2011 – Safety, Codes and Standards
Summary of Annual Merit Review of the Safety, Codes and Standards Sub-Program

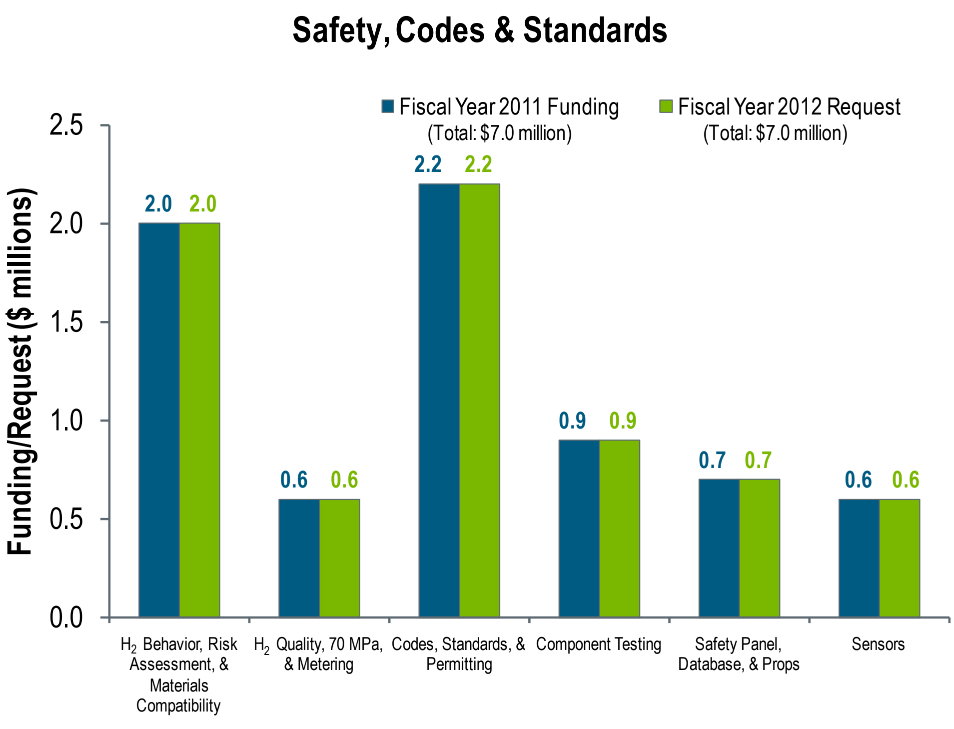
Summary of Reviewer Comments on the Safety, Codes and Standards Sub-Program:

The Safety, Codes and Standards sub-program supports research and development (R&D) that provides the critical information needed to define requirements and close gaps in safety, codes and standards to enable the safe use and handling of hydrogen and fuel cell technologies. The sub-program also conducts safety activities focused on promoting safety practices among the U.S. Department of Energy (DOE) projects, and the development of information resources and best practices. Reviewers observed that the sub-program continues to provide strong support in the following areas: hydrogen and fuel cell codes and standards permitting and education, hydrogen sensor technology, hydrogen components and material compatibility work, safety training for first responders and researchers, and development of an international hydrogen fuel specification standard. Reviewers also echoed observations from prior years that projects in this sub-program have effectively leveraged the resources and intellectual capital of academic institutions, standards development organizations (SDOs), national laboratories, government agencies, industry, and other offices in DOE.

In addition, this year reviewers commended the sub-program for focusing activities on high-priority items, such as indoor hydrogen fueling, and recommended increased emphasis on other activities that will help early market commercialization of fuel cells and hydrogen. Reviewers felt that the sub-program was well-focused, with the exception of the hydrogen sensor work, which some suggested might fit better under another sub-program. Reviewers praised the strong international presence of the sub-program.

Summary of Safety, Codes and Standards Funding:

The fiscal year (FY) 2011 appropriation was $7 million for the sub-program. FY 2011 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 2012 request of $7 million will continue these efforts.



Majority of Reviewer Comments and Recommendations:

In FY 2011, 13 Safety, Codes and Standards projects were reviewed, with a majority of projects receiving positive feedback and strong scores. Reviewers' scores ranged from 2.8 to 3.6, with an average score of 3.3.

Hydrogen Behavior, Risk Assessment, and Materials Compatibility: Two hydrogen behavior, risk assessment, and materials compatibility projects were reviewed, both receiving a score of 3.3. Reviewers praised the projects for sound technical teams, good experimental design and implementation, and rigorous analysis. The reviewers thought these projects provided additional benefit with close links and direct involvement with code development organizations (CDOs) and SDOs. Reviewers suggested a clearer description of how progress and success are measured to make accomplishments more apparent. According to reviewers, greater international collaboration and increased communication with system integrators and equipment manufacturers would be beneficial.

Hydrogen Quality, 70 MPa, and Metering: One hydrogen quality, 70 MPa, and metering project was reviewed, which received a score of 3.2. Reviewers praised the rigorous technical R&D approach used to determine levels of constituents in hydrogen. The reviewers also commended the project's persistence in conducting the long, extensive testing that has been required to provide the necessary data to publish a sound international standard. Reviewers suggested incorporating more industry perspective (e.g., automotive original equipment manufacturers) and testing on combinations of contaminants, lower catalyst loadings, and higher performance membrane electrode assemblies.

Codes and Standards and Permitting: Two codes and standards and permitting projects were reviewed, with an average score of 3.4. Reviewers praised the coordination and collaboration activities with all relevant CDOs, SDOs, and technical committees. Reviewers felt projects were comprehensive with good technical teams, approaches, and communication plans. Reviewers suggested developing a project that would provide more detail for future efforts by conducting an analysis to determine the key gaps that need to be addressed.

Component Testing: Two component testing projects were reviewed, with an average score of 3.5, tied for the highest average score of all key areas. The highest scoring component testing project received a 3.6, the highest score awarded in the sub-program. Reviewers applauded the technical talent involved with each project and the excellent collaboration, communication, and information exchange between these projects and SDOs. Reviewers felt additional industry participation to better understand industry's needs would be beneficial as well a method for assessing the contribution of the various technical studies for the SDOs.

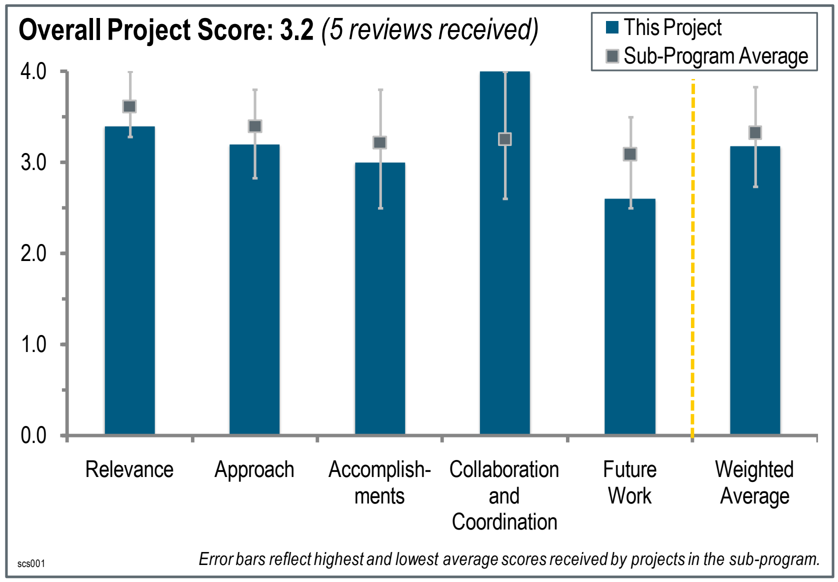
Safety Panel, Database, and Props: Four projects in these areas were reviewed, with an average score of 3.5, tied for the highest average score of all key areas. Two projects received a 3.6, tying for the highest score awarded in the sub-program, while the lowest scoring project in this area received a 3.2. Reviewers praised the technical expertise of the project PIs and team members. Reviewers feel the project members have an excellent mix of expertise, experience, and enthusiasm. These projects are critical to the commercialization and safe deployment of hydrogen and fuel cell technologies and reviewers thought they were managed well. Reviewers suggested trying to quantify audiences reached and incidents captured. Reviewers felt additional partners and greater dissemination would benefit the projects.

Sensors: Two sensor projects were reviewed, with an average score of 3.0. Reviewers appreciated the progress and R&D approach taken for sensor development. They observed that these projects have made key advancements in turning a basic material into a sensor prototype and that they have collaborated efficiently with national laboratories and industry to develop robust sensors. Reviewers cautioned about the potential for cross-sensitivity and felt cost analysis and manufacturing assessments would be useful.

Project # SCS-001: National Codes and Standards Template

Carl Rivkin; National Renewable Energy Laboratory

Brief Summary of Project:



The objectives of the project are to: (1) conduct the research and development needed to establish sound technical requirements for renewable energy codes and standards with a major emphasis on hydrogen and fuel cell technologies; (2) support code development for the safe use of renewable energy in commercial, residential, and transportation applications with a major emphasis on emerging fuel cell technologies; (3) advance renewable energy safety, code development, and market transformation issues by collaboration with appropriate stakeholders; and (4) facilitate the safe deployment of renewable energy technologies.

Question 1: Relevance to overall U.S. Department of Energy objectives

This project was rated **3.4** for its relevance to U.S. Department of Energy (DOE) objectives.

- Codes and standards (C&S) have been identified as key barriers to the safe deployment of hydrogen and fuel cell technologies, so it is critical to get the necessary codes and standards in place to avoid delays. It is important to conduct the research and development (R&D) activities necessary to establish sound technical requirements to enable the development of codes and standards that are acceptable to and adopted by the authorities having jurisdiction across the country.
- Coordinated efforts to keep codes and standards for infrastructure, components, vehicles, fuel quality, and overall safety are required for successful deployment of new technology. It is already several years into the effort, but many C&S are coming to completion with support of carefully validated models combined with quantitative risk assessment and real-world data.
- Coordination of codes and standards development is critical for the Program, but there should be more emphasis and information on consequences and impacts of coordination and the National Renewable Energy Laboratory's (NREL) specific contributions to the development of regulations codes and standards (RCS) for hydrogen and fuel cell technologies. The third slide in the presentation refers to safe deployment of "renewable energy technologies," but it seems the C&S work under this project should be specific to hydrogen and fuel cells.
- The project is aligned with the key need for providing the essential C&S for commercialization of hydrogen vehicles, which is critical to the DOE Hydrogen and Fuel Cells Program objectives.
- The complexity of C&S development process requires coordination, which is provided by NREL.

Question 2: Approach to performing the work

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

- The approach of working closely with all the relevant code development organizations (CDO)/standards development organizations (SDO) and coordinating the work of the various technical committees that control the

C&S documents is excellent. Interacting with all the key players is the best strategy for understanding their individual needs and how they interact with each other as they search for common ground and consensus on national C&S. Also, performing some of the R&D that provides the technical basis for the C&S is a good approach to influence the process and cement a position as a key player.
- Coordination should be up front through committees to bring SDOs together and avoid conflicts throughout process, e.g., SAE International (SAE) and CSA Standards (CSA); providing support through work at national laboratories and hosting targeted workshops in all areas is an excellent comprehensive approach to identifying and covering gaps and shortcomings in codes development.
- The general, overall approach is good but the presentation did not address gap analysis, which is critical to focusing future activities and priorities in more detail and what needs to be done to fill the key gaps in R&D, testing, analysis, and RCS development. The approach should build on how to fill the key gaps. Slide five in the presentation overstates NREL's role in general and the NREL project manager's role in particular in the C&S development process. The principal investigator (PI) should be more specific about NREL's role in performing its work.
- The general idea of assisting the various SDOs and CDOs with their technical development is good but further specific information could be provided regarding the role of the project in coordinating and accelerating various standards.
- The researchers need to manage, as well as participate, in C&S development activities.

Question 3: Accomplishments and progress towards overall project and DOE goals

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

- The publication of National Fire Protection Association (NFPA) 2 this year is an outstanding accomplishment that should help streamline the hydrogen and fuel cell facility permitting process. Support of SAE and International Organization for Standardization fuel quality standards and CSA component standards, through technical committee participation, equipment/component testing, and data analysis, is also commendable.
- The researchers are getting close or have arrived at several standards from SAE, CSA, and NFPA.
- There is too much listing of "what," and not enough discussion of the "why" and "so what." There should be more assessment of accomplishments and progress toward overall DOE goals, especially those having critical RCS in place to enable deployment of hydrogen and fuel cell technologies by 2020. In the presentation, slide seven, like slide five, overstates NREL's role. The reviewer wants to know what work NREL has done with the International Association of Plumbing and Mechanical Officials, American Society of Heating, Refrigerating and Air Conditioning Engineers, American Petroleum Institute, and Hydrogen Association of India. The reviewer also questions what NREL does with the International Civil Aviation Organization (ICAO), other than manage a subcontract that enables a staff person from the Fuel Cell and Hydrogen Energy Association to work with ICAO. While the work is important, the researchers must be clearer about NREL's role and responsibility. Regarding slide eight in the presentation: "Manage C&S development directing"..."work on HIPOC [Hydrogen Industry Panel on Codes]," it is important to show how NREL directs work by HIPOC. It should be noted that slides eight and ten are duplicative and conflicting, and the researchers need to edit their presentation more carefully. In addition, slide 12 of the presentation takes credit for work of many others.
- The progress directly linked to this project was difficult to assess. Certainly, SDOs and CDOs are making progress on developing their documents, but it would be helpful to have a metric or the specific areas that were assisted by the project.
- The project has successfully completed or addressed a wide variety of tasks and activities.

Question 4: Collaboration and coordination with other institutions

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

- The collaboration with all the key stakeholders in the hydrogen and fuel cell C&S development process, both national and international, is outstanding.
- The presentation shows a comprehensive list of SDOs and CDOs with accomplishments including yearly accomplishments.

- Collaboration, coordination, and interaction with key SDOs and other organizations are very good and maintain, and in some cases expand, work begun many years ago.
- The project collaborates with a large number of pertinent groups.
- The project involves an extensive amount of collaboration.

Question 5: Proposed future work

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

- The scope of future work will likely have to be reduced if Program funding is cut in fiscal year 2012. It is necessary to focus on the most critical C&S gaps if funding is limited (e.g., the need for sensors for indoor refueling of forklifts).
- Proposed work in fuel quality, indoor fueling, and workshops are all necessary to advance the technology toward commercialization. Of particular interest is hydrogen safety sensor testing to quickly detect low levels in vehicle interiors.
- The PI missed an opportunity to show how future work can be based on a gap analysis. It is essential to examine the potential added value of future work, and the gap analysis could have provided a basis for this examination. Future work (see slide 18) seems to be taken from the annual operating plan; there should be more specific information and direction to future work. Also, a supplemental slide (see slide 24) should have been incorporated into the presentation.
- The future work for this project needs to be further developed. It would be helpful to have a clear status and next steps for the various standards.
- Work should continue, as many of the tasks are long term in nature.

Project strengths:

- There is an awareness of domestic and international RCS activities, interaction with key actors and stakeholders in the hydrogen and fuel cell RCS community, and a good grasp of and interaction with the C&S development process.
- The project is facilitating many SDO and CDO activities that are critical to the commercialization of hydrogen vehicles.
- The success of NREL's extensive national and international coordination and collaboration efforts has been extremely valuable over the last few years.
- The project continues to support the development of the industry toward commercialization. It is comprehensive in scope and is achieving its goals.

Project weaknesses:

- Funding may not be available to continue at the same level of effort, so only the highest priority collaborations should be pursued (i.e., those that will have the greatest positive impacts on emerging hydrogen and fuel cell technology deployments in the United States).
- There are too many lists of activities without identifying NREL's specific contributions to those activities (e.g., slide 13). More specific information on NREL's accomplishments and value-added is needed. The project seems at times to focus on taking credit by association with key actors and stakeholders.
- The project should include a tracking mechanism of the various documents in order to evaluate if the SDOs and CDOs need assistance to publish documents in a timely and high-quality manner.

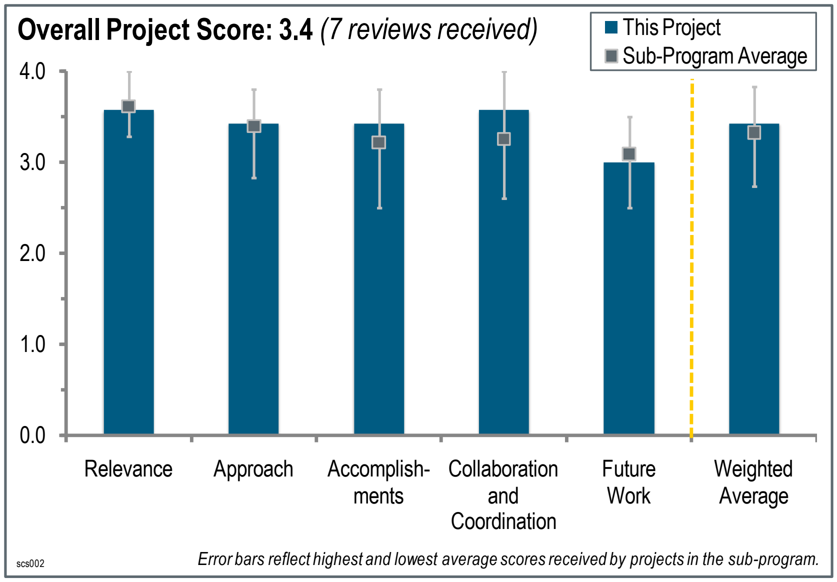
Recommendations for additions/deletions to project scope:

- Researchers should incorporate the gap analyses with the technical accomplishments and progress shown in slide 15 and conduct a detailed examination of the time frame for the RCS to be in place to enable market deployment of hydrogen and fuel cell technologies and associated infrastructure by 2020.
- Work on streamlining the national and international C&S development process and minimizing duplication of effort is recommended.
- The project should consider a method to specifically identify the contribution to the SDO and CDO development effort.

Project # SCS-002: Component Standard Research and Development

Robert Burgess; National Renewable Energy Laboratory

Brief Summary of Project:



The objective of this project is to develop component-level hydrogen codes and standards by identifying gaps and working with industry to close those gaps by providing national laboratory research and development support. Hydrogen infrastructure technology gaps include: (1) additions to the American Society for Mechanical Engineers Boiler and Pressure Vessel Code test standard for composite overwrapped pressure vessels; (2) non-communication fill tables for hydrogen vehicle fueling for the SAE International (SAE) J2601 Fueling Protocol, designed to ensure temperature limits are not exceeded; (3) new performance-based standards for temperature-activated pressure relief devices; and (4) hydrogen sensor performance requirements for leak detection, safe alarm, and shutdown.

Question 1: Relevance to overall U.S. Department of Energy objectives

This project was rated **3.6** for its relevance to U.S. Department of Energy (DOE) objectives.

- Certainly there is a need to improve hydrogen sensors in the industry; however, research is needed on the most recently developed sensors, i.e., mesowire sensors.
- The principal investigator stated that codes and standards (C&S)/permitting are the number one issue for deploying hydrogen systems. C&S must keep pace with the rapidly expanding markets for emerging technologies (e.g., indoor refueling of hydrogen-powered forklifts). Components of hydrogen and fuel cell technologies must be safe and reliable and there must be a sound technical basis for the standards that dictate their design and operation. The project fully supports the DOE Hydrogen and Fuel Cells Program goals and objectives.
- The projects that are funded through the National Renewable Energy Laboratory (NREL) are useful both in the support of the technical objectives, but also keep industry talent in standards development activities. These support contracts are critical to the future success of hydrogen.
- The project is aligned with the key need for providing the essential codes and standards for commercialization of hydrogen vehicles, which is critical to the hydrogen and fuel cell program objectives.
- Component standard research and development (R&D) is critical to the Program and fully supports DOE R&D objectives. Development of new and improved standards will remove roadblocks to technology commercialization.
- Sensor and other component testing are consistent with Program goals.

Question 2: Approach to performing the work

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

- The project staff work on C&S technical committees is to identify knowledge gaps, define the R&D activities needed to address the gaps, test components (e.g., sensors) and analyze the resulting data, and provide the results

to the technical committees as the basis for the standards development process. The project is clearly focused on the critical barriers.
- Some of the barriers addressed here have also been identified through work conducted by the U.S. Department of Transportation, i.e., low-temperature leaks/performance in hydrogen storage system through valves, SAE J2579 validation testing, and sensor testing.
- Testing of existing sensors against program targets is a useful activity.
- The research approach is generally successful. Sensor and hydrogen pressure relief device work offer immediate tangible benefits to industry. Support of industrial truck applications will lead to increased demand for actionable component standards.
- The approach of working with C&S technical committees to identify knowledge gaps is good.

Question 3: Accomplishments and progress towards overall project and DOE goals

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

- Proprietary sensor testing for industry is an important activity for the deployment of a number of hydrogen and fuel cell technologies, and the aggregate data is useful for standards development purposes. Testing of other components (e.g., temperature-activated pressure relief devices, tanks, hoses, fittings, nozzles, and breakaways) is also important. The project appears to be making significant progress.
- The facility is up and running. Composite sensor test results may be useful.
- NREL support of standards development organization (SDO) activities has been commendable. The component workshop yielded positive results. Collection of data from non-automotive applications can be fed back into the SAE process to further improve system development and evaluations.
- The development of the test protocol and the progress in hydrogen sensor round-robin testing are notable progress items within this project.
- The reviewer would like to see more active presentation of data to support international standards.

Question 4: Collaboration and coordination with other institutions

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

- Sensor development partnerships with other national laboratories and field deployment collaborations with General Motors and The National Aeronautics and Space Administration (NASA) are excellent interactions for the project team. The ability to protect proprietary industry data and still be able to use it in aggregate is an important feature of this project. The collaborations are well coordinated.
- This project is working with international groups, such as the International Organization for Standardization, International Electrotechnical Commission, and Global Technical Regulation .
- The project is weighted somewhat heavily towards the national laboratories. The reviewer would prefer some of the funding to go industry.
- The project has demonstrated excellent collaboration among national laboratories, industry, and SDOs/code development organizations (CDOs).

Question 5: Proposed future work

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

- Continued testing of sensors and other hydrogen components and support for the development of technically sound component standards are worthy activities to help overcome the barriers to achieving national consensus on hydrogen and fuel cell technologies codes and standards. The project should continue.
- The project has a good plan for future work and interactions.
- The tank testing in conjunction with NASA data should go a long way towards harmonizing SAE and CSA Standards documents. There are several key issues that still need to be addressed. There are some projects that have been stalled by SDO bureaucracy that need to be addressed.
- Plans for future work certainly builds on the past progress and has a clear vision for technical work for assisting SDOs and CDOs.

- Plastic O-rings are used in high-pressure hydrogen systems. The reviewer thinks the effect of hydrogen on sealing plastic O-rings should be added.

Project strengths:

- This is obviously a very technically capable team. The reviewers are looking forward to seeing the results of the prototype sensor.
- Working directly with sensor manufacturers to test and evaluate the performance of their technologies, while maintaining the confidentiality of their proprietary data, is a strength of this project.
- The project is active with various SDOs and CDOs and is attempting to assist in technical areas that need to be addressed to close knowledge gaps. The development of the hydrogen sensor testing protocol and laboratory are a benefit to the overall hydrogen sensor development.
- NREL has built a good relationship with SDOs and industry.
- Based on the presentation, the sources of research topics are all good.

Project weaknesses:

- The reviewer wondered if the data obtained by this project will really enhance the understanding of sensor operating environments and lead to better designs and better standards. As another speaker said, “Sensors don’t work and they cost too much.” The reviewer questioned whether this project can provide the necessary data to address both of these critical concerns.
- The project has over-reliance on national laboratories. While good technically, the researchers need to be advised when they get an industry-usable answer.
- The project should consider a metric or method for assessing the contribution of the various technical studies for the SDOs and CDOs (i.e., change in standard values or completion of the standard based on this project’s technical contribution).
- Failure mechanism of sensors needs to be investigated.

Recommendations for additions/deletions to project scope:

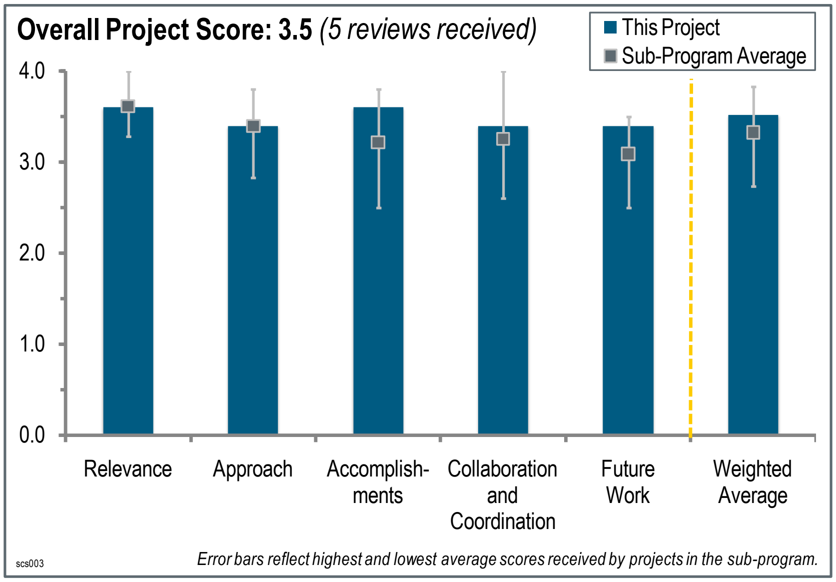
- Investigation of mesowire sensor is recommended.
- Potential funding cuts in fiscal year 2012, potentially resulting in reduced scope, should be considered.
- The project should add impact tolerance and ageing for hydrogen sensors in vehicles.
- Initiate (or reinitiate) the brinelling studies of the high-pressure hydrogen interface is recommended.
- The project could consider assisting SDOs/CDOs to survey their standards for opportunities for technical assistance or areas of concern to either improve the confidence or reduce cost (i.e., safety factors).
- Plastic O-rings are used in high-pressure hydrogen systems. If funding is sufficient, the reviewer suggests the effect of hydrogen on its sealing should be added.

Project # SCS-003: Codes and Standards Outreach for Emerging Fuel Cell Technologies

Carl Rivkin; National Renewable Energy Laboratory

Brief Summary of Project:

The objectives of this project are to: (1) advance renewable energy safety, code development, and market transformation issues by distributing information; (2) facilitate the safe deployment of renewable energy technologies; and (3) overcome barriers to emerging fuel cell technologies, specifically fuel-cell-powered forklift vehicles and stationary fuel cells used for back-up power; (4) communicate directly with code users and enforcers; and (5) provide publicly accessible information on codes and standards.



Question 1: Relevance to overall U.S. Department of Energy objectives

This project was rated **3.6** for its relevance to U.S. Department of Energy (DOE) objectives.

- This project goes beyond research and development (R&D) and into the real-world implementation and commercialization of hydrogen and fuel cells in all applications (vehicles, stationary, industrial, etc.). Early commercialization is the status right now; therefore, educating the authorities having jurisdiction (AHJ) on this technology has never been more important. Automakers have announced sale dates for fuel cell electric vehicles in 2015, stationary fuel cells are being implemented in businesses with real benefits, for example, fuel cell fork trucks projects are more numerous, and there is a DOE/Sandia National Laboratories project right now where the unit is essentially for sale.
- The objective of DOE is ultimately acceptance by the general public of alternate fuels. To ensure this acceptance, the necessary provisions to the fire and building codes need to be made to handle the new fuels correctly. System-level product safety standards need to be developed and component-level product standards need to be completed. This project suggests to industry the commercial practices documents that may be required. It monitors the generation of the aforementioned commercial practices documents and facilitates the acceptance of the aforementioned commercial practices documents by assisting industry in getting acceptance of the documents by the state and local authorities having jurisdiction.
- The codes and standards (C&S) that have been developed facilitate safe deployment of renewable energy technologies. As technologies change the C&S must be maintained to ensure safe use and there must be education/outreach to teach new users about the standards. This project achieves these objectives and active involvement in educating the public is evident.
- Although this project has been supported for more than 11 years, it still continues to be relevant to get current information to code officials and state representatives.

Question 2: Approach to performing the work

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

- The approach is an outreach method. While somewhat time consuming, it is the only viable approach. The documents are written by volunteers from industry. Without the industry support, the AHJs would not accept the documents as balanced commercial best practices and probably would not adopt the documents as regulation.
- The project should be, if not already, tied into the recent National Renewable Energy Laboratory (NREL) workshop to reduce hydrogen infrastructure cost as "streamlining the permitting process" was identified by NREL as one high-priority goal.
- There is solid evidence of activities to overcome barriers associated with R&D, coordination between standards organizations, and supporting technology readiness/market transformation. However, a barrier that was not apparent or directly discussed was educating future technology owners/users about the codes. While there have been nice templates and guides for owners built into a website, but if the website's existence is not known, its use/effectiveness is questionable.
- There should be an additional focus on returning to some of the existing facilities to evaluate how they are functioning and whether any of the promulgated codes should be changed based on their experiences.

Question 3: Accomplishments and progress towards overall project and DOE goals

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

- While the actual numbers may seem small, it is important to acknowledge it is a very focused and defined audience—the information being disseminated is to key targeted individuals who are getting or already have this technology in their jurisdiction.
- The project has very good accomplishments in conducting workshops where the market appears to be most active (California). One location on the East Coast was mentioned, but the time frame was not determined. Great progress was made developing permitting templates for hydrogen fueling stations, but more work is needed in disseminating this information.
- There has been good progress to identify barriers and provide some technical information to overcome them; however, the reviewer wondered what the outcome has been with all the work that has been accomplished. The reviewer also wondered if the permitting process has improved and if it is taking less time. If it has not improved, and improvements cannot be documented, the reviewer wanted to know what needs to change and if this change is part of the plan.
- The outreach has been fairly focused on the early adopters in California and is in step with industry.

Question 4: Collaboration and coordination with other institutions

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

- The collaboration and coordination with other institutions is sufficient for California but will need to be extended for roll out into other areas of the country.
- Overall, it is a very good collaboration; however, it is a moving target and attention on collaborations needs to be maintained.
- There has been very active involvement with industry and partners in California where the majority of hydrogen fuel cell activity are located. There appears to be close collaboration with the identified organizations (California Fuel Cell Partnership and Southern California Fire Protections Officers). The collaboration with industry is vague and not fully described.
- There needs to be more collaboration on the East Coast and with some of the East Coast universities.

Question 5: Proposed future work

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

- The future activities noted by the researchers are somewhat sketchy. This is probably due to insufficient input from the uncertain funding. The former can be easily corrected.
- It is very important and helpful to continue this work, especially in light of the recent NREL workshop on identifying barriers to commercialization, which highlighted the need to somehow "streamline permitting" for hydrogen installations, specifically. The site visit and template are excellent additions.
- This is an outreach project that appears to be very good and well coordinated in nearer term deployment areas in California. It is good to see that some relevant workshops on technologies, such as sensors, that are of interest to a broader audience perhaps where near-term deployment is less likely, are being sponsored and in other areas in the Midwest and East. The workshops held in California may need to be reprised in other cities.
- The proposed future work clearly builds on the identified barriers. The principal investigator understands the additional barriers (such as educational outreach) and will continue to work on this area. The items listed for upcoming work do meet the goals of the DOE research, development, and demonstration objectives.
- The project is too limited in scope. Perhaps the researchers should pick a project like a Washington, D.C., Shell station, for example, and complete an analysis to determine if the station closed for business reasons or if the cost of safety is too high and not affordable.

Project strengths:

- The strengths of the project are the knowledge and dedication of the project members.
- The project brings together individuals with little to no experience in hydrogen installations and those with experience, along with the experts for NREL to educate and share knowledge, and build upon those experiences. While there is an element of "streamlining," it could be better captured.
- The information and resources developed by this project provide industry and the public a great springboard for navigating the codes and standards world.
- The project has a good technical team, good approach, and good communication plan.

Project weaknesses:

- The weaknesses are the lack of sufficient input for the industry members on specific needs and target regions. This weakness is beyond the project members' ability to correct.
- This project primarily works with California-based companies/industry and does not appear to provide the national-level resource that it could be. Education outreach pertinent to pointing people to the tools/resources developed for permitting certain applications is needed. Partnerships/collaborations with industry were not well described. While it is known the researchers have partnerships/collaborations, the inclusion and description of this participation was not fully presented.
- There was too much of the same material presented. There is a need to expand the scope and impact.

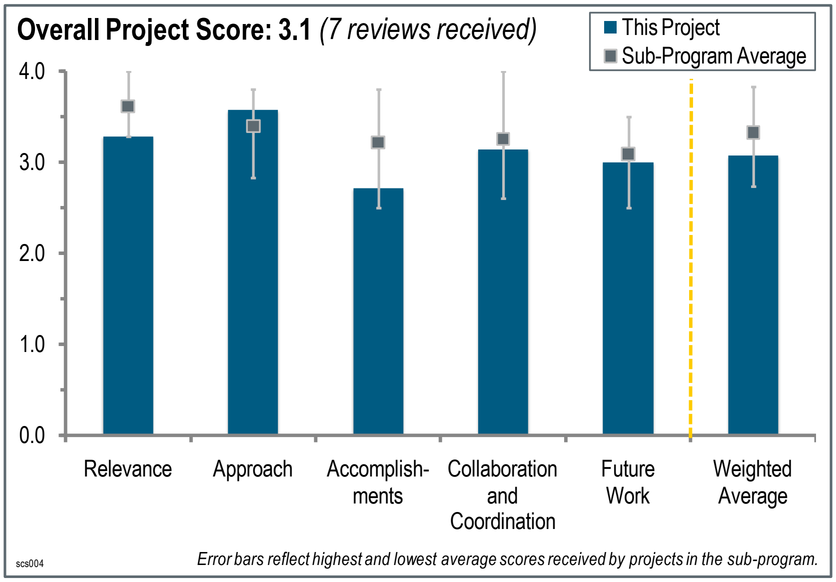
Recommendations for additions/deletions to project scope:

- A closer association with U.S. DRIVE and with the non-U.S. DRIVE original equipment manufacturers for specific input on near- and intermediate-term target regional markets is recommended. The researchers should create a base of this information, working through the state governments (offices of the state fire marshal and state building inspectors) in those regions to supply the relevant information to the local fire marshals, building inspectors, and first responders. If this information were transmitted in a form that would result in continuing education credits, there would most likely be better interest and acceptance of training.
- A marketing or education outreach activity could be asking industry partners (such as fuel cell manufacturers) to attach hyperlinks on their websites to the permitting-template for assistance in understanding the installation codes and standards. It would be nice to see more national collaborations.

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

Eric Brosha; Los Alamos National Laboratory

Brief Summary of Project:



The objectives of this project are to: (1) develop a low-cost, low-power, durable, and reliable hydrogen safety sensor for vehicle and infrastructure applications; (2) demonstrate working technology through rigorous life testing and application of commercial (reproducible) manufacturing techniques; (3) disseminate packaged prototypes to the National Renewable Energy Laboratory (NREL) and ultimately commercial parties interested in testing and fielding advanced prototypes and pursuing transfer of the technology to industry; and (4) seek NREL's help and guidance to evaluate sensor performance and keep progress on track through adherence to codes, standards, and field evaluation performance requirements.

Question 1: Relevance to overall U.S. Department of Energy objectives

This project was rated **3.3** for its relevance to U.S. Department of Energy (DOE) objectives.

- Hydrogen sensors will become more critical to codes and standards as hydrogen fuel cell devices become more common place in the market. The ability to ensure these devices are safely functioning depends on a reliable feedback mechanism. Hydrogen sensors will act as that feedback mechanism. This sensor meets the targets and has made great progress towards a commercially viable sensor platform.
- The project is very relevant to any large introduction of hydrogen technologies. The reviewer appreciates the relevance of the Lambda sensor, if this technology has the same level of impact, it would open the market for hydrogen fuel cell systems.
- The relevance to DOE objectives is clearly outlined in the project objectives. Exactly how far the project meets the specific DOE technical objectives is unspecified in the presentation.
- The development of low cost and highly reliable sensors is an important element for various hydrogen applications.
- Such a device is necessary.

Question 2: Approach to performing the work

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

- This project has taken a proven platform (Lambda sensor) and modified the materials to make this into a reliable hydrogen sensor. The step-wise approach of addressing spurious signals, responses to different variables, and then responses to multivariate interferences is logical and well demonstrated. The work plan for fiscal year 2012 looks to be straightforward and accomplishable within the time frame.
- The researchers are going through a lot of research. There are already a number of commercially available similar devices used around high-pressure and high-cost compressors. These devices are larger in size than those shown in the project. If approached and a profit by market demand could be proven, the private sector would develop the sensor.

- The researchers have an excellent approach, low manufacturing cost, and a potential for very reliable and repeatable results.
- The researchers have a logical approach to develop a better hydrogen sensor based on an existing technology whose shortcomings have been identified and addressed. It appears that NREL performance testing results have been incorporated effectively to improve the technology.
- The approach of this project seems to be appropriate. Further details regarding the manufacturing and cost analysis would be useful.

Question 3: Accomplishments and progress towards overall project and DOE goals

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

- Having only two sensors does not demonstrate reproducibility—especially when one sensor had an anomalous baseline.
- The principal investigators demonstrated that the sensor meets the projected goals for sensitivity, selectivity, response time, accuracy, and for the most part ruggedness. However, there is still a need to demonstrate long-term stability and operability at the NREL test stand.
- Industry would probably have been ahead of the curve.
- A reviewer hoped more bench and system demonstration work had been accomplished. There is a need to push for more integrated testing to confirm the technology can replicate the same type of reliability as the Lambda sensors.
- While the accomplishments and progress are clear, these are not measured against specific performance indicators for the period being reviewed. Major milestones appear to have been met.

Question 4: Collaboration and coordination with other institutions

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

- The team demonstrated the ability to bring in the appropriate partners such as BJR Sensors LLC to mitigate challenges. The fact that the team is working with U.S DRIVE shows that they have buy-in from the automotive original equipment manufacturers, which will be the ultimate test of success of this sensor platform.
- It is not clear if private industry/companies are being consulted, and the reviewer is not familiar with ElectoScience Laboratories Corporation.
- The researchers have good collaborations, and hopefully more meaningful system tests will be made after breadboards are manufactured that would more closely resemble commercial units.
- There is a clear assignment of roles and responsibilities between the partners/collaborators mentioned. The collaborations appear appropriate, effective, and well coordinated.
- The project appears to have good collaboration among national laboratories and industry.

Question 5: Proposed future work

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

- The project has a limited scope of work. There is a need to focus beyond a single small sensor and limited sensing medium. Also, the Japanese, Chinese, and member countries of the European Union must also be working on this issue. The researchers did not establish required reliability and availability. These two items are critical for success. Perhaps by staying with a few types, these may not be able to be maintained. Once reliability and availability is established, this becomes a metric for success. There is a need to better resolve the issues with temperature and altitude—2%, 3%, etc.; volume is the same regardless of altitude. At increased temperature the flammability limits are wider, see Bureau of Mines Bulletin 503 for more information.
- There is a critical need for reliable, quick hydrogen sensors for use in vehicles. Experiments conducted by Battelle indicate that several sensors may be required within a vehicle. Reliability, aging, and crash pulse tolerance need to be evaluated.
- It is certainly hoped that future work will look into the anomalous baseline issue.
- It appears future work is adequate to develop a viable, commercial-ready sensor.

- The reviewer would have liked the private sector partner to fabricate more systems and conduct integrated testing to validate short-/longer term testing.
- Future work proposed in the presentation is sometimes unspecific and vague, e.g., no details on proposals to improve sensors and packaging are given.

Project strengths:

- The project is based on an existing and demonstrated sensing platform. There is efficient exploitation of in-house expertise and techniques. It is a promising technology, and contacts with industry strengthen the project.
- Using the Lambda sensor platform as a model and modifying from that point gives this project a logical platform to expand upon.
- The researchers are trying to go after a number of items that may or may not be critical issues. At some point, it will be necessary to determine what has credible value to continue the work.
- The researchers have excellent staff, excellent approach, and excellent results to date.

Project weaknesses:

- Perhaps cross-sensitivity to anything which is easily oxidized or reduced will be an issue with this sensor platform unless higher order electronics are introduced to analyze phase angle distribution.
- It would seem that if there is really a market out there, that the potential profit from these devices would allow the private sector to develop a sensor that would have a high availability as well as high reliability.
- There has been too little field testing to confirm potential.
- Future planning is lacking some detail and in some cases, it is not directly relevant to the development of a hydrogen safety sensor (e.g., developing testing protocol for mixed potential type gas sensors). Commercialization needs to be considered, and it needs to be determined whether this is possible with the current industrial partners.

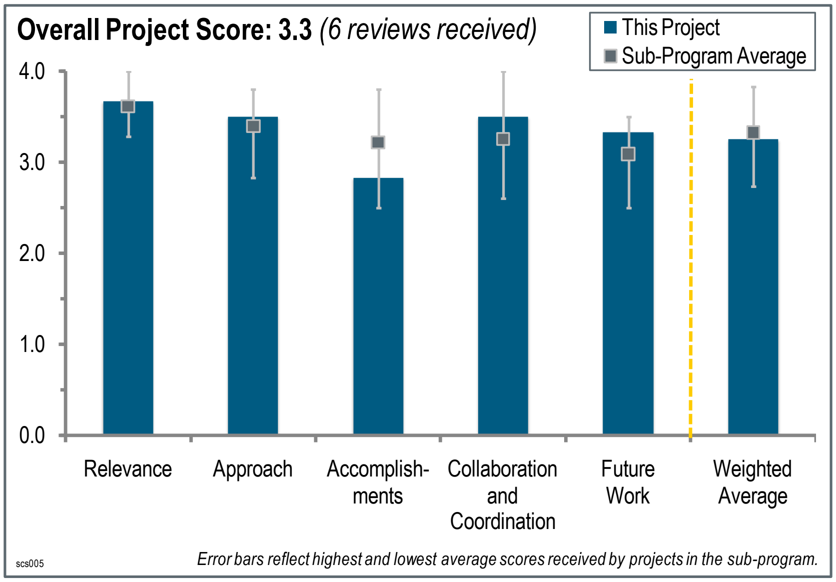
Recommendations for additions/deletions to project scope:

- The researchers should consider use of open path sensors so one area can be covered with a single point. It is imperative that the sensors in the field are to be developed for the appropriate electrical classification. If a release occurs, it would not look too good if the sensor detected it at 2% volume, it ignited at 4% volume.
- There should be more focus on commercialization and identification of target market applications. The researchers should consider the need to be involved in developing a testing protocol for mixed potential type gas sensors.
- It may be interesting to include a high-level comparison of the various sensor technologies.

Project # SCS-005: Materials and Components Compatibility

Brian Somerday; Sandia National Laboratories

Brief Summary of Project:



The overall objective of this project is to enable market transformation through the development and application of standards for hydrogen components. Objectives are to: (1) create a materials reference guide (a "Technical Reference") and identify material property data gaps; (2) execute materials testing to meet the immediate needs for data in standards and technology developments, such as fatigue life test methods and measuring weld properties; (3) improve efficiency and reliability of materials test methods in standards, such as optimizing the frequency for fatigue-crack growth testing in American Society of Mechanical Engineers' (ASME) Article KD-10 tank standard; and (4) participate directly in standards development, including component/system design qualification standards such as ASME Article KD-10, CSA Standards (CSA)-America Compressed Hydrogen Powered Industrial Trucks (forklifts) Onboard Fuel Storage and Handling Components working group (CSA HPIT 1), SAE J2579, and material testing standards such as SAE International (SAE) and CSA.

Question 1: Relevance to overall U.S. Department of Energy objectives

This project was rated **3.7** for its relevance to U.S. Department of Energy (DOE) objectives.

- Vessels will always be a question in this work. It is better to understand and do it correctly than to have to do it twice after a recall.
- The work that has been performed is critical to the success of the hydrogen program; however, within the context of the available funding, more methods need to be developed outside of the code developers that evaluate accelerated methods for testing failures. Dog bones are great, single rig crack testing is fine, but the time it takes for the information to be developed, models to be written, and papers to be published are too long to support all the existing demonstrations.
- An assessment of materials compatibility with hydrogen is critical for hydrogen applications. Besides the steels investigated in the project, compatibility with other material classes also needs investigation. This assessment should be aligned with Japanese and European efforts.
- The research is critical to standards development organization (SDO) efforts to specify materials and expand the known universe of acceptable materials.

Question 2: Approach to performing the work

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

- The reviewer asks if this analysis has been compared with the work done for the Nelson curve by the American Petroleum Institute. There was a lot of information used to develop these curves. One area evaluated was welding and post-weld heat treatment effects in normalizing the metal. This included a lot of chromium-molybdenum steels and various stainless steel types, mostly 300 series. There is also a lot of other data that may not be as relevant for furnace tubes, such as Larsen-Miller data and omega data. Granted this is data that is more

related to creep analysis, but there may be some applicable information that might apply to this project. The reviewer states that he seems to learn something new every time he reviews the data.
- The researchers have very good experimental approaches, but it is taking them too long to generate the database that will have much impact on early acceptance of these technologies.
- This group provides exceptional technical support to both SAE and CSA.
- The organization of the November 2010 workshop is appreciated. However, it is unclear what the main outcome is, apart from expressed need to work on welds. Also, it is unclear where need for variable temperature testing in high-pressure hydrogen originates.

Question 3: Accomplishments and progress towards overall project and DOE goals

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

- It is not clear that outcomes are being set forwarded and highlighted. They may be there, but it was necessary to search the details for results. For example, it would have expected to have a list of specified materials need for certain criteria. Also, since so much work was done around heat affected zone of welds, more comment around this area and/or issues in this area would have been expected.
- Progress has been made on a number of critical material systems. It is not clear how the information is used by original equipment manufacturers (OEMs) that are involved in the project. It is not clear if the results since initial project funding have made any difference to the design or materials selection on any funded project.
- Support of J2579 technical issues is critical for both fuel cell system design documents, but also to regulators working global technical regulations issues.
- In absence of any other information, the number of test results presented at the annual merit review meeting, and included in the presentation, seems low for one year of work.

Question 4: Collaboration and coordination with other institutions

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

- Collaboration is particularly evident with leadership in committees, e.g., Sandia technical staff serve on the committees of the SDOs, such as ASME, SAE, CSA, and the International Organization for Standardization.
- The organizations involved are very good although more OEMs would be better. The biggest question is how the information flows to the companies, hopefully not just through workshops. For example, the reviewer wanted to know if test materials are made and used in follow-up experiments.
- The project has close cooperation with the OEM community as well as worldwide academics.
- The researchers are well embedded in the United States and have clearly identified links with Japan on research and development (R&D). However, deliverables from that R&D collaboration were unclear until now, and probably some R&D experience from other countries could be exploited.

Question 5: Proposed future work

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

- There is a need to optimize evaluation of data generated in different national as well as international programs, in particular with respect to crack growth in the different metallurgical zones of commercial welds.
- More materials should be tested under various pressures in order to assess the effects of load-cycle frequency on fatigue crack growth in high-pressure hydrogen gas. Based on the presentation, the reviewer could only see measured effects at 21 megapascals (MPa) which is much lower than the current pressure of storage tanks for portable, stationary, and vehicular use.
- Of particular interest is the work on effects of welds.
- There is still a lot of work to be done on tanks, including how tank vendors can apply the work.
- There is not enough detail to evaluate. It looks more like the same.
- The project has good comments from the Japanese on homogeneity of material composition and its effect on embrittlement.

Project strengths:

- The project is necessary and on the correct track.
- There is a strong technical team with a good analytical approach and good experimental approach and data collection.
- The work is being performed by the right team.
- There is a good experimental facility direct link with SDOs.

Project weaknesses:

- Fatigue crack growth rate data presented in slide seven are not conclusive for frequency dependence. The crack growth rates observed at two different delta-K levels as a function of frequency may well be within experimental data scatter for a full da/dn versus delta-K curve at the reference frequency of 1 hertz presented in the figure. Obviously, full da/dn-delta K curves at a range of frequencies are needed to confirm this. When this is precluded because of too long testing times, a possibility may be to perform tests with step changes in frequency (both increasing and decreasing and check for the reestablishment, or not, of the previously obtained crack growth rate. This issue needs clarification because it seems to be the major reason for the proposed adaptation of test methods for assessing susceptibility to hydrogen embrittlement.
- Project PD025, "Hydrogen embrittlement of structural steel," also presents the same results of X52. The reviewer wants to know why two projects use the same results.
- The researchers could have summarized accomplishments a bit better without requiring reviewers to search for the results. There are still a lot of open items in the presentation notes. For example, they did not actually present types of events or materials or conditions that failed the test. This would be very interesting. For example, out of "X" samples tried, "Y" and "Z" failed for this reason.
- There was no observed outcome, except to attend meetings, hold workshops, and participate in consensus standards development. Test articles using new or advanced techniques based on this work would be a better work scope for future activities.
- The project has complicated and expensive engineering.

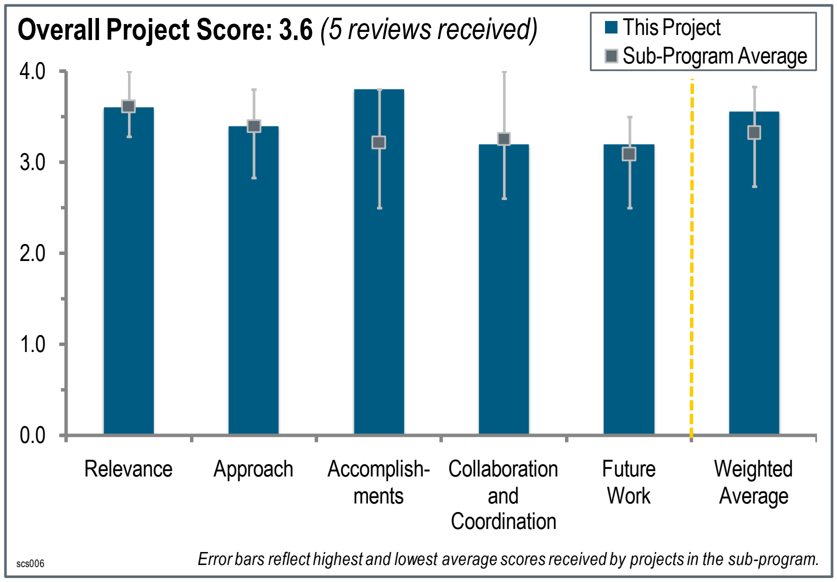
Recommendations for additions/deletions to project scope:

- For future tests, the project needs to look at effect of "V" notch on fatigue and crack growth. According to the reviewer's experience, every failure event started with some type of a "V" notch as opposed to a rounded notch. When a V is found, the procedure is to grind to a round. The Vs are the ones that catch the design in both fatigue and stress. More on details of welding requirements are needed. For example, can stick welding do the job, or is it necessary to place the container in a jig and use a laser guide. Also, what type of testing of weld is necessary for certification needs to be determined.
- A clear criteria and identification is needed of fatigue crack initiation.

Project # SCS-006: Hydrogen Safety Knowledge Tools

Linda Fassbender; Pacific Northwest National Laboratory

Brief Summary of Project:



The objectives of this project are to: (1) capture the vast knowledge base from hydrogen experience and make it publicly available in a living document to provide guidance for ensuring safety in U.S. Department of Energy (DOE) hydrogen projects, while serving as a model for all hydrogen projects and applications and (2) collect information and share lessons learned from hydrogen incidents and near misses, with the goal of preventing similar incidents from occurring in the future. Goals for this year are to: (1) update the Hydrogen Safety Best Practices Online Manual to improve existing content and add new content, (2) achieve a target of 220 records in the Hydrogen Incident Reporting and Lessons Learned Database, and (3) analyze the lessons learned from incidents.

Question 1: Relevance to overall U.S. Department of Energy objectives

This project was rated **3.6** for its relevance to DOE objectives.

- The project certainly fits into the over-arching goals of DOE and their emphasis on safety. It also ties into other areas, such as permitting and emergency response, and possibly codes and standards, as well. This project is a very good resource!
- The project augments the DOE Hydrogen and Fuel Cells Program and provides an effective avenue for the Program to share information and distill safety knowledge gained from laboratories, industry, and other stakeholders.
- The project serves as a point of reference to learn from the past. The reviewer is from industry, and he always points new hires to the website to check/research for prior relevant incidents. New hires are also directed to check the best practice section when they are looking at practice development or for ideas/brainstorming items for procedure hazard reviews.
- The work and information collected supports the objectives to maintain a high safety standard for all projects supported by DOE. The database provides a great source of information for new and existing projects and gives the private sector access to information that would be otherwise be out of reach.

Question 2: Approach to performing the work

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

- Anonymity is key to the willingness of organizations to participate. The reviewer would like to see if this research could be used in the hydrogen infrastructure/fueling station insurance issue (as a reference data base, but perhaps limited to fueling).
- The approach is effective and has improved each year. The project manager is very responsive to suggested additions to improve the information content and relevance of both websites.
- A critical barrier (singular) is potential liability from reporting of incidents. The reviewer noted he approached his management and told to not try.

- The project is a good approach, although resource limited. It seems this project should have more funding since it has a great impact on safety and sustainability. Information exchange still is a major barrier, especially on safety systems. This project is one that seems to allow private and public sectors to provide good information in a timely manner.

Question 3: Accomplishments and progress towards overall project and DOE goals

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

- The content of the website is much better; however, the overall appearance is still uninviting. While it is oriented for a more academic audience, there needs to be some visual stimulation to help guide people on the site and keep their attention while trying to find information. This may seem cursory; however, it could be a real bonus to the site.
- Additions to both websites have improved the information provided and the relevance of that information. The addition of the Lessons Learned Corner is good.
- There are excellent additions to the materials with indoor refueling, basic hydrogen information, and storage.

Question 4: Collaboration and coordination with other institutions

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

- While an extensive data base may not sound positive, the fact that there was a higher number of incidents added indicates the willingness to anonymously share experience and learning with others in industry.
- The principal investigator should report on status and progress of international collaboration and potential benefits of collaboration so that both tools can benefit from and add value to the larger international community of stakeholders.
- The project could be improved with more industry input. While the reviewer is not sure how to get it with direct details, in a general/concept sense, the researcher may be able to get some additional input.
- The project is resource limited, but has reached out to many companies and organizations for data and educational materials.

Question 5: Proposed future work

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

- The principal investigator and project staff should strive to get to a point where incidents and subsequent lessons learned and best practices are reported, not sought. The value of this work must be sufficiently obvious to industry and other stakeholders so that they report incidents (in a standard, normalized format) for the good of the industry as a whole.
- It is recommended the researchers continue to add more information and educational content. Hopefully more content will be added from California Fuel Cell Partnership and technology development projects supported by DOE.
- The project appears to be resource short, but continues to improve.

Project strengths:

- Expand the lessons learned to other relevant technologies. For example, the quarterly Lessons Learned Corner could perhaps be expanded to a broader audience or just a larger audience in general. The addition of disclaimers/safety notices is great, as well as the general hydrogen information. The project researchers are proactive in obtaining incidents, and do not just wait for something to be submitted to them.
- The fluid incident reporting tools, lessons learned, and resources for best practices are critical to deployment of new technologies, especially a technology like this one where accident consequences could be severe. This project is critical to the advancement of the technology. It also appears to show that the overall hydrogen program is being managed successfully, as there are more near incidents than sever incidents reported in the database.

- The project has become a little stronger and better defined each year.
- The project is well used by many.
- The project has excellent staff, good accomplishments, and is a well-organized project.

Project weaknesses:

- The project continues to grow by accretion of more incident records and extraction of lessons learned. While it acknowledges that the incidents database is not comprehensive, there is yet not a sense of what percentage of incidents is being captured or the significance of what is being captured.
- It is difficult to maintain interest and maintain at the same level excellence.
- There is too limited funding to expand this work and increase its relevance.

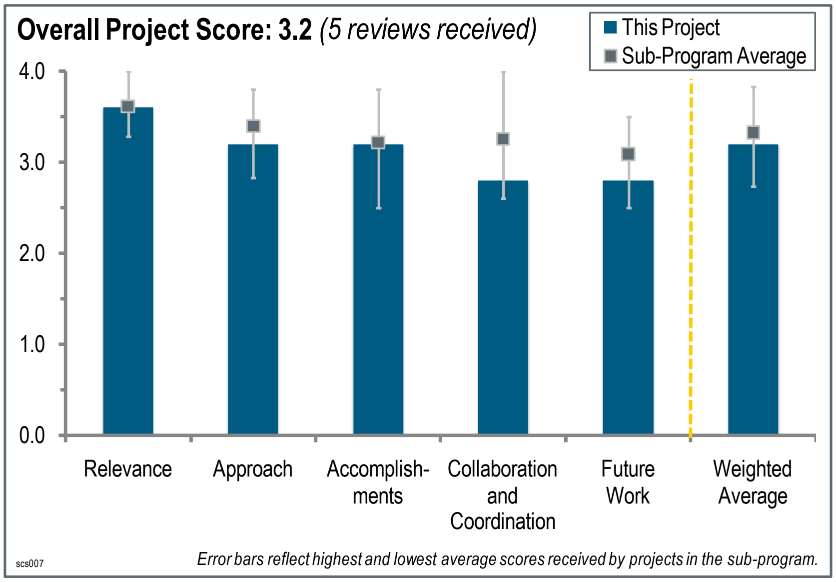
Recommendations for additions/deletions to project scope:

- The project needs a stronger analytical and evaluative component; perhaps a survey of industry and key stakeholders on the value-added of the project would be useful.
- It is recommended to confirm/consider checking the contributors to events and to verify if they are covered under the best practice section. The best practice gap analysis could also be completed by looking at findings from the Safety Panel reviews. This will require additional resources, but it would be dollars well spent.

Project # SCS-007: Hydrogen Fuel Quality

Tommy Rockward; Los Alamos National Laboratory

Brief Summary of Project:



The objective of this project is to help determine levels of constituents for the development of an international and American National Standards Institute standard for hydrogen fuel quality (ISO TC197 WG12). For the past five years, open discussions and meetings have been held, and are still ongoing, with original equipment manufacturers, hydrogen suppliers, other test facilities from the North American Team, and international collaborators regarding experimental results, fuel clean-up costs, modeling, and analytical techniques to form a common consensus with respect to an "international fuel standard."

Question 1: Relevance to overall U.S. Department of Energy objectives

This project was rated **3.6** for its relevance to U.S. Department of Energy (DOE) objectives.

- The researchers are doing what DOE said needed to be done under the scope of work.
- The project is very relevant to hydrogen quality.
- The three constituents in this project are critical to the success of the developing fuel standards.
- Hydrogen quality standards are essential for hydrogen sales to consumers.

Question 2: Approach to performing the work

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

- There appears to be a lack of industry input on this work.
- Air may also be a problem by introducing issues.
- The project has complicated testing, and a methodical, rigorous approach.
- The testing has been extensive over a long period of time. The project team has been persistent and succeeded in providing the data necessary for standards to be published.

Question 3: Accomplishments and progress towards overall project and DOE goals

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

- There has been good progress in support of standards development organization constituent values. There has also been good corroboration between testing results and draft specification contaminant values proposed by the SAE International and International Organization for Standardization. Presentations made to industry were credible and coherent.
- There may be problems with the test facility that could be introducing the problems, or at least some of the problems. Tests with only a few cells do not give confidence in the results. It is important to understand variability potential in the results.

- The testing for this project has been extensive and long. The project team has been persistent and succeeded in providing the data necessary for standards to be published.
- There is still a lot of work left to be done.

Question 4: Collaboration and coordination with other institutions

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

- The reviewer questioned where the input was from the automakers. The reviewer also questioned if the researcher verified that the membrane electrode assembly (MEA) and fuel cell setup being utilized is representative of that from the industry. Finally, the reviewer wondered if the researchers know how their data compares with that from the automakers.
- Collaboration in this project is with other similar institutions, and there is no industry input.
- The researcher has a very good relationship between researchers and industry.
- The data has been widely distributed, which is a strength of the project.

Question 5: Proposed future work

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

- Perhaps an analysis or a comparison of differing levels of these three constituents emerging from the most prevalent hydrogen production methods is called for to determine if these levels are what can normally be expected from all processes or if it is more indicative of a reformate. While this may seem obvious to some fuel industry professionals and researchers, it is not to the more “casual” observer.
- There is still much left to study. Combinations of contaminants can be tested, as well as testing of lower loadings and higher performance MEAs.
- The project is staying within scope of stated work. The researchers need to look beyond the scope of work for additional opportunities. Also, they should look at the impact of air contaminations on the system. It is not unusual for air to have 0.1 parts per million (ppm) of hydrocarbons, trace ammonia, as well as some carbon monoxide and a lot of carbon dioxide. The researchers also need to work on impacts of combinations of impurities at the same time.
- The researchers must address the new targets for loading at 0.125 grams per kilowatt.
- The reviewer would like to have a better understanding of the hole creation in the MEAs.

Project strengths:

- The project is following established program requirements.
- There is a good relationship between researchers and industry.
- The project has good collaboration and is undertaking persistent work on a long difficult project.

Project weaknesses:

- It is very costly to achieve 0.004 ppm hydrogen sulfide in large commercial (lower cost) operations. At that point, the cost of fuel is well above gasoline.
- It takes a long time to make results publicly available.
- Some phenomena remain unexplained, and more work needs to be done.

Recommendations for additions/deletions to project scope:

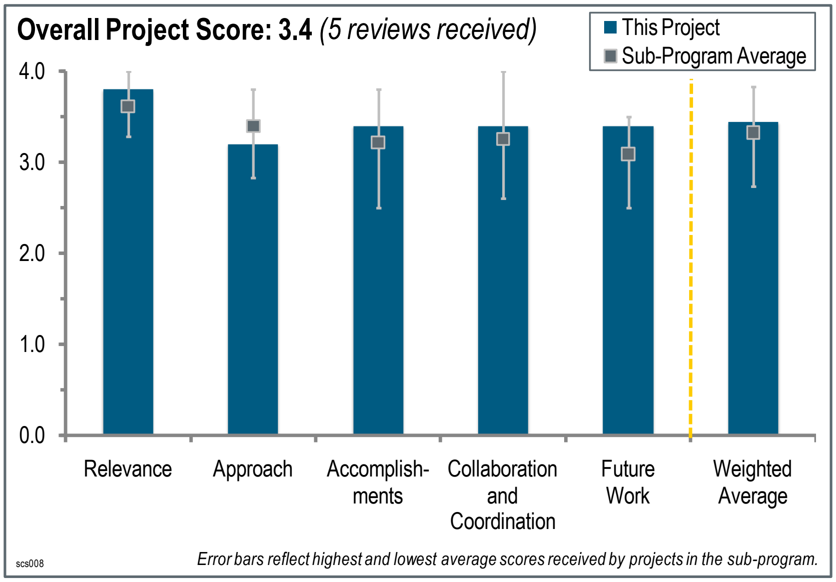
- DOE needs to see if the amount of impurities can be revised upward to provide a lower cost.
- More work on combinations and higher performance MEAs and lower catalyst loadings could provide useful data.

Project # SCS-008: Hydrogen Safety Panel

Steven Weiner; Pacific Northwest National Laboratory

Brief Summary of Project:

The objectives of this project are to: (1) provide expertise and guidance to the U.S. Department of Energy (DOE) and assist with identifying safety-related technical data gaps, best practices, and lessons learned and (2) help DOE integrate safety planning into funded projects to ensure that all projects address and incorporate hydrogen and related safety practices.



Question 1: Relevance to overall U.S. Department of Energy objectives

This project was rated **3.8** for its relevance to DOE objectives.

- Safety has been, and will likely be, a high-priority topic with respect to hydrogen and DOE projects.
- The safety panel is critical for the success of the DOE Hydrogen and Fuel Cells Program and has evolved each year to meet needs of the Program.
- The safe use of hydrogen by industry and also academia is a critical aspect in the development of this technology. This project is very relevant to the advancement of this type of fuel.
- Oversight organizations such as the Hydrogen Safety Panel can be very effective to ensure safety is a primary concern.

Question 2: Approach to performing the work

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

- The slight change in direction, in terms of turning from laboratory to deployment projects, the "Safety Planning Guidance for Hydrogen and Fuel Cell Projects," are an excellent incorporation of the feedback from last year's review and are reflective of the move in industry from research and development to commercialization.
- The approach is logical, organized well, and generally effective. More discussion concerning the integrated approach (slide two) would be helpful and show how centralized management of safety and education projects at Pacific Northwest National Laboratory helps to integrate these efforts in order to address barriers in a comprehensive and cost-effective way.
- Diverse panel participation lends credibility to its efforts.
- The approach shows that the project is getting out to the sites in the field and making evaluations at the site, which is necessary. Follow up meetings are held by teleconference, which might not be as effective as another site meeting, especially when the recommendations are extensive. A review of designs prior to construction is a strength of the project.

Question 3: Accomplishments and progress towards overall project and DOE goals

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

- The level of initial investigation and the follow-up activities illustrate the genuine interest in promoting a safety culture in this technology, and the effort to work with industry.
- The safety "scorecard" (slide 11) is impressive in terms of number of activities performed, but there doesn't seem to be a good idea of how close the Program and the project are to achieving the vision (slide six). As stated in previous reviews of this project, more analysis and evaluation of effectiveness are needed, including criteria other than number of visits, safety plans reviewed, etc. Slide 14 of the presentation is a good start, but there should be an evaluation of the significance of the recommendations being implemented or not and the safety effects of "partial" implementation. No action concerning two recommendations on emergency response seems more important than implementation of recommendations on "housekeeping." Also, of the total of eight recommendations not implemented, five concern safety vulnerability mitigation analysis, which seems to require further evaluation on panel effectiveness.
- The review of safety plans is an excellent accomplishment, and it was good to see there were other fuel cell applications canvassed.
- Subject to funding constraints, the work has been continuous, which is a strength of the project.

Question 4: Collaboration and coordination with other institutions

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

- The project has excellent collaboration.
- Collaboration is implied, but not specifically addressed. More details on slide two of the presentation could have addressed collaboration and was a missed opportunity.
- Good progress was made since the last review in getting industry involved. The fact that the team reviewed 295 safety plans is commendable. Also, the fact that 90% of the panel's safety recommendations were completed or are underway is a good sign that the users are responsive to the team's approach.
- Collaboration with stakeholders has been extensive and this is a key project strength. Additional collaboration with underwriters and insurance companies might be helpful.

Question 5: Proposed future work

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

- Perhaps this project is a forum to gather information or create a data base for the insurance industry. There are organizations that are working with the gasoline station owners, and their insurers/underwriters are involved, but perhaps there is a need for a central location for hydrogen-related information (industrial, fueling station experiences, etc.) According to the reviewer, Air Products and Chemicals, Inc. was or is working with FM Global insurance to supposedly gather some information. Since there was a representative formerly on the panel, the reviewer wanted to know if this work has already started in some capacity.
- The project will continue reviewing safety plans, conducting site visits, etc. There should be more emphasis on providing a better overall sense of progress in the safety of Program activities, what may lie ahead in terms of safety issues and concerns, and a strategic component to project planning.
- It is good to see the researchers are going to get more international exposure at the September meetings of International Conference on Hydrogen Safety. It would be interesting to see more inputs from international users, either industrial or academic, which could perhaps be solicited at the September meeting.
- The work is expected to continue "for the life of the program," but it is not clear when and how it will be transferred to industry. This would be an improvement.

Project strengths:

- There is excellent technical expertise on the panel, and the principal investigator is very effective in managing the panel and in coordinating with other activities within the Program and with other stakeholders, both domestic and international.
- The project indicates a "soft" approach that complements the "clients" existing processes, which is an excellent technique.
- Good collaboration, site visits, design reviews prior to construction, and continuous diligent effort.

Project weaknesses:

- Not so much a weakness, as a challenge (which was mentioned during previous talks) is disseminating the information. People in the industry need to know this information is available as an excellent resource. The reviewer wondered if there are mechanisms to more broadly distribute the information, such as linking to other DOE projects, for example, National Renewable Energy Laboratory's (NREL) outreach or the emergency responder program.
- There seems to be a certain "comfort level" regarding the panel's role and activities. A larger, more comprehensive view of hydrogen safety and the value-added of a panel of safety experts is needed to better utilize the full value of the (largely voluntary) panel.
- There remains reluctance to share information unless there is a negative event. The reviewer suggested that there could be mandated compliance at certain levels.
- Since the project is subject to DOE appropriations, it cannot be counted on to contribute the hydrogen industry safety for the long term. When funding ran out, the work stopped.

Recommendations for additions/deletions to project scope:

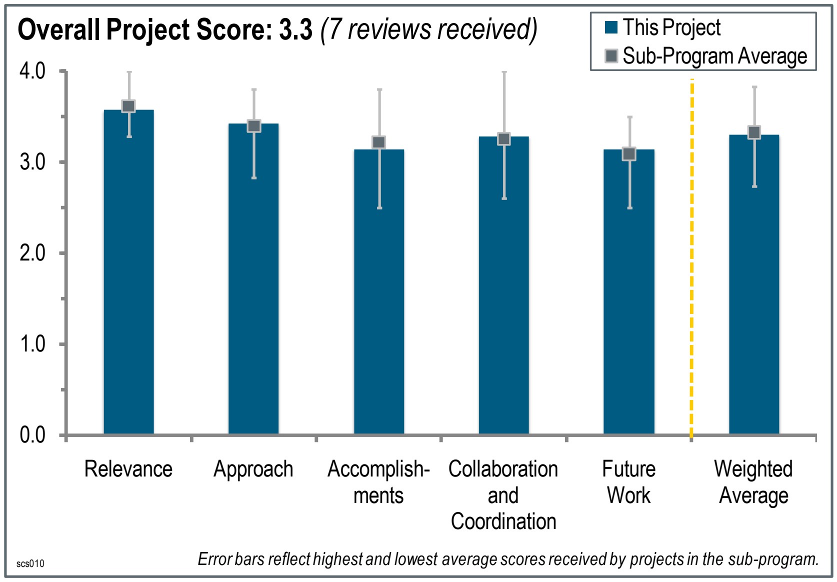
- Perhaps the project could develop a format to provide more detailed information on the value-added of the panel's activities, such as the review of the NREL facility (slide 15) while protecting necessary confidentiality of the information. The reviewer wondered what safety improvements emerged from the discussion with NREL staff on electrical classification, ventilation design, and hydrogen supply and usage that could be valuable for other laboratories.
- It is recommended the project find ways to transport the hydrogen safety mock up device training to all states with the pertinent information.
- Development of a succession plan, to turn over the work to industry, could be beneficial to both industry and government.

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

Daniel Dedrick; Sandia National Laboratories

Brief Summary of Project:

Hydrogen codes and standards need a defensible and traceable basis. The objectives for this project are to provide the scientific basis for hydrogen codes and standards through: (1) physical and numerical experiments to quantify fluid mechanics, combustion, heat transfer, and dispersion behavior; (2) validated engineering models and computational fluid dynamics models for consequence analysis; (3) established quantitative risk-assessment methods for informed decision making and identified risk mitigation strategies; and (4) an understanding of hydrogen's effects on structural materials when applied to components and systems.



Question 1: Relevance to overall U.S. Department of Energy objectives

This project was rated **3.6** for its relevance to U.S. Department of Energy (DOE) objectives.

- This project is developing sound technical data that should improve the understanding associated with hydrogen as a fuel. However, while the work has very high technical merit, there does not appear to be sufficient engineering around the basis for the experimentation. By this time in the project's schedule, the experiments should be focused on "real" expected outcomes based on probability analysis. Experiments should not just validate the model, but be used to engineer safe systems. The reviewer wanted to know the following information: (1) the levels of leakage that are really economically viable, (2) if the model can be used to ensure no deflagration, (3) if catalytic recombiners can be recommended as part of the tank filling to eliminate the probability of unintended consequences, and (4) how the National Fire Protection Association (NFPA) is using the data to specify procedures for refueling.
- Completion of the objectives of this project is critical to the eventual success of the DOE Hydrogen and Fuel Cells Program. It provides the basis for performance-oriented standards.
- This project is an agglomeration of different subprojects (SCS-005, 012 and 011). As such, the comments to the individual subprojects apply. It is recognized that the three subprojects constitute necessary elements to the overall goal.
- Material capability is critical work, since this has been the largest issue with hydrogen in industry. Pressures greater than about 4,000 psi are largely unknown. Temperature effects with pressure around 1,300°F are also not known.
- Translating hydrogen physical behavior to safety requirements is critical to establish appropriate guidance for hydrogen technology deployments.
- All projects display significant relevance. While the reviewer does not have specific comments, he encourages the researchers to continue along their current path.

Question 2: Approach to performing the work

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

- The approach seems to be productive and relevant. It is recommended to stay with the same approach.
- The combination of modeling, physical validation, and outreach/communication activities is well designed to address hydrogen safety-related barriers.
- Between 2010 and 2011, the objectives were changed to include hydrogen effects in structural materials and components, but nowhere in the presentation was there a link to how the data collected is used to solve engineering challenges. It appears all the data is provided by standards developers and the engineering recommendations are determined by them or by a consensus of stakeholders. The reviewer wondered if the role of this project is only to provide data to others to overcome barriers, or if the engineers of this project from SRI International and Sandia National Laboratories are also proposing engineering solutions to facilitate the introduction of hydrogen technology. The reviewer also wondered what real-life experience has resulted from this work, especially in the operation of fuel-cell-powered lift trucks.
- The project has an excellent scientific approach, and participation by key research personnel in standards development organization (SDO) activities has enhanced the resulting impact of their work.

Question 3: Accomplishments and progress towards overall project and DOE goals

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

- Overall progress is very good.
- There are many publicly available prior studies that relate directly to this work. For example, Mike Swain and University of Miami, L. Shirvill from Shell UK, HSE (UK), Baker Risk, and Bureau of Mines (in or around 1953). A lot of the data being gathered and tested in the program is available in these reports. Using this data as background would greatly increase the research speed or make some programs duplicative.
- Overall, progress of work and dissemination of results to both national and international codes and standards communities is excellent. Establishing a solid technical basis for separation distances in key documents like NFPA 55 is a significant achievement.
- The project has accomplished some very good validation of models and collected a great deal of valuable data. The data now needs to be implemented into real systems for some integrated systems testing under actual operating conditions to see if problems can be mitigated.
- The hydrogen behavior work should be winding down as the results feed into the quantitative risk assessment part of the project. The materials compatibility team has achieved good results that are useful to industry.
- For the experimentally oriented sub-projects 005 and 012, the actual number of tests reported seems to be rather low for a full year of work.

Question 4: Collaboration and coordination with other institutions

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

- The project has excellent coordination with industry and the "real world," and with the incorporation of feedback, which is not always the case between academia and industry.
- It seems there is no real collaboration with other organizations that are doing similar work, especially in Japan, China, United Kingdom, and Germany. There is an end-user interface, e.g., with NFPA, but beyond that the customer is not clear.
- Collaboration with and dissemination to the international codes and standards community has been well done.
- There should be more collaboration with system integrators and equipment manufacturers by this time. Refueling systems, instrumentation and controls, heating, ventilation, and air conditioning, etc., all these original equipment manufacturers (OEM) should be using the data to build and test fully integrated buildings to demonstrate that the data collected and modeled will ensure safe and cost-effective systems for the introduction of advanced hydrogen technologies. Partners should now include companies such as Honeywell, Robert Shaw, Baldor, Siemens, Coleman, etc., that will engineer, build, and install these systems in businesses.

- The project has excellent participation of the materials compatibility team with industry members. Both the automotive and industrial truck applications benefit from this work.
- Direct collaboration with code development organizations (CDOs) and SDOs on industry-prioritized problems is very good.

Question 5: Proposed future work

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

- While not called out specifically, but incorporated into the presentation and question and answer, it seems that future work will continue with current projects and with the coordination efforts with SDOs to identify needs and gaps and address these as needed.
- The work on materials is good, but the other areas seems a bit of a problem when looking into what has been done by others and not duplicating that work.
- The project plans on addressing key issues including hydrogen ignition initiation, indoor fueling characterizations, and localized fire effects.
- Future work should start applying the knowledge to more practical applications. It is recommended to work with OEMs to establish equipment specifications and work to build real systems for integrated tests to demonstrate "safe" operation. These systems should be modeled to show the work resulted in reduced inherent risk.
- Completion of materials work is essential.
- Identified areas of future work stem from individual sub-projects 005, 011, and 012. The path forward identified there seems logical and appropriate.
- International collaboration is critical to obtain sufficient technical data to support standard revision or development.

Project strengths:

- Testing of materials is a project strength.
- It is a well-designed and executed program that is providing concrete hydrogen safety guidance.
- The project has a good technology team, good experimental design and implementation, and good data analysis.
- Cooperation with other players in the global technical regulations process.
- The project has close links with and direct involvement with CDOs and SDOs.
- There are validated engineering models of hydrogen dispersion and ignition.

Project weaknesses:

- One of the more interesting points made during the presentation was the "isolation" that had to be established for the tests to enable better validation of data. If the data is to have "real" application, then realistic experiments or applications must be demonstrated to improve engineering and installation of these systems. Collect the most accurate data and then apply it to show it will improve the performance of advanced technologies.
- Caution must be used in relying too much on risk-based gaseous hydrogen separation distance. The risk of hydrogen storage vessels is sensitive to many factors such volume, pressure, environmental conditions, and vessel structure. The failure model of completely multi-layered steel vessels under operation is leak-before-break. Leakage can be monitored and safely handled. Therefore, a completely multi-layered steel vessel is safer than a monopoly vessel.
- The "upstream research and development" work could possibly benefit from better international collaboration.
- There is duplication of work with the work of others. It seems like duplication or results could be quickly collaborated.
- The effort could use a clearer description of how progress and success are measured.

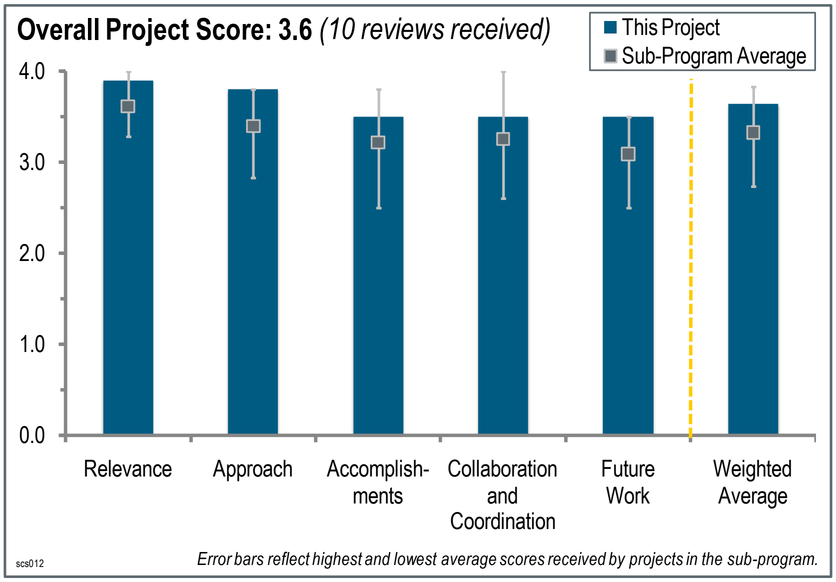
Recommendations for additions/deletions to project scope:

- Push materials testing as higher priority. For properties, look into prior work and collaborate. Most of this data is available from others, including industry (if not proprietary).
- Enlarge the scope of materials and applications covered beyond steel tanks for forklifts.

Project # SCS-012: Forklift Tank Testing and Analysis

Chris San Marchi; Sandia National Laboratories

Brief Summary of Project:



The objective of this project is to provide a technical basis for the development of standards to define the use of steel (type 1) storage tanks by: (1) using an engineering analysis method to validate a fracture mechanics-based design approach in American Society for Mechanical Engineering (ASME) Boiler and Pressure Vessel Code (BPVC) Section VIII, Division 3, Article KD-10; (2) using a performance evaluation method to provide data to help determine if time for crack initiation can be reliably credited in the design qualification process; (3) quantifying failure characteristics, such as leak-before-break; and (4) participating directly in standards development for component design standards such as ASME BPVC Section VIII, Division 3, Article KD-10 and the CSA Standards (CSA) Hydrogen-Powered Industrial Trucks (HPIT) working group.

Question 1: Relevance to overall U.S. Department of Energy objectives

This project was rated **3.9** for its relevance to U.S. Department of Energy (DOE) objectives.

- The project is providing the technical basis for the development of standards for all-steel hydrogen storage tanks for forklifts. Currently there is insufficient technical data to revise the standards. Project staff also participate directly in the development of standards for these tanks. The market for hydrogen-powered forklifts is expanding rapidly and is very important to the DOE Hydrogen and Fuel Cells Program.
- The relevance of the project is very apparent with the growing implementation of fuel cell forklift trucks across the country and DOE's involvement with those projects.
- The project is critical to sustain a major emerging market application of hydrogen and fuel cells and is an essential project in DOE's research and development (R&D) portfolio. It has already contributed important pressure cycle test data for the performance of type 1 tanks under a duty cycle (accelerated) for material-handling forklifts. The data from the project will be highly relevant to emerging and potentially very large market applications in Europe and in Asia.
- The project is very relevant to the industrial truck industry. Investigation of crack initiation is a useful tool in manufacturing steel tanks.
- The project contributes directly to addressing a specific issue of tank integrity and safety for indoor use.
- This project supports a key safety issue regarding an important fuel cell market application and was a very high priority for the fuel cell industry.

Question 2: Approach to performing the work

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

- The project's approach (full-scale tank testing with engineered defects, materials testing at high pressure, and participation in the standards development process) is directly focused on addressing the identified barriers related to materials compatibility, tank standards, and lack of technical data.

- The project is very comprehensive and follows established test models for other hydrogen tanks and uses (i.e., light duty vehicle tanks) with some new techniques like the machined defects.
- The experimental design (including as-manufactured tanks and those with engineered flaws) is excellent and serves as a model for other testing projects to qualify pressure vessels for other duty cycles. The collaboration with key industry stakeholders and standards development organizations (SDO) also serves as a model for how R&D and testing can be integrated with and strengthen the codes and standards development process.
- Full scale is the only way to go. Test results are directly applicable to industry.
- Experimental evidence of crack initiation could be obtained from strain measurements near the location of artificial defects.
- The testing and analysis have been conducted in a most professional manner consistent with the best practices for safety and quality as evidenced by the presenter's information.

Question 3: Accomplishments and progress towards overall project and DOE goals

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

- Sandia National Laboratories (SNL) maintains significant infrastructure and expertise for full-scale tank testing. The project is quantifying the failure characteristics of all-steel hydrogen tanks from different manufacturers. To date, there have been no catastrophic ruptures of any tanks; all the tanks have failed with slow leaks. The project team wants to see some tank ruptures in a controlled environment (secondary containment behind a blast door), so they have machined multiple defects into some tanks and pressure-cycled them for tens of thousands of cycles. The tanks have lasted for more cycles than predicted.
- To date, the project has very good results, especially given some of the early challenges with component failure, equipment failure, etc. Please note there have been no catastrophic failures.
- Although delayed by equipment problems, the project has completed a large number of cycles on test tanks and made significant progress toward providing data critical for the development of key requirements in standards. These standards will govern the application of hydrogen fuel cells that use type 1 tanks and that have duty cycles with frequent fills. These data can be important in improving requirements in other countries where use of type 1 tanks for hydrogen service is potentially extensive, particularly India, China, and Brazil.
- It would be good to have a larger denominator (tanks tested) so when results are declared there will be a tighter tolerance on data.
- Additional information regarding compressor design will be valuable for future projects.
- Difficulties and setbacks in performing cyclic experiments are acknowledged. Observed compressor failures should be included in the incidents data base.
- Although some schedule delays have resulted from decisions made early in the program to use equipment that was not well suited to the application, the engineering team has responded well and corrected the problems and is nearing completion of the project.

Question 4: Collaboration and coordination with other institutions

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

- The project has excellent collaborations with some of the key players in this field. Peer reviews of the project's testing plan were obtained from the CSA working group on hydrogen-powered industrial trucks, the Fuel Cell and Hydrogen Energy Association forklift task force, tank manufacturers, and fuel cell manufacturers (Nuvera and Plug Power).
- The project has a very organic collaboration with the SAE International (SAE) and CSA.
- The collaborations with industry and key technical committees of SDOs preparing the governing codes and standards (CSA, SAE, and ASME) serve as a model for how R&D and testing should be incorporated in the codes and standards development process.
- It is good that the project has explored the literature to find similar research done by others. There project should also explore if there is similar research being done by the U.S. Department of Defense/DOE (White Sands) and in ongoing work in Japan, European Union, and probably China.

- A peer review testing plan will yield usable results. The project is tied in very closely with the CSA HPIT and SAE J2579 groups.
- Collaboration to share leak rate experience with other SNL personnel working on related issues is a strength of the project. It would be preferred to have more communication with other portions of the hydrogen program outside of SNL, including incident reporting to the h2incidents.org website at Pacific Northwest National Laboratory.

Question 5: Proposed future work

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

- Proposed future work is not applicable because the project is scheduled to end this month.
- The presenter mentioned that the project team was pushed to move on this project very rapidly, and conveyed that sense of urgency from the oral presentation. The benefit is that there is a wealth of knowledge that can be drawn upon from the current documents on hydrogen tank safety performance testing (although tank materials and pressures are different). To that, the suggestion is to be cautious and not overlook some component of testing, or be too rushed in interpreting the data. The reviewer believes the teams working on this are completely capable and experienced.
- The proposed future work is appropriately focused on completing tests until the tanks reach 50,000 cycles or fail. The data will be shared with the appropriate SDOs so that more rigorous requirements based on scientific data can be incorporated in engineering design and qualification through performance testing. If funding is available, the project should be extended to improve knowledge about crack initiation.
- The project needs to come to a conclusion, but the reviewer would support looking at additional tests of various other conditions.
- Completion of the testing cycle is important to the development of CSA, HPIT, and Hydrogen Gas Vehicle documents.
- Clarification of crack initiation is interesting for improved prediction of actual service life, particularly in view of observed discrepancy between crack growth life and total fatigue life, which indicates that the majority of life is spent in the initiation phase. In this context, it would be useful to: (1) investigate the effect of the shape of artificially induced defects on total fatigue life, (2) monitor deformation by appropriate strain gauging, and (3) obtain some experimental laboratory data on short crack growth.
- The conclusion of the work and factoring the data into ASME design requirements is essential to the success of the industry and needs to be continued.

Project strengths:

- The project strengths are the SNL facilities and infrastructure and staff expertise to conduct this work, as well as the excellent collaborations with SDOs and industry players.
- The project has an extensive base to build upon.
- This project is targeted to the specific application and tank type, as it should be. The reviewer agrees with previous reviewers that leak before break has not been studied enough for non-metallic cylinders, but that is out of scope of this project. The project is also good in that results are being carried back to inform SDOs with performance data.
- The project has excellent experimental design and testing procedures to address a key shortcoming in existing requirements in codes and standards that govern an important emerging domestic and international market for hydrogen fuel cells.
- The project has done actual testing without a lot of theory involved. Thus, it is easy to apply, sell, and understand.
- There is an excellent engineering and scientific work ethic consistent with quality, safety, and performance. It has a highly professional staff, good collaboration with other SNL areas, and excellent analysis tools and application.
- The challenge for maintaining infrastructure for tank cycling has been resolved.
- The project has an excellent set of researchers.
- There is a direct link with code development organizations and SDOs.

Project weaknesses:

- The principal investigator stated that the project has experienced multiple equipment failures (e.g., tanks, compressors, ball valves, O-rings, fittings). This equipment failure data should be provided to the h2incidents.org database, along with the key lessons learned from the failures. At this point in time, no incident records have been provided to the database from this project.
- It is possible to miss something, so the researchers should think outside the box.
- Some test equipment and component failures have delayed the project, but these failures have been overcome and lessons-learned applied.
- Based on the data presented, any inference of occurrence of leak before a break must not be made because of the reduced volume of pressurized hydrogen, which is not representative of actual service conditions.
- Collaboration with other laboratories has sometimes been slow to occur. Some early decisions to use equipment not suited to the task delayed the work.
- Performance evaluation method based on test data is not being adequately addressed.
- The project was over too quickly.

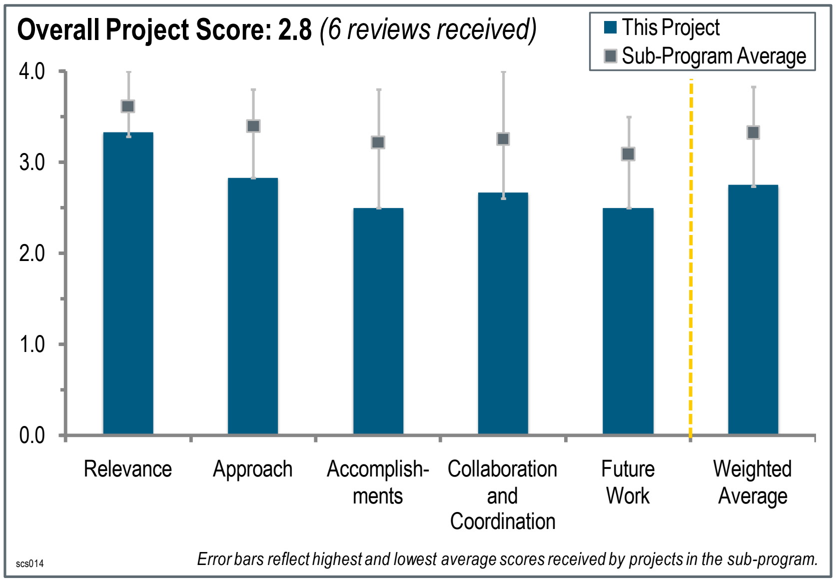
Recommendations for additions/deletions to project scope:

- The project is providing important insights for experimental design and testing procedures that will benefit future projects that will address qualification requirements and testing for other applications of hydrogen components that undergo pressure cycling. If funding is available, more tanks should be acquired and tested to better correlate engineered and as-manufactured flaws that can lead to failures. More R&D and testing to acquire a better understanding of the variables important in crack initiation is also important and should be undertaken if funding is available. International collaboration with India, Brazil, and China on pressure cycle testing of type one tanks with hydrogen-compressed natural gas mixtures for duty cycles that may exacerbate fatigue cracking should be considered again if funding is available along with in-kind cost share by these countries.
- If funding is received, the reviewer suggests trying different depths and length (ratio to circumference) of cracks (flaw versus defect, etc.) to determine failure potential. At 50,000 cycles, assuming one fill per day would get 136 years of use from one tank, so multiple fills/day are assumed. It might be good to look at how many times a tank might be filled in its life based on energy use required, establish cycles, and then determine a safety factor to identify number of cycles needed. For example, two fills/day, 20-year life, five days/week, ~10,400 lifetime cycles, and an assumed safety factor of 3.5 = 35,400 tests. Also, the reviewer suggested giving guidance as to what size crack can be accepted when performing a wet mag or other form of testing.
- Additions to the scope should include completion of the work and active collaboration with ASME to update their design standards. This appears to be planned, but may not be funded. This funding needs to be provided, either by DOE or by industry. Failure to do so means that much additional work will need to be repeated in order to support deployment of this important product type.
- The fatigue behavior of materials in hydrogen gas is sensitive to testing variables such as surface condition, defect size, load-cycle frequency, and pressure. It is important to depend more on manufacturers to participate in the processing of tanks and implementation of engineering defects.
- The project is scheduled to end soon, so this reviewer does not have any recommendations.

Project # SCS-014: Safe Detector System for Hydrogen Leaks

Robert Lieberman; Intelligent Optical Systems, Inc.

Brief Summary of Project:



The project goal is to select and finalize hydrogen sensor technologies by: (1) designing and fabricating scalable prototype sensors and (2) investigating and establishing the end-user market size and cost analysis. The overall objectives are to: (1) integrate Intelligent Optical Systems' (IOS) proprietary hydrogen indicator chemistry into a complete optoelectronics package with well-defined sensing characteristics and a known end-use market and (2) identify different formulations and physical embodiments to meet specific market requirements. Technical objectives for 2010–2011 are to: (1) select and finalize hydrogen sensor components and outline scalable cost analysis; (2) finalize sensor data processing algorithms with minimum false alarms; (3) fabricate, test, and validate performance of 14 fully packaged prototypes; (4) deploy prototypes at four different field test sites; (5) collect and analyze real-time test data under various deployment conditions; and (6) reach end users through field demonstrations and field trials.

Question 1: Relevance to overall U.S. Department of Energy objectives

This project was rated **3.3** for its relevance to U.S. Department of Energy (DOE) objectives.

- This goal for this project is to develop a suitable, low-cost, high-reliability hydrogen leakage detector. This is one of the pieces needed to generate a hydrogen infrastructure.
- The goal of the project meets safety, codes and standards *Multi-Year Research, Development, and Demonstration Plan* goals and objectives. However, there are questions whether the project can feasibly meet those goals.
- This project is a prime example of collaborative use of industry in the public domain. If it works well they have a market and will have payback for their efforts.
- The link to specific DOE targets and the barriers which this project addresses is very clear. Fast, reliable, low-cost, sensitive hydrogen sensors are essential to the safe use of hydrogen.
- The development of low-cost and highly reliable sensors is an important element for various hydrogen applications.

Question 2: Approach to performing the work

This project was rated **2.8** for its approach.

- The project seems to be somewhat disorganized. The principal investigator (PI) needs to focus on the sensor basics. The project team needs to address cross sensitivity and be able to incorporate that into their analysis algorithm to move to a commercially viable platform. The PIs seemed to be more focused on the sleek packaging rather than complete sensor performance.
- The researchers seemed to lock onto a single technology. Maybe this was the direction they were given.
- The approach is well structured and designed; however, integration with other efforts is not obvious. The feasibility of the sensor with respect to costs is also unclear.

- The approach appears to be well thought out and appropriate for this task.

Question 3: Accomplishments and progress towards overall project and DOE goals

This project was rated **2.5** for its accomplishments and progress.

- There does not seem to be much progress from fiscal year (FY) 2010 to FY 2011 in meeting sensor performance goals. Cross sensitivity was on the schedule for FY 2009 and is just being addressed in FY 2011. The reviewer questioned whether the PI has the appropriate facilities to perform the necessary tests for these tasks. The PI claims to have improved sensor chemistry but did not show work towards the sensor chemistry.
- The cost of 500–1000 per unit does not match up with "cost effective." This cost could be a deal killer on the open market. The discussion of "potential future costs" was a bit general.
- Project goals seem to be well addressed and achieved. The information provided on the sensor performance does not cover the complete DOE target ranges, e.g., performance at sub-zero temperature, sensor response time, etc. The reviewer wanted to know if achievement of these targets is feasible with further development of this technology.
- The sensor prototype refinement was a very good accomplishment for this project. Another useful accomplishment was the validation testing including repeatability, reversibility, rapid response, and others. The development and understanding of the alarm algorithm is an important element to the practical implementation of the sensor.
- The progress appears to be appropriate for this point in the project.

Question 4: Collaboration and coordination with other institutions

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

- The PI does not seem to have the expertise necessary to address electronics design or corrective algorithms. The PI needs to find a partner with expertise in multivariate analysis algorithms to address these needs. He seems to partner with the National Renewable Energy Laboratory (NREL) well to test hydrogen sensor performance, but he did not present results on cross-sensitivity testing clearly.
- The nature and extent of specific contributions from some partners is not specified, making this difficult to judge. However, at least two collaborations (NREL, Sandia National Laboratories) are mentioned with the results. The reviewer asks if other commercial market and partnerships have been established within this project, e.g., a partnership with NASA. Collaborations with other projects are not specified.
- The project had a good collaboration including national laboratories and industry partners.
- The collaboration is limited, as is expected in a project of this type.

Question 5: Proposed future work

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

- There does not seem to be a clear direction or idea of all the pieces necessary to complete sensor design towards a commercially available sensor platform. It would be good for the PIs to reevaluate the true progress and list all performance issues that need to be addressed before moving forward, and compare that to available funding. There may not be enough funding to cover all tasks, and it may not be worth funding considering the effort that has been put into the project thus far.
- Project coordinators seem to know what needs to be done and how to do it. The reviewer wondered, however, if the cost will be an issue for commercialization of this sensor. The hydrogen sensor concentration algorithm indicates low accuracy at low hydrogen concentrations, which is something that needs to be addressed.
- The future work builds on the past progress and is generally focused on the important elements to evaluate the sensor. It would be helpful if the project provided fault evaluation to be confident that future testing is evaluating these potential faults.
- Future work looks to be about complete. There are no next steps noted of how to go beyond the 14 beta modules or if additional items are in the future.
- The proposed work is appropriate for the progress at this point in the project.

Project strengths:

- The project strengths appear to be the concept and the need for low-cost emergency sensors.
- The project has a novel optical platform with reasonable response. It could be fairly rugged.
- Looks like there are not any poisons for the sensors, which is a real plus. Also, it resets after the event clears.
- The sensor is based on an intrinsically safe technology. A lot of progress has been made to develop a sensor from a basic material into a functioning sensor prototype.
- The project involves a hydrogen sensor technology that appears to be robust and have many benefits in the design as compared to traditional catalytic sensors.

Project weaknesses:

- The weaknesses appear to be limited.
- The PIs do not seem to understand the cross reactivity response to various analytes (interferences), which will cause this sensor platform to fail.
- It is not clear that cost reduction has been included as part of the development.
- Operation at low temperature seems to have strong influence on response. The reviewer asks how seriously the project's progress will be hindered if cross contamination proves to be an issue. Sensor response time does not yet reach the DOE target of less than one second.
- The project would benefit from a failure modes assessment to identify the key weak links in the design during the life of the sensor. The project would benefit in providing a cost analysis and manufacturing assessment.

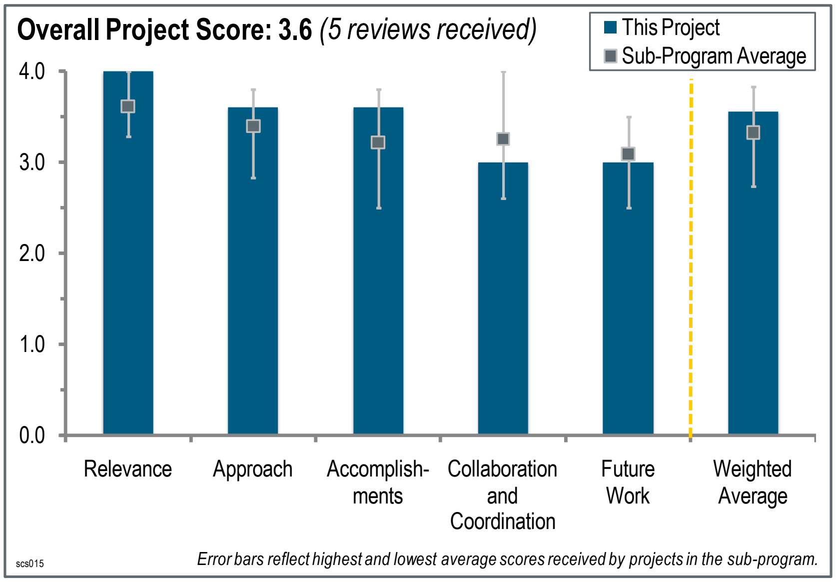
Recommendations for additions/deletions to project scope:

- It is unclear if the sensor will reset after the detected hydrogen released has been addressed. It is also unclear if there have been adequate tests for interference and false positives. If this instrument is to be used in a home, tests on fumes (including gasoline, liquefied petroleum gas, compressed natural gas, tobacco smoke, latex paint, and burnt food) may also be suitable.
- The product appears to require recalibration every three months. While this is reasonable in an industrial and commercial setting, it probably would not happen in a residential setting,, such as the many home smoke detectors that are not operational because the owner didn't change the battery. Reconsidering this area may be appropriate.
- The researchers need to look into lowering cost or market share that will not hold up in free markets. The reviewer said he did not note if this qualifies as a Class I Division II (or I) group B requirements for electrical equipment. This will be key because it can detect and hopefully will not ignite. Reliability and availability targets need to be established for the unit.
- It is necessary to broaden ranges of ambient parameter tests and include field testing of distributed sensor format. In addition, the project should test and validate the performance in the absence of oxygen. Lifetime tests are also needed.
- If not already in the scope, the project should provide a detailed cost analysis and risk assessment. Also, it may be interesting to include a high-level comparison of the various sensor technologies and then provide the attributes of the IOS optical sensor.

Project # SCS-015: Hydrogen Emergency Response Training for First Responders

Monte Elmore; Pacific Northwest National Laboratory

Brief Summary of Project:



The long-term goal of this project is to support the successful implementation of hydrogen and fuel cell technologies by providing technically accurate hydrogen safety and emergency response information to first responders, including fire, law enforcement, and emergency medical personnel. The objectives for fiscal year (FY) 2011 are to: (1) offer the one-day operations-level course utilizing the U.S. Department of Energy's (DOE) fuel cell electric vehicle (FCEV) prop at the U.S. Department of Defense's Defense Logistics Agency fire training centers; (2) continue to provide the one-day, operations-level, first responder training course at civilian fire training centers in California; (3) continue to support the internet-based, awareness-level course (launched in FY 2007); and (4) continue outreach activities by disseminating first-responder hydrogen safety educational materials at appropriate conferences to raise awareness.

Question 1: Relevance to overall U.S. Department of Energy objectives

This project was rated **4.0** for its relevance to DOE objectives.

- Training of first responders is a major component of getting the general public to accept a hydrogen infrastructure.
- This is an extremely important project to ensure public acceptance of fuel cell and hydrogen technologies. Higher priorities and funding to implement additional modules and props to cover refueling and use with forklifts would have been preferable.
- This project is very relevant for hydrogen safety training.
- First responder training is essential to eventual public acceptance of hydrogen as a fuel.
- The project definitely contributes across topics (Safety, Codes and Standards and Education) to the DOE Hydrogen and Fuel Cells Program objectives.

Question 2: Approach to performing the work

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

- The approach appears to have been hampered by funding issues rather than technology. The only weakness for the project is that there should have been more effort for outreach and virtual training. Since the instructors and course material are well received, some of the limitations, such as the number of training courses and course materials, might have been resolved if U.S. Department of Transportation had been approached earlier.
- The FCEV prop-based approach is the preferred method of instruction. The reviewer understands the economics, but a hands-on approach is preferable to the internet-based solution.
- The three-pronged approach is appropriate for this topic.

Question 3: Accomplishments and progress towards overall project and DOE goals

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

- There has been great progress towards the objective to have safety officials trained on these advanced technologies. This project needs more funding to sustain the efforts.
- The accomplishments and progress on this task are appropriate for the point in the funding cycle.
- Having the training package online is a positive step. The fueling station model will be useful.

Question 4: Collaboration and coordination with other institutions

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

- Since the subject is so critical, more outreach is needed along with satellite facilities, virtual training, and more workshops with local officials. This requires more collaboration to make it happen.
- The collaboration is adequate for California, but may not be adequate for roll out in future markets.
- The project has excellent collaborative work.
- Project expansion beyond California is a good idea.

Question 5: Proposed future work

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

- Perhaps this course should be considered for qualifying for continuing education credits. Continuing education is a requirement for some jurisdictions and may enhance attendance.
- The future work should include consideration of expansion beyond California.
- The project is too limited and localized. More development efforts should be made on the East Coast.

Project strengths:

- The quality of the training is a project strength.
- The project has excellent staff, an excellent record of accomplishments, and good support for California efforts.
- The project has an enthusiastic instruction crew. Hands-on training is always better.

Project weaknesses:

- The apparent lack of path for expansion of the training to other regional markets is a weakness. Guidance from the various vehicle or original equipment manufacturers would be appropriate.
- The project is too limited in scope and focus. More national exposure and training is recommended along with training for the trainers.
- The project cannot make enough use of the FCEV teaching props.
- It is unclear how data and experience from hydrogen incidents database is exploited.

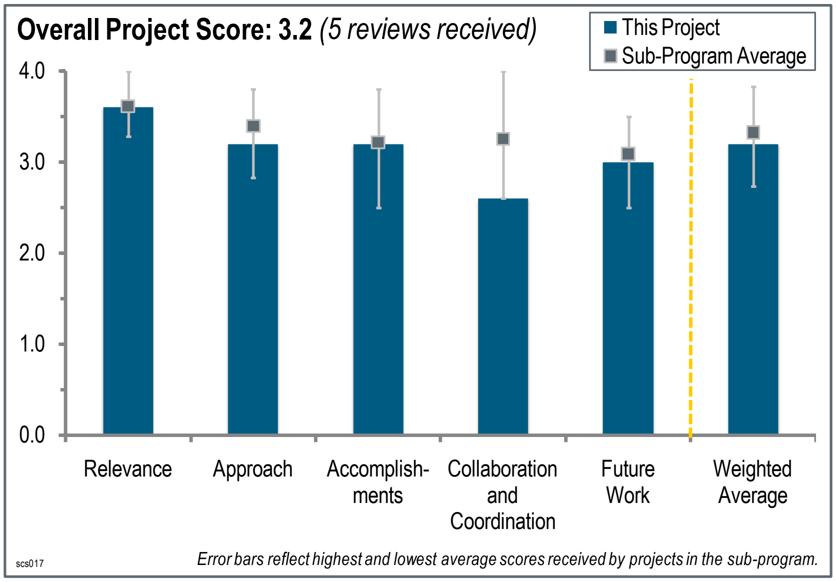
Recommendations for additions/deletions to project scope:

- The project should offer Continuing Education Units as part of the training.
- Find ways to transport to all states the hydrogen safety mock-up device training with the pertinent information.
- There should be a wider availability of the classes to more first responders.

Project # SCS-017: Hydrogen Safety Training for Researchers and Technical Personnel

Salvador Aceves; Lawrence Livermore National Laboratory

Brief Summary of Project:



Appropriate hydrogen safety instruction is the key to avoiding accidents. Laboratory researchers handling small amounts of hydrogen need basic information on pressure, cryogenics, flammability, asphyxiation, and other risks and precautions for using hydrogen. Technical personnel in charge of operations need comprehensive instructions on components, system design, assembly, and leak testing. This project seeks to minimize the risk of accidents and maximize productivity through improved knowledge of hydrogen properties and procedures. Objectives are to: (1) develop a four-hour, internet-based class for laboratory researchers handling hydrogen and (2) create a three-day, hands-on safety class for technical personnel in charge of designing, assembling, and testing hydrogen systems.

Question 1: Relevance to overall U.S. Department of Energy objectives

This project was rated **3.6** for its relevance to U.S. Department of Energy (DOE) objectives.

- Lawrence Livermore National Laboratory (LLNL) has a hydrogen safety class for laboratory researchers and technicians. The need for this type of training has become obvious based on the number of incidents or near incidents that have been reported in the past several years. Incidents of this type would needlessly, adversely affect the establishment of a hydrogen infrastructure.
- An internet-based course for laboratory use of hydrogen contributes to program objectives; a hands-on class at LLNL would have a more limited impact resulting from the time and expense of travel. Perhaps a "train the trainer" approach linked to key potential stakeholders such as vocational schools would have a larger contribution to Program objectives.
- Training for workers who work around hazardous materials is required by both federal law and good sense. Developing such training is necessary too, of course. The effort in this project is strongly supportive of the program.
- This project is very critical to ensure no safety accidents derail the program.
- Comments from the audience certainly reflected a need and use for both the internet-based and hands-on training.

Question 2: Approach to performing the work

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

- The internet-based course contains the necessary modules, but it is not clear from this year's presentation or the 2010 presentation how the course is different from other internet-based courses (code officials, first responders) developed with support by the program. Perhaps a single internet-based course with common modules for essential background and modules clearly designated for specific user categories should be considered.
- The approach of an internet-based class followed by hands-on training is appropriate.

- The use of the videos is excellent.
- The principal investigator (PI) has done an outstanding job, especially in focusing on all of the critical areas.
- The approach appears to be thorough and effective, with adequate details to illustrate the topics.

Question 3: Accomplishments and progress towards overall project and DOE goals

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

- The completion of the training packages in and of itself is a notable accomplishment. The roll out to the various laboratories is also very interesting. However, the content is suspect. It does not conform to the American Society of Mechanical Engineers (ASME) piping code.
- There is a wonderful diversity of backgrounds and institutions of people who completed the class. It seems this is very much needed for many facets of research.
- It appears that there has been little progress on the hands-on portion of the course since last year's annual merit review. The number of safety class completions is not large and is declining. There should also be more evaluation of the value of the class to users and whether there have been any lessons learned that could improve the internet-based course. There should be much more progress and accomplishments for the $550,000 invested to date in the project.
- The project has made excellent progress, and this project should be expanded and continued since it has such a large impact on the success of the program.
- The class has been completed.

Question 4: Collaboration and coordination with other institutions

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

- Collaboration seems to be limited to the Hydrogen Safety Panel and "Laboratory Safety Manager," who are not identified by institution. Collaboration with industry and vocational education organizations should have been included in the project. The hands-on part could benefit from interaction with industry. The reviewer questioned if industry would benefit from such hands-on instruction and, if so, how and where should the instruction be conducted to maximize benefits and impact.
- There is excellent collaboration with Safety Panel and safety engineers. This is as valuable as the deployment portion of the Safety Panel.
- Collaboration with other organizations might be improved. The internet-based class participation might be improved by more outreach. The hands-on class needs funding to be offered. These are both barriers to using the program.
- The selection of partners was not adequate for this activity. The list of users of this product is more impressive.
- Perhaps not a collaboration, but there was a diverse group from various countries and organizations who utilized the course.

Question 5: Proposed future work

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

- Although not stated, the future work is obvious—continued roll out of the training to additional laboratories after the deficiencies are corrected. It is highly suggested that procedures like this be vetted by knowledgeable industry members prior to being used outside a specific national laboratory.
- There is a definite need and want for this work, at least for the research side, perhaps by expanding the curriculum for use in industry (perhaps such as adding components similar to the suggestion for welding). Additionally, the suggestion for implementing the training in university programs with hydrogen equipment and stations is a good one.
- Future plans are clearly identified and build upon past progress.
- The project looks like it is in wind-down mode. In fact, the project should be expanded to cover more projects and organizations, including other government agencies.
- More outreach for the internet-based class and funding for the hands-on class could improve the project.

Project strengths:

- The PI and LLNL have excellent expertise, capability, and experience in hydrogen and hydrogen safety. The project attempts to build on and extend DOE support for safety training and outreach.
- The expertise of the team members is a strength of the project.
- The project has an excellent PI with good technical capabilities.
- The project has good technical detail. It is well thought out from an engineering standpoint.

Project weaknesses:

- The procedures espoused are not in accordance to the ASME piping codes and the tooling used are not readily available to most laboratories.
- The project as presented shows little measurable progress since last year, other than the number of course completions. Much more evaluation of project effectiveness and value is needed (with fewer slides on pressure reducing regulators). Collaboration is limited and should be expanded.
- The project is winding down instead of being maintained and expanded.
- There is a lack of outreach for the internet-based class and lack of funding for the hands-on class.

Recommendations for additions/deletions to project scope:

- Recommendations from this reviewer include:
  - Revise the procedures to include additional best practices and match current commercial practices which have been adopted as regulation in the states in which the laboratories reside.
  - As a best practice, tube cutting is recommended—deburring and chip removal of the inner surface of the tubing cut. Cutting tubing with a roll cutter often results in a “rolling in” of the tube, making effectively an orifice. The tube “roll” needs to be removed. In addition, chips and burrs have a tendency of coming loose and causing damage downstream. These defects should be removed prior to installation.
  - Address component cleanliness and welding.
  - For commercial practices:
    - State laws require the piping inside a facility or a product meet the requirements or the ASME B31 piping code. Most states require that the fabricator conform to section 3 (B31.3). The leak and pressure testing shown in the presentation do not conform to the code but are more stringent. It is recommended that the code requirements be followed. A review of ASME B31.3 Paragraph 347 parts 5.4 and 5.5, ASME B31.12 Paragraph IP10.8 reads the same. The fabricator may elect to follow the more stringent requirements in B31.1, but the procedure is the same—the test levels are higher than 110% of maximum allowable working pressure (MAWP) versus 120% to 150% MAWP.
    - The leak detection fluid used should be a non-chloride fluid. Commercially available fluids include “Leak-Tec” and “Snoop.” The term zero leakage means no bubbles. This value means leakage is less than 20 standard cubic centimeters per hour (scc/h).
    - Use a helium test that is currently used in industry or academia.
    - The test apparatus should be operated in a properly ventilated area.
    - Apparatus using flexible or hose lines often include a thermal choke orifice to limit leakage in a catastrophic failure such as guillotine break or detached hose.
- It is not clear from this year’s presentation and the 2010 presentation that the internet-based course should stand on its own. It may be strengthened if all of the internet-based courses are integrated and then branched out to address specialized users.
- Increased outreach for the internet-based class could further utilize the work. Increased funding could allow more people to participate in the hands-on class. More classes could be developed on other topics. Additional work to describe welding requirements and different types of joints could be added to the class curriculum.
- Increase project funding and scope due to the project’s success.