2013 — Safety, Codes and Standards
Summary of Annual Merit Review of the Safety, Codes and Standards Program

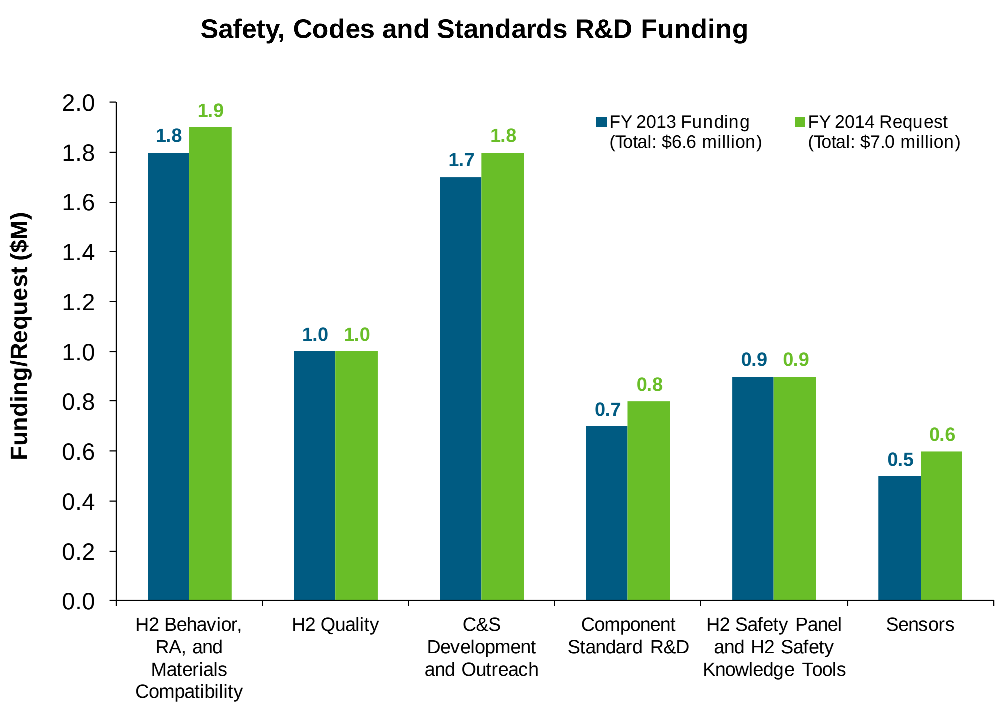
Summary of Reviewer Comments on the Safety, Codes and Standards Program:

The Safety, Codes and Standards program supports research and development (R&D) that provides the critical information needed to define requirements and close gaps in safety, codes, and standards to enable the safe use and handling of hydrogen and fuel cell technologies. The program also conducts safety activities focused on promoting safety practices among U.S. Department of Energy (DOE) projects and the development of information resources and best practices. Reviewers recognized that the program continues to provide strong support in the following areas: hydrogen and fuel cell codes and standards including domestic and international harmonization, permitting and education, 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 program have effectively leveraged the resources and intellectual capital of academic institutions, standards development organizations (SDOs), code development organizations (CDOs), national laboratories, government agencies, industry, and other offices within DOE.

In addition, this year, reviewers commended the program for the strong international participation with the focus toward international harmonization for the safe deployment and early market commercialization of fuel cell and hydrogen technologies. Reviewers felt that the program was well focused and well managed, but noted that closer coordination with industrial partners and improved publication and outreach of technical work in safety implementation aspects of the program would enable better stakeholder and industry feedback on technical developments.

Summary of Safety, Codes and Standards Funding:

The fiscal year (FY) 2013 appropriation was $6.6 million for the program. FY 2013 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 2014 request of $7 million will continue these efforts.



Majority of Reviewer Comments and Recommendations:

In FY 2013, nine Safety, Codes and Standards projects were reviewed, with a majority of the projects receiving positive feedback and strong scores. Reviewers' overall scores ranged from 2.8 to 3.6, with an average score of 3.3.

Hydrogen Behavior, Risk Assessment, and Materials Compatibility: Three hydrogen behavior, risk assessment, and materials compatibility projects were reviewed, with an average score of 3.2. Reviewers commended the strong analytical approach and methods found within these projects, strong research and experiments in validating data and models on hydrogen release behavior, and engagement with industry to maximize the impact on standards development. The reviewers suggested collaborating more closely with appropriate industry partner SDOs and CDOs, increasing publication and outreach to enable review and stakeholder feedback for future work, and considering applications for evaluating risk associated with equipment or processes.

Hydrogen Quality: One hydrogen quality project was reviewed, receiving a score of 3.4. Reviewers commended this project for its focus and alignment with near-term real-world needs and for being a key stepping stone toward the implementation of hydrogen fuel quality standards. Reviewers suggested reexamining the project scope to leverage other technical resources, investigating the cost-effectiveness of the analyzer technology, and collaborating with industrial partners to advance commercialization efforts.

Codes and Standards Development and Outreach: One codes and standards development and outreach project was reviewed, receiving a score of 3.3. The reviewers commended this project for its coordination with critical SDOs and CDOs, and for the importance of the work being done in California. However, the reviewers suggested that the project scope, approach, and plan should be improved to address a range of needs for codes and standards for hydrogen quality, metering, and certification of components and systems.

Component Standard R&D: One component testing project was reviewed, receiving a score of 2.8. The reviewers commended the project's strong coordination with SDOs and CDOs and national and international laboratories and the effective exchange of information between stakeholders. Reviewers suggested strengthening collaboration and coordination with industry and improving the definition of the project scope and milestones to better evaluate the project.

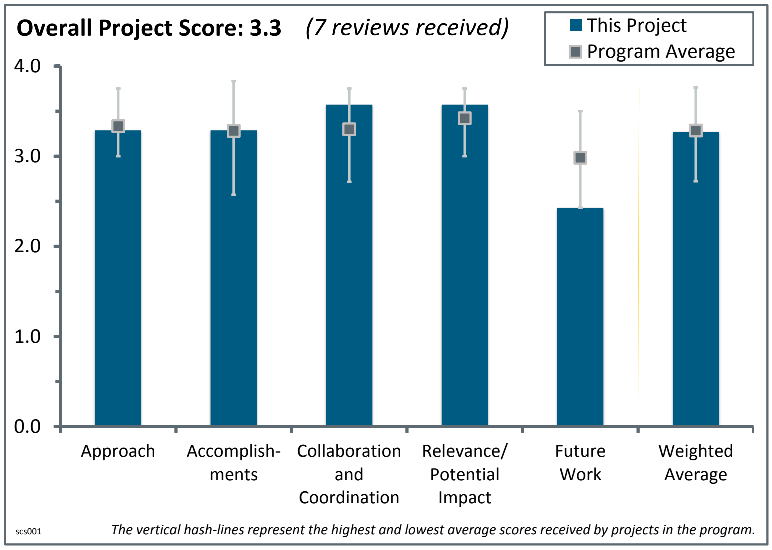
Hydrogen Safety Panel and Hydrogen Safety Knowledge Tools: One project in this area was reviewed, receiving a score of 3.6. Reviewers stressed the importance of this effort in providing information, guidance, and tools to improve industry awareness. Reviewers identified the need to involve third-party certifiers, improve coordination between the Safety Panel and safety planning in DOE-sponsored projects, and coordinate with SDOs and CDOs to build on the success of mobile platform safety knowledge tools.

Sensors: Two sensor projects were reviewed, receiving an average score of 3.3. Reviewers applauded the overall project management and strong collaboration and coordination with international and industrial partners. However, reviewers recommended improving communication regarding the role of sensors in meeting safety requirements and developing durability requirements and manufacturing, maintenance, and other cost estimates and targets for relevant applications. Reviewers also suggested investigating cross-sensitivity to methane and the use of wide-area detection and contact sensing technologies for early detection of leaks.

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

Carl Rivkin; National Renewable Energy Laboratory

Brief Summary of Project:



The objectives of this project are to: (1) support code development for the safe use of hydrogen in commercial, residential, and transportation applications with a major emphasis on infrastructure for hydrogen fuel cell vehicle technologies; (2) advance hydrogen safety through collaboration and coordination with stakeholders; (3) facilitate the safe deployment of hydrogen technologies by working to incorporate safety data into codes and standards (C&S) projects and hydrogen technology deployment projects; (4) distribute hydrogen safety information through the most effective channels, including websites, technical reports, webinars, and in-person presentations to reach key audiences such as project developers and code officials; (5) and conduct the research and development (R&D) needed to establish sound technical requirements for the safe use of alternative fuels with a major emphasis on hydrogen and fuel cell technologies.

Question 1: Approach to performing the work

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

- The approach is well designed and has been coordinated with industry and standards organizations.
- The overall scope and approach of this work are very good. In the 2012 Hydrogen and Fuel Cells Program Annual Merit Review, this project was criticized for being too broad. However, the breadth is needed to adequately cover the critical regulations, codes, and standards (RCS) domain. The principal investigator (PI) clearly understands this space very well.
- The development of the templates provides a very useful resource. The National Renewable Energy Laboratory's (NREL's) work with California on hydrogen infrastructure is of high value as well; however, the approach (slide 4) needs to maintain its path as it expands—not shift entirely.
- Coordination work has been very effective in aligning resources and achieving harmonized C&S. Gap analysis is useful in prioritizing future work. Outreach is helpful, though hydrogen station permitting still seems to be a significant challenge.
- NREL has recognized that the major effort to develop C&S is close to completion—at least on the top level—and is wisely turning its emphasis to infrastructure issues as well as focusing more on outreach/communication.
- It is difficult to understand from the presentation what work researchers pursued, as well as why and when they pursued it. This makes it difficult to judge the approach. Presenting a project plan may be more useful next time.
- The focus appears to be limited to model building and fire codes, the International Organization for Standardization (ISO), and the United Nations' Global Technical Regulations (GTRs). These venues are important, but they are only part of the picture. Design codes, such as ASME B31.12, and product safety standards, such as the Canadian Standards Association (CSA) HGV4.1, also need support. The model codes indicate that hardware is to be "approved" or "listed;" however, the product safety standards need to be supported to make the model building and fire codes actionable. Additionally, much of the hardware being generated for hydrogen infrastructure is being developed by small companies. These companies

might not have the cash flow to fund the testing needed to become “approved” or “listed.” It is unclear if these issues are under consideration.

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.

- Important foundational work has been accomplished and key C&S are in place.
- The fact that much of the RCS for hydrogen and fuel cells have been developed is a significant accomplishment. NREL’s coordination effort is a significant part of that. NREL’s efforts aimed at furthering the acceptance of National Fire Protection Association (NFPA) 2 is very important, especially in getting it recognized by the International Fire Code (IFC). The NREL Hydrogen Safety Handbook will serve as a good complement to Pacific Northwest National Laboratory’s (PNNL’s) Hydrogen Best Practices website.
- The PI and NREL have done a very good job at keeping a focus on C&S and moving forward in a harmonized way. The harmonization between NFPA and the IFC codes was critical and very important. A lot of what the PI called “accomplishments” are really activities. This section still deserved a high score because those accomplishments that were listed were important and critical to the rollout of the infrastructure.
- The accomplishments regarding hydrogen safety and hydrogen fueling have been very good. There has especially been a lot of important information from NREL to assist in the J2601 standardization. However, efforts to accelerate analytical methods in the ASTM D.03 group have not been effective. The current activity in hydrogen quality is not focused on first finishing these sets of standards with round-robin tests, etc. Trying to find other ways of testing, such as in-line testing, are quite frankly misplaced and should be prioritized after that goal.
- Showing “Codes and Standards Basically Complete” in fiscal year 2013 is a gross misrepresentation of the state of C&S. The comment that industry will take over addressing all relevant C&S overestimates the manpower industry has to support this effort. Industry will have to prioritize the C&S to which it can dedicate manpower and therefore some will fall through the gaps. This is a critical point in time for support to meet commercialization needs. Work with Sandia National Laboratories (SNL), particularly on material compatibility and NFPA 2, was critical and a great accomplishment.
- The accomplishments noted by the PI are limited; more progress has been made in key areas. The PI is correct in reporting that NFPA 2 and the IFC/International Building Code work is progressing, and that ASME has amended Section VIII, Division III of the Boiler and Pressure Vessel Code for fracture mechanics (article KD-10) and added a new book section to the B31 Piping Code. Although, to this reviewer’s knowledge, nothing has been changed in articles 500–505 of NFPA 70: this should be verified. Other accomplishments include a domestic hydrogen fuel standard, SAE J2719, and an international standard that was harmonized with the domestic standard. The hydrogen fuel nozzle product standard, J2600, has been revised to define pressure classes so that the terminology of the automotive people and the stationary people agree; add the H70 hardware definition; and require the hardware to meet the national pressure technology requirements. This document, SAE J2600-2013, is published. ISO has also published a harmonized version of this document. It would be helpful to industry and DOE to expand the list of major accomplishments and include a status list on the progress of the remaining key documents.
- The statement that the C&S are essentially complete is misleading. It is true that much progress has been made, but there is still work to be done for more development and/or revisions, as well as for implementation. The assumption that industry will take over at this early date is not necessarily a good one. There was truth in the comment from an audience member who said that he “take[s] exception to the statement that industry needs to ‘do the heavy lifting.’ For the rest of industry (aside from the automotive original equipment manufacturers) this is very difficult, as there are not a lot of engaged parties—there is no short-term demand...” The work with California is extremely helpful and hiring a consultant (Bob Davidson) to work on the IFC proposals was also a great accomplishment. The Hydrogen Safety Handbook will also be good to see. If not done so already, it would be good to see positions supported by NREL (via DOE funding) re-engaged at this most critical time.

Question 3: Collaboration and coordination with other institutions

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

- The liaison work is very useful; it would be good to see more/continued efforts.
- DOE and NREL have very good connections both nationally with key standards development organizations (SDOs) (such as SAE, CSA) and code development organization (CDOs) (such as NFPA, the International Code Council [ICC]), and internationally with ISO and the GTR. The R&D collaboration with the Japan Automobile Research Institute (JARI) and others has been exceptional.
- By necessity (and successfully), this project collaborates well with the appropriate interested parties (such as NFPA, ICC, the Fuel Cell and Hydrogen Energy Association [FCHEA], other laboratories [SNL and PNNL], and particularly the California Fuel Cell Partnership).
- Working, collaborating, and coordinating with SDOs, authorities having jurisdiction (AHJs) in various areas, and others involved with furthering the development and implementation of hydrogen and fuel cells C&S is like herding cats. NREL is to be commended for its effort.
- The list of collaborations is sketchy. It is notable that the nationally recognized testing laboratories—which are working to develop the product safety standards—are not noted.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- This project is very relevant to the needs of the DOE Safety, Codes and Standards program and to the rollout of the infrastructure. The role of coordinator is needed and executed well by this project.
- The relevance of appropriate RCS is obvious. Without it, market introduction of applicable technologies is limited.
- This work has been critical for supporting hydrogen infrastructure, where stakeholder resources are limited and significant learning is still required to achieve commercial readiness.
- This project is absolutely critical to the success of hydrogen and fuel cells—the expertise and coordination in C&S development is paramount to success, as outlined particularly in slides 11 and 12. There is no question that outreach and education on the progress is essential as well, but maintaining support in the development of C&S is still a high priority.
- Without RCS that are accurate, complete, acceptable, and understood, the implementation of hydrogen fuel cells will not happen on anything but the smallest scale. NREL's project is central to the development and implementation of RCS as well as to bringing the message to the hydrogen community, especially key AHJs. An emphasis on California is proper.
- The relevance is self evident. However, a more inclusive approach that is not limited to model building and fire codes would be helpful.
- Most project aspects align with the Hydrogen and Fuel Cells Program and DOE RD&D objectives. Much of the work in standardization is done; however, hydrogen quality cannot be measured universally due to the lack of finalized analytical standards.

Question 5: Proposed future work

This project was rated **2.4** for its proposed future work.

- The proposed future work is focused on the right areas.
- The project team should keep up the coordination in all areas.
- NREL plans to continue work in C&S coordination on a smaller scale, passing much of the work over to industry. NREL will focus on infrastructure C&S issues. NREL also appears to be stepping up its outreach activities, working with key AHJs. As hydrogen deployment ramps up in key areas (e.g., California) the outreach aspect will become more and more important. NREL's future work direction is proper.
- The proposed future work is discouraging. The task is only just started. Expanding the monitoring and support to be more inclusive by not being limited to the model building and fire codes would be helpful.

- To say C&S are complete is incorrect. Significant effort needs to go into addressing the U.S. Department of Transportation (DOT) requirements for shipping hydrogen tanks with hydrogen. Currently, this requires a special permit and is seen as a barrier for many market applications, such as mobile fueling. Additionally, industry has asked for years for a "hydrogen cleanliness spec" for hydrogen stations (e.g., what solvents can be used to clean a station after it has been built or maintained). This has never come to fruition and has apparently fallen off the table, if NREL states that all C&S are essentially complete. It is unclear where this is in NREL's gap analysis.
- While there is truth in the notion that some of the heavy hitting has been accomplished by the CDO community to enable an infrastructure, there are still critical elements that are seriously needed (e.g., metering). So while the outreach efforts to support education in preparation for the infrastructure rollout are important, attention still needs to be given to the critical rate-limiting elements (such as metering, fuel quality, international harmonization, etc.). Now is not the time to pull back on the development of C&S for those critical elements, and now is not the time to lose track of the need to harmonize the U.S. efforts with international RCS activities.
- The conclusion slide and the responses to questions for proposed future work were very vague and weak. The plans have little relevance to eliminating barriers or advancing the Hydrogen and Fuel Cells Program. DOE should work with industry to make a list made of the top items left to assist in the commercialization of fuel cell vehicles and hydrogen infrastructure. Surely a concrete roadmap to get hydrogen metering to within 1.5% accuracy and analytical methods are some of the items that are needed as soon as possible, and the industry should be surveyed through the U.S. DRIVE Codes and Standards Tech Team and elsewhere to determine where support is needed.

Project strengths:

- The focus of the project is a strength.
- This project has helped to guide, inform, and coordinate a broad array of complex activities.
- The coordination with NFPA, IFC, and ASME is critical and very helpful to the industry.
- Strengths of this project include the researchers' level of expertise and knowledge, progress/success to date, and coordination.
- Strengths of this project include its concise safety goals, communication, C&S coordination through FCHEA, and support of SAE Hydrogen Fueling (J2601).
- This project features coordination of a large number of C&S activities with various officials, SDOs, researchers, etc. Having the NREL Technology Validation database to draw from is another strength.

Project weaknesses:

- The project needs clear, significant deliverables and associated timelines.
- The focus of the project is also a weakness. The development of supporting design codes, product standards, and test methods needs support.
- There is a lack of planning to "finish the job" related to near term C&S development (Proposed Future Work).
- The outreach effort lacks metrics.
- It would be good to see three or four well-designed charts that visually tie all of the pieces of this work together. The project team should replace slide 6 (with the pyramid to the right) because this chart seems to depict the vehicle C&S as a roll-down of primary building and fire codes. The team should also connect to real-world goals: stations and vehicles and their interaction.

Recommendations for additions/deletions to project scope:

- C&S involving hydrogen quality needs to be addressed.
- Researchers should monitor field experience to confirm that the statement that "key C&S are in place" is really true.
- There should be work regarding the DOT requirements on composite tank shipment (on-road) with hydrogen.

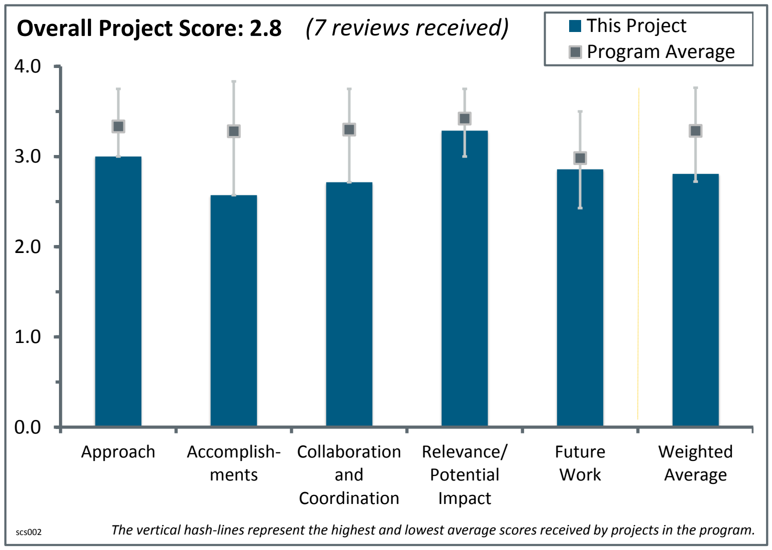
- The project team should expand the scope to include the supporting design codes, product standards, and test methods.
- The project team should continue to work with industry—the hose study is a good example—to facilitate progress in areas that may be of smaller relative scope (e.g., a hose versus a model fire code) but with just as much overall importance. Following are areas to expand upon (which are being addressed to some extent now): metering, the ability to sell hydrogen, and third-party certification of components and systems.
- The project team should create a "Near Term R&D Needs" document for C&S and canvas industry members at ASTM/CSA/SAE regarding needs, etc., to determine a roadmap. The team should be a part of "accelerating key" industry C&S. It should also delete all hydrogen sensor work; this is not valuable to the industry at all, per technical papers from the industry related to the status of hydrogen sensors. The team should also take the following actions:
    - Work with the ASTM D03 Gaseous Fuels Team to accelerate the hydrogen quality analytical methods that need to be finished as soon as possible. The other work being done for hydrogen quality is not as high of a priority as getting this standards round-robin testing completed and motivating the team and convener to finalize the technical work and publish the first set of standards. This is important.
    - CSA and SAE are not aligned regarding acceptance of materials compatibility; perhaps this needs to be accelerated. The stainless steels with high-nickel content needed for hydrogen storage systems are not available in North America—this is important. They must be shipped in from Europe or Japan or a custom order must be made at a steel mill. The standards could be a motivator, but they must be aligned.
    - Materials capability: This was stated a few times, but -50°C must be used to determine embrittlement. It is unclear when SNL will have this capability.
    - CSA standards on dispenser components: The hose, breakaway, and connectors standards have not been tested before incorporation by the American National Standards Institute; this should be investigated with data.
    - SAE J2578/J2579: need data to validate before making recommendations to the standards. Topics such as stress rupture are inadequately covered in those documents.
    - Setback distances need to be aligned between the ISO and SAE worlds. This should be a coordinated data effort with the Japanese and European Union counterparts.
    - The hydrogen sensor work is obsolete because the industry has sensor solutions available in its production vehicles and stations. It is recommended to halt this project.
    - Hydrogen metering: Hydrogen metering is being evaluated through NREL, and there is already an additional funding opportunity announcement to investigate this. However, there needs to be a follow-on project that incorporates testing flow meters not only in the laboratory, but also in the field until a commercially acceptable flow meter is found to get within 2% accuracy.
    - Field testing (continuation of laboratory tests): Fueling standards should be further validated at a designated development station to show the positives and negatives (e.g., SAE J2601 versus the MC Method [total heat capacity method]). This station could also be a basis for metering and hydrogen quality testing.

Project # SCS-002: Component Standards Research & Development

Robert Burgess; National Renewable Energy Laboratory

Brief Summary of Project:

Safe deployment of hydrogen fuel cell technologies is dependent on components that are proven to perform safely and reliably as measured against new safety and performance standards. This project works with manufacturers, installers, and the National Renewable Energy Laboratory's (NREL's) Technology Validation program to prioritize gaps, then to close those gaps by conducting hydrogen component research and development (R&D) and performance validation. Root cause analysis and R&D testing are conducted to improve the safety and reliability of hydrogen system components.



Question 1: Approach to performing the work

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

- The presentation featured a good, top-down hierarchal description. Making use of the NREL Technology Validation data is a good approach to advancing the safety database. The project's nature means that a significant portion of the work appears to be reactive—this is not necessarily a bad thing for this type of work.
- The project seems well coordinated with project SCS-001, with a good flow of information between NREL and standards development organizations (SDOs)/original equipment manufacturers (OEMs)/station providers.
- This project has the potential to bridge a gap in industry by providing capabilities for "in situ" testing of components in a high-pressure hydrogen environment. This is a critical need for industry. However, this work needs to be a collaborative effort with industry and recognized third-party testing laboratories. It was unclear in the presentation whether the information on "near misses" and incidents is being fed into the hydrogen incidents database and subsequently communicated to the appropriate SDOs. If not, this should be incorporated in order to provide important data to support the standards development. This presentation frequently referred to component-level issues being addressed in codes and standards. This needs to be corrected—component-level requirements and some system-level requirements are addressed in the safety standards. Codes are for installation and not to make component-level evaluations.
- Globally, the component R&D approach is good. It addresses several key barriers and will significantly contribute to close technology gaps that are essential to ensure safety. Although progressing well, further efforts could be done regarding the collection/integration of real-world data from OEMs and station providers. This is critical.
- The approach and input appear to be limited. The focus, based on this presentation, appears to be limited to work at SAE International (SAE) and the National Fire Protection Association (NFPA). Discussions with the generators of the design codes, product safety standards, and material test methods would be worthwhile. The project team should look at Tom Rockward's presentation as a way of handling multiple objectives.
- It would be good to see tighter partnering with other laboratories in this area—specifically the material science team at Sandia National Laboratories (SNL). The presenter did list the materials activities at SNL; however, on slide 6 under mechanical element testing, only a verbal comment was made with regard to SNL's efforts. This project and the materials science activities should be a close teaming effort; both

initiatives can benefit. It would also be good to see a focused approach to define which components are higher on the priority list for testing. For example, components needed for the commercial deployment of hydrogen should be placed higher on the list than those needed for production. There is an urgent need for dispensing and commercial equipment now in order to meet the infrastructure needs for a 2015 rollout.

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

This project was rated **2.6** for its accomplishments and progress.

- The project seems to be on track. It is hard to fully evaluate the project at this stage, but this work and the capabilities developed should prove increasingly important over the next 5–10 years.
- Good progress has been made supporting codes and standards, especially SAE 2601. However, the rest of the accomplishments presented relate to "ad hoc" support activities that cannot be considered as tangible achievements (e.g., a webinar on refueling protocols). Efforts are needed to define a clear direction in terms of objectives and deliverables.
- It may be a result of the reduced budgets, but the funding for research to provide technical support for component-level standards has not been forthcoming. In situ PRD testing is needed and has been requested for several years (more than four years). With this project's mandate to work closely with SDOs and develop data to provide technical justification for standards development, this needs improvement.
- The progress to date is gated by industry.
- It is concerning that some of the "accomplishments" presented were particularly weak. For example, NREL took credit for putting on a webinar that presented the status of SAE 2601; in reality, the presentation was given by two other representatives, neither of whom were NREL employees or part of NREL's project. NREL's role was one of support. This support role is also mentioned on other "accomplishments"—SAE J2601/NFPA joint call, and Non-Metallic Materials Workshop Participation. These listed accomplishments are not relevant to this component testing project. Next year, hopefully there are concrete accomplishments directly relevant to component testing, clearly differentiated from support, participation, and internal environmental safety and health requirements to enable an activity (periodic health assessments, etc.)
- Being able to support the SAE J2601 standard development by showing that, prior to refueling, hydrogen tank temperature (as a function of ambient temperature) is not as high as previously suggested by the standards committee is significant and may alleviate some refueling restrictions. But the presenter did not appear to know the tank temperature measurement locations. In addition, mention was made of the Emeryville incident (i.e., the hydrogen bus hydrogen leak/fire), but it is not exactly clear what this project's involvement was in the investigation.
- This project suffers from a lack of technical achievements on components. There is no shortage of component-related issues; however, this project seems to have failed to identify, commence an analytical assessment of, or develop relevant project partnerships to achieve technically relevant results. It is unclear what the staff is doing beyond attending standards development committee meetings and generating quarterly, annual, and DOE Hydrogen and Fuel Cells Program Annual Merit Review reports. It is unclear what benefit the hydrogen community gains from this effort. The "Component Testing Report" was not available through the website even after an advanced search in the overall database. Furthermore, the presentation did not highlight the findings of the report. The summary states that "root cause safety/reliability issues" were identified by utilizing statistical data. The presentation only articulated one such statistical analysis—a vehicle fueling rate and temperature analysis. These results consist of already available data from the Technology Validation effort. It is unclear what value this effort provided besides communicating results to the technical committee (a useful but not technically significant achievement). The Emeryville incident investigation was a shared effort with many SCS laboratories that did not mention their participation as a major achievement (i.e., Pacific Northwest National Laboratory; Hydrogen Safety Panel members; and SNL, which conducted the majority of work in a contract for the California Air Resources Board). It is unclear why this project is articulating an achievement by mere involvement and what technical achievement beyond participation the project provided.

Question 3: Collaboration and coordination with other institutions

This project was rated **2.7** for its collaboration and coordination.

- There is a large list of collaborators among standards developers, industry, and academia, both domestic and international. The project team appears to be well connected.
- The project shows very good collaborations with SDOs and international testing laboratories. However, more inputs from the industry will be required for testing activities at all component levels.
- The proposed future work areas are fantastic; however, there are an underwhelming number of project collaborators given the immense potential of the new capabilities (i.e., the Energy Systems Integration Facility [ESIF]) and previously spent efforts to develop project partners. The industry is a critical partner in this effort; this project seems entirely devoid of tangible and relevant industrial partners. This must be corrected in fiscal year (FY) 2014 for any benefit to result.
- This project/laboratory is “poised” to fill a gap in industry regarding the evaluation of components in a system-level, pure hydrogen environment. However, there are capabilities that exist through other nationally recognized testing laboratories (NRTLs) that need to be leveraged and coordinated with—especially given the fact that funds/budgets are tight. Capabilities of other NRTLs need to be investigated and coordination testing could be performed. Other laboratories have the capabilities to test some components. Given that the one purpose of spending DOE funds is to increase capability in the United States and build industry, pursuing collaboration with industry partners that currently provide third-party testing would serve this purpose. In addition, the third-party testing laboratories have staff that are trained and knowledgeable in testing products—to reproduce any of this at a national laboratory would put the laboratory in direct competition with industry/the private sector. Collaboration would provide the opportunity for the private sector to make manageable investments in what otherwise would be viewed as “high risk” activities. On slide 18, line 4.9 speaks of “certification and listing of components”—this is strictly the work of NRTLs, and NREL should not compete with the private sector. There is an “apparent” strong relationship between NREL, SAE, and NFPA. The presentation speaks of NREL working to provide “enforceable code language” for J2601. Similar activity needs to be initiated for other component-level national standards to drive “enforceable code language” for all systems and components where standards exist.
- The collaboration list does not appear to agree with the approach. The collaboration list implies a more expansive approach, which should be lauded.
- It would be good to see a much closer teaming collaboration between other activities supported by the DOE SCS program and outside SCS programs. There was mention of collaborative activities with others (e.g., the Emeryville incident and material mechanical component testing); creating a constructive teaming relationship with the appropriate parties rather than simply participating with other activities would strengthen this activity greatly. The project team should develop collaborative projects with others, such as by developing collaborative teaming activities. There is a perfect opportunity for NREL and SNL to team up on component testing and materials science and possibly other topics using the unique capabilities of NREL’s and SNL’s new fueling stations. Another example is the collaboration between NREL and the Joint Research Centre on sensor testing.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- This project fills gaps by providing shared capabilities that industry cannot yet maintain individually.
- This activity is very relevant to the needs of SCS and the general concerns of infrastructure rollout. This project should stay well informed with respect to the international community on component testing/qualification. The Japanese, for example, are very keen on the need to develop International Organization for Standardization (ISO) standards for station components.
- There is no doubt that component standard R&D is of high relevance for the rollout of hydrogen refueling stations. Components must comply with existing safety standards in the very short term and the new NREL

laboratory facility (the ESIF) will fully contribute to this goal. This project is therefore critical to the Program and DOE RD&D objectives.
- The emphasis on the component level to provide data to support compliance to existing standards is relevant to being able to use these components in deployed systems. Use of NREL's ESIF to test components is worthy. Showing incident and near-miss data from the Technology Validation program was eye opening in that most (appears to be about 90%) of the near-miss data—more than 200 near misses—showed major or minor hydrogen releases (with no ignition).
- Slide 20 states that "NREL will continue to work with codes and standards technical committees to identify R&D gaps and to utilize the ESIF laboratory to conduct basic engineering R&D aimed at closing technology gaps." A concern regarding the relevance and impact of this activity is that research dollars/space/time should be equitably allocated to the components that make up the systems. In addition, careful consideration needs to be taken to avoid competing with the private sector and to leverage knowledge and capabilities of third-party testing laboratories.
- The description of the approach does not represent the meat of the presentation. The meat is evaluating a generic fueling facility, determining the failure modes, and indicating where development work is required to reduce the safety risks associated with high-pressure gaseous systems. Outreach to the NRTLs is needed to assure them that NREL does not intend to compete with them, but rather provide support when requested by a NRTL.
- The unfortunate circumstance of this project is that it has incredible potential for impact to SCS efforts, but it has not delivered on that potential. There is a low degree of confidence that continued efforts, despite substantially improved capabilities (including the ESIF), will produce timely, trustworthy, or relevant results.

Question 5: Proposed future work

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

- The shift in emphasis toward safety and the reliability of components was a good idea.
- The project's good list of future test priorities includes compressors, flow meters, hoses, a vehicle nozzle receptacle, and materials in service.
- Several gaps have been identified with regard to research and testing that is needed at the component level to support standards revisions/development. If NREL works to collaborate and provide the research support needed for SDOs with component-level standards, the progress and future work is in alignment. Collaboration with third-party testing laboratories is critical to establishing capabilities in the United States.
- The establishment of the ESIF laboratory is excellent news. Its technical capabilities are huge and will help overcome many barriers to the goals. Future test priorities have been planned, but further details could have been provided (e.g., connections with the industry). It was difficult to get a clear idea from the presentation about future accomplishments and the associated timeline.
- The proposed future work areas are fantastic; however, there are an underwhelming number of project collaborators given the immense potential of the new capabilities (i.e., ESIF) and previously spent efforts to develop project partners. The industry is a critical partner in this effort; this project seems entirely devoid of tangible and relevant industrial partners. This must be corrected in FY 2014 for any benefit to result.
- The future plans for this activity are good. It is not clear whether NREL has the capability in place to provide the necessary analysis and experimental data to provide input into the needs of flow meter accuracy. It will be very important to understand the mass flow rate as a function of time over the pressure and temperature domain as specified by a SAE J2601 compliant fill. It appears that the device being made for California is an end-point device; it is intended to measure the quantity delivered after the delivery has completed, not to quantify the mass flow rate during a fill. The ability to accurately measure the mass flow rate as a function of time at the required accuracy (dictated by HB44 and J2601) is critically needed to correctly qualify any mass flow rate meter. This is a particularly challenging effort. To qualify a meter, the testing device needs to be at least 10 times more accurate. For example, this means to qualify a meter at 1.5%, the qualifying device needs to be 0.15% accurate. Someone in the project needs to do this, and it does not appear that this is in NREL's plans. The principal investigator should work on developing a well-thought-out, focused plan and developing testing priorities, among other items, to provide direction to this project.

- The future work is nebulous. The proposed work is limited to testing. The testing makes sense but does not appear to concur with the "approach." A clarification on the work being done would be helpful.

Project strengths:

- The testing and implied collaboration with the NRTLs are strengths of this project.
- This project has the potential to provide in situ testing of components in high-pressure hydrogen environments. This will provide information on hydrogen compatibility and suitability for high-pressure hydrogen environments.
- This project's strengths include the availability of ESIF, coordination with the Technology Validation data, and use of the wind-to-hydrogen project data.
- This project features effective information flow and fills gaps in resource-limited hydrogen industry capabilities, especially on the stationary side.
- This project's strengths are in its capabilities and potential to deliver near-term, high-impact results. These strengths are substantial and unfortunately further underscore the project's weaknesses and tepid results.
- Component testing is critically needed to advance the hydrogen infrastructure and to advance relevant regulations, codes, and standards. Basically, this project is well positioned to execute on this need. The new laboratory, when it is up and running, will clearly be a valuable asset to this community.
- Very good interactions with SDOs and national/international laboratories have been developed, which are clear strengths. The new laboratory facility, ESIF, is very promising and shows very high potential. This can provide a great leap forward in component R&D, thus overcoming most of the barriers. That is a very strong point.

Project weaknesses:

- The discussions on the project approach (goals) need some work.
- The presentation needed to elaborate more on the reasons for including the Emeryville incident.
- This project is still in its early phase and the results presented so far are still limited and lack consistency. A more consistent approach is needed to define clear, intermediate steps. Connections with the industry could/should be strengthened.
- There needs to be increased coordination/collaboration and support for the components and component-level standards that make up the system. Codes revisions need to be focused on installation issues, and the component safety requirements belong in the component-level safety standards. It is concerning that NREL is establishing "business" capabilities that will directly compete with private-sector, third-party certification laboratories. NREL needs to be in touch with these organizations to ensure they are not duplicating efforts/capabilities that already exist. Increased collaboration with existing laboratories is needed.
- The project's weakness is its inability to use the unique position of frequent interaction with potential industrial partners through substantial codes and standards participation to develop any project partners. With the commissioning of the new laboratory capabilities, there are high expectations for this project to deliver substantial results. Unfortunately, it appears that opportunities to acquire project partners in advance of capabilities have been squandered and that the principal investigators will need to double efforts in FY 2014 to both acquire partners and produce results.
- Some of this project's deficiencies could be because the project is relatively new and has a new laboratory. There is a strong need to team aggressively with others in the field to differentiate from simply participating. This will dramatically improve the quality/impact of the work, reduce overall cost, and help keep the work relevant and correct (cross-checking results).

Recommendations for additions/deletions to project scope:

- This project should deliver substantial results or face significant change considerations in FY 2014.
- The project team should improve teaming activities with other groups inside and outside the DOE SCS program.
- The project scope should be better defined, with clear milestones indicated.
- Leaks appear to be focused on the dispenser and compressor. In the stationary natural gas world, lines above 5 psi are required to be welded and instruments are seal welded or use non-tapered thread joints (i.e.,

pipe threads). It is unclear if the hardware tested meets the requirements in the B31.12 piping code. Compressor leakage is not surprising. Additionally, low mean time between failures would not be surprising for positive displacement pumping (compressors) hardware.

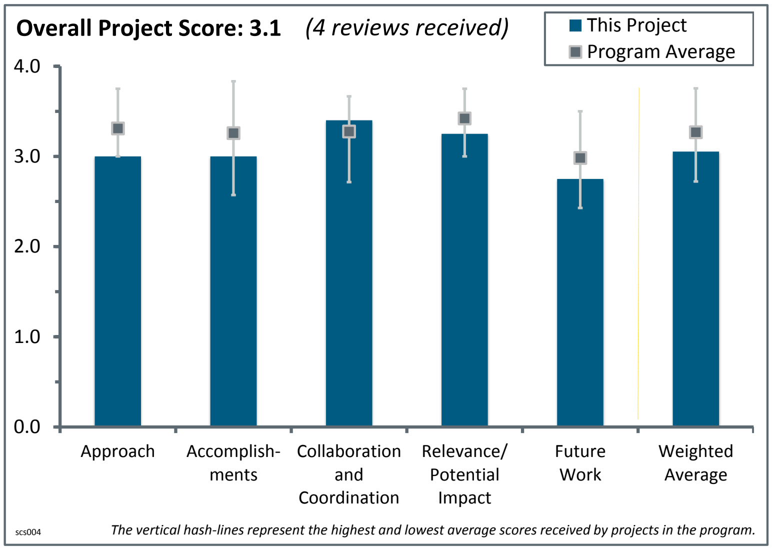
- It is important to stay one step ahead of industry. The project team may want to also add outreach at some point to transfer knowledge as industry grows and suppliers become ready to establish in-house capabilities.

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

Eric Brosha; Los Alamos National Laboratory

Brief Summary of Project:

The objective of this project is to develop hydrogen safety sensors for vehicle, stationary, and infrastructure applications and to demonstrate the technology through performance evaluation in simulated laboratory and field tests. Sensors are designed to be low-cost, durable, and reliable; they are subject to rigorous life testing to evaluate their performance in relation to codes and standards. Development of manufacturing methods and long-term testing in conjunction with industry partners will move the sensor technology toward commercialization.



Question 1: Approach to performing the work

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

- The approach adopted in this project appears to be focused and coordinated. Shortcomings in sensor performance, highlighted by the National Renewable Energy Laboratory's (NREL's) testing (e.g., anaerobic operation), are addressed coherently and with positive results.
- This project approach has all of the hallmarks of a national laboratory/industrial collaboration—strong scientific results, good milestones, and an industrial "off-ramp" leading to a commercial product and step change to the current commercial ecosystem.
- Over the course of the project, durability, reliability, and sensitivity issues have been identified and systematically addressed to come closer to the sensors required to assess hydrogen leaks and concentrations in and around vehicles in accordance with safety criteria specified in codes and standards, such as SAE 2579 and the hydrogen fuel cell vehicle global technical regulation (GTR).
- As a higher level comment on sensor R&D, there have been multiple issues regarding moving toward an approach that can be adopted by industry for various reasons. The lack of sensor manufacturers at the table who can be available for discussion within the working group and are willing to come forward to address potential standards issues hampers the work needed to roll out a solution for industry. Sensor manufacturers need to be involved.
- Sensor development must be driven by the needs identified by the end users and system integrators. The workshop's influence on the development R&D program seems minimal, at best. As a whole, it is not clear how the approach will lead to a sensor that meets the targets specified. If not carefully managed, this project could be an open-ended sensor technology development process.

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.

- It appears that good progress has been made toward understanding the limitations and issues associated with these specific sensor technologies.
- The accomplishments listed under the Round 2 testing at NREL indicate significant progress has been made toward objectives and overcoming barriers. The principal investigator summed up the

accomplishments as “faster, better, and cheaper,” if technologies are moved from prototypes to commercial products.
- The results demonstrated are worthy of praise. In terms of value, it appears that DOE’s contribution of approximately $5 million will produce a substantial benefit to the hydrogen and fuel cell industry and provide “backward compatibility” with the overall hydrogen and flammable gas safety market (a substantially larger commercial market in the near term). This “backward compatibility” is critical to the survival of sensor manufacturers ahead of vehicle deployments in 2015–2020. This project team has clearly identified that need and delivered a result that encompasses that critical aspect.
- Accomplishments toward the development of a sensing technology that shows promising selectivity to hydrogen, a robust working electrode, and resistance to changes in ambient temperature are encouraging. Accomplishments claimed in terms of “faster” and “cheaper” (unit cost) are difficult to evaluate based on the material presented. Nevertheless, the preparation for field trials and the focus on applying lower cost fabrication techniques suitable for mass production indicate the technology’s development in the right direction to achieve the objective to develop a low-cost, durable, and reliable hydrogen safety sensor for vehicle, stationary, and infrastructure applications.
- The sensor manufacturers need to be involved. In addition, standards need to be developed/identified that reflect the specific application for the sensor device.

Question 3: Collaboration and coordination with other institutions

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

- This project demonstrates excellent coordination and utilization of the developed sensor testing capabilities at NREL. This provides a good model for future sensor development efforts funded by the DOE Fuel Cell Technologies (FCT) Office.
- This project features lots of collaboration between agencies, with complementary expertise with sensors, industry, and end users.
- The partnerships established with national laboratories and industrial entities appear to be appropriately and effectively coordinated. The involvement of industry lends confidence in the sensing technology’s ability to reach commercialization.
- The collaboration is good. Unfortunately, there seems to be a continued miscommunication between the project team and the NREL test laboratory. In addition, it is difficult to determine if the industrial partners are small start-ups or developed companies with established market share. It is important not only that a balance exists, but that the technology transfer has a very good chance of surviving in the market.
- The sensor manufacturers need to be involved. In addition, standards need to be developed/identified that reflect the specific application for the sensor device.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- This project is very likely to be transformative to the industry and provide a usable product for many applications.
- Devices that ensure the safe use of hydrogen are critical for the success of the transition toward a low-carbon, hydrogen-inclusive society. Clearly the development of a robust, cost-effective, accurate hydrogen sensor will increase safety and accelerate confidence in hydrogen technologies.
- As evidenced in existing and draft codes and standards and through the hydrogen incidents database, sensors for mobile and stationary applications are absolutely necessary to ensure safety. It has been clear that at the outset, sensor technology was not sufficient to meet the durability, response time, and sensitivity requirements of various applications. Safety is the first requirement of the deployment of new technologies. For hydrogen fuel cell vehicles, hydrogen sensors are absolutely necessary to manage fire and asphyxiation hazards.

- It is not clear that sensor development will have a big impact on the deployment of hydrogen and fuel cells systems (especially in the near term). It is not clear that this specific technology deserves so much focus by the DOE Hydrogen and Fuel Cells Program.

Question 5: Proposed future work

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

- All future work in sensor technology development funded by the FCT Office should be competitively selected. This project provides a good template for how the NREL facility can be leveraged by future sensor technology development activities.
- Continuing field testing, developing test protocols, and seeking commercial development partners will be useful in supporting affordable introductory products to the marketplace. It is unknown whether costs will be acceptable and whether all barriers to commercialization will be addressed.
- It is important in the final year that the future work includes a summary of the effort, not just a smooth transition to industry without a summary of the lessons learned and broader impacts that safety devices (more than just sensors) might have on the industry.
- The expectation for the coming year is that the field trials will validate the sensor's performance under laboratory conditions. Such field trials will demonstrate the sensor's performance under real-life operating conditions. Continued independent testing by NREL is encouraged; however, whether this should include "developing testing protocols" is questioned. The focus should now be toward fine tuning and commercialization.

Project strengths:

- The collaborations with industrial partners are commended. The progression from laboratory testing to field testing is very encouraging and will test the sensor's real-life performance and provide a true test of this technology. The results from these field tests are eagerly awaited.
- The project team has a strong scientific competency in sensors. The project demonstrates good coordination with critical partners (e.g., NREL test facility).
- This project features great project management, good project partners, and a clear vision from start to finish with high confidence that the project will come in on time and on budget with a high likelihood of commercial success.

Project weaknesses:

- As a whole, it is not clear how the approach will lead to a sensor that meets the targets specified. If not carefully managed, this project could be an open-ended sensor technology development process.
- The influence of some species on the sensor baseline is of concern. This is particularly the case with CH_4, a species that may feature in future hydrogen applications such as refueling stations, where the influence on the baseline is extensive.
- It is unclear whether the industrial partners are robust enough to market and allow the substantial DOE investment to survive the next few years until light-duty vehicle deployment and the broader fuel cell market take hold. The principal investigator should articulate this in the final presentation in fiscal year 2014.

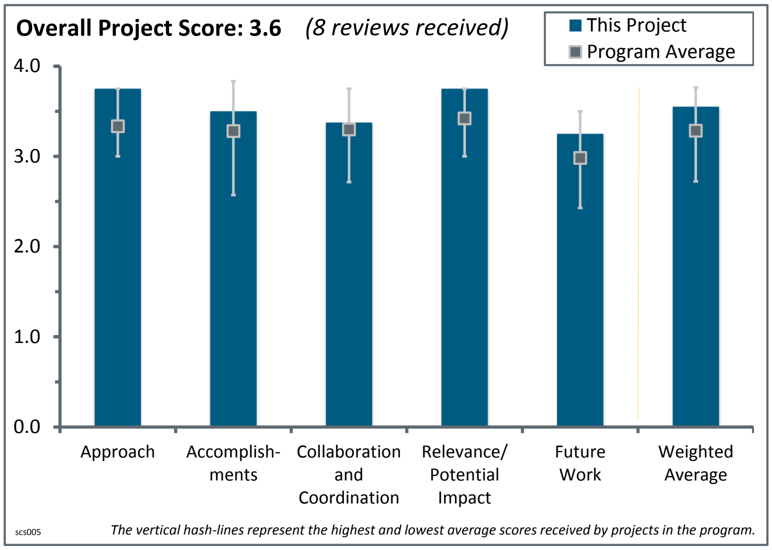
Recommendations for additions/deletions to project scope:

- All future work in sensor technology development funded by EERE should be competitively selected.
- Specific applications for these sensors are unclear, and it is also not clear whether there are specific cost and durability requirements for each application.
- The project team should further investigate cross-sensitivity to CH_4 to understand the unusual response to CH_4 observed in the presence and absence of hydrogen. Information on sensor manufacturing costs and indicative costs for maintenance/calibration would also be useful.

Project # SCS-005: R&D for Safety, Codes and Standards: Materials and Components Compatibility

Aaron Harris; Sandia National Laboratories

Brief Summary of Project:



The Safety, Codes and Standards program coordinates critical stakeholders and research to remove technology deployment barriers. The overall objectives of this project are to enable technology deployment by providing science-based resources for standards and hydrogen component development and to participate directly in formulating standards. The goals for fiscal year 2013 include developing and maintaining a material properties database, identifying material properties data gaps, developing more efficient and reliable materials test methods in standards, designing and qualifying the safety of standards for components and materials testing, and executing materials testing to address targeted data gaps in standards and critical technology development.

Question 1: Approach to performing the work

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

- The approach taken to address the barriers identified was presented very clearly, as was the relevance and importance to standardization. The importance of providing robust data for the development of effective standards cannot be overestimated. The project has provided such data and has proposed improved test methods.
- The work presents a logical structure, a logical approach, and logical involvement of relevant stakeholders. It contributes to filling necessary knowledge gaps.
- The approach is consistent with current industry practice.
- The project is addressing targeted data gaps, transferring data and conclusions to standards development activities, and providing effective international engagement to increase harmonization and reduce potential for competing requirements.
- Sandia National Laboratories (SNL) is using a valid approach to provide material/component data that will allow codes and standards to be modified or augmented. SNL is addressing several key compatibility issues including hydrogen effects on steel used in pressure vessels and hydrogen effects on welds. SNL is also working with standards teams. The approach appears to be a good one.
- The current approach is sound and accurate; however, it could be improved. It contributes to overcoming only some of the barriers. Researchers must develop the capability to test to -50°C or else the results are questionable.

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

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

- This activity clearly supports DOE Hydrogen and Fuel Cells Program goals.
- Good work has been done on materials that are of interest to industry. Learnings have been used as the basis for standards development.

- This project has featured very good accomplishments to date. SNL should be complimented on its leadership in accelerating and assisting in completing the hydrogen compatibility standards.
- Completion of the test matrix of two different steels is an important accomplishment. The fact that this has been done in collaboration with industry (steel suppliers) compounds its relevance to the industry. The investigation on the effects of welding practice on tensile ductility yielded interesting behavior. A deeper understanding of the reasons for these effects may be relevant.
- The work is still ongoing. The project team has made excellent progress in developing test methodologies to accelerate data generation without compromising data accuracy. This is important to fill data gaps where long-term testing would otherwise be required. It allows data gaps to be filled more quickly.
- The project addresses a number of challenges that have been identified. The progress in mechanical testing does not seem substantial compared to the previous year.
- SNL has found that crack growth for a lower strength steel is not affected as much by hydrogen pressure as a higher strength steel. However, it is not clear from the presentation whether the testing proves that steel strength is the reason. It appears that more types of steel should be tested. It is recognized that testing is necessarily slow. SNL has also shown that welds, due to their microstructures, are more likely to become embrittled by hydrogen than non-welded materials.

Question 3: Collaboration and coordination with other institutions

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

- There is great collaboration with the European original equipment manufacturers (OEMs) (i.e., Opel, BMW) and standards development organizations (SDOs) (i.e., Canadian Standards Association [CSA] and SAE International [SAE]).
- SNL is working with SDOs, industry, and international researchers; these are all necessary and proper for furthering the completeness and accuracy of standards. SNL is also working with universities, specifically using student design teams. Training the next generation is always good.
- The project focuses not just on research and development, but also on active participation of project personnel in SDOs—this is highly commended and facilitates the direct injection of the results of this scientific research into standards. More explicit information on the nature and degree of the collaborations with the named industry partners would be useful to critically evaluate the effectiveness of these collaborations.
- It is excellent that project members are participating directly with appropriate standards development committees. One slide provided for reviewers only (Critical Assumptions and Issues) notes the following: "We must maintain and expand relationships with industry partners and SDOs not only so that we have a supply of materials but also access to their input into materials testing parameters." Active participation in Fuel Cell and Hydrogen Energy Association (FCHEA) working groups may be a suitable way to achieve this. SNL is already a member of FCHEA and has access to the working groups.
- Collaboration covers the correct range of stakeholders, both for guiding the issues to be addressed and for dissemination to safety, codes and standards (SCS) committees. Because hydrogen embrittlement and compatibility issues between hydrogen and materials in general have been widely investigated in the past by a large number of research programs across the world, it may be useful to identify in the presentation the efforts that have been made in exploring the relevance of this body of knowledge for the Safety, Codes and Standards program to avoid duplication with earlier work.
- The National Institute of Standards and Technology (NIST) (Colorado) is doing similar work. It would be preferable for SNL to collaborate with NIST and other researchers to avoid duplication and possibly share equipment and tooling to reduce cost and expedite data generation by minimizing non-recurring engineering costs (set up time, fixtures, etc.). ASME might be a good venue for this coordination. It is public and would hopefully be the beneficiary of the research (via inclusion in the pressure technology codes).

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- This activity is clearly relevant for a hydrogen infrastructure.
- The direct input of robust, independent scientific research into standards is essential. This project contributes positively to standards development and the material properties knowledge base.
- Filling gaps in the knowledge of materials behavior in a hydrogen environment and feeding the information into standards and code development organizations is a necessary precondition for technology deployment.
- A solid understanding of materials behavior in intended hydrogen operating environments is crucial as industry shifts from small-scale demonstration toward commercial volumes with optimized designs.
- The methodologies allow data development of critical gaps in knowledge. The results of the work on welds are relevant and unique. The results help answer many questions from the technical community on pressure vessel and hydrogen system construction.
- SNL was a key reason why the appendix SAE J2579 was so successful.
- There is obvious relevance; there is a need for data that will allow standards to be set. The presentation implies this but does not state it. However, the emphasis on targeted data was stressed many times and focuses the project in relevant areas.

Question 5: Proposed future work

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

- The proposed future work seems to build suitably on the work performed to date. Complementary work in direct collaboration with industry would give added value.
- SNL is looking to continue the mechanical properties work to further the understanding of crack initiation and growth in materials and welds. Most of the future work seems to focus on this important area.
- Project principals are documenting work done so far; it will be good to read about the details of the work.
- Researchers must show a plan when -50°C capability will be possible.
- The majority of the proposed work makes sense. It must be pointed out that pipelines operate in a small temperature band, but storage, pressurization equipment, and appliances see a much higher range (i.e., -40°C to 85°C for vehicles, and up to 500°C for hydrogen generators). The effects of temperature should be examined.
- To enhance the transferability of laboratory results to real-life applications, the project should consider screening the effect of residual stresses in the fatigue test program. The relevance of testing weldments (1) under pre-charged conditions rather than directly in a hydrogen environment and (2) in short-term tensile tests only should be explained and justified. An explanation should be given on the need for and relevance of testing in hydrogen under variable temperatures.

Project strengths:

- This project is doing fundamental work on materials in hydrogen applications unique to transportation or early hydrogen and fuel cell markets.
- This project features effective interaction with SCS bodies.
- Strengths of this project include its communication with industry, analytical methods, and integrity of data.
- A solid scientific approach is adopted in this project. The direct relevance and input to standards development is clear.
- The collaboration with ASME and the pipeline needs are strengths of this project.
- This project is making it possible to fill data gaps more quickly than previously possible. Other strengths include how it is focused on the highest impact data and its direct involvement in standards activities to transfer data.
- This project features a good collaborative team with the International Institute for Carbon-Neutral Energy Research (I^2CNER). Another strength is how it is getting international "buy in." Obtaining sufficient

information on specific hydrogen effects on metals and alloys as functions of temperature, pressure, and concentration is very important.

Project weaknesses:

- This project features limited testing capability to date.
- Stronger direct support to industry would strengthen this project (i.e., relevance to industry needs).
- The project team must show the capability to test at -50°C to have credibility for embrittlement testing.
- The data on two steels is not enough to draw conclusions about steel strengths versus crack growth.
- Weaknesses include the lack of collaboration with other government-funded related research and limited data at alternative temperatures.
- This project is not as comprehensive as it could be with sufficient resources and time. While it is not possible to test every material under every condition, the presentation spurred a desire to see more. More direct and focused discussions with the fuel cell and hydrogen industry may aid in identifying parameters of greatest interest and in obtaining suitable materials.
- To clearly demonstrate the lack of potential duplication with related research elsewhere in the world, clear identification should be given of how the project’s work plan is different. This includes gaps identified, specificities and/or complementarities addressed, etc.

Recommendations for additions/deletions to project scope:

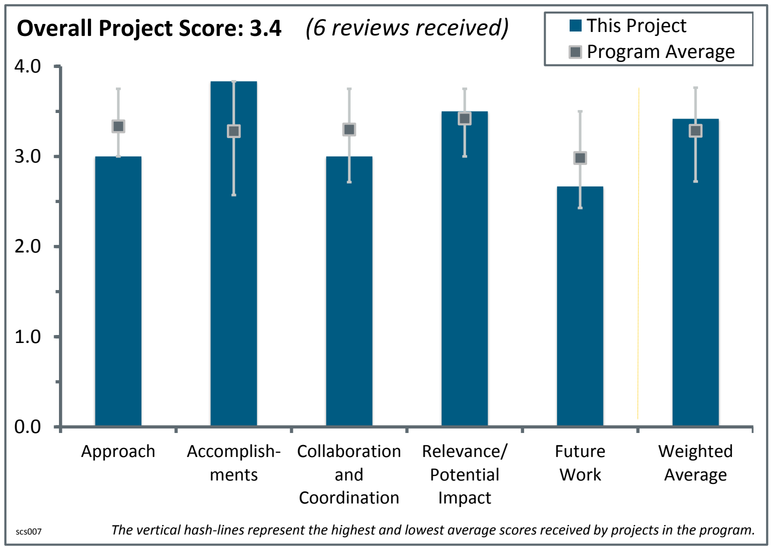
- This project should address the weaknesses identified by reviewers.
- Further investigation of the influence of welding practice on material properties may yield useful information.
- In addition to addressing weaknesses, the project team should assist in the harmonization between SAE and CSA, especially with regard to the accepted stainless and aluminum materials list proposed by the OEMs.
- The project team should pursue more publication of research and preliminary results and conclusions to enable review and feedback for future work. This may also facilitate additional research by others to both validate and expand upon this project. It would be nice to see some data over a larger temperature range.

Project # SCS-007: Hydrogen Fuel Quality

Tommy Rockward; Los Alamos National Laboratory

Brief Summary of Project:

Qualifying the hydrogen fuel grade for polymer electrolyte membrane fuel cell (PEMFC) systems is a priority to ensure fuel cell viability. Minimal amounts of impurities are detrimental to the performance and durability of PEMFCs, and an in-line hydrogen analyzer to continuously monitor impurities is needed. The objectives of this project are to develop an international standard for hydrogen fuel quality by determining levels of impurities that become detrimental to fuel cell performance and to demonstrate proof-of-concept of an electrochemical analyzer designed to detect impurities.



Question 1: Approach to performing the work

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

- This project has three approaches (goals). The presentation is divided into three sections. This is a wise approach.
- The work on the in-line analyzer is much needed. It will be good to see its implementation at a station.
- Great work has been done, but at some point a cost trade-off model should be added to the project to look at the balance between stack cost reduction (reduced platinum loading) and fuel costs (increased purification effort). In addition to studying the effects of the maximum allowable impurity levels, the project team should also look at "expected" impurity levels.
- This is very important, good work. The only concern is with the in-line fuel quality analyzer. It is not clear that attention is being given to the final cost of the technology. If this is going to be widely implemented in dispensers, then the technology needs to be cost effective. The principal investigator (PI) needs to address this issue, and if the technology cannot meet a reasonable cost target, then this needs to be addressed. A techno-economic analysis really should be made to ensure that this will yield a cost-effective solution. Priority should be given to this part of the project. The measurement of fuel quality as delivered is necessary for a successful rollout of the infrastructure, which is targeted for 2015–2016—less than two years from now.
- The approach for publication of ASTM methods is unclear. There is no project plan for the interlaboratory study (ILS) (precision and bias statements) process for each standard test method. This needs to be addressed. Although these standards have been published, very few, if any, laboratories know how to use these methods. Without laboratory capability to test hydrogen contaminants at the levels required by ISO 14687-2 and SAE J2719, the fuel quality standards, and now regulations, are moot. It is unclear what the project plan is for moving ASTM standards through ILS and getting more laboratories set up to test hydrogen to these levels.
- The approach suffers from distracting priorities. The work should either focus on developing an in-line analyzer or work in membrane electrode assembly (MEA) impurity testing. At this point, MEA work should fall under the Fuel Cells program, not the Safety, Codes and Standards (SCS) program. In-line analyzer development and test method round-robin efforts are closely aligned and would greatly benefit the industry. If this project were to refine the approach and use the sensor testing effort at Los Alamos National Laboratory (LANL) as an example, a significant accomplishment could result. This would require

refocusing the project to identify potential commercial partners for this analyzer and dedicating efforts toward that end. This is the best option for this project.

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.

- LANL is without a doubt one of the most highly regarded hydrogen quality experts. The testing being conducted and methodologies being developed are innovative.
- The progress and accomplishments to date meet DOE goals.
- Participation with ASTM and completion of ISO 14687-2 are very good and important accomplishments. The attention to fuel quality effects on stacks is a natural next step; this is also an important teaming opportunity with others in this area (e.g., the Joint Research Centre [JRC]).
- Full standards for hydrogen fuel quality are now in place.
- It is clear that the technical competency of this group is world-class. Progress toward the goals should be refined to focus the efforts, perhaps by bifurcating this work into a Fuel Cells project examining the MEA impact of impurities and an SCS project aimed toward an in-line analyzer.
- There is a need to better communicate these successes to those in the fuel cells world (but outside of the "hydrogen quality" world) as a message to policymakers that progress is happening.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.0** for its collaboration and coordination.

- The emerging relationship with the Japan Automobile Research Institute (JARI) is very encouraging. It would be good to see this activity also team with other international entities that are working on (or will be working on) fuel quality issues on stacks. The efforts with the standards organizations are excellent.
- Regarding the comment from last year's DOE Hydrogen and Fuel Cells Program Annual Merit Review on collaboration, this is a good start. Perhaps there is an opportunity to collaborate with others (e.g., Germany). The project team should maintain contact with industry stakeholders as a "check" on synergy between the "real world" and research.
- The collaboration with various institutions is adequate. The lack of feedback to the SAE J2719 team is a notable oversight.
- Contributions and collaborations from project partners identified on the opening slide were not clearly detailed in the subsequent presentation, except for a scoping meeting with JARI and, of course, the work with ASTM. This project would substantially benefit from deeper collaboration with industry, particularly if the suggestions to focus on developing an in-line analyzer are followed.
- There was no apparent collaboration with laboratories conducting hydrogen quality sampling in the real world, such as Atlanta Analytical and Smart Chemistry. It is unclear if the project team has identified the needs of these laboratories and how the project can provide support. The project team could use its expertise to help other laboratories, such as California's Division of Measurement Standards (DMS), which will be required by law to regulate the quality of hydrogen. It is unclear if the project team has worked with California DMS. Also, on slide 24, JARI highlighted the need to look into particulates. It is unclear if the project team is doing any work on that, or if there is a plan for particulate work.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

This project was rated **3.5** for its relevance/potential impact.

- LANL's innovation and expertise in hydrogen quality is and has been very influential for determining constituent levels in fuel.

- The effects of fuel impurities on PEMFCs and the requirements to minimize certain impurities in hydrogen set the requirements between the station and the vehicle. This is the key link between fuel provider and fuel consumer.
- This work is critical for implementing hydrogen infrastructure and fuel cell vehicles (cars, buses, etc.) and needs to keep a rapid pace. If additional personnel are needed, it seems appropriate to allocate the funding.
- Fuel quality standards for delivered fuel are a necessary element for the commercial sale of hydrogen and for the performance of the stack. This work is spot on, and it is recognized globally for its contribution to the standards community.
- Researchers need to look at cost trade-offs. The requirements seem somewhat one-sided from the stack perspective versus the fuel provider perspective.
- The opportunity for impact from this project is substantial if it can refrain from becoming distracted by efforts in characterization of MEAs (which appears to be a legacy activity now caught in an SCS project—a bad omen from a project management standpoint). The utility of a commercial product in-line gas analyzer in the next 3–5 years is a substantial need within the industry and perhaps represents a “step change” innovation for the commercial sale of hydrogen (a potential barrier to vehicle deployment).

Question 5: Proposed future work

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

- Researchers should add a cost trade-off model.
- The project team should try to keep some focus on near-term needs, along with innovative advancements.
- There is no clear project plan for the ASTM standards.
- The focus on NH_3 and CO as a function of catalyst loading is important. The focus on H_2S as a function of catalyst loading is not. Experience shows that sulfur is either present in large quantities or not present. Thus, additional data on the effects of sulfur concentration versus time and catalyst loading may not be as profitable as data on the effects of the other impurities, which are generated in the fuel processing. Recovery techniques that can be done on the vehicle would be very useful.
- It would be good to see an economic analysis and/or a discussion on the cost effectiveness of the in-line analyzer. The commercial development of such an analyzer is critically important to the commercial sale of hydrogen. The clock is ticking—indeed, one can argue that this development is already late. With that said, it is strongly recommended that the analyzer development effort aggressively seek an industrial partner suited to the commercialization of this technology, positioning it for deployment during the early rollout of a hydrogen infrastructure. In addition, it would be good to see outreach to others proposing work on fuel quality effects on stacks, such as JRC.
- This project suffers from competing technical interests—MEA characterization for speculative loading targets and gas quality analysis and analyzer development. The project should have identified this growing distraction and suggested steps to address it. If this issue is not addressed, this project will likely under-deliver on both technical areas, thus missing the potential impact of a more focused project. In short, the technical aspirations of the project are spread too broadly for the available resources for the project and the overall scope of the funding available to the Fuel Cell Technologies Office.

Project strengths:

- This project is the basis for successful implementation of hydrogen fuel quality standards.
- This project’s strength is the project team’s expertise.
- Focus and dedication are the strengths of this project.
- The ASTM D03.14 work (publications) and in-line analyzer work show great alignment with near-term/real-world needs.
- This project’s strengths are the project team’s technical aptitude and capability to produce transformative commercial product prototypes in gas analysis at LANL, as demonstrated by the SCS-004 project presentation.
- This PI has been working on fuel quality effects on membranes for several years. The contribution to this very important problem is very good and well recognized. This project is making a significant impact in the

field and is satisfying a very important need. The participation in relevant standards bodies and leadership provided in these bodies (i.e., ASTM) is excellent.

Project weaknesses:

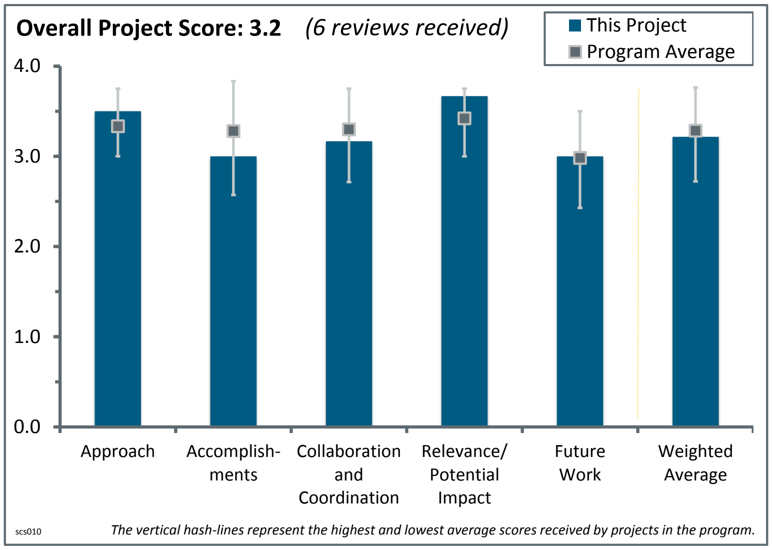
- The reluctance to put sulfur to bed is a weakness of this project.
- Perhaps this project needs more support in terms of person hours/personnel.
- It is concerning that attention to the cost practicality of the in-line analyzer has not been explored; at least, it did not come out in this review. An industrial partner to accelerate the commercialization of the in-line analyzer needs to be found.
- It would be good to see cost analysis—stack materials costs versus fuel purification costs and respective impacts on total vehicle cost of ownership. It would also be good to see data on actual contaminant levels in fuel streams from state-of-the-art hydrogen supply chains and dispensing equipment.
- This project suffers from competing technical interests—MEA characterization for speculative loading targets and gas quality analysis and analyzer development. The project should have identified this growing distraction and suggested steps to address it. If this issue is not addressed, this project will likely under-deliver on both technical areas, thus missing the potential impact of a more focused project. In short, the technical aspirations of the project are spread too broadly for the available resources for the project and the overall scope of the funding available to the FCT Office.

Recommendations for additions/deletions to project scope:

- The project team should put ASTM standards through ILS to train laboratories and share its expertise.
- The project team should investigate the cost effectiveness of the in-line analyzer. The work needs to be on track to develop a low-cost, effective device. An industrial partner to accelerate the commercialization of the in-line analyzer needs to be found.
- The project team should focus on the tolerance of cells at various catalyst loadings to process impurities (not housekeeping impurities such as sulfur) and recovery techniques for all impurities that can be incorporated into the vehicle design. A previous DOE-supported contract was a quality control process improvement project (ION Power) that might include periodically supplying improved MEAs to the researchers.
- The project team should delete the project scope for MEA characterization at low platinum loading levels. This is the right technical group to perform this work but the wrong FCT program to fund this effort. This should be done under the Fuel Cells program, which would allow this work to better align with all of that program's efforts in low platinum targets. The researcher should add the development of a commercial in-line gas analyzer to the project scope to help target both the round-robin test method validation and the in-line gas analyzer efforts toward a "Specific, Measurable, Achievable, Relevant, and Timely" (SMART) project goal.

Project # SCS-010: R&D for Safety Codes and Standards: SCS Project Overview – Hydrogen Behavior

Aaron Harris; Sandia National Laboratories



Brief Summary of Project:

The objectives of this project are to conduct experiments to understand dominant release, ignition, and combustion phenomena for unintended hydrogen releases and to provide data for the development and revision of regulations, codes, and standards (RCS), as well as best practices. The research will support consequence analysis in the "risk informed" approach, model release dynamics from relevant leak scenarios, determine ignition and flame-up probabilities, and quantify thermal radiation and overpressure hazards. The research will address the lack of safety data and technical information relevant to the development of codes and standards (C&S) for hydrogen delivery.

Question 1: Approach to performing the work

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

- This project features a good approach.
- This science-based approach is quite relevant for the development and revision of hydrogen safety C&S. There is no doubt that the conducted experiments (e.g., noncircular openings) and the project's inputs into the integrated quantitative risk assessment (QRA) toolkit (via the consequence module) address critical barriers.
- The research being done on characterizing gas dispersion is important to supporting the development of C&S requirements. The "science" has been missing for quite some time in this area and different propagation and mitigation methods need to be modeled and validated in order to understand what could happen once the systems are installed. This work will also support first responders and repair and maintenance technicians in understanding how they approach leaks.
- The approach is comprehensive, scientific, and clearly targeted to inform RCS that govern hydrogen leakage, dispersion, and ignition under comprehensive use conditions. Continuing support for the integrated QRA algorithm will continue to increase confidence in accurate predictions of the consequences (and causes) of hydrogen release.
- The project fits into a well-defined overall concept (namely an integrated QRA algorithm) that aims to address and quantify the effects of unintended hydrogen releases in general. The oral presentation mentioned that the special consideration of separation distances is but one of the applications of the approach; however, the information contained in the slide presentation seems to unduly emphasize this particular application.
- Hydrogen behavior, particularly with hydrogen releases, has been identified by industry, both nationally and internationally, as an important aspect to ensure safety in design and installation. This project leveraged data and used it to improve data sets and the accuracy of QRA. It will be clearer how this work addresses critical barriers when it is complete and can be implemented by stakeholders.

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.

- Good progress has been shown.
- This project is still in the discovery phase of understanding and characterizing different leak modes and their effects and ignition distances. Further research to develop a base understanding of how hydrogen behaves is important. Good progress has been made to date.
- This project meets the Safety, Codes and Standards (SCS) program goal of performing high-priority research and development (R&D) that benefits C&S data needs. Data goals seem to be progressing well. A concern for this project is that in order to support consistent RCS, much more outreach is required in the form of publications and presentations to stakeholders, both nationally and internationally. This is needed to inform stakeholders about the work and to solicit feedback that helps identify any potential inconsistencies with outside research and shape future work.
- The broad scope of hydrogen behavior as it relates to the different industry partners—including component, cylinder, and automotive manufacturers; fuel suppliers; stations; local authorities having jurisdiction (AHJs); standards development organizations (SDOs); and end users—breaks this project down into several areas. The project is a long one, spanning 13 years. Every year there are additional technical accomplishments in various areas, with various collaborators, that are pulled together through harmonization efforts. Accomplishments are on target for data-driven C&S in all of these areas (with regard to large hydrogen releases).
- The integration of the consequence analysis module into the QRA algorithm represents excellent progress. Good progress has been made with regard to data collection and the development of the different modules (overpressure module and radiative heat transfer model). However, it is difficult from the presentation to really assess the level of progress on these modules and the associated gaps. Also, no slides were presented that highlighted the current progress made in terms of impacts to RCS and harmonization. Good results have been obtained from ignition probability experiments, but they were not addressed during the presentation. These accomplishments should have been incorporated in the main presentation rather than in technical back-up slides. The future integration of the results stemming from the noncircular opening experiments into the QRA toolkit could have been discussed in more detail. Fast-fill experiments and modeling activities were conducted in fiscal year (FY) 2012. It is unclear if this research work stopped in FY 2013.
- The work definitely addresses DOE Fuel Cell Technologies Office and SCS program goals. However, it is unclear from the presentation whether and to what extent the items for future work that were identified in the 2012 DOE Hydrogen and Fuel Cells Program Annual Merit Review have been addressed, and what progress has been achieved with respect to those items. This comment applies both to the R&D and the input that the project has provided to SDOs.

Question 3: Collaboration and coordination with other institutions

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

- The collaboration with other national and international institutions is outstanding.
- The project has very good collaboration with international private and public partners that have great experience in hydrogen behavior experiments and modeling. However, the slide on collaborations only provides a list of names; additional information could have been provided about the type of collaboration and how this benefits the project.
- The project features good industry support; it needs to include SDOs and the Fuel Cell and Hydrogen Energy Association in the mix to understand how this can support the research done by manufacturers. SDOs can act as the buffer between the specific needs of the integrators in driving research that will meet their needs. Organizations such as the Compressed Gas Association (CGA) and CSA Group should specifically be included in these discussions because they are the SDOs that represent the industry's voice. There is apprehension with the station integrators in regard to operating outside of the published code

requirements. There is general agreement that the code requirements are very conservative due to the risk of litigation in the event of a catastrophic failure.

- The collaboration with the relevant groups is good; however, it is unclear what level of involvement the partners listed on the Overview slide actually have. It is not clear if there are defined roles for these partners or whether they are simply groups that have been identified as stakeholders with whom formal or informal channels of communication have been established. It is not clear how the collaboration with the International Energy Agency (IEA) Hydrogen Implementing Agreement (HIA) Task 31 impacts RCS. A sentence or two on this would be useful. One or more papers published on the subject would help connect a few dots. It is important to distinguish between IEA Task 31 and IEA-HIA Task 31. More discussion on how the collaboration efforts further the aims of the project may be beneficial.
- Though much U.S. collaboration has been shown, the collaboration with the newly formed International Organization for Standardization (ISO) TC 197 hydrogen technologies working group needs to take place. There is a major rift between the setback distances in Japan, the United States, and Europe. QRA is not widely accepted, and before the project concludes it must not only investigate the National Fire Protection Association approach, but also the approach used in other European countries and in Japan.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- The project addresses a critical step in an overall approach for acceptance of hydrogen fuel cell technologies.
- This project meets the DOE objective of performing high-priority R&D. It also helps to develop science-based requirements for RCS.
- The research and collaboration here are very relevant to the goal of safe deployment of hydrogen vehicles and infrastructure. More research is needed to address the safety of cryogenic hydrogen.
- This project addresses technical gaps that are critical to DOE's objectives through experiments/modeling (and validation) of hydrogen release behavior that is crucial for the development and revision of C&S. Support to the QRA process development (project SCS-010) through the integration of reduced order models (consequence analysis) is of high relevance.
- Siting and supporting the AHJs is critical to the successful launch. This research will hopefully go directly into the codes to provide greater confidence for safe placement of on-site fuel storage. Further research on different plume dispersions as well as liquid fuel releases needs to be done to complement the work that has been done on compressed fuel. Separation distances have been and continue to be a big barrier to installing hydrogen stations in public access areas. Right now the separation distances are so large that the typical refueling station property is not suitable to provide the necessary room for storage and other forecourt equipment. Reducing setback distances will be important if hydrogen is to be placed in existing locations.

Question 5: Proposed future work

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

- The proposed future work aims to improve past technical accomplishments and the QRA toolkit, which offers support for international research collaboration and RCS harmonization.
- It is critical to expand the research to include other types of fuel releases and modes to further the knowledge base for station designers and ensure safe placement of fuel storage devices and piping. The plan is still quite open because the project is still in the learning phase. Once the base research is done, a more deliberate plan on how the research can be pragmatically applied to the codes and other outreach papers will be important. Also, it will be critical to develop more quantitative risk values that can feed into the QRA model.
- The proposed future work is consistent and will provide valuable inputs to the consequence analysis for QRA. However, given the complex nature of the project, the research gaps to be filled should be prioritized. Significant progress is necessary with regard to the radiative heat transfer and ignition probability models in support of the QRA toolkit. This was not stressed enough during the presentation.

- This was an OK proposal, but this QRA approach must be judged by more of the industry (perhaps also by members of the fueling community, such as oil companies and more hydrogen providers) than what is listed in this presentation.
- The project focuses on quantifying consequences of unintended releases on humans (in particular, health). It is definitely correct to emphasize this first. However, in the future, the effects on neighboring infrastructure, equipment, and installations should also be investigated.
- The effect of gas temperature is planned to validate QRA models, including the overpressure reduced order model. An investigation into sustained flame and efforts to produce accurate prediction of conditions that lead to jet light up will also be conducted. This project is presently planned to be completed in September 2015. It is not certain that the goals will all be realized by that time. Additional time for feedback loops and additional follow-on that may be identified may be warranted. Feeding the results into RCS activities that have multi-year development cycles will be a critical activity to meet the goal of impacting C&S.

Project strengths:

- This project is analytical and features good planning for model validation.
- This project's strengths include its scientific competence and thoroughness, both experimental and numerical.
- This project features in-depth research and experiments to validate data and models and to begin to fill in data gaps.
- The research collaboration, support for C&S development, and international harmonization efforts are all excellent.
- This project feeds directly into the output of the QRA model—this is a good attempt to provide quantitative risk values. The project team needs to run more scenarios.
- The project team has great experience in conducting experimental and modeling research activities on hydrogen release behavior throughout all stages. The researchers have also developed very good collaborations all over the world, which is a clear strength. The outcomes of their research are of great importance for both the industry and SDOs through the revision/creation of standards.

Project weaknesses:

- Researchers still face challenges regarding equating this work into the codes, which is a driver for this work. This research cannot be used as a basis for code development—it is a good understanding of the physics. The models will need to be tested and vetted.
- Not enough information about the work is easily accessible to the public. It would be good to see more frequent publication with focused topics to help a general audience understand the importance of the work and the impact of the research. It is unclear how some of the collaborations are working.
- The project team should conduct more work on cryogenic release.
- The project is relatively complex and ambitious. The researchers should make efforts to simplify/clarify the objectives and provide a comprehensive overview of the progress made so far and of future plans. For instance, no information was provided about the research activities on fast-filling that were presented last year.

Recommendations for additions/deletions to project scope:

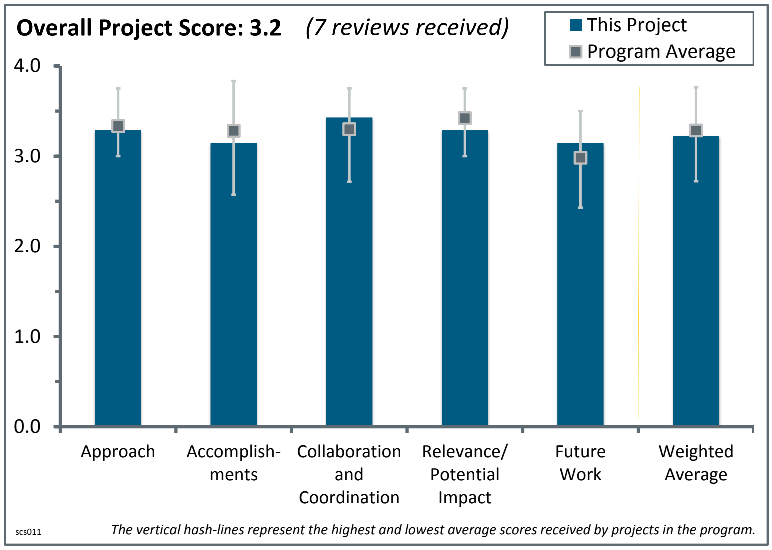
- Because of the conservative nature of the gas suppliers, gaining their direct support for this project will be difficult. Their direct input will be needed in order to make this successful. The project team needs to consider including underground storage in the fuel storage matrix.
- This project needs more frequent and widespread publication and outreach, as well as more time for following RCS activities through multi-year development cycles.
- There is a lack of international coordination, especially with ISO TC 197.

Project # SCS-011: R&D for Safety Codes and Standards: SCS Project Overview – Risk

Aaron Harris; Sandia National Laboratories

Brief Summary of Project:

The objectives of this project are to develop and demonstrate methodologies to support the use of quantitative risk assessment (QRA) as a tool for development and revision of regulations, codes, and standards (RCS), as well as safety best practices. The project will address the lack of safety data and technical information relevant to the development of codes and standards (C&S). A QRA toolkit will be developed through identification of risk drivers and their associated consequences. Engaging with stakeholders will build awareness of QRA and related activities to reduce risk.



Question 1: Approach to performing the work

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

- The approach adopted in this project is robust and focused. The project has made major progress in communicating the usefulness of QRA to the hydrogen community.
- The project team used a pragmatic approach to pursuing the goals that were in alignment with U.S. Department of Energy (DOE) objectives. The approach was aligned with industry needs and kept industry involved throughout the process.
- The use of QRA as a tool is critical to assuring safety without relying on overly restrictive requirements. This project includes significant engagement with the relevant industry and regulatory stakeholders. The project also developed algorithms to facilitate tools for enabling access to the data. It is good that the data algorithms are being developed by the same organization that developed the QRA model. This increases confidence that any resulting tools will represent the data accurately. Development of the algorithms also appears to have facilitated refinement of the risk model.
- The approach has been integrated with other efforts, specifically the hydrogen behavior program, to apply risk assessment techniques for use in the development of C&S and best safety practices. Engaging stakeholders to use the QRA to inform RCS aids harmonization and increases confidence in safety metrics.
- The approach is very good. Although somewhat complex, this integrated QRA process combines all processes into a single code. The consequence module will be regularly improved thanks to research and development efforts from the hydrogen behavior task (project SCS-010), which is a very good point.
- As outlined, the overall approach—as well as its breakdown into a number of consecutive steps—is targeted at establishing a validated QRA toolkit. The availability of such a toolkit constitutes an important element for customer and public acceptance of hydrogen technologies. The work presents a logical structure, approach, and involvement of relevant stakeholders. It contributes to filling necessary knowledge gaps. Once the tool is available, measures should be put in place to ensure that the strength of the tool cannot be "abused" by non-specialists using it in an incorrect way.

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 project team quantified an approach to risk that outlines risk assessment in the environment that is within this application. The QRA model was actually represented.
- Progress is noteworthy in terms of reaching DOE goals for increasing access to and the availability of safety-related information and data, as is the project's contribution to the development of C&S. Use of the fatal accident rate (FAR) metric conveniently allows risk comparison with other industries. The project is successfully creating a toolkit to provide robust and reasonably accurate results to the user.
- This year, the researchers have developed a QRA toolkit to provide results for specific scenarios that should be addressed in RCS. They have applied the QRA toolkit to the indoor fueling scenario, have improved the previous QRA process by including the FAR metric for comparisons to other industries, and are developing a hazard to harm module.
- It is acknowledged that this work is not the end product; however, the work is required to develop the tools that put the data within easy reach of users. This work is unique and will enable the data developed over the past few years to be used in QRA toolkits. Future work for acquiring user feedback and improving the toolkit is an important step in getting the data in an easy-to-use form into the hands of users. This will facilitate installations.
- The project has demonstrated good accomplishments. In addition to the creation of the integrated QRA algorithm, significant progress has been made through the estimation of the FAR for comparisons to similar industries, and the integration/developments of modules. However, the predicted FAR value is obviously subject to many uncertainties that could have been mentioned during the presentation. Although partly covered in SCS-010, it would have been interesting to see the progress made on the development of ignition probability models, which are critical for such analysis. Also, one slide could have been presented highlighting the main differences between QRA v.0 and QRA v.1 (and the upcoming versions).
- The project strongly contributes to the Safety, Codes and Standards (SCS) program goals. However, for the reviewers to be able to express a judgment on the achieved progress as well as on the efforts deployed in achieving it, the presentation contained insufficient detailed information on progress regarding the topics identified for further work in the 2012 DOE Hydrogen and Fuel Cells Program Annual Merit Review. It is suggested to include a traffic-light table on the identified topics of future work in the presentation. It is not clear how and to what extent frequency data provided by industry partners have been considered and used. Although the importance of having access to reliable "denominator numbers" was stressed in the oral discussion, no information has been provided on whether the provision of such data has been successful (i.e., whether it has proved fit-for-purpose) and sufficient.

Question 3: Collaboration and coordination with other institutions

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

- This project features collaboration with national and international stakeholders, standards development organizations, and government regulators.
- This project shows very good collaborations and is connected to many industry and research partners. Support and feedback from the industry will be essential for the development of the QRA toolkit.
- The outreach activities of the project and the input of feedback from stakeholders appear to be an effective way to further develop and improve the QRA toolkit. Activities such as the International Energy Agency workshop provide tangible means to evaluate whether the research coordinates with industry and other stakeholders needs.
- The principal investigator continues to seek out collaborators to further develop his model. He should collaborate with the natural gas vehicle (NGV) industry and compressed natural gas (CNG) utilities because they have real application data for this type of environment—this can be the basis for qualifying similar models for hydrogen where the data set is limited.
- This step—collaboration and coordination with other institutions—will become more important with the next stage. The QRA toolkits will be limited by the data sets available to the users. The principal

investigator suggested that this is a limitation that the researchers would like to continue to address. This is good, and it will be nice to see healthy discussions of relevant stakeholders to minimize limitations and increase take-up of the tools.
- Collaboration covers the correct range of stakeholders, both for guiding the issues to be addressed and for disseminating information to SCS committees. It is strongly recommended to have the tool "vetted" by other experts who are not involved in the current project.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- This project provides feedback for revision to codes task groups on specific hazardous scenarios.
- The project addresses a critical step in an overall approach for the acceptance of hydrogen fuel cell technologies.
- There is a need to develop a quantifiable risk-based approach. This is a novel way of presenting the data to outline the true risk associated with the applications.
- This is important work in a highly specialized area. It is a multi-year effort and needs to continue in order to realize its ability to support progress toward SCS program goals.
- The development of this integrated QRA tool is quite relevant to support the development/revision of hydrogen safety C&S. Although it is in its early stage, the QRA toolkit is introducing science into the risk assessment process and will constantly benefit from research efforts of the hydrogen behavior project SCS-010 (consequence models). This project fully supports DOE RD&D objectives.
- The relevance of this work to the development of specific standards is alluded to in slide 12, but it is not explicitly described in the presentation in terms of the degree of Sandia National Laboratories' contribution and the work performed.

Question 5: Proposed future work

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

- The proposed way forward is logical and builds on previous achievements.
- This is important work in a highly specialized area. Future work to engage stakeholders, as defined by the principal investigator, is necessary to prove the ability of this project to support progress toward the Program's goals. Future work needs to engage industry to help guide the direction for improvement.
- Continued improvement of the toolkit is important, but it would be interesting to investigate how the scope of the toolkit could be broadened.
- The proposed future work addresses critical barriers and is planned in a logical manner. Alongside incremental improvements of the different modules, key points refer to the integration of a sensitivity analysis and the access to data. However, it would have been interesting to see a prioritized list of research efforts for the different modules. Also, improving ignition probability models was already a point to be addressed for fiscal year (FY) 2013 (as outlined in the 2012 presentation). It is unclear what the progress has been in FY 2013.
- Future work focuses on integrating the overpressure model, improving ignition probability models, facilitating industry adoption of the QRA database/toolkit, and gaining user feedback. When that starts to occur, expect the value of the QRA to be easier to quantify.
- There are inherent challenges to the direction of the project because the assumptions that are critical to the QRA project need to be mitigated and adapted. There is a significant challenge due to the immaturity of the application. Trying to understand when the algorithm is truly reflective of the actual risk will be a challenge, given the sparse and unrefined data set. It is recommended that researchers try QRA on other fuels, such as propane and CNG, because a more mature application may provide more data to develop and validate the assumption set. Experimental and empirical data will need to be developed to truly test some of the more critical assumptions. The project team may want to consider some kind of affinity or sensitivity analysis to understand what factors have the greatest impact on the models.

Project strengths:

- The ability to compare risk with other industries (through the FAR metric) is a major improvement.
- The project is based on best practice approaches at refiners and nuclear reactors. These applications are well defined and risks can be mitigated early on with controlled access of trained operators and staff. The challenge is that the Hydrogen Refueling Station application is open to untrained laymen, and therefore a QRA for this application needs to be very carefully vetted if it were to be adapted into practice by industry.
- This project is highly specialized. It is critical for enabling siting of hydrogen projects—particularly refueling stations in real-world spaces.
- The project has very good technical capabilities and benefits from science-based inputs from SCS-010, which is clearly a strength. The researchers also have very good collaborations, which is another strength.
- This project's strengths include its scientific competence and thoroughness and its relevant and timely involvement of stakeholders. There is a possibility of parameter screening for assessing the impact on resulting risk numbers and using the results to feed back into an improved design.
- Two reviewers did not respond to this question.

Project weaknesses:

- Most of the critical assumptions are based on limited data: this therefore challenges the validity of the result. The approach is good, but quantification of the "numerator" and "denominator" of the risk still needs improvement.
- This is in the early but critical stage of the work—the project team needs to engage stakeholders in the next phase.
- It is unclear what other scenarios will be modeled in future versions besides indoor refueling.
- There are no apparent weaknesses at present. In the future, a potential weakness may be the inappropriate use of the QRA toolkit by non-experts.
- There are questions about how misuse of the toolkit will be prevented, whether there could be liability issues, and whether access to the toolkit will be controlled or will users have to be "trained" in order to ensure that the tool is used and the output interpreted correctly.
- The relative complexity of this QRA toolkit could be considered a weakness, especially if the tool is to be manipulated by end users. It is a very ambitious project that is still in its early development phase. Although it is on the right track, there is a long way ahead before it can provide tangible results that can be used for revising/creating standards. Collaborations with industry partners are essential in this respect.

Recommendations for additions/deletions to project scope:

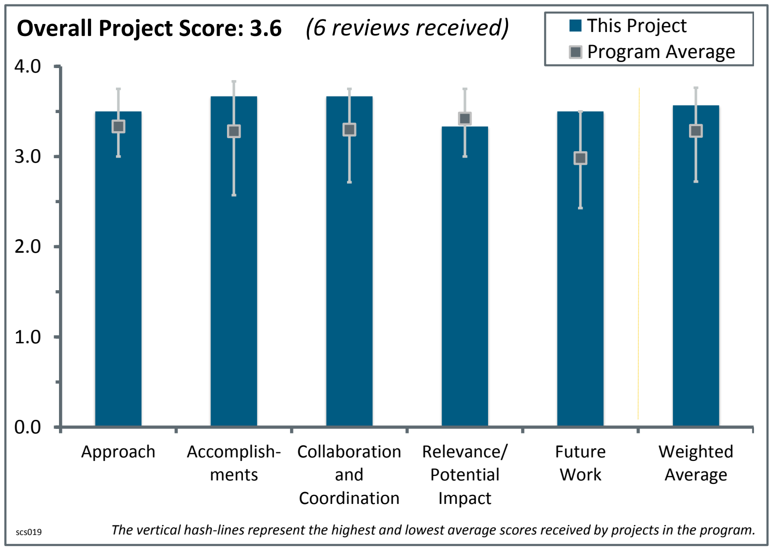
- This project should be continued, with stakeholder input to be used to shape future work.
- It would be interesting if the toolkit could be applied, not only for FAR but also for the risk to equipment or processes.
- Component standards for critical components related to the risk (e.g., leaks) need to be considered as a method to better quantify and drive the behaviors of industry. Insurance companies would directly benefit from this approach.
- This effort should be compared with HySafe in the European Union.
- There are no specific recommendations, but given the time frame (i.e., 2015), the project should try to better plan future research work in order to be more efficient.

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

Nick Barilo; Pacific Northwest National Laboratory

Brief Summary of Project:

The objective of this project is to provide expertise and recommendations for identifying and integrating safety planning and best practices into funded projects to ensure that all projects address and incorporate hydrogen and related safety practices. Collecting information and sharing lessons learned from hydrogen incidents and near-misses will help prevent similar safety events from occurring in the future. A vast and growing knowledge base of hydrogen experience will be captured and made publicly available to the hydrogen community and stakeholders.



Question 1: Approach to performing the work

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

- The approach is clear.
- The three-pronged approach is rational.
- Industry practices are critical and need to be maintained, managed, and broadcast to the public.
- This work on the Hydrogen Safety Panel (the Panel) is very important, and the approach is spot on. Indeed, the principal investigator embraced the suggestions of the reviewers in previous reviews. The field app is a direct result of previous reviews—this is excellent.
- The Panel is continuing to thrive under the management of Nick Barilo. Pacific Northwest National Laboratory (PNNL) demonstrated an exemplary leadership transition process. The Panel's focus on participation early in the projects (e.g., kick-off meeting participation) is valuable. The Panel is clearly adding value to safety planning and finding ways to help projects be successful.
- This project has done a good job at identifying issues; working toward solutions with industry; and, when necessary, getting the information into the hands of the standards development organizations (SDOs) that need the information to revise the standards. With the future focus of understanding "third party certifications," it seems appropriate that the Panel should include representatives from this industry/area. Third-party certifiers are well versed in laboratory testing and field evaluations. This could provide additional insight for addressing situations with "existing equipment/installations" as well as moving forward. Allowing the system to work—"standards-> codes-> third-party certification"—supports the work of authorities having jurisdiction (AHJs) and will serve to expedite the process.

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

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

- The progress to date is suitable and appropriate.
- It appears that this project has been quite successful in gaining AHJ approval and implementing best practices. Safety should continue to be the number one priority. It was good to see the metrics for site visits on slide 8.

- The Panel is an excellent resource for the Safety, Codes and Standards program. The review of hydrogen projects is critically important and the work load is not insignificant. The statistics on reviews, actions, etc., speak for themselves. Particularly impressive was the "self improvement" exercise by the Panel entitled "...What have we learned about our review process."
- The project has made significant progress each year and is providing tools to industry for the deployment that is happening in the "precommercialization" phases. The next step of evaluating how third-party certification impacts the role/job of the AHJ is a much-needed step for commercialization. Other industries have demonstrated that the system works—"standards-> codes-> third-party certification"—this supports the AHJs, expedites the process, and increases consumer safety in a large-scale manner.
- The effort in Hawaii provides a good example of how the Panel has added value to the DOE Hydrogen and Fuel Cells Program by staying at the forefront of technology research, development, and demonstration (RD&D). It is also able to perceive gaps in safety understanding that are then fed back into the research and development (R&D) program. The mobile application for the safety knowledge tools is forward thinking and innovative. A plan should be drafted to ensure sustained upkeep and maintenance of this software tool. There should be a partnership with an entity that is well positioned to push the product forward in the years to come.
- The project team needs to accelerate the work from the Panel that is related to defining the certification requirements for industry. This will be critical for AHJ support. The app for project planners and AHJs is a very useful tool to support the best practices and the review of locations and construction.

Question 3: Collaboration and coordination with other institutions

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

- The Panel, as shown on slide 4, appears to be a solid mix of laboratories and industry, which is critical.
- This project has demonstrated superb coordination with stakeholders that is enhanced by demonstrated integrity and technical excellence.
- PNNL is tied very closely to the leading organizations who are working to move hydrogen to a commercial solution.
- The collaboration and coordination are appropriate. At this point, outreach to the various state and municipal fire and building authorities may be appropriate.
- The increased awareness and dissemination of information to the SDOs to address issues is excellent. Given the increased focus of the Panel and this activity to understand certification and the role it plays for society and AHJs, representation from third-party certifiers in the fuel cell and hydrogen area needs to be incorporated in the Panel's discussions. Without that portion of industry representation, the Panel may be duplicating or performing a role that existing third-party certifiers are already equipped to handle.
- It is a bit hard to accept the list of "collaborators" provided on slide 20 of the presentation (e.g., a Panel meeting at the Hawaii Natural Energy Institute hardly counts as a collaboration, and the National Fire Protection Association [NFPA] Conference and Expo is a conference, not a collaboration). However, the breadth of the Panel in-and-of-itself provides an outstanding span of collaboration.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- This activity has the potential to facilitate the introduction of hydrogen infrastructure.
- This activity is critically important and relevant to the safe performance of the Hydrogen and Fuel Cells Program. It is clear that the level of attention to safety and the impact this project has had on the overall safety culture is excellent. The outreach (publications, white papers, etc.) is excellent.
- This project is critical and enhances safety through knowledge development and information sharing. The Fuel Cell Technologies (FCT) Office needs to be more proactive in leveraging the Panel to encourage improved and consistent safety planning in its entire portfolio of programs.
- This has been one of the best ways to capture, catalog, and reference field incidents and reports of field failures. The direct support of SDOs and codes development organizations is critical to ensure that these

lessons learned can be captured in the regulations, codes, and standards. The proactive approach is also very important to ensure that future station construction is reflective of the best practices.
- There is some skepticism about usage of the mobile app.
- Education and outreach are critical to successful deployment of hydrogen and fuel cells. Assistance with the initial deployments/permitting of stations, etc., is a key component of this outreach. Incorporating the third-party certifiers in the process will help the Panel understand the capabilities of nationally recognized testing laboratories (NRTLs) and will also assist in educating the AHJs (if they are not aware). As industry moves forward, this activity will need to be picked up by the NRTLs—now is a good time to get all involved parties at the table to build awareness from all sides.

Question 5: Proposed future work

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

- The proposed future work is good. The development of the mobile app is right on and moving it to Android devices is a necessary (and recognized) move. The only concern is that there needs to be attention given to establishing a mechanism to maintain the mobile app. This seems to be missing in the current and proposed scope of work.
- It appears that the safety plan review has been quite successful. Industry support of any input to NFPA 2 is critical.
- The proposed work is appropriate. A caution on the app is in order. The project team should define the audience and then address the app to the audience. If the intended user is an AHJ, the project team should write the information in the app for a fire marshal, not a PhD or a researcher. This is easier said than done.
- In general, the project is a good tool set for the industry stakeholders to make them aware of and to support the application of best practices in the field. PNNL has a pragmatic approach and understands its role as a communication content provider. The new and innovative methods to expand visibility of the database are important. Other innovative platforms are expected with anticipation.
- The FCT Office should be more proactive in encouraging Panel participation in all funded projects to help provide consistency in safety planning and engineering.
- With the increased focus of the Panel and this activity to understand certification and the role it plays for society and AHJs, representation from third-party certifiers in the fuel cell and hydrogen area needs to be incorporated into the Panel's discussions. Without that portion of industry representation, the Panel may be duplicating or performing a role that existing third-party certifiers are already equipped to handle. In addition, as industry moves forward, this activity will need to be picked up by the NRTLs—now is a good time to get all involved parties at the table to build awareness from all sides.

Project strengths:

- This project's strengths are its focus and dedication.
- This project provides guidance and tools to increase awareness for industry as new technology is introduced. It is providing feedback to SDOs to support revisions to standards to address known safety risks.
- This Panel is performing very well and providing a critical service to this community. The construction of the mobile app demonstrates the willingness to grow beyond traditional roles—this is excellent.
- The Panel is providing a critical forum for sharing safety information, enhancing safety planning, and identifying safety R&D gaps. The information tools are a consistent resource for industry, laboratories, and universities because they provide valuable information.
- The Panel and its collaborators are strengths of this project. Keeping these Panel members is critical to the success of this initiative. This project should continue to be funded at its fiscal year 2012 levels so that the innovative ways of getting this out to industry are expanded.

Project weaknesses:

- There is not enough funding.
- The project team needs to involve third-party certifiers (NRTLs) in the process.

- Weaknesses include the limited safety reviews and the need to determine the audience for the app.
- The FCT Office needs to be more proactive in leveraging the Panel for encouraging adequate safety planning in projects with DOE Office of Energy Efficiency and Renewable Energy investment. There is evidence that the link between the Panel and the projects has been not been as consistent as needed. The FCT Office needs to incentivize interaction with the Panel. A strategy needs to be developed for the continued development and maintenance of the safety knowledge tools. These are critical and it would be bad to see them get stale.

Recommendations for additions/deletions to project scope:

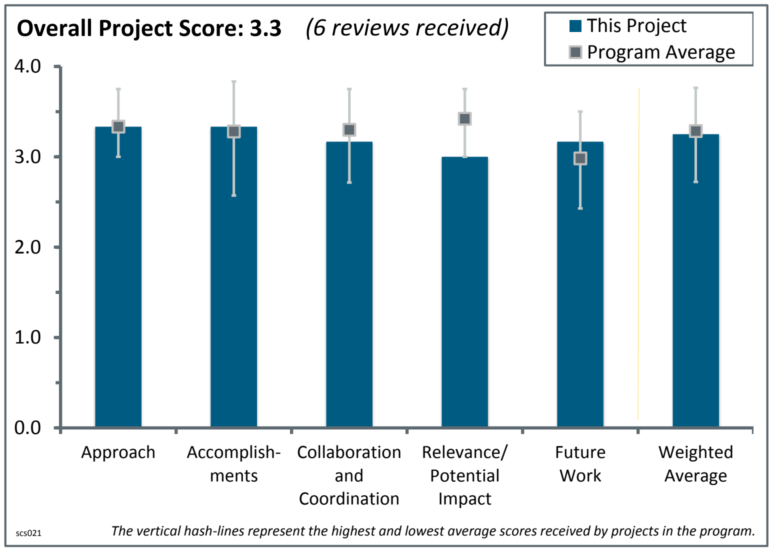
- The Panel should continue to seek out ways in which the enormous talent of its members can continue to be exploited on behalf of the hydrogen community. Keep it up!
- The project team needs to involve third-party certifiers (NRTLs) in the process and continue providing feedback to SDOs.
- The project team should increase the safety reviews and start outreach to the AHJs.
- The concept of providing safety knowledge tools on mobile platforms to increase value is innovative and critically important. It is a great idea to build on this initial effort to develop a comprehensive strategy around mobile platform application development—this has the potential for the highest impact in the field.

Project # SCS-021: NREL Hydrogen Sensor Testing Laboratory

Bill Buttner; National Renewable Energy Laboratory

Brief Summary of Project:

Sensors are a critical hydrogen safety element and will facilitate the safe implementation of hydrogen infrastructure. The objective of this project is to provide critical safeguards including an alarm at unsafe conditions, ventilation activation, and automatic shutdown to hydrogen delivery systems. Safety systems need to detect and mitigate circumstances such as a lack of hydrogen detection, a lack of combustible gas monitoring or training, or alarms that do not specify the danger detected.



Question 1: Approach to performing the work

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

- This is a good project and the overall approach is very good.
- The project presentation mainly focuses only on a single fiscal year effort, and it is recognized that funding is determined annually. It seems, however, that the success of the project depends on multiyear support. It would be helpful to see the approach and planning in the context of the overall long-term goals as well as the annual goals for the work, and progress for both. This was addressed late in the presentation, under future work. Early discussion of the importance of the longer term goals would be beneficial.
- All of the barriers identified are important, especially barriers F, G, and H (from the *Fuel Cell Technologies Office Multi-Year Research, Development and Demonstration Plan*), which this project is targeting. The project team should keep focused on the ultimate goal of ensuring that end users get the sensing technology they need; for example, facility sensors (as highlighted in slide 5) versus vehicle sensors.
- The approach is sound. However, direct detection of leaks may not be appropriate in many applications. Currently, sensors are costly, require maintenance, and are often unsuitable for a number of applications. The results are often spurious alarms or no detection—both are issues. Sensors might become an issue and not a solution.
- The independent assessment and qualification method for the development of sensors is valuable. The workshop provides a forum for influencing the work that is performed. It is not clear if (a) the most critical end users are adequately involved and (b) the feedback from industry participants is actually influencing the project.
- The National Renewable Energy Laboratory's (NREL's) dual approach of providing independent sensor testing to developers, end users, and codes and standards developers together with gap identification is very good. One caveat, however, is that testing must be entirely independent of development. The project team should not be involved with sensor research and development (R&D).

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.

- All in all, the project has a very good path forward. The project team has achieved nice accomplishments to date and is realistic about the barriers and issues that still need work.

- This project features an excellent mix of accomplishments. The collaboration with the Joint Research Centre (JRC) seems especially valuable and produced some very interesting outcomes, including the lack of accuracy of sensors tested in the round-robin testing and the inappropriateness of oxygen displacement sensors for hydrogen measurements. Also significant was the gap analysis result that sensor maintenance is a large cost and that sensors need to be calibrated often (the researchers suggest no less often than semi-annually). In the past, some sensor manufacturers would claim that their sensors could be calibrated every couple of years.
- The ability to assess sensors with a vehicle crash test is nice. Whether there is a need to include a sensor on a vehicle is still open to debate.
- Supporting the Global Technical Regulation (GTR) was a critical accomplishment; however, there was no mention of the previous work by Sandia National Laboratories on hydrogen concentration in vehicles (a GTR-driven study). This is cause for concern; perhaps these researchers are operating a bit in the dark. The finding that one-third of the sensors tested did not even perform as well as the manufacturers' specification is incredible. This finding alone is critical.
- It is not clear that the work in support of the GTR resulted in quantifiable recommendations for the proposed requirements. NREL's sensors team needs to develop strategies for quantifying performance of deployed sensors. The Fuel Cells and Hydrogen Joint Undertaking (FCH-JU)-funded JRC collaboration resulted in consistent results in both laboratories showing value in the round-robin testing.
- It was not clear from the presentation how R&D on sensors directly contributes to DOE goals. There is a reference to the *Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan*. The presentation could be more effective by going back to specific goals and demonstrating how the project contributes to achieving the goals. It was worthwhile for the presenter to clearly articulate the important role of this project in helping industry develop sensors that can meet existing and future standards. As sensors do not yet meet the existing standards, this project provides a cost-effective way to evaluate and improve developing sensor technologies.

Question 3: Collaboration and coordination with other institutions

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

- This project features excellent collaboration with JRC.
- The collaboration with JRC is excellent.
- This project demonstrated outstanding coordination through the round-robin testing. The coordination with the FCH-JU-funded project provides a good template that the FCT Office (can leverage for other international efforts. Better domestic coordination could be achieved through leveraging the needs identified for sensors from Technology Validation or other FCT Office investments.
- The collaboration with JRC is commendable. The presentation included an excellent, clear description of this collaboration, showing clear benefits. The presentation could be improved by providing more details on the collaboration and coordination efforts with the other named partners and collaborations.
- The collaboration appears to be limited to other national and European Union laboratories. Outreach to major manufacturers (MSA, RKI Instruments, Detronics, etc.) is not mentioned.
- NREL talks about its collaboration with JRC and the U.S. Department of Transportation quite extensively, but it does not list them on its collaboration slide. It does list Element One and the Colorado School of Mines, among others, but includes no explanation about these collaborations.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- This project is very relevant for applications at hydrogen fueling infrastructure and repair facilities.
- There was a very good discussion of the relevance of sensor work. The discussion of NREL's approach implies that its work is relevant to the overall sensor need.
- The overall relevance of this work to the Safety, Codes and Standards program and the community is very good. Sensors are required by code, so the quantification of sensor performance and reliability and working

with the codes development organization/standards development organization community is also very important. The execution of a round-robin test was also very nice.
- The option for a robust sensor(s) is attractive and relevant. It is not clear whether a sensor is the best technical solution.
- This project does not address a critical need facing the deployment of hydrogen fuel cell systems. It is not clear what critical issues will be overcome if this project is 100% successful.
- It would be good to see the presentation more specifically discuss the existing standards relating to sensors—particularly those used for qualifying sensors to existing regulations, codes, and standards—particularly ISO 26142: 2010 Hydrogen Detection Apparatus - Stationary and UL 2075 - Gas and Vapor Detectors and Sensors, as well as progress in the development of sensors to meet existing standards. More discussion is needed on how the project helps to harmonize requirements for sensors. Sensors do not yet meet the existing standards, so this project provides a cost-effective way to evaluate and improve developing sensor technologies.

Question 5: Proposed future work

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

- The proposed future work is rational and appropriate.
- The proposed future work is excellent. The future work discussion mentions plans to investigate wide-area monitoring. Wide-area monitoring will overcome the shortcomings of point-wise measurements.
- NREL presented a reasonable schedule for the next several years in the hydrogen sensor area. It is proposing to include wide-area sensing as part of the plan. It appears that much of NREL's future work will be based on it moving into the new Energy Systems Integration Facility (ESIF).
- This project needs to focus on independent testing and test methods development. It was stated that future work will be 50% new sensor development. Any new sensor technology development needs to be competitively selected and should be led by industry. EERE should not directly fund sensor development through a non-competitive process.
- It was very good to see the multi-year project plan in the presentation. Future guidance on sensor placement is a concern. While industry and other stakeholders are interested in guidance on hydrogen sensor placement, it is critical to avoid any misperceptions that sensors are the only way to achieve the desired levels of safety. Researchers delivering messages relating to sensor placement are advised to use caution to be clear that the guidance applies when sensors are chosen as a method for achieving the desired safety parameters. Performance-based standards for systems and equipment are careful to specify a required level of safety, but they do not specify the method to achieve it. Therefore, sensors can be considered one of many options for achieving the safety levels desired.
- It seems that the ESIF will be instrumental in future work, especially in assisting with field testing. It may be difficult (depending on the application) to do comparisons in the "field," so setting up real-world scenarios at the ESIF might prove very useful.

Project strengths:

- This project's focus and dedication are its strengths.
- This project is very good, relevant, and well executed, and it features good teaming with international partners.
- This project provides an excellent example of effective collaborations with projects funded by the FCH-JU.
- This project provides an avenue for sensor developers to improve sensors and measure progress toward goals (DOE goals and those stated in published standards).
- This project is working to understand needs from industry.
- The collaboration with JRC is yielding some very good results. The ESIF will increase the team's capabilities. Gap analysis revealed the need for increased scrutiny on calibration.

Project weaknesses:

- The concept that sensors are required is an area of weakness. However, that is a policy question.

- This project is at risk of appearing to develop and test sensors for the sake of developing and testing sensors rather than to address a critical need facing the deployment of hydrogen and fuel cell technologies.
- More information is needed on collaborations outside of JRC (as this collaboration was adequately described). More context is desired at the beginning of presentations, publications, and workshops to help put the role of sensors into context with other methods available to meet requirements to ensure safety.
- The collaboration with Element One and the Colorado School of Mines is unclear.

Recommendations for additions/deletions to project scope:

- The project team should ensure that there is continued focus on sensor calibration protocol.
- The project team should add a caveat "for applications requiring a sensor."
- This project needs to stay clear of sensor development. The FCTO needs to rely on a competitive process for any sensor development activities.
- The project should include messaging to avoid confusion about the role of sensors to achieve safety levels defined in codes and standards.
- The project should investigate (or reinvestigate) the use of wide-area detection. Also, contact sensing technologies (color change, etc.) should be investigated. The potential for such technologies in many applications could prove to be very valuable (more so than point measurement systems) in early detection of leaks from common sources such as valves, joints, welds, pipe fatigue cracks, etc.