2012 — Safety, Codes and Standards
Summary of Annual Merit Review of the Safety, Codes and Standards Sub-Program

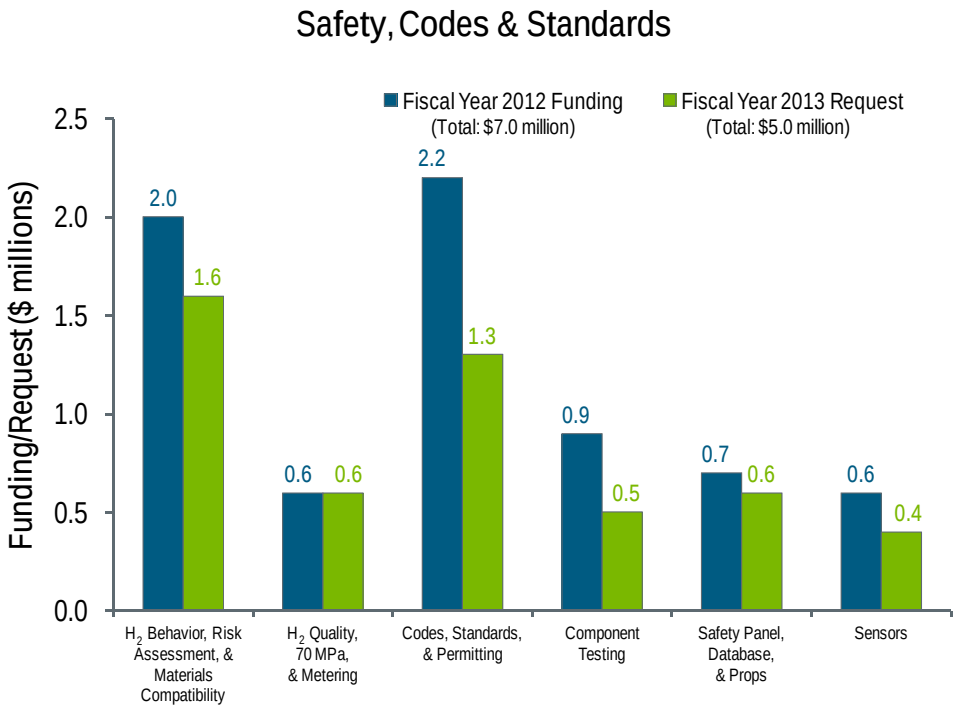
Summary of Reviewer Comments on the Safety, Codes and Standards Sub-Program:

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 developing 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 repeated similar 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 a strong international participation with a focus on international harmonization for the safe deployment and early market commercialization of fuel cells and hydrogen. Reviewers felt that the sub-program was well-focused, but better alignment between the R&D and safety implementation aspects of the sub-program would allow for better cohesion.

Summary of Safety, Codes and Standards Funding:

The fiscal year (FY) 2012 appropriation was $7 million for the sub-program. FY 2012 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 2013 request of $5 million will continue these efforts.



Majority of Reviewer Comments and Recommendations:

In FY 2012, 10 projects were reviewed in the Safety, Codes and Standards sub-program, with a majority of projects receiving positive feedback and strong scores. Reviewers' overall scores ranged from 3.0 to 3.8, with an average score of 3.3.

Codes and Standards and Permitting: One codes and standards and permitting project was reviewed and received a score of 3.4. The reviewers commended this project for its strong core team and coordination with critical codes and standards development organizations. However, the reviewers suggested that the project should focus more in the State of California, where deployment will happen in the near future.

Component Testing: One component testing project was reviewed and received a score of 3.0. The reviewers commended the good progress and strong coordination with sensor manufacturers. Reviewers suggested that testing in higher concentrations of hydrogen would be beneficial.

Hydrogen Behavior, Risk Assessment, and Materials Compatibility: Three hydrogen behavior, risk assessment, and materials compatibility projects were reviewed, with an average score of 3.3. Reviewers commended the technical expertise found within these projects and the impact on standards development. The reviewers suggested continued collaboration with appropriate SDOs, incorporation of sub-zero temperatures for materials compatibility, and publication of a web-based qualitative risk assessment tool for indoor releases.

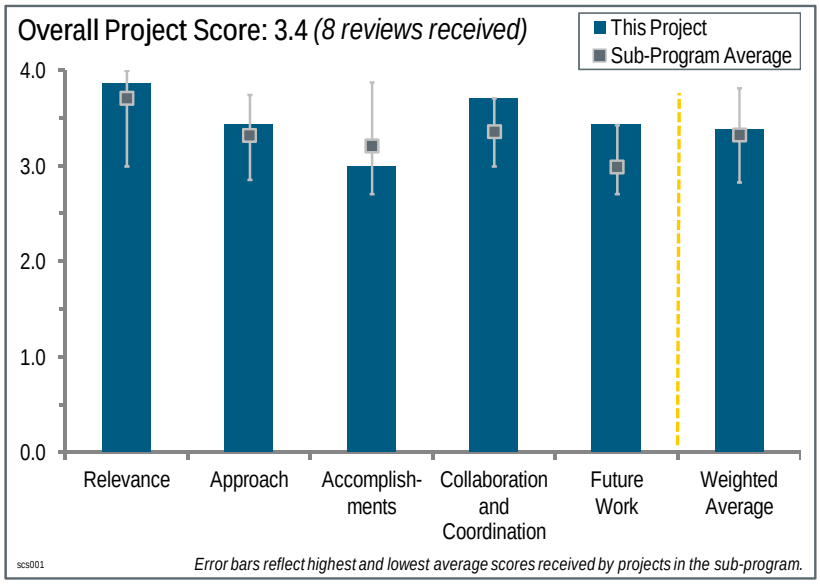
Hydrogen Quality, 70 MPa, and Metering: One hydrogen quality, 70 MPa, and metering project was reviewed, which received a score of 3.8. This project was awarded with the highest score within the sub-program. Reviewers commended this project for making steady progress with the advancement of the technology. Reviewers suggested the incorporation of short stack testing as a next step.

Safety Panel, Database, and Props: Three projects in these areas were reviewed with an average score of 3.4. Reviewers stressed the importance of these projects to the deployment and commercialization of hydrogen and fuel cell technologies, especially in the case of the Safety Panel. Reviewers highlighted the importance of the information dissemination for the databases. They suggested further alignment with key agencies such as the national fire academy, various regional/state organizations, and emergency medical services.

Sensors: One sensor project was reviewed, which received a score of 3.0. Reviewers saw good progress toward developing a reliable, cost-effective hydrogen safety sensor, which will be used for hydrogen infrastructure and stationary fuel cell applications. The reviewers commented that a more active role from the industry partner and a cost analysis of manufacturing would be beneficial.

Project # SCS-001: National Codes and Standards Coordination

Carl Rivkin; National Renewable Energy Laboratory



Brief Summary of Project:

The objectives of this project are to: (1) conduct research and development (R&D) needed to establish sound technical requirements for renewable energy codes and standards with a major emphasis on hydrogen (H_2) 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 H_2 fuel cell electric vehicle technologies; (3) advance renewable energy safety and code development by collaboration with stakeholders; and (4) facilitate the safe deployment of renewable energy technologies by working directly on key codes and standards projects and H_2 technology deployment projects.

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

This project was rated **3.9** for its relevance to DOE objectives.

- This work is critical in enabling the transition from demonstration to true commercial deployment.The project is an essential component of the overall SCS sub-program, and its effectiveness is critical for the success of the sub-program.
- Continued funding of this project is absolutely critical in order to continue the progress of creating and shepherding the necessary codes and standards (C&S) to develop a hydrogen and fuel cell economy.
- The project is inputting data to the C&S development process, and is currently working on many codes. The National Renewable Energy Laboratory (NREL) should coordinate the different projects to establish sound technical requirements for R&D and support code development.
- This project is critical and well aligned with the needs of the Safety, Codes and Standards (SCS) sub-element of DOE's Fuel Cell Technologies Program. As the roll-out for 2015 moves forward, the SCS activity, including this project, is on a critical path.
- Coordinated C&S development, gap analysis, research support, and national and international outreach are crucial to facilitating deployment of vehicles and refueling infrastructure that meet consumer expectations of safety, reliability, and convenience (i.e., on par with conventional personal transportation). Every year this effort builds on previous successes and targets new areas in need of support to ensure international harmonization of C&S.

Question 2: Approach to performing the work

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

- The project approach appears solid, has sufficient collaboration, and is addressing a very comprehensive list of standards organizations.
- The project employs a good, comprehensive approach to addressing C&S internationally, achieved through various coordinating committees, targeted workshops, and a web-based information compendium.

- The project should address conflicts for C&S. Coordination is a key element; gap analyses provide a framework for which projects to address first; California is a focus; hosting workshops is critical.
- The project appears to be very connected with the relevant C&S organizations. The principal investigator (PI) clearly brings a great deal of expertise in this community. The PI clearly understands the process and what is rate limiting, which is critical to best focus resources and efforts on those rate limiting, critical road blocks that might get in the way of the code development process.
- This project has shown good work done to date on national coordination and gap analysis. A good next step would be to coordinate with key international fuel cell market regions on key topic areas. Also, the project needs to engage the International Organization for Standardization (ISO) at some point and work toward better coordination.
- The overall approach is based on coordination, but more specific information on the project's role in this coordination is needed. Much of the presentation is at a programmatic level, not at the individual contributor's (project) level. There is too much cataloguing of organizations associated with the project's effort and not enough on what is unique or important about the project's approach in overcoming barriers by increasing synchronization of national C&S and access to safety data and information. The "coordinating tool" (slide 5) may be a useful tool for coordination, but it is not obvious from the slide itself how effective the tool has been and what impact it has had on increasing coordination among standards development organizations (SDOs) for the benefit of the Safety, Codes and Standards sub-program.

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

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

- The project has done excellent work tracking the efforts of C&S communities.
- This project has made good progress on its goals and has a well-identified plan of future work with Federal Motor Vehicle Safety Standards (FMVSS).
- It is important to continue this work through 2020. The capabilities and connections that have been established will be a key resource for parties involved in commercial deployment of H_2 stations and fuel cell vehicles.
- This project's accomplishments include work on the National Fire Protection Association (NFPA) Hydrogen Technologies Code (NFPA 2), coordination and direct support of the C&S development process, the 2020 vehicle deployment plan, and its management of several contracts.
- In general, the project showed programmatic accomplishments and progress, but not enough of its specific contributions and how essential they were. For example, slide 7 shows the "hierarchy" of regulations, codes, and standards (RCS), but not what the project did to build or solidify the pyramid, only that "NREL did extensive support" to build it. Slide 8 shows highlights of the 2020 Vehicle Deployment Plan, while slide 9 claims that NREL has "defined a key path to deployment of HFCVs [hydrogen fuel cell electric vehicles] in the United States." This reviewer questioned whether the Vehicle Deployment Plan is this path. If so, much more detail about the plan is needed. Slide 8 shows only "key findings"—not a path to deployment. More detail is also needed on slide 9: for example, this reviewer questioned what "guidance documents" the project produced to help California deploy vehicles and what were its "major contributions" to the Society of Automotive Engineers (SAE) J2601 and the CSA H series. In summary, the project failed to show important details of its work, how its work was integrated into the overall DOE program, and how its work contributed to meeting the program's overall goals.
- The project's accomplishments and progress continue. This work has supported various C&S development over the years for components, vehicles, buildings, and refueling. The vehicle deployment plan for 2020 identifies key issues/barriers in RCS, and NREL is working with California closely as the lead market for rolling out vehicles and infrastructure. The work's focus and facilitating RCS in California is a good testbed for expanding lessons learned there to a wider national and international deployment. If similar markets exist, for example, in Japan, NREL should work with those nearer term market areas as well. A lot of contracting support for C&S for NFPA, SAE, ISO, CSA, and supporting projects for Global Technical Regulation (GTR) and NFPA 2.
- Developing the 2020 plan helps focus the efforts on what is necessary to accomplish the goal. This project does a nice job in keeping abreast of a diverse selection of code development organizations (CDOs) and SDOs and brings the needs forward to DOE to address gaps as they emerge. Indeed, there are examples of NREL sub-contracting to individuals to accelerate the harmonization of codes between NFPA and the International Code Council (ICC). This activity was put into play to accelerate the efforts of the Hydrogen Industry Panel on Codes

(HIPOC) in harmonization of domestic codes. This project provides a valuable activity to keep tabs on the C&S organization, providing an integrated point of contact for activities and identifying gaps, problems, and opportunities.

Question 4: Collaboration and coordination with other institutions

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

- The project's component testing must be performed in coordination with the R&D activities.
- This work has lots of partnerships, collaborators, and teamwork involved.
- It will be important to strengthen international collaborations going forward.
- This project is very well connected in the CDO and SDO community. This activity is vital to the acceleration of the deployment of H_2 technology. Indeed, this project is well connected to those who are trying to roll out the infrastructure, such as California through the California Fuel Cell Partnership.
- The project works with all key domestic and international SDOs and has played an important role in coordinating C&S development. Participation by and involvement of SDOs on the H_2 fuel cell C&S Coordination Committee conference calls are excellent.
- This project has displayed a lot of collaborations with national laboratories; CDOs and SDOs such as SAE, CSA, ISO, NFPA, the California Fuel Cell Partnership, and international organizations such as the International Partnership for the Hydrogen and Fuel Cell Economy (IPHE), and the World Forum for Harmonization of Vehicle Standards (WP29) GTR; and information shared through meetings of the U.S. DRIVE Partnership's Codes and Standards Technical Team.

Question 5: Proposed future work

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

- This project is well planned and executed; the future planned work is right on.
- This project will work at the leading edge of vehicle deployment; component testing must be coordinated.
- This project identifies future work with FMVSS and slides 8–9 help demonstrate the planned activities and partnerships needed to continue progress.
- Future work includes continuing past work with a focus toward developing GTR/FMVSS, assisting code officials, focusing on key deployment areas (California), and working at the leading edge of deployment to reduce barriers to refueling station deployment. This is a needed natural progression from SDOs for safe vehicles to C&S for infrastructure to support the vehicles. Future work is needed to assist in refueling infrastructure as the next step in deployment.
- Proposed future work is again very general, with a lack of detail: stating that the project will "work at the leading edge of vehicle deployment to reduce barriers to fueling station deployment" is almost nonsensical. The development and promulgation of FMVSS were deemed not critical for the targeted 2015 deployment of fuel cell electric vehicles by a key auto original equipment manufacturer during review of the 2020 plan, but this is one of the "key project areas" that the project will support (slide 15). Project plans (brought out during the questions and answers session) to hold a workshop on component testing and certification and to develop a fueling station permitting template for California are good and should have been highlighted in the presentation. Note that the guidance to AMR presenters should place more emphasis on providing details of proposed future work.
- Recommendations for future work include: (1) investigate the needs of maintenance bays at dealerships (i.e., sensors, permitting, etc); (2) provide support for developing a new flow meter that can operate within the fueling protocol limits with 1.5% accuracy or better; (3) support the American Society for Testing and Materials (ASTM) Inter Laboratory Study to validate ASTM standards (the current process is lengthy and will not establish precision and bias statements within the five years required by ASTM); and (4) support the development of an H_2 cleanliness standard. As stations are being built, there needs to be a specification to clean equipment to.

Project strengths:

- This project displays a good framework for domestic building codes.
- This project is comprehensive and, in general, is moving forward/closing gaps in vehicle C&S development to infrastructure.
- The PI and team are well connected and very knowledgeable. One could not have asked for a better team to engage in this particular critically needed activity. The team is very good, and the execution is very good.
- The project has played a key role in the national coordination and international harmonization of H_2 and fuel cell RCS and continues to work along a path that is well established. The project interacts with all of the essential domestic and international SDOs and remains a key player in the RCS community.
- The project organizes and coordinates across a broad array of organizations and topic areas. It provides a roadmap for a C&S world that can be overwhelming to new players and even to established industry players undertaking new projects, such as the retailing of hydrogen fuel.

Project weaknesses:

- One reviewer felt there were no weaknesses.
- The project's weakness is the length of time being taken to develop the codes, standards, and regulations. This looks to be a 15- to 20-year program.
- Many codes exist and it may be time to focus on the implementation of these codes, especially in California. As the community gets real experience deploying real systems to real customers, the program should focus on learning and improvement.
- The project needs to better define its performance indicators, how to measure its progress against these indicators, and how to determine its contributions toward DOE goals. The project's recent presentations at the AMR have been overly general, reflecting DOE programmatic activities, but not providing sufficient detail on the project's role, contribution, and effectiveness in meeting DOE goals and program objectives.
- The project needs further work to simplify the key messages on what's needed, what's in place, what the gaps are, and where the risks are. All the information seems to be there, but still seems to be missing an effective executive summary format.

Recommendations for additions/deletions to project scope:

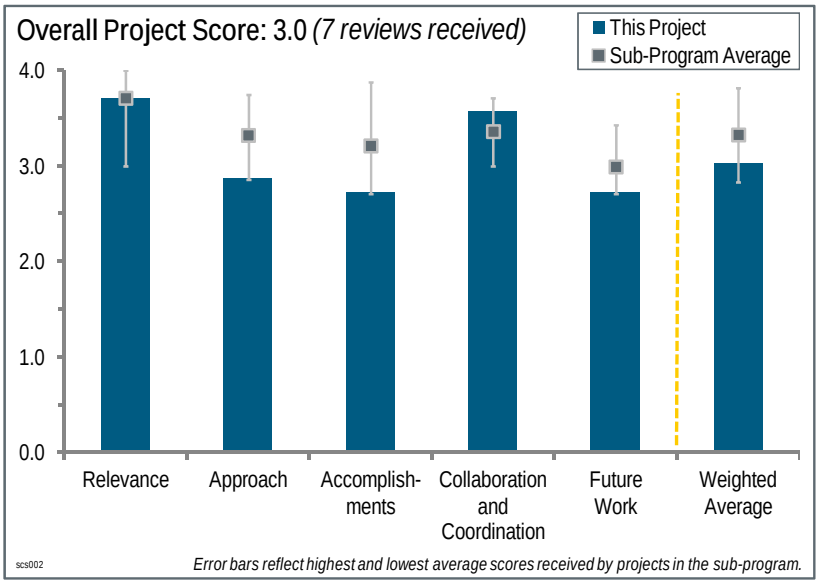
- The team should plan on working directly with the authorities having jurisdiction in California.
- It is difficult to address this as the project scope is large and general—a more targeted project scope should be defined by NREL, one that can be assessed against specific performance indicators.

Project # SCS-002: Component Standard Research & Development

Robert Burgess; National Renewable Energy Laboratory

Brief Summary of Project:

The objective of this project is to help ensure safe deployment of hydrogen (H_2) fuel cell technologies by conducting hydrogen component research and development (R&D), both through the National Renewable Energy Laboratory's (NREL's) internal testing efforts and through subcontract programs, thus determining which components are proven to meet new safety and performance standards. Additionally, NREL's component R&D accomplishments have provided a sound technical basis for new H_2 codes and standards requirements and have supported industry by providing independent third-party assessment of performance against those requirements.



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

This project was rated **3.7** for its relevance to DOE objectives.

- Development of sensor and component standards is absolutely critical to future program success.
- Sensor testing is very relevant to the eventual commercialization of H_2 technologies.
- The project did at one time have relevance to DOE's objectives, but the industry already has H_2 sensors on the market that meet the objectives for safety, etc.
- Component and sensor testing is a critical path issue for H_2 technology roll out. Timing is critical, as the industry and governments prepare for the 2015 vehicle deployment around the world and domestically in New York and California.
- Components of H_2 and fuel cell technologies must be safe and reliable. There is a need to acquire technical data, especially on the most recently developed technologies to support/revise standards. Therefore, component standard research and development is critical to the Hydrogen and Fuel Cells Program and fully supports the DOE objectives.
- The general focus of getting the science correct before writing H_2 component specifications is good and is required for new technologies. This presentation leans heavily on the discussion of point sensor developments and the facility NREL has constructed in Colorado. The second section of the presentation concerned NREL support for standard development organization (SDO) efforts at standardization. Testing is critical to getting adequate specifications. Both of these areas (sensors and component testing) are important to the H_2 economy.

Question 2: Approach to performing the work

This project was rated **2.9** for its approach.

- The testing methodology is adequate.
- Working with sensor developers and manufacturers is effective.
- The testing being performed in this project is essential to future sensor development efforts. However it is difficult to pull out of the presentation how this information is being used to affect codes and standards.

- There are limited facilities that perform the types of testing required for component development. NREL is to be commended for creating a facility that can perform some of this testing. However, there should be more participation from industry members.
- The approach is good and contributes to overcoming some barriers. The participation in different technical committees and the work performed during international cooperation with different laboratories allow researchers to identify knowledge gaps and could offer immediate benefits to the industry. The project could be improved by obtaining stronger cooperation from the original equipment manufacturers (OEMs) for the identification of real standard conditions and environments faced by the fuel cell components in different applications. Nevertheless it is recognized that such cooperation is difficult to obtain.
- This is a nice piece of work and much needed to understand the performance characteristics of point sensors. Providing capabilities to quantify how to use, response functions of, and domain over which the sensors behave (response function) are all critically important to ensure the sensor application is correct and the output is interpreted correctly. However, a critical element that is missing is the investigation (characterization) of large area sensor technology. NREL would be well advised to develop the laboratory investigation capability necessary to investigate the class of sensors of wide area detection.

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

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

- Sensor testing is going well, but the sensor workshop results were not published in a timely manner.
- Sensor progress has been good. Testing in support of J2579 and the Global Technical Regulation (GTR), as well as the CSA standard on pressure relief devices for compressed H_2 vehicle fuel containers (HPRD1) has been useful.
- The project showed a sensor technology that has already been in fuel cell electric vehicles (FCEV) since 2004 (helium sensors).
- This program has made good progress. It is moving a little slower than expected, but that might be driven more by available funding than any fault of the principal investigator (PI) or NREL.
- This presentation highlights predominantly test activities and results, showing a small amount of progress on standards development. Good progress has been made supporting sensor developers and participating on standards groups for technical guidance. The presentation, however, does not specifically highlight codes and standards progress.
- Providing an independent, third-party assessment of the performance of fuel cell components is an accomplishment of high value and corresponds with significant progress toward the objectives. The new H_2 codes and standards may acquire a sound technical basis through the work performed in NREL. Performing "post mortem" analysis of deficient components could also help the industry to improve its product. This could be taken into consideration for the future.

Question 4: Collaboration and coordination with other institutions

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

- This project has good collaborations with international testing laboratories.
- There are good collaborations with institutes and international efforts.
- The project team is very much engaged with the sensor community and the relevant standards organizations.
- Increased participation by NREL personnel within the code development community has been useful in presenting technical data and interpreting that data for code writers.
- Collaboration with codes and standards committees, national partners, industries, and international institutions is close and appropriate, and coordination is granted.
- The international collaborations developed by this team are very good: in particular, the collaboration with the Joint Research Center (JRC) Institute for Energy and Transport (IET) is very constructive. The two facilities are similar (but complementary), providing a natural cross check on results and a leveraging opportunity, which has been/is being exploited. In times of shrinking financial resources, this type of collaboration is critically needed. Nicely done!

Question 5: Proposed future work

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

- This project will continue to work with technical committees.
- This project does not align with industry needs anymore, so proposed future work is not needed. Standards (ISO TC 197, WG 13 and UL) already have baseline information.
- The future plan for creating a prioritized list of needs for component standards validation testing indicates that the project has a goal but doesn't indicate how any potential barriers will be overcome.
- Some of the sensor work should be shifted to wide-area sensors, as this is the mostly likely area where there will be a need. The infrastructure is attempting to comply with building and fire codes with inadequate wide-area sensors.
- The effect of H_2 on valve and pressure gauges, which are in contact with H_2, should be added. To determine long-term sensor stability, real-world deployment scenarios should be mimicked. Forty weeks is not enough time.
- The proposed future work is planned in a logical manner and considers possible barriers to the goals. Stronger cooperation with OEMs could be considered, even if it is difficult. Sharing results with other research centers instead of trying to perform all tests is an excellent initiative and will help to disseminate these results internationally.
- A critical element that is missing is moving this program to investigate wide-area sensors. We are on the threshold of aggressive fueling station deployment (globally) where wide-area sensing is needed to ensure the detection of an unintended failure. This reviewer was disappointed that investigation of wide area sensors was not on the future plans for this program.

Project strengths:

- The analytical methodologies for testing H_2 sensors are a strength of this project.
- Excellent relationships with the SDOs and the sensor manufacturers are clear strengths of the project.
- The technical capabilities of the national labs are excellent. If the laboratories continue to perform testing and supply the industry with the data, everyone benefits.
- H_2 detection and sensor development is a critical part of the safety and performance of any H_2 system. As was stated during the presentation, there is way more work than any one laboratory can perform. This project has great collaboration and interaction with other test laboratories as well as SDOs.
- The program has developed a nice facility (not fantastic but adequate) to measure the operating characteristics of a variety of point wise sensors. The program works well with industry (particularly the sensor manufacturers), but also with the code development/regulatory (U.S. Department of Transportation) stakeholders. The international collaborations, in particular the JRC, are a very good and strong point. Largely, the work done on the pointwise sensors and working with the development and end use industry is critically important and clearly a strength.

Project weaknesses:

- This project is no longer connected to industry needs. Some testing is questionable, such as crash testing in a conventional vehicle.
- This project does sensor testing only, and diagnosis of failure is not part of this work. This testing-only effort may not be appropriate for a national laboratory.
- The presentation does not do this project justice, as it does not highlight the good work being done on standards development.
- The definition of real operating conditions and environment for different applications could improve the obtained results and their use in defining new codes and standards.
- As pointed out above, wide-area sensors must be embraced as part of this activity. It is disappointing to see that this was not even in the future planning for this work. As pointed out earlier, wide-area sensors are critically needed to ensure safe operation of H_2 infrastructure implementation, like fueling stations. This is a critical shortcoming of this work.

- This work takes an inordinately long time for data to get publicly released. As an example, as referenced in the reviewer comments from last year, the brinelling issue, which was brought to the Society of Automotive Engineers (SAE) in 2003 with an update from Japanese OEMs in 2008, has been pending for years. The priority of the technical investigation into this problem has slipped.

Recommendations for additions/deletions to project scope:

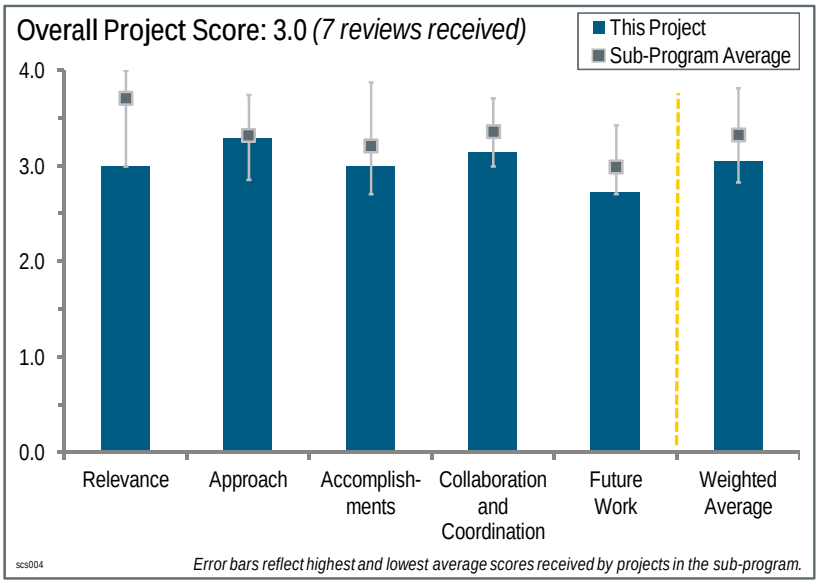
- Include wide-area sensor technology as part of the overall sensor portfolio.
- This project should include work on wide area sensors. It is also recommend that plastic material be investigated for use in the low-pressure side of fuel cell systems. This would be a relatively short test program, with a good payoff to the industry.
- One reviewer suggested that this project be cancelled.
- Work already appears to be in progress on this, but testing is at higher H_2 concentrations. This next recommendation may best be addressed by creating another project, but what is needed for large-storage H_2 systems is development of wide-area sensors, not just point sensors.

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, durable, and reliable hydrogen (H_2) safety sensor for vehicle, stationary, and infrastructure applications, through material selection, sensor design, and electrochemical research and development (R&D) investigation; (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 work toward commercialization by engaging appropriate industry partners; and (4) pursue transfer of the new sensor technology and commercialization through industry partnerships. NREL will evaluate sensor performance and ensure adherence to codes and standards, field evaluation, and performance requirements.



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

This project was rated **3.0** for its relevance to DOE objectives.

- The development of low-cost, durable, and reliable H_2 safety sensors for vehicle, stationary, and infrastructure applications is an important need for the DOE Hydrogen and Fuel Cells Program.
- Given that point sensors will be used for their H_2 detection ability, this is a very relevant project.
- It is unclear if this project has support from automotive and station original equipment manufacturers. This reviewer wonders if the industry need has been demonstrated.
- The principal investigator (PI) has successfully developed an H_2 sensor that meets the detection criteria for an H_2 safety sensor: detection at 25% of the H_2 lower flammability limit (LFL) with tolerance of up to 10% water.
- These relevance objectives are similar to objectives used by the power electronics researchers at Oak Ridge National Laboratory. The objectives involve working with industry to find a viable approach to an issue, in this case sensor drift, and working to mitigate that problem within an industry, not an academic, framework.
- The project supports the safe use of H_2—specifically by developing H_2 leak detection technologies such as sensors. End users have indicated that they require robust, reliable, high-performance, and cost-effective H_2 sensors; as such, the market for these sensors is confirmed. Research to develop such sensors is essential to supporting their use and commercialization, thereby facilitating the safety of H_2 applications.
- The project aligns with DOE objectives to develop reliable, cost-effective H_2 safety sensors. The focus of this development should be primarily for H_2 infrastructure applications and secondarily for stationary fuel cell applications. An objective of the project is to develop a safety sensor for both applications and also for vehicular applications (slide 3). The sensor technology can address all three applications, but if NREL is to "evaluate sensor performance and ensure adherence to codes and standards," a more focused project objective would be better and more likely to meet DOE objectives. Furthermore, it will be difficult for NREL to conduct "field evaluation and performance requirements" (slide 3) for all three application areas within the project time and scope. The pursuit of industry partners for technology transfer and commercialization is in good alignment with DOE objectives.

Question 2: Approach to performing the work

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

- It is excellent to see the focus on using commercial manufacturing processes.
- The work has been very logical in developing the sensor, performing testing, and addressing issues.
- The work does focus on one sensor technology only. The stability issue seems to be on the road to a solution.
- The overall approach is focused on the critical barriers for H_2 sensor technology.
- The approach to transfer a demonstrated technology from one application (oxygen [O_2] detection) to another (H_2 detection) is commended. The choice of developing this particular technology, which is claimed to be conducive to miniaturization, suggests amenability to cost-reduction, which is a critical factor for successful commercialization.
- Most of the work was to fix a signal interface problem with diagnostic equipment. The researchers solved the problem and appropriately isolated the sensor from the diagnostics—this is necessary for a real-world application. Even though it may have seemed to be specific to the NREL measurements, it is applicable to a broader application space, which is good.
- Basing the approach on the Lambda O_2 sensor and working with industry partners is good. The industry partners are helping to address the mass fabrication of the sensor element and interface electronics (slide 7). Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL) have addressed key sensor parameters of aging, reproducibility, and selectivity in laboratory devices, but it is not clear how these parameters and others identified (long-term stability, drift, exposure to the environment, etc.) have been addressed in the context of technology transfer and commercialization (a key objective—slide 4). With the project 80% completed, it would seem that the commercial industry partner (ElectroScience Laboratories, [ESL]) would be much more involved in addressing the challenge of meeting key performance parameters at a given price point.

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

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

- This is cutting-edge technology—the project is a good demonstration of robustness and response time.
- The progress is good, but not outstanding.
- The project only focuses on one sensor technology. Control electronics are certainly critical, and the work accomplished to date is encouraging.
- The PI made adequate progress since the last DOE Hydrogen and Fuel Cells Program Annual Merit Review. The team demonstrated 6,000 hours of sensor life, performed further testing at NREL, and resolved electrical issues with measurements performed at NREL.
- The pre-commercial prototype performed well in a static volume testing experiment, but this hardly seems to qualify as a “more real-world” scenario (slide 8). The aging and tolerance to humidity and temperature response testing at NREL are good technical accomplishments for the laboratory development of an advanced sensor; however, there is little indication of accomplishment and progress toward technology transfer and commercialization with one year remaining until project completion.
- Based on the literature listed in the references to the presentation, the sensor is expected to show good performance. Nevertheless, the measurements reported in the paper show a number of deficiencies, the cause of which is neither clear nor explained. Other comments from this reviewer include:
  - Regarding the very long t90 response time in the graph on slide 8, it is unclear if this is caused by a leaking chamber, and whether the last part in the graph corresponds to chamber evacuation. It is unclear why the sensor response in the graph on slide 8 does not match that in the top graph on slide 12 (claimed to be initial, i.e., pre-NREL tested response).
  - There is contradictory information from both graphs in slide 9. The right-side graph indicates an increasing output signal with increasing H2 content (as expected, and also complying with the logarithmic concentration dependence). However, the left-side graph shows a decreasing signal magnitude with increasing concentration (likely due to an incorrect legend in the figure).
  - Contrary to the claim made in the first bullet on slide 9, the sensor is not reliable during the first 1,000 hours (as shown in the left graph).

- Results in the right-side graph suggest the presence of non-negligible hysteresis, which is not further elaborated upon.
- Data shown on slide 11 not only show "strange baseline behavior," but also a substantially decreased sensitivity. The label on the left vertical axis in both graphs is wrong.
- No explanation is provided for the quicker response and for saturation of the sensor response, as apparent from the bottom graph on slide 12.
- Regarding packaging, in addition to the evidence provided in the graph on slide 14, the stability of the sensor under environmental conditions (i.e., varying temperatures and pressures) should be demonstrated.
- In terms of the second bullet on slide 15, the high impedance buffer (HIB) does not protect the response of the sensor; it may protect the sensor during handling, although there is no direct evidence of that.
- Regarding the top graph on slide 16, the magnitude of the sensor response at saturation (75 mV) for 2% H2 is quite different from what is shown in all of the other graphs, but there is the comment appended to the graph about the "correct" sensor output obtained without use of gain. This reviewer wants to know how this discrepancy can be reconciled.
- The bottom graph of slide 16 indeed shows high signal-to-noise ratio when HIB is enabled. However, the logarithmic sensitivity dependence seems to have vanished.
- No indication is given about the threshold level of the sensor or how this is affected when using HIB. In summary, some progress seems to have been made to bring this sensor to the pre-competitive stage, including incorporation of the resistive temperature detector (RTD) and control electronics. However, the results presented do not allow this reviewer to confirm these claims. Because this reviewer is of the opinion that this is more due to the low quality of the presentation and the lack of information provided in the slides and during the actual oral presentation, a score of "fair" is maintained. However, lessons should be learned for the future. Also, issues regarding cross-sensitivity to other species, identified in previous years, do not seem to have been addressed. Results from a larger number of sensors are definitely required to demonstrate performance reproducibility.

Question 4: Collaboration and coordination with other institutions

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

- The level of collaboration with other national laboratories and industry partners appears to be very good.
- The manufacturers/developers are fully involved. That is an asset.
- One reviewer would like to see industry support beyond sensor manufacturers.
- Collaboration with industry indicates the potential for this technology. The roles of the collaborators have been clearly defined and there seems to be appropriate coordination of project activities.
- The team coordinated with Sandia National Laboratories and NREL to perform tests and address issues related to sensor electrical circuit and noise. The team is starting to coordinate with small companies to address commercialization.
- This project is a development activity and does not lend itself to extensive outside collaboration. Within the constraints of intellectual property and partners, another reviewer thinks the calibration is about as extensive as possible at its current stage of development. The researchers need to embrace a manufacturer as part of the team sooner rather than later. This also leads this reviewer to wonder if these are the correct people to move this to the manufacturing stage as opposed to a manufacturer.
- Collaboration among national laboratories (LANL, LLNL, and NREL) is excellent, and the industrial partners are playing essential roles in the project. It is not clear to what extent, if any, ESL (the "commercial industry partner"—slide 2) is involved or concerned with the commercialization of the technology.

Question 5: Proposed future work

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

- The plans for future work are a logical continuation of previous efforts. Other technologies would be good.
- The focus on a low-cost commercial product is essential. The team did good work in identifying the issue at NREL.

- The project is on track, but progress is a bit slower than one would have expected. It took a year to understand and isolate the signal processing issue.
- The future plans were focused on commercialization, but that plan seemed somewhat vague. This reviewer is not sure that a national laboratory is the right institution to be focusing on commercialization of the sensor system.
- A commercial development partner (or partners) should have been involved by now in the project. The future work should focus on issues that most affect commercialization of the technology, because the project is 80% completed.
- The proposals for future work clearly build on the results achieved to date. Seeking commercial development partners seems premature for the stage the sensor is currently in—more evaluation and R&D is required, particularly with regard to long-term stability under real-world conditions, cross-sensitivity, and reproducibility. Detection threshold and response time characteristics should also be addressed.
- The project should have a future task to complete a comprehensive cost analysis based on a complete commercial product assessment, including electronics. Slide 7 indicated that the focus was on technology commercialization and listed key commercial-related tests and criteria. The future work appeared generic rather than focusing on these key commercial requirements.

Project strengths:

- The project features a strong partnership with industry.
- The project seems to be making excellent progress with a potential low-cost sensor technology.
- The PI and the team have a good understanding of technical aspects of the sensor system and how to tune the functionality of the mixed-potential-type sensors.
- This technology shows sufficient promise to merit further development. Miniaturization of technology offers potential cost and performance benefits.
- The technical competence of the national laboratory partners is strong, and the involvement of industry partners in technology development and scale-up is good. The use of NREL's sensor testing facilities and expertise is also a strength.

Project weaknesses:

- Because of funding restrictions, only this type of sensor will be investigated to this degree.
- There is no manufacturer on the team.
- The team needs to perform a higher-fidelity analysis of the manufacturing costs before pursuing commercialization.
- The lack of commercial development partners at this late stage in the project is an area of weakness. The project's success will depend on the transfer of the sensor technology to industry and the commercialization of the technology so that the sensor can improve the safety of H_2 facilities and applications. To date, there is little evidence that the technology will be fully transferred to industry and result in a cost-effective safety product.
- The team needs a better approach to align the test set-up at NREL with LANL and LLNL to avoid the issues with anomalous behaviors that are seen at one laboratory and not at another. This issue of inconsistent results appears to have increased the development time.
- Cross-sensitivity to other species has been consistently identified by sensor end users as an important performance criterion. Cross-sensitivity is an issue with this technology. Response stability and reproducibility may also be of concern. The project has not identified for which application(s) this type of packaged sensor is most suitable. The impact of packaging on the additional features (RTD, HIB) and on overall power consumption has not been addressed. The quality of the presentation of the results constitutes a weakness in the execution (probably not in the actual performance of the work and in the scope) of the project.

Recommendations for additions/deletions to project scope:

- The team should find a manufacturer to partner with or turn over the lead to.
- The team should pursue directed testing for infrastructure applications (i.e., refueling installations).
- High-fidelity cost analysis should be conducted by an independent organization that has experience with design for manufacturing and assembly (DFMA).

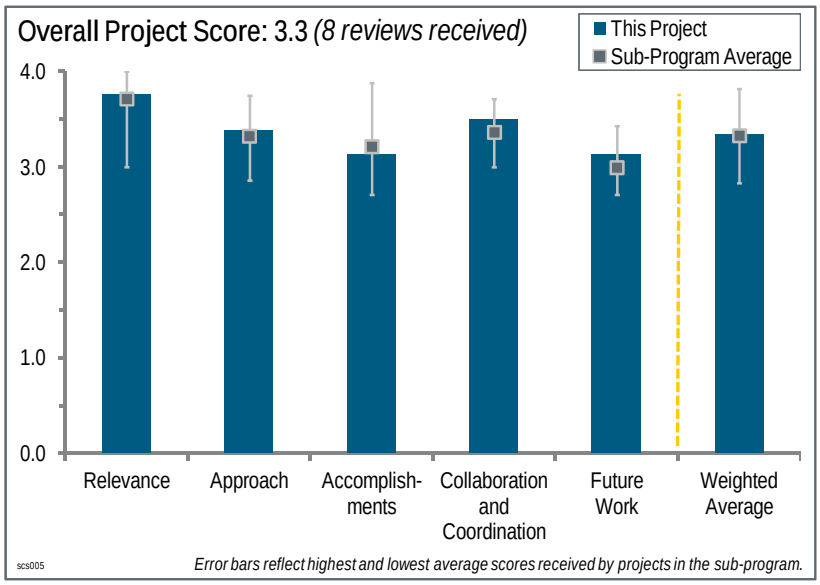
- The team should focus on what is critical for technology transfer (for a commercial development partner to cost-share in the remaining portion of the project).
- Potential markets for this sensing technology should be investigated, as should manufacturability and the potential for cost reduction. Additional (exhaustive) tests should clarify the performance of the sensor in terms of threshold level, accuracy, hysteresis, and sensitivity.
- This reviewer recommends adding to the project an effort to work with a codes and standards organization to develop an industry-accepted guideline to qualifying a sensor for aging, selectivity, etc. The project needs to include a complete cost analysis with an industry partner.

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

Daniel Dedrick; Sandia National Laboratories

Brief Summary of Project:

The two objectives of this project are to: (1) enable technology deployment by providing science-based resources for standards and hydrogen (H_2) component development and (2) participate directly in formulating standards, including design and safety qualification standards for components and materials testing standards. A materials reference guide will be updated, reflecting the latest understanding of material property data gaps. Materials testing will be executed to address targeted data gaps in standards and critical technology development. More efficient and reliable materials test methods will be developed.



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

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

- The work is focused on specific data needs to allow the development of science-based standards.
- This project has been one of the major references in the H_2 industry for H_2 compatibility worldwide.
- Clearly an important activity, this work goes to the very core of the Safety, Codes and Standards sub-program. This work is generating critically important information.
- Sandia National Laboratories (SNL) has extensive materials compatibility testing and expertise pertinent to influencing standards. Utilization of their expertise and continued support on this project will help to enable further standards development.
- The project's goals clearly relate directly to DOE program objectives. For the safe deployment of H_2 technologies, knowledge of the effect of H_2 on materials' mechanical properties (under static as well as cyclic loading conditions, and covering base materials and welds) is an absolute prerequisite.
- This is important work to confirm the safety of type 1 storage vessels already being deployed in material handling. Also, it is important to confirm light duty vehicle materials currently in use and open the pathway for approval of new materials in the future.
- As noted in the questions, the research and development effort needs to be expanded to reflect field applications and the temperatures and pressures anticipated by industry. Current vehicle applications will see temperatures in the -40°C to -70°C range, and the data should support the standards development efforts in that area. In addition, it is industry's desire to be able to specify a starting point for materials. If the research can be expanded to incorporate this, it would be helpful for industry in moving forward.

Question 2: Approach to performing the work

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

- This project is using very good materials science techniques applied to highly relevant structures and samples.
- SNL is providing standards development organizations (SDOs) with empirical data as evidenced in slides 6 and 7.
- This team is actively participating in relevant committees, including serving in leadership roles.

- The methods are correct for H_2 embrittlement studies; however, pre-charged probes tested in air are not the extreme case encountered with probes tested in pure H_2. This should be recognized and communicated. Other work in Germany and Japan has shown these differences.
- This work has been effective in characterizing existing materials and establishing test protocols. Its ultimate goal should be a deep understanding of H_2 effects and predictive capabilities or guidance on measures to retard or prevent material degradation in a H_2 environment.
- Even though this reviewer is identifying an area that needs to be addressed to significantly overcome barriers, the project/effort and research has contributed significantly to the advancement of the safety codes and standards activities. As noted in the questions, the research and development effort needs to be expanded to reflect field applications and the temperatures and pressures anticipated by industry. Current vehicle applications will see temperatures in the -40°C to -70 °C range and the data should support the standards development efforts in that area.
- The approach that consists of identifying gaps in knowledge, establishing and validating representative test methods and methodologies, performing a limited amount of targeted testing, and ensuring adequate knowledge transfer to SDOs and code development organizations (CDOs) is fully correct. However, the exchange of views and cooperation with non-U.S. advanced materials testing experts (in addition to the Japanese institutions mentioned), should be further explored to increase efficiency of the work and disseminate its outcome.

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

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

- Although this kind of activity is inherently expensive and time-consuming, steady progress is being made.
- This project has filled in key gaps in materials knowledge.
- This work measured the properties of H_2-exposed welds and aluminum alloy and optimized fatigue crack growth testing in ASME Article KD-10 tank standard.
- This project has provided a good evaluation of the current protocol. It is developing a procedure to accelerate the tests, with some success, and is working to incorporate scientific results in existing standards.
- The project has met all objectives and should be used as a baseline for the important understanding in the United States.
- This project has done a nice job developing a faster method to perform testing and gathering data and to get buy-in from the SDOs from the new methods. Also, the work has done a great job identifying progress on existing milestones/accomplishments.
- This research is providing the needed data to support the development of the standard to address material compatibility and is contributing significantly to fill a gap in information needed by industry. As recommended previously, the research work should be expanded to include the low temperatures that will be seen in the application.
- It is difficult to rate the degree of progress because two out of three “metrics for success” listed on the third slide are not directly applicable to the activities. Although during the oral presentation it was mentioned that the range of experimental conditions used in the fatigue testing is defined on the basis of industrial input, this does not seem to be sufficient from a materials science point of view. Indeed, important aspects that govern the component behavior (as opposed to pure material behavior), such as the presence of residual manufacturing stresses and of natural defects, do not seem to have been explicitly taken into account for their consequence on the parameter range that should be covered in the tests (e.g., other stress ratios, both positive and negative). The non-availability of experimental data under these additional conditions reduces the ability to assess and predict component behavior based on analysis of results obtained on test specimens. For some material/load combinations, this may result in non-conservative safety assessments.

Question 4: Collaboration and coordination with other institutions

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

- This project is collaborating with relevant experts around the world.
- This project is truly international (including standards organizations, original equipment manufacturers, and research institutes) and should be used as a benchmark for future collaborations.

- This project has displayed excellent involvement, participation, and demonstrated leadership. Representatives meet commitments in a timely manner.
- This project should continue outreach to industry to understand the requirements of materials in service and to prioritize research.
- This project has a good list of collaborators, but it is unclear how much true "collaboration" has been going on. There should be more cross-referencing with testing performed at other sites.
- The presentation highlighted multiple collaborators. The level of collaboration on this effort with industry partners is unclear, that is, whether they are customers or test collaborators. Similarly, the participation from international collaborators is not explicitly identified in relation to what way they are contributing.
- Collaborations with relevant institutions and organizations within the United States seem purpose-oriented and sufficient. Reaching out to non-U.S. materials testing houses is recommended for two reasons: (1) to increase density of experimental data sets, and (2) to include other materials (in particular nickel-steels) that are used for H_2 applications elsewhere in the world.

Question 5: Proposed future work

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

- Plans are well conceived.
- The work proposed seems sufficient, but some changes could be made to further assist the industry.
- This work should continue and accelerate; plans to do this seem to be in place.
- A large amount of work (important tasks) is identified as still ongoing. The work identified is well within the capabilities of SNL; few barriers are apparent.
- The mechanism of the effect of vol% on fracture toughness should be studied.
- This research is providing needed data to support development of the standard to address material compatibility and it is contributing significantly to fill a gap in information needed by industry. As recommended previously, this research work should be expanded to include the low temperatures that will be seen in applications.
- The topics identified for further work (fatigue crack initiation, welds) are correct and need consideration. However, no attention seems to be paid to other, non-metal material classes. This should be seriously considered.
- Safety in early applications, such as material handling, is important, but future work should focus on on-road transportation (buses and light duty vehicles) and fast-fill fueling infrastructure. Also, it is important to support H_2 delivery technical needs.

Project strengths:

- This project has an excellent team with the required expertise.
- This project has a solid methodology, exceptional empirical results, and communication directly to those in the "need to know."
- This project uses a good experimental technique and has a good choice of materials/structures to study.
- This program is filling a significant need in industry; this is the basis for helping industry determine what materials are used in applications in industry.
- Strengths of this project are the soundness of the approach, the diligence of execution of experimental work, and the direct link to SDOs and CDOs.
- This project has a great organization of the project's objectives. It has clearly stated approaches, accomplishments, and future work (and discussion of work-arounds when problems were encountered). There are extensive H_2 material compatibility experts involved in this project.
- This project has unique capabilities and research results that are directly applicable to the design and safety assurance of commercial products. Direct participation in standards development work brings technical expertise to the table and has helped to move key documents forward.

Project weaknesses:

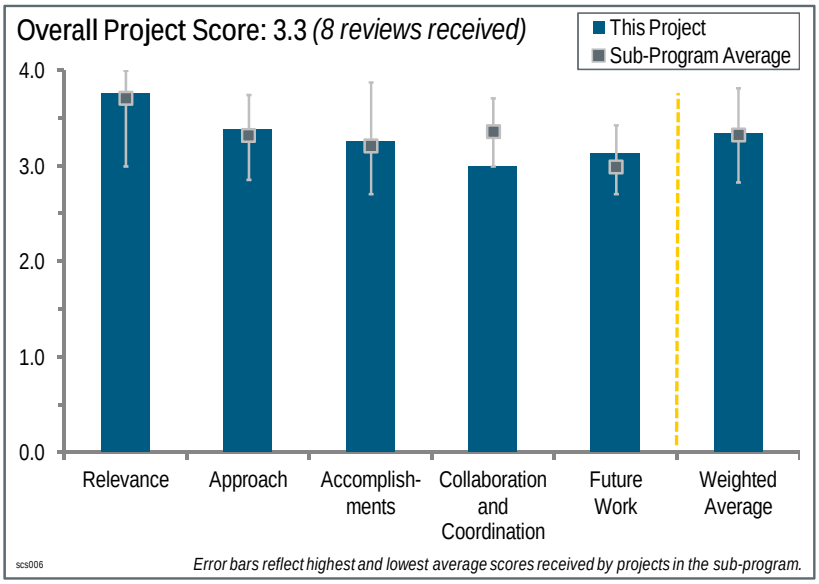
- Currently, the project's only weakness is that the program needs to address the temperatures that will be seen in applications and consistent with temperatures specified in current component and system locations.
- The project's weakness is using pre-charged H_2 probes versus. work done in pressurized gas.
- The project needs to continue to work toward international agreement on and acceptance of test methods.
- Weaknesses are the "U.S.-internal" orientation, the limitations of the experimentally covered ranges that do not really allow assessment of component behavior from the test specimen results, and the non-inclusion of other material classes.

Recommendations for additions/deletions to project scope:

- As recommended previously, the research work should be expanded to include the low temperatures that will be seen in applications.
- Now that the team has well-established procedures and practices, and significant experience, the work should be ready to speed up.
- One reviewer recommends future testing at -40°C, where most H_2 embrittlement occurs, adding more materials to the test matrix, and testing materials in commonly used components such as manual valves (not just tank materials).
- Another reviewer recommends testing an industry-recommended (SAE J2579, etc.) list of stainless steel materials in environments up to "end of life" (that is, equivalent to 20,000 hours of use, etc.) and compare present results of pre-charged H_2 samples verus pressurized, cold (-50°C) testing.
- A third reviewer didn't have any deletions, only additions to address some weaknesses.

Project # SCS-006: Hydrogen Safety Knowledge Tools

Linda Fassbender; Pacific Northwest National Laboratory



Brief Summary of Project:

The objective of this project is to establish and maintain two websites: www.H2incidents.org, for incident reporting and lessons learned, and www.H2bestpractices.org, for safety best practices. The objectives specific to H2incidents.org are to: (1) collect and share lessons learned from hydrogen (H_2) incidents and near-misses, with a goal of preventing similar safety events from occurring in the future; (2) increase the number of records in the database by encouraging "incident owners" to share lessons learned with the H_2 community; and (3) analyze and summarize lessons learned from incidents and near-misses. The objectives specific to www.H2bestpractices.org are to: (1) capture the vast and growing knowledge base of H_2 experience and make it publicly available and (2) update existing content and add relevant new content based on Hydrogen Safety Panel guidance and other means.

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

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

- This project is a key component of DOE objectives for H_2 implementation.
- This is a nice adjunct to the main thrust of the Safety, Codes and Standards (SCS) sub-program. This reviewer personally finds the websites interesting, and sometimes very useful.
- Communication of incidents and lessons learned is critical to developing a safe H_2 economy. This project has high relevance to the goals and objectives of the DOE Hydrogen and Fuel Cells Program (the Program).
- The project involves the creation of a safety repository for H_2 incidents and near-misses. The team will manage the repository based on input from stakeholders in the H_2 industry.
- This project corresponds to a cross-cutting activity that is critical to all projects supported by DOE. There is a clear need to centralize, in a database, the knowledge generated by all DOE projects with regard to safety; to make this database anonymous and open to anybody interested in the field; and to link this database with the other databases existing in the world.
- This project directly aligns with Barrier A from the Fuel Cell Technologies Program Multi-Year Research, Development, and Demonstration Plan (MYRDDP) with regard to promoting and promulgating safety data and information. Maintaining this resource is critical to breaking the "tribal knowledge" tradition of safety as this market emerges. It will be difficult to quantify how many lives and injuries will not occur due to this resource, but it is clear that it has a significant impact.
- The project has developed useful tools for disseminating experience and lessons learned from a number of persons and organizations working with or exposed to H_2 technology applications. As such, it is a valuable and necessary contribution that is assisting the safe deployment of H_2 technologies. However, the project does not address any research and development issues, and as such it has a "special" position in the Program.

Question 2: Approach to performing the work

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

- The success of this project is evident in that there is good participation from industry to add to the knowledge base.
- The approach—establishing and publicizing easily used websites—is a good one. Migrating to "social media" should be in the mix.
- The ranking scale does not allow for an "A-" evaluation. This reviewer thinks that the approach of the project is outstanding but lacks a few things; this reviewer would give it a 3.7–3.8 on this scale. The presenter articulated efforts to promote or market the Internet tools, but the formal approach does not highlight this as a core part of the process. If there are barriers to the growth of the project or to evaluation of its effectiveness, those were not clearly identified by the presenter.
- There is a lot of data available from other organizations outside of DOE-funded projects. For the incidents that occur on DOE-funded activities, this project does a great job of harvesting, verifying, and posting the critical information. This reviewer recognizes that many difficulties arise when trying to gather incident data that occurs in the private sector or with the U.S. Department of Defense.
- The approach of establishing two separate websites is expected to be complemented by efforts to increasingly link them. It is unclear why the number of visits to both websites is so different. This may require some further evaluation. The population of the incidents database could definitely benefit from a DOE requirement that all DOE-funded projects should feed their findings and experiences into it.
- The approach to update the database is good. A clear and independent analysis of the reported incidents is needed before publication. This analysis allows for anonymity, which needs to be maintained. The problem is that the project is strongly dependent on the willingness of the organizations to participate and to report the incidents. Even if it is strongly suggested to the beneficiaries of DOE funding to participate in the reporting, should any problem occur, there is no such action for all the other projects that are privately supported. Following Devlin's presentation, when DOE is investing in one forklift project, there are five similar projects privately supported. Because security concerns everybody, a more pro-active approach of all concerned actors including insurance companies, authorization delivering officials, and firefighters' organizations could be recommended.

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

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

- The project's accomplishments are consistent with the goals.
- Steadily increasing Internet traffic (except for the anomalous jump in 2008) indicates that the approach is working.
- The content of the website is improved, and the content of the database increased even with the reduced budget. The project features a great website and management of the information. Another accomplishment is providing the recommendations for best practices. The funding needs to be continued.
- The lessons learned corner is a nice addition. The team should consider adding the website (Safety Snapshot, at minimum) to a listserv for California emergency responders and permitting officials.
- The number of consultations is continuously increasing, which is a clear signal of the interest generated by the project. Many companies outside of the fuel cell and H_2 community are using (compressed) H_2-rich gases (petrochemical, chemical, and steel companies). Consultations of these companies on incidents do not seem to have been performed, but they could improve the project.
- Although there were 11 incident additions since the last DOE Hydrogen and Fuel Cells Program Annual Merit Review, the most significant accomplishment is the number of site visits. This indicates that the site is useful to groups in this industry. It would be nice to see a breakout of which country is accessing the site the most. This is a DOE-funded activity, and it would be nice to see U.S. industry utilizing this tool. It is still really good information for everybody globally, but perhaps more targeting could occur if it were determined that U.S. companies are not utilizing this information. Unfortunately the "Best Practices" section has not been updated due to funding issues.

- As mentioned in the oral presentation, reduced funding has resulted in a backlog of inputs to both websites. This trend should be reversed. Information should be provided on the time and effort required for "vetting" an entry into the incidents database and identifying which specific problems arise, if any, once an incident has been provided for input. Also, information should be provided on the number of and justification for submitted entries that eventually are not included. The addition of the "Safety Snapshot" feature to one of the websites is positive.

Question 4: Collaboration and coordination with other institutions

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

- The project features good collaboration with the Hydrogen Incident and Accident Database (HIAD) and other laboratories.
- There is a very good connection into other organizations to gather incident data. There appears to be international collaboration as well.
- The team should increase efforts to investigate how collaboration and cross-referencing with the IA-HySafe HIAD could be enhanced.
- The collaboration with other peers is good. It still seems like the project needs to be more widely disseminated. It is a great resource that is unknown. Perhaps the use of social media or linking to other websites to get the word out about the best practices section, for example, would make a useful addition. However, there needs to be consideration as to what the general public readily sees (to avoid over-dramatization).
- Collaboration with the HIAD database is mentioned, but during the presentation it was not clearly explained how this collaboration took place and if there is now a uniform procedure for recording and introducing new events. Moreover, there are at least three projects led by the Pacific Northwest National Laboratory (PNNL) (projects SCS006, SCS008, and SCS015) that deal with safety at different moments of a project's life. There is a clear need to identify precisely the goals of each project, to show that there is no overlap between the different tasks performed in these projects, and to show how each project may benefit from the experience gained in the other two projects.
- The relationship with HySafe is certainly a key contact, but it is unclear what new collaborations were established. It was also unclear how this project reaches beyond the H_2 safety and national laboratory community to achieve the goals specific to the barriers. There is no dispute that this database is a marquee for pro-active, behavior-based safety; this reviewer wants to know why the U.S. Chemical Safety and Hazard Investigation Board (CSB) compliment has not been further leveraged and made visible to the broader safety community. This reviewer wonders if there is any other industry that has such an extensive database. If not, this reviewer wants to know why this is the case and what insights other industries/communities could gain from this resource. This reviewer wonders how much effort or activity has been put into investigating this interest and the potential to leverage collaboration or other safety incident databases.

Question 5: Proposed future work

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

- The team should further expand on plans to offer value as a communication document.
- The suggestions from last year's review are good ones—a brainstorming session could yield more good ideas for promoting the site.
- The team has identified ways to overcome a number of comments that have been made in previous reviews. These should be implemented, provided that sufficient funding is made available.
- An insurance company may have accident data. This reviewer suggests the principal investigator contact such a company.
- The plans are built on excellent past progress, but a "routine" seems to be put in place without a clear strategy on how to encourage the private-sector to submit records of incidents. This strategy may not be in the hands of the persons responsible for the project, but perhaps DOE could "strongly encourage" such a report.
- The future work plans are good, but they do not "excite" this reviewer with how this project would grow or needs to grow. It was unclear if the project administration should concentrate on making the process more efficient because some people do not want to grow the project. Four items in the list of proposed future work

suggest continuing the activities of the project, and three items suggest solicitation for improvement (gap analysis, survey, and brainstorm). This reviewer wants to know what the project leader wants to do. This reviewer also wonders, with all of this great work, what the next stage is in the strategy of the project. A few suggestions are provided in this review, but the project leader should articulate where this project is going and what the project's long-term aspirations are (e.g., increase efficiency by lowering costs to posting incidents, website overhaul, collaborations with various organizations, cross-reference with various safety databases).

Project strengths:

- This project should be continued—it is valuable in many ways, from the public relations benefits to the substantive support of the project's stakeholders.
- This is great information that is used by many. The site is getting lots of visitors, which indicates that people are seeking this type of information.
- It is important work to provide a resource for authorities having jurisdiction (AHJs) and the like as commercialization progresses. The international exposure is excellent.
- Safety concerns everybody and is absolutely necessary for public acceptance. It must be obvious to the public sector that reporting incidents in a standard, normalized, and anonymous format is for the good of the society as a whole if one wants to change the initial opinion of the population when H_2 is mentioned (e.g., a reference to the Hindenburg accident or the nuclear bomb). PNNL has developed a strong and consistent approach with the three other projects to introduce safety concerns at each step of a project dealing with H_2 and fuel cells. This must be maintained and reinforced.
- The ongoing work to keep the database relevant and trustworthy is the key benefit of this project, and the growth of recognition and use is a testament to that. The recognition by the CSB is a tremendous compliment and shows the impact of this database on the broader safety professional community.

Project weaknesses:

- The value that this provides is communication.
- The team needs to reach out beyond the audience of the "usual suspects."
- The team could consider the approach of other industries that have been dealing with H_2 for many years: this could bring added value. New approaches to obtain more data must be encouraged.
- The project staff seems to be "resting on its laurels" a bit. The websites are good, but improvements in visibility and content could be made.
- This reviewer recommends identifying which countries are visiting the site and developing a strategy to increase the number of visits from countries with developing H_2 economies. Another weakness, sadly, is the lack of funding given to this project.
- The website tools provided by the project do not seem to be exploited to their full potential. To achieve this, continued and possibly increased financial support is needed, and the awareness of the availability of the tools and of their potential should be increased. For the latter, an increased number of hyperlinks from other public websites relevant for H_2 technologies should be investigated, as well as possible usage of social media.
- The project seems resistant to implementing new ideas and concepts based on responses to previous reviewers. The project seems to lack a direction to grow; the proposed future work includes a gap analysis by an existing and closely linked collaborator (rather than a broader request for analysis, perhaps from a professional safety organization). The proposed future work also includes "brainstorm." The compliment by the CSB is undercut by the fact that the database's existence is not widely known, and the project seems to lack a cohesive strategy to address this. Based on barriers identified in the MYRDDP, it is not clear how the project addresses treating safety as a continuous process. This is left to the reviewer to infer. Based on the barriers identified in the MYRDDP and the comments above, this reviewer wants to know how the project plans to use this fantastic database to address the lack of H_2 knowledge by AHJs.

Recommendations for additions/deletions to project scope:

- A stakeholder survey to obtain feedback on the utility of the websites is clearly a very valuable initiative that could bring a lot of side effects, especially if this survey contacts persons who do not report incidents.

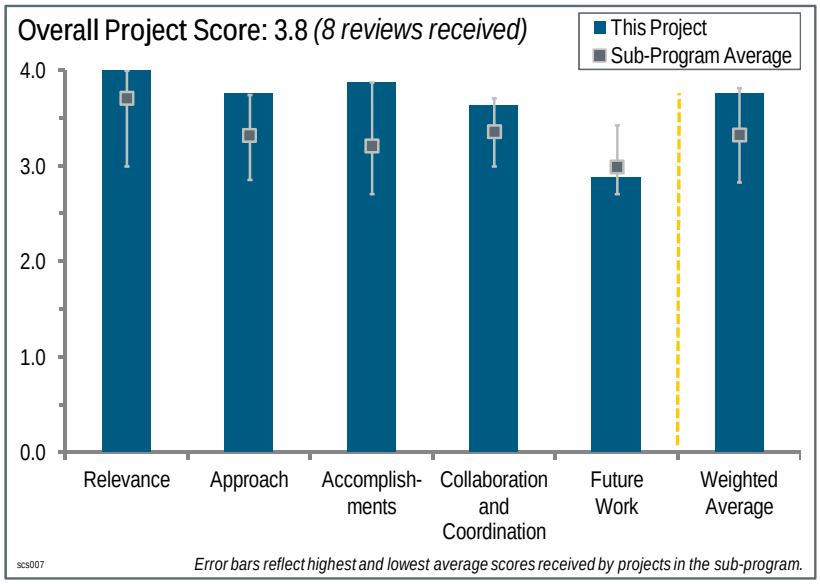
- The team needs to consider this as a reference site for AHJs to reference. This should be referenced in any and all templates and tools used in the commissioning of the stations, as well as with the operation of vehicles and fleet managers.
- Funding should be maintained to continue, build, and improve upon the project. This resource is valuable to point AHJs to—even if they do not use it, they know it is there and it provides some level of assurance and comfort that someone is tracking and watching the industry. It adds a level of transparency that is critical to infrastructure deployment.
- The team should expand collaborations beyond national laboratories and HySafe. It could develop a marketing strategy to promote the site through other Safety, Codes and Standards sub-program elements and contacts. The team could also reach out to the professional safety community or submit articles to the journal *Professional Safety*. One reviewer wants to know how the insurance community values this resource.
- Whatever was done in 2008 to increase website visits should be tried again. Adding more sophisticated "tracking tools" would help the team understand the customer database and its interests, and it also might provide DOE with insight into newly developing safety trends or concerns of the H_2 community.
- Another reviewer suggested the addition of compressed natural gas vehicle incidents due to their similarities with H_2 issues. This reviewer recommends identifying which countries are visiting the site and developing a strategy to increase the number of visits from countries with developing H_2 economies.

Project # SCS-007: Hydrogen Fuel Quality

Tommy Rockward; Los Alamos National Laboratory

Brief Summary of Project:

The objectives of this project are to: (1) determine the allowable levels of hydrogen (H_2) fuel contaminants in support of the development of science-based international standards for H_2 fuel quality (International Organization for Standardization [ISO] TC197 WG-12) and (2) validate the American Society for Testing and Materials (ASTM) test method for determining low levels of non-H_2 constituents. Los Alamos National Laboratory (LANL) will apply expertise in ultra-low impurity measurement and analysis capabilities for single-cell testing to the development of a science-based international standard for H_2 fuel quality.



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

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

- Fuel contaminant testing is necessary for commercialization.
- This project is essential work that serves as a basis for establishing commercial fuel-quality requirements.
- This data was used directly for standardization (Society of Automotive Engineers [SAE] J2719), and is a basis for validation that the levels in the standard are proper to avoid significant degradation of fuel cell performance.
- Establishing universally accepted, science-based fuel quality standards is absolutely essential to the future acceptance and widespread use of H_2 as a fuel.
- Developing and publishing fuel quality standards are essential to the successful commercial roll out of fuel cell vehicles. Understanding the effects of constituents in H_2 fuel and validating sampling and analytical methodologies is likewise critical.
- This project developed a tolerance in the fuel quality testing to determine the maximum contamination allowed before mitigation strategies need to be included. This will directly be able to establish fuel quality specifications and standards and supports the SAE 2719 specification levels.
- This is very nice work and critically important to understanding the effects of fuel impurities on fuel cell performance. This type of work might be argued as being a bit premature only in that the fuel cell technology is still under development. Presumably, the tolerance of the stack to impurities will change with development improvements of the stack. With that being said, this work is relevant to the understanding of impurities as the stack develops. The researchers have done nice work.
- The project has played a critical role by conducting single-cell tests to help determine the effects of low levels of contaminants, especially CO, H_2S, NH_3, and their mixture, on polymer electrolyte membrane (PEM) fuel cell performance in road vehicle applications. The project has also provided significant data and understanding of how such contaminants affect performance. The validation of ASTM standards via inter-laboratory studies is critical for the application and verification of the ISO and SAE fuel quality specifications.

Question 2: Approach to performing the work

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

- This project seems to have a very good approach, given the limitations of available test materials at this time.
- This project has a well-equipped laboratory, highly experienced personnel, well-planned experiments, and a winning approach.
- The analytical approach with round robin testing, etc. is very clear and has been accepted by the entire industry.
- Conducting measurements at the levels necessary to understand tolerance levels is a very challenging task. The researchers have done some nice work.
- LANL continues to have knowledge and capabilities far beyond most laboratories. These projects are well designed and the results are extremely valuable.
- While single cell testing is important, greater relevance can be had by expanding to stack testing. This issue will get more relevant as commercialization gets closer to reality.
- This project is focused on testing three contaminant families (CO, H_2S, and NH_3), and on testing at varied temperatures, relative humidity levels, and the concentration of contaminant. This project developed a validation of the FTIR contamination measurement for H_2O and NH_3.
- This project conducted state-of-the-art testing and diagnostics on fuel quality to support the development of ISO and SAE standards deemed essential for the commercial deployment of fuel cell electric vehicles (FCEVs). The approach to testing and focusing testing at catalyst loading levels that meet DOE targets help the project to address critical barriers. The project is well integrated with both fuel cell research and development, and codes and standards development.

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

This project was rated **3.9** for its accomplishments and progress.

- ASTM FTIR testing on ammonia and water was completed.
- This work has been very carefully executed.
- H_2 quality standards are in place for first generation(s) of commercial products.
- Studies have focused on the industry-identified primary contaminants, which is good. Participation in the ASTM FTIR validation effort is also a positive accomplishment.
- The accomplishments work towards furthering the durability targets (5,000 hours) and enables understanding of other degradation factors, such as carbon corrosion and catalyst degradation.
- Steady progress is being made in this project. The H_2S test results are particularly interesting and using FTIR to verify concentrations is a good idea. The mass flow controller-driven mixing can sometimes provide misleading results.
- Understanding of the CO effect on the membrane electrode assembly (MEA) is critical to DOE's efforts, including the canary species for steam methane reforming (SMR). H_2S and ammonia work is similarly critical as its effect on the fuel cell is critical. This project has done excellent work supporting the FTIR method and produced valuable data, which will be integrated into the ASTM standard.
- This project made excellent progress toward a systematic understanding of the effects of CO, H_2S, and NH_3 on single-cell PEM fuel cell performance and durability. The accomplishments of the project were a significant factor in establishing technical consensus on the levels of these contaminants that are tolerable and that can be defended in a standard. The project also made an important contribution toward the validation of an ASTM standard needed to help verify compliance with the standard.

Question 4: Collaboration and coordination with other institutions

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

- LANL has support from industry and government, and has kept on target with timelines and deliverables.
- Industry, academia, and government have been working well together on H_2 quality for several years. That cooperation continues.

- This project has been collaborating with the Fuel Cell and Hydrogen Energy Association (FCHEA), numerous universities, three DOE technology teams, and directly with the standardization efforts.
- This project is well linked with a number of relevant organizations. The round-robin testing as implemented in this project is absolutely essential to wide acceptance.
- It is unclear if the H_2 suppliers have been fully engaged and if they provided input in the costs of purifying hydrogen. This reviewer wondered about system studies that would inform the tradeoff between projected fuel cell stack degradation and fuel cost.
- This is an area that could be strengthened. While working with WG12 is important, the principal investigator (PI) could benefit from others in the field by engaging in a "technical" collaboration. This work should seek out technical collaborations to accelerate, leverage, and share results. The PI should stay connected with the activities of the International Partnership for the Hydrogen and Fuel Cell Economy's Regulations, Codes and Standards Working Group (IPHE/RCSWG) as they organize a round robin in this very area.
- The PI is internationally recognized as a leading contributor to the development of both the ISO and SAE standards. The project has been an integral part of the DOE effort and the PI is a critical member of the DOE team of experts. LANL and the PI have worked very effectively with other DOE team members and with the international experts who worked on the standard.

Question 5: Proposed future work

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

- The proposed program is good, but stack-impact studies on these same contaminants should be added.
- This project should do additional testing of other species critical to the fuel cell performance.
- The tie into system degradation mechanisms and cathode side degradation has not been made clear.
- Continuing on this very productive path is a good idea. This reviewer wondered if the team will turn to studying other impurities.
- LANL's work to support future ASTM Interlaboratory Study Program (ILS) efforts is critical for validation of ASTM test methods. It would be beneficial to the industry for LANL to have a more active role in ASTM.
- More detail is needed on how testing conditions will be varied to provide more data (slide 20). Test data that can illuminate recovery mechanisms under PEM fuel cell systems and FCEV operating conditions would be especially valuable. The close collaboration with the Fuel Cell Technologies Team to address the effects of shutdown/start-up procedures and operating strategies would be valuable as well.
- Looking at combinations of impurities seems like the best next step. It may also be possible now to test newer materials or to test at the stack level, since fuel cells are moving into commercial applications. It might also be useful to understand what contaminants are in dispensed H_2 and test their combined effect. There should be some field work that could guide the direction of future lab work.
- The PI recognized the importance of combining contaminants to understand the interplay. This is a very appropriate and timely direction for this work. The PI should embrace the notion of contaminants coming from a "system" installation (i.e., particulates, contaminants from improperly cleaned delivery systems, etc.). The researchers should also pay attention to the response of the fuel cell and the influence of impurities under operating conditions typical of what might be seen for steady state operation of stationary applications, such as CHP, in addition to the periodic operation of the transportation applications. The stationary application is out of the scope for WG12, but it is very relevant to the fuel cell development community and fuel quality specifications for the stationary applications.

Project strengths:

- The expertise at LANL on impurities remains superior.
- This project has knowledgeable researchers and clear directions from industry.
- This project uses very good science, both in planning and execution. This project is highly relevant to DOE's H_2 mission.
- This project has a clear methodology, an industry condensed plan, clear results, and communication with the industry.
- This project followed the disciplines of the ASTM testing regimes: good correlation with results and theory.

- This project has a world-class team of scientists and engineers that can be called upon as needed, state-of-the-art laboratories, and an established history of collaboration with industry.
- This project has a strong analytical approach and good tools have been developed. This project is directly relevant to the commercial use of H_2 as a fuel for fuel cells.
- This project is well thought-out with carefully executed experiments. It is yielding very valuable data on the performance of the fuel cell in response to various containments in the fuel stream. This work is well positioned to stay up-to-date with the changes in fuel cell technologies to make sure the fuel quality standards do not adversely hinder deployment, which is critically important.

Project weaknesses:

- Budget constraints limit the evolution of stack testing.
- The connection between system degradation mechanisms and cathode side degradation is not clear.
- The lack of access to commercial dispensed H_2 and commercial fuel cell stacks is a problem that should be resolved over the next 3–5 years.
- This project should have focused more on the bottom line. It was unclear what the current standards for fuel quality are and how this work supports, extends, or overrides those standards.
- This project needs a stronger technical collaboration element. While working with WG12 helps to keep this work relevant to the standards development community, a stronger technical interaction will help to ensure the data is of high quality (cross checking), and that the program is leveraging the efforts of other domestic and international facilities.

Recommendations for additions/deletions to project scope:

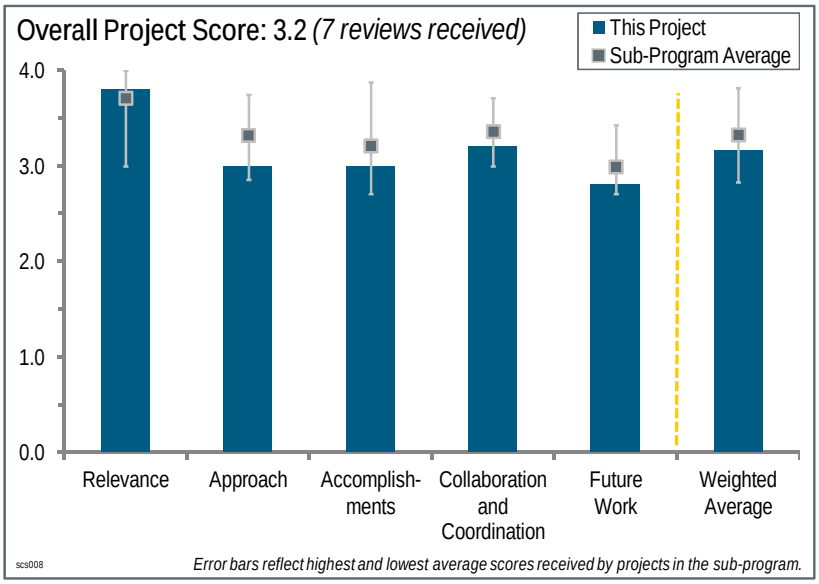
- This project should continue with system testing (short stack system) efforts up to 5,000 hours.
- These researchers and facilities should continue investigating other impurities.
- This project needs more effort and allocation of resources to lead the preparation for testing the review paper (slides 19 and 20).
- There should be further identification of the variables to be addressed as research is moving from single-cell to multi-cell fuel cells, as well as changes in the platinum loading to meet.
- A slide listing all of the current best guesses at maximum allowable impurity levels and the assumptions that led to them would be very useful.
- The work needs to include competing effects with other contaminants (this is being planned, which is good). The work also needs to include the class of contaminants that one might find in a system environment (the balance of the fueling station from storage to delivery), and the work should increase its technical collaboration with other capabilities globally. The IPHE/RCSWG will be a possible vehicle to enable this collaboration.

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 recommendations 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 (H_2) and related safety practices. Pacific Northwest National Laboratory (PNNL) conducts safety planning activities and safety evaluation site visits to accomplish these objectives.



Question 1: Relevance to overall DOE objectives

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

- As a decision on commercialization approaches, this work is relevant if their recommendations are heeded.
- This project is critical for the objectives of safety data and information, but it is insufficient for technical data.
- External peer review of safety plans for DOE-funded projects is very relevant to the deployment of H_2 technologies, as safety is first.
- This work is directly relevant to the DOE Hydrogen and Fuel Cells Program (the Program) goals; this activity is critical to the mission of the Safety, Codes and Standards sub-program.
- In order to increase public acceptance of H_2 and fuel cell technologies, it is very important to be sure that all new deployment, demonstration, and research projects using these technologies are safe or at least have a safety plan that will minimize the consequences of any encountered problem. This “ex ante” analysis performed by the Hydrogen Safety Panel (the Panel) plays a critical role for the success of the Program.
- The work of the Panel is critically important to the success not only of the Safety, Codes and Standards sub-program but of the Program overall and is a major component of the Fuel Cell Technologies Program Multi-Year Program Plan. The Panel embodies the need to make safety management a priority in every key aspect of the Program.
- The objectives of this project are to provide expertise and recommendations to DOE and assist with identifying safety-related technical data gaps, best practices, and lessons learned, and help DOE integrate safety planning into funded projects to ensure that all projects address and incorporate H_2 and related safety practices. This work is valuable in reviewing existing safety plans and providing feedback; however, this reviewer doesn't see any direct correlation between the activities in the project and the advice that DOE provided. There was obviously work performed and reviews conducted; however, there is no reflection of whether the recommendations were implemented or how the feedback was used by DOE.

Question 2: Approach to performing the work

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

- The approach is straightforward: provide safety plan guidance, review, site visit or phone interview, and follow-up.
- The approach of site visits and plan reviews has been effective where applied.

- This is a well-focused project: taking a “big tent” approach (getting members from many segments of the industry involved) from the start was a good idea. A possible improvement might have been to put in place formal “bylaws” that describe governance, membership requirements, and maybe even “terms of office.”
- The composition of the Panel and the advisory role is critical to the elevation of critical issues. Integration of safety planning into projects is valuable, along with "continuous and priority attention” and the composition of the team.
- The project approach, as noted in slide 7, seems thorough and comprehensive. The application or end result is unclear and this information would be beneficial to understand the effectiveness of the program. Slide 10 does indicate that 90% of the recommendations are implemented voluntarily, which is great. However, this reviewer wants to know about the other 10%. This reviewer questions what the implications are of the recommendations that are not made and how these will be followed up. This reviewer also questions what the impact is on the overall Program.
- The approach, based on historical experience with continuous increases of knowledge and insights gained, is good and will clearly help to overcome barriers. A more systematic use of the Panel is recommended not only for DOE-funded projects but for all projects implementing H_2 and fuel cell technologies. Contacts with the insurance companies that will insure new installations (who could possibly offer a financial incentive like a reduction of the insurance costs if the safety plan is analyzed by the Panel and recommendations implemented) could benefit the project via an increased number of safety plans to analyze. The project could also benefit from a more regular follow-up of the analyzed safety plans, especially in the case of incidents.
- The project’s approach improves each year and is becoming more comprehensive and strategic. The project still does not have an operating plan that integrates responding to current needs and identifying and incorporating potential emerging safety issues. For example, the “lessons learned” from site visits and safety evaluations provide valuable information about deployment (slide 9), and the Panel could apply its own “lessons learned” as a panel of experts and how its expertise and experience have been applied and could be applied more effectively. How an “integrated approach to project safety planning” (slide 9) can be achieved could have been explored in the presentation, perhaps under future work (slide 17) as could scenario and safety vulnerability analyses for key anticipated deployment pathways.

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

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

- The project has increased general awareness of safety issues with H_2, which is good for the industry.
- This work is fairly straightforward. Its accomplishments are listed as activity counts, and activities implemented or in progress. The scale appears to be proportionate to the funding level.
- The Panel clearly has been accepted by the community, and provides a valuable service.
- The program is good and definitely is an area needed by industry. It is time to determine if this is an area that will be required for industry on a continuing basis. If the answer is “yes,” then it may be time to begin to transition at least portions of this work to the private sector.
- This project is an active and appropriate response to the need for more activity through an integrated approach to safety planning of early market fuel cell deployment. The Panel has been evaluating the deployments with a risk perspective, meaning that scenarios are considered. Regarding outcomes, 90% of recommendations are in progress or completed as well as five safety evaluations.
- The thorough and integrated approach is a significant progress area. The scorecard shows clearly that most of the recommendations proposed by the Panel are implemented. This highlights the value of the work performed by the Panel. There is nevertheless a too large difference between the number of safety reviews conducted and the number of follow-up interviews. Publication of standard good examples of safety plans for different applications and types of projects (i.e., laboratory experiments and demonstration or deployment projects) would benefit the project.
- There has been improvement on defining performance indicators and measuring progress against them, but they are still not completely convincing—there are overlapping categories, and it is difficult to evaluate the effect or impact of work on safety of individual projects or H_2 deployment in general. The strategic examination of its work (slide 13) is a good step, but the "new initiative ideas" should have been evaluated and expanded upon; for example, it was unclear if there were any consequences or changes emerging from the strategic examination.

Collaborative work with the University of California Los Angeles (UCLA) is a good example of the value of the Panel.

Question 4: Collaboration and coordination with other institutions

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

- This project has very good collaboration from industry and international associations.
- This project has excellent collaboration. It seems the interest in the programs is growing and it seems logical this will increase as we approach the roll out of more vehicles and increase in infrastructure.
- The collaboration of this project is good. Collaboration is on a national and international level through appropriate conferences, working groups, national laboratories, and industry.
- This project has good interfaces with "customers" and maintains some international presence. It could be better hooked into the codes/standards community.
- This project displays good coordination with stakeholders through engaging industry in the Panel's activities. It has a good mix of laboratories, fire officials, and industry. The UCLA workshop on safety planning demonstrates the value of the Program.
- The Panel has worked extremely well with industry, universities, and DOE national laboratories. The Panel could explore potential collaboration (and learning new ideas and activities) from other federal safety panels and perhaps also with safety agencies or boards in states such as California and New York, which are leading the deployment of H_2 fuel cell technologies.
- There are at least three projects led by PNNL (SCS006, SCS008, and SCS015) that are dealing with safety at different moments of a project life. There is a clear need to identify precisely the goals and targets of each project, to show that there is no overlap between the different tasks performed in these projects and to show how each project may benefit from the experience gained in the other two projects. Cross-fertilization is important, but duplication of tasks must be avoided (for example, the incident investigations appear to be more the responsibility of project SCS006 than of this project, even if it is reported here). The collaboration with other institutions could be better explained and presented notably at the international level.

Question 5: Proposed future work

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

- The future work follows from past accomplishments.
- The future work described for fiscal year 2013 is very general and could be more specific and informative (see comments under "Approach").
- Proposed future work was described well, a few specifics were identified, and the remainder is to continue conducting site visits and making recommendations, which sounds good. This program wants to get involved sooner in projects to improve safety. Future work includes more comprehensive data integration from safety learning and experience, which is critical to the risk activities. Future work includes a safety checklist.
- The project will continue reviewing safety plans and conducting site visits. It looks to be in a "routine" mode without any clear plan on how to enlarge the scope of activities and how to face the increasing number of projects (funded or not by the DOE) dealing with H_2 and fuel cell technologies.
- The ongoing services of the Panel, particularly site visits and Safety Plan evaluations, should be continued. This reviewer agrees that the function is too important to be left to commercial stakeholders. DOE support for the Panel gives it the independence it needs in order to do an unbiased job. It is a good idea to link more closely with the standards-generating organizations, particularly as the data collected by the Panel continues to grow.

Project strengths:

- The project's strength is the composition of the Panel.
- This project has an excellent panel of experts and support management.
- This project has an excellent working relationship between both team members and industry.
- This project provides the education, training, and safety review needed by industry. This also promotes awareness, understanding, and acceptance by the public.

- This project displays really excellent interface with customers. It is definitely providing a "go-to" resource to the community.
- The methodology and the experience gained are clear project strengths. The expertise acquired by the Panel is extremely valuable and the high rate of success for the implementation of its recommendations illustrates the good contacts with the different stakeholders.
- The Panel essentially provides a peer review of safety plans and practices. Utilizing a broad-based panel representing expertise from industry, national laboratories, vehicle original equipment manufacturer, and fuel suppliers to review safety plans, make recommendations, and conduct site visits is essential to ensure that the demonstration projects all benefit from the peer review of safety plans and site visits inspections.

Project weaknesses:

- Committee membership seems a bit static—only one position turned over between 2011 and 2012.
- There is not enough detailed documentation of the results of Panel actions and recommendations.
- The project's weakness includes the challenge of getting stakeholder buy-in. It is critical that safety planning and the Panel be integral to the future DOE-supported deployments.
- As the number of H_2 and fuel cell technologies implementations is constantly increasing, there is a clear need to increase the visibility of the Panel and, if possible, to make "mandatory" a contact with the Panel. The project needs to develop a strategy to be able to face an increasing number of demands.
- While this is not a project weakness, one reviewer pointed out that only stats (activity counts) are presented for the entire project and for the current year, and this reviewer would like to see a slide discussing the safety reviews and white papers that will be generated for the current year, like the list on slide 21.
- It is not mandatory that sites follow recommendations. There are many reasons for this, most of them economic. Until full commercialization happens, the safety team will only see about 90% incorporation. Another reviewer questions if there are statistics that show how many installations/facilities declined a visit from the Panel.

Recommendations for additions/deletions to project scope:

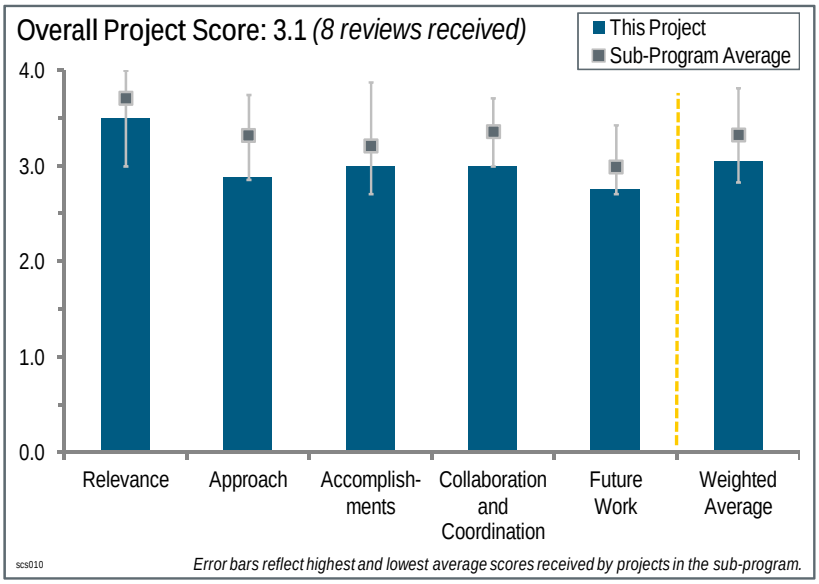
- Follow-up visits are good. Bringing these safety findings to the first responders table would be very good and could be added to a training program.
- There may be overlap with National Renewable Energy Laboratory (NREL) data collection. It is agreed that better data collection is needed, but it is best to coordinate directly with NREL.
- To improve the project, one reviewer recommends reinforcing the feedback loop after analysis of a safety plan and preparing "model" safety plans that are published on the web.
- Another reviewer questions if the project could tie in some information on how often sites are contacted, how many there are, what is the safety review cycle for each participant, and if new projects are coming on board each year. This reviewer also questions if some projects have expired and what the areas of focus are (such as how many are vehicle related, research related, authorities having jurisdiction [AHJs], demonstrations, etc.).
- A third reviewer recommends adding some "new blood" to the committee. Experience is golden, and certainly turnover should be relatively slow, but membership shouldn't be a sinecure.
- An annual report on "the state of hydrogen safety in the [United States]," and (in a more general sense) internationally, would be informative and would help cement the value and role of the Panel. The Panel could explore with NREL how business-sensitive safety data (slide 11) can be archived and shared in an aggregated form as was done in the Technology Validation and Learning Demonstration project.

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

Daniel Dedrick; Sandia National Laboratories

Brief Summary of Project:

The objectives for this project are to: (1) develop a science basis for hydrogen (H_2) safety, codes and standards (SCS) and (2) harmonize H_2 SCS development. Activities in the past year included experimental examination of fast-fill H_2 fueling of Type IV tanks in support of Society of Automotive Engineers (SAE) J2601, the Global Technical Regulation, and other regulations, codes, and standards; examination of the characteristics of predictive choked flow dispersion models; qualitative high-speed ignition imaging; and measurement of radiative heat fluxes from large-scale H_2 flames.



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

This project was rated **3.5** for its relevance to DOE objectives.

- This work is critical to the success of H_2 commercialization efforts.
- Most of the work seems relevant to DOE's H_2 Safety, Codes and Standards sub-program goals.
- The project addresses issues that are critical to the safe deployment of H_2 technologies.
- The data being generated as a result of all the testing and modeling has direct applicability to DOE's objectives.
- The work being done on risk evaluation, H_2 release behavior, flame radiation, and the collaboration on H_2 safety are very relevant. However, the fast fueling work is so irrelevant that the results (average) can only be fair.
- The goal is to develop a science basis for H_2 SCS. Therefore, a long term program to support data-driven SCS though experiments, modeling, and validation is necessary (H_2 behavior during release, ignition, and radiation). Additionally, research support for the fast-fill protocol is a specific requirement for vehicle deployment.
- The project is critical to achieving program objectives, along with other Sandia National Laboratories (SNL) projects, and is a major component of the Fuel Cell Technologies Program Multi-Year Research, Development, and Demonstration Plan (MYRDDP). For example, fast-fill modeling and validation are essential to establish performance-based requirements for SAE J2601 that, in turn, is critical for the widespread deployment of H_2 fueling stations. The same case for relevance to DOE's objectives can be made for SNL's other research and development (R&D) activities covered in the presentation.

Question 2: Approach to performing the work

This project was rated **2.9** for its approach.

- What was presented was a collection of individual science experiments, not a coherent research project.
- The approach is the right one. However, a concern is that the researchers are creating science projects with no end.
- The project addresses relevant issues in terms of pre-normative research and certainly contributes to closing some of the crucial knowledge/understanding/modeling gaps.
- The approach on slide 9, discussing risk reduction, is useful in understanding the gaps that are being addressed in the research. It shows how it may be integrated with other aspects of H_2 behavior, though it does not show for the other topics what has or has not been addressed so far under the program.

- The approach is good, but the presentation needed better correlation between project objectives and data being generated. For example, slide 5 outlines the project milestones and objectives, but the subsequent slides present topics that are not found on slide 5.
- R&D activities included in the project are well-designed and provide important data and information in support of the codes and standards development process. The presentation should show more clearly how the R&D activities are integrated. They are described as discrete activities, and one has to infer the context in which these activities are related and contribute to a better understanding of H_2 behavior. The entire SCS session (as well as the DOE Hydrogen and Fuel Cells Program Annual Merit Review [AMR] plenary and sub-program overviews) could be better integrated as well.

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

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

- Several results were presented and many of them may have been good, but it was hard to tell.
- A lot has been accomplished in studies to assess H_2 leak and ignition behavior over the course of the project.
- The accomplishments of the risk evaluation and flame radiation work are outstanding. The H_2 release behavior and collaboration on H_2 safety is good. However, the work being done on fast fueling is so poor the progress (average) can only be fair.
- There has obviously been lots of progress on various tests and model validations. The relevancy of this work to affecting codes and standards is a bit difficult to discern from the presentation. The reader has to make certain assumptions and it is left to the reader to determine how the data fits the Safety, Codes and Standards sub-program.
- The risk-informed approach developed through this program is indeed a useful tool for both national and international code sets. The fast-fill modeling will be useful in evaluating the performance of refueling processes for verification of J2601. The other H_2 behavior work is interesting.
- The individual R&D activities presented have provided good results. However, a more integrated presentation would better show progress toward DOE goals. Success metrics are identified in slide three, but there is no measurement against these metrics for the individual activities described. The project milestones (slide 5) mention SAE J2601 under H_2 behavior/fast-fill experiments, but there are no relationships to codes and standards development in the other two activities under H_2 behavior. For fast-fill modeling validation, the maximum pressure is only 2,000 psi, far short of the 5,000/10,000 psi typical/planned for commercial stations. “Standards advocacy” in slide five should be replaced by “participate in codes and standards development process to ensure….”
- Good accomplishments were shown in the presentation. However, it is not easy to clearly identify from the presentation the level of progress related to last year and to what extent 2012 progress contributes to the achievement of the final target of the research in each field of investigation. It is not clear from the slides which topics have been already closed or are near to being closed. The percent complete (80%) in a very long timeline (2003–2015) is too generic for the AMR. Values for the metrics for success identified in the third slide are not given. In terms of fast filling, the experimental facility has the interesting capability of measuring the temperature inside the tank material. However, data is limited to 2,000 psi maximum; going up to 10,000 psi and finalizing the task within 2012 is definitively challenging. The very interesting work on turbulent jets should be supported by experiments at higher pressure than 1,000 psi. It is not clear from the presentation for which specific investigations there was an input/contribution to regulations, codes, and standards (RCS).

Question 4: Collaboration and coordination with other institutions

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

- This project has a good number of good-quality international collaborations and a good connection with industry.
- Because of the cost and nature of this type of work, most of the work is performed among the national laboratories with some industry input. Those industry members who can cost-share this testing have an advantage.

- There is collaboration with other expert institutions on experiments and modeling and the results are made available to outside institutions. Additional collaboration with others is mentioned in the future work.
- This project seems to have performed joint research projects with five other groups. It is not clear what SNL's participation was, nor how it fostered further joint work.
- Slide 23 indicates that collaborations between various international partners had occurred, but does not indicate in what way the collaboration was beneficial to either party. The particular slide format appears more as a biography or reference list rather than collaboration.
- The project is very well integrated with both the domestic and international codes and standards development process. Project experts understand the codes and standards development process, and work well with and often serve as technical committee members who prepare codes and standards. The technical exchange of a researcher from China on the fast-fill model is an excellent example of collaboration, as is the involvement of a tank manufacturer (slide 6).
- The accomplishments of the risk evaluation and flame radiation work are outstanding. The H_2 release behavior and collaboration on H_2 safety is good. However, the work being done on fast fueling is so poor the progress (average) can only be fair. There were statements made that the work would be presented in the J2601 team. The work should have been first coordinated with U.S. industry before collaborating with the Chinese effort. It is unclear what the purpose of showing external temperatures and testing only to 2,000 psi was. The project is at best pretty slides, and has no merit whatsoever.

Question 5: Proposed future work

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

- These are very ambitious plans, but it looks like another year of "odd jobs," rather than a coherently planned research project.
- The maximum final pressure of H_2 fast filling should be raised from 2,000 psi at least to 5,000 psi. The higher the final pressure, the greater the temperature increase.
- The National Fire Protection Association (NFPA) indoor refueling work, burst pressure ratio performance testing, and model validation activities are all important activities for the near term. They will also feed into other standards development organization (SDO) work.
- The future work identifies additional complementary research on H_2 behavior, and other work that feeds directly in to codes, standards, and protocols for fast fill, burst testing, and indoor refueling requirements.
- It appears that there is a lot of work remaining in fiscal year (FY) 2012 and no indication that these projects would be completed. The future work presented is a good mix of H_2 test activities, but does little to highlight how the work affects SCS. The only standards organizations that are mentioned are NFPA and the International Organization for Standardization (ISO), but the references are subtle and vague in terms of what specific tasks need to occur to "finalize indoor fueling requirements" and "incorporate mitigation table into NFPA and ISO codes."
- The proposed future work could be more informative if described in a table that shows the R&D category (e.g., H_2 behavior), the specific activity (e.g., validate burst ratio performance test), the codes and standards that will benefit from this activity, and the relationships to and/or extensions of current work. More details on future work would also allow better evaluation of project progress to be reviewed in the following year. This may require a change in the format of the AMR presentations.
- Some of the points identified are obvious continuations of the ongoing efforts. It seems that the effort or at least the number of topics is decreasing in 2013. For the fast filling, the plan to go up to 10,000 psi and finalize the task within 2012 is a challenging task. There was no mention of fast filling in the 2013 plan. It is not clear in FY 2012 who the collaborators are. They are not mentioned explicitly in the collaboration slides, at least for that topic.

Project strengths:

- This project has excellent technical capabilities.
- There seems to be some good science in this project; it shines through the obfuscation.
- Producing data for science-based codes and standards, and developing protocols to remove specific deployment barriers are strengths of this project.

- This project has a significant amount of good H_2 behavior testing. The data generated is surely useful to codes and standards groups.
- This project has outstanding and focused R&D that demonstrates excellent experimental design and state-of-the-art experimental facilities and modeling capabilities.
- In terms of H_2 release behavior, this project has done excellent work on H_2 forklift and tunnel releases indoors. This is very valuable for the industry.
- In terms of flame radiation, the project has access to well equipped test facilities and diagnostic equipment, which are critical for validating models on consequence estimations of H_2 releases and flames.

Project weaknesses:

- All the work being done on fast fueling and simulation is poor and a waste of effort.
- This work is stretched out and the researchers need to define shorter term goals. This type of research takes time, but getting data out of the national laboratories and into the hands of the industry and SDOs is an issue.
- The range of conditions that can be investigated in some of the experimental facilities is not large enough to cover the range of experimental conditions that can be experienced in real-scale systems (e.g., pressures up to 10,000 psi). The identification and use of performance indicators will be beneficial to monitor the status of the projects and better demonstrate actual progress to reviewers.
- The presentation was very poor. It was disorganized, far too data-jammed, and not really responsive to the evaluation criteria. It was also notable that the responses to reviewer comments were virtually identical to those given at the 2011 AMR, with one minor addition. The project clearly needs to be less scattershot and to focus more on communicating results in a clear and usable way.
- The presentation did not adequately address how this project is helping certain SDOs with updating or creating standards. There is good work being performed, but the presentation style did not close the loop showing how this all fit together (or the relevance to the Probabilistic Risk Assessment [PRA] approach). Unfortunately for this project, its counterpart presentation was placed afterward, so reviewers were left very confused with what relevance this information had with codes and standards.
- This project includes a number of complex experiments related directly to a number of different code and standards development activities, and it is difficult to understand the breadth of the totality of these experiments and their implications for other codes and standards issues. Perhaps with an R&D program as complex as that of SNL, an overview presentation (not subject to review) should be given so that the presenters of the R&D work can go into depth with the scope and overall purpose, relevance, and outputs of the R&D understood by reviewers and the audience. This comment reflects more on the structure of the AMR and less on the project's weaknesses.

Recommendations for additions/deletions to project scope:

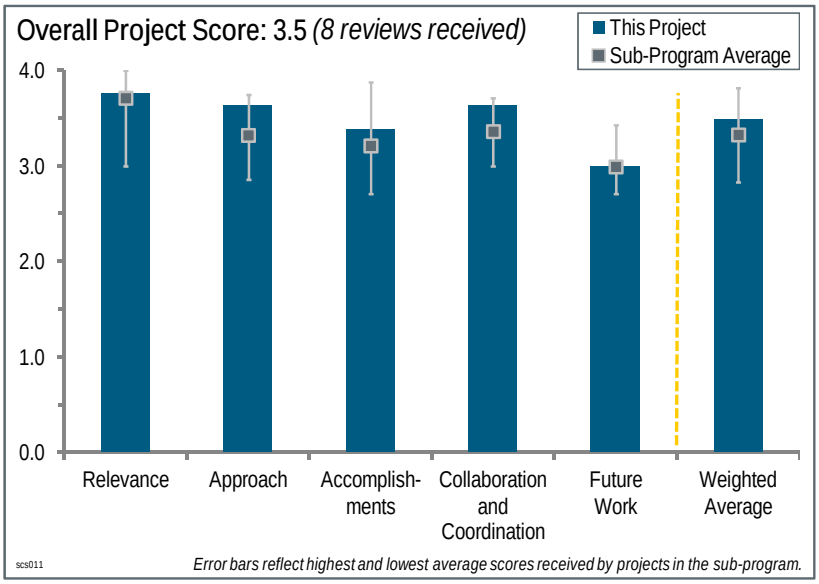
- This project should include relevant additional accident scenarios identified in recent gap analyses.
- Continue working with SDOs to accomplish any validation testing required to get a refueling standard published.
- Next time, have senior management thoroughly review and revise presentations by this principal investigator (PI) before they are given in public.
- This reviewer would suggest that the PI improve his charts to highlight the correlation between SCS activities and the work being performed by this project. The work being performed is critical and substantive in nature and is beneficial to SCS, but the presentation had too much information crammed into such a short time and out of context because the presentation that should have preceded it was moved to a later time slot.
- Efforts should continued as planned; however, all efforts in the national laboratories should be canceled, as this has provided no benefit for the industry and has been a waste of time, effort, and funding because no coordination was asked for by industry or standardization efforts (like 2601). This project should help establish a U.S. 70 MPa (up to 87.5) fast-fueling facility at an institution comparable to the current monopoly in Canada, such as the Gas Technology Institute. A third party is needed in the United States, but not a national laboratory.

Project # SCS-011: R&D for Safety, Codes and Standards: Risk Assessments

Daniel Dedrick; Sandia National Laboratories

Brief Summary of Project:

Sandia National Laboratories (SNL) is using validated simulations, field data, and expert input to determine risk through quantitative risk assessment (QRA). The objectives of this project for fiscal year (FY) 2012 are to: (1) understand confined releases of hydrogen (H_2) through experimentally validated simulations, (2) update the risk model based on the consequences of confined spaces, (3) inform the National Fire Protection Association (NFPA) 2 Code Development Committee of updates; and (4) harmonize other codes and standards.



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

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

- This project is most relevant when it informs standards on mitigation strategies or setback distances.
- The work and leadership from the SNL team has been critical to support the standards/code development.
- The incorporation of risk assessment into codes and standards is important to the development of realistic and effective codes and standards.
- This project is essential for the DOE Hydrogen and Fuel Cells Program's (the Program's) success as it provides an analytical foundation for the research and development (R&D) conducted to identify, evaluate, and specify requirements in codes and standards.
- R&D activities, as performed in the project, coupled with input of the findings in codes and standards activities, are absolutely critical in order to enable a deployment of H_2 technologies which are accepted by the public.
- The development of a QRA methodology supports the DOE's research, development and deployment (RD&D) objectives. The main focus is to obtain quantitative information and to be able to incorporate these data into a robust model that could impact safety, codes, and standards (SCS).
- This project is relevant to the goals of the Program. The models it generates can be useful tools for evaluating potential safety hazards. Quantitative risk assessment is hard to get right and it is good to see an attempt to get H_2 on a firm footing.

Question 2: Approach to performing the work

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

- This seems like a sound and thorough approach to risk analysis.
- The risk-informed approach is exceptional and by far the best that could be done in such a project.
- SNL is providing important risk-informed input to code developers. Using a strong team with good communication skills, they are making progress in incorporating risk into codes to better serve the safety community and the public.
- The risk-informed approach is sound, but the difficulty lies in the quantification of the different probabilities, as the number of experiences is limited with fuel cell and H_2 technologies. The project must base at least some of the calculations on data coming from other industries and applications.

- The project was methodically planned and the plan is being carried out. A bit more aggressive scheduling might have resulted in more rapid progress. Clear experimental validation under well controlled conditions is the key to establishing and tuning any risk-assessment model. Ultimate validation, though, will rest on the success or failure of the model in accurately predicting the probability of major safety events when the model is applied to a real-world situation.
- A risk-informed approach provides a critical link among H_2 behavior, system and facility design, hazards and harm, and a structured context for code development. The project has systematically established the capabilities, tools, data, recognition, and understanding by code developers to implement a risk informed approach. This presentation should have preceded the other SNL presentations to provide context for them.
- Science-based, risk-informed assessment with its consecutive phases as documented in the presentation is a correct approach. The term "informed" should be stressed more in the presentation and in the slides. What has not been stressed sufficiently in the presentation is the absolute need for coupling back to ongoing H_2 technology validation exercises in order to obtain H_2-specific metrics of frequencies and postulated initiating events to better document and quantify steps in the risk-informed analysis. This is needed in addition to the input that can be retrieved from "H_2-like" industrial and technological applications (which was mentioned in the presentation, but needs additional expertise to "translate" into H_2-relevant metrics). The comment in red font in the lower left hand corner of slide 10 is perfectly true and should be taken up at the level of the overall Program.

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

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

- Steady progress is being made toward the goal.
- Progress has been very good at incorporating risk into the code development process.
- The work and leadership from the SNL team has been critical to support the standards/code development.
- Ignition delay/location is a key factor, but does not seem to have been adequately studied yet. The application of this work could hinge on key questions as to whether ignition can be prevented or whether ignition should be induced sooner in some cases to mitigate the consequences of delayed ignition. The work on tunnel ventilation raises this question.
- The harmonization of NFPA 2 (H_2) and NFPA 502 (Tunnels) is perhaps the best possible outcome to the risk analysis and release simulations. The commercialization of fuel cell vehicles also needs to have the codes aligned regarding H_2 safety in enclosures and tunnels. Without this work, the timeline would be considerably threatened for the near-term fleets.
- The project has made outstanding contributions to the Safety, Codes and Standards sub-program. The project previously enabled incorporation of a risk-informed approach in preparation for NFPA 2, and direct participation by project experts in key NFPA 2 task groups is essential for the modification and improvement of NFPA 2. More discussion is needed on how the project met its metrics for success (slide three), although this is implicitly addressed by its impacts on regulations, codes, and standards (RCS) development.
- Significant progress towards the objectives has been made, but in view of the limited funding available, the choice of a limited number of problems to be treated is necessary. Instead of using data from related industries, like nuclear power plants and offshore oil and gas, the project could benefit from inputs coming from industries constantly using H_2-rich gases, such as producers of H_2 gas, the steel industry (coking gas contains at least 60% H_2), the chemical industry (chlorine and chlorate production sites emit large quantities of H_2), or the petrochemical industry (H_2 plants). Nevertheless, it is recognized that it could be difficult to obtain the expected data.
- It is unclear how the last step in the QRA sequence graphically displayed on slide 5 (nice picture) is addressed in this work, namely moving from hazard probability to harm probability. Members of the general public more easily understand "harm" than "hazard." This translation from hazard probability to harm probability needs an additional factor, namely "likeliness and frequency of exposure" (people, as well as grey and green infrastructure) to the considered hazard. Good accomplishments were shown in the presentation. However, it is not easy to clearly identify from the presentation the level of progress related to last year and to what extent 2012 progress contributes to the achievement of the final target of the research in each field of investigation. It is not clear from the slides which topics have been already closed or are near to be closed. The percent complete (80%) in a very long timeline (2003–2015) is too generic for an annual merit review. The actual values for the metrics for success defined in the third slide are not given. Anticipated work on telecommunication towers

(mentioned in the 2011 DOE Hydrogen and Fuel Cells Program Annual Merit Review [AMR] as future work) seems not to have taken place.

Question 4: Collaboration and coordination with other institutions

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

- This project has the appropriate set of collaborators with the right skills and needs.
- The work and leadership from the SNL team has been critical to support the standards/code development.
- Close and appropriate collaboration with other institutions was presented and resulted in the harmonization of standards.
- Coordination with NFPA has been very good, however work with the International Code Council (ICC) and other collaborations internationally, such as with Germany and Japan, would be beneficial.
- This project has a good number of good-quality international collaborations and also a good connection with industry as shown by the list of industrial partners.
- It sounds like there needs to be a process put in place to receive private sector inputs with a "clean room" type of approach that ensures confidentiality.
- This project has a good relationship with all the right organizations. This project is beginning to take an active role in standards organizations and applying early QRA results to help generate rational codes and standards.
- Collaboration and coordination are outstanding with the project playing essential roles in important codes and standards development under NFPA, Society of Automotive Engineers (SAE), Canadian Standards Association (CSA), and International Organization for Standardization (ISO), among others. The project has also made notable contributions to the International Energy Agency's (IEA) tasks 19 and 31. Its collaboration with Canada is also valuable for international cooperation and sharing of expertise and data.

Question 5: Proposed future work

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

- The proposed future work is presented in a logical manner and is built on past progress and experience. In view of the limited funding available, a clear definition of the problems to be addressed is needed.
- In addition to the analysis approach and tools, it would be good to see some papers written that demonstrate the application of learnings to real-world designs or that provide insights relevant to real world applications.
- The present list is valuable; however, it does not address a few near term needs. H_2 fueling standardization and codification needs to have immediate priority to help the build-up of infrastructure.
- An increased focus on "industry outreach" is planned now that the team is comfortable with the laboratory-validated model, and this is good. A plan to move more quickly into applying QRA to "real world" standard generation is needed.
- There will be a continuing need for this effort, partly because there is so much that needs to change in existing codes to incorporate the concept of risk in decision making. This is an unending "calling" that will need to be carefully applied to the most critical situations.
- Some of the points identified are the obvious continuation of the ongoing efforts. It seems that the effort, or at least the number of topics, is decreasing in 2013. Decision points and possible alternate pathways are not explicitly identified in the slides.
- More detail on the planned future work is needed. Such detail would show how current work is being extended and improved. This comment may require a change in the format for AMR presentations. Future work is treated almost perfunctorily: one summary slide with little detail. More emphasis on continuity, consequences, and building upon current work is needed.

Project strengths:

- This is an excellent team at SNL with a deep understanding of the application of risk to decision making.
- The work and leadership from the SNL team have been critical to supporting the standards/code development.
- This project has a structured approach to risk analysis that can be adapted to multiple equipment or facility executions.

- This project has a very strong, methodical, approach to building and validating a QRA model for H_2 release events.
- A robust methodology based on a scientific approach is a clear strength of the project together with the good contacts with the codes and standards task groups.
- The researchers have excellent technical expertise in QRA and extensive experience in its application. The risk-informed approach that the project has built, and the incorporation of this approach in the codes and standards development process are major accomplishments for the Safety, Codes and Standards sub-program.
- The main strength lies in the method applied; namely, risk-informed analysis based on relevant scientific input obtained from targeted numerical and experimental efforts coupled with appropriate consultation and input from stakeholders. The project tackles crucial issues in risk assessment, generating progress in the field in a context of close collaboration with the relevant stakeholders (e.g., industry, codes, and standards groups/committees, other research institutes).

Project weaknesses:

- This project has difficulty with quantifying risk.
- The efforts must be devoted to obtain reliable data from the industries already dealing with H_2 production and use.
- The presentation has absolutely no discussion of relative risk. The project doesn't mention QRA models developed for related industries, such as natural gas. It should be relatively easy, at least in theoretical model systems.
- The communication of results, such as pressure relief panels, should be brought to the forefront. This could be some good additional knowledge that industry could benefit from, such as with small enclosures for test vehicles.
- It seems that the issue of the level of uncertainties involved in risk assessment is not addressed (it is at least not mentioned). A methodology that provides the level of uncertainties of the risk assessment should be developed or included. The identification and use of performance indicators will be beneficial to monitor the status of the projects and demonstrate the progress achieved.

Recommendations for additions/deletions to project scope:

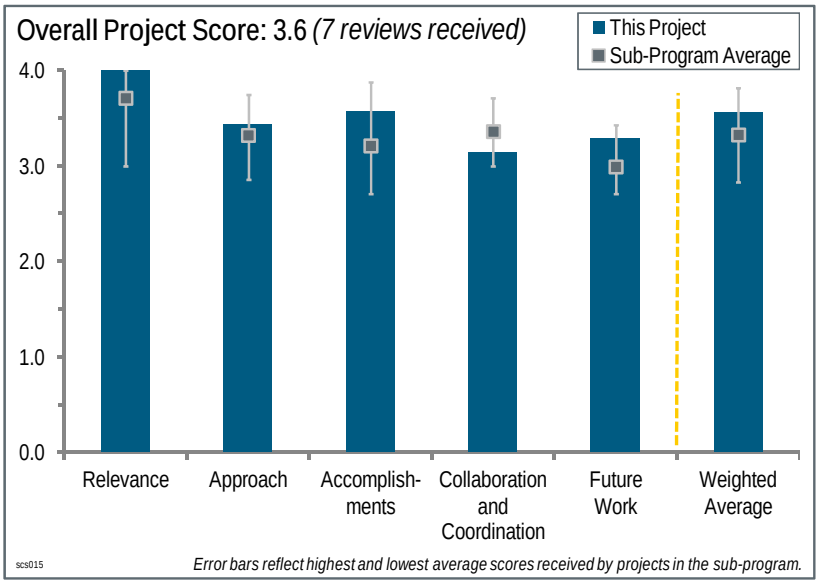
- This project should address uncertainties in the different stages and their propagation to the final outcome of the risk-informed assessment. There needs to be a dedicated effort to translate from “hazard” to “harm.”
- This project should help the standards for fueling including SAE J2601 putting their standards into the H_2 codes and NFPA 2 ICC to enable a safe infrastructure. This project should restart the Hypoc in the near term to accommodate changes in the codes to accomplish DOE 2015 goals in the code cycle.
- This project should attempt to provide statistical verification of the model by applying it to an ensemble of real-world installations and comparing the risk prediction with actual occurrences (or non-occurrences). It should be relatively easy, at least in terms of using the now-validated model, to compare relative risks incurred by H_2 storage with those associated with other energy storage methods (from gasoline to dammed water). Surely QRA models exist for those methods as well. This could be a very illuminating comparison.
- Development of a web-based QRA tool has been discussed for several years, but it has not been seriously considered or undertaken. Perhaps the “comprehensive reference for H_2 system QRA” (slide 14) can lead to the development of such a tool that will facilitate widespread adoption of a risk-based approach to designing, siting, operating, and approving H_2 systems. The evaluation of the effects of obstacles after ignition in indoor releases (slide 8) would be a valuable addition to project scope.

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

Monte Elmore; Pacific Northwest National Laboratory

Brief Summary of Project:

The long-term objective of this project is to support the successful implementation of hydrogen (H_2) and fuel cell technologies by providing technically accurate H_2 safety and emergency response information to first responders. The specific objectives for fiscal year (FY) 2012 are to: (1) offer the one-day operations-level course utilizing the U.S. Department of Energy's (DOE's) fuel cell electric vehicle (FCEV) prop at appropriate fire training centers; (2) continue to support the web-based awareness-level course (launched in FY 2007); and (3) continue outreach activities by disseminating first responder H_2 safety educational materials at fire training conferences to raise awareness.



Question 1: Relevance to overall DOE objectives

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

- This project is critically relevant to serve the first responder community with training specific to alternative fuel technologies.
- This course directly addresses the education needs of the first responder community around a new/unknown vehicle and fuel technology, which is critical to the implementation and commercialization of H_2 and fuel cell vehicles.
- This project is extremely relevant to the DOE support of the commercialization of FCEVs. Without this program, there would be an uncomfortable void in the first responder community when discussing FCEVs.
- This project is clearly relevant to the DOE Hydrogen and Fuel Cells Program—both for its great contribution to public safety and its educational value with a key constituency. Fire departments are the "boots on the ground," and they will most likely be the ultimate enforcers of codes and standards, at least at the local level.
- The training of first responders is of critical importance for the public acceptance of H_2-linked technologies. The project is mainly focused on transport applications, but extension to stationary applications and early markets such as forklift or backup power installations is required. This project will need increased funding in order to acquire or build new modules and props. The project is definitely in line with DOE objectives. It could be extended, provided that extra funding is available, to emergency medical personnel and volunteer firefighters.
- Training for first responders is critical to the deployment of any alternative fuel. The public has an expectation that first responders will know how to proceed when they arrive on the scene of an accident or incident. The first responders must also have the training and confidence to approach such accidents, understand and mitigate the risks to passengers and to themselves, and bring the situation under control.

Question 2: Approach to performing the work

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

- The project is focused on the barrier of understanding what to do when encountering an FCEV that is in dire straits.
- The project's training prop, one-day course, web-based training, outreach, and near-term focus on California deployment are all very positive. The project is able to reach a large audience with a low budget.
- The approach was tightly focused on the mission: to provide relevant, timely training to first responders in the most effective way. It is hard to see how the team could have done a better job on such a limited budget.
- The flame prop appears to be an extremely useful tool. More consistency among state and college programs would be beneficial.
- The hands-on approach is probably the best way to instruct firefighters. This is why the building of props covering other H_2 applications than cars is suggested. Problems of bursts and high-pressure leaks in flexible materials could be better observed and treated. In Europe, firefighters need to give their approval for the building and operation of equipment that uses explosive compounds. Information on how the H_2 is diffusing in close environments and how to ventilate correctly in these environments could be added to the training. The decreased number of consultations of the website is raising some questions regarding its content and maintenance. An effort to make it more attractive and highlight the recently added elements could be realized.
- This course could be adjusted so that it is easily scaled to meet the needs of the particular department being trained in order to accommodate time frames, for example (i.e. truncate the in-class time) or to allow for the experience of the students (e.g., modify the prop portion)—all of which would maintain the quality of the course and the information delivered.
- The approach is consistent with the expectations of the project sponsors and the barriers. This reviewer asked whether the approach for the target audience (first responders) has changed with regard to more comprehensive training in all types of alternative fuel vehicle response techniques. If so, this reviewer would like to know whether this project has revised its approach to address this change. In addition, this reviewer asked whether activities in other industries could benefit from pooling resources for the community, and whether there is a private company that is interested in assuming responsibility for this material as an end result of this project.

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

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

- Progress has been excellent. This training has been well received by the first responder community.
- This is an excellent and very well received course; however, DOE has funded other emergency response programs on alternative fuel and/or H_2 vehicles that may not have the same quality of vetted information or messaging.
- This project has trained more than 21,000 web users and 710 on-site training attendees, more than 600 of whom work in jurisdictions along the California Hydrogen Highway. The project has made impressive progress.
- The number of trained officials is constantly increasing, and the feedback received from trainees is very positive. Last year, it was recommended to enlarge the geographical distribution of the training sites and to go outside of California. Unfortunately, it seems that in 2011, training only took place in California. This starts to be more and more critical in view of the deployment of an increasing number of H_2-powered forklifts outside of California.
- Outreach activities were limited by the budget, particularly the live training with the FCEV prop. This reviewer would have liked to see some work on leveraging DOE resources. With a bit more funding, many more fire departments could have been visited. The course material may be getting a bit stale; however, this looks like it will be addressed in the coming year.
- Training accomplishments are excellent, particularly the number of participants, given the limited resources. The impact of training was unclear. For example, this reviewer wondered whether there is a means for evaluating incident responses where training has occurred versus incident responses where training has not yet occurred. There are several recent incidents (in the H_2 incident database) where the responders were not provided this training. It was also unclear whether the trained first responders have had any incidents, even false alarms; and whether there are any conclusions that can be drawn by comparing the responses. This comparison

might help provide a critical data point (i.e., the value of this training), which seems to be missing from the accomplishments and progress measurement.

Question 4: Collaboration and coordination with other institutions

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

- This project has achieved excellent collaboration with the first responder community.
- This project has demonstrated very good collaboration thus far, both locally in California (California Fuel Cell Partnership) and through the International Association of Fire Chiefs (IAFC) and the U.S. Department of Transportation (DOT).
- There appear to be redundant efforts in developing first responder training funded by DOE. Optimizing training material and reducing duplicative efforts would increase the value of this program.
- Collaboration exists, but it appears to be limited to California. Even if it is recognized that California is probably the most advanced state for FCEV deployment, efforts to cooperate with other institutions for other types of applications could improve the project.
- Collaborations and coordination suggest that this project has created a premier educational tool that has been very beneficial in targeted communities. This reviewer wondered why state fire academies are not included in the list of collaborators. Even negative responses would be beneficial and would credit this project with investigating options for growing the project. It seems that the project funding has significantly declined, which raises a question about how strategic collaborations can play a role to leverage the existing funding to ensure that project goals are met. This reviewer also asked what training would interest the fire service, if they are not as interested in this training (e.g., would they be interested in a combination of all alternative fuel vehicles in a single class). If such a concept was appealing and supported by the fire service or the Federal Emergency Management Agency (FEMA), this reviewer asked whether this project has identified the potential collaborators. In addition, this reviewer asked whether the project has investigated the potential for federal facilities to act as 'early adopters' of H_2 technology and the opportunities to train U.S. Department of Defense (DOD) first responders. The Defense Logistics Agency is highlighted, and it is unclear whether there are plans to expand this interaction to other fuel cell and H_2 technology deployments.

Question 5: Proposed future work

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

- This reviewer recommends focusing on early market areas for fuel cell vehicles.
- H_2 applications are developing progressively. The proposed future work, built on past progress, focuses on new barriers for new types of applications, but it could be more ambitious in terms of its geographical distribution and addressed topics.
- With the commercialization of H_2 fuel cell vehicles and the implementation of fueling infrastructure in California and on the East Coast, there needs to be continued and increased funding for the delivery of this course.
- This project should focus on on-site training for up to 500 additional responders in the coming year, mostly in California, and possibly on the East Coast. It would be beneficial to expand the training eastward.
- Expanding the training to include material handling equipment is an excellent idea. It's a bit surprising that responding to events at refueling/storage sites isn't already in the course, but perhaps firefighters consider themselves to already be trained to respond to similar incidents.
- It is unclear where this project is going, and how much funding is required to support it. It would appear that there has been a precipitous decline in funding that is inconsistent with the project's future plan and possibilities. The same future work was proposed in 2011, and funding was not received, so this reviewer asked what other avenues are possible for this project if funding remains so low, what level of funding is too low to support the project at all, and whether there is a way to leverage some funds for a targeted effort in a different direction (e.g., the state fire academy assumes responsibility, the national fire academy provides sponsorship, FEMA provides funding, a private company shows interest, and so on).
- The purpose of this training is to familiarize the first responders about what to do with the hardware they encounter. However, in large metropolitan areas, 80% or more of the first responders are emergency medical

services (EMS) personnel. This reviewer asked whether there can be some focus on the physiological aspect of exposure to H_2 fuel in an accident scenario. This reviewer also asked whether students are given a material safety data sheet for H_2, or whether that is left to individual organizations to see to their own EMS training. Putting some emphasis on the physiological effects of H_2 exposure may work.

Project strengths:

- This project is a good value for the money.
- The training is credible, with hands-on applications.
- The quality of the training and the hands-on approach are clear project strengths.
- These are excellent instructors with a wealth of knowledge. The course is comprehensive and features excellent hands-on time with the prop.
- This is very necessary training. It is beneficial to provide on-site and online training first in critical deployment areas, and then follow up with on-site training for the rest of the country prior to deployment in those areas.
- The project has created a comprehensive education program consistent with its project goals. The impact of the project to those who have used it appears to stretch beyond the metrics presented (i.e., there is more value than the metrics presented).

Project weaknesses:

- Budget constraints limit the scope of this program. This reviewer expressed the hope that funding will accelerate as a commercialization decision nears.
- There are duplicated efforts on this same topic(s) that have been funded through other DOE programs, and there is no obvious tracking/monitoring of the material, content, and messaging throughout these efforts.
- Should increased funding become available, the project could be extended in scope and focus. The training of other categories of first responders (firefighter volunteers, medical emergency personnel, and private company personnel) could be considered.
- There are no project weaknesses, except that funding appears to be very low. It would be beneficial to expand on-site training or at least have some way to ensure that online training is well advertised. The project should collect stats on regional participation in online training, and it should provide some outreach to authorities having jurisdiction throughout the country and (perhaps) to schools that have fire technologies in their curricula.
- There is a need to reach more firefighters with the hands-on course and to increase website traffic. It is disconcerting that more users are not signing up—H_2 usage is growing, and it is important to train as many first responders as possible, in case major incidents occur.
- The project has created an educational program that exceeds the needs of the target community. While this was perhaps the intention of the project's charter, given the decelerated pace of light-duty fuel cell vehicles, it is unclear what the project has done to respond to the accelerated use of fuel cells in 'early' or 'niche' markets, such as backup power and forklifts. It seems that this project is in danger of losing funding before vehicles are on the road and before the training becomes very relevant. It is unclear how the project is prepared to bridge this gap and whether the project is leveraging all of the resources in the DOE Safety, Codes and Standards sub-program and the Fuel Cell Technologies Program to identify sources of collaboration to address the funding and strategic goals. This reviewer also asked whether all of the Safety, Codes and Standards sub-program leads are aware of this project, and whether they promote its use among industry relationships; whether the H_2 and fuel cell industry is a user and promoter of this program for its installations and interactions with the fire service; how this program could reach those "friendly" marketing networks to better reach targeted audiences (e.g., local fire departments and state officials involved in fuel cell and H_2 deployments); and whether the industry views this project as a helpful tool for its deployments, and if so, whether there is value in their support.

Recommendations for additions/deletions to project scope:

- This reviewer recommends widening the scope of the training.
- Cooperation with other projects as regards the exploitation of real incidents and how to act in front of these incidents could improve the project.
- The project should consider leveraging fire academies, DOD, DOE program advocates, and industry advocates. It should also identify alternative support mechanisms beyond the Safety, Codes and Standards sub-program. In

addition, it should explore the insurance industry's view of the value of this training (e.g., would they consider training as a value to their risk evaluation).

- The project should try to arrange an "East Coast road trip" paid for by industry/insurance companies/DOE. Also, they really need to freshen up the web course. It is surprising that the number of users is shrinking, rather than growing, considering the growth in the number of deployed H_2 fuel cells and refueling/storage sites. This reviewer strongly recommends increased funding for next fiscal year.
- The material in this course has been vetted by industry and is comprehensive in its information and accuracy (although updates are needed). Some funding should be made available to allow for a comprehensive review of all DOE-funded ER programs (e.g., the National Alternative Fuels Training Consortium and National Fire Protection Association programs) and collaborative efforts (e.g., the DOT/IAFC and DOD-Tank Automotive Research, Development and Engineering Center collaborations) that include (or intend to include) H_2 in order to identify gaps in messaging, content, accuracy, and so on. If multiple programs are being funded by DOE, they need to be consistent in these areas. Additionally, this course should be the primary "go to" course (along with the online portion), meaning that more advertisement is needed. This reviewer recommends continued and increased funding for deployment, at least through 2015. The project could potentially decrease spending by printing fewer hard copy materials (every attendee does not need/want a book). The project may also consider providing online access to materials (via password after the course has been taken).

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