned about the utility of this information, and that it may hinder, rather than ease, permitting of hydrogen infrastructure.

- It sounded like training deployment was well-received, but people receiving the training sounded like they wanted more information on how code requirements could be applied to an actual project.
- Progress is measurable but could be larger with increased availability of resources (as also mentioned in last year's review).

### Question 3: Collaboration and coordination with other institutions

This project was rated **2.9** for its collaboration and coordination.

- The project has a nice extensive list of collaborators.
- The CDO/SDO coordination list is impressive but has a couple of key omissions. The American Society of Mechanical Engineers (ASME) is also highly active on a newer section of the B31 Piping Code, specifically, Section 12. The next chapter for Section 12 would cover residential/commercial applications. The envisioned activity would be to address guidance in Class 150 or lower pressure classes, borrowing from ASME B31.2 and NFPA 54 for experience-based input on important design considerations.
- The list of collaborators on slide 16 would seem to be great partners, but the presentation did not highlight the extent of involvement or significant activities in which each collaborator has been involved. The interactions should be better highlighted.
- The project seems to have interfaced with appropriate organizations.
- NREL needs to strengthen their teaming/collaborations on this project. The partners need to be working with the PI to develop the C&S outreach and documents (permitting guides, training, etc.). There are several examples; the PI discussed the need to address separation distances in the NFPA model codes specifically in liquid hydrogen applications, yet no mention was made of teaming with others in this program who are also addressing this issue—specifically the quantitative risk assessment work from SNL. During the Q&A session, this shortcoming was noted several times, i.e., requests to embrace industry, OEMs, fuel suppliers to be part of the team to ensure there is alignment with vested industry interests. The PI did comment that the training sessions are open to the public, so all the aforementioned groups can attend. However, these stakeholders need to be on the development side of this activity, not just the receiving side. International CDO/SDO involvement in the product development needs to be strengthened as well; the comment was made that NFPA needs to be updated/fixed. NFPA is on a five-year cycle. International Organization for Standardization Technical Committee (ISO/TC) 197 is now back on track, and indeed a couple of the working groups (WGs) are on a fast track (WG 24 – gaseous hydrogen fueling stations, for example). This ISO product will be completed before the next NFPA cycle is complete. WG 24 will proceed without the benefit of this NREL effort as a result of the project's waiting for NFPA to complete its work. Often ISO documents are used as backup supporting language if there is a gap in local codes (per the reviewer's private discussion with CaFCP). Therefore, making sure these efforts proceed with cross-fertilization is important. This effort needs to have a less nationalistic focus and be more open to the international community. The lack of teaming/collaboration with other key stakeholders in this field was almost singularly the reason for a score of 2.5. This is a serious shortcoming of this work and its approach.
- Evidence has been provided that interaction takes place with other organizations (however exclusively within the United States). From the information included in the slides and presented at the DOE Hydrogen and Fuel Cells Program Annual Merit Review, it is difficult to assess whether the interaction has also led to effective collaboration/coordination of activities. There is no evidence provided on the mentioned interaction with ISO/TC 197.
- Documents that serve the needs of industry were produced by this group with no industry feedback. The deployment training has been “sold” to the state of California without any vetting from the industry participants putting in the stations. California is trusting that DOE has oversight of the development of this type of reporting and training material. This project would benefit from additional oversight to ensure sufficient peer review criteria for use as a training tool and published report.

#### 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 relevance and impact from this NREL project in conjunction with the PNNL H2 Safety Panel are key to the success of hydrogen and fuel cell commercialization—not only for reaching a commercial phase but for sustaining it, either directly or indirectly. The response to the reviewer comments is encouraging and on the right path; it is good to see the continued work in developing C&S and their application. The project should keep up the good work!
- Promulgating national model codes to local AHJs is critical to the deployment of hydrogen technologies. Indeed, since rollout of fueling infrastructure is happening now, there is an immediate urgency for this to enable safe rapid deployment. The purpose and relevance of this project is right on.
- This activity is becoming critical path for the adoption of hydrogen as a transportation fuel. Completion of the first editions of the various documents is a must. Revision based on usage of many of the existing documents is needed.
- Training AHJs and getting their approval on hydrogen applications is crucial to future system deployment.
- This is an indispensable activity that could benefit from additional resources.
- C&S are very relevant to the successful roll-out of hydrogen fuel stations.
- This project has a great deal of potential relevance but does little more than participate in activities. Building consensus and eliminating technical barriers is a proactive role. It does not require leadership of the committees, and in fact, government should not be leading standards development activities unless specifically requested by the committees. But this project could be doing the work of building consensus—communication between meetings to determine the differing points of view and to see whether and how relevant science or information can help establish a resolution to those differences.

#### Question 5: Proposed future work

This project was rated **2.9** for its proposed future work.

- The liquid hydrogen work had stalled, and now it has restarted. A similar concentrated push is recommended for two additional areas: (1) separation distance to lot line and how to handle this, and (2) mitigation means to reduce distances.
- Constant assurance that the workshops and guide are in line with industry is imperative. The presenter commented that the project team will “accelerate rather than decelerate the momentum—going through the California Fire Code and specifying the requirements and getting feedback from AHJs. Training sessions are not limited to just permitting officials—they are open to project developers as well.” The effort to track the permitting timeline of stations with the training may be cumbersome but provides a valued statistic—especially in California as a model for the rest of the nation—and something that H2USA can run with. It is very important to show the international collaboration with ISO!
- The proposed future work is appropriate for this overall activity. This group needs to aggressively embrace the efforts of others in the development of NREL’s work product. It would be good to see an activity that is focused on developing that team in a couple of areas: (1) national and international tools (PNNL, FCHEA, SNL, H2FC [Europe], ISO, etc.), and (2) training and workshops (embrace OEMs, fuel suppliers, industry, etc.).
- It appeared that a significant amount of work was planned for the future. During the presentation, the speaker would make the following comments: “We still need to do that,” or “...in the future, we will do that,” etc. Sometimes it seemed like work that was supposed to have already occurred had not been accomplished.
- The project should enhance coverage of and interaction with international activities.

**Project strengths:**

- This PI is very knowledgeable and enthusiastic about RCS, specifically in code language, process (from AHJs through model code development), permitting, etc.
- The project lead has a wealth of knowledge. There is ability for a broad reach from a respectable source (or team of sources).
- The scope and breadth of the project is a strength.
- The project has great potential.
- There is good focus.

**Project weaknesses:**

- It really boils down to the closed nature of this work. Significant improvement needs to be made in embracing from a teaming perspective in the creation, execution, and delivery of the work products. Excluding others who are working in the specific area can lead to duplication of effort or, worse yet, inconsistency in information, resulting in a work product that is not as complete or powerful as it could be. This is a serious shortcoming in the execution of these work products.
- It is of concern when NREL chairs the authoring of documents in this arena, especially fuel cell documents. The product standard and the installation standards have been in use for about 20 years. These documents are embedded in both the International Code Council (ICC) International Mechanical Code (ICC IMC 924) and NFPA (NFPA 5000 – 6.4.2.61) code sets and have been used to site thousands of power plants in the United States. If another fuel cell document is desired, the effort should be led by the FCHEA, not a national laboratory.
- The effort needs to be broadened to more “hot button”-type issues that also cause practical constraints on siting of hydrogen systems.
- The project should reevaluate its scope and implement a more rigorous approach so that this work can reach its potential.
- The project lacks international dimension.

**Recommendations for additions/deletions to project scope:**

- The project should work across the board with other DOE and laboratories/programs—specifically, the Hydrogen Safety Panel and their resources and efforts in C&S outreach, education, and harmonization. There is certainly synergism among these projects that would result in an even stronger result!
- More attention and support must be paid to the piping code and the CSA HGV activities.
- The project should add coverage of international activities.
- The project should establish clear guidelines for success and expectations.



## Project # SCS-002: Component Standard Research and Development

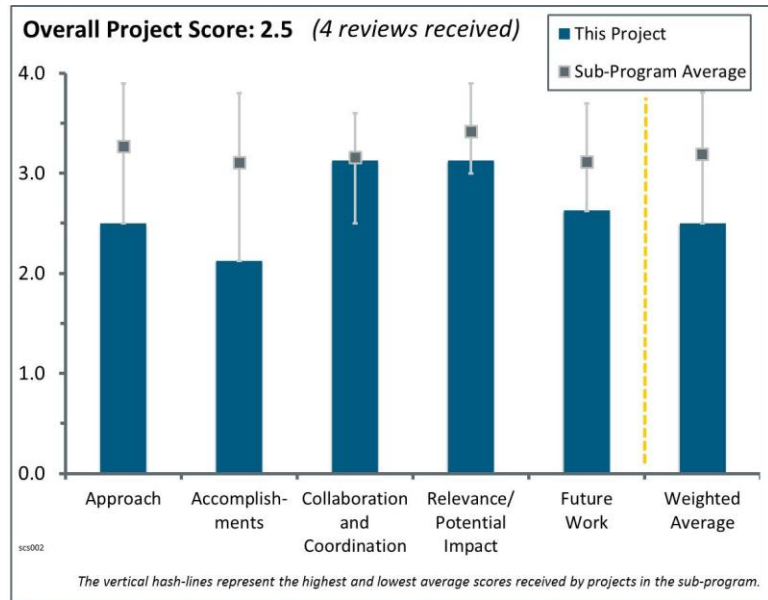
Robert Burgess; National Renewable Energy Laboratory

### Brief Summary of Project:

Successful deployment of hydrogen infrastructure will require components that are proven to perform safely and reliably as measured against new safety and performance standards. National Renewable Energy Laboratory (NREL) component research and development test efforts are focused on supporting component manufacturers and system installers so that fully tested and certified hardware is available.

### Question 1: Approach to performing the work

This project was rated **2.5** for its approach.



- This work is critical and directly supports the program objectives and addresses key barriers. Test results will be used (in the future) to inform Safety, Codes and Standards (SCS). International Organization for Standardization /Technical Committee (ISO/TC) 197 has already begun international working groups to write standards on many of the component topics being addressed by this work. It would be very worthwhile to ensure project investigators are directly engaged with these efforts sooner rather than later. This will not only inform the standards developers sooner, but also may provide some specific direction to follow-on activities.
- Working from the systems level and piecemeal down to the sub-component level is a good approach in the testing and qualifying of systems and components. This team really needs to work much more closely with the Materials Group at Sandia National Laboratories (SNL). There is much proposed overlap in capability and activity. SNL has been working in hydrogen effects on materials for many decades and is the globally recognized expert in this area. This project can benefit greatly from not reinventing this space, but from teaming with the SNL staff in hydrogen effects in materials. The word teaming is used instead of collaborating to denote a teaming at the time of project planning and participation rather than an occasional consultation, as was described in the valve testing work. For example, instead of the NREL team performing stress fracture fatigue testing at NREL to “understand” the fundamental processes of crack growth, this part of the effort should be moved to SNL, where the equipment and staff have decades of leadership in this very area. Components testing at NREL and the fundamental fatigue crack growth work done at SNL would make for a powerful activity. The discussion on slide 15 was an unnecessary investigation into the Emeryville failure on a problem that has already been thoroughly investigated by the SNL incident investigation team—which included the staff material scientists. The topical area of fatigue crack growth on a fundamental level is being investigated by the SNL team, and those results are being published in the refereed literature and promulgated to the appropriate ASME codes. This NREL activity is a duplicative effort with one this office is already funding. There is value in understanding component and systems behavior (which is what this project was presumably all about)—the fundamental material behavior in hydrogen environments is the focus of the SNL materials work. Teaming between these two activities will prove to be very valuable. This activity needs to partner with SNL, not duplicate and compete with SNL. A major activity for this project is to build up the new Energy Systems Integration Facility (ESIF). It is of concern that this approach does not seem to be embraced as one executes individual projects. The current example is the relief valve project; the temperature and pressure range for the *facility* should be made to represent the domain required for the hydrogen infrastructure. There are regions of the world that will reach -40°F and upwards of 80°F (Alaska and Palm Desert above black sun-backed

asphalt, respectively). Also, contemporary fills needs to be J2601-compliant, which also involves the -40°F to 80°F range, as well as operations at ~87.5 MPa for a 70 MPa fill—this laboratory falls short operating in this domain and will have to be upgraded in the future as projects (components) are tested that need to operate in this more challenging domain. If one builds up a new facility and does not configure it for foreseen near- to long-term measurement domains in the beginning, it simply means that the facility will have to be modified in the future at greater expense in time and financial resources. In this particular example, temperature and pressure domains are specified by J2601 fill protocol and environmental conditions found around the world—as noted above. There is no evidence that this approach is being implemented with the construction of the new facility. Indeed, it appears that the capability is designed around the testing campaign at hand, leading to restricted temperature and pressure range of operation ( $T \leq 0^\circ\text{C}$ ,  $T \geq 50^\circ\text{C}$ , 48 MPa, as shown in slide 13—albeit the project team is planning to upgrade the facility to 70 MPa, but there was no mention of upgrading the temperature range). This alone might indicate that the appropriate capability is being constructed; however, during the question and answer period, this point was identified as a weakness, and the presenter did not supply a defending answer to suggest embracing a more correct operating domain. This is a serious shortcoming since it will lead to unnecessary delay and additional funds to upgrade the facility to perform testing in the appropriate domain. Teaming and collaboration is critically important for this project in developing and executing all work products.

- There appears to be good coordination between the barriers being addressed and the subtask developed to address it. At the same time, however, there appears to be a good deal of risk involved in relying on so many other projects to provide the bulk of the data. The Fuel Cell Technologies Office (FCTO) SCS-funded project itself appears to be involved with only the pressure relief valve (PRV) failure mode investigation, and this project is relying on other resources to address compressor reliability (FCTO Technology Validation sub-program), flow metering (State of California), hose reliability, receptacle wear and nozzle durability (FCTO Delivery sub-program), and low-temperature sealing (dependent on ESIF readiness and availability). While this may result in successful data acquisition, it appears to focus risk from these other resources on this project.

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

This project was rated **2.1** for its accomplishments and progress.

- This is an early-stage effort for components—an important activity. It would be good to see more workshops with industry and code development organizations/standards development organizations (CDOs/SDOs), as well as discussions at the National Hydrogen and Fuel Cell Codes and Standards Coordinating Committee (NHFCCSCC) on this effort.
- Accomplishments presented in this review are really discussions of activities and sometimes future planned activities, not accomplishments. Only three activities are recognizable as accomplishments: (1) the publication of an internal NREL technical report; (2) the successful launch of the Hydrogen Fueling Infrastructure Research and Station Technology project (H<sub>2</sub>FIRST), which is a noteworthy accomplishment, but this is an accomplishment for a larger team at NREL/SNL, not just this one project; and (3) the identification of the failure mode of the pneumatically operated valve, which would result in release in a vent pipe. A weak publication output is expected for a laboratory that is being moved and/or under new construction since the time is spent on the upstream side of research projects. However, this laboratory has been operational since the summer of 2013 (about one calendar year; see slide 6), and the project has been active since October 1, 2013. This implies that it has been operational since last summer to produce the studies/testing on components it is intended to perform. Results from this work should be evident by now, yet the only accomplishment that was presented was identifying that the failure mode would release into a vent pipe. A more substantial discussion on the year's accomplishments was expected. Indeed, a discussion of a test plan for a pneumatically operated valve was presented, but it appears that even this fell short of what would be expected, as that opportunity was not used to configure the facility for efficient operation in the future. This is a big concern. This is funded at a level of about 0.7 full-time equivalents (FTEs); there should be more concrete output from this project—at least concrete preliminary data/results from initial component testing; only one simple straightforward observation was presented.

- There seem to be good data being generated for PRV failure, but it was stated that the failure mode tested was for failing open, while valves failing closed or partially open would be necessary failure modes to consider as well. No data were reported other than PRV data.
- It was very difficult to discern what value this project brings to the SCS sub-program. It is quite unclear what the results of this investigation will uncover, other than not using this particular valve with hydrogen, which the manufacturer already prohibits.

### Question 3: Collaboration and coordination with other institutions

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

- The peer-reviewed NREL publication, the collaboration with the Colorado School of Mines metallurgy laboratory, and the NREL Component Webinar, which is now planned for July, are all commendable. This activity is in the early stages, developing data that will be available for specific regulations, codes, and standards (RCS) activities in the future. It is good to see the collaboration with the National Institute of Standards and Technology to exchange knowledge to improve metering work. This work is critical to H2USA and other efforts. Monthly engagement on this project with the NHFCCSCC would benefit industry.
- A large list of collaboration partners includes other national laboratories, industry, universities, and SDOs.
- The work/collaborations with CDOs and SDOs, manufacturers, and system designers are critical, so this interaction is very good. Stronger teaming with other laboratories will strengthen this work and keep it unique. A stronger teaming with SNL material staff was specifically noted as needed to ensure efficient use of DOE funds and to avoid duplication of effort. H2FIRST will help in this area if the teaming approach is embraced aggressively. The collaboration criterion was scored solely on the type and quality of the collaborators.
- It is impossible to distinguish what unique collaborations this project provides, as so much of the project presentation and information references other projects (e.g., compressor reliability, H2FIRST, etc.).

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

This project was rated **3.1** for its relevance/potential impact.

- Understanding component safety and failure potentials is extremely relevant to preventing catastrophic failures. If the project team is able to pull in all the variously sourced data, it will be most valuable.
- Infrastructure requires components that meet performance safety standards. This work is much needed and extremely relevant to deployment of hydrogen technologies and the development of the fueling infrastructure.
- Flow meter accuracy and hose reliability are both critical issues for developing RCS.
- This project could be very relevant and have a tremendous impact, as components are important. Based on that potential, this project is missing on all elements: scope, vision, planning, execution, results, presentation, etc.

### Question 5: Proposed future work

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

- The future work plan is good, provided teaming with appropriate institutions is embraced.
- The list of future work tasks seems to cover the areas that NREL has included in their overall plan. However, most of these areas (hose reliability, nozzle and receptacle wear/durability, flow metering) appear to be funded by sources other than SCS. The future work area really needs to emphasize the work to be done for the SCS sub-program.

- Proposed future work is not yet well-defined, as it is largely dependent on results of current efforts and DOE direction. Review of developing component standards in ISO/TC 197 is highly recommended for possible suggestions of future work.

#### Project strengths:

- This project in principle should prove to be very valuable to the community in identifying failure modes and quantifying system behavior in hydrogen service under conditions expected for operating hydrogen systems. This can only be obtained with constructive partnering (teaming) with others who are working in similar and related activities.
- The overall concept of treating standards development at the component level is very necessary as part of the entire standards development effort. The coordination with other entities and the breadth of the entire proposed component work are other strengths.
- Strengths include working with manufacturers and system installers to provide data to ensure tested and certified components are available.

#### Project weaknesses:

- Overall concrete accomplishments for the second year of a program are weak. This team needs to re-evaluate their teaming approach. This project in particular needs to establish a team/collaboration with other facilities that have expertise and background in the fundamentals of hydrogen effects in materials, particularly stress and fatigue fracture growth physics. SNL is the facility suggested.
- While the overall description of the components addressed is good, it seems like the specific technical work directly for the SCS project is narrow and only involves PRVs at this point. In addition, it seems only one PRV failure mode is being addressed.
- The biggest weakness is the limited industry engagement in this project.
- The project's purpose, scope, and approach should be reevaluated to ensure that the project team's expertise and collaborative efforts with industry are optimized to add critical value to this research area.

#### Recommendations for additions/deletions to project scope:

- A serious gap is not yet being addressed, and that is one of metering. The current NREL mass measurement device satisfies the California Division of Measurement Standards' current need to measure the mass of delivered hydrogen in a way that complies with NIST Handbook 44 (HB44), which is all very good. In the immediate future, however, the fueling infrastructure needs the ability to qualify mass flow rate meters that have the capability to satisfy HB44 under a J2601-compliant fill. Mass as a function of time needs to be measured accurately from the consumer's perspective and one must be able to integrate accurately to get the total mass delivered at any point in the fill process. A meter is needed that will deliver performance in a similar fashion to today's consumer's experience with conventional fueling stations. The consumer needs to be able to stop the fill when the quantity filled satisfies the consumer's fill constraints. There are several technology gaps that currently prevent this from occurring: (1) a fueling station mass flow rate meter that meets HB44 under a J2601 fill does not exist, (2) a mass flow rate device to qualify this meter does not exist (note: it needs to be 3 to 10 times more accurate than item [1], a "master meter"), and (3) a facility to qualify the master meter very likely does not exist (another factor of ~10 times improvement in accuracy). This is a serious gap, and attention to these gaps needs to be given.
- The project needs to find a scope. A great use of this project would be a comprehensive report on components—all components for a given part of the infrastructure. Instead of in-depth investigation of a single component (which this project is not equipped to do correctly anyway), the project should instead focus on a higher-level overview and exist as a resource that publishes periodically the status and opportunities with respect to components, perhaps choosing only components at a hydrogen forecourt or similar segment of the hydrogen delivery and use pathway.
- Component certification issues would be a welcome addition for discussion at the monthly NHFCCSCC meetings.
- The project should widen the scope on PRV work to include other types of failure modes (e.g., the valve never opens).

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

Eric Brosha; Los Alamos National Laboratory

### Brief Summary of Project:

The objectives of this project are to develop a low-cost, durable, and reliable hydrogen safety sensor for stationary and infrastructure applications that can be extended to use in vehicles; to demonstrate working technology through performance evaluation in simulated laboratory and field tests, initiate rigorous life testing, and evaluate sensor performance in relation to codes and standards; and to pursue commercialization of the new sensor technology through industry partnerships.

### Question 1: Approach to performing the work

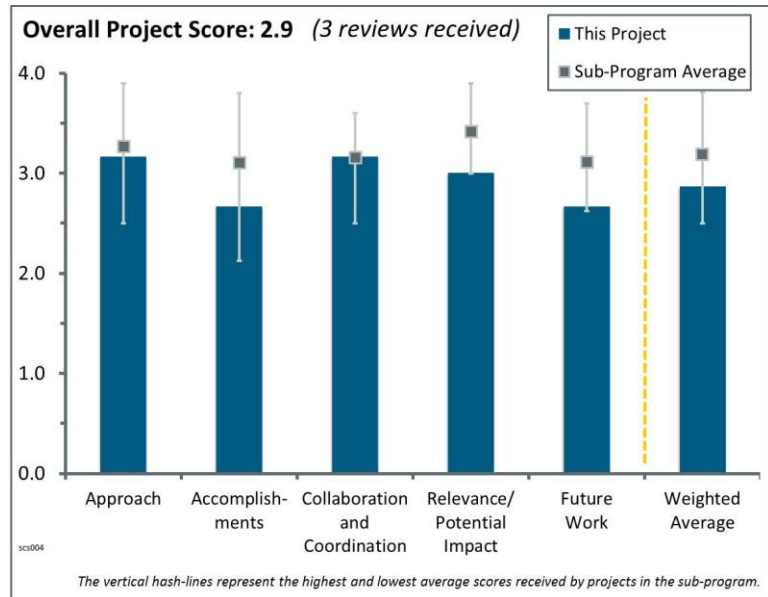
This project was rated **3.2** for its approach.

- Tailoring the already very successful automotive O<sub>2</sub> sensors for hydrogen is very good. Success should lead to a cost-effective sensor. Running the ignition study at the minimum ignition energy (MIE) (22% to 26% hydrogen) would have been better than 20%—ignition energy varies by a couple of orders of magnitude (this is really an issue in execution). The presenter agreed to address this in the future.
- The main effort is to develop a reliable hydrogen-specific sensor. Success would enable wider use of sensors in hydrogen technologies; however, there are other ways to detect leaks without detecting hydrogen.
- The technology is interesting and appears viable. Some of the approach regarding the ability to have a certified product may not be robust or valid. The true benefit seems to be low operating/maintenance cost. There is discussion of “low cost.” The sensor itself is a small cost of a total package, so whether the sensing element is \$1 or \$5 won't affect a \$500 list price item.

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

This project was rated **2.7** for its accomplishments and progress.

- This is a modestly funded program (~0.5 full-time equivalents [FTEs] at Los Alamos National Laboratory, ~0.25 FTEs at Lawrence Livermore National Laboratory). This project has been making good steady progress appropriate for the amount of funding received. Last year, the project team successfully solved some signal processing issues; this year, they have systematically moved into a testing phase utilizing the National Renewable Energy Laboratory (NREL) sensor testing laboratory with good results. They are ready to go to the field. From a safety perspective, however, it would be good to see a bit more assurance that there is no potential for ignition in an upset condition. While safeguards are in place to ensure that the heating unit does not exceed a nominal temperature, an upset could occur resulting in significant over-temperature of that unit. The principal investigator (PI) ran some experiments in hydrogen/ air mixtures up to 20%; however, the MIE point is between about 22% and 26%. Albeit the curves are fairly flat in this region, the ignition energy does vary by several orders of magnitude depending on energy deposition characteristics (in this example, spark gap). The experiment should be repeated with a mixture closer to the minimum MIE; measurement or calculation of the hot zone temperature should also be known. The auto-



ignition temperature for an MIE mixture is on the order of 773 K to 858 K. It should be ensured that the hot zone of this device never gets to these temperatures to ensure that ignition from this thermal source does not occur.

- While there has been some demonstrated improvement in sensors because of this project, there remain significant challenges. In particular, there are not yet manufacturers on board to produce sensors for the necessary applications. It is not yet clear this project will lead to commercially available, economically viable sensors.
- There is good progress for now, but the lack of involvement of a main-line sensor manufacturer is getting critical. Without that, there will be little potential for mass deployment.

### Question 3: Collaboration and coordination with other institutions

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

- This project team has proven to be very valuable to this project, advancing the development of this device at a very appropriate pace. At this stage of development, however, a commercial manufacturer of these systems should be sought. This project team understands this need and pointed it out during the presentation.
- Several partners are involved, but the project needs a name brand sensor manufacturer with the manufacturing and marketing muscle to use the product.
- Sensor testing is conducted in enclosed spaces only. The NREL sensor laboratory seems to be looking at using sensors at refueling stations (outdoors). There may be a disconnect here.

### 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.

- There is a fundamental problem with point sensors in hydrogen applications. They have proven to be largely an unreliable method of detection (not that the sensor is unreliable but that the use of point sensing technology is unreliable). Unfortunately, the safety community (NFPA, etc.) requires the use of point sensing for detection in these environments. This project is very relevant, given the community's requirement for these devices.
- Sensors are important but not critical to mass deployment. They are a small percentage of overall cost, both capital and operating. There are solutions, albeit not perfect, in the marketplace. It is not clear yet whether this effort will yield a meaningful benefit or a small incremental benefit of relatively low value.
- This project is focusing on filling the gap of good sensors around the lower flammability limit. This is a very specific target technology. Hydrogen sensors are not the only way to detect hydrogen leaks.

### Question 5: Proposed future work

This project was rated **2.7** for its proposed future work.

- The “real world” testing is good, but it is in a very benign climate. Consideration of extremes of heat, cold, and humidity would be important. The project should take place in Chicago, not Los Angeles.
- Risks are well-defined; however, some of these may not be influenced by project outcomes. It is not clear that fuel cell electric vehicle manufacturers want hydrogen sensors, even if performance is improved and costs are reduced. Perhaps this issue could be addressed at a workshop with significant original equipment manufacturer participation.
- Future work plans are right on to move this to a commercial product. In response to the safety concerns mentioned during the question and answer session, the presenter did comment that the team would investigate the ignition question, further per reviewers' comments.

**Project strengths:**

- The presented overview of project activities since 2008 was excellent, showing the progress over the years. This is a good project that includes testing to determine whether the sensor itself is an ignition source. The project took advantage of an excellent opportunity to run parallel testing to compare the sensor with an expensive commercially available alternative. Other key features include wireless communications and backward compatibility.
- This project is making good progress, given the funding levels. The makeup of the team is appropriate for the development phase of this project. The team understands the need to embrace additional commercially oriented partners to move this to the commercialization phase.
- The technology appears to have potential for improved sensors. The advantage is in the operating, not capital, expenses.

**Project weaknesses:**

- While attention was given to the safety aspects of this technology, it fell a little short of being as thorough as it should be. With that said, however, the presenter did agree to include the necessary studies in the program. No real weaknesses were noted.
- Lack of a mainline manufacturer means that: (1) final market pricing cannot be determined, so it is unclear what the overall savings are, (2) actual certifications cannot be done in a professional, knowledgeable environment, and (3) the technology will not necessarily be commercialized effectively, as it needs the appropriate marketing/sales channels.
- No analysis of sensor performance versus International Organization for Standardization (ISO) 26142: Hydrogen Detection Apparatus was shown.

**Recommendations for additions/deletions to project scope:**

- Analysis of sensor performance for use in refueling stations in accordance with ISO 26142: Hydrogen Detection Apparatus would be useful information to provide to the standard committee for this ISO Standard for potential revision or to find additional uses for the sensor technology beyond those described in the project report. Analysis of potential benefits of hydrogen detectors in fuel cell electric vehicles would be interesting. It is not certain that this project is important to the target market today.
- The project should get a mainline manufacturer onboard with a business plan as soon as possible. Cost savings should be defined in operation/maintenance for an overall life cycle cost.

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

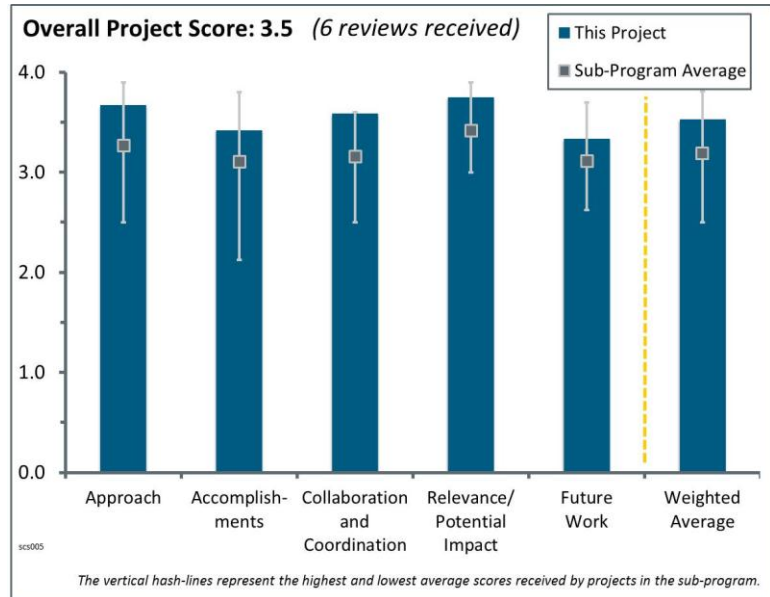
Chris San Marchi; Sandia National Laboratories

### Brief Summary of Project:

The objective of this project is to enable technology deployment by providing science-based resources for standards and for hydrogen component development. This project will also participate directly in formulating standards for use in development and testing of materials and materials compatibilities in hydrogen systems. The standards database will be expanded through materials testing targeted at data gaps in the existing body of research.

### Question 1: Approach to performing the work

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



- The approach is fully correct and consists of identifying gaps in knowledge, establishing and validating representative test methods and methodologies, performing targeted testing and ensuring adequate knowledge transfer to Standards Development Organizations (SDOs) and Code Development Organizations (CDOs). Exchange of views and cooperation with non-United States (US) advanced materials testing experts (in addition to the Japanese institutions mentioned, and in particular within the European Union) should be further explored to increase efficiency of the work and disseminate its outcome. (Note that the recently extended EU-US Scientific and Technical Agreement can provide a frame for such a collaboration.)
- The overall approach to addressing targeted data gaps is addressed through comprehensive CDOs and SDOs evaluation. Working with the relevant SDO/CDO, gaps are being identified, and data are being generated to revise various materials and component standards that comprehensively cover high-pressure system safety.
- The idea of generating a database is nice, but what is really needed is for the information to be in Section II of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code and to be in Section 12 of the ASME B31 piping code. The avenue for both might be the ASME B31 T committee. This ASME venue will hopefully be the final repository.
- The project is a good exploration of automatic versus hand-welded specimen testing.

### 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.

- Several accomplishments for the year are listed and easily identifiable on the publications and presentations page and elsewhere in the slides. Concrete progress in informing/developing standards is presented. Populating the materials properties database will make safety data information more easily available and accessible.
- The literature search on plastics is very nice; sharing the information with the ASME B31-12 and the ASME National Modeling and Simulation Coalition (NMSC) would be better. This ASME venue is, one hopes, to be the final repository.



- Compared with the future work identified in the 2013 DOE Hydrogen and Fuel Cells Program Annual Merit Review (AMR) slides, relatively little progress seems to have been made in the execution of mechanical tests. This impression is strengthened by the facts that: (1) no information is provided on a number of activities identified as proposed further work in the 2013 AMR, and (2) the fiscal year (FY) 2013 funding is double that expected in 2012 (\$0.8 million versus \$0.4 million). The addition of the composites chapter to the technical report is commended.

### Question 3: Collaboration and coordination with other institutions

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

- SDO/CDO representation is excellent. Industry partners and international research institutions appear to be excellent collaborations as well. This reviewer has no knowledge of who the big players are in this area, though. It is assumed that they are adequately represented because of the codes and standards (C&S) that are being developed through evaluation of relevant materials supplied by vendors.
- There is great highlighting of international and partnership work sharing and milestones.
- Collaboration with relevant institutions and organizations within the US is purpose-oriented and sufficient. Reaching out to specialized non-US testing houses is recommended to increase density of experimental data and to include materials extensively used for hydrogen applications in other parts of the world. Including international standardization bodies is also recommended.
- Additional outreach is necessary at ASME. In many large organizations, the left hand and the right hand do not communicate. Oftentimes, multiple approaches need to be tried to get to the parties that would welcome the data.
- The project should maintain relationships with the international community and SDOs. This can also be a source of material and information, as mentioned in the “Critical Assumptions and Issues” slide.

### 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.

- As presented, materials and components compatibility data and test methods have impacts on multiple standards relating to high-pressure system safety, which is the paramount issue with fuel cell fuel storage and delivery systems.
- This activity is highly relevant and has the potential to make a major impact in the development and acceptance of hydrogen-related C&S.
- The project effectively addresses a knowledge gap.

### Question 5: Proposed future work

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

- Proposed future work continues similarly to develop and evaluate test methods to evaluate component performance. Proposed procurement of variable-temperature testing equipment to test at low temperatures should be continued.
- The proposed future work follows logically from the achievements to date.
- The data being produced are really good, but engineers who can use this data need to be educated, or some recommendations on how to apply this data to real-world systems would be a good idea.
- The proposed work is interesting but could be considered incomplete. Sandia National Laboratories seems to have forgotten the end goal: the support of the American National Standards Institute (ANSI) standards.

**Project strengths:**

- Strengths include value for industry, potential cost reduction by use of lower cost steels (such as 304L, etc.). There is applicability to welded pipe fittings in hydrogen stations; results suggest that automated welding is preferred because of fusion zone consistency compared to results of manual welding.
- The project appears to be addressing gaps in test procedures and material property data that are relevant and concurrent with industry progress.
- The work has a direct impact on current and near-term decisions and standards in development.
- There is a direct link to SDOs and CDOs.
- The research is a strength.

**Project weaknesses:**

- The project targets implementation aspects in C&S used for the assessment of material behavior in a hydrogen environment. It does not address the adequacy/relevance of these standards and codes in terms of being representative of actual service conditions of these materials (temperature range, loading conditions, and presence of residual stresses).
- There are limited resources. Also, the project needs to develop further international relationships.
- A weakness is the lack of distribution of lessons learned information to station builders/design engineers.
- There is a lack of understanding as to who the end customers are.

**Recommendations for additions/deletions to project scope:**

- The project should add materials modelling to establish validated material behavior laws in terms of static and cyclic performance and fracture under hydrogen and relevant loading conditions to: (1) enable fast screening of materials and (2) provide input to identify testing requirements to be included in codes and standards to better cover actual service conditions. The project should work with the ASME B31.12, ASME B31 T, and ASME NMSC committees to get the information into a venue where it will be used.
- The project should conduct notched-specimen testing of welded tube–tube samples.

## Project # SCS-007: Hydrogen Fuel Quality

Tommy Rockward; Los Alamos National Laboratory

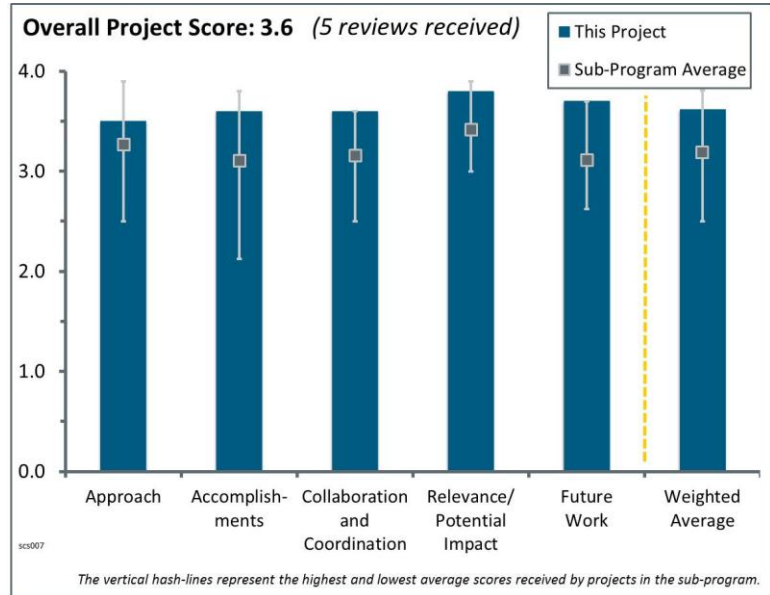
### Brief Summary of Project:

The objectives of this project are to carry out the duties of the ASTM sub-committee chair for D03.14 gaseous hydrogen fuel efforts; to investigate the impacts of contaminants at the levels indicated in the Society of Automotive Engineers (SAE) J2719 and International Organization for Standardization/ Technical Committee (ISO/TC) 197 Working Group (WG) 12 documents using 2015 U.S. Department of Energy (DOE) loadings; to collaborate with international partners to harmonize testing protocols; and to develop an electrochemical analyzer to detect low levels of impurities in hydrogen fuel.

### Question 1: Approach to performing the work

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

- The continuous in-line fuel quality monitor to alert to fuel grade onboard, in-stream, and in the nozzle is important for commercialization of fuel cycle electric vehicles. This technology would allow users to have confidence in hydrogen fuel quality at the pump. The research is well-thought-out, yet flexible enough to increase focus as results begin to appear or industry needs change.
- The inter-laboratory round robin of the ASTM test methods in SAE J2719 is the final step to completion. Activity on one of these methods is a good start. The in-line impurity detection device may be a useful exercise. It is of concern that the end users will not maintain (or even purchase) such devices, based on their track record with security camera systems. The cocktail work is interesting.
- The project is well-focused on evaluation of hydrogen fuel quality to ensure fuel cell life. Participation with international partners (Japan Automobile Research Institute (JARI), the European Union [EU]) and ASTM, SAE, and ISO will assist with international harmonization of fuel quality standards.
- The inclusion of an activity on harmonizing testing protocols with international partners (JARI, EU) is necessary and highly welcomed. The approach used for experimental activities is solid and correct.
- The description offered by the presenter is one of project overall task identification rather than a technical or philosophical approach. The list of projects is very appropriate and advances the topical area of fuel quality from the perspectives of standardization (ASTM) and fuel quality assurance (in-line fuel quality). This is done in conjunction with international collaboration (JARI and the EU). The category score was somewhat reduced because there was really no discussion on approach. Some discussion on approach was provided throughout the presentation—but fell short of providing the needed technical or philosophical information.



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## 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.

- Milestones have been completed in several areas covered by multiple standards limiting contaminants, and the project has begun development of an in-line fuel quality analyzer. Work is finely targeted to fuel quality effects and assessment.
- The presentation addressed previous reviewer comments very effectively. Experimental data are relevant to developing regulations, codes, and standards.
- Considering the cost of a full-time equivalent (FTE) plus direct costs, this project is funded at the level of about one experimental FTE. The quantity and volume of work is good for this level of funding. Nice progress has been made in overall detectability. Significant progress has been made in overall sample characteristic timing from five hours to one hour. When asked what the final response time target is, the presenter answered that the target fill time is four minutes; therefore, the response time target is four minutes. While this is an appropriate target, this answer glossed over reality. A response time of four minutes from an hour demonstrates that this technology has a long way to go. The project team successfully reduced the time by a factor of five (five hours to one hour); however, this technology needs another factor of 15 (60 minutes to four minutes). At the current response time, this maps to about 15 fills before detection is achieved. The continued work on contaminant effects on membrane electrode assemblies (MEAs) continues to be very good. The contributions to ASTM are excellent and very much needed.
- The inter-laboratory round robin of the ASTM test methods in SAE J2719 is the final step to completion. Activity on one of these methods is a good start. The reviewer does not know the status of the other 12 ASTM test methods.
- The project addresses a number of critical issues and is structured accordingly. Whereas progress has been clearly demonstrated for the development and performance characterization of the in-line analyzer and for impurity testing at low platinum group metal loadings, it is difficult to assess the progress over the last year for the standardization work, in particular that related to the follow-up of the ISO TC 197 WG 12 activities.

## Question 3: Collaboration and coordination with other institutions

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

- The international collaboration with JARI and the EU is very appropriate and good for this work. Listed collaborations with code development organizations (CDOs) and standards development organizations (SDOs) are not all-encompassing but sufficiently broad with appropriate industrial breadth to ensure this project remains focused on hydrogen fueling infrastructure needs. The focus on hydrogen fueling infrastructure needs is appropriate since SAE and ISO have both published hydrogen fuel quality standards that are driven by fuel cell needs, to which this team contributed significantly. Attendance on the National Hydrogen and Fuel Cell Codes and Standards Coordinating Committee (NHFCCSCC) call may not qualify as collaboration.
- Collaboration with United States (US) entities is purpose-oriented and effective and includes the relevant players. Efforts targeted at harmonization of test methodologies at the international level are highly welcomed. (Collaboration with EU institutes on this topic could be framed under the recently extended EU–US Scientific and Technical Agreement.)
- Collaboration with international organizations, including JARI and the EU, is very good. This project could benefit from more regular updates (at least quarterly) with the NHFCCSCC.
- Partners are hydrogen fuel and fuel cell suppliers, international SDOs. Partnerships appear well-coordinated, with full participants.
- Collaborations are appropriate.

#### 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 is doing excellent work to determine analytically valid approaches to recover electrode performance following exposure to hydrogen. The project effectively incorporated DOE lower targets for platinum loading into the investigation quickly. In-line monitoring success will facilitate fuel quality and confidence.
- The implementation of hydrogen technologies needed to establish the hydrogen fueling infrastructure requires the technologies being developed in this project. Active participation in ASTM helps keep this activity well-focused and keeps the testing techniques established by ASTM aligned with the needs of the industry. While the code community is debating the question of “how to guarantee that the fuel quality as established by SAE J2719 is delivered to the vehicle,” the development of an in-line detector is very relevant to answering the question and providing a possible technology to satisfy this need.
- This effort is critically needed for enabling deployment of fuel cells in transportation.
- Hydrogen quality and international harmonization of hydrogen quality assessment tools are necessary to deployment of fuel cell technology.
- The round robin and the cocktail work are highly relevant and have the potential to be high-impact. The sensor work may have acceptance issues with station operators.

#### Question 5: Proposed future work

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

- Future work is well-thought-out and includes significant collaboration. It is good to see plans for international round robin testing and to see consideration given to testing to SAE standards. It is excellent to see the project begin incorporating recirculation effects.
- The proposed future work and direction are good. Some thought should be given to the sample technique for the in-line detector to make sure the overall system response time is appropriate for a four-minute fill. It is important to consider this system notion rather than just the detector itself. This system design needs to, of course, consider detector temperature and pressure of operation as compared to the fill protocol as specified by J2601.
- Proposed future work is a continuation of improving test methods and hardware, improving standards, and expanding international collaboration. The proposed work is needed to harmonize standards and provide technical data and evaluation tools.
- It is recommended that the project include, from the outset, international partners in the efforts (workshop and subsequent experimental activities) on hydrogen storage system cleanliness. Interaction with JARI and the EU should be strengthened, including the identification of commonly agreed loading cycles (stressors) representative for automotive applications, in addition to the harmonized test protocols which should be expanded from MEA to stack level.
- The proposed future work makes sense.

#### Project strengths:

- The fundamental notion presented by this technology could prove to be very valuable to hydrogen fueling infrastructure to guarantee fuel quality meets the desired specification for each fill. The current state of this technology is appropriate and showing promise.
- Strengths include technical data development and strong international collaborations.
- The project addresses many issues that are critical path to a hydrogen infrastructure.
- Every year this project reports progress in evaluation of fuel quality and the effects of contaminants.
- The project has a clear focus.

**Project weaknesses:**

- Attention needs to be given to the sample system when assessing the response time and the quantity of hydrogen needed to sample for detection.
- The lack of reference and apparent support of SAE J2719, which is the fuel standard for the US, is not understood. ISO documents are not adopted in the US as state regulation.
- This project could benefit from more regular national outreach/feedback opportunities.

**Recommendations for additions/deletions to project scope:**

- The project should increase the pace and scope of the round robins to quickly validate the ASTM test methods. The team should consider applying the impurity sensor in a manner suitable for the state regulators to do spot testing at stations during the metrology/inspection visits.
- SAE J2799 compliance testing might be a good future addition.
- The project might extend international harmonization of test methods to include commonly agreed representative automotive loading cycles. The team should extend testing from MEA to stack level.

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

Katrina Groth; Sandia National Laboratories

### Brief Summary of Project:

This project provides a science and engineering basis for assessing safety (risk) of hydrogen systems and facilitates the use of that information for revising regulations, codes, and standards (RCS) and permitting stations. The project goals are to develop and validate hydrogen behavior physics models to address targeted gaps in knowledge, to build tools to enable industry-led codes and standards revisions and safety analyses, and to develop hydrogen-specific quantitative risk assessment tools and methods to support RCS decisions and to enable a performance-based design (PBD) code-compliance option.

### Question 1: Approach to performing the work

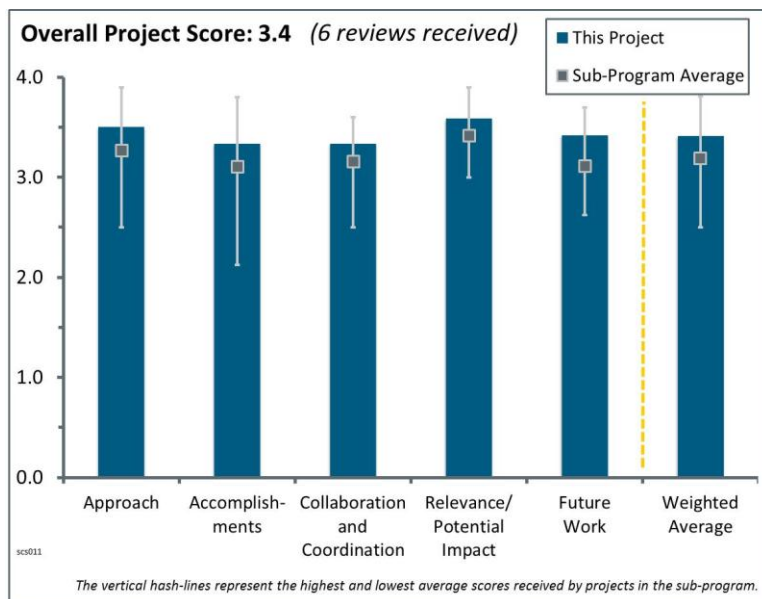
This project was rated **3.5** for its approach.

- The chosen approach has struck a fine balance between theory and practice. The approach has a strong focus on quantitative risk assessment (QRA) and impact on RCS through participation in National Fire Prevention Association Standard 2 (NFPA2) and the International Energy Agency's Task 31, etc.
- Use of coordinated activities in applying research and development (R&D) in RCS, QRA methods and tools R&D, and hydrogen behavior R&D increases relevance and usefulness of project output.
- Based on input/questions at the merit review, there appears to be room to expand literature research and verify whether previous research has covered some of the topics under investigation in this project/program.
- It is unclear how benchmarking from Sandia National Laboratories (SNL) leads to an 18% increase in station readiness. It is not certain that there are code officials who agree with this number, nor is it clear how the QRA information is currently being used/applied to safety, codes and standards (SCS).
- The project draws on efforts and deliverables from a number of sub-projects that were presented individually in previous AMRs. In that respect, it is not straightforward to judge on this question. However, for the main activity of the project, namely the development of Hydrogen Risk Assessment Model (HyRAM), the approach is scientifically sound. It is unclear how the information provided on slide 5 (metric) relates to the overall project. This seems a standalone activity aimed at providing a post-hoc justification of the work for HyRAM. Such a justification is not needed.

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

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

- The project has the following accomplishments: (1) demonstrating performance-based design in NFPA 2, (2) helping socialize the PBD approach with industry and authorities having jurisdiction (AHJs)—which is excellent work, and (3) developing a curved flame model that better represents physics and shows lower heat flux as the flame curves up, allowing for reduced separation distances. The project addressed past reviewer comments very well.



- Metric benchmark development is good accomplishment, but based on “hydrogen-targeted California sites,” a 0% to 18% improvement sounds like giving too much credit to this effort alone when applied to reality. It is not clear which “sites” are targeted (because it depends on context of station owners’ willingness, site selection process, AHJ requirements and use of codes and standards in jurisdictions, additional requirements, etc.). Regarding the curved flame model, the maximum height at which this model is applicable is not stated. Ground-level release downstream heat flux may exponentially change at higher heights, owing to atmospheric influences not accounted for (wind, etc.), so this information may be helpful in adding to model presentation and interactions with AHJs/design engineers. Other accomplishments are good progress!
- The project is well-directed to apply QRA to PBD, but it is not clear how the developed QRA tools are being verified and validated, nor how they compare with other QRA tools used by industry—not necessarily for hydrogen but for oil and gas as an example. One should bear in mind that operators do not typically approach universities/research laboratories; they turn to some established consultancy organizations such as the DNV GL Group in Europe and Bakers Engineering in the United States. Hence it is not clear how all these can feed to the evolving hydrogen industry, how the knowledge and tools will be transferred to industry, and how industry can be convinced to use these tools. The R&D work on curved flame model is based on solid fundamental research and should lead to simplified correlations that can be used in QRA. The presentation provides insufficient details about the maturity of the overpressure model; essentially, this is a collection of previously developed simplified models by SNL and others. Care should be taken about the range of the validity of each model and its integration/selection in an overall QRA. It is also of concern that hydrogen ignition probability is derived from industry data on hydrocarbons. Research and accident databases have shown that the probability of hydrogen ignition is much higher than with hydrocarbons – this is also consistent with the fundamental combustion-related properties of hydrogen.
- The information provided in the slides and during the AMR presentation demonstrates that progress has been made for HyRAM, as well as in some aspects of behavior and consequence modeling. For the latter, however, it is difficult to identify the amount of progress that has been realized in the last year. (The last slide in the set reserved for the reviewers only identifies one milestone in fiscal year [FY] 2013; all others are in the future.)

### Question 3: Collaboration and coordination with other institutions

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

- The project has excellent international collaboration. Commendable work is being done with AHJs and the international community. It is good to see collaboration with H2USA. There is direct input into developing RCS.
- Effective collaboration exists with some limited industrial organizations. The data exchanges with Air Products, Linde, and SRI are encouraging and beneficial to the project aims. Collaboration with HySafe should benefit activities in this area on both sides of the Atlantic and eventually avoid duplication of efforts. Obviously, there are additional benefits in publicity and knowledge sharing. Collaboration with more operators of refuel stations in addition to Linde and car manufacturers should be pursued in the future. It is not clear what value the collaboration with Tsinghua University is adding to the project. There is no doubt that the institution is top-class, but the quoted academic does not appear to have a track record in the subject and is relatively unknown to the community in terms of jet and jet fire research.
- Collaboration with U.S. entities seems to be purpose-oriented and effective. The scope, intensity, and impact of collaboration with non-U.S. partners cannot be judged on the basis of the information provided.
- The project should consider collaborating with the Energy research Centre of the Netherlands (ECN) and German counterparts in addition to HySafe.
- Two private companies (Linde and one other) have provided feedback, but their participation and interaction was not highlighted significantly enough to warrant a higher score.



#### 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 critical to modifying relevant documents to allow reasonable requirements while maintaining safe hydrogen filling stations.
- Once validated and proven easily accessible, the HyRAM toolkit will be a major enabler for a risk-informed PBD for a number of hydrogen applications. As such, it clearly directly contributes to the DOE program goals.
- The potential impact is excellent overall, but critical uncertainties remain, as described in the presentation.
- There is scope for improvement. However, it will have positive impact on the DOE R&D goals and objectives in the hydrogen and fuel cell area.

#### Question 5: Proposed future work

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

- The proposed future work is relevant to DOE R&D goals and objectives in the hydrogen and fuel cell area and in line with the original objectives of DOE funding for SNL. The plan for FY 2014 is basically a continuation of the work reported here. The proposed development for liquid/cryogenic hydrogen experimental capability should be of particular relevance to the immediate needs of the industry and contribute towards filling some knowledge gaps in the area.
- The proposed future work follows logically from the past and ongoing activities. Although external financial support for future work is obviously useful, this should not be a *conditio sine qua non* (should not be indispensable).
- Proposed future work is consistent with DOE Hydrogen and Fuel Cell Program goals, industry needs, and needs of developing RCS.
- The project should continue working with industry partners to address the heavy near-term needs.
- There are more critical uncertainties than there is DOE funding.
- Planning/mapping activities/goals could be better defined in the presentation.

#### Project strengths:

- Addressing challenges with siting hydrogen stations at gas stations is an immediate need. It is good that the project highlights that PBD can be an alternative.
- Project strengths include facilitating use of the safety data and information, and demonstrating evidence of supporting market growth (a number of sites that can readily accept hydrogen).
- The work absolutely has the potential to affect code in a positive way (reducing quantity-distance restrictions, thus making fueling stations fit better in current footprints). The largest hurdle is going to be getting code officials to understand this QRA approach and to adopt it. The current project does not have a planned goal for this, however.
- The project has excellent industry partners and is working on key areas.
- The project has a solid science-based approach towards the establishment of a powerful tool for facilitating (1) improvement of RCS and (2) PBD. This avoids subjectivity in the assessment and contributes to enhanced confidence of AHJs in the application of this approach, which will in turn promote deployment of hydrogen systems.
- The project has very good relevance to RCS development. There is a strong focus on QRA and PBD. The work is well-publicized and -disseminated.

#### Project weaknesses:

- There is a lack of resources for diverse objectives and a multitude of gaps that require future work.

- Critical uncertainties remain, but the project is filling gaps as well as possible, utilizing partners and proposing future work.
- It is not clear whether the claimed accomplishment about having a toolkit is finalized. The project hosted a meeting, received input, and updated the model, but it is not clear who can currently access the toolkit and use it for their application. This was ostensibly part of the goal.
- H2First is currently not making fast progress, which may hinder project progress/value overall, with many stations being funded for construction in the coming two years.
- It is not clear how validation and verification of the models is handled. Collaboration with more operators of refueling stations in addition to Linde and car manufacturers should be pursued in the future. There is no clear plan for how the models/QRA tools developed will be exploited by the end-user community.

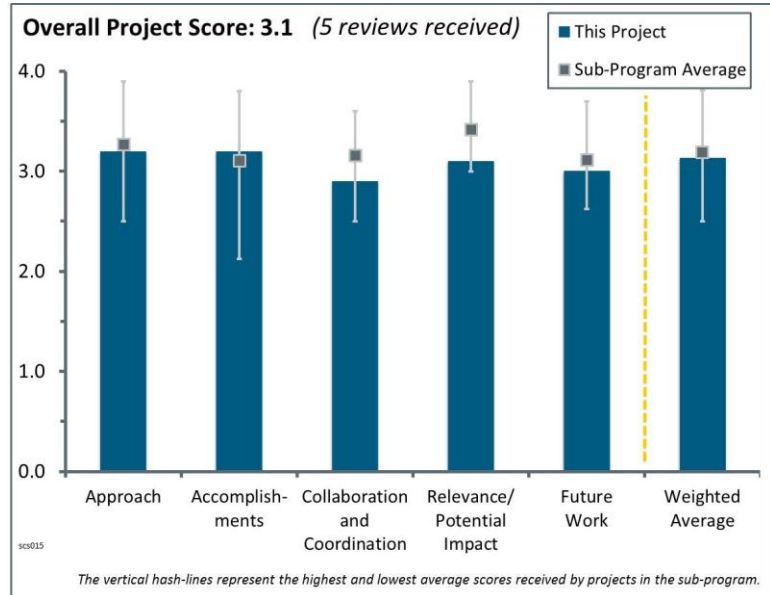
**Recommendations for additions/deletions to project scope:**

- The project should: (1) consider what underground liquid hydrogen storage can do to mitigate separation distances, (2) expand collaborations (ECN and Germany), and (3) explain this project's future potential by defining the maximum percentage of targeted gasoline stations that could be available to house/host a hydrogen station, based on findings and codes and standards limitations.
- The project should clearly identify future participants (who the AHJs that are going to use this toolkit are) and the timeline to complete the teaching and hand over the toolkit. Targets need to be better clarified/defined with clear metrics. The project should clarify who is working on approving the alternative compliance (PBD) from a codes perspective and how this is being planned/mapped.
- This may not actually constitute an addition to the project scope, but from the information provided, an explanation is lacking on how data from (validated) behavioral and consequence modeling are actually transferred to the QRA module, realizing that the model outcomes are affected by assumptions for initial and boundary conditions that may quite well differ from those in the actual case considered.
- The liquid hydrogen work should be explicitly included in the plan for out-years.

## Project # SCS-015: Hydrogen Emergency Response Training for First Responders Monte Elmore; Pacific Northwest National Laboratory

### Brief Summary of Project:

The long-term goal of this project is to support the successful implementation of hydrogen and fuel cell technologies by providing technically accurate hydrogen safety and emergency response (ER) information to first responders. Objectives for fiscal year 2014 include: (1) developing and implementing a national hydrogen ER training resource with downloadable training materials that are adaptable to the specific needs of first responders and training organizations, and (2) exploring mutually beneficial collaborations with other programs and organizations to enhance first responder training content, techniques, and delivery.



### Question 1: Approach to performing the work

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

- The online and in-person approach is balanced and useful.
- The approach for a national template is good.
- The project is getting “old,” with little new to report. It might be time to look for ways to end the project and/or transition resources to a new project that can look for fresh ground to cover.

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

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

- The project has made great progress and is headed in the right direction.
- The training events are encouraging. However, no training appears to have been done in 16 months. It would have been better to see more training events and refresher training.
- Overall progress since 2004 is good, but progress in the last couple years has stalled. There are notable successes in terms of a few training classes provided, but this is anecdotal and sparse at only two per year. It is not certain that the effort is worthwhile. A good indication would be from: (1) feedback from class participants, and (2) the ability to charge for the service. Then it will have demonstrated value.

### Question 3: Collaboration and coordination with other institutions

This project was rated **2.9** for its collaboration and coordination.

- The team seems well-connected to relevant stakeholders.
- There are documents within standards development organizations (SDOs) being created for first responders. It was not mentioned in the presentation, but if needed, aligning these is recommended.
- There does not seem to be collaboration in the setting up of the training materials for ER—at least, it is not apparent from the information provided. The presentation and presenter indicate collaborations, but the identified partners are recipients of the ER training rather than collaborators. It is unclear to what degree

feedback from the training recipients or from the partner organizations organizing the training is included in revising/updating training materials. The opening up to the European Union through the interaction with HyResponse is welcome.

- The collaboration and outreach do not appear to be reaching the target organizations. Several things are not clear: (1) what, if anything, is being done to reach out to the local fire departments and police departments; (2) whether the project team is working through the trade organizations; and (3) whether the project team is working with and through the state public safety departments.
- Collaboration is shown with “name brands,” but it is not clear that these organizations can really move this forward. A collaboration with a future owner of this material 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 **3.1** for its relevance/potential impact.

- This work will be relevant for the next decade.
- The project definitely contributes to enabling further deployment of hydrogen technologies.
- This activity is highly relevant to a hydrogen infrastructure.
- This does not add critical value to the DOE goals of establishing a hydrogen infrastructure. If this program went away, few would notice, and the need would be met elsewhere.

#### **Question 5: Proposed future work**

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

- Apart from finalizing the national program, the proposed further work seems to be targeted at increasing the number of recipients of the ER training. The project should actively exploit the experiences collected in the “lessons learned” included in <http://h2tools.org/lessons/> for inclusion in the ER training materials. Vice versa, the project should check on a continuous basis any exposure of emergency responders to a hydrogen-related event and collect/evaluate their experiences for updating the training materials and for inclusion in the H2tools hydrogen-lessons-learned (H2LL).
- The future work does not appear to be creative in getting people interested in training, nor does it appear to have a sense of urgency.
- There need to be more specific goals for future work. As-is, the project will not add much on-going value.

#### **Project strengths:**

- A very thorough program was created with an appropriate approach.
- The project addresses a demonstrated need.
- The material is useful and helped fill a void, but it needs to transition to a long-term home.

#### **Project weaknesses:**

- It seems that the project could use more outreach for participants. The reviewer hopes the increased funding will contribute to increased awareness and participation.
- If H2USA is intended as the link to industry feedback, then the project leads should have a more consistent message that demonstrates this link.
- Weaknesses include a lack of funding, the need to make training materials more accessible and coveted for stakeholders, and the lack of a more proactive approach and stakeholder engagement strategy.
- This cannot be the long-term forum to provide this information. An “owner” or “sponsor” should be found who is willing to take over this information and present in the future.

**Recommendations for additions/deletions to project scope:**

- The project should make two additions: two-directional interaction with H2LL from H2tools and interactive virtual reality tools.
- The project needs more creative outreach, more training with the goal of increasing the number of students each quarter, and refresher training.
- The project should ensure training material aligns with new SDO documents and modify the material appropriately.
- The project should find an organization willing to own this going forward and/or start charging for the service to make this cost-neutral.

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

Salvador Aceves; Lawrence Livermore National Laboratory

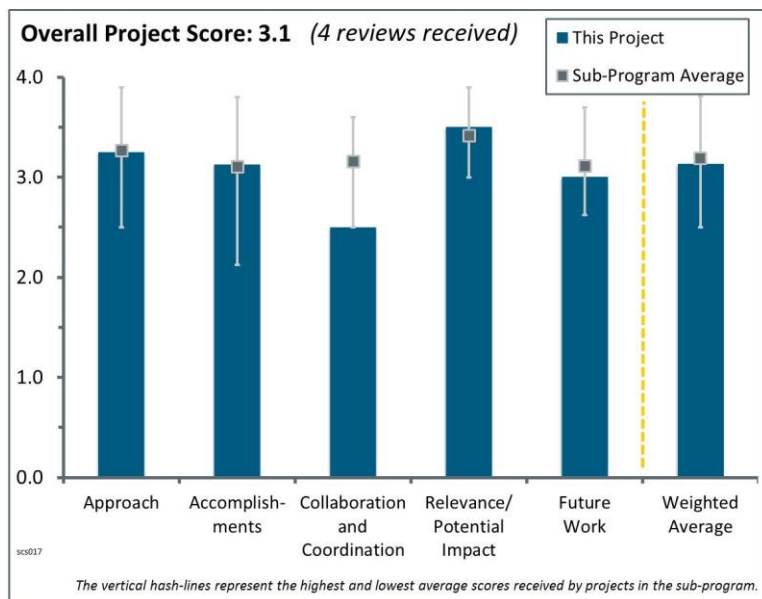
### Brief Summary of Project:

The overall objective of this project is to develop a hydrogen safety training program and instructional materials for laboratory researchers and technical personnel. During 2013/2014, the goal 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 **3.3** for its approach.

- Hands-on training in hydrogen safety is of tremendous practical use, and having such a course is a definite need for the Fuel Cell Technologies Office (FCTO). As part of this, handling of hydrogen at high pressure is extremely important. This course, however, seems to be more pressure-based than hydrogen-based. This is not altogether a bad thing, as non-hydrogen compressed gases are often utilized in the same process as is hydrogen gas, and learning how to handle them is important. However, it seems that it is too large a part of this training program.
- The project is certainly a good use of available resources in Lawrence Livermore National Laboratory (LLNL) expertise. The class length is long. It is nice that there is a website for referral.



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

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

- The attendance/participation is consistent. The use of hands-on training aids is very good.
- Again, the development of the hands-on training instruction seems too generic. While learning handling of high-pressure gases in general is useful and should not be eliminated, there needs to be some focus on hydrogen and how it differs physically and chemically from other gases, and what special care is necessary. One hopes this will be remedied during review by the Hydrogen Safety Panel (HSP). While the presenter's statement—that the all-inclusive nature of the class (covering all compressed gases) is needed because no one else is doing it—may be accurate, focus should not be lost.

### Question 3: Collaboration and coordination with other institutions

This project was rated **2.5** for its collaboration and coordination.

- The HSP review of the classroom work was a good approach, and appears that it will continue for the new current training. It is not clear how review by "laboratory safety personnel" will provide assistance to a potential industrial hands-on training class, nor whether this refers to LLNL safety personnel or a wider group.
- The reviewer agrees with comments during the presentation about getting this out to a larger audience—universities, other laboratories, etc.
- As noted over at least two DOE Hydrogen and Fuel Cells Program Annual Merit Reviews (AMRs), coordination with other entities doing similar work would be greatly beneficial.

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**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 **3.5** for its relevance/potential impact.

- Relevance to the success of the overall FCTO is large in that the training promotes hydrogen safety and reduces the possibility of a catastrophic high-pressure hydrogen event; such an event would be tragic in itself, and could also derail the DOE Hydrogen and Fuel Cells Program. It is important that focus remains.
- Safety is always important but seems especially so with hydrogen, given its imminent commercialization and use by the general public.

**Question 5: Proposed future work**

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

- The project should focus on finishing the hands-on safety class! The web-based class should need only minor updates, if any. This type of program is needed, but progress is slow. The project team should check with industry/universities to see whether there is a demand for such training, as the number of people being trained is trending lower.
- Development of the promotional materials is certainly a valuable addition—the project could even consider the social media route!
- It looks like a sound path forward.

**Project strengths:**

- LLNL has extensive expertise in high- and very-high-pressure work with gases. The web-based class was quite good and appears to have been well-received.
- This project is important for safety in the industry. The approach—having the web-based and hands-on safety class—is nice.
- It seems there is a need for this type of training.

**Project weaknesses:**

- The project should get a project vision and find out how to transition out of the laboratory. This valuable work is “hidden behind a fence.”
- LLNL is a good organization for developing this training but not for disseminating it.
- There is some concern about the degree of focus on hydrogen gas and hydrogen systems. While the more generic high-pressure material is important as well, it should not overwhelm the effort.
- The progress seems slow for over four years of work, and outreach is insufficient.

**Recommendations for additions/deletions to project scope:**

- The project team should certainly consider the suggestions from AMR attendees of performing a “train-the-trainer” and passing it off. The project should get this onto the web portal with the HSP and the emergency response material as a resource.
- An exit strategy and long-term vision to provide to the industry are needed.
- The project should either be funded adequately to complete the objectives or allowed to unwind if there is no industry need for training.
- The project should include teachings on how hydrogen is different. Sanity checks on the course curriculum should be kept going by including periodic reviews by either the HSP or other experts.

## Project # SCS-019: Hydrogen Safety Panel and Hydrogen Safety Knowledge Tools

Nick Barilo; Pacific Northwest National Laboratory

### Brief Summary of Project:

This project provides expertise and assists in identifying safety-related technical data gaps, best practices, and lessons learned through a hydrogen safety panel. The panel also helps integrate safety planning into U.S. Department of Energy (DOE)-funded projects. Safety knowledge tools are a collection of information and lessons learned from hydrogen incidents and near misses, with a goal of preventing similar safety events from occurring in the future. The tools also capture a vast and growing knowledge base of hydrogen experience and make it publicly available to the hydrogen community and stakeholders.

### Question 1: Approach to performing the work

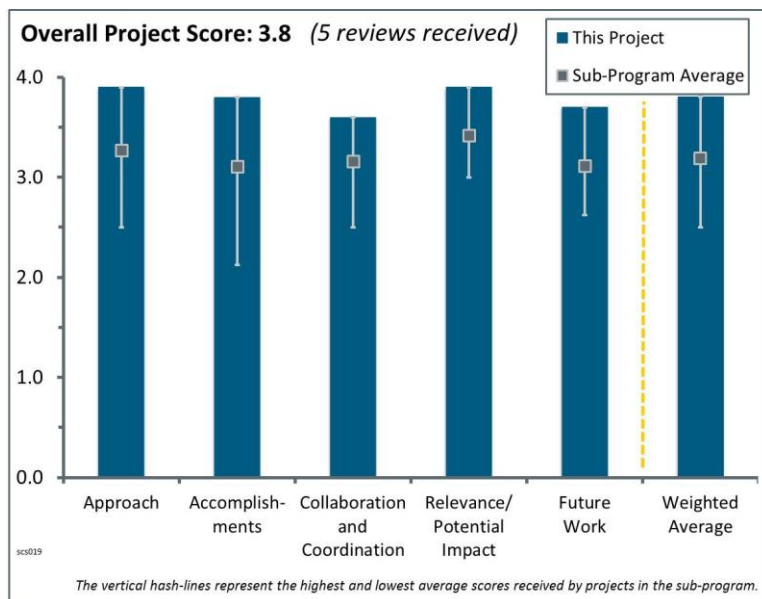
This project was rated **3.9** for its approach.

- The Hydrogen Safety Panel (HSP) part of this project is spot on and receives a score of 4.0. The motivation and work of the panel is to ensure that DOE-funded programs adhere to a high degree of safety, identify gaps, and report to DOE. Changing the approach to reviewing early in the project life will yield much more powerful results, making sure that the project operates with the highest degree of safety for as much of the project duration as possible. The knowledge tools part of this project is also very good and receives a 3.5. A one-stop shop that is portable-device-enabled in today's mobile environment will make the work of DOE and others in regulations, codes, and standards (RCS) readily available in a convenient format. Moving this tool to a portal makes this no longer just available to Apple devices (iPhone, iPad, etc.) but enables the use of all devices (Android, etc.). This is perfect. This activity needs to embrace collaboration with others who are working in similar areas (the Fuel Cell & Hydrogen Energy Association, the National Renewable Energy Laboratory, etc.) to strengthen the product and remove duplication of effort.
- The project does an excellent job working with DOE and developing strategy to have the needed tools in place for next stage of commercialization. The interaction on real projects is the key to success.
- Expanding use of the expertise on the panel from last year is not only good utilization of a valuable resource but also shows growth and flexibility as hydrogen and fuel cells are commercializing.
- The size and diversity of the HSP are a positive. Safety does have to be treated as a continuous process. The reviews and incidents and best practice databases are complementary functions in disseminating safety information and getting current information out to new projects before a problem exists.

### 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 HSP portion of the project receives a 4.0. Over and above the required safety reviews, some of these activities are exactly the type in which the HSP should be engaged, e.g., reaching out to other projects, such as the trip to Flint Michigan to visit a fueling station and repair garage. This activity helps to extend the panel's impact and at the same time brings back to the HSP experiences of those who are deploying the hydrogen technologies in the early stages of the infrastructure rollout. Branding the HSP is a great idea and





should help a great deal to improve the visibility of this resource. The HSP has responded well to previous reviewers' comments for outreach. The tools portion also receives a 4.0. It is a minimally funded project (~0.3 full-time equivalents [FTEs]), but even so, its accomplishments are good. The creation of the one-stop shop mobile device tool via a portal will help the community access this information in a more convenient manner, and it is already showing this success through the number of hits received to date. In addition, this project motivated the first live webinar presented at the Fifth International Conference on Hydrogen Safety (ICHS5) meeting in Brussels—which proved to have the largest attendance of all webinars held by DOE to date. This activity has done its due diligence to answer the question: “Do we have the right tools?” The workshop held earlier this year had an impressive array of appropriate people. The output from this workshop should prove to be very powerful. Much has been accomplished with this minimal level of funding—the community is getting a very good bang for the buck.

- The reach of the panel—providing input to the project, identifying issues, and offering solutions—has been outstanding this past year. The project should keep on that path. The branding is excellent; it will be interesting to see results next year—good to include on Linked In! (Other laboratories/projects should follow the lead.) There has been a positive outcome of more frequent meetings; the project should continue the meeting frequency. Regarding safety knowledge tools, the Electronic Safety Resource Tools Planning Session provided 136 unique ideas for resources! That is a wonderful outcome and includes *new* ideas that are contemporary and take advantage of current methods to disseminate knowledge and share learnings. Another excellent accomplishment is the *NFPA Journal* article (May/June 2014) and emergency response education/training with the U.S. Fire Administration.
- It is excellent to see early project engagements of the HSP on early design reviews. Early stages of branding the panel should lead to increased awareness and use, leading to better safety knowledge in future projects.
- Safety is the most important goal of any new technology. This project continues to provide comprehensive safety information, and the project improves upon previous methods for getting the information out to wider audiences.

### Question 3: Collaboration and coordination with other institutions

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

- It is commendable that coordination includes general outreach, such as a webinar and two papers at an ICHS conference, as well as specific outreach to HSP participants, national laboratories, the International Energy Agency (IEA), and project developers and reviewers.
- Much effort is being made to reach out and collaborate—and not just on the receiving end but also in acquiring information.
- The HSP section receives a 4.0. This activity does not really lend itself to embrace collaboration in a traditional sense. The tools section receives a 3.0 and is intended to be an all-encompassing collection (or access tool) for the community; however, there are some significant gaps in the collaboration that have led to gaps in the resources being utilized and/or duplication of effort. This team needs to reach out and include in this work activities of FCHEA and NREL.
- NFPA, the International Code Council, and the U.S. Fire Administration are included under this section, as are the IEA, Joint Research Conference Sandia, as HSP affiliates as well as authorities having jurisdiction (AHJs) on a case-by-case basis.

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

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

- The HSP portion receives a 4.0. The basic motivation is to ensure that DOE projects are performed as safely as possible and are executed in keeping with hydrogen safety best practices—spot on! The tools portion also receives a 4.0. These tools enable a one-stop shop to make the vast safety, best practices,

permitting, etc., available to the professional needing this information in an easy comprehensive manner—spot on!

- The project very effectively takes on Hydrogen and Fuel Cells Program goals and objectives and puts real-time solutions directly into the hands of those who are deploying hydrogen technologies.
- The wealth of knowledge and expertise of this panel is highly valuable. In working together with other projects (NREL's, for example), it is a powerful resource!
- This is a comprehensive safety assessment and outreach program—very nice.

### Question 5: Proposed future work

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

- Development of the tools, outreach plans, and direct engagement with project developers and those seeking to review projects is all excellent. The presenter referred to a desire for the hydrogen safety web portal to be a one-stop shop for credible, reliable safety information. This is also objective of the FCHEA hydrogen and fuel cell safety report website. People who are looking for safety information when considering a hydrogen or fuel cell project are likely to look to FCHEA for information. The project lead should consider ways to utilize the FCHEA website as an outreach mechanism.
- Proposed future work is a continuation of the same necessary activities and improved education and outreach. This is necessary work.
- The HSP portion of the work receives a 4.0. This is right on track. The tools portion also receives a 4.0. Given the minimal funding this project has, the future plans are appropriate.
- For the white papers (and other input to safety, codes and standards), the project should coordinate or work with organizations and working groups such as FCHEA and the U.S. DRIVE Partnership's Codes & Standards Technical Team. (This may be happening now, as some panel members are also members of these other groups.)

### Project strengths:

- The HSP portion has proven to be an excellent resource for the DOE programs and the hydrogen community at large. Indeed, imitation is the best form of flattery—the International Association for Hydrogen Safety's HySafe is working to create a similar tool under the auspices of the Fuel Cells and Hydrogen 2 Joint Undertaking. Regarding the tools portion, the notion of a one-stop web-based tool accessible from all the mobile devices now in general use is very good. This should prove to be a very valuable resource to those deploying hydrogen technologies.
- The team has done a great job organizing an approach, workflow, and execution to meet the real barriers that exist today.
- This project is showing real innovation and forward thinking in how best to utilize this valuable resource!
- Strengths include outreach with insurance groups and AHJs to better understand user needs.

### Project weaknesses:

- Excellent tools are being developed. This reviewer wonders whether more could be done to promote the tools, such as more interface outside the hydrogen community. The article in the *NFPA Journal* is an excellent start.
- This is not so much a weakness as a suggestion: it would be good to see the HSP continue to look for areas where its enormous expertise can provide value. Regarding the tools portion, the team needs to work harder at being more inclusive with collaborators and the efforts of others so as not to duplicate effort or create gaps.
- This is not so much a weakness of the project but a general observation: there seem to be some repeat efforts in similar arenas, so DOE needs to align these.
- It may be just a temporary glitch, but the reviewer was having difficulty with the incidents database the day before the review. The search was not working properly.
- Funding for the hydrogen safety panel at over six times the safety knowledge tools portion is questionable. The funding for the HSP seems excessive for the scope of work.

**Recommendations for additions/deletions to project scope:**

- The project should consider working with FCHEA to avoid duplication of effort with fuel cell safety report website goals. The project should begin to consider long-term possibilities of safety reviews for projects without DOE funding.
- The project should revisit HSP tasks and future work and adjust the budget accordingly. The funding amount is large and does not seem to be used efficiently.

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

William Buttner; National Renewable Energy Laboratory

### Brief Summary of Project:

Sensors are a critical hydrogen safety element and will facilitate the safe implementation of the hydrogen infrastructure. Through this project, the National Renewable Energy Laboratory (NREL) sensor laboratory tests and verifies sensor performance for manufacturers, developers, end-users, and standards development organizations. Information collected on sensors through testing is used to support codes and standards (C&S) development and improve sensor performance with manufacturers.

### Question 1: Approach to performing the work

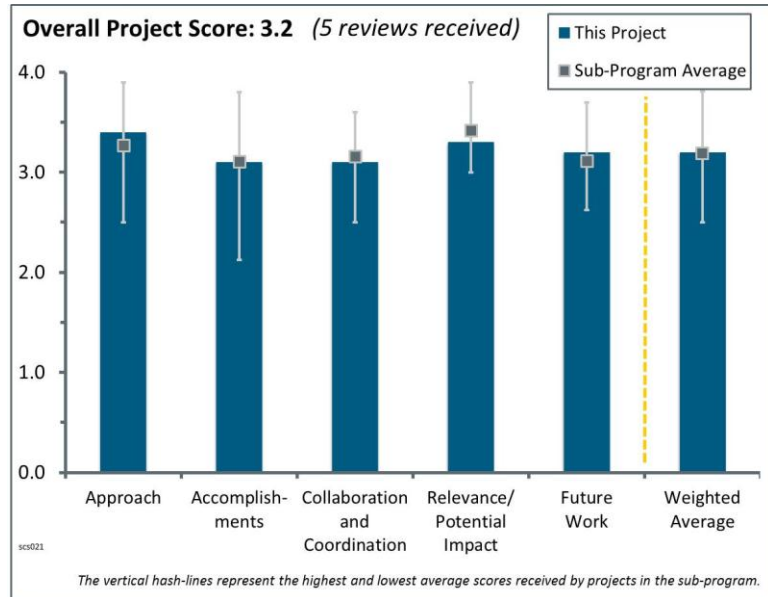
This project was rated **3.4** for its approach.

- Independent evaluation of sensor performance is critical to providing confidence and verified sensor performance. Indeed, the collaboration with the sensor testing facility in the Joint Research Centre (JRC) helps to leverage resources and to make sure that the data obtained has a high degree of confidence. Attention is given to ensure this knowledge is provided to the C&S development activities. The attention to client confidentiality is necessary and excellent.
- The approach followed by the project correctly covers a number of relevant technical activities, as well as interaction with industrial stakeholders and with standards development organizations and regulators.
- Sensors to detect hydrogen leakage seem to be a worthy cause. Present sensors have reliability, durability, and cost issues.
- The project provides independent assessment of hydrogen sensor performance. Efforts are now qualifying sensors for specific applications. This activity is somewhat integrated with other efforts but tells only part of the story.

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

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

- With effectively one full-time equivalent (FTE) of effort, this project's accomplishments are substantial, particularly when it is recognized that the new facility just came online and the new testing laboratory was recently moved and approved for operation. During this laboratory move and configuration, the principal investigator remained active and produced a number of relevant publications, lectures, and presentations (12) and co-authored a book. There needs to be some caution in measuring the output for this funding period since the laboratory is just now coming back online. Though some claimed accomplishments refer to work that is forthcoming, the accomplishment noted is one of establishing the relationship—this, in and of itself, is indeed an accomplishment (it shows initiation of many projects). The reviewer looks forward to seeing concrete output in the coming years with the new collaborations/partnerships and the new facility. The absence of concrete output from these new relationships is the reason for a score of 3.5 instead of 4.0. This rating is simply a result of the drop in concrete results due to the move and laboratory restart.



However, the work on hydrogen sensing by looking at O<sub>2</sub> displacement—the Global Technical Regulation (GTR)-driven investigation—is particularly impressive. These results are critically important technically and critical to ensuring that the GTR and other codes do not make the same error that Phase I of the GTR did. This is outstanding!

- The project clearly contributes to the high-level DOE goal of safe deployment of hydrogen technologies. Progress has been made in the integration of the experimental project activities in the Energy Systems Integration Facility.
- The focus appears to be having sensors on vehicles, but stationary applications may be more relevant. For example, many state building codes require fire (and carbon monoxide) detectors in a home. It would not be a stretch to assume a hydrogen sensor will be required in a private domicile garage.
- There is some correlation between this project and the DOE barriers listed on slide 2; however, this project is focusing on very specific technology rather than the broader analysis to determine whether this is the right technology to focus on. While much work has been done, there seems more yet to do than progress already realized. This is expected to be the case in basic research projects. This project seems more basic research than facilitating deployment.

### Question 3: Collaboration and coordination with other institutions

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

- The collaboration/partnerships with the private sector (five partnerships and agreements) are very good—this presumably refers to sensor manufacturers to be tested. The government collaborations are all appropriate and good; particularly impressive is the continued relationship with the testing facility at the JRC. It is recommended that outreach be made to the Asian community to secure collaboration there. The new facility in Japan (HyTrec or I2cner at Kyushu University) and facilities in China should be investigated as potential collaborators.
- There is good outreach through publication of a book, technical reports, and peer-reviewed journals. Collaborations with Europe, the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), Parker Aerospace for the aviation market, and the JRC in the Netherlands are all commendable. Collaborations with Bundesanstalt für Materialforschung und –prüfung's (BAM's) Fuel Cells and Hydrogen Joint Undertaking, as well as NREL, and H2Sense participation, are noteworthy. The project should have close coordination with fuel cell electric vehicle original equipment manufacturers (OEMs). The presenter responded to previous review questions by saying sensors are critical because other hydrogen detection technologies do not exist. At this point, hydrogen-specific sensors listed to Underwriters Laboratories (UL) 2075 do not exist either. It is not clear that the car manufacturers are saying what they really need is a cheaper reliable hydrogen sensor. Perhaps it would be beneficial for DOE to look at this project in the context of the overall aim of safety. Hydrogen-specific sensors may or may not be the ultimate solution. Perhaps there should be more research in alternative technologies that can achieve an equivalent level of safety to the UL-listed hydrogen-specific sensors that do not exist.
- There is a purpose-oriented interaction and collaboration with a number of relevant entities, including non-U.S. ones, as demonstrated by an extensive record of joint publications and presentations.
- The collaboration does not appear to be suitable to going forward. Collaboration with instrument manufacturers and building code officials may be a better approach for both requirements (and features) and acceptance.

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

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

- This project supports hydrogen vehicle repair facilities (sensors mandated by the International Code Council [ICC]). The expected significance is a hydrogen sensor for a turn-key safety system. Regarding NREL support of the Department of Transportation's National Highway Traffic Safety Administration on hydrogen safety requirements for Federal Motor Vehicle Safety Standards, the testing showed oxygen

depletion is not a suitable detection method for vehicles. It is not clear whether this assertion has been vetted with vehicle OEMs. Slide 3 says sensors for safe hydrogen deployment are mandated by National Fire Protection Association (NFPA) 2 (Sections 10.3.19.1 and 3.3.219.2.2). There is no Section 10.3.19.1 in NFPA 2 (2011 published edition). This may be a typographical error, as there is a Section 10.3.1.19.1, which states that “dispensing equipment shall be provided with gas detectors, leak detection, and flame detectors such that fire and gas can be detected at any point on the equipment [52:9.2.1.14].” It is worth noting that hydrogen-specific sensors are not mentioned. NFPA 2 Section 3.3.219.2.2 is a definition, not a requirement. The NFPA 2 code does not mandate hydrogen-specific sensors. The ICC’s International Building Code (IBC) does have more specific requirements. It is very important to note that IBC requires that sensors be listed in accordance with UL 2075. There is no mention of UL 2075 in this presentation. If there are no hydrogen-specific sensors capable of being listed in UL 2075, it might be better to focus work on updating the code text rather than continued long-term testing of sensor technologies.

- This activity is relevant. The potential impact for the stationary market would be positive.
- Point sensors in hydrogen applications are inappropriate and indeed can lead to a false sense of security and safety. The issue is not with the sensor but with being able to identify a leak in an environment where one cannot know the location or direction of a leak. Sensors are required by code, however (NFPA, ICC). With this said, it is good to see this project investigating wide-area detection—which, if it can be made cost-effective with suitable detectability in space and in concentration,—will solve these concerns.

### Question 5: Proposed future work

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

- The direction of this work remains focused on the growing needs of sensor technologies—particularly wide-area detection (monitoring). The continued collaboration with the laboratory at JRC remains a very good aspect of this work. The interaction with the industrial community to help ensure safe operation and appropriate use of sensors is good and necessary.
- The proposed future work is aggressive and all-encompassing. It appears to be encroaching upon the work done by the Nationally Recognized Testing Laboratories (NRTLs). It is not clear how the project is addressing this or addressing the liability associated with testing designs generated by commercial interests.
- The proposed future work is a logical follow-up of past and ongoing activities.
- On slide 19, the project lead refers to alternate means of hydrogen detection as “hypothetical,” then goes on to describe significant challenges and barriers in the development of a suitable hydrogen-specific sensor. The tone of this slide, as well as the slides describing responses to last year’s reviewer questions, suggests bias toward hydrogen-specific sensors at the expense of suitable alternatives.

### Project strengths:

- This project is largely spot-on with good output for a one-FTE effort. The direction is good, the output appropriate, and so forth.
- A strength is the international cooperation allowing exploitation of synergies between laboratories resulting in higher testing throughput.
- There appears to be good international collaboration on basic research.
- The project is working to address real challenges in both the near and far term.
- The scope is a strength.

### Project weaknesses:

- This project could use more direct collaboration with automotive OEMs. The project could benefit from a more balanced approach in communicating strengths and weaknesses of hydrogen-sensing technologies.
- It would be good to see this project reach out to the Asian hydrogen community and establish an appropriate collaboration.
- It seems that the project is waiting for participants and project collaborators to come to them.
- It is unclear how “lessons learned” from collaboration with industrial partners (subject to confidentiality) are fed back into the future work program.

- The apparent focus is on vehicles, and the OEMs do not appear to be receptive to hydrogen sensors. The apparent limited focus on stationary applications is a weakness.

**Recommendations for additions/deletions to project scope:**

- It is suggested that less attention be spent on vehicle sensors and more on stationary applications. It is suggested that potential conflicts with NRTLs be addressed. It is suggested that an approach be generated to address the liability associated with testing designs generated by commercial interests.
- It would be good to see representation and participation in an independently facilitated industry workshop to discuss the needs of automakers, the code requirements, and what it will take for hydrogen-specific sensors to be listed to UL 2075. If this is not feasible, consideration should be given to revising the ICC's IBC to remove a requirement that is impossible to meet.
- The project should have active outreach to relevant stakeholders.
- Wide area monitoring is now included in the project (although no results have been presented so far). The new effort on hydrogen fuel quality detection should be aligned with related activities in other sub-programs of the DOE Hydrogen and Fuel Cells Program (e.g., Hydrogen Production and Delivery, and Safety, Codes and Standards).

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

Karen Hall; Fuel Cell & Hydrogen Energy Association

### Brief Summary of Project:

This project supports and facilitates 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. The project ensures best safety practices underlie research, technology development, and market deployment activities supported through U.S. Department of Energy (DOE)-funded projects.

### Question 1: Approach to performing the work

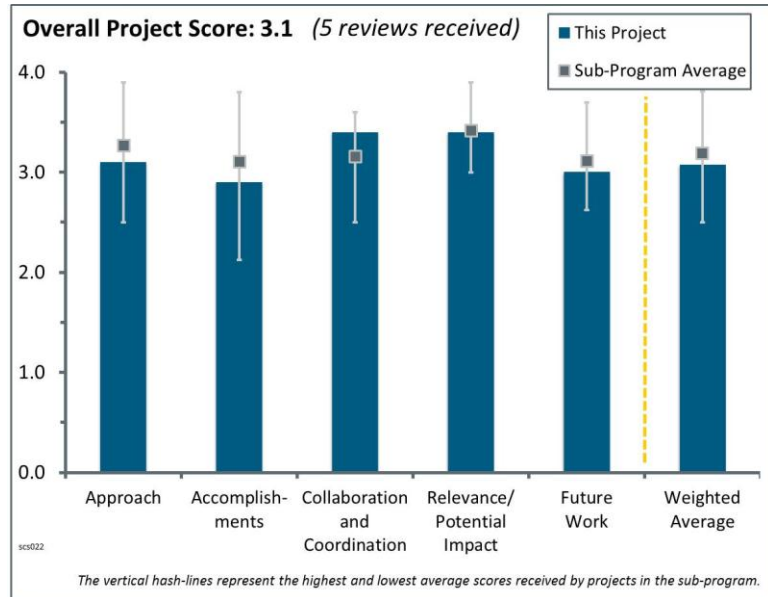
This project was rated **3.1** for its approach.

- The general approach has good disciplines and good objectives, and the activities follow a logical flow. The coordination of hydrogen safety information through reports, websites, and meetings is very helpful. Besides the tracking matrix, it would be helpful to identify the methods and approaches that are specifically conducted by the project to accelerate the efforts by code development organizations and standards development organizations (CDOs/SDOs). The project has a wide focus on multiple industries (transportation, stationary power, portable power, etc.), and monitoring these is helpful, but the project may want to identify priority sectors to manage the project's limited resources.
- The approach is similar to the approach used by the U.S. Fuel Cell Council (USFCC) in that there are working groups of industry members. However, there is no longer a high visibility at the organizations generating the standards. For example, the USFCC used to have a representative at the SAE Fuel Cell Standards Committee to contribute and function as a liaison. The approach also consists of a coordination call between the trade organizations and the SDOs. The attendance and input from the SDOs is limited. A more proactive outreach to the SDOs may be warranted.
- Working as the liaison to set up interactions between businesses and DOE and actively participating in several of the national codes and standards organizations demonstrates that the return on investment (funding) is being maximized with this group.
- The Fuel Cell & Hydrogen Energy Association (FCHEA) leads working groups that address the major safety, codes, and standards (SCS) activities for all types of hydrogen/fuel cell areas of interest (portable and stationary power and transportation).

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

This project was rated **2.9** for its accomplishments and progress.

- The information provided on their website (<http://www.hydrogenandfuelcellsafety.info>) has up-to-date information on the status of various codes and standards and links to a variety of hydrogen safety information. Quick observation: April 2014 is missing from the archive page. The website is not all-





encompassing of everything hydrogen but does a reasonable job capturing most of the SCS tasks of U.S. interest.

- The project is doing good work in coordinating and helping standards to be developed and information to be disseminated. Both the national and international interfacing are valuable.
- The project has made accomplishments in communicating and coordinating information regarding various hydrogen codes and standards. The specific contributions of the project should be highlighted in future reviews. It is unclear whether the project is simply monitoring or actually involved in accelerating the standards.
- The accomplishments listed are dated and reflect previous activities conducted as USFCC. A more proactive approach, as conducted by other trade organizations, may be warranted.

### Question 3: Collaboration and coordination with other institutions

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

- This project has excellent collaboration with multiple SDOs/CDOs and other organizations.
- One of FCHEA's main reasons for existing is collaboration. They are well-tied-in and do this well.
- This is a trade organization. A more visible presence with the SDOs and the assisting of the SDOs in getting experienced personnel active in the generation of the product safety standards would accelerate the process and improve the quality of these standards, which are the supporting documents to the building and fire codes.

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

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

- The project performed by FCHEA has a high degree of relevance to the DOE Hydrogen and Fuel Cells Program's (the Program's) SCS objectives. FCHEA's support/facilitation role in coordinating the groups that develop standards and communicating/sharing safety and standards information is very important. FCHEA's role of linking industry to the Program is an important one.
- The project provides an important role in coordinating and progressing the critical hydrogen codes and standards for commercialization. The focus of the project has a direct link to a majority of the DOE research, development, and demonstration objectives.
- The work is relevant, but the current activity does not appear to optimize the potential of the membership within a trade organization.

### Question 5: Proposed future work

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

- The project's proposed work appears realistic.
- The proposed future work is adequate as it stands, but it is not nearly as aggressive as the work conducted in the past and does not impart a sense of urgency with the CDO and SDO management and working groups.
- The future work was outlined but appeared to be an extension of stated accomplishments rather than a clear focus on the next critical items needed for commercialization.

### Project strengths:

- The project team has many years of experience promoting and coordinating efforts that connect DOE to industry and facilitating SCS activities. The project has a unique role in representing industry.
- The project has demonstrated very good meeting disciplines and coordination. It is also serving an important role in communicating the progress of hydrogen codes and standards.
- A strength is the access to and support of the membership of a trade organization.

**Project weaknesses:**

- A weakness is the lack of leveraging the membership to help populate the various SDO working groups to generate high-quality, timely product standards.
- This project needs more visibility and a cohesive strategy.
- The project could improve in identifying its specific contributions and influence to accelerating hydrogen standards.
- The project does not actually develop standards, uncover best practices, or perform research and development that validates standards.

**Recommendations for additions/deletions to project scope:**

- No changes are needed.
- The project should pursue opportunities to receive the voices of key stakeholders in various industries regarding their barriers to commercialization. The project seems very diverse across many hydrogen industries and appears to be missing key barriers for the transportation market (e.g., an infrastructure path to saleable hydrogen, such as flow controller, was not identified). Also, the project should include direct input and feedback regarding hydrogen field issues into the SDOs/CDOs.
- The project should become more engaged with the activities of all the SDOs and leverage the membership to generate high-quality, timely product standards.

## Project # SCS-023: Hydrogen Leak Detector for Hydrogen Dispenser

Igor Pavlovsky; Applied Nanotech

### Brief Summary of Project:

This project's goal is to make a low-cost, robust, durable hydrogen sensor. The reliability and maintenance burden of the leak detection systems at hydrogen dispensers will improve with sensor immunity to dust, poisons, and organic vapors. Sensors developed under this project will demonstrate stable, repeatable performance across wide temperature, pressure, humidity, and hydrogen concentration ranges.

### Question 1: Approach to performing the work

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

- The approach was to take two microresonators (one open and one closed) and utilize the change in local gas density in the presence of hydrogen to affect the frequency of the microresonators over a wide temperature range. The idea is proven and validated. This is very nice work for a Small Business Innovation Research Phase I project.
- It would be good to see some interference gases added to the testing. Interference to common household solvents, natural gas, gasoline, etc. should be evaluated.

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

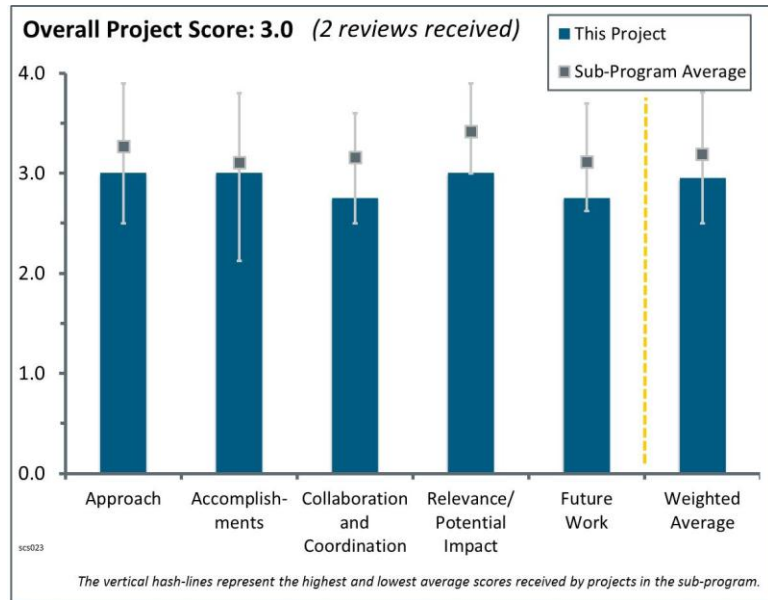
This project was rated **3.0** for its accomplishments and progress.

- The team demonstrated repeatability and high accuracy at up to 2% over a wide temperature range. The project has great use of thermal modeling to troubleshoot the power usage to reduce heat load. It would be interesting to see the results from the sensor that was shipped to the National Renewable Energy Laboratory (NREL).
- The reviewer would like to see results of the independent NREL testing. These testing data should be used to evaluate the suitability of this technology for a Phase II award.

### Question 3: Collaboration and coordination with other institutions

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

- The independent testing at NREL is a good collaboration. At least one partner that uses hydrogen (fueling stations, original equipment manufacturers [OEMs], etc.) should be added if Phase II is funded.
- The team seemed to work well with NREL, but the collaboration with the Northeast Gas Association is less clear. The project might need to highlight that function better.



**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.

- The cost, durability, and calibration stability make this sensor very impactful to the commercial hydrogen rollout and would be very interesting to a station developer or even automotive OEM.
- Development of low-cost robust hydrogen leak detection would help in the faster adoption of hydrogen technologies.

**Question 5: Proposed future work**

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

- It seems that there will be testing at NREL, but it is unclear if that will happen if Phase II is not funded, although it would be useful. It is not very clear that this would need the whole of Phase II funding (\$1 million), as this seems as though it just needs a little bridge funding for the sensor to be commercialized. Maybe that aspect could be expanded a bit.
- The proposed future work is dependent on Phase II funding. Interference testing should be added to this before field trials. The sensor-to-sensor reproducibility should be evaluated. Long-term durability testing should be added.

**Project strengths:**

- The technology is simple and seems to be low-cost.

**Project weaknesses:**

- There are no interference data. The entire response to 2% hydrogen is <2% of the baseline. It is not clear what the sensor drift will be. The PI claims that the team plans to calibrate once every two years. However, there are no long-term data to show that this is even feasible.

**Recommendations for additions/deletions to project scope:**

- Phase II should be funded only if the NREL testing shows promise for this technology.