2019 – Safety, Codes and Standards
Summary of Annual Merit Review of the Safety, Codes and Standards Subprogram

The Safety, Codes and Standards (SCS) subprogram supports research and development (R&D) that provides critical information needed to define requirements and close gaps in safety, codes and standards to enable the safe use and handling of hydrogen and fuel cell technologies. The subprogram also conducts safety activities focused on promoting safety practices among U.S. Department of Energy (DOE) projects and the development of information resources and best practices. The SCS subprogram includes research on liquefied and cryogenic hydrogen release physics, contaminant detection and sensor technology, and quantitative risk assessments and consequence analysis. The subprogram also focuses on domestic and global codes and standards harmonization to enable large- and small-scale hydrogen applications.

Summary of Safety, Codes and Standards Subprogram and Reviewer Comments

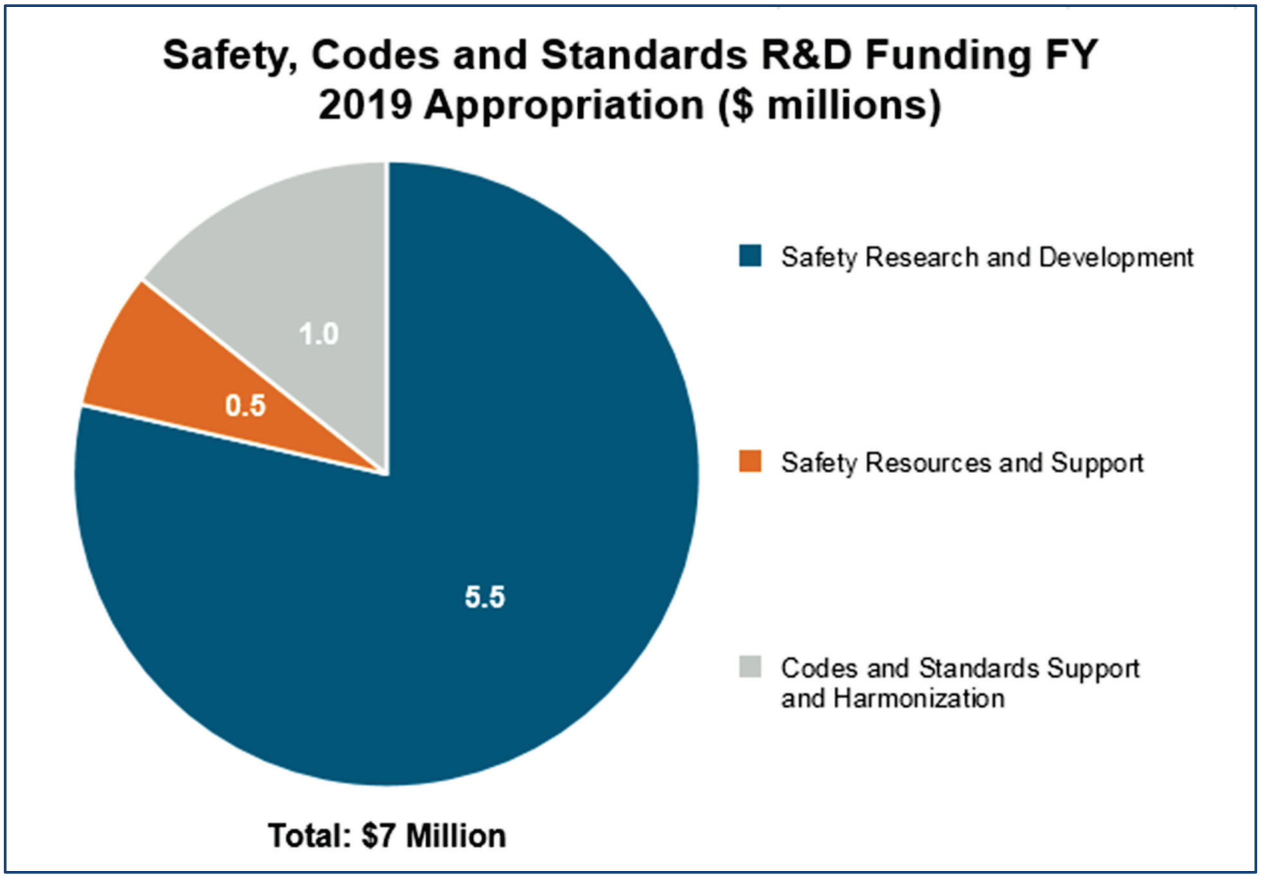
Hydrogen and Fuel Cells Program reviewers were highly supportive of the SCS projects and noted that the work of the SCS subprogram enables accomplishment of the broader goals of DOE and the Fuel Cell Technologies Office. Reviewers recommended further inclusion of a safety element across all subprograms. Reviewers applauded the subprogram for its alignment with industry and stakeholder needs and stated that SCS work is an essential framework for hydrogen and fuel cell activities. Reviewers encouraged the subprogram to identify means of increasing industry stakeholder participation in SCS activities. Reviewers praised the subprogram's increase in international engagement activities and particularly applauded the contribution of the subprogram to organizations such as the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE). The reviewers also noted the importance of continued SCS participation in international regulations, codes and standards forums.

Key accomplishments identified by reviewers include the launch of the Center for Hydrogen Safety (CHS) and the R&D feedback to enable a significant reduction in the separation distances for bulk gaseous hydrogen storage in the National Fire Protection Association (NFPA) 2 Hydrogen Technologies Code. Reviewers felt that the CHS addressed a critical need for stakeholders in terms of safe deployment of hydrogen and fuel cell technologies. Reviewers continued to praise the science-based approach and the provision of feedback to code development organizations and standards development organizations. Key recommendations for SCS R&D include expanded quantitative efforts and data dissemination. Reviewers praised R&D efforts to enable cost reduction and encouraged the subprogram to balance experimental activities with analytical and computational efforts. Reviewers also recommended that materials R&D be expanded to disseminate materials selection guidance and lessons learned.

Nine projects were reviewed, receiving scores ranging from 2.85 to 3.7, with an average score of 3.43. Each of the individual project reports in this section contains a project summary, the project's overall score and average scores for each question, and the project-level reviewer comments.

Safety, Codes and Standards Funding

The fiscal year 2019 appropriation for the SCS subprogram totaled $7 million. The funding was focused on safety R&D, and the breakdown is shown in the following figure. The funding is expected to provide continued support of SCS R&D and efforts on domestic and international collaboration and harmonization of codes and standards. Future work in the subprogram is expected to focus on facilitating reduced regulatory barriers, such as by providing scientific anlaysis for revised bulk liquid hydrogen separation distances.


Safety, Codes and Standards R&D Funding FY 2019 Appropriation ($ millions)
1.0
0.5
5.5
Safety Research and Development
Safety Resources and Support
Codes and Standards Support and Harmonization
Total: $7 Million

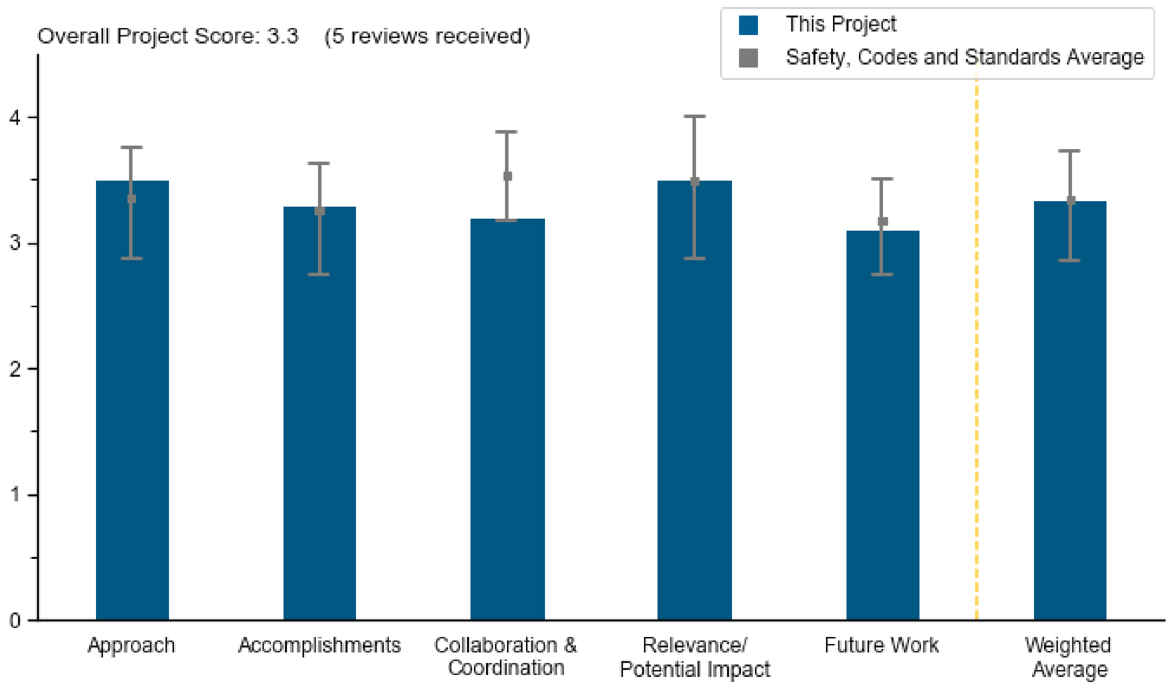
Project #SCS-001: National Codes and Standards Deployment and Outreach

Carl Rivkin, National Renewable Energy Laboratory

Brief Summary of Project

The objective of this project is to further the deployment of hydrogen fuel cell technologies with particular focus on the infrastructure required to support fuel cell electric vehicles. This outreach and training project supports technology deployment by providing codes and standards information to project developers and code officials, making project permitting smoother and faster.

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Safety, Codes and Standards projects.

Question 1: Approach to performing the work

This project was rated **3.5** for identifying and addressing barriers, project design, feasibility, and integration with other relevant efforts.

- This project accomplishes what it set out to do: work to provide to the standards development organization (SDO) and code development organization (CDO) community with technical data and analysis that will help to build a consistent set of regulations, codes, and standards. This is done by participation in the code and standard writing process; the principal investigator (PI) chairs National Fire Protection Agency (NFPA) 2. By working with other research entities, this project ensures that relevant research in the community, such as in other national laboratories, is efficiently communicated to the SDO and CDO communities and with each other. This is done through the Inter-Laboratory Research Integration Group (IRIG). This project also has branded an iterative process for code development called Continuous Code and Standards Improvement (CCSI). CCSI is intended to easily describe the iterative process for code development that embraces deployment, field performance, research and engineering analysis, and finally modification or development of codes. This methodology for code development brings all the relevant pieces to the development table. In today's science-based code development process, this iterative process is very good.

- The project's approaches include collaborating with stakeholders, leveraging of existing resources, and developing safety requirements, which should be effective for the objective of the safe deployment of hydrogen technologies.
- The approach with the CCSI and IRIG is well-thought-out and can serve the Safety, Codes and Standards community very well.
- The accomplishments for this project are a moving target. NFPA 2 is on a code cycle and will require several generations to optimize the recommendations. Still, the progress to date has been notable.
- The overarching plan and the specific iterative practical accomplishments of this project support real and sustained progress. Embracing the concept of continual refinement in light of field experience, technological evolution, and market dynamics is relevant but also balanced by specific, identifiable, logical, and progressive outcomes in this review period. Engagement and leadership are both integral parts of the approach, and both are essential for progress in codes and standards. It would be beneficial to maintain a more disciplined focus on differentiating tangible accomplishment of important outcomes from activities when reporting accomplishments. For example, presentations such as the one made for the Canadian code committee demonstrate good collaboration and engagement and might support future harmonization; ongoing work with Sandia National Laboratories to address setback for liquefied systems is also important. Both of these have merit and can support future outcomes of note; however, these are not themselves significant accomplishments (as they have been presented). The methods for presenting the newest tangible work products produced by the project are in some cases unclear and somewhat confusing. Going forward, the project should continually refresh the content on accomplishments to be clearer about what specifically was done (e.g., papers and reports published) in the immediate past year, rather than lacking precision about when accomplishments were made over the course of numerous years. It is recognized that technical work products might take several years to result in an identifiable code or standard revision. However, the project should focus on reporting relevant accomplishments in the previous year and dismiss past outputs from the reporting, such as paper publications from numerous years ago.

Question 2: Accomplishments and progress

This project was rated **3.3** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- Chairing the Hydrogen Technologies Task Group for the NFPA 2 Hydrogen Technologies Code is an important role to advance evolving code requirements that are appropriately based on foundational safety concepts. Because of NFPA scheduling reallocations, fiscal year 2018 included the second draft meeting and corollary actions to support the finalization and publication of the much-needed next edition in 2019. Also, the Permit Checklist Task Group, chaired by the National Renewable Energy Laboratory (NREL), developed a standardized approach for permitting stations with gaseous/liquid storage that should promote more rapid approvals and allow for relaxation of safety setback distances while still providing for safe deployment.
- Much progress has been made, which includes the standard permit for gaseous/liquid hydrogen fueling stations, the proposal to reduce safety setback distances, component failure analysis, and so on. These accomplishments and progress all go toward the objective of safe deployment.
- The accomplishments for this project are a moving target. NFPA 2 is on a code cycle and will require several generations to optimize the recommendations. Still, progress to date has been notable.
- All of the accomplishments on slides 8 and 12–17 are valuable and useful. On slide 18, coordination is seen between the NFPA, the International Organization for Standardization (ISO), and the Canadian Hydrogen Installation Code (CHIC). This activity is live now, but the individual performing this activity is leaving, and it is unclear if there is a plan in place to account for that departure. The accomplishments on slides 9, 10, and 11 are surprising; the language is quite strong that the NREL directed the production of 2020 NFPA 2 and its task forces. This is an industry consensus code, and as such, the NFPA Hydrogen Technologies Technical Committee "directs" the changes; the chair is supposed to facilitate the discussions that happen in that process. Slide 19 states that the NFPA 2 technical committee voted not to include the document in the appendix of NFPA 2. With regard to the standard permit checklist, that is not a product or deliverable. As a member of the technical committee and a member of that task force, this reviewer's knowledge of that document is that there was an NFPA 2 supplemental ballot back in March, and there has not been any

further information from then until this poster (i.e., the technical committee has not been made aware of the status or any progress on the standard permitting checklist).
- The IRIG ranking of safety projects seems a little weak to deserve the level of credit that the PI is giving it; however, the leadership and work on NFPA 2 with the five task groups (Emergency Response, Storage, Equipment Enclosure, Permit Checklist Task Group, and Alternative Fuels group) deserve much credit and are very good. This work resulted in a significant reduction in some significant separation distances in the 2020 edition of NFPA 2 compared to the previous version; this is excellent. The development of a standard permit for hydrogen storage will also be extremely helpful in reducing cost and time for permitting; this is also excellent. The development of the component failure analysis for facility owners is very good and should help a great deal in learning about systematic failures in the field for similar systems. This project scored a 3.0, not a 4.0 or 3.5, because the accomplishments for the IRIG were not as strong as expected. It would have been good to see not just a ranking but a true working group among the members, which does not seem to have happened. This needs to be much more than simply NREL polling the national laboratories to rank order priorities. A true working collaboration on projects was anticipated—for example, a working group collaboration on the component failure that would involve a true collaboration with Sandia National Laboratories (SNL) and NREL. It might exist but was not seen in the presentation. The impression is given that the analysis on the failure is not done in a collaborative manner but rather in a stove-piped manner; the part is sent to SNL for materials analysis, but the analysis does not include SNL in the front-end failure determination. The analysis is done in series, not collaboratively in parallel.

Question 3: Collaboration and coordination

This project was rated **3.2** for its engagement with and coordination of project partners and interaction with other entities.

- Collaboration and coordination are emphasized in this project. Industrial gas companies, SDOs, DOE national laboratories, regional fire and building officials, and regional hydrogen advocacy groups are involved in this project and have specific different divisions of labor.
- Standards and codes are by their inherent nature collaborative, involving many different parties, and in that sense, the project includes robust collaboration. While there is value in being engaged in a standards development process, the project should focus on enabling or catalyzing new results. Being strategic and focused on identifying, enacting, and reporting on specific collaborations toward outcomes that might not occur, might not occur as soon, or would not otherwise occur would be an appropriate objective and benchmarking process for this project. Coordination among codes and standards is an area of specific and ongoing need for hydrogen technologies, and this project can play a more prominent role in identifying and closing those gaps among codes, standards, and geographies. Some of that work has been initiated, and it should be maintained and amplified.
- This presentation is addressing a myriad of tasks. The collaboration is appropriate for each task. The coordination appears appropriate.
- The only thing on the list of collaborations that can truly be named a collaboration is the partnering with a collaborator to measure leak rates at the facility. Having other entities sit on the same committee as NREL does not itself constitute a collaboration. The fact that NREL, SNL, Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory, and Los Alamos National Laboratory all sit on the NFPA task force groups does not mean they are collaborators. If, however, NREL and SNL collaborate on a failure analysis that occurred in the field and collectively wrote the report to present collectively to the relevant NFPA task force, that would constitute a collaboration. Providing information and performing outreach events does not constitute collaboration; it is outreach but not a collaboration. Providing input to help develop state regulation is not collaboration. If, on the other hand, NREL worked closely with the state regulators in the development of the regulations (i.e., sat on their committees), that would constitute collaboration and/or coordination. NREL has worked with station developers on the component failure project and developed permitting tools; this is a collaboration and/or coordination.

Question 4: Relevance/potential impact

This project was rated **3.5** for supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- The overarching project intent related to refinement and advancement of hydrogen safety codes and standards remains relevant. The outcomes accomplished in this review period on codes and standards are very good, in light of the impending publication of the 2020 edition of NFPA 2 and its new content, driven in part by the project.
- The potential impact of this project is large. Just liquid spill mitigation is a home run. Component failure modes are also of high value.
- All in all, this project is very relevant and has already shown significant impact in the dissemination of information; possibly most important is the work on NFPA, all task forces, and in particular the resulting reduction in separation distances.
- There is no doubt that the content of this project will have significant impact on hydrogen technology deployment.

Question 5: Proposed future work

This project was rated **3.1** for effective and logical planning.

- The project's proposed future work for supporting codes and standards for H2@Scale is relevant. A more specific roadmap would help ensure the project would facilitate deployment of H2@Scale. The project would benefit from more specific planning in preparation for upcoming NFPA 2 and other revision cycles. "[Continuing] to identify the needs of safety information users and provid[ing] information to meet those needs in the most accessible and intelligible form possible" can certainly have value in some cases but is quite amorphous. The project should either define more clearly what that would constitute that is not being accomplished by other entities (such as the Center for Hydrogen Safety), or supplant that work with specific tangible efforts, such as codes and standards, gap analyses, and gap closure. The component failure analysis effort can provide a rich basis for transforming field experience into targeted, substantiated codes and standards proposals for continued enhancement of requirements. This does not seem to have yet occurred, and as presently laid out, the plan to accomplish that is not entirely clear. The project would benefit from a clearer articulation of the specific actions that will result in the fault analyses and how they will be used to surgically elevate the safety requirements. The project would also benefit from clearer bidirectional coordination with the NREL National Fuel Cell Technology Evaluation Center efforts, including the safety aspects of the Hydrogen Fueling Infrastructure Analysis, to minimize redundancy and optimize outcomes. Sharing findings and data with the Hydrogen Risk Assessment Model (HyRAM) is logical and appropriate, but the plan for that to have a clear impact on codes and standards needs to be clarified or the projected outcomes might need to be re-evaluated in this regard. As the permitting checklist was an important outcome for this review period, more actions to address the rollout would be beneficial. This includes promoting awareness of the new tools through mechanisms such as webinars. Furthermore, planning to engage with regulators and other stakeholders to determine whether the tools are as effective as intended, as well as to find specific areas for improvement while preparing for the next edition of NFPA 2, would be relevant.
- The proposed future work is an evolutionary extension of the current effort, which is fine, but there should be a revolutionary proposed next step, maybe proposing efforts to advance hydrogen use in very nontraditional applications, such as in airplanes or in maritime settings onboard ships.
- The proposed future works are specific and will be effective in addressing the key issues.
- The project should continue down the current path.
- It is unclear what is meant by "Structure hydrogen vehicle fueling requirements to better match infrastructure projects." Additionally, "Publish Hydrogen Fueling Station Permitting Guide" is listed as part of future work, but the previous accomplishment slides make it seem like it is published.

Project strengths:

- The project has a strong value proposition in terms of promoting continual refinement of hydrogen codes and standards. Leading work on the impending next edition of NFPA 2 and the permitting checklist comprise practical, effective advancement. The staff executing the project has been well connected with relevant stakeholders in the community to promote ongoing collaboration.
- The project's strengths include the ability to leverage existing resources and the ability to conduct testing at the fueling station; that, along with input from industry experience, feeds into the code development process.
- The issues under this project are very important for the safe deployment of hydrogen technology; the accomplishments and progress are on a good path.
- This is a very important activity with demonstrated value to the community.
- The project's strengths include its plan and new leadership.

Project weaknesses:

- The project's weaknesses include the heavy influence in/on the NFPA 2 process, particularly with the standard permitting checklist process. There is no argument that this kind of document will be helpful; it was more the way in which the process was executed.
- Aside from the direct actions related to codes and standards development, the project does not seem clearly focused on specific actions leading to tangible outcomes. There are opportunities for improvement in striving for catalyzing new outcomes in hydrogen codes and standards that would not otherwise occur, rather than solely being a committee participant. Recognizing that codes are on a cyclic schedule, there does not seem to be a staged plan of planned actions for progress over multiple cycles. The outreach aspect of the project is ambiguous and might be best fulfilled by other entities in practice. A clearer plan is needed for using component failure analyses to drive specific codes and standards proposals. It seems that in some aspects, the project is resting on accomplishments from several years ago, rather than the immediate past, and overvaluing activities as accomplishments in some cases. Leadership roles in code activities have played a large role in successes in the past year, and continued success may be linked to staff maintaining those leadership roles (especially in the present construct).
- NREL should work to develop activities, partners (like the IRIG members) with whom to truly collaborate. It should be that both parties contribute to the root cause of a failure, both parties contribute to the analysis, and both parties contribute to the report. NREL making a presentation at a CHIC meeting is not a coordination; however, NREL coordinating the requirements of NFPA 2 with CHIC and ISO 19880-1 is.
- The project should be aware of tunnel vision and vested interests from advisers.
- The path proposed is not very specific about the hydrogen safety issues identified in the range of applications dictated by H2@Scale.

Recommendations for additions/deletions to project scope:

- As the hydrogen market and community continue to evolve, reconsideration of the coordination and most impactful and specific future work plan would be beneficial. Optimizing and articulating coordination with other work, such as the Center for Hydrogen Safety and the National Fuel Cell Technology Evaluation Center, will help minimize redundancies and best promote impact. With respect to collaborations and coordination, being more focused in general would be beneficial. Standards and codes are by their inherent nature collaborative, involving many different parties. Being strategic and focused in identifying, enacting, and reporting on specific collaborations would be appropriate for the project. Coordination among codes and standards, especially as they evolve on different cycles by the actions of different standards organizations, is an area of specific and ongoing need for hydrogen technologies. This project can play a more prominent role in proactively identifying and closing those gaps. Especially with the cyclic nature of code development, it would be helpful to have an active plan to identify the issues that will need to be addressed in future editions and then plan in advance to build the necessary materials in the intermediary periods.

- The project team should maintain NREL as a resource, for example, for station validation exercises that allow for the advancement of the technology, rather than try to be an influencer in the same capacity as industry or an industry association, like the Compressed Gas Association, for example.
- Years ago, NREL was evaluating a relief valve failure and dropped the evaluation after duplicating the failure. The team should consider reassessing the project. NREL has a test protocol and a test vehicle (the failed valve). The next step would be to substitute other materials for the wetted components and test per the previous test plan. Several assemblies could be tested simultaneously.

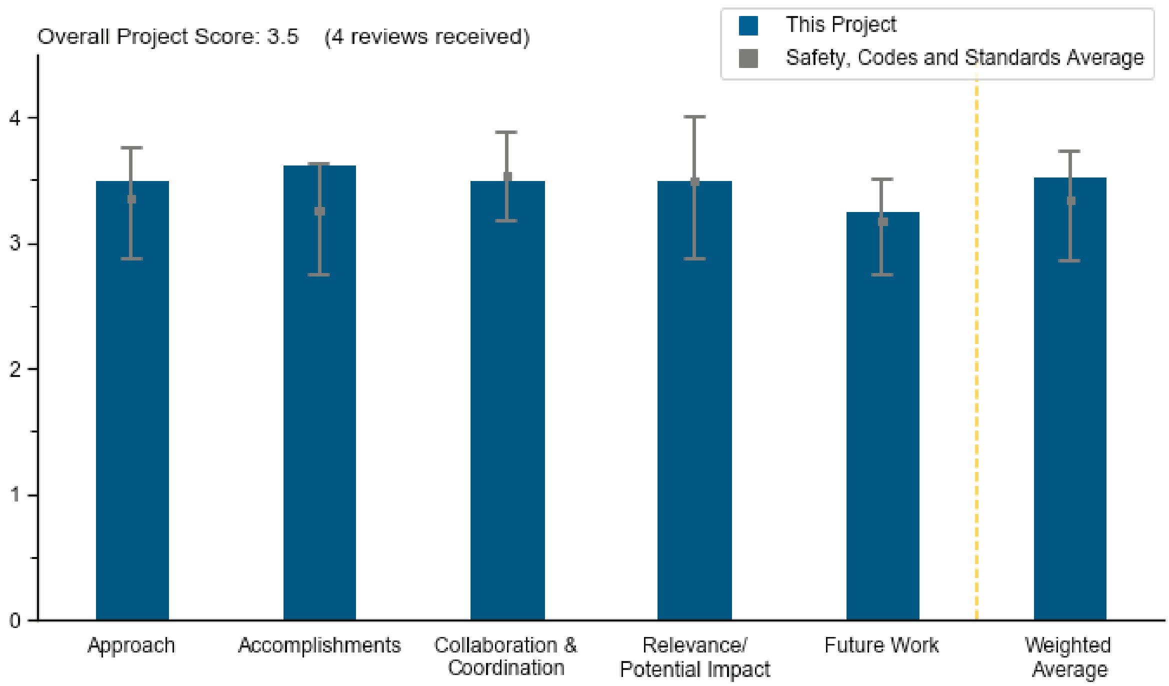
Project #SCS-005: Research and Development for Safety, Codes and Standards: Materials and Component Compatibility

Chris San Marchi, Sandia National Laboratories

Brief Summary of Project

The main goal of this project is to enable technology deployment by providing science-based resources for standards and hydrogen component development and to participate directly in formulating standards. The project will (1) develop and maintain a materials property database and identify materials property data gaps, (2) develop more efficient and reliable materials test methods in standards, (3) develop design and safety qualification standards for components and materials testing standards, and (4) execute materials testing to address targeted data gaps in standards and critical technology development.

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Safety, Codes and Standards projects.

Question 1: Approach to performing the work

This project was rated **3.5** for identifying and addressing barriers, project design, feasibility, and integration with other relevant efforts.

- The approach uses a sound physics-of-failure basis for considering the critical attributes and assessments for materials in hydrogen service. Using both design principles and performance principles, tailored to specific applications, is reasonable and will promote different valid options to be explored.
- This project continues to advance the development of science-based codes and standards that are required for commercial hydrogen storage and transport applications. Highlights are capabilities to perform measurements in high-pressure hydrogen, the strong international collaborations, and the development of consensus leading to new American Society for Testing and Materials codes and standards. The approach for use of wet air as opposed to wet hydrogen needs verification. Regarding the aluminum alloys, there may be a need to evaluate oxide surface scales as a function of gas conditions and stress state.
- The approach for this work is excellent. The end goal is to incorporate the data into the ASME Pressure Technology Code, making the data accessible worldwide.

- The approach addresses the technology barriers. It has been in progress for a number of years, and reviewer comments from prior years are addressed in a considerate and objective manner.

Question 2: Accomplishments and progress

This project was rated **3.6** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The Sandia National Laboratories Hydrogen Effects Database (Granta MI) is accessible to the public. Identifying the critical limiting behavior of fatigue performance has supported specific protocols to be focused and advanced, contemplating a conservative safety factor. Efforts on stationary pressure vessels have demonstrated advancement, including approval of ASME Code Case 2938 (which will be effective upon its impending publication) and design curves addressing options for high-strength steels. A proposal for a standardized international approach on materials compatibility testing has been developed, but agreement is still in progress. Work to address complex geometries and welds is ongoing, but its completion will be essential moving forward.
- Significant accomplishments include the approval of ASME Code Case 2938, which is a direct result of the work funded by the DOE Office of Energy Efficiency and Renewable Energy.
- The progress to date is impressive. The results will ultimately reduce costs and improve safety on hydrogen infrastructure projects.
- The overall project goal is not well defined. Material performance in various hydrogen environments could be researched through never-ending combinations of conditions and materials. However, good progress in some areas has been made to date, and integration with various databases and other efforts has been considered.

Question 3: Collaboration and coordination

This project was rated **3.5** for its engagement with and coordination of project partners and interaction with other entities.

- International collaborations in both Asia and Europe are a highlight of this work. Partnerships have been established with leading institutions such as Kyushu University in Japan (and the Japanese National Institute of Advanced Industrial Science and Technology [AIST]) and appear to be truly working relationships with important deliverables on international codes and standards.
- The project incorporates effective collaborations with industry, academia, and standards development organizations to advance the practical outcomes of the project's work. Collaboration spans geographies in the Americas, Asia, and Europe. Connections with the Hydrogen Materials Compatibility Consortium (H-Mat) are identified appropriately and are being addressed.
- The collaboration/coordination/partner list is extensive and international. Additional U.S. companies and researchers might be appropriate.
- Other interested institutions and stakeholders have been identified, and collaborative efforts are under way. Maintaining that collaboration and obtaining consensus may be difficult barriers that were not identified.

Question 4: Relevance/potential impact

This project was rated **3.5** for supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- The issue remains relevant, and the project is showing real advancement in addressing the issues in moving from a science-based foundation to practical protocols that are affecting, and will continue to positively affect, the hydrogen community. Work to scale solutions globally is relevant and in progress.
- This project makes significant impacts by bridging the scales from the basic science of fracture mechanics to the implementation of applicable codes and standards.
- The project is very relevant and could have a significant impact.

- This activity is highly relevant. A little more focus on tungsten inert gas and metal inert gas field welding might be in order. These welds will most likely be issues.

Question 5: Proposed future work

This project was rated **3.3** for effective and logical planning.

- The planned future work to address welds and aluminum is appropriate and well framed. The feasibility of ongoing revision of technical references rather than planning for fiscal year 2020 should be considered.
- The project scope is good, but plans and future work beyond 2019 are unclear. Note that the project end date is 2022.
- The proposed work appears appropriate.

Project strengths:

- This project constitutes relevant work that is using a physics-of-failure approach to leverage science into practical design and performance criteria, differentiated based on applications. The project has an effective network of global partners and collaborators. These have resulted in tangible and significant advancements.
- The project scope, collaboration with other institutions and stakeholders, and attention paid to past criticisms and suggestions are all project strengths.
- The team (collaboration), test staff, goal focus, and application are project strengths.

Project weaknesses:

- Continued future progress on some aspects, such as further acceleration of fatigue testing, might not be practically possible without breakthroughs in other efforts such as H-Mat.
- Based on the information presented, one weakness of the project seems to be plans for future work beyond 2020.
- There is plenty of European and Asian input but seemingly no input from U.S. academic researchers.

Recommendations for additions/deletions to project scope:

- Consideration of the practical execution of the performance testing is not explicitly addressed but would be beneficial to ensure the highest penetration of the solutions. Validation testing of the protocols using known valid and vulnerable designs, to the degree possible, is not essential but would be instructive.
- Gaps in the existing data should be defined. There should be an explanation as to what “science-based codes and standards” and “science-based test methodologies” mean in the context of this effort.

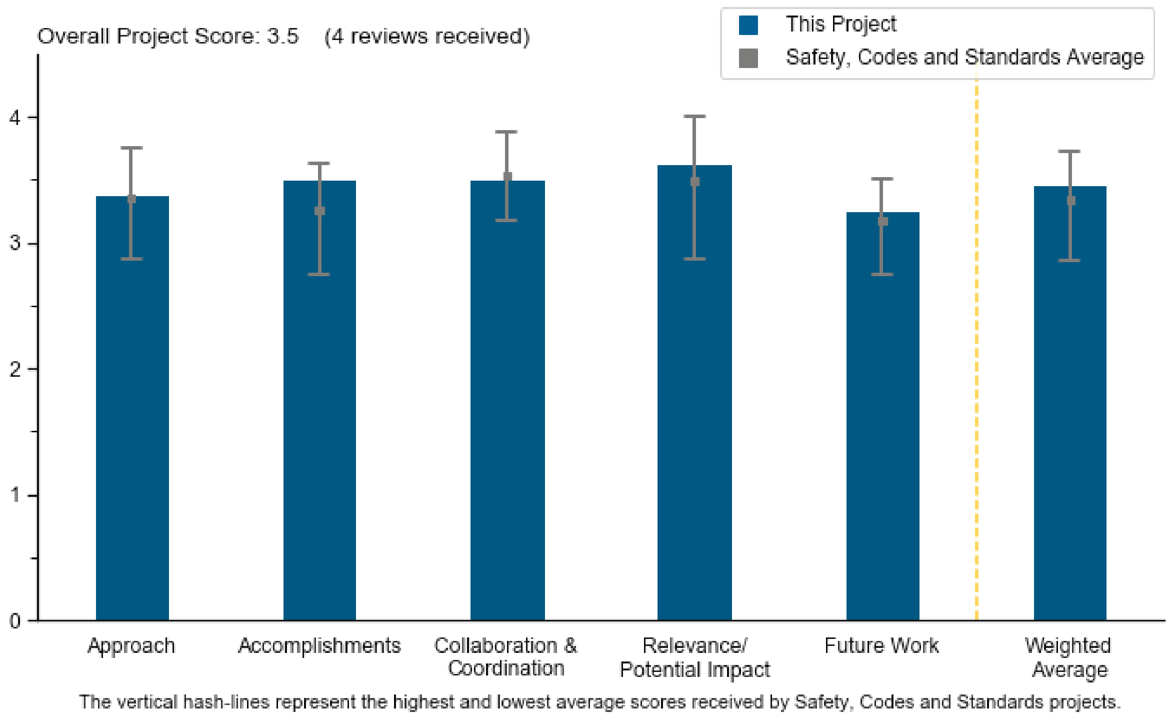
Project #SCS-007: Fuel Quality Assurance Research and Development and Impurity Testing in Support of Codes and Standards

Tommy Rockward, Los Alamos National Laboratory

Brief Summary of Project

The objectives of this project are to (1) focus on polymer electrolyte membrane fuel cell testing and collaborations and work with the American Society for Testing and Materials to develop standards and (2) develop an electrochemical analyzer to measure impurities in the fuel stream. The analyzer will be inexpensive, will be sensitive to the same impurities that would poison a fuel cell stack, and will support quick responses to contaminants.

Project Scoring



Question 1: Approach to performing the work

This project was rated **3.4** for identifying and addressing barriers, project design, feasibility, and integration with other relevant efforts.

- The project's approach is well thought out, the execution is excellent, and the overall technology used for the detection of contaminants is excellent. The research team addresses problems in a systematic and appropriate technical manner. The team quantifies the results before moving on. This is a very nice project.
- Overall, this project continues to make good progress. It has taken some time, but it is nice to see the hydrogen contaminant detector (HCD) analyzer being validated at a commercial hydrogen refueling station (HRS). Even though the focus on CO makes sense, the detection of other impurities needs to show further development and flexibility.
- There is a minor error on slide 1: the Project 2 end date is September 30, 2022 (not September 30, 2012). There are HCD fuel quality analyzers for offline (Project 1) or in-line analysis (Project 2). Project 2's approach seems to have improved based on feedback from Project 1. The approach now includes partnership with a small business to commercialize the technology, which is very promising. It is a bit concerning that there are significant unverified changes between Project 1 and Project 2 in order to achieve

true in-line testing. While some results are promising, others indicate the need for further changes to meet the requirements of in-line fuel monitoring. It is not clear that the technology is ready for commercialization, although it is needed in the field now.
- The approach is sound and yielding results. It is unclear how the lack of humidification or how the corrosive effects of H_3PO_4 are being addressed, or how the moisture being released by the electrolyte is affecting the water threshold.

Question 2: Accomplishments and progress

This project was rated **3.5** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The project is meeting its milestones. It takes the current state of the art and advances it incrementally to achieve the desired product. The project team has developed polybenzimidazole (PBI)-based and tin pyrophosphate (TPP)-based HCD technology that performs as the previous version but without the need for water, which is perfect. This will also reduce system complexity and cost and, most importantly, will possibly be able to operate in-line. The initial results are very interesting. Both the PBI and TPP membranes show very good promise in producing a HCD that shows promise of developing a technology that will work in this application. Work still needs to be done in increasing understanding of CO and H_2S poisoning for the PBI system. The assembly of the TPP composite membranes needs to be finished. The steady progress this project has accomplished is largely impressive.
- The project's progress is as should be expected. It is unclear how the performance is to be temperature-compensated, whether this is a software correction or a change in material selection. Slide 8 suggests a software tweak. The PBI results are an extender. H_3PO_4 has a vapor pressure that is very low, but measurable. This would slow the evaporation of the electrolyte, which would be a good thing. It is unclear whether the evaporation can be stopped (which would be the better thing) or if this is a case of "better" being the enemy of "good." It is also unclear whether TPP is viable. It seems 1,2-pentanediol may be a contaminant in and of itself. Both ethylene and propylene glycols are catalyst toxins.
- A significant accomplishment is the development of the wicking scheme that solved the hydration issues of dry hydrogen gas. The application of prototypes into real-life stations has resulted in meaningful improvements to the technology. The main concern is the rate of progress, as there has been no testing of the range of contaminants of interest, and improvements are still needed on the response time for CO detection. It is still too early to tell whether the project will ultimately be successful.
- The project has made good progress in the last year, mainly driven by the ability to validate the analyzer under real-world conditions.

Question 3: Collaboration and coordination

This project was rated **3.5** for its engagement with and coordination of project partners and interaction with other entities.

- The collaborators on this project are perfect: H2 Frontier, Inc., is a no-cost field test site; Skyre, Inc., is a support activity under the Small Business Voucher (SBV) program and collaborates with the National Renewable Energy Laboratory (NREL) on HCD development; and Los Alamos National Laboratory (LANL) provides support to Southwest Sciences, Inc. (SSI) in HCD development. These collaborations are very good and help the development community make use of LANL's capability and expertise; however, it is not clear what LANL gets out of these. This project did not score a 4 because, while these collaborations and coordination should continue, LANL needs to get something tangible out of the effort.
- The presentation did not get into detail regarding how well coordinated the partnerships and collaborations might be, although the collaboration on DOE Small Business Innovation Research (SBIR) and SBV proposals for the technology commercialization partner is noteworthy. The project partners are all suitable collaborators, including H2 Frontier, Inc., Skyre, Inc. (formerly Sustainable Innovations), SSI, NREL, and Bill Buttner. It would be beneficial to see collaboration with SAE International in some way, as well as with the California Fuel Cell Partnership, or one or more partners that work with fuel cell electric vehicles.

- This is an excellent team. Doug Wheeler might be a helpful consultant. He has phosphoric acid fuel cell (PAFC) experience.
- The project demonstrated great collaboration and coordination with other national laboratories and appropriate industry stakeholders.

Question 4: Relevance/potential impact

This project was rated **3.6** for supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- There is no doubt that an HCD is critical to the successful deployment of HRSs, now and in the future. The fuel quality delivered to the vehicle must be guaranteed to meet the SAE International and International Organization for Standardization (ISO) standards for contaminant-specified levels, or this technology will fail in deployment. Having HCDs at the fueling station, and more importantly at the nozzle, is critical to the success of fuel cell technologies.
- This activity is highly relevant. Assuming that the trials are successful, it would be beneficial to know if the product will be listed or if, at a minimum, it will be tested for ATEX (International Electrotechnical Commission [IEC] 60079) or the North American equivalent. This should be the final hurdle to commercialization.
- Depending on how the field trial finishes up, the project team should work with the Fuel Cell Technologies Office on how to best transition the technology and support a glaring need at HRSs. There was mention of partnering with a company, but if the Technology Commercialization Fund opportunity does not happen, there should be a plan for the next step.
- It is excellent that a commercialization partner has been identified so that the resulting technology may be able to get to the marketplace. There is concern about the pace of the progress being made.

Question 5: Proposed future work

This project was rated **3.3** for effective and logical planning.

- The proposed technology transfer activities are a very good and necessary role for the national laboratories. The proposed future work is very good. Continuing the development of PBI and/or TPP is appropriate. The proposed future technical work in this area is systematic, well thought out, and based in fundamentals; this is perfect. The project has a focus on commercialization; this will keep the team focused on the endgame.
- The steps defined in the presentation for Project 2 appear to be very basic first steps that will take a minimum of four years to develop into a product that, if successful, may have commercial relevance. The project team should develop a PBI-based analyzer (lower-technology-readiness-level work started in October 2018, based on the four-year proposal).
- The membrane development and evaluation are important, but it is uncertain what happens next. It would be good to see a Gantt chart showing the intended next steps and the final endgame.
- The proposed future work is acceptable.

Project strengths:

- This is a very important activity. It is founded in fundamentals and has extremely talented personnel and excellent facilities, which are applied to LANL's technologies as well as competing technologies from other entities through outside avenues (e.g., the SBV program). This is a perfect role for a national laboratory.
- The project's strengths include its team. Doug Wheeler may be a reference for PAFCs and derivative membranes.
- The project has good collaboration with its partners and is doing important work.

Project weaknesses:

- Slow progress is being made toward the availability of a useful product that can be reliably deployed. There is no guarantee that the project will result in the development of an in-line hydrogen analyzer suitable for commercial refueling stations.
- The team has spent too much time focusing on CO, even though CO can be seen as a canary species.
- The end game and the definition of “success” are unclear.

Recommendations for additions/deletions to project scope:

- The team should make an attempt to identify another partner that could help speed up the development of the PBI-based analyzer.
- The project team needs to define the steps to commercialization.

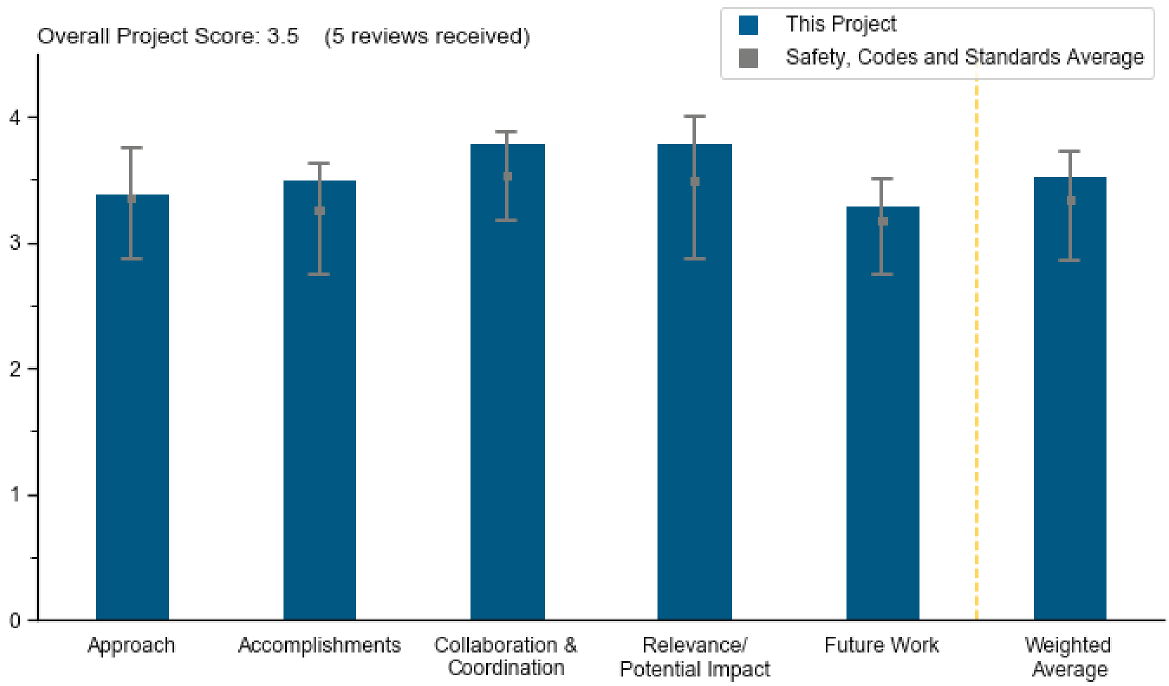
Project #SCS-010: Research and Development for Safety, Codes and Standards: Hydrogen Behavior

Ethan Hecht, Sandia National Laboratories

Brief Summary of Project

The project's purpose is to perform research and development (R&D) to provide the science and engineering basis for the release, ignition, and combustion behavior of hydrogen across its range of uses (including high-pressure and cryogenic). The research includes model and tool development to facilitate the assessment of the safety (i.e., risk) of hydrogen systems and enable use of that information for revising regulations, codes, and standards (RCS) and for permitting stations. Sandia National Laboratories (SNL) is working to address the lack of safety data and technical information relevant to the development of safety, codes and standards (SCS) by (1) providing a science and engineering basis for understanding the release, ignition, and combustion behavior of hydrogen across its range of use (i.e., high-pressure, cryogenic), (2) generating data to address targeted gaps in the understanding of hydrogen behavior physics (and modeling), and (3) developing and validating scientific models to facilitate quantitative risk assessment of hydrogen systems and enable revision of RCS to accelerate permitting of hydrogen refueling. The project began in 2003.

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Safety, Codes and Standards projects.

Question 1: Approach to performing the work

This project was rated **3.4** for identifying and addressing barriers, project design, feasibility, and integration with other relevant efforts.

- The approach used was multifaceted and involved not only this project but project SCS-011, Hydrogen Quantitative Risk Assessment (reviewed in 2019), and project SCS-025, Hydrogen Infrastructure through Science-Based Codes and Standards (not reviewed in 2019). Coordinating with these other activities, as well as developing and executing experiments for predictive modeling, combines for excellent research. Getting to worst-case scenarios will help in the predictions. Comments on the 2022 edition of National Fire Protection Agency (NFPA) 2 will be needed before long.

- SNL's approach to R&D for SCS is very sound. The team has an impressive pedigree of previous success. There are no issues here.
- This is an excellent approach that addresses all barriers via an intelligent pairing of controlled laboratory experiments with outdoor, real-equipment releases.
- The approach presented is detailed, pertinent, and focused on accomplishing the objective.
- The approach for the specific tasks is good. For the analysis on the non-circular cross-sections, the project team should consider a cross-section that is not planar but radial in nature to simulate a circumferential leak from threads or a crack. This would have the effect of possibly diffusing the leak in different directions as opposed to in one direction. For the truck vent releases, it is not clear whether this is for actual analysis of this activity or only for validating the model. Validating the model seems appropriate because of the variability of that activity. Presumably, the flow rates will be well documented for model comparison.

Question 2: Accomplishments and progress

This project was rated **3.5** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The project has made outstanding progress that answers a number of critical questions related to cold hydrogen behavior. In particular, the project team has shown that a circular release orifice can be used as a representative orifice for modeling and predicting heat fluxes from all possible shapes of ignited leaks, and that a lower hydrogen temperature leads to higher thermal flux from ignited plumes of the same flow rate. These contribute to a more accurate analysis for hazard distances associated with venting or leaks of cold hydrogen gas.
- The open-source release of the modeling is terrific; however, it will open the door to further inquiries that will need responses. It is suggested that the project team consider having a "frequently asked questions" page on the Hydrogen Risk Assessment Model (HyRAM) and Center for Hydrogen Safety (CHS) websites so that some common questions could be answered without taking up valuable resources. It is unclear whether moving the information from HyRAM to the CHS will allow the progress of the project's work to continue to be available at no cost. It is suggested that the project team consider a model that accounts for different temperatures in order to measure the flame length and heat flux. The work planned for Lawrence Livermore National Laboratory (LLNL) is exciting; hopefully the project team will see the proper weather conditions for the releases.
- The accomplishments of the specific tasks are good and useful. Progress has been made in these areas. However, other useful work is needed. The project team made mention of NFPA 2 and separation distances. There is still limited progress in the area of liquid hydrogen (LH_2) to recommend revised separation distance tables for exposures based on experimentation or the use of validated models. One goal mentioned is to affect NFPA 2 for 2022. The time frame is likely for the 2023 edition, but that will require submitting information no later than the spring of 2021. This is a tight timeline, but there is not a corresponding schedule that shows the ability of this project to meet the required dates.
- The reduction of siting burdens is a critical factor that is preventing the proliferation of large hydrogen fueling stations (with on-site storage that can hold thousands of kilograms). There is an issue with one of the statements made by the presenter: the premise that liquid ground storage was the only way forward for large fueling stations. This premise is incorrect in light of recent press releases from companies, such as the Nikola Motor Company, that plan to use on-site generation and compressed hydrogen storage for up to 32 tons/day.
- The project's accomplishments and progress are very good. However, it is not clear whether these accomplishments are the best way or method to meet the goals. For instance, it is unclear how worst-case scenarios will be determined and evaluated.

Question 3: Collaboration and coordination

This project was rated **3.8** for its engagement with and coordination of project partners and interaction with other entities.

- The project has outstanding collaborations with other national laboratories (including the National Renewable Energy Laboratory and LLNL), as well as in the international hydrogen safety community (including the Pre-normative Research for Safe Use of Liquid Hydrogen [PRESHLY], funded by the Fuel Cells and Hydrogen Joint Undertaking, as well as the HySafe Research Priority Workshops and the International Conference on Hydrogen Safety).
- The project's collaboration with outside companies (Linde, Shell Oil Company, and others), NFPA, the Compressed Gas Association (CGA), and partners outside the United States looks to be outstanding.
- The collaborations are outstanding and numerous. The project team should keep up the great work. Continued active participation with NFPA 2 is necessary so that the code can be updated to include science-based information.
- There is good collaboration with NFPA, CGA, and European projects such as PRESHLY.
- The project's collaboration with other organizations is effective, in both technical content and experience.

Question 4: Relevance/potential impact

This project was rated **3.8** for supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- The work is very relevant and can affect hydrogen fueling stations in a positive way by reducing the footprint and lowering setback values for LH_2, etc. The timing to coordinate with the NFPA 2 Technical Committee (TC) in order to advise the committee is well planned. The modeling and data from the experiments (and the scaling for actual vent stacks) will be critical.
- The project has very high relevance and impact, as the project results are critical for the wide market deployment of a hydrogen fueling infrastructure and public acceptance of fuel cell electric vehicles and other technologies using LH_2 in non-industrial settings.
- Separation distances are critical to safety and also to the deployment of hydrogen into areas where it has not traditionally been installed.
- The R&D work correlates directly to DOE targets, namely by identifying ways to reduce siting burdens that prohibit the expansion of hydrogen fueling stations. It is very important work.
- This project is critical not only to the DOE Hydrogen Fuel Cells Program but also to commercial partners and the safety of the general public.

Question 5: Proposed future work

This project was rated **3.3** for effective and logical planning.

- The proposed future work is very nicely presented for the remaining fiscal year (FY) 2019 and FY 2020. The data generated from the other crack patterns of the releases will be interesting. The critical path will be in completing the modeling and experiments in time to have solid data for the NFPA 2 TC to consider for the 2022 edition. The 40% reduction in station footprint is exciting and could be a real game changer.
- The proposed future work is outstanding, keeping the balance between laboratory experiments, computational fluid dynamics modeling, and outdoor, cold-hydrogen-venting non-ignited releases. The contribution to CGA of ignited experiments on liquid tanker venting is also important.
- The project team has good plans for future work that is key to meeting DOE goals and supporting the industry. Perhaps some efforts should be directed toward testing to validate the use of walls for optimizing separation distances.
- The schedule for the LH_2 separation distance work continues to slip, and there are not definitive timelines for this work to be completed and/or to meet the timeline of NFPA 2. The project needs a detailed schedule for when validation of the LH_2 model will be completed and when testing can be completed. The analysis of the releases for depressurizing tankers is relevant only to the validation of the model. The main area of

concern would be inadvertent releases and failures. These are the primary scenarios for which separation distances are required. One of the primary issues with NFPA 2 has been mitigation via barrier walls. A gap that exists between NFPA and common practice is the use of four barrier walls for gaseous hydrogen and three to four barrier walls for LH_2. Analysis on the impact of these additional walls, either via modeling or experimentation, would be useful to the NFPA committee. This would have high relevance to NFPA and the resolution of some alternative means and measures that are commonly used. In addition, the use of barrier walls is not permitted for some of the separation distances that are more difficult to meet. It would be helpful to understand the impact of these walls and their height on these separation distances.
- The presentation does not make clear how the various large-scale spill experiments relate to the eventual planned customer facilities.

Project strengths:

- The work was nicely presented, including the project's objectives, relevance, work to date, goals, barriers, and project partners. Having this work presented and ultimately accepted into the next edition of NFPA 2 will be very meaningful for the hydrogen industry.
- The project team has strong knowledge and expertise in measurement techniques and modeling capabilities, as well as strong industry ties, national laboratory collaborations, and active participation in relevant international activities.
- This work has direct influence on NFPA separation distances. The work is required for the NFPA TC to make informed decisions.
- The project has great focus on R&D to serve DOE goals and to meet the needs of siting large-storage hydrogen fueling stations.
- There are two overall project strengths: the critical relevance of the project and the technical expertise of SNL, including the partnership and synergy with LLNL.

Project weaknesses:

- There are not many project weaknesses; the project team seems to cover all the bases. It is perhaps advised that there should be slightly more recognition of equipment and practices that are relevant to the real world.
- It does not seem certain that there is adequate funding for this project to accomplish everything necessary. While there are many partners, it may be that the project team should collaborate with these organizations to make the information more broadly available to stakeholders.
- The timeline continues to slide, and it is critical not to miss important submission deadlines for NFPA documents. The lack of large-scale release testing is being addressed with the development of a project to perform these tests, but the schedule is vague and needs to be accelerated.
- There are two main weaknesses: the project schedule for future work is somewhat vague (without very many milestones), and future funding seems variable and uncertain.
- The presentation did not speak directly to NFPA 2 footprint reduction.

Recommendations for additions/deletions to project scope:

- There are no recommendations for additions or deletions; the current plan is excellent. As a suggestion for the planned cold hydrogen venting at LLNL, the project team should compare a typical vent stack termination with a T-shape (that has bull horns) to the single-outlet termination that is currently planned. This should contribute to a better understanding of the effect of wind and other weather conditions on the dispersion of the cold hydrogen plume.
- One of the primary issues within NFPA 2 has been the mitigation via barrier walls. A gap that exists between NFPA and common practice is the use of four barrier walls for gaseous hydrogen and three to four barrier walls for LH_2. It would be useful to the NFPA committee if analysis were done on the impact of these additional walls, either via modelling or experimentation, and what configurations might be effective and safe. This would have high relevance to NFPA and the resolution of some alternative means and measures that are commonly used.
- The project should perhaps do testing to validate the use of walls in measuring and optimizing separation distances.

- It is recommended that the project team more thoroughly consider weather conditions and future hydrogen facilities (e.g., size, materials, and operating conditions).

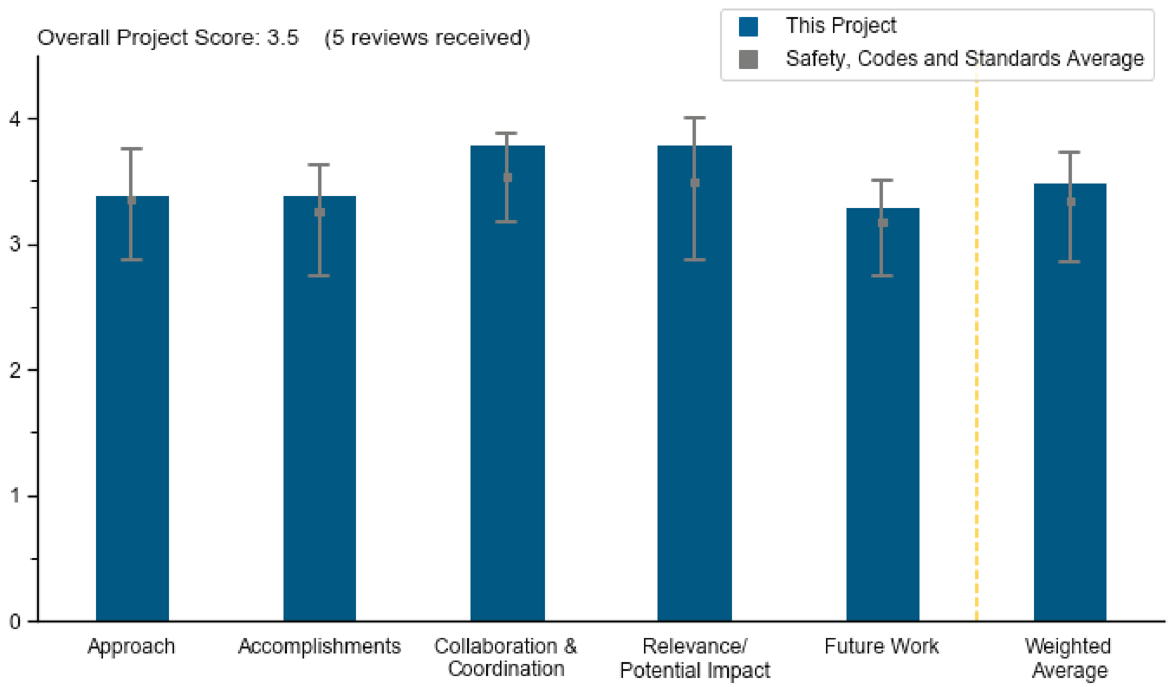
Project #SCS-011: Hydrogen Quantitative Risk Assessment

Alice Muna, Sandia National Laboratories

Brief Summary of Project

The primary objective of this project is to provide a science and engineering basis for assessing the safety of hydrogen systems and facilitate the use of that information for revising regulations, codes, and standards (RCS) and permitting stations. Sandia National Laboratories (SNL) will develop and validate hydrogen behavior physics models to address targeted gaps in knowledge, build tools to enable industry-led codes and standards revision and safety analyses, and develop hydrogen-specific quantitative risk assessment (QRA) tools and methods to support RCS decisions and to enable a performance-based design code compliance option.

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Safety, Codes and Standards projects.

Question 1: Approach to performing the work

This project was rated **3.4** for identifying and addressing barriers, project design, feasibility, and integration with other relevant efforts.

- Over the long history of this project, the data-and-analysis-based evaluation of risk modeling has been excellent. This is work that would be difficult for an industry member or industry trade association to do, and the credibility and longevity of the project, as well as the model development in the laboratories, has been key to the work's success and impact.
- The first comment on slide 12 is still relevant. It was surprising to hear that the Hydrogen Risk Assessment Model (HyRAM) is oriented for station analysis and that tunnel information will be incorporated next. It would be beneficial to know what other scenarios are planned for future focus, as well as how HyRAM can be used for general analysis.
- This project has been very responsive to the needs of the industry and in addressing the issues that are present in the deployment of infrastructure.
- The displayed approach continues SNL's excellent work to systematically address and overcome barriers.

- Overall, the project has a good approach, but there could have been more technical information added to the main presentation.

Question 2: Accomplishments and progress

This project was rated **3.4** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The project's accomplishments are many and positive. As to the expansion of HyRAM beyond hydrogen, it would be beneficial to better understand the need for the other alternative fuels. However, this does make the playing field more "even," as it does not put hydrogen in the spotlight for safety, so this could be a positive thing.
- The project continues to provide the basis for developing and validating the safety standards for stations and other hydrogen applications. The recent work on liquid hydrogen (LH_2) and tunnels has been instrumental in developing a pathway to introduce these technologies in the field.
- The HyRAM team made significant progress in expanding the toolkit capabilities by enhancing the fault tree analysis in the QRA module, as well as enhancing models of physical effects. This allows for a broader use for HyRAM beyond hydrogen fueling facilities.
- LH_2 storage is key to hydrogen infrastructure. The characterization of hazards arising from liquid leaks and cold plumes is critical. QRA will be deficient until such hazards data can be added to HyRAM. The work completed is solid, but more progress is needed.
- Good progress has been made. However, it would be good to see more progress with respect to the LH_2 activity.

Question 3: Collaboration and coordination

This project was rated **3.8** for its engagement with and coordination of project partners and interaction with other entities.

- The HyRAM team continues an outstanding effort, collaborating with a wide range of North American and global stakeholders. The plans for the release of an open-source version 2.0 will allow for even more engaged participation from the international hydrogen safety community, further enhancing HyRAM capabilities.
- This project has excellent collaboration and coordination. This is highlighted especially by the support of all the cooperative research and development agreements and the impact on codes and standards development.
- The collaboration and participation by laboratory experts and industry representatives have been excellent, as good as with any DOE project.
- The list of collaborators is long, signaling that excellent feedback and input is going into the project.
- The external collaborators have excellent reputations, but how they have contributed is not completely clear from the presentation; slide 13 notes their "roles."

Question 4: Relevance/potential impact

This project was rated **3.8** for supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- This project represents exactly the type of project that DOE should have in its portfolio. It addresses an important, relevant topic that calls for the independent and credible participation of laboratory staff, and it has the longevity needed for safety, codes and standards work. It would be difficult, if not impossible, to enter new markets or bring new technologies to market without this type of work being done in support.
- This project's results are critical for broad market deployment of hydrogen infrastructure and public acceptance of fuel cell electric vehicles and other technologies. HyRAM has already contributed to the significant reduction of separation distances in NFPA 2 and NFPA 55 related to bulk compressed

hydrogen, and the modeling is expected to have a similar impact on the existing separation distances for LH_2.
- This work is critical to a proactive execution of codes and standards, and it will become even better appreciated when the infrastructure applications move from experimental and trial usage to the mainstream.
- This project is one of the most relevant, if not the most relevant, to the industry and issues of the day.
- This project is relevant and has a high level of impact to support commercial rollout.

Question 5: Proposed future work

This project was rated **3.3** for effective and logical planning.

- The future work looks impressive. The only potential oversight is in the lack of resources associated with the release of the open-source version 2.0. It is reasonable to suggest that the international community will receive this release with great enthusiasm, and hence will be willing to engage in enhancing HyRAM capabilities, which is the intent. This, in turn, may require some "babysitting" of potential interface or interoperability issues that may arise between the core HyRAM code and external models. It is thus advisable that the HyRAM team be prepared to deal with this appropriately.
- The Fuel Cell Technologies Office is encouraged to prioritize and focus heavily on completing the LH_2 leak scenarios to provide input for the code, as well as to support the modeling of specific tunnels so as to aid in the discussions with the authorities having jurisdiction in those jurisdictions. The non-destructive tank inspection methodologies are also interesting, and necessary, but not as high of a priority at this time.
- The future work shown is an extension of the ongoing work related to LH_2 and tunnels; formalizing these results into usable tools and methodologies for these applications is appropriate.
- The project team should include a work item that would evaluate how a more general QRA can be applied to help users address scenarios outside of the main focus to date.
- A more detailed future work strategy would be appreciated. The information provided seemed too high-level.

Project strengths:

- Overall, the project has achieved excellent results. HyRAM has gained broad international recognition and is referenced in International Organization for Standardization (ISO) 19880-1, the international standard on gaseous hydrogen fueling stations. If the aftermath of the release of an open-source code is handled adequately, it can become a global platform of choice for hazard and risk assessment of hydrogen facilities and applications.
- The project couples SNL's experimental and modeling capabilities with industry experience to address codes and standards development. The QRA tool and applied datasets give systems developers an agreed-upon basis for addressing safety requirements directly. This is critical where there is no experience for rolling out hydrogen infrastructure.
- The project's impact, longevity, and response to industry needs have all been excellent. The team is highly collaborative and supportive of short-term, high-priority requests and of interfacing with regional policymakers and stakeholders.
- There is excellent interaction with stakeholders and response to the needs of the community; the project has demonstrated quality deliverables and relatively quick turnaround, which is critical for addressing real-world needs.

Project weaknesses:

- If it can be viewed as a weakness, HyRAM was going through "growing pains," which of course are natural. Some chosen physical effects models (e.g., for enclosure dispersion and overpressure) are limited to very specific boundary conditions, yet the models could be used beyond their original limiting parameters. Thus, it could be desirable to provide a warning to the user if the model is being used outside its validated range.

- Though it is not so much a weakness of the project as it is a resources issue, the LH_2 experiments need to get completed in time to get the information to the NFPA 2 task force and get a proposal into the next version of NFPA 2. This could require some creative funding solutions.
- A larger effort is needed. At the funding levels available, the team can address issues only in a measured way. Addressing the needed cryogenic hazards data is involved and requires time, but the QRA models are needed as soon as possible.

Recommendations for additions/deletions to project scope:

- This project continues on a good path. No significant changes are recommended.
- The project team needs to address how systems developers can use existing data in HyRAM to address general scenarios involving other applications, systems, and components.
- The project team should have a plan to support the open-source code version 2.0.

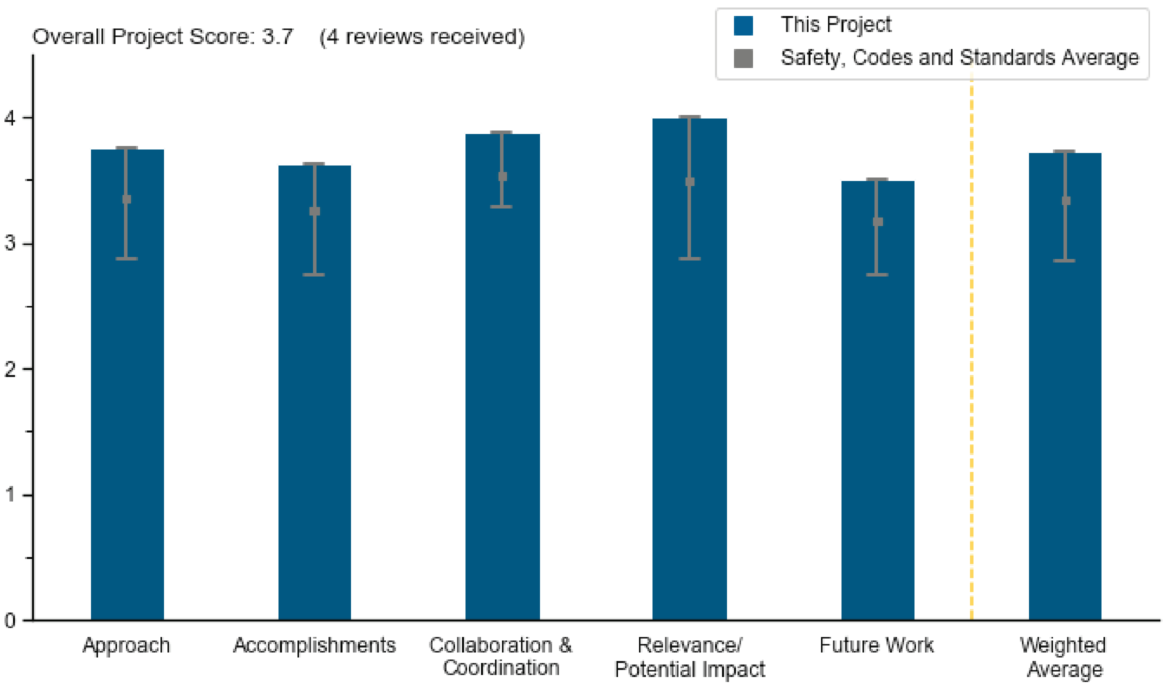
Project #SCS-019: Hydrogen Safety Panel, Safety Knowledge Tools, and First Responder Training Resources

Nick Barilo, Pacific Northwest National Laboratory

Brief Summary of Project

This project provides expertise and recommendations through the Hydrogen Safety Panel (HSP) to identify safety-related technical data gaps, best practices, and lessons learned, as well as help integrate safety planning into funded projects. Data from hydrogen incidents and near-misses are captured and added to the growing knowledge base of hydrogen experience to share with the hydrogen community, with the goal of preventing safety events from occurring in the future. The project also aims to implement a national hydrogen emergency response training resource program with adaptable, downloadable materials for first responders and training organizations.

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Safety, Codes and Standards projects.

Question 1: Approach to performing the work

This project was rated **3.8** for identifying and addressing barriers, project design, feasibility, and integration with other relevant efforts.

- This project is really an assembly of three distinctly separate tasks: the HSP, outreach (Hydrogen Tools [H2Tools]), and emergency training. All three of these activities are well thought out, well planned, and well executed. Each of the activities scores a four in this category. The HSP has been challenged in the recent years because of the need to grow and change direction a bit. The principal investigator found a very creative solution, one that will turn out to be extremely good for the panel and the U.S. Department of Energy Hydrogen and Fuel Cells Program (the Program) at large. The creation of the Center for Hydrogen Safety (CHS) under the auspices of the American Institute of Chemical Engineers (AIChE) promises to be an excellent move. The increased exposure to a much larger relevant community and having a much larger community to draw on to support outreach and other such activities (e.g., workshops and educational and safety-related activities) will be very good. In addition, the exposure to a relevant community that is different from the traditional hydrogen community will prove to be an excellent move. The international community has expressed concern more than once about competing with other established entities (such as the International Association for Hydrogen Safety [HySafe]). Time will tell, but this concern has been recognized, and the desire is clearly to collaborate with HySafe and grow the mutual activities, learning and leveraging from each other.

- The approach is definitely logical, and there are clear lines that can be drawn between the objectives, the barriers addressed, and the individual tasks of this project. In addition, the approach of this project is exemplary in the way that it responds to stakeholder needs and has found a solution to one of the most pressing reviewer concerns from the previous year.
- The stated approach (priority, attention, and visibility) is a good statement of the need. The team should consider how the transition to the CHS will maintain or enhance this approach.
- The project's approach is to use the HSP for the team's eyes, the responder's training for the team's voice, and the knowledge tools for the team's collective knowledge. HSP's doing reviews for the state is concerning. Up until this point, the team shared knowledge and best practices. It should be determined whether this is morphing into formal, state-mandated approvals and, if so, whether the team members are licensed practicing engineers for each state where reviews are being conducted and, if an incident occurs, where the legal liability falls: the team member, the customer, or the state.

Question 2: Accomplishments and progress

This project was rated **3.6** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The HSP continues to be one of the gems of the Safety, Codes and Standards subprogram. The move to AIChE should prove to be an excellent opportunity for the safety community, and specifically for the HSP, by exposing this resource to a broader community and providing the HSP with expanded resources. Here is just a sampling of accomplishments to demonstrate this point: 499 safety reviews, 388 projects, more than 100 publications, 25 panel meetings, 10 white papers, and four investigations. A site visit to the U.S. Navy site in Keyport, Washington (Naval Undersea Warfare Center Keyport Division) was performed; a task group on mobile applications was formed (funded by the California Energy Commission [CEC]); a testimony letter was sent to the City of Walnut Creek in California; and a station review was completed by HSP during the California Program Opportunity Notice application. With respect to the H2Tools portal, excellent progress continues to be made in this part of this project. The portal has clearly demonstrated its value to the hydrogen community, internationally and domestically. It contains 2,944 pages, 2,297 bibliographic references, 217 "lessons learned" pages, and 142 best practices; 56% of the pages reviewed are outside of the Americas. The first responder training was well received in the Northeast (United States). Every aspect of this project is excellent.
- There has definitely been excellent progress, although the objectives that this project addresses are a bit more difficult to evaluate in a quantitative manner (there are not really enumerated targets for this project to meet). However, the team found an elegant solution to a pressing problem that previously existed by moving to AIChE to ensure the longevity of the project while maintaining much of the expertise, capability, transparency, and public availability.
- This long-term project counts significant accomplishments over many years in making safety plan reviews the norm, providing resources for a variety of stakeholders, and culminating in the transition to the CHS: a transition from a government-led activity toward an industry-driven resource.
- Partnering with AlChE is another way to reach out and share lessons learned with designers. AIChE should have mechanisms in place to partially protect the team from liabilities.

Question 3: Collaboration and coordination

This project was rated **3.9** for its engagement with and coordination of project partners and interaction with other entities.

- This project in particular interfaces with stakeholders consistently, almost out of necessity. Through these collaborations, the project is having a direct impact on the deployment of hydrogen applications. In

addition, because of the activities that it has taken on, the project is helping to inform and improve the capabilities of technical staff industry-wide.
- The HSP has done a great job of collaborating with local, state, and federal government, as well as industry and other organizations, to take advantage of a broad array of expertise and to disseminate information.
- The team make-up is fine. If any additional current or former fire marshals for states or major cities could contribute to the team, that would be helpful. It is suggested that the project recruit fire marshals from East Coast cities (New York, Boston, Chicago, or Atlanta). The National Association of State Fire Marshals may be a path to obtain the recruits.

Question 4: Relevance/potential impact

This project was rated **4.0** for supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- This is one of the highest-impact projects within the Program, and it has clear impact on hydrogen deployment in California today. It is good to see that the project is also looking to other regions, such as the Northeast, as other places to focus its efforts. This will be absolutely necessary and likely only to expand as other regions of the country begin to more seriously adopt hydrogen and fuel cell electric vehicles.
- There is no doubt that this work has contributed immensely to the impact on the community, the safe execution of DOE projects, and the safe deployment of hydrogen technologies (e.g., hydrogen fueling stations). The emergency responder training is always well received and appreciated. The project's relevance to the hydrogen community and the impact on helping to enable safe hydrogen deployment is extremely high.
- Safety needs to be front and center in this industry. For building confidence with stakeholders and authorities having jurisdiction (AHJs), the tools deployed by the HSP are a critical part of this "safety culture." Although it is still sometimes difficult to get data from private companies when an incident occurs, the HSP allows for as much information as possible to be collected, and the safety review process helps instill the expectation that safety will always be a primary design element for any hydrogen project.
- The relevance is obvious. However, some of these tasks should start to be moved to licensed professionals within their respective states.

Question 5: Proposed future work

This project was rated **3.5** for effective and logical planning.

- The proposed work is very good, particularly with regard to the creation of the CHS.
- The proposed future work is fine. It would be nice to start migrating these tasks (i.e., inspection, review, and training) to the proper authorities at the state and major city levels. Database management and document distribution might better be addressed by AIChE and the National Fire Protection Association.
- The project does have much remaining and continuing work left to complete, and all of this was appropriately identified in the future work that was discussed. However, it would be good for this project to begin to look beyond these most immediate needs. Especially with the resources available through the new structure and home at the CHS, the project should begin to scope out the future needs that it will have to address. This should especially concentrate on the regionalization of information-sharing and analysis and the evaluation of designs and concepts for deployments in different regions. In addition, the team should begin to anticipate the expanding scope of potential applications for which the CHS will need to be able to act as an expert.
- The transition of activities to the CHS will require some adjustment, but it will allow for focus on the core activities needed to support the DOE, CEC, and outreach activities. At this point, it appears that a focus on outreach in the Northeast will be critical to be successful with AHJs there and to establish the routine permitting of hydrogen stations in the United States.

Project strengths:

- This project is, and has been, a gem of the Program. With the creation of the CHS, the excellence is expected to continue.
- The project's strengths include the depth of expertise represented by the HSP and the established processes for design reviews, plan reviews, site visits, and incident fact-finding, analysis, and support.
- The project's greatest strengths are its direct applicability and the impact that it is having in launching hydrogen deployment.
- The project's strengths include the team's focus and dedication to the task.

Project weaknesses:

- No particular project weaknesses were identified.
- The project should consider whether it is time to start migrating some of these tasks to other individuals and organizations.
- A weakness for the project is the difficulty in getting detailed information about safety incidents and near-misses that occur in private industry.

Recommendations for additions/deletions to project scope:

- The project should begin to anticipate the future needs to help spread hydrogen to new regions and into new applications. Planning appropriately for this expansion will be crucial to ensuring the longevity of the project's efforts in their current form at the CHS.
- At this time, it makes sense for the HSP to complete the transition of activities to the CHS and get settled into the new routine that the move may entail before considering any additions to scope.
- The team should consider how the HSP will move to the CHS.

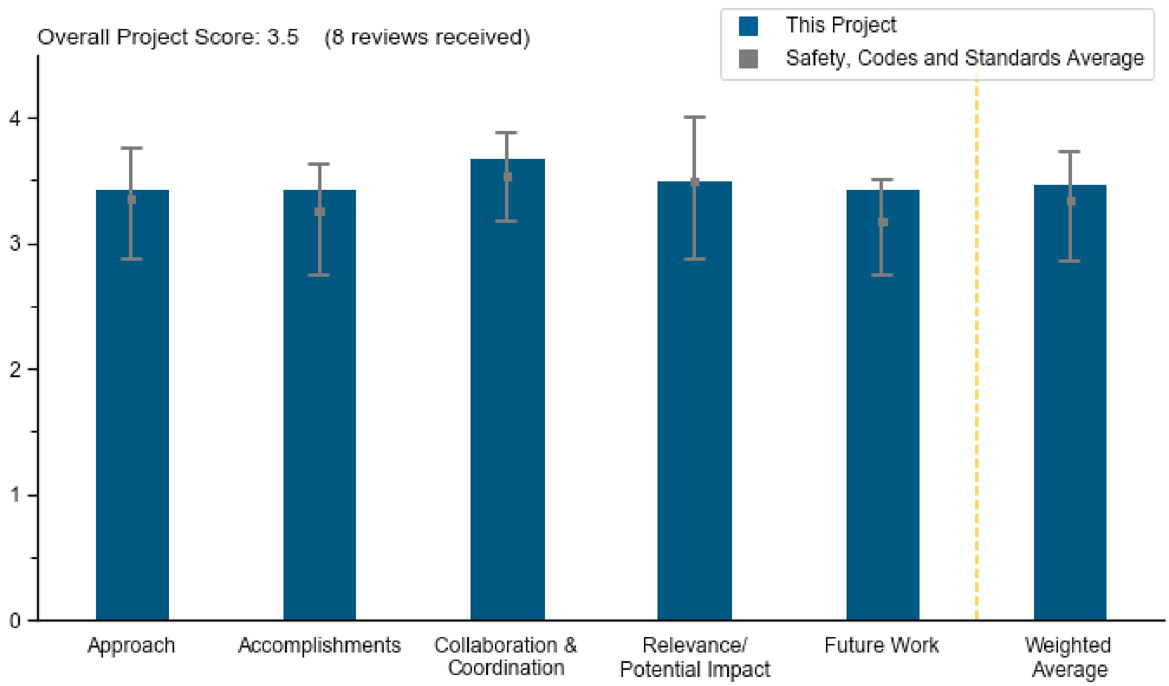
Project #SCS-021: National Renewable Energy Laboratory Hydrogen Sensor Testing Laboratory

William Buttner, National Renewable Energy Laboratory

Brief Summary of Project

Sensors are a critical hydrogen safety element and will facilitate the safe implementation of the hydrogen infrastructure. The National Renewable Energy Laboratory (NREL) Sensor Testing Laboratory tests and verifies sensor performance for manufacturers, developers, end users, and standards-developing organizations. The project also helps develop guidelines and protocols for the application of hydrogen safety sensors.

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Safety, Codes and Standards projects.

Question 1: Approach to performing the work

This project was rated **3.4** for identifying and addressing barriers, project design, feasibility, and integration with other relevant efforts.

- This project has matured, and continues to mature, from testing individual sensors to understand the performance of sensors, to implementing an array of sensors to create a "wide-area monitoring (WAM) system," and then to making sensors an integral part of an integrated safety system approach to reducing risk at a deployment site (such as a hydrogen fueling station). This approach of making sensors an integral part of the safety system to actively contribute to the design and risk mitigation effort is very nice. This could be a game-changer in the approach to mitigating risk in these systems. This principal investigator (PI) is very rigorous in his approach, combining detailed laboratory work with that of field deployments (including indoor, outdoor, and medium-to-large facilities to understand hydrogen release behavior). This PI makes sure that the information generated is available to the appropriate customer. This project does, at times, work on and produce output that needs to be protected intellectual property (IP). The project has been criticized in the past because of the need to protect IP; this is necessary at times, but this PI works hard to distribute the knowledge gained from this work appropriately.

- The approach to the work has been finessed over the years of the laboratory's existence. While the laboratory continues to evaluate the performance of sensors for industry, more research is being conducted to help with characterizing hydrogen behavior for the purposes of affecting safety and reducing the hydrogen station footprint.
- This project continues to support the industry in the area of hydrogen detection. It was good see a stronger link to the hydrogen release and quantitative risk assessment (QRA) work at Sandia National Laboratories (SNL). In addition, the focus on WAM is important, especially for the work looking at sensor placements in enclosures.
- The approach makes sense and addresses the needs of the hydrogen community. The sensor evaluation work is ongoing. The new efforts include the evaluation of sensor position in various scenario applications and the use of sensor data to feed into QRA.
- The project team is focused on meeting specific needs for sensors. The approach is well defined to meet these needs while remaining flexible enough to address emerging technologies and applications.
- This project has done well in its collaboration for the vehicle sensor component in the development of the SAE International (SAE) document.
- There are two ways to look at the approach: proactive and reactive. From a reactive point of view, the approach has been to support all requests. This is helpful and useful. However, there does not seem to be much proactive direction or research to improve future detection technology and deployment. This is a gap in the project.
- The approach is sound. It is unclear why a number of CO detectors that trip on exposure to hydrogen are not being screened. The detectors usually have product safety listings, production lines, sales channels, and name recognition.

Question 2: Accomplishments and progress

This project was rated **3.4** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- Many accolades are due to the NREL Sensor Testing Laboratory for the publication of the SAE J3089 technical information report (TIR) for onboard vehicle sensors, and for meeting the United Nations Global Technical Regulation (GTR) requirements. The Sensor Testing Laboratory always seems to have student internships that benefit both the student and the industry. It is easy to imagine that the students enjoy working with Dr. Buttner, and it seems they are given great experience for their next career moves. Other projects may have interns assisting in the research work, but this project continues to showcase the student research assistants.
- The publication of the SAE TIR is a noteworthy achievement. The GTR-13 verification work seems to be starting off well. The guidance on indoor sensor placement work is at early stages, but it looks promising. The hydrogen WAM (HyWAM) modeling progress is good.
- Good accomplishments and progress have been made. It is not always obvious, but the work found within this project supports a wide range of codes and standards development for the vehicle, refueling, and infrastructure.
- The team is congratulated for publishing SAE J3088. Perhaps there is a CSA Group (CSA) version to address the limitations of, and compete with, the existing Underwriters Laboratories 2075 or the International Organization for Standardization document.
- There is a clear demonstration of commitment to this project.
- There is no question that this work has helped advance DOE goals for other projects where sensors are a key parameter for completion. However, this project primarily supports other projects, and this project does not have a clear objective as to what it is supposed to deliver. This is a gap, moving forward. This might be expected of any 10-year-old project.
- DOE goals are being met; however, the accomplishments were modest because of the late receipt of funding.

Question 3: Collaboration and coordination

This project was rated **3.7** for its engagement with and coordination of project partners and interaction with other entities.

- This PI is very proud of the project's collaborations and coordination with entities outside of NREL, and he should be. This project has had a quite impressive list of collaborators, from a very productive laboratory-to-laboratory relationship with the JRC on sensor performance evaluation, to a true collaboration with A.V. Tchouvelev & Associates (AVT) to understand sensor placement for various positions and release scenarios for indoor releases, to mentoring young researchers. This project engaged in true collaborations with other entities (such as AVT) to make the project more impactful than it would have been without the collaboration. There are some who think that making a presentation at a meeting is a collaboration; this PI understands what it means to collaborate, and he engages and embraces the collaborative nature of research. This is very nice.
- This project is well connected to national and international key players: SAE, Prenormative Research for Safe Use of Liquid Hydrogen, AVT, SNL, Lawrence Livermore National Laboratory, the Compressed Gas Association, the National Fire Protection Association (NFPA), and others. Frequent outreach and engagement with industry has been demonstrated.
- Excellent collaboration is demonstrated with the WAM work, which examines hydrogen release in industry containments, supports modeling efforts, and coordinates findings with standards requirements. This project features good coordination between partners and other institutions.
- The project's collaboration with industry, government, academia, and original equipment manufacturers enables the research and allows the project to expand its impact. The project's participation with SAE, NFPA, and the GTRs will help support work in codes and standards.
- Collaboration and coordination has always been strength of this project, especially with the mentoring of students from the Colorado School of Mines.
- There are many collaborators, and it was made clear that the extent of collaboration is also significant.
- The list of organizations is impressive, but it should be updated annually on such a long-running project. This is less a "project" than a "continuing support" that is funded annually. The "collaboration" is more a list of organizations that are supported, as opposed to the traditional approach of organizations that are assisting DOE in achieving the DOE objective. It is not clear how projects and support are prioritized.
- The collaboration list is long on national laboratories, Colorado universities, and very small companies. It is unclear why some of the industrial and home CO sensor manufacturers are not at the table, including the Mine Safety and Health Administration, Detector Electronics Corporation, Kidde-Fenwal, Inc., First Alert, etc.

Question 4: Relevance/potential impact

This project was rated **3.5** for supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- The performance of sensors (original effort) is critically important to (1) satisfy code requirements, (2) ensure the highest possible level of risk mitigation (WAM), and (3) support the new thrust of aggressively pursuing sensors as an integrated part of risk mitigation strategy; this makes this activity very relevant and impactful to the safe deployment of hydrogen technologies. This project is critically important.
- Doing basic research, modeling, and practical experiments to facilitate the risk-informed determination of the placement of hydrogen sensors has the potential to contribute to the improved safety of future installations. The main effort verifies the performance of sensors to increase confidence in their use and thereby increase safety. The liquid hydrogen (LH2) release work is important and timely.
- The need for the Sensor Testing Laboratory to support safety research is critical. The potential impact is being seen in the results of SAE J3089 TIR and HyWAM. This laboratory is a resource to the hydrogen community.
- It is important to support the hydrogen sensor industry with a neutral test capability for evaluating new sensor technologies. Additionally, it is important to provide definitive information on how to use and place sensors in common applications. Both of these activities will support the hydrogen community.

- There is a need for accurate hydrogen sensing, regardless of application. A low-price, robust, accurate, and reliable design will find a market. The team should speak with existing CO sensor manufacturers.
- As the project continues, it will be important to evaluate the progress and how the progress relates to the development of H2@Scale. It will be important to evaluate some of the other sectors, such as industrial usage, grid integration, electrolyzers, etc.
- The support provided is relevant, but there are two comments: (1) It is not clear how this support is prioritized or what metrics are being used to decide what to support. (2) The HyWAM seems to be a system that has a series of point-detector locations for supporting testing, as opposed to a device, system, or technology that could be more easily deployed in an actual field site or system. In that regard, it is not clear that the system is a tool and not a product. Making a low-cost and effective technology for mass deployment might be a useful objective.
- The vehicle sensor work is very relevant; however, other areas (outdoor sensors, for example) may not be as critical, given that other methods of detection are being employed in other projects. While the collaboration in Europe is positive, perhaps the United States should work to influence the focus. It is suggested that the project team re-evaluate the targets.

Question 5: Proposed future work

This project was rated **3.4** for effective and logical planning.

- The proposed work for active monitoring as a mitigation strategy to help with the LH2 setback distances is worth the price of admission. Station footprint reduction in the next NFPA Hydrogen Technologies Code (NFPA 2) is critical; this sensor laboratory work coordinates well with other projects. There are many aspects of this work and equipment that can be commercialized.
- The future work addresses lowering costs for facility integration and further development of research tools to support developing codes and standards; Task 3 (Hydrogen Contaminant Detector [HCD]) also addresses on-site HCD systems. There is a critical need for work on LH2 facilities, so it is very good to see that present in the plans and integrated with NFPA 2 activities.
- The project's movement into using sensors as part of a risk mitigation strategy is excellent and a game-changer.
- The continued work on hydrogen deployment and the proper use of hydrogen sensors is critical.
- The inline fuel quality work is very necessary and timely.
- All of the proposed subsequent work appears rational.
- In terms of future work, much of fiscal year 2019 is reactively supporting other DOE and industry projects. It would be helpful to develop an overall objective for the project and then a subset of specific items to support that objective. The objective could be structured so that many of the existing activities are included, but with additional ones that would advance the technology in a positive direction. In particular, HyWAM needs more definition as to what it is and what it is intended to do.
- For the short term, the project has good direction, but it is encouraged to look more outward and to its impact on the sensor targets.

Project strengths:

- This is, has been, and remains a gem of the Program. Even when the laboratory was being moved and was not functional, this PI continued to contribute to this space by staying active and publishing in open literature. This work is really appreciated.
- The NREL Sensor Testing Laboratory has developed a strong collaboration network throughout the years, and its coordination with the national and international community is a huge asset. The laboratory continues to see interest at SAE, NFPA, and the GTR committees. The work with student interns is mutually beneficial for the hydrogen and alternative energy industry. The opportunity for new market applications (e.g., shipping, rail, marine) provides great potential. The collaboration with SNL (involving Ethan Hecht) on LH2 behavior is exciting news and can help with the NFPA 2 updates for LH2 station footprint reduction and science-based setback distances.

- Bill Buttner is very clearly the right person for this project, as he has a real vested interest and seems to very much enjoy the work. There are some really good things that have come out of this project, along with other things that seem more like busy work. All in all, it is a strong project.
- The project is making clear progress in the development of more reliable, lower-cost sensors, as well as methodology for sensor placement. The HyWAM work and the plans to study LH2 release behavior are areas needed by industry, and they are natural additions to build upon the work done to date in this project. NREL's history and future plans for working with industry to commercialize new technologies are certainly strengths.
- The laboratory has good leadership, and it is productive and engaged with good partners.
- The diverse set of partnerships covers a wide range of capabilities.
- Furthering sensor technology is important, as is supporting other projects with sensor technology.
- The project's strengths include the knowledge and dedication of the research team.

Project weaknesses:

- This is more of a need than a weakness, but the project needs the development of an outward strategy as it pertains to H2@Scale—for example, in heavy-duty vehicles and industrial applications.
- The cause of the continued "funding uncertainties" is not well understood. There is much technology transfer and commercial work; it seems this project is perhaps becoming self-sustaining. The comment that "the royalties from SAE J3089 will keep a teetotaler in beer" did not go unnoticed (and was appreciated). The team should consider how this might change so that more stakeholders might be interested in the good work being done with this project.
- The weakness is in the inconsistent DOE funding, which is not a fault of the laboratory.
- The project's weaknesses include the HyWAM project. While it is true that there is no good guidance from the manufacturers on sensor placement (what area one sensor covers, for example), it seems that with 20+ years of sensor use at various facilities, there are learnings that can and should be collected to create some best practices on sensor use. This can and should also be given back to industry for industry use and/or published as guidance or as reference for industry customers.
- While it is clear that optimizing sensor placement will increase safety and minimize costs, it would be beneficial to see more emphasis in the project on reducing costs for sensors, including capital costs and operation and maintenance costs.
- There is a lack of objective; the project needs an overall objective. Lacking an objective, the project is wandering and somewhat reactive. Perhaps those projects that request support should fund that support. There is also a loss of focus on new technology sensors. There seems to be less of a focus on the development of new types of sensors that otherwise improve upon the behavior of those that already exist. It is stated that sometimes sensors work, and sometimes they do not. It is not clear what is being done to directly improve that performance and perception. There is also a weakness in the HyWAM definition; this has exciting potential but needs better definition. There is a reference to "standoff" devices; this is the technology that could provide a breakthrough, but there is very limited information provided on this potential.
- There is a lack of major sensor manufacturers involved with the team.

Recommendations for additions/deletions to project scope:

- The team should continue with the plans given in the presentation.
- The team should perhaps consider validating HyWAM on future projects that are under review by the Hydrogen Safety Panel.
- The team should add an overall objective for the project. The team should also develop a method to prioritize requests for support and proactively develop new activities to further the technology of sensors. The team needs to list specific priorities for technology advancement, better define HyWAM as either a tool or a product, and evaluate the next steps for the technology. While it can be used to support NFPA research, it is not clear that it is a product that can be used effectively as a mitigation tool at this point.

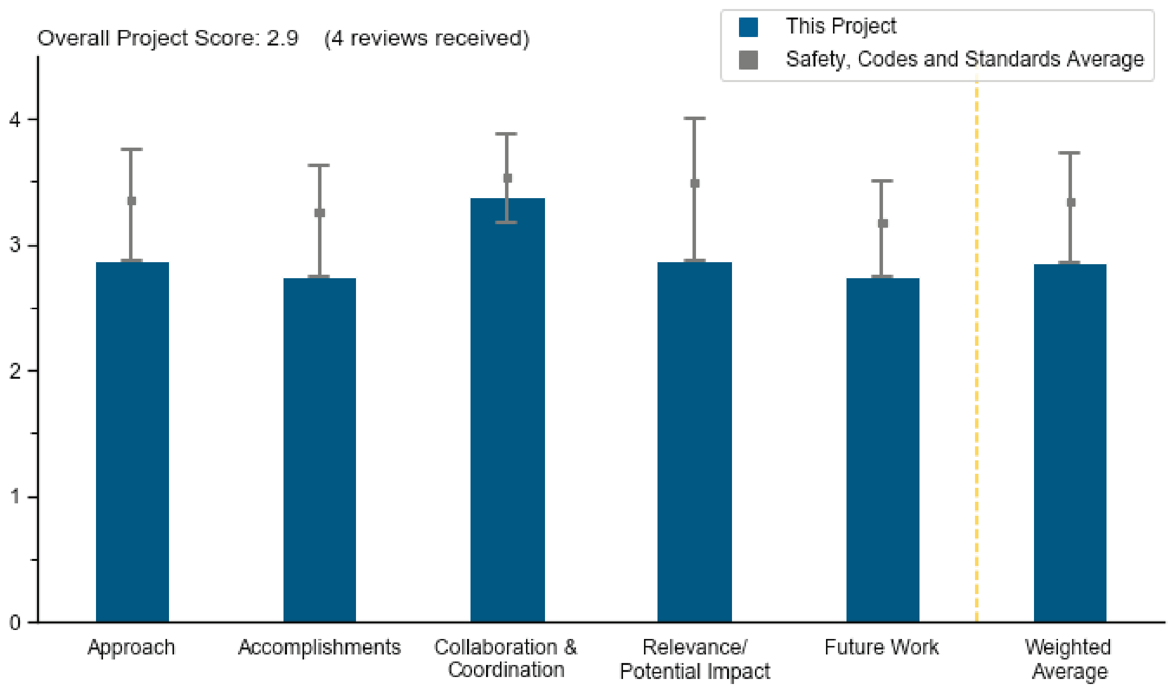
Project #SCS-022: Fuel Cell and Hydrogen Energy Association Codes and Standards Support

Karen Quackenbush, Fuel Cell & Hydrogen Energy Association

Brief Summary of Project

The goal of this project is to support and facilitate development and promulgation of essential codes and standards to enable widespread deployment and market entry of hydrogen and fuel cell technologies and completion of all essential domestic and international regulations, codes, and standards (RCS) by 2020. The Fuel Cell and Hydrogen Energy Association (FCHEA) participates directly in key domestic and international RCS technical committees and encourages its members to participate directly in technical committees, working groups, and discussions. FCHEA also develops and enables widespread sharing of safety-related information resources and lessons learned with first responders, authorities having jurisdiction, and other key stakeholders.

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Safety, Codes and Standards projects.

Question 1: Approach to performing the work

This project was rated **2.9** for identifying and addressing barriers, project design, feasibility, and integration with other relevant efforts.

- Overall, the approach is sound and well reasoned for its intended purpose. Three FCHEA working groups provide industry feedback on new RCS, with outside experts invited to contribute as needed. Diagrams and bullet points facilitate the conveyance of information. The presenter had in-depth knowledge of the industry and the relevant stakeholder groups. Coordination, outreach, and resolving technical challenges were identified as focus areas consistent with the mission of the U.S. Department of Energy (DOE) Hydrogen and Fuel Cells Program (the Program). It is suggested that the team include a page that defines all of the acronyms used in the presentation.
- Overall, the approach for the project seems reasonable and logical, but it does seem to lack an ability to be nimble. In addition, for a facilitation role, the approach seems to rely a bit more on stakeholders approaching the project for involvement than might be expected. This is especially true given that one of

the barriers identified for this project to address is the limited business participation in code development. Furthermore, it is unclear whether the working groups are limited to FCHEA membership. Many times, smaller business stakeholders, who may not have budgets for memberships, have important, real-world feedback for things like safety, codes and standards (SCS), and it was not clear that these members of the business community were being reached. This would likely require proactive engagement in this project; even though FCHEA staff run the project, they would have to proactively seek input outside their members.
- Standards and codes are important enablers of technologies, including hydrogen systems. Private-sector participation in standards development activities, especially from industry, is generally funded by the industry. The specific standards development organizations identified would all offer the opportunity for membership and/or input (e.g., proposals or comments) from the industry through various avenues. It is not clear why the industry requires DOE funding in order to be engaged in standards development activities that directly affects industry. Aside from standards meeting attendance, the activities identified comprise teleconferences, meetings, working groups, and posting of summaries, which are all done via simple communication or can be accomplished that way with minimal effort.
- The project approach has merit in assisting the development of codes and standards, although the effectiveness of creating separate working group forums is unclear. It would seem that if an FCHEA member has the time to attend these working group meetings, then that member could attend the codes and standards meeting directly and influence the direction of a standard directly.

Question 2: Accomplishments and progress

This project was rated **2.8** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The team noted appropriate progress in the presentation, with respect to information sharing and data exchange among industry stakeholders to facilitate a collaborative process within the working groups.
- The project's progress is difficult to measure, based on the nature of the project's goals and the fact that some of the ultimate outcomes are dependent on other individuals and organizations. However, it is important that the project has established working groups for coordinating among several varying stakeholders.
- The explanation of the project's accomplishments does not clearly map to tangible outcomes that are moving toward DOE goals, but rather seems to consist of activities. The benefits of the project in accomplishing outcomes, or in promoting advancement that would not otherwise occur through ongoing standards development activities, are not clear. The publication of the Hydrogen and Fuel Cell Safety Report provides information about field experiences.
- The specific accomplishments of this project are vague and difficult to quantify. The project has activities such as monthly meetings and bi-monthly safety reports, but it is unclear if these are actually making a difference to advance codes and standards. The slides appear to be similar to those from previous years, and the progress from the past year could have been further clarified.

Question 3: Collaboration and coordination

This project was rated **3.4** for its engagement with and coordination of project partners and interaction with other entities.

- RCS development, review, and prioritization is a key focus of the collaboration. The project's collaborative efforts involve a very wide cross-section of the industry that includes universities; government laboratories and agencies; trade associations; manufacturers of fuel cell materials, components, and systems; hydrogen producers and fuel distributors; utilities; and other end users.
- The collaboration for this project is assumed to be high, based on the nature of the activities and number of FCHEA members. The main focus of this project is on providing collaboration and coordination between FCHEA members and the various standards organizations.
- Aside from the issues noted in a prior response from stakeholders outside of FCHEA, it was a logical and intelligent choice to begin establishing working groups that leverage the organization and relationships provided by the existing FCHEA organization.

- The collaboration with Oak Ridge National Laboratory is noted. By their inherent nature, standards and codes are collaborative and involve many different parties, and in that sense, the project includes collaboration. Industry associations, similarly, inherently exist to be a platform for collaboration among industry. However, the team does not note any specific collaborations that unlock outcomes beyond simply participating. While there is value in being engaged in a standards development process, the project should focus on enabling or catalyzing new results. It would be an appropriate objective and benchmarking process for this project to be strategic and focused in identifying, enacting, and reporting on specific collaborations toward outcomes that might not occur, might not occur as soon, or would not otherwise occur.

Question 4: Relevance/potential impact

This project was rated **2.9** for supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- The work that is being addressed by this project is clearly important and must be done. The work also has great potential for impact. However, it does not yet seem that the project has had enough time to demonstrate the full potential impact it could have, especially with regard to international harmonization. It is recommended that the project take a more active role in seeking input and identifying needs, rather than waiting on industry representatives to identify issues and come to the project. Based on prior experience and for RCS concerns in particular, industry often appears to be more reactive and focused on short-term pain points, rather than long-term codes and standards development efforts that might be needed.
- The relevance of the work was provided in sufficient detail and was significantly augmented by the speaker's knowledge and experience. The speaker provided detailed answers to questions; however, it is suggested that the team more specifically cite in the slides what affected the industry when addressing potential impacts.
- The project has a good overall objective to support the development of essential codes and standards for hydrogen and fuel cell technologies. The alignment of the impact to the Program's goals could be improved since the project discusses a wide variety of applications beyond transportation, such as stationary, portable power, and drones.
- The publication of the Hydrogen and Fuel Cell Safety Report is noted as a mechanism to communicate about incidents. Other than information sharing, translating this data source to the advancement of specific codes and standards has not been established. The team had not established the relation and bidirectional coordination of the Hydrogen Fuel Cell Safety Report with the NREL National Fuel Cell Technology Evaluation Center efforts, including the safety aspects of the Hydrogen Fueling Infrastructure Analysis, to minimize redundancy and optimize outcomes. This project's impact on specific codes and standards development has not been made clear.

Question 5: Proposed future work

This project was rated **2.8** for effective and logical planning.

- The presentation provided significance and a take-home message to reinforce important accomplishments and highlight the progress that is under way. The project's output included monthly discussions and bimonthly reports.
- Addressing the transportation aspects of micro fuel cells in airline carry-on bags and luggage presents a legitimate technical concern. Ultimately, these policies are addressed by the United Nations, International Civil Aviation Organization, etc. Additional information would be needed to determine whether this is or will be happening at a frequency that would merit prioritization of the standards effort to overcome a significant barrier. If the market expectations support a significant impact, then the project group can consider the question of whether to fund an industry organization to convene an International Electrotechnical Commission working group. The comments about continued task group work for the 2020 edition of National Fire Protection Association (NFPA) 2 are unclear, as it is in the final stages of publication by the NFPA; as of August 2019, new additional input will not be allowed, and no action should be required to "complete the revision cycle." "Review" of a published NFPA standard—that the

industry participated in developing with funding under this project—does not comprise an appropriate aspect of funded future work. Similarly, continuing to review standards is an ambiguous basis for future work.
- It seems unclear what the project staff's role is for the remaining work, especially for the coordination with international standards. There is mention of industry partners putting in effort to ensure harmonization, but it is unclear whether the staff is looking to be an active part of that. It is not evident that the project staff is carrying out proactive facilitation of U.S.-based and foreign-based individuals.
- The proposed future work seems generic and could be improved with specific items. The effort in portable power, in terms of checked baggage, does not necessarily align with the Program's goals. DOE funding should encourage this project to focus on the Program's goals, rather than on a variety of applications.

Project strengths:

- The project achieved its goals and continues to provide a key role in the harmonized development of RCS.
- The strength of the project is in its structure for leveraging partnerships and collaboration through the already existing FCHEA members in order to get a participation base for the tasks being executed.
- The strength of this project is the number of FCHEA members and the project's collaboration with this membership.
- The publication of the safety report provides incident information to the community.

Project weaknesses:

- The need, value, and outcomes for funding industry group participation in codes and standards development are not clear; this seems best addressed by the private sector. For most of the defined standards work, specific advancements and outcomes are not clearly identified. The project seems to be overvaluing activities as accomplishments. Much of the defined work seems to consist of meetings, teleconferences, information dissemination, etc., which can be accomplished effectively through the use of communications and work-sharing technology. On the topic of incident reporting, optimizing and articulating coordination with other work, such as the Center for Hydrogen Safety and the National Fuel Cell Technology Evaluation Center, will help minimize redundancies and best promote impact. The proposed future work plan needs significant development to substantiate relevant, significant outcomes.
- The team is likely overlooking other business entities who could have pressing SCS needs or who could provide valuable insight, but who are being overlooked simply because they are not FCHEA members. This is especially a problem given that one of the barriers that this project intends to overcome is the lack of business participation.
- The weakness with this project is that, while many activities are occurring, its specific contribution is not clearly communicated. The scope of this project is too broad and is not focused on the key areas.
- A project weakness is the inability to independently track, measure, and evaluate results and outcomes against DOE and industry goals.

Recommendations for additions/deletions to project scope:

- The codes and standards matrix is interesting, although it is just being used for comments regarding the status of documents. This document could be expanded to capture critical issues with each standard and include the project's contribution. A recommendation is to reduce or eliminate activities in this project that are not directly aligned to the Program's goals. The FCHEA website could be improved to help the industry, especially in the area of tracking the codes and standards, which is currently disabled.
- While it may not have been relevant so far in the project's lifetime because of the schedule of code cycles, there did not seem to be much work directed toward heavy-duty applications, including vehicular, marine, and other applications. Given the growing momentum around hydrogen in these applications, activity in this area may need to be increased.
- It is suggested that the team provide more details about the challenges of implementation, techniques for accelerating deployment, and lessons learned, as well as an assessment of the project's current standing compared to the amount of work remaining. This can be done either graphically or diagrammatically, when applicable.

- This project needs the addition of value-adding work that will substantiate specific outcomes that would not otherwise be accomplished.

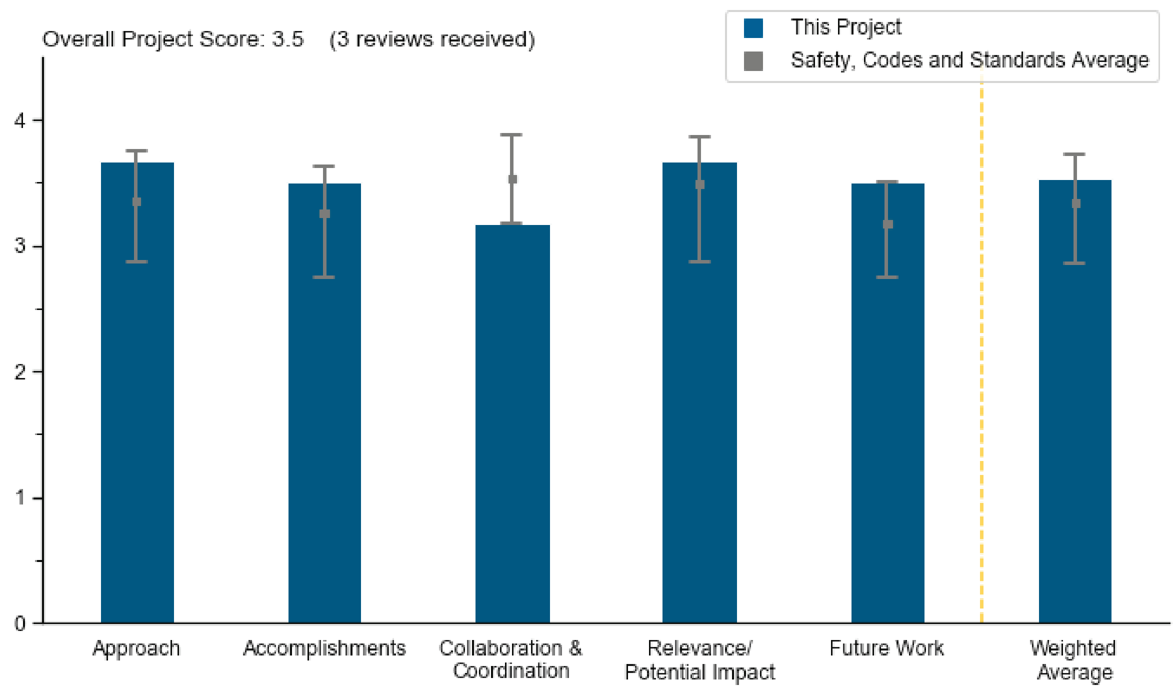
Project #SCS-026: Hydrogen Materials Compatibility Consortium (H-Mat) Overview: Polymers

Kevin Simmons, Pacific Northwest National Laboratory

Brief Summary of Project

The project objective is to fill a critical knowledge gap in polymer performance in hydrogen environments. Investigators are gathering and assessing stakeholder input about the challenges, materials, and conditions of interest for hydrogen compatibility. Findings inform the project's development of standard test protocols for evaluating polymer compatibility with high-pressure hydrogen, characterizing polymers, and developing and implementing an approach for disseminating the information.

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Safety, Codes and Standards projects.

Question 1: Approach to performing the work

This project was rated **3.7** for identifying and addressing barriers, project design, feasibility, and integration with other relevant efforts.

- The combination of analysis that is followed by model development, followed by test method development, followed by validation is excellent. The difficulty of bringing the number of materials and the number of conditions of interest down to a manageable level is daunting, but in general, the initial selection (commonly used materials) and the defects and failure modes that were selected for analysis make sense.
- This project covers a large number of related activities, including the study of degradation, modeling, the identification of suitable formulations, and materials for cryogenic hydrogen service. Early engagement with relevant stakeholders is demonstrated. Direct inroads to the development of the Compressed Hydrogen Material Compatibility (CHMC) 2 standard are clear.
- The approach seems well thought out and effective. A challenge that is acknowledged is how to address the wide variety of non-metallic materials. The presentation did not state whether a prioritization based on commonly used materials has been completed.

Question 2: Accomplishments and progress

This project was rated **3.5** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- Obtaining the stakeholder feedback and distilling that into a prioritized matrix of materials and failure conditions to test is a worthy accomplishment. It is recommended that the principal investigator(s) do a sense-check on that matrix to make sure that they agree that no high-priority materials or failure modes have been omitted. Likewise, the initial tribology studies and the initial work on the test methods document represent significant accomplishments in the first year of the project.
- The project's progress is good; the published database is highly anticipated, but that appears to be a fiscal year 2019 objective.
- The project is in the early stages. Engagement with relevant stakeholders was performed early to inform the effort. The prioritization of failure mode and effects analysis was essential to ensure that industry priorities are being addressed.

Question 3: Collaboration and coordination

This project was rated **3.2** for its engagement with and coordination of project partners and interaction with other entities.

- The project has excellent multi-laboratory and industry collaborations. There is great early engagement with stakeholders. NASA was engaged early in a call but had very little to share regarding polymers. It is noteworthy that NASA is interested in this project's work.
- The team should consider whether it would it be helpful if there were additional materials or seal manufacturers directly involved as partners.
- Other than the listing of the laboratories participating in the Hydrogen Materials Consortium, there was not much discussion of the collaboration. It would be helpful to know, for example, who the stakeholders are who were surveyed in developing the list of materials and failure modes.

Question 4: Relevance/potential impact

This project was rated **3.7** for supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- This project is foundational for the goals of DOE and industry, as it will underpin the design and deployment of safe hydrogen systems, and it will also play a key role in improving the reliability of systems and equipment, such as hydrogen dispensers and compressors.
- The early results are promising. The tribology study report is in publication. Having cutting-edge research data available will aid confidence in design. The work on CHMC 2 is relevant. The work already led to discovering plasticizers that can migrate to the crack edge following exposure to hydrogen.
- Extensive information is available on metallics, but it is needed for non-metallics as well.

Question 5: Proposed future work

This project was rated **3.5** for effective and logical planning.

- The future work is well scoped for the resources of the project and for the fact that it would be pretty easy for the scope to grow too far, given the number of materials that could be considered and the daunting task of developing both models and test protocols for a wider range of failure modes.
- The project has a good plan.
- The project is just getting into the heart of the research.

Project strengths:

- This work is critical, as understanding non-metallic material compatibility with hydrogen is a significant, long-standing knowledge gap. Collaboration with DOE, multiple laboratories, and Ford Motor Company instills promise that the work will be directly relevant to current industry needs and will facilitate the development of CHMC 2, the new, developing standard on hydrogen compatibility with non-metallic materials.
- This is a well-organized project, with clear focus on issues critical to the safety, reliability, and cost of hydrogen production, transport, and dispensing.
- Providing knowledge on non-metallic materials will be helpful to the industry. The project seems to have an ordered approach and has sought extensive stakeholder feedback.

Project weaknesses:

- This is more of a challenge than a weakness: there is not much previously published information available upon which to build.
- It would be beneficial to more clearly see who the industry collaborators are, what the range of materials and failure modes submitted in the questionnaire were, and how the priorities were chosen.
- The project's weakness is in being able to address multiple materials and variations of the same material from different manufacturers.

Recommendations for additions/deletions to project scope:

- The project has a potentially very broad scope already, so additions are not necessarily recommended, but it would be helpful if it were possible to state the goals in terms of something like "for applications such as sealing a ball valve under 700 bar hydrogen pressure, we recommend material X."
- The team should expand from "cryo-compressed" to liquid hydrogen and perform testing down to 20 K. It is not clear that testing at temperatures this low is being considered, but it is necessary as part of the material properties.
- Perhaps in the future, formal collaboration with international research entities could be considered.