

## 2010 Safety, Codes and Standards Summary of Annual Merit Review of the Safety, Codes and Standards Sub-program

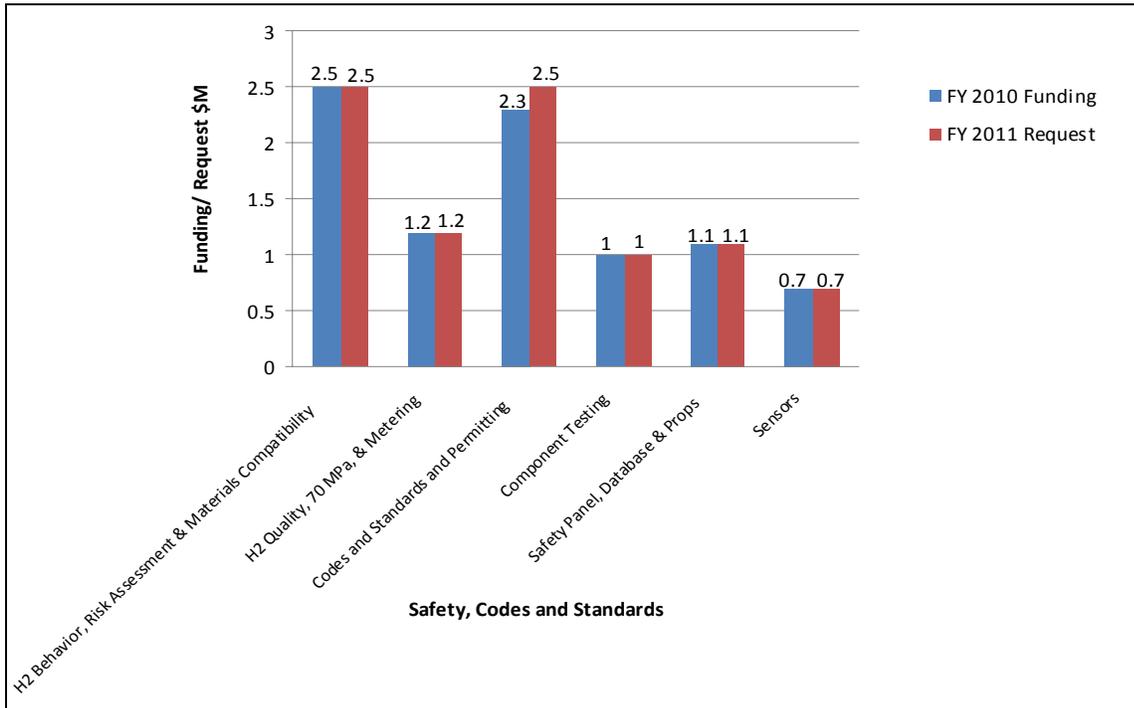
**Summary of Reviewer Comments on the Safety, Codes and Standards Sub-program:**

The Safety, Codes and Standards (SCS) sub-program supports R&D that provides the critical data and 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. In FY 2010, reviewers recognized the progress, coordination, and organization of each project towards the overall goal of the safe deployment of hydrogen and fuel cell technologies. Reviewers were impressed by each project’s breadth and commitment to information sharing and R&D collaboration. Reviewers also recognized each project’s success in connecting relevant stakeholders.

Reviewers identified strong sub-program 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 a hydrogen fuel specification. Reviewers also appreciated each project’s efforts at leveraging the resources and intellectual capital of academic institutions, standards development organizations (SDOs), national laboratories, government agencies, and industry, as well as other offices in DOE.

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

The sub-program funding for FY 2010 allowed for the continued strong support of the necessary R&D and domestic and international collaboration and harmonization to support hydrogen and fuel cell early market commercialization. The following chart indicates FY 2010 appropriations and the FY 2011 budget request.



**Majority of Reviewer Comments and Recommendations:**

In FY 2010, 14 SCS projects were reviewed, with a majority of projects receiving positive feedback and strong scores. Reviewer's scores ranged from 3.0 to 3.8, and the average score for projects was 3.4. The project receiving the highest score was Hydrogen Safety Training for First Responders.

**National Codes and Standards Template:** Reviewers recognized the value of the template and in particular noted the template's comprehensive content and ability to bring relevant stakeholders together. In particular, reviewers praised the data-driven codes and standards analysis resulting from experts' use of the template. Reviewers suggested expanding the template's level of detail so it can be more relevant for stakeholders, including fuel quality efforts, and providing funding to ensure continual updates to the database.

**Codes and Standards Training, Outreach, and Education for Emerging Fuel Cell Technologies:** Reviewers praised the project's critical role in implementing hydrogen and fuel cell technologies and its focus on forklifts and backup power, two early market deployments. Reviewers also recognized the collaboration with local fire departments and praised holding workshops at locations where hydrogen and fuel cell technologies are deployed. Reviewers suggested increasing project funding to allow for more training sessions and to allow the project scope to expand into other alternative fuels.

**Component Standard Research and Development:** Reviewers appreciated the project's well-coordinated alignment of its test program with industry and the appropriate SDOs. Reviewers also praised the round-robin safety sensor testing and international collaboration with Europe's Joint Research Center (JRC). Reviewers suggested fostering additional outreach to industry stakeholders to better understand industry needs. Reviewers suggested the project complete a list of components under consideration, to identify gaps.

**Materials and Components Compatibility:** Reviewers admired the project's focus on forklifts and its relevance to the early market deployment of hydrogen and fuel cell technologies. Reviewers commended the project for its test facilities, thorough and engineering-based data collection, and test methodology. Also, most reviewers commended the direct interaction with codes and standards committees, tank manufacturers, forklift integrators, and working groups. However, reviewers noted that progress has been slow on material system evaluations and the application of the fatigue crack growth law. The fatigue crack growth law is based on the hypothesis of "leak before break," and it is unclear how the testing program will incorporate the hypothesis into its testing procedures.

**Hydrogen Fuel Quality:** Reviewers praised the rigorous technical R&D approach used to determine levels of constituents in hydrogen. The reviewers also commended the project's contribution of critical data to the International Organization for Standardization Technical Committee (TC) 197 Working Group 12. Most reviewers noted the strong collaboration between investigators, the strong work plan, and the iterative approach to refine data results. Reviewers suggested including more depth on durability testing at the cell level and greater collaboration with fuel providers.

**International Energy Agency Hydrogen Implementing Agreement Task 19—Hydrogen Safety:** Reviewers recognized the project's important role in international collaboration. Reviewers commended the project's data collaboration, strong link for input into [www.hydrogenincidents.org](http://www.hydrogenincidents.org), and efforts to foster international collaboration. However, most reviewers commented that the project's focus is vague and Task 19's goals need to be better defined. Also, some reviewers noted the project needs to increase collaboration with SDOs such as ISO and the International Electrotechnical Commission.

**Hydrogen Release Behavior:** Reviewers recognized the strength of the project’s research protocol, which translates into a “defensible and traceable basis” for codes and standards development. In particular, reviewers praised the outstanding transformation of scientific analysis into actual safety guidance, and also commended the work done on tunnel release. Reviewers identified areas for improvement, including fostering greater industrial collaboration on indoor refueling and clarifying the direction of tunnel release work.

**Hydrogen Safety Knowledge Tools:** Reviewers praised the project’s depth, breadth, and distribution of hydrogen safety resources. Reviewers also noted other strengths such as the applied expertise of the Hydrogen Safety Panel to the online resources. Reviewers suggested improvements as well, such as greater dissemination of the Web site and increased involvement of energy companies.

**Hydrogen Safety Panel:** Reviewers agreed that the Hydrogen Safety Panel (HSP) provides critical expertise for ensuring the safety of hydrogen and fuel cell projects. Reviewers thought there was an excellent mix of expertise and experience on the HSP and were impressed with its accomplishments thus far. Reviewers praised the HSP’s safety recommendations, which are based on incident reviews, as an excellent resource. Reviewers expressed concerns over how the HSP’s effectiveness is evaluated and commented that the HSP might be over-funded.

**Hydrogen Safety Training for First Responders:** Reviewers praised the project’s relevance and important role in advancing the safe deployment of hydrogen and fuel cell technologies. Reviewers identified a number of important strengths, including the focus on real-time training, the accurate targeting of relevant audiences, the well-designed curriculum, the hands-on training afforded by the fuel cell prop, and the ability to move the course to a variety of locations. However, reviewers suggested including increased collaboration with the DOD, onsite training on the East Coast, training specific to forklift operation, and greater outreach to more audiences and locations.

**Hydrogen Safety Training for Researchers:** Reviewers praised the relevance of the course and its sound technical approach. Reviewers noted that the Web site has an excellent graphical layout and the course reaches out to the correct audiences. Reviewers also saw the strength and importance of the technical expertise and facilities at LLNL that were used to develop the training. Some reviewers noted that it might be useful for the course to be tailored to specific laboratory settings. Also, the course might need to be modified for audiences with different education levels.

**Optically Read MEMS Hydrogen Sensor:** Reviewers recognized the project’s good coordination and technology transfer as strengths. In particular, reviewers noted excellent cooperation between the government and industry. Reviewers suggested improving collaboration with nationally recognized testing laboratories like Underwriters Laboratories (UL) during the testing process.

**Safe Detector System for Hydrogen Leaks:** Reviewers noted the project’s successful R&D towards a commercially available sensor. Reviewers also said the project is “well executed” and has fostered “good collaboration with potential customers.” Reviewers supported the project’s approach toward sensor development and testing, including collaboration with NREL. Reviewers identified significant technological barriers, including cross interference, humidity, and carbon monoxide poisoning. Also, most reviewers noted the project should not suggest to the public to install sensors in residential garages. Reviewers recognized that the project needs to complete a more thorough cost analysis and clearly identify the size of the end-user market.

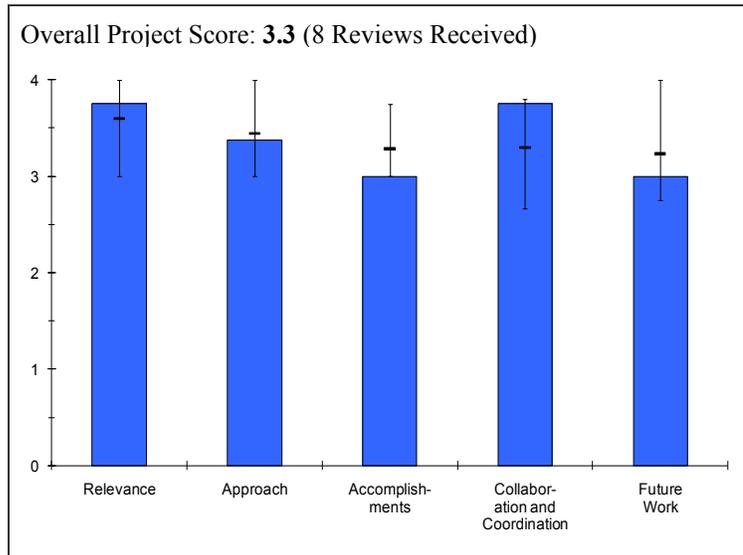
**Hydrogen Safety Sensors:** The reviewers appreciated the integrated technical approach to R&D and specifically the collaboration between the two national laboratories. Reviewers also supported the inclusion of an industry partner into the sensor testing process. Reviewers praised the project’s solid

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work towards a stable sensor response time, long-term testing, and evaluation of sensor materials and designs to improve long-term stability. Reviewers suggested the project better define the industry partner's role, competencies, and contributions to the project in an effort to improve collaboration. Some reviewers also expressed concern over the project's approach to commercialization in regard to cost goals, performance, and calibration requirements and ultimately the private sector's role in sensor commercialization.

**Project # SCS-01: National Codes and Standards Template***Carl Rivkin; National Renewable Energy Laboratory***Brief Summary of Project**

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

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **3.8** for its relevance to DOE objectives.

- Hydrogen and fuel cell technologies, as well as various forms of feed-stock fuels, are not yet an established industry with a legacy record. Instead, it is an emerging technology with many similar, as well as distinctly different properties and safe operating characteristics. Hydrogen and fuel cells are emerging technologies and it is important to have broad engineering and technical freedom to facilitate establishment of commercially viable products. As a custodial government department with many tasks for emerging technology initiatives, the Department of Energy (DOE) has the charge to help ensure that while development is not hindered by restrictive, non-scientifically set requirements, it is facilitated in a socially (including all aspects of life and environment) safe and aptly responsible introduction into the United States and global market.
- The National Codes and Standards Template is extremely useful for organizing hydrogen and fuel cell codes and standards and presenting an overview of the domestic coordination. The R&D that is conducted to establish sound technical requirements is critical to the development of reasonable hydrogen and fuel cell codes and standards that are acceptable to jurisdictions across the country.
- Data driven codes and standards for stationary and mobile applications, supporting the deployment of infrastructure, permitting, quality and safety, are critical to advancing this industry. The codes and standards template that has been developed is comprehensive and addresses all aspects of the technology.
- The project addresses a fundamental need in the path to adoption of hydrogen and fuel cell technologies. The gap analysis on stationary applications is especially relevant, given the current direction of the Fuel Cell Technologies Program.
- This program is a single leg of a three-legged stool. Without it, the stool falls.
- The work aligns with the Program goals to ensure sound engineering practices are developed and used for technical standards and building codes.
- There was an extremely large budget reduction from the 2008 actual, the plan for 2009 and the actual for 2009 which impacted all of the work. However, the Principle Investigator (PI) never mentioned this in the presentation or its impacts on milestones, standards development organizations or the work that was not completed on component testing.
- This project is a critical enabler for progress in hydrogen and fuel cell technologies.
- A comprehensive directory of standards and regulations is a great help to researchers, developers, users and authorities having jurisdiction over buildings as well as the general public.

**Question 2: Approach to performing the research and development**

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

- It has been almost ten years in the making, but when one reflects back eight or ten years to the many chaotic, separate orbits of the state of technology regarding safety, codes and standards and regulatory work and initiatives, one can appreciate the current state of work and how far we have come. The approaches have at times seemed long and tenuous, but the merits of step-by-step patience and persistent coordination are now starting to pay big dividends for this technology's move to full commercialization.
- DOE and national laboratory involvement in key technical committees is an excellent approach to drive toward the completion of codes and standards. Holding multiple stakeholder workshops to gather input from the field is a good approach to identifying gaps in the codes and standards that need to be addressed.
- The template is comprehensive, the project brings stakeholders together and several research projects have been initiated through the program to develop data driven codes or standards to address identified gaps.
- The project encompasses a very broad range of topics, but manages to do so in a concise and coherent manner. In this case, it is difficult to be “sharply focused”, but the project still manages to address all relevant aspects of codes and standards development for hydrogen and fuel cells.
- International cooperation should be emphasized.
- The work supported in 2010 appears more supportive than prior years. Since the budget was reduced, it appears all R&D component testing was stopped, but no data was provided and any impact on current consensus standards was not discussed.
- If there was a gap analysis and an evaluation on program impacts on safety, codes and standards activities, it was not reported and the recommendations on future directions were not clearly indicated.
- Having researchers involved in standardization committees is critical, and this is well implemented. International collaboration in research leading to standards and addressing gaps could be strengthened.
- A comprehensive listing of federal regulations for hydrogen and hydrogen usage was available at one time at [www.hydrogen.gov](http://www.hydrogen.gov). This listing has been removed, but should be provided to stakeholders for their information. This would be an improvement and would restore this resource.
- The comprehensive listing on [www.fuelcellstandards.com](http://www.fuelcellstandards.com) is more complete than the codes and standards template. Although the template has value, the [fuelcellstandards.com](http://www.fuelcellstandards.com) resource is actually significantly more complete. Harmonizing the template with [fuelcellstandards.com](http://www.fuelcellstandards.com) would be an improvement.

**Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.0** based on accomplishments.

- I have moved up my assessment recently in this area. Several pressing engineering, technical and servicing issues have not been given the attention and/or funding over the years. However, there has been very encouraging progress in this area in recent reporting cycles. I envision continued support in this area. Slides 14 and 15 are outstanding and should be utilized in specific stakeholder coordination meetings.
- The draft gap analysis that the National Renewable Energy Laboratory (NREL) produced for fuel cell technologies shows that there are no significant gaps for fuel cells, but some work is needed on component standards for high and low-pressure systems. This is an important accomplishment to focus future efforts where they are most needed. Analysis support for the National Fire Protection Association Hydrogen Technologies Code (NFPA 2) is also a key contribution.
- Advancements have been made in many areas: refueling, building codes, permitting, pressure vessel safety, fuel quality, sensor development and harmonization of codes and standards.
- The technical accomplishments for this year have made significant progress toward achieving the project goals, bearing in mind that codes and standards work is an ongoing process. As mentioned above, the inclusion of a gap analysis for stationary applications is a good example of the accomplishments of this project.
- The progress is steady. The national codes and standards template is a useful tool for tracking projects, gaps and collaborations.
- The PI has stated that the gap analysis was completed and identified where additional codes and standards work was needed, but did not state it in the presentation.

- The PI stated issues identified component standards, but did not provide any details or if they had made any progress.
- The PI stated modeling and analysis of data was conducted to support NFPA 2, but did not provide any details.
- Future work did not identify how the effort would deal with budget issues, curtailing of the component testing or any details on evaluation or analysis activities.
- Based on the work reported, the only real progress was attending technical committee meetings.
- Project name "National Codes and Standards Template" is misleading for the activities the Project actually covered. Obviously, two templates are available and hence the project goal is achieved. However, main project activities consist of associated needed research and active involvement in and facilitation of standards development organization (SDO) and code development organization (CDO) activities. It is difficult to assess, based on the information contained in the presentation, to what degree these have progressed against (non-communicated) performance indicators.
- Note that templates shown are different from those on the DOE website ([www.hydrogenandfuelcells.energy.gov/codes/pdfs/cs\\_templates.pdf](http://www.hydrogenandfuelcells.energy.gov/codes/pdfs/cs_templates.pdf)).
- The template is useful, but lacks specifics. Grouping the various aspects of hydrogen standards into the various genres of "Vehicles", "Fuel Delivery and Storage", "Fueling, Service, Parking Facility", "(Vehicle Systems and Refueling Facilities) Interface", "Hydrogen Generator", "Portable Fuel Cells", "Stationary Fuel Cells", and "(Stationary and Portable) Interface" is helpful, but this breakdown is not sufficient for use by stakeholders. More detail is necessary for stakeholders to appreciate the applicable standards and to access them for their work.
- There is a significantly different technology that has been omitted. "Micro" fuel cells are portable and operate at low voltages and currents. This type of fuel cell needs to be separately addressed, since such systems are expected to be routinely used in public spaces, as well as on board planes, trains and automobiles. The regulations for such usages are important since flammable, corrosive, explosive and water reactive fuels for such devices are typically not allowed in public places and on board public transportation. This is a sensitive issue that needs to be addressed carefully.
- Conducting gap analyses on a periodic basis is very valuable. Including industry in these analyses is vital to Project success.
- The Hydrogen Industry Panels on Codes (HIPOC) is limited to the NFPA and International Code Council (ICC), but many more interrelated standards are involved in the codes and standards issue. Either expanding HIPOC to include all interrelated standards or eliminating it in favor of using other aspects of the program would be an efficiency improvement.

#### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **3.8** for technology transfer and collaboration.

- The U.S. national codes and standards landscape is now at a point of relative predictability. Consistent, patient and persistent efforts have breached perceived silos of code and standards makers.
- The Project has outstanding collaboration with industry, national labs, SDOs and CDOs. Extensive collaboration and coordination efforts with all the key players are highly commendable. These collaborations ensure that multiple perspectives will be articulated, with the end goal of finding common ground and achieving national consensus on hydrogen codes and standards.
- Collaboration is excellent between DOE and all applicable SDOs, industry, the national labs, other federal agencies and local authorities and international partners.
- The project has significant collaboration from all relevant stakeholders.
- The coordination is good, while the collaboration is only as good as the desire of the partner.
- The coordination plan was well conceived and executed. However, it's difficult to keep everyone focused on a single outcome if there are insufficient funds to support the needed work.
- If budget issues continue, the scope and goals of this effort should change to reflect the reduced funding and ability to accomplish the template objectives.
- I got a positive impression that effective collaboration is in place with the listed collaborating institutions.
- As stated earlier, HIPOC is limited in scope and could either be expanded to include all interrelated standards or eliminated in favor of using other aspects of the program to coordinate between the various standards for hydrogen. This would be an efficiency improvement.

- The collaboration and coordination with national and international SDOs, as well as collaboration with national and international regulatory bodies, is impressive.

### **Question 5: Approach to and relevance of proposed future research**

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

- Future outlooks based on the PI's outlook summaries being right on track. Ensuring close scrutiny in the integrity of task work and deliverables, as well as analysis and data disbursement and feedback, is critical at this point.
- Future work includes a good combination of component testing, data analysis, collaboration/coordination with SDOs and CDOs and outreach activities to assist code officials and project developers using the codes and standards in the real world. Evaluation of indoor releases of hydrogen from forklift refueling operations is a timely undertaking.
- The approach to and relevance of proposed future research are both good. The plans build on past progress.
- Inclusions of forklifts in the future work as well as ongoing component testing and fuel quality work are all good indications that the future of the project has been well thought-out. It would have been nice, however, to see some more specific timelines for some of the work.
- The identification of low pressure system requirements, plastics and composites, and the need for standards development in this realm will be key in both vehicle and stationary applications. More emphasis should be given on international standardization.
- As stated earlier, the scope of work should reflect the budget to be obligated to the project. The current plan is too broad, based on the expected budget, and cannot support any R&D activities on components, unless industry is willing to provide the funding.
- The presentation discussed future work that was not precisely involved in the codes and standards template itself, but rather indicated component work and release evaluations and hydrogen quality efforts, as well as direct support of SDOs. This listing is not precisely the implementation of the template.
- It would be helpful to get more information on how the template will continue to be updated and how industry input will be obtained.

### **Strengths and weaknesses**

#### Strengths

- This activity has been at a relatively high pace for the last six+ years. The amount and importance of stakeholders, though significantly reduced over the years, is still significant and should be sustainable through "establishment" of needed rules, regulations, standards, codes and recommended practices.
- The key project strength is the extensive collaborations with industry, national labs, SDOs and CDOs to create nationally accepted codes and standards. The integrative approach of blending R&D activities with committee work on codes and standards makes good sense. Holding workshops in areas where hydrogen and fuel cell projects are happening is also an important contribution.
- This project has been active for several years and has become very comprehensive in scope, which makes it a natural go-to entity to facilitate smaller, more focused, individual research topics. For example, research to support the development of SAE 2579's durability and expected service life test protocol for onboard hydrogen storage cylinders was funded through this project. Similarly focused projects to address gaps (such as sensor sensitivity, for example) can be initiated rapidly through similar methods, since relationships with stakeholders are well established.
- The coordination and collaboration efforts are key and a strength of the program.
- Good history and overall accomplishments in getting ICC and NFPA codes developed and adopted.
- A strength was the focus on the central point on regulations, codes and standards.
- The goal of a comprehensive listing of hydrogen and fuel cell standards is laudable and valuable. The significant level of effort involved is appreciated by all stakeholders. The project and the program are showing excellent effort and progress towards these goals.
- Expanding the template to include the detail necessary for it to be used by the experts, such as standards titles and scope, would be an improvement.

Weaknesses

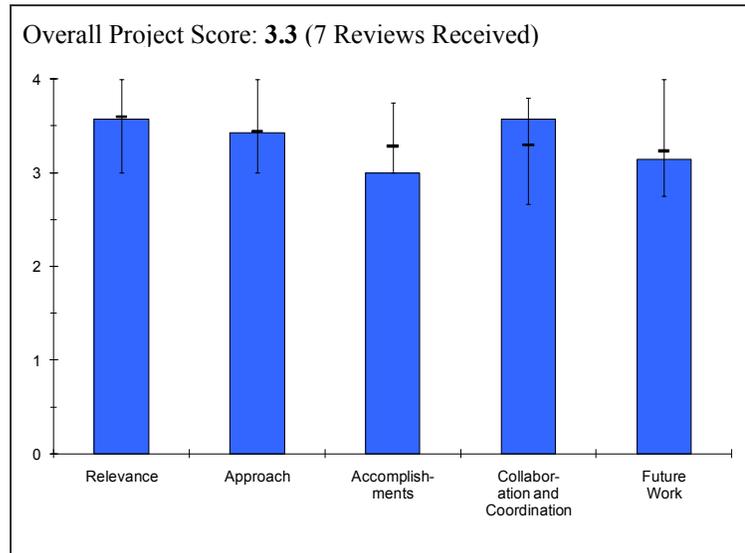
- Funding and ensuring that there is a sustainable flow of historical knowledge is a weakness.
- It seems transfer and key stakeholders pass "point-of-contact" batons.
- R&D results may lag behind codes and standards revision cycles.
- Funding may be insufficient to do much more than maintain the template. Is there a list of unfunded projects to support research to address gaps in codes and standards?
- The Project should refocus activities based on budget realities.
- The dissemination in the international arena about scope of activities and accomplishments could possibly be improved.
- The format of the template is not detailed enough to be really useful to knowledgeable stakeholders. The comprehensive listing at [www.fuelcellstandards.com](http://www.fuelcellstandards.com) is more useable. It would be helpful to have a more comprehensive template, or just reference [www.fuelcells.com](http://www.fuelcells.com) or portions thereof.
- The original concept of assigning responsibility to a specific organization for a specific topic has been somewhat lost due to overlap of standards, subsidiary standards and the competitive nature of standards development.
- The American National Standards Institute (ANSI) system of assigning responsibility to a particular organization for a particular topic is in place, and DOE does not need or want to replicate this function. Any idea that DOE is regulating standards work needs to be modified to be sure that ANSI is not superseded.

Specific recommendations and additions or deletions to the work scope

- It may be beneficial to start tracking "joint U.S. Technical Advisory Group efforts" with regard to specific task items within the various International Organization of Standardization (ISO) and International Electrotechnical Commission (IEC) activities. A better understanding of international protocols within the ISO, IEC and Global Technical Regulation (GTR) processes should reap significant dividends.
- The Project should continue along the same path.
- A single comprehensive database for national and possibly international codes and standards as applied to hydrogen and hydrogen systems should be implemented.
- Keep work focused on application of the model codes through training, workshops, and outreach activities. Perform more analysis and modeling activities since they are less expensive and get more technical papers published on these efforts.
- Include balance-of-plant related impurities in the fuel quality standard.
- The permitting of hydrogen refueling stations.
- Expanding the template to include the detail necessary for it to be used by the experts, such as standards titles and scope, would be an improvement.

**Project # SCS-02: Component Standard Research and Development***Robert Burgess; National Renewable Energy Laboratory***Brief Summary of Project**

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

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **3.6** for its relevance to DOE objectives.

- The four projects discussed in the presentation do address areas in codes and standards development where data or adequate hardware (sensors) is lacking.
- This project provides vital technical work which helps to overcome gaps in the current codes and standards for hydrogen and fuel cell technologies. As such, the results are essential to the DOE Fuel Cell Technologies Program.
- The project is aligned with Program needs.
- Hydrogen system component testing performed in this project is critical to the development of performance standards for SAE, CSA and ASME. The test program is generally aligned with industry.
- The project appropriately addresses a number of subjects requiring standardization.
- Component standards are essential to safe and cost effective development of hydrogen and fuel cell technologies.

**Question 2: Approach to performing the research and development**

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

- These projects are focused on specific technical barriers that need to be addressed.
- The project is directly linked with the national codes and standards template development and addressed gaps which have been identified through that effort. The approach taken in each of the four gap analyses that were discussed is thorough, comprehensive and unbiased.
- The overall approach needs to be clarified and better articulated.
- The work is subcontracted to appropriate outside experts.
- A direct line of communication between the standards development organization (SDO) and National Renewable Energy Laboratory (NREL) technical staff is helpful to industry. Regular updates to those SDOs allow corrective feedback from industry. I would like to see targeted briefings more frequently during the project lifetime summarizing work-to-date and emphasizing results relevant to that SDO.

- The topics addressed respond to priorities expressed by stakeholders. They seem to be appropriately covered either by in-house activity or by subcontracting.
- The technical work appears to be rigorous and well done and based on previous research and experience. The laboratory work is state-of-the-art.
- The primary effort appears to be on sensors.

### **Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.0** based on accomplishments.

- The progress made is good. The rate of progress is a little slow.
- Most of the accomplishments discussed were for the work on sensor testing. This work has made significant advances in the last year and specifically on the sensor analysis.
- There was little discussion on the progress of the pressure relief device (PRD) hydrogen service suitability. Though it is understood this is ongoing work, more detail would have been appreciated.
- There was too much technical data in the accomplishments section. Bullets are needed regarding specific components under consideration. The presentation makes it hard to discern exactly what has been accomplished in the past year.
- Various subcontractors are providing results.
- Safety sensor testing is showing progress.
- Fueling protocol testing will need to be expanded to include industrial trucks. This is a need for the industry.
- In the absence of any communicated performance indicators or milestones it is difficult to quantitatively assess the degree of progress. From a qualitative point of view, progress certainly seems positive.
- All progress appears to be timely and continues to support industry needs.
- The use of round-robin testing for sensors appears to be an excellent approach. This is a project strength.

### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **3.6** for technology transfer and collaboration.

- The collaborations are well coordinated, and all the right entities are involved (SAE, CSA, National Institute of Standards and Technology (NIST), etc.).
- This project has a long list of collaborators. It was especially nice to see interaction with the international community. The round-robin testing with Joint Research Center (JRC) is a good illustration of how international collaboration can be used to further a technology.
- It is hard to tell from the presentation how well partners are coordinated and if they are full participants or simply subcontractors.
- The project has good working relationships with subcontractors and some of the many sensor manufacturers.
- Industry and government are both represented in working groups within individual SDOs.
- The project allows for informal updates and real-time information exchange.
- There was collaboration with relevant partners beyond the United States.
- Based on the presentation, the sources of research topics are all good, but could be expanded to include more comprehensive polling of industry stakeholders in order to include more industry and standards developers as well as all national labs and the research community.
- The collaboration on round-robin testing is a strength.

### **Question 5: Approach to and relevance of proposed future research**

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

- The plan to collaborate with National Aeronautics and Space Administration (NASA) on tank level stress rupture testing is a good one. Some research to verify a leak before burst failure mode for composite overwrap pressure vessels would improve safety by preventing catastrophic rupture of Type IV cylinders.

- The future work is well presented, and takes into account further progress which must be made on the PRD task. It would have been nice to see some timelines suggested for the work.
- The inclusion of computational fluid dynamics (CFD) modeling for sensor placement is also a very good idea as the project moves forward.
- This was an appropriate continuation of existing subcontracts and collaborations.
- I would like to see permeation testing of plastic materials for use in low-pressure hydrogen applications.
- Completing the sensor work is essential. The next sets of work topics will most likely change as industry input is received. The Program needs to be flexible and funded for emerging issues. One good example is forklift fuel tanks where the issue developed quickly and DOE was quick to implement vital research. This component program needs to be funded at a level that allows such flexibility.

### **Strengths and weaknesses**

#### Strengths

- The project provides much needed technical information to address gaps in hydrogen and fuel cell codes and standards. The thoroughness of the work, as well as the collaboration with industry and international laboratories, are all project strengths.
- The specific component work is crucial to overall DOE objectives.
- There are appropriate subcontracted efforts. The collaboration with international experts should improve project output.
- There is close cooperation between industry and performing labs.
- The project follows stakeholder prioritization.
- The international collaboration is a strength.
- The technical excellence on display was a noticeable strength.
- The round-robin testing was beneficial.
- The collaboration with national and international stakeholders and labs is a project strength.

#### Weaknesses

- Is funding sufficient to continue sensor and composite overwrap pressure vessel testing?
- A comprehensive list of components under consideration would be helpful in identifying gaps in hydrogen-specific component needs.
- It seems like a lot of work is required on sensors to generate an "abstain" vote at the international level. One would like to see more active presentation of data to support international standards.
- It is always difficult to ferret out the needs of industry. Additional outreach to industry stakeholders will almost always bear fruit. Additional outreach is encouraged.

### **Specific recommendations and additions or deletions to the work scope**

- Add component testing in a low-pressure hydrogen environment.
- Add permeation testing of plastics for low-pressure hydrogen applications and industrial truck refueling protocols.
- There needs to be microstructural investigations on failed or inadequately responding sensors to clarify limiting factors for detector performance and durability (preferentially to be done in collaboration with external partners).
- More outreach to stakeholders and industry partners is encouraged.

## Project # SCS-03: Codes and Standards Training and Outreach and Education for Emerging Fuel Cell Technologies

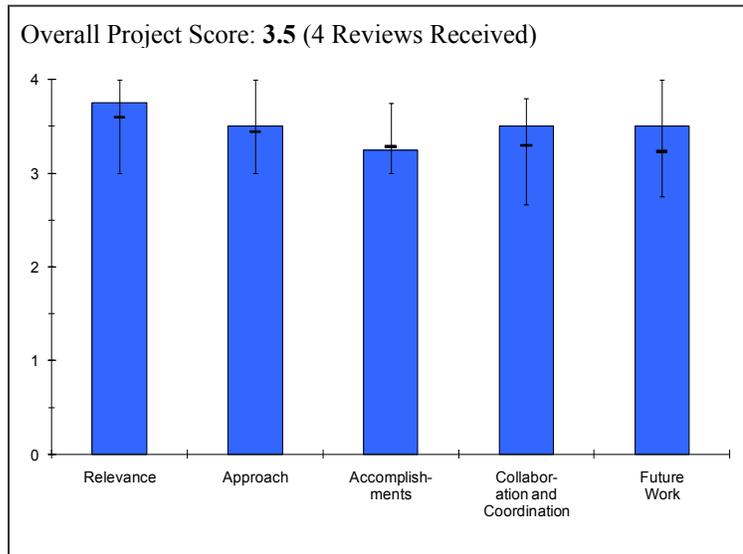
Carl Rivkin; National Renewable Energy Laboratory

### Brief Summary of Project

The objectives of this project are to: 1) advance renewable energy safety, code development and market transformation issues by distribution of information; 2) facilitate the safe deployment of renewable energy technologies; and 3) overcome barriers to emerging fuel cell technologies, and specifically fuel cell-powered forklift vehicles and stationary fuel cells used for back-up power.

### Question 1: Relevance to overall DOE objectives

This project earned a score of **3.8** for its relevance to DOE objectives.



- This is a keeper. The PI has done an outstanding job with this program as he came onboard during the first "hard lesson" session then refined it to the value-added product that it is today!
- Providing information on safe deployment to code officials and project developers is critical to furthering the implementation of hydrogen and fuel cell technologies. Offering practical guidance on how to apply hydrogen and fuel cell codes and standards will speed up the time required for project development and final reviews.
- This work is critical to the efforts in implementing hydrogen and fuel cell technologies (vehicles and fueling stations, stationary applications, etc.).
- DOE coordinating and leading this project is key. This emphasizes the move to commercialization and demonstrates a real leadership and progressive role of the government.
- The project directly correlates to addressing DOE objectives. The focus on forklifts and backup power is relevant and needed at this stage of commercialization.

### Question 2: Approach to performing the research and development

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

- It took several iterations to hammer out a professional and palatable (to the target audience) product, but the final product is truly outstanding!
- Holding workshops in locations where there are actual hydrogen and fuel cell applications makes good sense. Such workshops will make code officials and project developers aware of the codes and standards and how to apply them, facilitate safe technology deployments and help define future R&D needs.
- There was good coverage of many types of hydrogen projects (stationary, forklift and passenger vehicle fueling). It is important to demonstrate the similarities in the permitting processes of these various technologies.
- In-person interactions are proven time and again to be the best way to work with authorities having jurisdiction (AHJs). It's good to see such a focus on those interactions and to see positive results as indicated by the workshop participants. The web-based part is also important since the folks in the workshop and others will have a way to access the same information if they are unable to attend the workshops.

### Question 3: Technical accomplishments and progress toward project and DOE goals

This project was rated **3.3** based on accomplishments.

- Continued focus on feedback and perhaps targeted "revisits" are the correct and chosen approach. Well done!
- Several workshops were held and others are planned. The project works directly with the local fire departments and the California Fuel Cell Partnership (CaFCP). The web-based information compendium was developed and maintained and the code official training course was successfully deployed. A site visit and case study report on stationary fuel cells for backup power was completed.
- Keep the progress moving. This project is needed on an ongoing basis with the advancement of technology implementation (i.e. as new technologies are developed and the current technologies become more widespread).
- Accomplishments and progress are really hard to measure, but from the information given it appears that the project has been quite successful. I am troubled by the use of the term "electric vehicles", which seems to only apply to battery vehicles. Electric vehicles include fuel cell electric vehicles. Every time we use this term incorrectly (as so many people do), we're teaching the wrong perspective to our target audience. I suggest changing the language to use electric vehicles when actually referring to vehicles powered by fuel cells and/or batteries; and using battery vehicles or fuel cell vehicles when only referring to those individual technologies.

### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **3.5** for technology transfer and collaboration.

- The initial efforts ran through a gambit of stakeholder groups and individuals. The core team seems to be doing a splendid job.
- Collaboration with local and regional fire departments and the CaFCP is good.
- It is difficult to address the challenge of reaching the exact right people. It is critical to have the input of the collaborators to correctly target the geographical locations (cities) and individuals in those areas.
- It's quite clear that the coordination is far reaching including all the major organizations that are involved in safety, codes and standards development. The only improvement that I can see is incorporating speakers from other organizations in the agenda. The Jefferson Parish workshop agenda, for example, only NREL speakers. I realize there are cost restrictions and the current approach seems to work well, but that would be one place to improve collaboration especially as it's perceived by the audience.

### **Question 5: Approach to and relevance of proposed future research**

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

- The project plan appears to be on-track and still targeted to the correct audience in order to bring the most value-added outreach and education where needed. Again, well organized and well done!
- A site visit and report on indoor hydrogen forklift refueling is planned. NREL plans to continue the workshops and safety reviews and collaborate with local and regional organizations. The workshops will be used to help define potential hydrogen and fuel cell codes and standards issues and future R&D needs.
- It can be beneficial to the permitting officials to demonstrate similar features in the permitting process between hydrogen and other alternative fuels, however, the other alternative fuels tend to be more similar to conventional fuels permitting (compressed natural gas, ethanol, natural gas, etc.), where hydrogen is/can be quite different. For this reason, the primary focus should remain on hydrogen.
- Approach and relevance are very good. The current work should continue.

### **Strengths and weaknesses**

#### Strengths

- Brings "real-time" expertise and information to "real-time" installations and projects. The work supports where it is actually needed.
- The key project strength is getting out into appropriate locations in the field to provide information directly to code officials and project developers on hydrogen and fuel cell technologies. It helps these individuals to then understand the context so they can more efficiently apply the codes and standards in their own projects.
- Good early outreach. Good early outreach is much needed both from an educational perspective and in a practical sense.

- The project gives permitting officials good resources of information, which will ultimately instill confidence in the technology (some evidence of this is in the comments slide).
- A strength of the project is tracking the changing codes and standards and updating AHJs as needed through both the workshops and the online resources. This keeps progress advancing.
- This project represents the main ways that we know work well to develop codes and standards and aid their implementation; workshops and online materials. This bread and butter approach works and simply needs to be executed more often to more people.

#### Weaknesses

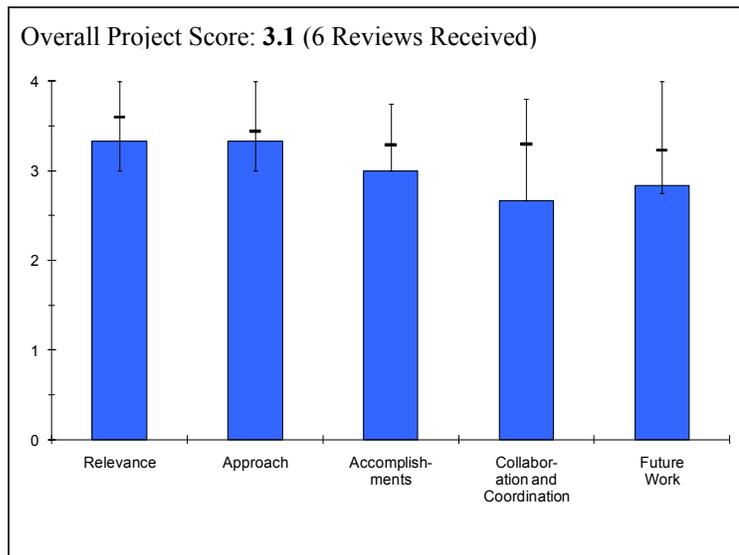
- An additional team would be beneficial.
- Code officials wanted to know how the information might affect their daily lives. Thus, more attention should be focused on this issue during the workshops.
- Moving away from the hydrogen focus and adding other alternative fuels potentially expands the scope to a degree that makes it very difficult to organize and manage.
- There are very few weaknesses. There could be some increased collaboration and volume of outreach to more people and the change in terminology with "electric vehicles".

#### **Specific recommendations and additions or deletions to the work scope**

- Add more funding to allow for return/follow-up sessions.
- Perhaps an occasional outreach to a regional training center that caters to a number of volunteer stations and shops.
- NREL needs to develop materials to publicize the availability of the web-based code official training and the local workshops.
- My preference is for the focus to remain on hydrogen fuel cell vehicles, fueling stations and stationary installations.
- This bread and butter approach works and simply needs to be executed more often to more people.

**Project # SCS-04: Hydrogen Safety Sensors***Eric Brosha; Los Alamos National Laboratory***Brief Summary of Project**

The objectives of this project are to: 1) develop a low-cost, low-power, durable and reliable hydrogen safety sensor for vehicle and infrastructure applications; 2) demonstrate working technology through application of commercial and reproducible manufacturing methods and rigorous life testing results guided by materials selection, sensor design and electrochemical research and development investigation; 3) recommend sensor technologies and instrumentation approaches for engineering design; and 4) disseminate packaged prototypes to DOE laboratories and commercial parties interested in testing and fielding advanced commercial prototypes while transferring technology to industry.

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **3.3** for its relevance to DOE objectives.

- The development of accurate, low-cost and robust hydrogen gas sensors is important for both stationary and mobile applications.
- There is a critical need for a low-cost, low-power, durable and reliable hydrogen sensor for vehicles and stationary applications to help foster the transition to the hydrogen economy. This project directly addresses several key barriers identified in the DOE Multi-Year Program Plan by developing robust solid-state electrochemical hydrogen sensors.
- This is an issue that may be better served by the efforts of private industry. This project should not be viewed as a critical path in support of the hydrogen program goals.
- Development of sensors that can meet DOE targets is an important part of the Fuel Cell Technologies Program. The project, if successful, will provide robust and low-cost solid-state sensors for vehicular applications. It is not clear how much value the success of developing and commercializing such sensors will have for stationary applications, such as fueling stations, above commercially available safety sensor technology.
- Cost-effective hydrogen sensor technology is an enabler for more robust hydrogen safety practices.
- Sensors appear to be a necessary component of vehicle and stationary and portable fuel cell systems. Some developers are unwilling to include standards due to concerns regarding reliability, false alarms, stability and cost. Having reliable and cost-effective sensors is essential.

**Question 2: Approach to performing the research and development**

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

- The approach taken is sound.
- The project objectives are to develop and demonstrate the sensor and then disseminate it to other national laboratories for testing while simultaneously transferring the technology to industry for commercialization. The approach utilizes two national laboratories with unique and complementary expertise, as well as an industry partner with the ability to engineer commercial prototypes. That appears to be a smart and integrated approach.
- Approach is fine but may be better with more involvement of private industry.

- Integration of commercialization parameters into the RD&D is an approach that should be encouraged, particularly for projects that should lead to widespread deployment in one or more industries. The partnership between Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL) is a good example of combining complementary expertise and experience. The presentation could have shown better how the project is addressing not only the identified technical barriers, but also each of the DOE hydrogen sensor targets.
- The project is claiming to be 60% complete, yet there is no manufacturability, packaging or cost information presented. Some assessment of these aspects should have occurred by this point. The durability technical performance target of five years between calibrations is suitable for vehicular applications but is overly stringent for fixed installations.
- Using a DOE workshop to set the goals could be a good method provided that industry was involved.

### **Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.0** based on accomplishments.

- The accomplishments to date are encouraging.
- One question comes to mind. One example given has a high operating temperature. If the operating temperature is above the autothermal ignition point of the gas being sampled, does the sensor become the ignition source during a catastrophic failure of the gas containment (e.g. hose break)? Is this being considered in the development process?
- In Fiscal Year (FY) 2009 the team completed an early commercial prototype sensor platform which significantly exceeded their 500-hour testing goal and obtained industry input on commercialization potential. Milestones were accomplished for sensor prototype development, achievement of a stable sensor response over time, long-term testing, evaluation of sensor materials and designs to improve long-term stability and characterization of alternative modalities.
- Accomplishments have been impressive but commercialization efforts are the realm of private industry.
- The project has demonstrated progress in meeting objectives specified in its project plan. Although funding issues have impeded progress, it is not clear how 60% of project completion aligns with the key project objective of developing a prototype sensor that can be transferred to industry for commercialization.
- The progress towards technical targets is not presented clearly and there is no cost information available. It is difficult to interpret some of the results, since they are presented as sensor signal output rather than translated into hydrogen concentration readings (and errors). The project claims that mixed potential sensors have exceptional stability but the test results presented do not seem to exhibit even acceptable stability.
- The presentation showed that problems in design have been overcome with good engineering. Design improvements continue.

### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **2.7** for technology transfer and collaboration.

- The collaboration partners seem to be sufficient. It would have been nice to see collaboration with a potential end user to validate that the device will meet the application needs.
- LANL is working with LLNL and private industry on this effort and effectively utilizing the technical strengths of each collaborator.
- This effort should be passed off to private industry for further development and cost reduction for commercialization. This project has been a two horse show.
- The partnership between LANL and LLNL appears to be effective and has led to good science and research and development. The role, competencies and contributions of the industry partner, ElectroScience Laboratory (ESL), to the project are not clear although it appears that ESL has fabricated at least one prototype. Inclusion of an automotive original equipment manufacturer (OEM) as a partner would be helpful, especially as the sensor is intended for vehicular applications.
- While the partners seem to have appropriate experience with sensor technology development and are cooperating, the project needs more manufacturing, packaging and cost input.

- It appears that LANL and LLNL is actually developing sensors that are going to be used as commercial products. This is in contrast to other DOE programs where competitions and private company offerings are solicited, rather than using the national laboratory as the developer of the device. It is not clear which approach is better, but including additional experienced private companies cannot be detrimental to the program. The presentation only mentioned one private company partner, and they are not a sensor manufacturer. Additional private company partners, including sensor manufacturers, might provide additional benefits.

### **Question 5: Approach to and relevance of proposed future research**

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

- The future work seems appropriate for developing a prototype. Some thought needs to be spent on goals for commercialization. Additionally, unit cost goals were not mentioned.
- The team will continue to evaluate materials, designs and fabrication processes, fabricate prototypes with non-platinum electrodes, investigate mass production of sensors with long-term stability and assess sensitivity of the sensors to interfering gases and operating temperature variations.
- National labs should not be concerned with commercialization.
- The parameters of the go/no-go decision should be enumerated as should the status of the project in meeting performance measures that would contribute toward a "go" decision.
- Most, if not all, future work identified focuses on technical aspects. More emphasis needs to be placed on manufacturing, packaging and cost.
- New iterative designs are planned. Since LANL and LLNL are essentially inventing this technology, new configurations are planned. It is not clear where these developmental designs will lead.

### **Strengths and weaknesses**

#### Strengths

- The strengths appear to be the technology and approach.
- The project strength is the previous experience and capabilities of the project team members.
- The project has accomplished the majority of stated goals.
- This is good science that furthers understanding of materials issues involved in solid-state sensor development for hydrogen applications. Incorporation of low-cost, mass manufacturability into project objectives and design is a major strength of the project.
- The innovative design efforts were strong.
- The lab collaboration was strong.

#### Weaknesses

- The weaknesses appear to be the lack of thought on commercialization, cost goals, performance requirements and calibration requirements. A set of preliminary functional requirements (goals) might be helpful in guiding development.
- There are no weaknesses identified.
- It needs more explicit alignment with targeted end-use since the requirements for vehicular and stationary applications could be very different.
- The progress toward technical targets is not clear and there is no information regarding cost target progress.
- There does not appear to be any active sensor manufacturer involvement.

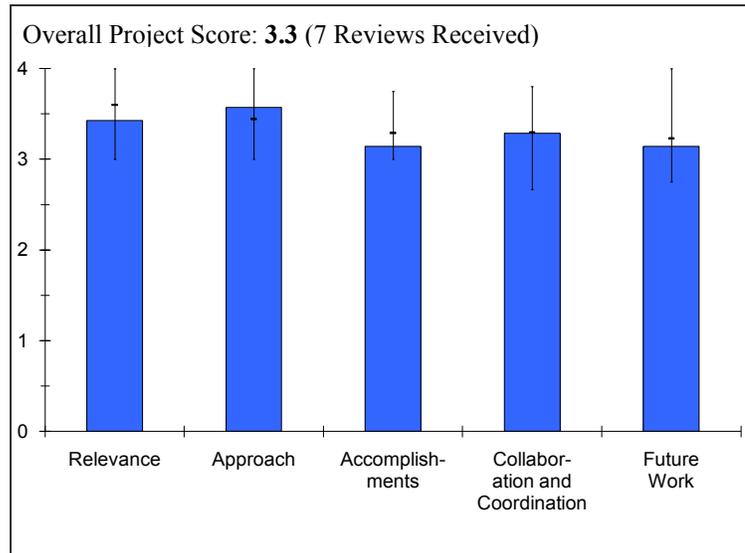
### **Specific recommendations and additions or deletions to the work scope**

- Could the operating range be expanded on the low-end to -50°C, which is the worst case in the populated areas on North America and Europe, and on the high-end to 85°C, which is the upper level limit for non-motor compartment (SAE J1211)?
- Is environmental testing to the U.S. Military Standard (MIL-STD-810) or the American Society for Testing and Materials (ASTM) equivalents envisioned?

- Is a product listing to the Underwriter Laboratories (UL) Standard for Safety Gas and Vapor Detectors and Sensors (UL 2075) under consideration?
- They should continue with planned scope.
- Details of the go/no-go decision parameters should be addressed and requirements for the most feasible applications should be considered in project metrics.
- More collaboration with sensor manufacturers is recommended to add value to the program.

**Project # SCS-05: Materials and Components Compatibility***Daniel Dedrick; Sandia National Laboratories***Brief Summary of Project**

The overall objective of this project is to enable market transformation through development and application of standards for hydrogen components. Objectives are to: 1) create materials reference guide (“Technical Reference”) and identify material property data gaps; 2) execute materials testing following existing standards to meet immediate needs for data in technology deployment, with an emphasis on steel hydrogen storage tanks in FY 09-10; 3) provide data that demonstrates how to improve efficiency and reliability of materials test methods in standards, with an emphasis on fatigue crack growth test methods in FY 09-10; and 4) participate directly in standards development, including component/system design qualification standards such as ASME Article KD-10, CSA Hydrogen Powered Industrial Truck (HPIT)<sup>1</sup>, SAE J2579 and materials testing standards such as SAE/CSA.

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **3.4** for its relevance to DOE objectives.

- The work carried out in this project provides valuable data which is useful to safety, codes and standards committees as they develop new codes for hydrogen and fuel cell technologies.
- The test methodology is keystone to the development of safety, codes and standards.
- The data collection and evaluation provide an important service to researchers and developers.
- The work conducted by Sandia National Laboratories (SNL) on metallic tank failures is important for manufacturers of current high pressure tanks, but should only be a reference to establish a baseline for advanced material systems and designs.
- Since the current focus of fuel cell powered forklift vehicles seems to be a high priority, using this system as the initial material system seems reasonable. However, based on advanced modeling and analysis techniques, accelerated methods of testing need to be established to better use the single SNL facility.
- Work ties in with development of both United States and international standards. The successful completion of this project will provide a materials qualification guide for bringing new materials into acceptable use.
- The topic treated is relevant for application of hydrogen technologies, but seems to be very specific in terms of testing method, component type and material.
- The work contributes to advancing the development of hydrogen use.

**Question 2: Approach to performing the research and development**

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

- The approach is focused on certain pressing issues (like the steel hydrogen storage tanks) and is carried out at state-of-the-art testing facilities.
- Direct participation with the SDOs fills not only immediate needs in standards development, but sets the groundwork for future development as well.
- It is a well-integrated approach to identifying needs, filling data gaps and communicating results to stakeholders.

- Interaction with the ASME has led to the development of recommendations using data-supported improvements of the test method, which is an important, cost-effective and technical contribution to the field.
- The current work is focused on dealing with the barriers of existing technology and material systems. However, these are not expected to be the technology needed for large market penetration.
- More work needs to be focused on the use of accelerated methods of testing both to reduce the cost, duration and complexity of this testing. New consensus standards for the ASTM or NIST using these accelerated test methods must be developed.
- Just as we have moved beyond dye penetration methods for crack propagation, we need to focus on other methods to examine and measure changes in material properties.
- The relationships with stakeholders are critical.
- Whereas the overall approach and quality of the work seems appropriate, there may be a deficiency in attempting to explain the observed fatigue crack growth behavior from the point-of-view of underlying materials science. No explanation is given for the non-traditional growth curve. Such understanding is needed for applying the measured crack growth law with some degree of confidence to predict in-service life. Also, extrapolation of crack growth measurements from uniaxial tests on compact tension (CT) specimens to multi-axially stressed components (because of internal pressurization and bending moments associated with presence of defects of considerable size), is not sufficiently clear (at least not from the information provided during the presentation and contained in the slides). The effect of test gas purity on results was not clear either.
- The test conditions must better simulate the real world for the result to be applicable.

### **Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.1** based on accomplishments.

- There have been significant accomplishments in this year of the project. The method that the presenter used to put the actual accomplishments into perspective, and show specifically how the experimental results have affected code -development is welcome.
- The specific work analyzing forklift applications has had good progress in a relatively short timeframe. This work will be essential as the market moves toward these types of early adoption.
- It has been good and steady progress.
- The proposed changes to the test method are well documented although the observed behavior is not completely understood.
- Additions to the materials database continue.
- The project is providing information in direct support of near-term market transformation applications.
- Although there has been an increase in data provided by SNL, the project still does not appear to be making much progress even with only a single lab focused on the work.
- Even though some of the OEM tank manufacturers have proprietary data and expertise on their designs, SNL must apply methods of material characterization to advanced systems and include them in the technical reference. If the budget cannot support extensive testing on these systems, more modeling of failure modes and safety margins for design consideration should be included until additional funding can be made available.
- Solving the test method issues will allow faster and less expensive evaluations of materials.
- In the absence of information on milestones related to the crack growth experiments, it is difficult to quantitatively assess progress. Procurement of tanks and introduction of artificial defects seems to have taken rather long.
- Good progress has been made.

### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **3.3** for technology transfer and collaboration.

- Direct interaction with the codes and standards committees, tank manufacturers, forklift integrators, as well as other DOE working groups ensures the relevant stakeholders receive data and have input into the direction of the project.
- Some international collaboration would be a good addition to the project, especially since the forklift market is growing everywhere.

- It was a good cross-section of SDO/industry/international partners.
- It was good to see collaboration with all important experts, both nationally and internationally.
- There was good collaboration. However, I would suggest involving NASA and their material scientists since the work has applications with their interests and they have developed additional database information on systems such as the National Association of Safety Professionals.
- Close participation between researchers in SDO working groups was very helpful.
- No evidence was given of interaction or collaboration with other materials testing institutes or establishments specializing in measuring fatigue crack growth and elucidating underlying physical mechanisms.
- There has been some collaboration, but more effort to seek out relevant partners should be made including forklift manufacturers and users to improve testing method and protocol.

### **Question 5: Approach to and relevance of proposed future research**

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

- The proposed work is good in that it addresses all goals which were established at the beginning of the work. It may be outside the mandate of this project, but given the recent decision of China to ban Type IV vessels, some mention of testing these systems would have been welcome.
- It was a very good proposal for future work, especially collaboration with CSA regarding fuel system component material testing protocol.
- The incorporation of materials characterization data into national and international standards is important for the development of performance-based codes, standards and regulations.
- Per the comments above, more work should be focused on accelerated methods of testing and analysis to reduce the amount of time for system evaluations.
- The planned work dovetails into emerging standards.
- Clear planning seems to exist.

### **Strengths and weaknesses**

#### Strengths

- They are working to develop quick and cost-effective testing methodology. The development of engineering-based and performance-based testing methodology is a strength.
- SNL has significant expertise in the required subject areas.
- They have proven to be an excellent technical team with outstanding laboratory capabilities.
- The researchers have the facilities and expertise to perform.
- This project supplies a direct feed into standardization.
- Although it was not presented, I found the relevance and usefulness of the materials reference guide very valuable.
- A strength would be their direct involvement in the standard setting process for maximum influence.

#### Weaknesses

- There is slow progress being made on material systems evaluation.
- It is limited by existing methods and new method development takes time and effort and can detract from the task at hand.
- Application of fatigue crack growth law to predict in-service behavior is based on the hypothesis of “leak before break”. It is unclear how the foreseen testing program will allow one to determine whether and under which conditions this is the case.
- There is not a lot of industry collaboration shown.

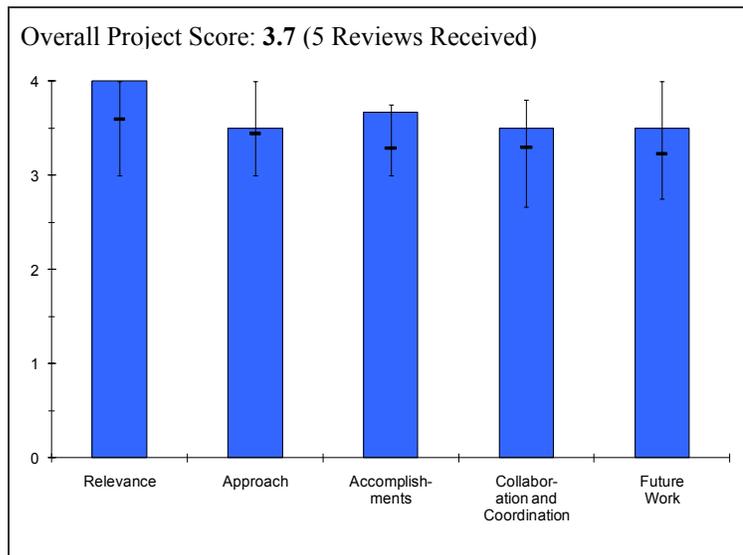
### **Specific recommendations and additions or deletions to the work scope**

- Two separate projects were presented consecutively but were supposed to be reviewed as a single project (this review is for the material compatibility work only). These projects were different enough and each funded at high-enough levels that they should have been reviewed separately.

- They need to spend more time on advanced material testing methods for accelerated studies and more development of models for predicting failure modes and their probabilities.
- It is more meaningful to have components develop leaks prior to failure by rupture from a safety standpoint.

**Project # SCS-06: Hydrogen Safety Knowledge Tools***Linda Fassbender; Pacific Northwest National Laboratory***Brief Summary of Project**

The objectives of this project are to: 1) capture the vast knowledge base of hydrogen experience and make it publicly available in a living document to provide guidance for ensuring safety in DOE hydrogen projects, while serving as a model for all hydrogen projects and applications; and 2) collect information and share lessons learned from hydrogen incidents and near-misses with a goal of preventing similar incidents from occurring in the future. Goals for this year are to: 1) update the Hydrogen Safety Best Practices Online Manual improving existing content and adding new content; 2) achieve a target of 200 records in the H2 Incident Reporting and Lessons Learned Database; and 3) analyze the lessons learned from incidents.

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **4.0** for its relevance to DOE objectives.

- The need for such tools is obvious. Most aspects of this initiative appear to be in-line with current emerging technology needs and critical information access.
- This is an excellent resource for all those involved in hydrogen. I have referred many fire professionals and project planners to these databases, as it is very important to have this type of resource.
- This is the only resource I know about that has this information. As such, it's essential to answer questions about the safety of the hydrogen industry.
- Best practices and incident reporting are important to furthering the goals of the hydrogen industry.

**Question 2: Approach to performing the research and development**

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

- It was not clear to me if non-disclosure agreement-type relationships were solicited to major hydrogen stakeholders and essential bulk or high volume users, except for NASA, in order to gain more information. Perhaps this might be an opportunity to establish "hold harmless"-type relationships that allow for a freer flow of incident reporting and sanitized details (in terms of liability issues and vulnerability).
- The project incorporates a straight-forward approach to creating best practices and cataloging incidents to answer questions about the safety of hydrogen. No changes suggested.
- The Hydrogen Safety Panel does a good job of corralling the hydrogen user community for relevant information.

**Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.7** based on accomplishments.

- I am concerned with dissemination regarding access to "novice users" as potential training aids. Perhaps a focused campaign to the various SDOs/CDOs/non-governmental organizations stakeholders as well as national, independent and academic research facilities would help the process.
- It was a good population of events. Although new events are added, it is not to the extent that it conveys a message of 'not safe', which is an important nuance.
- I expected to see a report on the amount of new data entered into the database, but to see all the different features added shows significant progress and accomplishment. It's good to hear about some of these new features which I'd like to use in other projects we have.
- The expansion of the incident database is a good thing. Contributors need to understand that this is not a "hit list", but a learning tool. Progress has been made since the last review in this area.

#### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **3.5** for technology transfer and collaboration.

- It might be advantageous to explore alternate avenues to information sharing and dissemination. This issue has previously been addressed and the team appears to be pursuing various paths. There is still a fair amount of progress needed.
- The communication between national labs and other organizations (NASA) seems to have expanded which is excellent.
- The project's coordination with organizations providing data is essential and obviously working well to collect the data needed for this project. If summary data/messages are developed, those could be shared with many additional groups.
- I would like to see more industry members (i.e. energy companies) on the safety panel.

#### **Question 5: Approach to and relevance of proposed future research**

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

- Pursuing indoor users, as well as bulk and sectional suppliers, is critical!
- Greater efforts should be focused in this area.
- Enhancing the web site utility may help to increase visits. This can be accomplished by making the site more 'friendly' and easy to navigate and also adding photos, graphics and videos. This will likely make it a more valuable resource.
- It was good to hear about future work on indoor forklift fueling. Addition of graphics and usability of the incidents data is also good. As a user, it would be nice to be able to pull out sound bites or summary points of the entire database, such as the number of hydrogen incidents represent 0.000X% of all hydrogen handling in a specific category. Data like this would allow one to compare hydrogen's safety record to that of other fuels. It would also provide more relevance to people who want to understand high-level data about hydrogen incidents, but don't want to get into a deep level of detail on individual projects.
- Continuing on with an increased emphasis on getting more energy companies involved is preferred.

#### **Strengths and weaknesses**

##### Strengths

- This may be an outstanding tool as sections "fill out" and collaborative efforts gain traction.
- This is an excellent resource and critical for those involved in the implementation of hydrogen and infrastructure as a 'go to' information source. The DOE and also PNNL are the most logical and appropriate organizations to do this.
- It is a unique and comprehensive collection of data, with a user friendly site, and the search features work well!
- The expert-based panels proved to be a strength.

##### Weaknesses

- Some weaknesses are the need for greater dissemination, a solution to "sanitizing protocols" and liability and identification vulnerability.

## **SAFETY, CODES AND STANDARDS**

- The potential inclusion of compressed natural gas information (the focus needs to stay on hydrogen) and the addition of other alternative fuels expands the scope such that it may very well become unmanageable.
- Tough to compare such different incidents and pull out high-level summary data. This project does a great job of doing so, but it's also the area where improvement could be made.
- There needs to be more energy company involvement.

### **Specific recommendations and additions or deletions to the work scope**

- Prioritize the establishment of workable agreements for the safe forward progress of the technology.
- Work with a graphics specialist on the overall layout to make it easier to navigate (improvements are good but it could use more).
- Add ability to generate reports of failure by component and cause (i.e. PRD, regulator, human error) to feedback about the SDOs on a bi-annual basis or coordinate with the meetings for revisions.
- See notes about pulling out high-level summary data on hydrogen incidents. For example, XX% of hydrogen incidents in the database had no resulting injury or XX% of incidents resulted in no loss of product.
- It would be good to know how much the website is being utilized (hits, visits, etc.) and whether the use is steady or growing (trends).

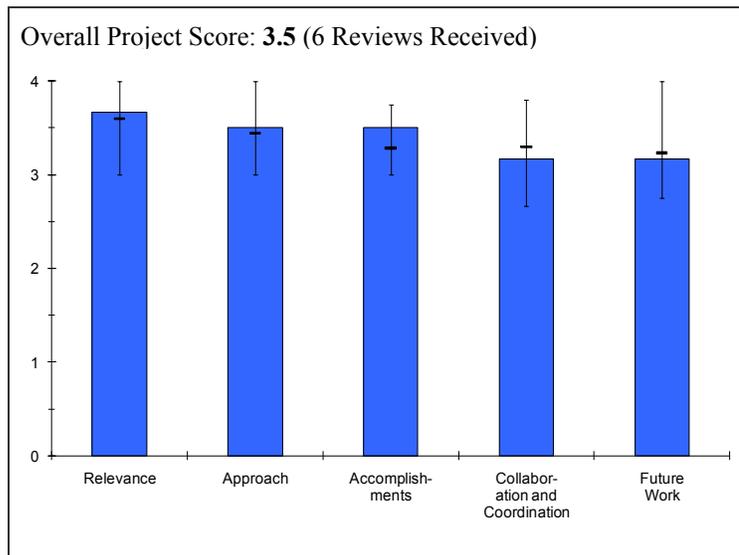
**Project # SCS-07: Hydrogen Fuel Quality***Tommy Rockward; Los Alamos National Laboratory***Brief Summary of Project**

The objectives of this project are to: 1) help determine levels of constituents for the development of an international standard for hydrogen fuel quality; 2) test the critical constituents (NH<sub>3</sub>, CO and H<sub>2</sub>S); and 3) present data at the Working Group 12 meetings.

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **3.7** for its relevance to DOE objectives.

- The purpose of this exercise is to generate data in support of an ANSI and an international hydrogen fuel standard for polymer electrolyte membrane fuel cell (PEMFC) vehicles. The ANSI document takes priority due to the immediate need to support the State of California Department of Weights and Measures as they need to comply with California statutes.
- The fuel quality standard is the lynch pin of the hydrogen economy. It will stipulate what non-hydrogen constituents the polymer electrolyte membrane (PEM) systems need to tolerate, and stipulate what non-hydrogen constituents the infrastructure is not to allow into the fuel.
- Setting and harmonizing standards for hydrogen fuel quality is extremely important to ensuring fuel cell life and durability.
- Since fuel cell technology is critical for the application of hydrogen as a vehicular fuel, understanding the relevance of hydrogen quality is of critical importance.
- This work tries to clarify levels and types of contaminants that could impact current PEM fuel cell technology. This foundation will be needed as the technology and membrane electrode assembly (MEA) materials change with continued development.
- This project is critical to the development of hydrogen fuel as a commerce item.
- The DOE objective to support and facilitate the completion of technical specifications by ISO for gaseous hydrogen is met. This is needed in order to complete the codes and standards needed for the early commercialization and market entry of hydrogen energy technologies by 2012.
- Hydrogen quality specifications are necessary to allow fuel cell developers to design their systems to cope with the expected level of impurities.

**Question 2: Approach to performing the research and development**

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

- The approach taken is valid. The data is currently limited to the capabilities of subscale testing. The results are based on quasi-steady state testing.
- There is more value in improving the detection limits for contaminants than in using data to set fuel quality standards that are more restrictive than previously set standards.
- It is clearly focused on the three major contaminants that affect fuel cell/MEA stability.
- The work resulted in an improved ISO fuel specification.
- Data indicates breadboard test modules are providing reproducible data that can be modeled for longer-term performance.
- There was limited feedback from OEMs.

## SAFETY, CODES AND STANDARDS

- The technical barriers (i.e., conflicts between domestic and international standards and insufficient technical data to revise standards) have been addressed. Also, integration with other efforts through collaboration appears to be the case.
- The presentation shows that the work has been well organized over time and addresses the technical barriers provided by the industry panels to support the national and international standards development work.

### **Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.5** based on accomplishments.

- The data generated and more importantly the collaboration between investigators should be considered the model on how to approach tasks like this.
- Improving detection limits supports standards tied to system and fuel cell performance.
- The project had good experimental and modeling results that were adopted by the international community.
- Provided major emphasis to improve the detection limits of these impurities for improved durability.
- Excellent work that needs to be fed into the modeling group to check their models.
- Significant progress has been made on the establishment of cross contaminant effects, according to project plan.
- The presentation shows that the work has provided data that can be used to set limits for contaminants. However, physical upscaling to stack and system-level experience has not been done.

### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **3.2** for technology transfer and collaboration.

- The collaboration on this project is fantastic. It is surprising that credit wasn't taken for the industry support and guidance on this task in regards to Air Products & Chemicals, Inc., Ballard, Chrysler, General Motors, Linde, Praxair, etc.
- Partners/collaborations were identified, but it was not clear what role each plays in the effort.
- There was excellent collaboration with universities, national labs and the international community.
- More active feedback from gas production and OEMs would move things along more swiftly.
- Collaborations with U.S. academia and national laboratories are clearly mentioned, but international collaborations are missing or not mentioned.
- There has been good collaboration with other labs and other stakeholders. Collaboration with fuel providers has been difficult. More collaboration with fuel providers could be an improvement.

### **Question 5: Approach to and relevance of proposed future research**

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

- The suggested future work is appropriate and should be seriously considered. Additionally, the collaboration effort should not be abandoned but rather expanded.
- Continuing research to develop the tools to assess the effects of reduced contaminant levels and harmonization of fuel quality standards will facilitate standards for hydrogen production and quality.
- There was not much provided on future directions except to communicate results and discuss them with regulators and manufacturers.
- Start/stop and some durability testing should be incorporated.
- The R&D is planned and performed systematically and conforms to common practices. Awareness of milestones and risks is evident.
- The future work seems to be well planned in order to complete the testing necessary to provide input to the hydrogen quality standards efforts, but system-level tests have not been planned and validation of model predictions have not been planned either. Depending entirely upon model predictions for stack performance under contaminant conditions may be a risky approach. Stack performance may be better or worse than predicted by the single-cell testing and the modeling.

### **Strengths and weaknesses**

Strengths

- The strengths are the collaboration and the testing methodology.
- A strength was the excellent technical team and the R&D approach.
- There was good research and relevant data.
- There was systematic planning and execution of R&D.
- There appeared to be good coordination with other laboratories.
- A huge benefit was the good implementation of testing techniques to predict cell response to contaminants.
- There was a good work plan using an iterative approach to refine results.

Weaknesses

- The weaknesses are only those limits inherent to sub-scale testing. Full-scale testing to validate results might be appropriate.
- There were no weaknesses.
- They need to go further with durability testing at the cell level.
- There was information missing or not mentioned concerning international collaborations with actors performing similar R&D elsewhere.
- The presentation did not show a high degree of collaboration with fuel providers. Additional collaboration with fuel providers might help to get their buy-in and get their input to the program.
- During the presentation, it was mentioned that some vehicle manufacturers have implemented shutdown sequences that might mitigate degradation. It would have been more expedient to have this input earlier. Additional collaboration might have been helpful and perhaps that information could have obtained earlier.

Specific recommendations and additions or deletions to the work scope

- This activity should be continued.
- Perform similar testing but at lower platinum levels.
- They should incorporate durability testing at the cell level.
- Additional collaboration with fuel providers and vehicle fuel cell stack developers could be an improvement.
- Stack-level testing could be added as an enhancement. System-level validation could also be added as an enhancement.

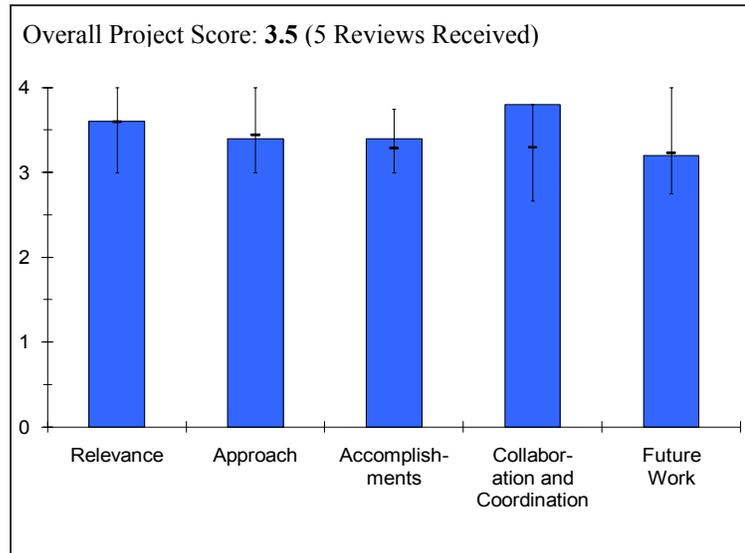
**Project # SCS-08: Hydrogen Safety Panel***Steven Weiner; Pacific Northwest National Laboratory***Brief Summary of Project**

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

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **3.6** for its relevance to DOE objectives.

- The overall importance of a cast of "go-to" practitioners (not simply academic or theoretical experts) cannot be overstated. This type of group is critical to the responsible forward progress of this emerging technology.
- This fits very well into the overall scope of Pacific Northwest National Laboratory's (PNNL) responsibilities for hydrogen safety and education.
- The Hydrogen Safety Panel is obviously necessary to provide oversight to all DOE-funded hydrogen projects. The panel of experts is fairly large and diverse, which is beneficial, as they each bring unique and different areas of expertise to the table to provide a comprehensive assessment of safety reviews.
- The Hydrogen Safety Panel is a critical component of the overall DOE safety, codes and standards sub-program. The Panel ensures that the standard operating procedures of DOE-funded projects conform to the best practices in safety. Over the past six years, the practices, procedures and priorities of the Panel have evolved to become a more integral part of the sub-program. The Panel provides a unique venue where critical safety issues, from assessing recent safety incidents to identifying impending needs, can be addressed by an expert group. The Panel has made important contributions to the sub-program.
- The project is relevant to the DOE RD&D objectives in that it identifies project leaders where hydrogen safety must remain a priority.

**Question 2: Approach to performing the research and development**

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

- It appears that many feel a more formalized entity (that also is utilized to a greater investigative and perhaps "oversight" capacity) would benefit this highly compartmentalized industry.
- The approach offers the ability to tap into the resources of the Panel (for example NASA).
- The approach to safety assessment is continuous, iterative and appears to be more rigorous each year with improved data collection and dissemination strategies.
- The Panel has kept its focus on safety, and its work continues to address a critical barrier to deployment of hydrogen and fuel cell technologies. The work of the Panel is better integrated with other efforts, particularly with work on the incidents database and best practices manual, as recommended in the AMR last year. There is still room for improving this integration. The presentation showed how the Panel is well integrated with PNNL's Hydrogen Safety and Education Program, but did not adequately address how it is integrated with the sub-program. This integration should be better addressed in the 2011 AMR.
- The Project makes good use of notable experts in the field. The project seems to be doing a lot of work, but it's confusing to me why the Panel is needed at almost \$1 million per year. Is there any evidence that the safety of

projects is so unpredictable and risk of incident so high that this extra check is required? If so, that should be better articulated. If not, what is the best use for this great group of experts? This role of the Panel was not clear to me.

### **Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.4** based on accomplishments.

- More investigative work as well as closer oversight and better established and organized feedback is needed. It is particularly valuable to see the group focusing on defined and specific application projects (like the use of indoor specialty vehicle fueling situations).
- There was some concern with the white paper on supplemental safety for 70 MPa fueling—this is a sensitive subject with the auto manufacturers.
- The Project has very good communications and outreach. The only reason I do not say outstanding is that I think that would imply that all bases are covered and the job is done. The accomplishments to date, including many recommendations and reviews coupled with very few incidents to investigate, indicate that the Panel is successful in achieving its goals.
- The preliminary metrics presented at the AMR to measure the accomplishments and progress of the Panel is a good start. The Panel should address these metrics more carefully and develop a set of metrics that it will use for self-assessment. A Panel self-assessment of its accomplishments and effectiveness in meeting the terms of its charter should be reported at the 2011 AMR.
- The statistics were very helpful, as were the examples of specific projects with which the Panel was engaged.
- Related to the comments in the approach, besides reports and suggestions that were given to DOE and project managers (which does have a value), I wonder what beyond that was really accomplished in terms of reducing risk or improving the execution of projects for the betterment of the industry.

### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **3.8** for technology transfer and collaboration.

- Collaboration appears to be moving in the right direction with the right stakeholders. It was not clear to me what off-shore agents or organizations were being utilized to their optimum capacities, so I see opportunity for further cooperation and inclusion in joint activities.
- The panel itself has a good representation and they engage others well outside the panel.
- Well-coordinated interaction with project teams is the point of the effort.
- Collaboration with other institutions is inherent whenever the Panel conducts a review of standard operating procedures for safety at research facilities and industrial organizations. The Panel has done an outstanding job of reviewing such procedures and following up on its reviews. The Panel approaches safety reviews as a collaborative effort with the institution being reviewed and is to be commended for this. The Panel's reviews are appreciated by the institutions being reviewed, as an independent third party review by safety experts is invaluable for the safe operation of research and development facilities.
- The Panel structure itself is collaborative with different organizations. Given the difficulty in getting safety information from companies, the collaboration seems to be quite good.

### **Question 5: Approach to and relevance of proposed future research**

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

- The target summary slide was generic, but we assume it includes all of the applicable fiscal year DOE projects.
- The work with the American Recovery and Reinvestment Act of 2009 fuel cell deployment projects is in line with the purpose and goals of the Panel. Conducting safety plan analysis for six fuel cell forklift installations and two backup power installations will instill confidence within the industry as a whole (reducing incidents and risk).
- The plans build on past progress.

## **SAFETY, CODES AND STANDARDS**

- Meetings are generally planned one at a time and held twice a year—an approach that encompasses an annual (or even broader) perspective based on key safety concerns that need immediate attention. Safety as an enabler of hydrogen and fuel cell technologies should also be considered.
- I have the utmost respect for the people involved and their expertise, but question what is really needed by the industry from this panel. If there is a real need, there's no doubt that the Panel could accomplish it, but maybe that needs to be better identified and the purpose of the Panel re-examined to determine maximum effectiveness from dollars spent.

### **Strengths and weaknesses**

#### Strengths

- There were varied backgrounds of experienced, seasoned and professional practitioners.
- Recommendations based on their review of incidents and the publication of the safety documents is excellent resources.
- The Panel is made up of a diverse group of highly qualified experts with excellent administrative management provided by PNNL. The Panel has conducted a number of site visits with follow-up and published relevant guidance documents. Its meeting provides an excellent forum to address both specific safety incidents and general safety issues.
- There was a very impressive collection of experts who are widely respected for their expertise in the area of safety.

#### Weaknesses

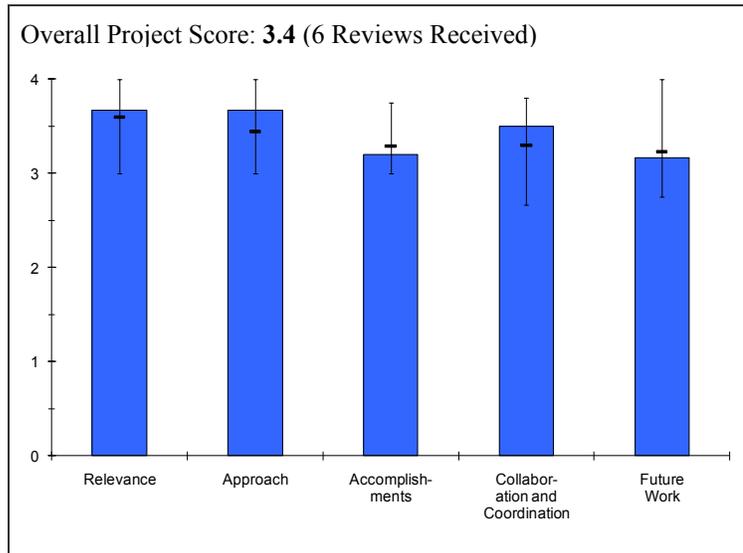
- The project should strongly consider "formalizing" this group in a more "established" organizational model, as well as allowing more capacity for greater access and oversight.
- It is very difficult to develop and implement metrics of effectiveness for an activity such as that undertaken by the Panel. The Panel has attempted to do this by accounting for the number of safety plans reviewed, site visits, etc., but more should be done to evaluate effectiveness if possible.
- There is a lack of clarity on the need for this panel. It's not completely clear to me why this panel is essential, and especially at the price tag stated (which I realize doesn't include the in-kind contributions). For example, when the Benning Road hydrogen station was put in, the companies involved were so concerned about safety a panel like this wasn't needed, in my opinion. That amount of oversight from many companies seems common. But are other companies much less reliable? And therefore is the Panel needed to help protect DOE and to reduce the risk of incidents with DOE projects, or projects where companies don't have the resources to conduct adequate safety reviews? The main need being addressed could have been clearer.

### **Specific recommendations and additions or deletions to the work scope**

- Other unique fueling scenarios should be visited. Similar approaches that were addressed concerning specialty vehicles have value. Portable and remote applications may be candidates, particularly those within the aerospace and aerospace support arenas.
- Perhaps an annual report on the status of hydrogen safety in the United States, key lessons learned during the year and critical issues to be addressed in the upcoming year would be helpful additions to the Panel's activities. Such an evaluation could be an agenda item during one Panel meeting. What has been the key value-added of the Panel's efforts during the current fiscal year?
- I feel uncomfortable making these somewhat harsh suggestions about a project run by people whose work I really respect, however, I think it would be worth looking into whether the purpose and function of the Panel needs to be reinvented. It's clear that this group could accomplish much, but I'm not sure that the current purpose is meeting an essential need. Maybe I'm missing something and if so, those missing elements or statements of critical need really need to be stated more clearly.

**Project # SCS-10: Hydrogen Release Behavior***Daniel Dedrick; Sandia National Laboratories***Brief Summary of Project**

Hydrogen codes and standards need a defensible and traceable basis. Objectives for this project are to: 1) use quantitative risk assessment for risk-informed decision making and identification of risk mitigation strategies; 2) perform physical and numerical experiments to quantify fluid mechanics, combustion, heat transfer and cloud dispersion behavior; 3) develop validated engineering models and computational fluid dynamics models for consequence analysis; and 4) provide advocacy and technical support for the codes and standards change process.

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **3.7** for its relevance to DOE objectives.

- This project is focused on tunnel and indoor fueling accidents. The need for this research is self-evident.
- This project provides valuable real world data which feeds into the development of codes and standards for hydrogen. As such it aligns well with the RD&D goals of the Fuel Cell Technologies Program.
- The science-based defensible and traceable development of codes and standards are key to overall DOE objectives.
- Providing engineering data for development of hydrogen codes and standards is critical to establish appropriate requirements for hydrogen technology deployments.
- The project is providing excellent support to both domestic and international standards with the separation distance work.
- The project provides vital information for the development of DOE R&D efforts in the hydrogen program.

**Question 2: Approach to performing the research and development**

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

- The approach on the tunnel testing is appropriate. It isn't as clear what the game plan is for the indoor fueling question. Are the warehouse fire safety facilities of Underwriters Laboratories (UL) in Illinois or Factory Mutual in Massachusetts being considered as test sites?
- The technical barriers addressed in this project are well planned and well executed. The approach taken, using models and then validating those models with real world experiments, is the way that hydrogen safety R&D should be done (as opposed to just doing the modeling compartment).
- The effort uses a well thought-out approach using a combination of modeling and physical validation activities to characterize hydrogen release behavior.
- The scenarios investigated are relevant to industry. The separation distance studies are critical to infrastructure development.
- Caution must be used in relying too much on risk-based decisions using probability alone without sufficient attention paid to severe consequences. Some effort should be spent on mitigation of low-probability high-consequence events, such as 300-year floods. Recent events such as Hurricane Katrina and the British Petroleum oil spill have led regulators and others to rethink the approach to manage risk and accidents. It would

not have prevented the accident from happening, but at least there may have been efforts devoted to a “Plan B” in case such events happen.

### **Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.2** based on accomplishments.

- The accomplishments on the tunnel issues are impressive. The progress on the indoor fueling is less clear.
- The spontaneous ignition results are interesting.
- The tunnel and semi-enclosed spaces work has resulted in significant advances. Relating the experimental work to actual risk statistics, to show that the frequency is less than that for everyday life, was a very good way of putting the issue into perspective.
- The work on “spontaneous ignition” has made significant progress as well. This is a bit of a controversial area in the hydrogen safety world. The results of this work, which highlight the effects of entrained particles, are therefore a welcomed advancement.
- The results appear to have been slow but steady.
- Overall, the progress of the work and the dissemination of results to the codes and standards community are excellent. The criticality of material entrainment and its influence on release ignition needs to be clarified. Indoor refueling characterizations need to be accelerated as early market deployments are well underway.
- The tunnel work is important. The results need to be distributed to the code official community.
- A model was completed and some testing was done.

### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **3.5** for technology transfer and collaboration.

- The collaboration for the tunnel issues appears to be appropriate. It is suggested that UL and Factory Mutual be approached on the indoor fueling issues for several reasons: test facilities, test methods, indoor modeling and acceptance of results by AHJs and underwriters.
- There is reasonable collaboration of this project both within the United States and also internationally through the International Energy Agency Hydrogen Implementing Agreement (IEA HIA).
- It was a good and collaborative effort involving SDOs and international agencies.
- Collaboration is largely relative to dissemination, with the most important aspect being dissemination to the codes and standards community.
- Collaboration with code organizations is critical to success.

### **Question 5: Approach to and relevance of proposed future research**

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

- The proposed future work is appropriate.
- The proposed future work is well in line with the milestones that were originally set out in the project. The inclusion of indoor refueling into the project is a very good direction.
- The low-temperature work is similar to work being carried out at the Health and Safety Laboratory (HSL) in the United Kingdom and it would have been good to see some mention of possible interaction with those researchers (data sharing, etc).
- It could be clearer how the work scope is evaluated, but overall future work identified is appropriately structured and important to the development of hydrogen safety, codes and standards.
- Indoor fueling work will be critical in 2011.

### **Strengths and weaknesses**

#### Strengths

- The strengths of this project are self-evident.
- There is an excellent translation of scientific study and analysis to concrete safety guidance.

- The expertise of the panel was a strength.
- The project provided some good data and a model for use.

Weaknesses

- The lack of accepted industry collaboration mentioned for the indoor fueling question is a weakness. Support and concurrence from UL and/or Factory Mutual will help with AHJ and underwriter acceptance of results and conclusions.
- It could use some additional clarity as to the direction of the tunnel release work.
- Time consuming studies are a weakness.

**Specific recommendations and additions or deletions to the work scope**

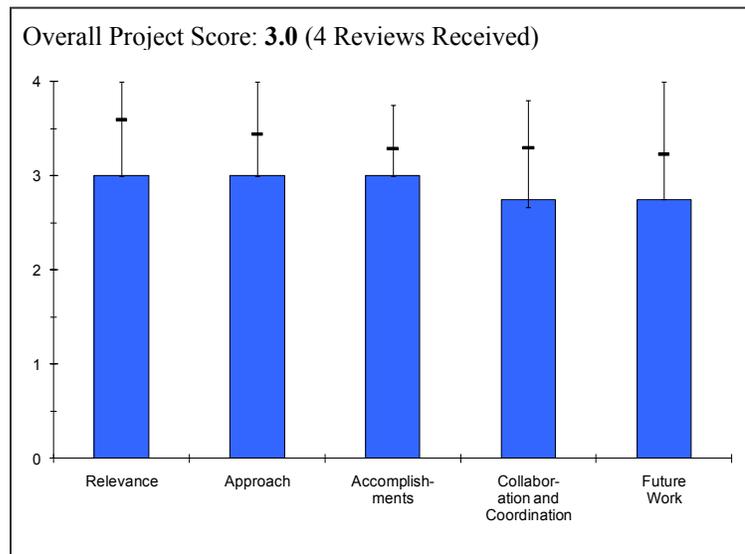
- The PIs should discuss the indoor fueling activity with the building fire experts at either UL and/or Factory Mutual. This should facilitate the acceptance of the testing results (instrumentation techniques) and may improve the applicability and fidelity. This is their bread and butter.
- It is not clear how significant an issue particle entrainment is.

## Project # SCS-13: International Energy Agency-Hydrogen Implementing Agreement: Task 19 Hydrogen Safety

William Hoagland; Pacific Northwest National Laboratory

### Brief Summary of Project

The goal of this project is to conduct a collaborative program to develop predictive methods, data and other information that will facilitate the accelerated adoption of hydrogen systems. Specific objectives are to: 1) characterize and assess risks and hazards and quantitative risk assessment methodologies, including risk informed criteria for permitting approval and simplified methods; 2) conduct collaborative testing program to validate the models that have been developed and to further refine those tools for use in real-life scenarios; and 3) document and convey results and data to reduce the barriers that inhibit commercial introduction of hydrogen systems.



### Question 1: Relevance to overall DOE objectives

This project earned a score of **3.0** for its relevance to DOE objectives.

- It appears that the collaborative efforts of the program are worthy as are most collaborative efforts and instruments, but it appears a bit vague as to the specific what, why and how.
- The mission to accelerate hydrogen implementation and widespread utilization (overall) is exactly in line with the DOE Fuel Cell Technologies Program on safety, codes and standards and that of the industry.
- The project is aligned with DOE goals.
- International collaboration is important to allow U.S. manufacturers to sell into international markets. International collaboration is also important to allow U.S. citizens to gain the advantages of technologies developed elsewhere.

### Question 2: Approach to performing the research and development

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

- Again, I have had some difficulty aligning what I am aware of as critical "needs" with regard to international coordination, cooperation and voice (particularly specific to the International Organization for Standardization (ISO), International Electrotechnical Commission (IEC) and Global Technical Regulation (GTR) and this program's specifics.
- Providing input to the risk-informed codes & standards development with input from experts around the world helps to ensure that the results are also accepted on an international basis. This is so very critical to hydrogen technology adoption.
- Analyzing how countries interpret risk and what they accept as such demonstrates international leadership.
- International experts share information and data. It was a good plan to disseminate results at the end of the task.
- It appears that the "risk-informed" methodology mirrors and parallels the SNL/DOE approach to risk assessment for hydrogen and fuel cell systems.

**Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.0** based on accomplishments.

- It appears that meeting support or expertise identification and access, which can at times be daunting, was the prime deliverable for this reporting period.
- The importance of the projects and accomplishments of the Task 19 Panel (vetted database, position papers that are a consensus of experts on major issues and a database of suggested models validated against the unintended release database) are indescribable.
- Fundamental data, modeling, component testing and mitigation resulted in engineering models, dispersion models for releases and a more detailed thermal radiation model that accounts for cross winds. All of this personally created a higher confidence level in these areas. Plus it's on an international scale!
- It was a logical subtask structure covering technical and communication activities.
- A bibliography has been developed and modeling has been done.
- A database has been developed.
- Hydrogen incidents have been provided to [www.hydrogenincidents.org](http://www.hydrogenincidents.org). This is a strength.

**Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **2.8** for technology transfer and collaboration.

- Perhaps a comprehensive listing of collaborative entities, institutions and organizations would better facilitate the understanding of this project's deliverables.
- This is an international effort which includes 11 countries participating, assuming that all are actively providing input, and is an excellent collaboration.
- There was excellent international participation and collaboration.
- If this work is international, it needs to feed into ISO, IEC, and IEC System for Certification to Standards Relating to Equipment for use in Explosive Atmospheres (IECEX), and other standards systems, as well as the European Norms (ENs) that are typically derived from the IEC and ISO standards in order to meet the European directives. It is not clear that this vital link will be made. In addition, if Japan is to be involved, the Japanese industrial standards (JIS) need to be linked to the program as well as the Japanese laws.
- Collaboration appears to be in place between the countries, but the collaborative goal needs to be better defined in order to support the goals of removing barriers to codes and standards.
- Collaboration with the U.S. labs seems to be in place.

**Question 5: Approach to and relevance of proposed future research**

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

- It ends in October 2010 and will have an end-of-task forum/workshop to disseminate results (which will be kept in a database that is closed for now but will be made public).
- The work will be completed in December 2010. The communication of final results of the activities will be critical.
- More information sharing appears to be the most robust function. Additional linkages to the actual standards, norms and directives would be helpful.

**Strengths and weaknesses****Strengths**

- The potential to link off-shore efforts and support to a unified task in harmonization is a strength.
- Incredible collaboration and data that delivers results is due to the level of experts involved.
- The strong international collaborative effort is a strength.
- Good collaboration between the countries is a strength.
- There appears to be good collaboration between the U.S. labs and the project.

- Input to the [www.hydrogenincidents.org](http://www.hydrogenincidents.org) project is a strength.

### Weaknesses

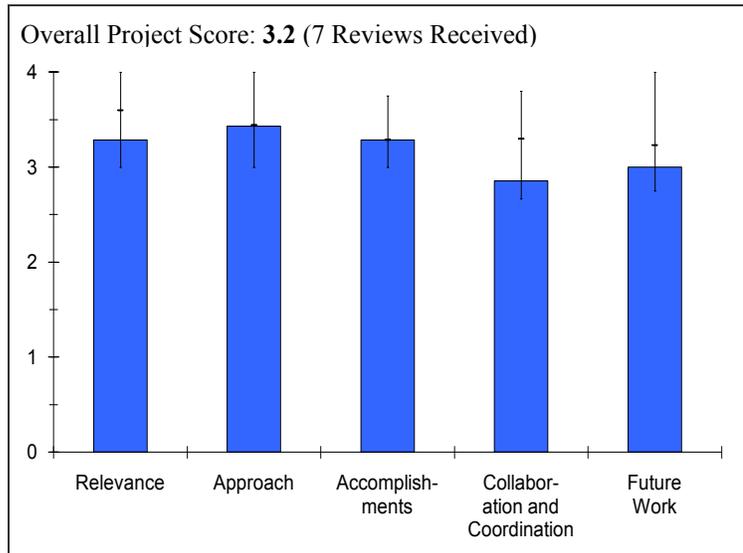
- It appears to be vague and essential elements were not identified.
- The project is ending due to lack of funding.
- There was a lack of well-defined linkage to ISO, IEC, IECEx, ENs, European directives, Japanese laws, JIS standards and Consumer Electronics (CE) certification.

### Specific recommendations and additions or deletions to the work scope

- I recommend that specific targeted collaborative partners are identified and relationships are somewhat formalized (i.e., through Memorandums of Understanding).
- Increase the access to the Hydrogen Technical Experimental Database (not the videos), so that the data can be incorporated into other safety-related activities supported by the DOE program.
- It would be valuable to establish a solid linkage to the IEC, ISO, IECEx, European Norms, Japanese laws, European directives, JIS standards and CE certification.

**Project # SCS-14: Safe Detector System for Hydrogen Leaks***Robert Lieberman; Intelligent Optical Systems (IOS), Inc.***Brief Summary of Project**

The project goal is to select and finalize hydrogen sensor technology, design and fabricate scalable prototype sensors and investigate and establish end-user market size and cost analysis. The overall objectives are to: 1) integrate IOS's proprietary hydrogen indicator chemistry into a complete optoelectronics package with well-defined sensing characteristics and a known end-use market; and 2) identify different formulations and physical embodiments to meet specific market requirements. Technical objectives for 2009-2010 are to: 1) select and finalize hydrogen sensor chemistry that possess the optimum sensitivity, reliability, reproducibility and aging performance; 2) finalize and fabricate optoelectronic board for hydrogen leak sensor; 3) assemble packaged prototype hydrogen point sensor that meets DOE specifications; and 4) test and validate the full packaged prototype performance at the NREL testing laboratories.

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **3.3** for its relevance to DOE objectives.

- The idea to put hydrogen sensors in residential garages is not in-line with the industry. There is no precedent, for example, no natural gas sensors for hot water heaters. The National Fire Protection Act does call for sensors in repair facilities, which this could very well fit into, but I would like to see them move away from the residential garage/home sensor. It sends a negative message to the public. Perhaps the panel needs to read up on residential garage modeling studies?
- In regard to the mentioned vehicles, vehicles do have sensors (now) and all of the OEMs have their vehicle sensors 'worked out' (either they make them themselves or have a supplier they are satisfied with make them).
- The development and deployment of safety sensors that meet DOE targets is an important part of the Fuel Cell Technologies Program. The relationship of performance targets (sensor product specifications) to the DOE targets should be discussed.
- Cost-effective hydrogen sensor technology is an enabler for more robust hydrogen safety practices.
- Flexible sensor technology is important for hydrogen safety. I'm not sure how this technology itself applies to overall programmatic goals, but it's good to see DOE helping technologies like these. These technologies are important to reach commercialization.
- Quality sensors are critical for the widespread use of hydrogen.
- Hydrogen sensors are essential for the safe use of hydrogen. As such, this project provides critical support to the safe deployment of hydrogen (from production to end use) by designing a sensor to meet the requirements of the application.
- Leak sensors appear to be a necessary component of vehicle, stationary and portable fuel cell systems, at least in most applications. Some developers are unwilling to include standards due to concerns regarding reliability, false alarms, stability and cost. Having reliable and cost-effective sensors is essential.

**Question 2: Approach to performing the research and development**

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

- The project is investigating various sensing platforms that could lead to a new technology, such as fiber optics for very small sensors (working with them now).
- The approach as shown in slides 6-11 shows a number of things (e.g., different application platform requirements, project plan, testing station, etc.), but does not add up to a coherent statement of technical approach.
- The project addresses technical barriers adequately.
- The approach incorporates an appropriate balance of technical, manufacturing and packaging R&D.
- The approach is systematic and well-developed. The technology development manager's suggestion to push towards a project in this area last year was good advice to make sure that a product, and hopefully testing, could result from funding received by this project.
- This was very focused work. This is a good example of a project run by industry and not academia.
- In general, it is clear how this project addresses the barriers identified with delivery, manufacturing and technology validation. The relevance to storage balance-of-plant components is less clear.
- The cost and durability of the optical sensor are not mentioned even though these two factors are explicitly mentioned in the relevant DOE Multi-Year Program Plan list of barriers.
- This project is using the goal targets from the 2007 workshop. This is a good approach, provided that industry was involved.

### **Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.3** based on accomplishments.

- A ten-hour battery life would be an accomplishment.
- The presentation states that Tasks 1-12 have been 100% accomplished (slide 7), but did not report on performance of a hydrogen sensor market study (Task 7). The requirements of targeted markets and an assessment of how objectives and accomplishments of the project align with these requirements would be helpful. More explanation of the cross-contamination testing (slides 17 and 18) and NREL's test results would also be helpful in determining the status of Milestone 1: "Complete cross contamination testing of sensor elements". According to the project plan (slide 8), the activity to "Establish commercial market and partnerships" started at the end of year one and should be about 90% complete. However, there was not enough information presented about progress on this activity.
- The nearly completed project has met most technical targets although it was limited to only 10% hydrogen concentrations. Issues with temperature and humidity are still being investigated but do not seem insurmountable. CO and H<sub>2</sub>S contamination issues still need to be resolved.
- The presenter was very clear about what has been accomplished and what remains to be done. It appears that of the challenges remaining, they all will be overcome. The cost and size reduction opportunities from potential volume manufacturing are encouraging.
- The segue from performance to goals is excellent. The end of the project will produce a usable device.
- Good progress has been made with respect to the project objectives. The sensing material has been successfully integrated with an optoelectronic interface and into a prototype unit that has been tested by collaborators. Further developments (e.g. polymer) will be necessary to extend the operating specifications to meet the targets. While problems of humidity and temperature influence on sensor performance have been addressed, this is only obvious for a very limited range. The sensor does not appear to be resistant to CO. In fact, the response appears to be permanently changed (poisoned) by CO.
- The presentation showed good progress towards a commercial sensor.

### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **2.9** for technology transfer and collaboration.

- Collaboration does not seem to apply in this project (private company with a product they want to bring to market).
- The collaboration with NREL is commendable, but it is not clear what role NREL's sensor laboratory played in the testing to date of the prototypes. My understanding is that the project benefitted from leveraging and

extending RD&D conducted under other federal programs. If so this should be noted, as it shows how DOE funding has built upon previous work funded by another federal agency. The extension and substance of collaboration with Intelligent Energy and Jadoo Power as "commercialization partner(s)" should be explained.

- The project has some experienced partners, but more clarity could have been provided regarding their contributions.
- Coordination is good. The PI seems to have coordinated with the appropriate kinds of groups, including a customer.
- It is a small group that is easily managed and has short communications lines.
- The collaboration with NREL as a testing and validation provider is visible and such independent testing by a national laboratory is very important and commended.
- The collaboration with and input from other named collaborators is less visible. The degree of coordination is also unclear.
- There is good collaboration with NREL and potential customers.

#### **Question 5: Approach to and relevance of proposed future research**

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

- They have essentially completed the program (doing marketing projects), and the next step is potentially a multi-site field test.
- As the project is 95% complete (slide 2), there was no explicit discussion of future work. The technical objectives to "assemble packaged prototype point sensor that meets DOE specifications" and to "test and validate the full packaged prototype performance at NREL testing laboratories" (slide 3) seem to be the most important work that remains to be conducted in FY 09 –10 and should be discussed in more detail.
- Project is effectively complete so this rating is effectively the average of the other category ratings.
- Plans to do testing of the product and to address the challenges remaining with regard to contaminants were clear and seem to be what's needed next in the development of this technology.
- Commercialization of this device will be good for infrastructure development, especially indoor refueling.
- The project scheduling is rather unclear (timeline 2007-2011 and project plan 2008-2011), so it is difficult to comment on. Future developments should lead to operating specifications that meet the targets given (slide 5) in terms of measuring range, temperature range and cross-sensitivity. It is not clear if and how this is planned. It is also unclear whether a prototype wide-area hydrogen sensor has actually been made or if only the point sensor has been developed.
- Continued efforts to perfect the technology are planned. The final outcome is not known at this time.

#### **Strengths and weaknesses**

##### Strengths

- It is focused R&D and engineering on applying fiber optic technology to address hydrogen safety sensor needs and targets. The sensor technology developed by the project has the potential to address safety sensor needs in a variety of applications and markets.
- A well executed project that is very close to delivering a commercial sensor.
- The product seems to have developed systematically and successfully through the R&D process. The end result so far works well, although some challenges remain.
- This is critical technology; an optical sensor with the potential to be intrinsically safe with wide-area monitoring is a strength.
- The development from basic material to sensor prototype is commended, and the independent testing of the unit (with NREL) is also commended.
- This is innovative technology.
- There was good collaboration with potential customers.
- There is good collaboration with NREL.

### Weaknesses

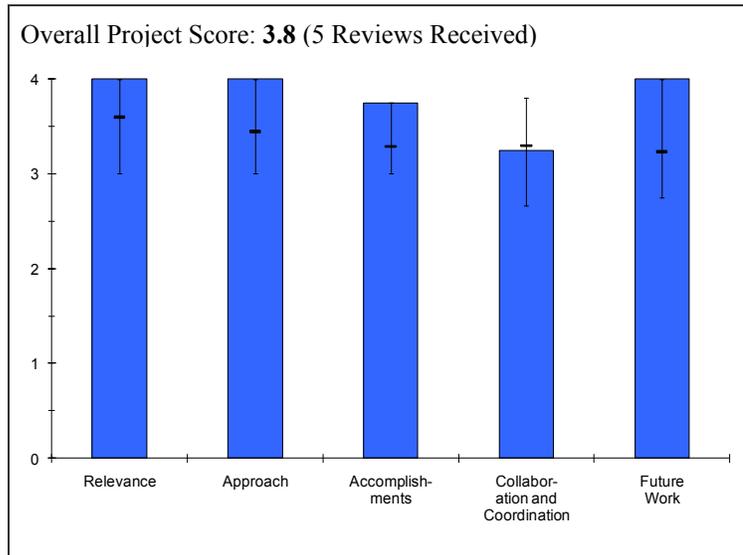
- While the technology appears to be unique and advanced, the push to get these installed in residential garages is not the message that should be propagated in getting hydrogen vehicles to the general public as it presents a negative and fear-based connotation towards hydrogen. The question may be raised, "Why would I buy a hydrogen car if it's dangerous enough that I have to put a special sensor in my garage?"
- A key project goal to "investigate and establish end-user market size and cost analysis" was not addressed.
- The presentation was weak on information regarding how this product might be used and coordination with additional potential partners. Since vehicles and garages are listed as potential users, is there any evidence that the automakers would be interested in such a product? How about people who construct commercial or residential garages? I'm not sure the customers identified would be the most likely to be interested in the product and, if the customer is different, would the product need to be developed or packaged differently?
- I see no weaknesses at this time.
- Their cost targets are a weakness. It is unclear how competitive they will be when compared with commercially available sensors.
- Methods to reduce cost should be addressed.
- Poisoning by carbon monoxide is an issue.
- Cross interference has not been solved yet.
- The sensors will not work in 100% relative humidity (condensing atmospheres). This could make them unsuitable for some scenarios.

### Specific recommendations and additions or deletions to the work scope

- See weaknesses listed above.
- I suggest looking more into how this product might be used. Since vehicles and garages are listed as potential users, is there any evidence that the automakers would be interested in such a product? How about people who construct commercial or residential garages? I'm not sure the customers identified would be the most likely to be interested in the product. If the customer is different, would the product need to be developed or packaged differently?
- The project needs the identification of a niche market for the sensor and a favorable comparison with available commercial sensors.
- Hold a demonstration of their distributed sensor as a potential improvement on current technologies.
- Sensor durability and lifetime needs to be demonstrated.
- Additional collaboration with laboratories and other manufacturers could be beneficial.

**Project # SCS-15: Hydrogen Safety Training for First Responders***Linda Fassbender; Pacific Northwest National Laboratory***Brief Summary of Project**

The long-term goal of this project is to support the successful implementation of hydrogen and fuel cell technologies by providing technically accurate hydrogen safety and emergency response information to first responders; including fire, law enforcement and emergency medical personnel. The objectives for FY 10 are to: 1) continue to provide a one-day first responder training course utilizing DOE's fuel cell vehicle (FCV) prop at the Hazardous Materials Management and Emergency Response (HAMMER) facility; 2) offer the FCV prop course at training centers in California for approximately 300 first responders; and 3) continue to support the web-based awareness-level course; and 4) disseminate first responder hydrogen safety educational materials at appropriate conferences to raise awareness.

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **4.0** for its relevance to DOE objectives.

- This was highly relevant, timely and essential!
- Providing safety training to first responders is critical to advance the safe deployment of the hydrogen economy.
- It is critical to move emerging knowledge generated by the scientific and codes and standards communities to those responsible for responding to potential hazards in real-world situations.
- Hands-on training is an essential part of building hydrogen awareness and preparing fire service personnel for greater commercialization of hydrogen technologies.

**Question 2: Approach to performing the research and development**

This project was rated **4.0** on its approach.

- Comprehensive efforts to provide this activity should be applauded!
- The approach to reaching the target audience is outstanding. Online training materials are designed to be engaging and provide training to the entire emergency medical service community. Outreach through conferences and hands-on training with the prop are other ways to engage people and let them really experience some of the unique properties of hydrogen and associated hazards.
- Using the TrainingFinder Realtime Affiliate Integrated Network (TRAIN) Website is also a great way to get the materials out there to the target audience. I was glad to hear about the TRAIN link.
- The multifaceted approach incorporating outreach, self-directed training and hands-on simulated training is designed to reach a wide audience.
- Use of the prop and procedure to teach fire personnel are appropriate, and from the quotes you can tell that it's just what they need.

**Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.8** based on accomplishments.

## **SAFETY, CODES AND STANDARDS**

- The project is well on the way to providing a much needed service for "initial training" as well as "recurring training" where the technology is in service.
- It is not clear how one measures success in this sort of effort (e.g., number/percentage/by region of responders or trainers trained) but given the feedback received by attendees, the program is having a positive impact.
- From the responses of the students, it seems that this project is accomplishing everything it needs to accomplish. It's good to see steps being taken to get the prop to many more people. The instruction seems to be working well, so steps should be taken to get the course to more students and locations.

### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **3.3** for technology transfer and collaboration.

- To the novice and outsider this program is still "hard to find", but is getting "louder" on the radar screen. Perhaps renewed efforts to identify other stakeholders would be helpful. Groups like the National Training Institute (NTI, formally the National Training Institute of the Electrical Industry), the National Joint Apprenticeship Training Committee (NJATC), as well as individual regional "union shops and houses" (fire and other emergency response teams), would be good collaborative options.
- Their collaboration and cooperation with other institutions is very good. There is probably even more feedback from other portions of the PNNL programs (incidents database, safety panel, etc.) that are not listed here since they are providing an integrated approach to safety and education.
- The partners are very appropriate, but some additional information regarding their contributions would be helpful.
- There was good collaboration with organizations like the California Fuel Cell Partnership (CaFCP) to assist with training and development of modules and with fire service personnel for course content.

### **Question 5: Approach to and relevance of proposed future research**

This project was rated **4.0** for proposed future work.

- Full support must be given to this outstanding effort. The identification of training sessions should start to focus on a greater emphasis of "recurring training" on an ongoing basis.
- The project approach and relevance are both outstanding. Enhancing the online training, taking the prop-based course on the road and continuing collaborations through CaFCP are all good.
- Off-site training opportunities and extending channels through Department of Transportation (DOT) and the International Association of Fire Chiefs will provide wider training opportunities. Forklift training variants will be useful as well.
- It is excellent to see plans that take the prop and course to other sites and also visits to other cities.

### **Strengths and weaknesses**

#### Strengths

- The project focuses real-time training for essential parties.
- This was a well-designed program showing very good results.
- Using a prop to give hands-on training and the ability to take it to other locations is clearly the strongest part of this project. The second most important part would be the awareness-level online course that is essential for the folks who can't come to experience the prop in-person.

#### Weaknesses

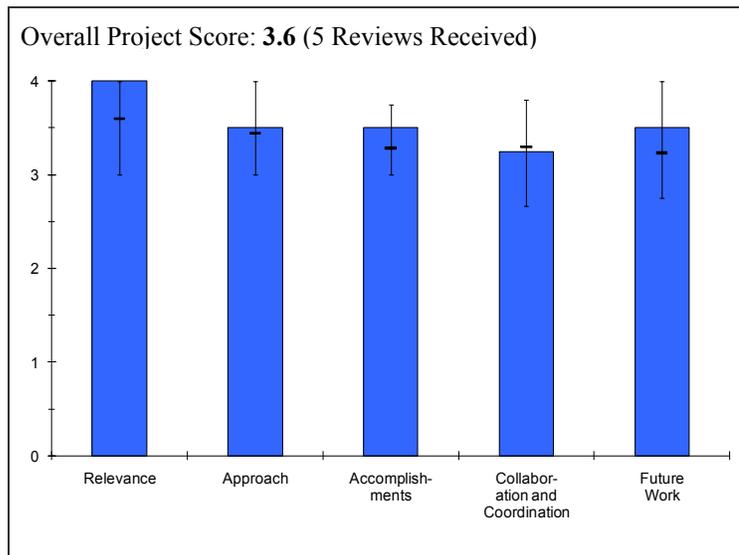
- Perhaps a site on the east coast will soon be in order. Cooperation and collaboration with the Department of Defense (DOD) would help.
- A forklift training variant should be given priority over other options (stationary power, portable power and auxiliary power).
- The project needs to get the prop to more people and more locations.

**Specific recommendations and additions or deletions to the work scope**

- They need to develop a "full up" simulator as well as a real-life training device that is the next generation of this already outstanding tool. They also should start to integrate the growing high-voltage drive train electrical intricacies, as well as perhaps the numerous electronic control devices for unintended active restraint devices. This is the real deal! Bravo so far!
- This was already suggested, but I cannot emphasize enough developing a cooperative and even perhaps collaborative relationship with prime stakeholders from the various service branches within the DOD!
- Non-vehicular responses should be integrated with personnel certification while providing feedback to the regulators. Public release for the emergency response guidebook and how they provide the right information in the right format is important. They need to be talking proactively with the DOT.
- It would be good to get a sense from the fire service personnel about how concerned they are with non-vehicular incidents. If they are aware, but not concerned, then the current focus on vehicles would seem the most appropriate. If they are concerned perhaps scope needs to be added.
- Data on the website usage of the awareness-level course would be good in order to show how strong interest is in that course and whether it's growing or not.

**Project # SCS-17: Hydrogen Safety Training for Researchers***Salvador Aceves; Lawrence Livermore National Laboratory***Brief Summary of Project**

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

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **4.0** for its relevance to DOE objectives.

- I think training is critical to the advancement of the hydrogen industry.
- Appropriate hydrogen safety training is critical to avoiding accidents. The DOE Fuel Cell Technologies Program sponsors many laboratory research projects that must maintain good safety records. There are two audiences for the LLNL hydrogen safety training: 1) laboratory researchers who are new to hydrogen; and 2) technical personnel who are in charge of laboratory operations and need more detailed information on component design, assembly and leak testing.
- Safety training (online and in-person) is essential for the safe operation of hydrogen research operations.
- The project has a simple yet important premise, to give inexperienced technical people at universities, companies and even government agencies a web-based tool to learn about hydrogen and related technologies.
- The project contributes to the safety in handling hydrogen.

**Question 2: Approach to performing the research and development**

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

- Two courses were developed to serve the two target audiences: a four-hour web-based class developed for laboratory researchers who work with hydrogen and a three-day hands-on class developed for technical staff in charge of designing, assembling and testing hydrogen systems that will be used by researchers.
- The activity provides both online and in-person (which is being developed) training. This approach is important to impact a large number of people requiring general training through the online course, and also offers a more intense in-person class for those working more closely with high-pressure systems.
- The class materials and approach are easy to replicate for other organizations.
- This is a simple, yet technically sound, approach to presenting complex materials.
- It provides good feedback on knowledge retention with testing after each module.
- The module for laboratory personnel should be divided into two, because the one presented may be too basic for many personnel. Many technicians have some basic chemistry training and a more advanced module specific to hydrogen would be more rewarding.

**Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.5** based on accomplishments.

- LLNL completed the six modules of the four-hour web-based course and they were peer reviewed twice by the Hydrogen Safety Panel. This course is now ready for use. Development of the three-day course is just getting started. A variety of components have been procured for the hands-on course (e.g., pressure vessels and regulators) in LLNL's high-pressure laboratory.
- Given the extremely low level of funding, this project is showing amazing progress, especially in comparison to other projects with much higher funding.
- Based on the budget, this project has done an extremely good job developing the web-based tool.

**Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **3.3** for technology transfer and collaboration.

- Hydrogen Safety Panel peer reviews of the web-based course resulted in valuable improvements to the modules.
- Peer review of the on-line material is excellent. LLNL has much experience in pressure safety training.
- There was good collaboration with Hydrogen Safety Panel and laboratory managers during the peer review.
- I would collaborate in the future with NASA technology managers and see if they can use it to train contractors.

**Question 5: Approach to and relevance of proposed future research**

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

- The project should maintain and improve the web-based class based on user comments and complete the hands-on class.
- The completion of the development of the in-person class is an important activity and should be fully supported.
- This work should become more of an educational activity with continued peer review by educators.
- Keep the same group to develop these expanded classes and fully fund the activity.

**Strengths and weaknesses**Strengths

- The Web-based course makes good use of graphics and provides opportunities for students to test themselves on what they have learned.
- The technical expertise and facilities exist at LLNL to develop and provide the training.
- This was a great approach and produced sound technical material.
- It provided good materials and setting for training personnel in the safe handling of hydrogen and reached out to the right audience.

Weaknesses

- Do students have to come to LLNL for the three-day course? It would be more useful to have it tailored specifically to their own laboratory facilities.
- I found no weaknesses.
- The web-based course may need to be a multi-pronged approach providing introductory modules and more advanced modules for laboratory personnel who have associate or college degrees.

**Specific recommendations and additions or deletions to the work scope**

- In the testing module, I understand that if you mis-number one item you fail the test. It may be helpful to offer immediate feedback on the questions in the test, whether or not this would occur during the actual test and be recorded.

## **SAFETY, CODES AND STANDARDS**

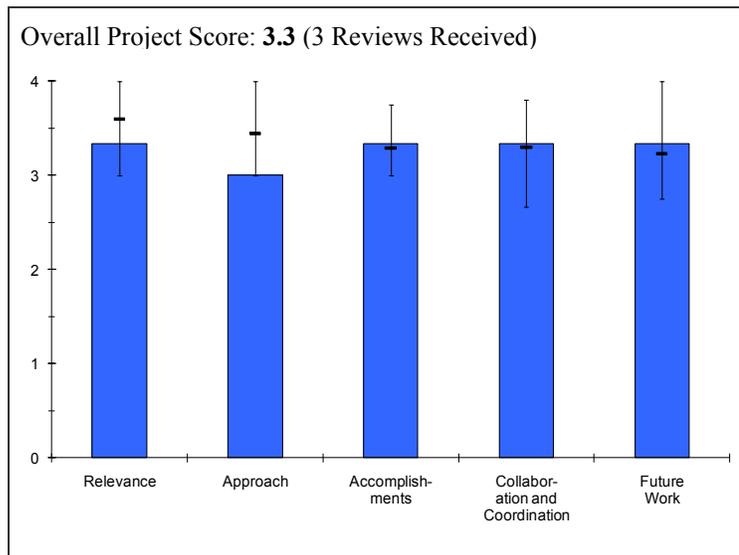
- The hands-on course should be thoroughly peer reviewed by the Hydrogen Safety Panel and other subject matter experts prior to offering it to prospective students.
- It is recommended to fully fund this activity, as it addresses many of the issues of safety for an expanded national effort to use hydrogen as an energy carrier.

**Project # SCS-18: Optically Read MEMS Hydrogen Sensor***Barton Smith; Oak Ridge National Laboratory***Brief Summary of Project**

The goal of this project is to develop optics-based sensing technology that achieves DOE research and development targets for hydrogen safety sensors. Milestones are to: 1) complete characterization of response time, recovery time, sensitivity and accuracy within the operating temperature range; 2) establish commercialization partnerships; and 3) demonstrate sensor performance and compliance with safety goals.

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **3.3** for its relevance to DOE objectives.



- The project addresses the standard practice of safety variations.
- The cost-effective hydrogen sensor technology is an enabler for more robust hydrogen safety practices.
- Sensors are critical for infrastructure development.

**Question 2: Approach to performing the research and development**

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

- The operational temperature range should be expanded to  $-40^{\circ}\text{C}$  on the low end. This would address applications in both vehicles and appliances.
- More detail could be provided regarding the work flow (not just milestone dates). Some discussion on efforts related to manufacturing and packaging would be useful.
- This was an excellent presentation of the approaches selected. The presentation does not say which, or how many, approaches were discussed and discarded.

**Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.3** based on accomplishments.

- The overall technical accomplishments and achievements are good. The improvements in instrument response and size are noted. The identification of commercialization partners is also noted.
- The technology is very promising showing very acceptable performance across the performance target metrics. Examination of potential poisoning agents (hydrogen sulfide, ammonia, etc.) should be investigated.
- Working with industry partners should accelerate the market penetration time.

**Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **3.3** for technology transfer and collaboration.

- The transfer of technology is noted.
- The project has a good mix of academic and industry partners with appropriate experience that are materially contributing.

- This is credible data in collaboration with private industry. Perhaps you could have some code people aware of the sensor work.

### **Question 5: Approach to and relevance of proposed future research**

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

- This is prudent in scope given the commercialization potential.
- The future work is well thought-out and structured, but more detail should be provided regarding potential decision points.
- The proposed work seems more academic than commercial, but that's the process. I suggest revisiting the number three and four technologies to see if there are chances for improvement.

### **Strengths and weaknesses**

#### Strengths

- Collaboration and technology transfer stand out as strengths in this project.
- A well-designed project that is delivering promising results.
- The cooperation between government and industry is encouraging.

#### Weaknesses

- I would have liked to see a nationally recognized testing laboratory like Underwriters Laboratories (UL) involved.

### **Specific recommendations and additions or deletions to the work scope**

- One of the biggest code hurdles to acceptance of indoor fueling, specifically home fueling, is the lack of an odorant in hydrogen. Code officials should be aware of the advances in hydrogen sensor technology and its relevance to their understanding of hydrogen as a fuel. Also, an organization like UL should be involved in evaluating their technical progress with an eye on the device commercialization process. UL, or any other Nationally Recognized Test Lab (NRTL), will eventually be responsible for certifying the safe operation of the sensor as well as its performance to established requirements for Code officials.