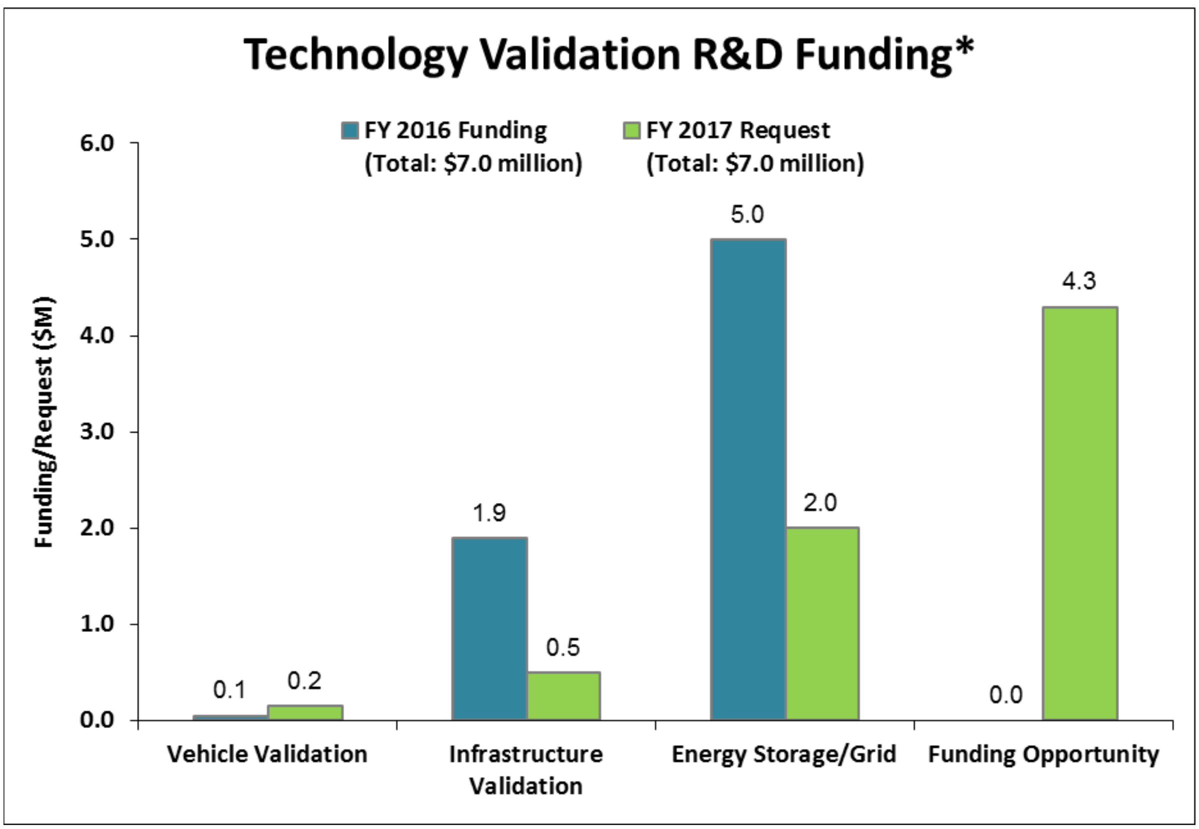
2016 — Technology Validation
Summary of Annual Merit Review of the Technology Validation Program

Summary of Reviewer Comments on the Technology Validation Program:

In general, reviewers commented that the Technology Validation program is well managed and follows an appropriate strategy, with an adequate balance of near- and long-term projects in its portfolio. They believed that effective collaboration with partners and successful management of large amounts of data furthered the program's goals and objectives. While reviewers stated that progress related to projects was adequately presented, they suggested that the issues faced by projects should also be highlighted, and recent progress should be compared to that of the previous year. Reviewers further recommended comparing data gathered from domestic stations against those from overseas; providing cost information on all of the projects, and developing more precise goals to coordinate topics for energy storage with both transportation and grid management.

Technology Validation Funding:

The Technology Validation program's funding portfolio will enable it to continue to collect and analyze data from fuel cells operating in transportation applications (e.g., light-duty vehicles, medium- and heavy-duty trucks, and buses), hydrogen infrastructure activities (e.g., fueling stations, components, and tools), and grid integration/ hydrogen energy storage activities. In coordination with the Office of Electricity and other offices in the Office of Energy Efficiency and Renewable Energy, a key focus in fiscal year (FY) 2017 will be hydrogen-based energy storage and grid integration activities, including "H2@Scale," an approach to enable decarbonization among multiple sectors. The FY 2016 appropriation was $7 million. The FY 2017 request of $7 million is subject to congressional appropriations.



* Subject to appropriations, project go/no-go decisions, and competitive selections. Exact amounts will be determined based on research and development progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements.

Majority of Reviewer Comments and Recommendations:

The reviewer scores for the 14 Technology Validation program projects had a maximum score of 3.80, a minimum score of 2.80, and an average score of 3.31. Key strengths identified by reviewers in all of the Technology Validation projects were the collaboration involving key partners and the potential for the projects to contribute valuable data to allow stakeholders to gain enhanced insights and successfully deploy hydrogen and fuel cell technologies.

Vehicles: Four projects relating to transportation applications were reviewed, with an average score of 3.3. The highest-ranked project in this grouping received a score of 3.7, while the lowest-ranked project scored a 2.8. The National Renewable Energy Laboratory's (NREL's) fuel cell electric vehicle (FCEV) and fuel cell electric bus (FCEB) evaluation projects were regarded as providing valuable real-world insight and were praised for the collaborations with industry stakeholders. Aging vehicles were the main concern. Reviewers thus suggested acquiring data from newer-generation FCEVs and normalizing FCEB data to account for aging buses and smaller sample size. Argonne National Laboratory's fuel cell electric truck (FCET) component sizing project and the Center for Transportation and the Environment's fuel cell hybrid electric delivery van project were both observed as having potentially promising impacts. It was recommended that modeling performed for FCETs be validated for real-world performance and that providing fueling for the delivery vans be a focus area earlier in the project.

Hydrogen Fueling Stations: Three projects focusing on hydrogen fueling stations were reviewed, with an average score of 3.1. The highest-ranked project in this category received a score of 3.3, while the lowest-ranked project scored a 3.0. Reviewers anticipated that the value of data collected and analyzed through NREL's hydrogen station data collection and analysis project would grow as more stations come online, but also recommended better context in presenting data analysis, while strongly suggesting that all retail stations fueling FCEVs report operational and cost data. The collaboration between GTI and Linde in the development and performance evaluation of delivered hydrogen fueling stations was commended by reviewers, and they suggested the collection and evaluation of additional data, such as fill variations and boil-off rates. While reviewers thought that there would be some useful learnings from the Brentwood (Washington, D.C.) hydrogen station case study performed by NREL, they were concerned about the limited nature of the applicability of learnings, as compared to investigating the implementation of hydrogen stations at retail sites.

Hydrogen Infrastructure Support: Six projects focusing on components, methods, and tools supporting hydrogen fueling infrastructure were reviewed, with an average score of 3.4. The highest-ranked project in this category received a score of 3.8, while the lowest ranked project scored a 3.1.

The hydrogen component validation project by NREL and the HyStEP (Hydrogen Station Equipment Performance) device project by Sandia National Laboratory were viewed as consistent with H_2USA priorities by providing crucial information for increasing hydrogen station reliability and accelerating station development. Increased collaboration with stakeholders through the H2Tools platform was recommended for the components project, while reviewers suggested feedback from potential users be obtained for the HyStEP device.

The advanced hydrogen tube trailers developed by Air Products and the cryogenic vessels and high-pressure liquid hydrogen pump fashioned by Lawrence Livermore National Laboratory (LLNL) were both seen to be of value to the development of hydrogen infrastructure. However, reviewers also cautioned that the LLNL project may be occupying a limited niche and strongly recommended collaboration with and input from more than one automaker. Reviewers further suggested that system cost goals and analyses be performed for both projects.

Reviewers believed that NREL's hydrogen meter benchmark testing could extract greater value by developing standards and methodologies that can be used across flowmeter manufacturers. Reviewers further suggested including station owners and operators with real-world experience in the effort, as well as reporting on how the meters are calibrated and the standard to which they will be calibrated, installation factors such as straight runs, orientation and vibration mounting, and other environmental factors relevant to the specific flow meter types.

The California Fuel Cell Partnership's Station Operational Status System project was praised for successful implementation in all California stations, and information provided by the system was regarded as vital to gaining customer acceptance. Reviewers suggested the addition of tank categories to accommodate vehicles with larger tanks, such as buses.

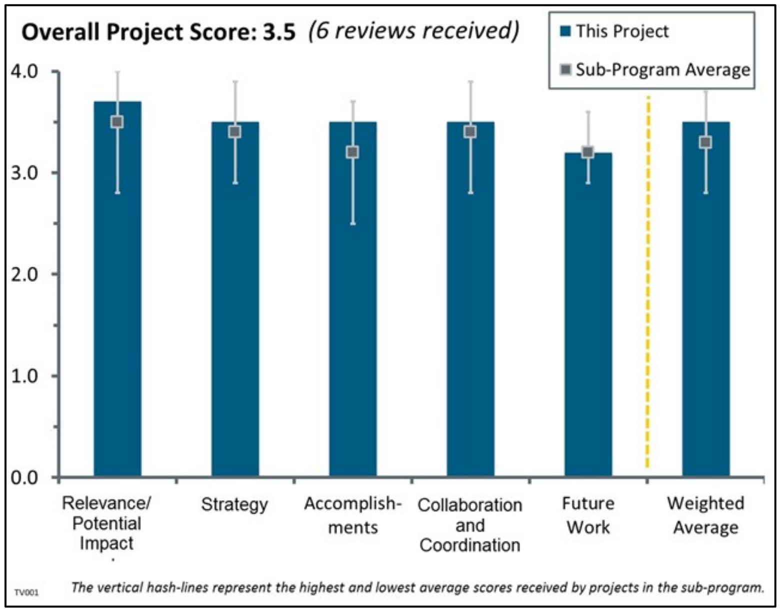
Hydrogen Energy Storage/Grid Integration: Idaho National Laboratory’s project on dynamic modeling and validation of electrolyzers in real-time grid simulation received a score of 3.3 and was regarded by reviewers as important for understanding how electrolyzers may benefit the grid and penetration of renewables may be increased. Reviewers recommended investigating revenue streams in the case of future higher penetration of renewables, evaluating the impact sub-systems supporting the electrolyzer will have in terms of response times, and increasing testing time to between 4,000 and 8,000 hours.

Project #TV-001: Fuel Cell Electric Vehicle Evaluation

Jennifer Kurtz; National Renewable Energy Laboratory

Brief Summary of Project:

The objectives of this project are to validate hydrogen fuel cell electric vehicles (FCEVs) in real-world settings and to identify the current status and evolution of the technology. The analysis will objectively assess progress toward targets and market needs defined by the U.S. Department of Energy (DOE) and stakeholders, provide feedback to hydrogen research and development, and publish results for key stakeholder use and investment decisions. Fiscal year 2016 objectives focus on analysis and reporting of FCEV durability, range, fuel economy, fueling behavior, and reliability.



Question 1: Relevance/potential impact on 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 was rated **3.7** for its relevance/potential impact.

- This project continues to measure the fuel cell stack and system efficiency to help meet the DOE target. Greenhouse gas (GHG) emission comparisons are now being evaluated. The FCEV durability, fuel economy, and driving range have now been documented over four years to demonstrate real-world conditions. The project continues to provide the six original equipment manufacturer (OEM) partners with essential data to improve the design and efficiencies of their FCEVs.
- This Technology Validation project has provided a wealth of information to support the development of FCEV technology that can meet commercialization goals. It is possible that the steadily declining number of participating vehicles and the age of the technology in them means that there is less benefit from this analysis going forward. The principal investigator’s comments that there will be valuable insights into certain metrics (such as durability) coming from the older vehicles are well taken. Nevertheless, the team’s goal of bringing some of the newer FCEVs into this data collection scheme will be important in addressing this concern.
- The project provides valuable real-world FCEV field data. It provides a clear and objective assessment of the current on-road status of automotive fuel cell technology progress. The real-world data are invaluable for suppliers, developers, investors, etc.
- This project focuses on FCEV evaluation, thus fully supporting the DOE Hydrogen and Fuel Cells Program.
- The project is to evaluate early FCEVs of high value to test durability, performance, fueling, and areas for improvement.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.5** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- There is no substitute for driving the vehicles and filling them in a real-world situation. Collecting the data has been the right approach from day one. The National Fuel Cell Technology Evaluation Center is doing an excellent job with the data analysis.
- The project tracks and highlights progress on the key performance commercialization barriers. The key barriers have been identified, and the progress is being tracked properly.
- The project's methodology is sound, and it provides a good number of valuable data. The additional GHG estimates are valuable.
- The strategy—to assess early-market FCEVs and to allow the benchmarking of vehicles to improve performance and durability—is sound.
- These are excellent approaches based on data collection from vehicle operators.

Question 3: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- The analysis and publication of data are impressive and should continue. The public needs to be made aware of the significant progress these vehicles have made over the past four years. With the newer-generation vehicles coming on line and the old vehicles being retired, the new data collected continue to be useful and important as feedback for efficiency and improved specifications for OEMs. Analysis of fuel cell degradation over time is impressive and essential for establishing a metric. There has been a measurable improvement in the fuel cell stack degradation. The stack and system efficiency has also improved. The hydrogen production shows that onsite renewable production is the most efficient. Maintenance and reliability were analyzed per vehicle. The slide showing causes and effects for stack maintenance was helpful. It showed there are some undetermined areas. The 16,000 fills is also impressive.
- Good benchmarking data have been collected from earlier vehicles and have helped with commercialization of new vehicles.
- The project is sharply focused on critical barriers (DOE targets).
- The project has done very well in measuring and demonstrating progress toward DOE goals. The main question is whether newer-generation fuel cell technology should be included to assess the impact of projects like this on the development of the technology.
- It is not clear what the progress has been since last year's review.

Question 4: Collaboration and coordination with other institutions

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

- This project has amazing collaboration from six OEM partners. These partners are solid, and this project could not have asked for a better collaboration.
- The project seems to be well integrated with other organizations examining FCEV technology. It would be useful to get a better sense of how the OEMs are using these data and the value to the OEMs, although that may be difficult for confidentiality reasons.
- There is excellent collaboration with vehicle manufacturers/operators.
- There is good interaction with FCEV OEMs for data use, benchmarking, and analysis.
- It appears that the automotive partners are appreciating the data crunching and reporting.

Question 5: Proposed future work

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

- The future work is clearly outlined.
- In the future, work with newer vehicles and with a driver–refueling interface would be of value.
- Bringing in newer vehicles would add to the project's value quite a bit.
- The customer feedback needs to be matched with the technical data.
- The relevance of the proposed activity "identify new opportunities to document fuel cell and hydrogen progress publicly" is unclear.

Project strengths:

- Overall, this is a well-designed project that has provided much valuable insight into FCEV performance. The composite data products are well thought out, and the team has been good at developing new products over time to show data in different ways.
- Six OEMs continue to be engaged. The data published are transparent and well organized. The public needs to be made aware of the significant progress.
- The collection and analysis of data and trends on FCEV operation are strong.
- The objective data collection and FCEV benchmarking is strong.

Project weaknesses:

- There are no significant weaknesses.
- The main weakness is in trying to make the connection between what is seen here and what is happening in the private sector's continued development of FCEV technology. It is to be hoped that adding in some new FCEVs will help demonstrate the progress (or lack of progress) made in FCEV development.
- The data from FCEVs are not direct from the transponder or users, but through OEMs. Additional information is needed for the driver–refueling interface. Data from older FCEVs should be normalized for comparison with new FCEVs.

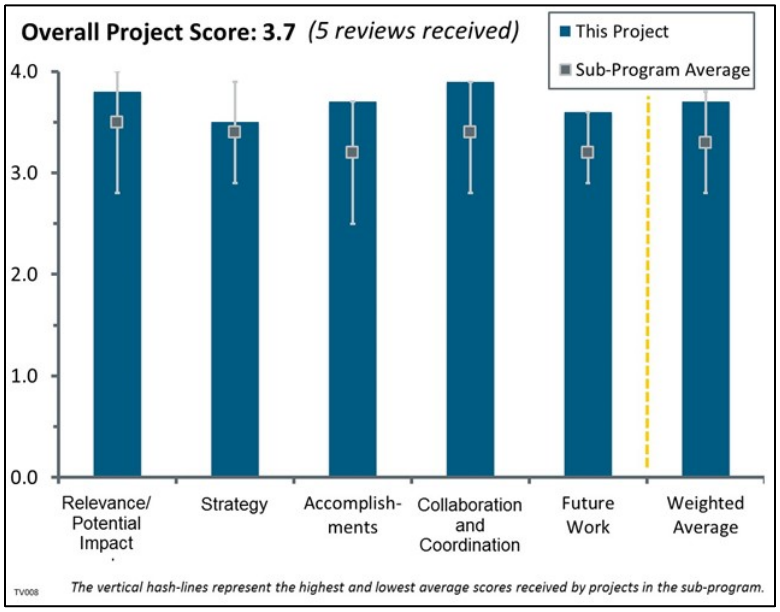
Recommendations for additions/deletions to project scope:

- It is recommended that data also be obtained directly from the transponder, if possible. Data should be collected for the driver–refueling interface. A new FCEV benchmarking is recommended with normalized or separated data of older FCEVs.
- It is recommended that the project make a publication and/or presentation—more public showings that customers can use hydrogen in a vehicle safely.

Project #TV-008: Fuel Cell Bus Evaluations

Leslie Eudy; National Renewable Energy Laboratory

Brief Summary of Project:



The objectives of this project are to validate fuel cell electric bus (FCEB) performance and cost compared to U.S. Department of Energy (DOE)/U.S. Department of Transportation (DOT) targets and conventional technologies and to document progress and lessons learned on implementing fuel cell systems in transit operations to address barriers to market acceptance. Annual FCEB status reports will compare results reported from transit partners and assess progress and needs for successful implementation of FCEBs.

Question 1: Relevance/potential impact on 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 was rated **3.8** for its relevance/potential impact.

- As FCEBs are critical to the advancement of fuel cells, the technology validation of FCEBs is an absolute requirement.
- With increasing attention on fuel cell technology application in trucks, this work becomes even more valuable—as it currently is for transit stakeholders.
- This continues to be an excellent project for assessing the progress of FCEBs toward the DOE/DOT targets for the current year and the ultimate targets.
- This project is necessary for FCEB commercialization.
- The correlation of DOE along with the 2016 targets and the ultimate target were explained very clearly.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.5** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The project works closely with bus fleet companies. The project provides industry data back to the industry on validation assessment and optimization.
- The strategy to objectively evaluate U.S. FCEB operations is sound.
- The project is well designed to track the performance targets set by DOE/DOT and to ensure that there is an apples-to-apples comparison with the buses. The weakness with this is that, with so few FCEBs in operation, there is limited ability to compare to other technologies such as pure electric against which fuel cells will be competing. It would be interesting to see more about the fueling part of the equation, since it is a little unclear how the infrastructure barriers specific to FCEBs is being addressed (for example, fueling times and time between refueling). It would be interesting to see the bus fueling data t side by side with the light-duty vehicle data.
- On slide 9 of the presentation (Availability Summary: 2015 Data), data from the top pie chart indicate that fuel cell system problems reduced total availability by 13% and accounted for more than half of the non-availability period. To improve the availability reported, vice actually improving availability as well as the

quality of the report, the National Renewable Energy Laboratory (NREL) removed the data for the two troublesome buses to get a better number. To their credit, NREL researchers are clear about what they did and did not try to lie, but they did fudge the numbers to provide a number that was not true, i.e., the second, lower pie chart reports only on good buses rather than all buses. Slide 13 provides comparison data for FCEBs vs. diesel and compressed natural gas (CNG) buses. It would have been nice to see a similar comparison of the data provided on slide 14 (Maintenance Cost per Mile by System), maybe a separate slide comparing a composite of *all* FCEB maintenance costs against similar costs for diesel and CNG buses. The chart would probably not have been favorable to fuel cells, but it would demonstrate just how much more improvement needs to be achieved.

Question 3: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- The buses run for five to six years, and their total hours of operation is most impressive at over 10,000 hours for each bus. The average bus availability has improved to 73%. The fuel economy has improved. Reliability continues to increase and has surpassed ultimate targets. Preemptive maintenance has resulted in many of the improvements.
- Given the task assigned, the project team appears to be clearly and sharply focused on the project goals and barriers.
- The project is well targeted to assess progress against key performance barriers.
- There is clear delineation of reported results compared to the previous year's results.
- Progress is good, but the value is being challenged by the overall small number of buses and older bus performance.

Question 4: Collaboration and coordination with other institutions

This project was rated **3.9** for its collaboration and coordination.

- The transit agencies are providing data, and they also review the reports before they are made public. The transit agencies have been cooperative and helpful. NREL has a good relation with the transit agencies.
- Collaboration is very good, as always. The international collaboration is especially interesting, even though the project cannot make direct comparisons against the international deployments because of the difference in operating environments. It would be interesting to see how the international deployments stack up in terms of progressing toward their own local goals compared to how the U.S. programs are progressing.
- There is broad collaboration with both industry and government stakeholders. The project should work with the DOE Office of Energy Efficiency and Renewable Energy Vehicle Technologies Office (VTO) on transfer of knowledge to increase durability and reliability of the fuel cell, battery system, and other components, especially where these components are used in other vehicle applications (such as VTO-funded hybrid- and battery-electric truck projects).
- Collaboration is excellent with transit districts, FCEB original equipment manufacturers, and other organizations. The challenge would be to secure data from other counties where FCEBs are operating.
- The NREL team, and especially the presenter, stated that a great deal of involvement was performed by a number of partner organizations.

Question 5: Proposed future work

This project was rated **3.6** for its proposed future work.

- Given the future necessity for FCEBs and the need to measure their performance, there is a requirement to continue with future work.
- The main interest is in seeing how the FCEBs will compare to a hybrid or battery bus, so it is good to see that NREL will be analyzing battery bus fleets shortly.

- Older bus data may affect analysis of new (next-generation) buses being introduced. Proposed work with parts, maintenance, and support providers is appropriate and valuable, especially for older bus support.
- Strong plan for data analysis/reporting on future bus projects.
- Data collection remains the number one need. Better tools and training are needed. Lessons learned should be documented.

Project strengths:

- A broad array of detailed data is reported. The number of vehicles is expanding. Most vehicles included in data reporting are in full daily revenue service, not demonstrator buses used for educational purposes.
- Objectivity; comparative analysis with FCEBs, diesel buses, and CNG buses; and detailed information on operational costs are all project strengths.
- The methodology is well established and sound, making this a credible, objective assessment of FCEB progress.
- The project is analyzing successful fleet operations and a total of 17 buses.
- This was a good, clear presentation, and the presenter was refreshingly direct and clear.

Project weaknesses:

- The biggest concerns are more to do with whether FCEBs are making sufficient progress toward the ultimate targets than with this project, which is very effective at doing what it is supposed to do. If certain targets appear to be too difficult to reach or other technologies, such as battery buses, will meet those targets first, then it seems we should start to question whether it makes sense to keep tracking FCEB technology in demonstrations.
- Project weaknesses include the low number of vehicles, performance as buses get older, older bus maintenance costs, and lack of collaboration with other bus users outside of the United States.
- A weakness is the need for a good relationship with transit agencies to obtain operational data. If this is part of the contractual obligation of transit agencies funded to operate FCEBs, this should not be an issue.
- It is recommended that NREL present all the data and facts as they are rather than as how NREL would like them to be.

Recommendations for additions/deletions to project scope:

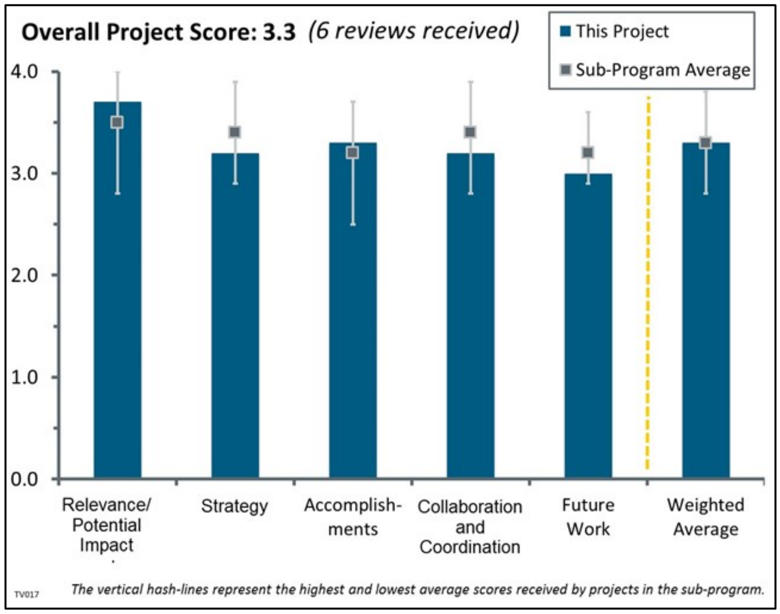
- It was asked in the question-and-answer session whether it would be possible to compare the FCEBs to electric buses. The difficulty of doing an apples-to-apples comparison is very clear, but it seems like this is an important goal to try to reach in some way, especially as electric buses are being deployed in moderately higher numbers over the next year or so. It is not clear whether the project has evaluated noise reductions from the buses. Perhaps this is self-evident, but it seems like it is another potential selling point for FCEBs. It is also a little unclear whether this project is tracking the powertrain cost or the overall bus cost. In addition, perhaps it would be possible to do a GHG assessment, similar to the one done for the light-duty vehicle technology validation project.
- The project should add potential assessment of similar drive systems for trucks (as drive systems are identified as a challenge affecting operational costs/miles). FCTO should include the FCEB supply chain for components and parts in the Manufacturing Research and Development program's efforts. There should be development of a neutral indicator of knowledge/expertise levels of maintenance staff at transit agencies in maintaining FCEBs (electrical systems, electrified components, electric drive/power train, gaseous fuel storage systems [CNG and hydrogen], and automated operational data collection).
- The project should continue with the intent to normalize data to account for older bus performance, increase the number of buses in the project with collection of bus data from operations outside of the United States, and assess costs attributable to high maintenance due to unique low-volume manufacturing.

Project #TV-017: Hydrogen Station Data Collection and Analysis

Sam Sprik; National Renewable Energy Laboratory

Brief Summary of Project:

This project will evaluate hydrogen infrastructure performance, cost, utilization, maintenance, and safety. Data analysis will support validation of hydrogen infrastructure, identify status and technological improvements, provide feedback to hydrogen research, and provide results of analysis for stakeholder use.



Question 1: Relevance/potential impact on 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 was rated **3.7** for its relevance/potential impact.

- This project is critical to the Fuel Cell Technologies Office (FCTO). Collecting and analyzing data are extremely important in assessing technical performance and cost over time, as well as informing FCTO's future direction. Simply put, what gets measured gets managed.
- The project metrics are reasonable and well defined. The U.S. Department of Energy (DOE) is getting good value from this project, as it addresses the critical areas that need data collection and analysis prior to commercialization.
- The project is an important way to address the hydrogen infrastructure challenge. The project's value will grow considerably as more stations come on line.
- The project is clearly very relevant since data on station performance are essential as hydrogen infrastructure grows.
- The project aligns with DOE research, development, and demonstration goals, but serious consideration needs to be given to how the National Renewable Energy Laboratory (NREL) is proceeding, as NREL's method may not be supporting and advancing progress.
- It is not clear until what point in the future these data have to be collected. At some point, issues are known, and hydrogen stations operate in a more or less unsupported commercial environment. Before this point arrives, the DOE/NREL focus for hydrogen station data collection/reporting should shift to bus/medium- and heavy-duty vehicle fueling stations.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.2** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The project defines what kind of retail outlet is wanted in the future. The project works closely with the California Fuel Cell Partnership, among others, and continues to make improvements. Every six months, the project publishes results. All the results are very transparent and are published on the project website.
- This analysis is a good foundation for assessing hydrogen stations and the targets for fuel cell electric vehicle (FCEV) and infrastructure viability. The project's value will grow considerably as more stations come on line, especially retail ones. It is a bit difficult to judge how some of the older stations reflect what

will happen in a retail environment. It would be helpful for the team to explain which site appears to have significantly more hydrogen dispensed than the others (on slide 9). One station seems to comprise a very significant amount of hydrogen dispensed. Also, on slide 18 it would be good to explain why the reformer failure rate is not considered worse than that of the compressors and what the significance of the reformer failure rate is.

- The strategy for gathering data from U.S.-based stations is adequate, but it would be even better if the strategy involved more stations. It is understood that, for confidentiality reasons, some of the stations do not provide data to the National Fuel Cell Technology Evaluation Center. However, the team could reach out to international partners in places such as Japan and Germany to gather additional information. Another potential idea is to gather component data from non-hydrogen refueling stations to compare their performance. It is problematic that the level of detail obtained from each partner varies. Potential approaches to resolve these issues include a streamlined data template, a help hotline to answer any questions related to data gathering and reporting, and a training program for new data reporters.
- As could be discerned from the question-and-answer session (Q&A), there was great confusion regarding the number of stations in the project. The presenter stated that there were 59 stations, but the project collected data from only 11. The status of the other 48 stations is unclear, as is how many are still in operation and, if they are operating, why the project did not collect their data, etc.
- The project should make sure *all* stations refueling FCEVs provide operational data into the DOE/NREL database to get even better insight into the challenges and status of hydrogen station technology. It is not clear how long (until what point in the future) these data have to be collected.
- The presentation advises that the barrier is the lack of current hydrogen refueling infrastructure performance and availability data, and while the presentation provides numerous charts, there is little if any discussion about overcoming the barrier listed.

Question 3: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- There are many stations working and reporting data. The volumes of fuel dispensed have increased, e.g., the average fill is 2.62 kg, and dispensing has become more efficient. Amount, time, and rate are all measured for each station and can be averaged. The utilization rate shows more cars can be filled. The project has identified some of the maintenance issues, failure rates, or kinks being worked out, e.g., compressor dispensers' entire safety storage reformer thermal management. There are compressor issues at all stations. One item was vandalism. There has been excellent progress made on this project over the past several years, and the project must continue to collect data and make improvements before commercialization. Monthly compressor maintenance is conducted. Maintenance cost over time shows $12,400 per station per quarter. Hydrogen quality is also measured. Safety reports by quarter are reported out, and there have not been many incidents except some minor leaks. Electrolyzer energy use per kilogram of hydrogen is tracked. Compressor energy and cost per kilogram of hydrogen are also tracked. This helps with identifying startup time efficiency. The project is very organized, showing major areas of how the project budget is broken down. The team looks at all the critical areas, such as utilization rates, fueling, reliability, cost, and permitting time.
- The team has been consistently delivering consolidated reports every six months and making them available to the public. This is important and ensures widespread data availability. For the general public, it is particularly important to share information on safety records.
- In the future, making a distinction between unique stations and same-design stations may be beneficial for determining whether the same issues continue to plague hydrogen stations when they are rolled out in larger numbers (and new designs). The project should include differences between small and large (capacity) compressor-based stations, as well as an assessment of differences between reported maintenance cost and true (possibly internal to companies) maintenance cost. The project should consider collecting the number of operational hours for station compressors and correlating this with the number of compressor issues reported.

- The project seems to be making good progress toward DOE goals. However, the newer stations will help make this project more relevant to DOE goals, since the newer stations are not intended to be demonstration stations but to show how retail hydrogen stations could operate.
- The presentation provided different answers on the number of hydrogen stations. Slide 5 noted 23 stations, while another stated there were 59. During the Q&A and after the briefing ended, NREL tried to explain that there are different definitions of what constitutes a single "station," but if the presentation is theirs, NREL should choose the best definition, get consistent numbers, and explain outliers as necessary. The briefing is titled Hydrogen Station Data Collection and Analysis, yet five years into the project, NREL advises that a barrier is a lack of hydrogen infrastructure performance and availability data. If there is a lack of performance and availability data, it is not clear how they generated about 40 pages of data for their briefing. Slide 7 (Hydrogen Infrastructure Composite Data Products) is interesting/disappointing. The chart advises that there are 61 composite data products (CDPs) in 9 categories—43 updated and 18 new—but there is no discussion about what the CDPs are or why they are important. The only clarification was from the oral and written statement that "a subset of the infrastructure CDPs [is] presented here." There is no explanation of the importance of the subset or the nature of the other CDPs. There is also no subset as offered. Slide 9 (Hydrogen Dispensed by Quarter) makes no sense; slide 10 makes less sense. When asked about the purpose and accuracy of the data points, the presenter remarked that a station could have opened in California this morning. The point of that response is unclear. By slide 11, it was tough to figure out the purpose of the charts being presented. It almost seemed like some charts were added solely to increase the page count so that the presentation was more of a book report rather than a management presentation. Slide 28 and 29 provide previous-year reviewers' comments. The first comment states that, despite templates being produced, the level of details and harmony of those data have impacts on conclusions from the NREL analysis. A reviewer commented that, despite templates being produced, the analysis is tough to follow. Yet NREL's response does not focus on addressing the confusion. The result is that the same problem exists this year as last. Another comment from the previous year states that there is no indication that NREL can manage data and analysis for 40+ stations. NREL's response did not provide details, just assurances. This comment is still valid, and NREL's ability to manage data and analysis for 40+ stations remains in question.

Question 4: Collaboration and coordination with other institutions

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

- Collaborations are excellent. The partners providing data are very impressive. The memorandum of understanding with the California Energy Commission (CEC) is very important. The California Air Resources Board (CARB) is also a partner in this project.
- Collaboration with international partners is critical to improve data collection from a wide set of technologies and operating conditions. The project could benefit from information exchange beyond safety. This would help benchmark performance and operation data, which could help accelerate the introduction of the most effective technologies and best practices.
- Collaboration is forced in this project because data collection requires inputs from the various station owners.
- The project needs to make sure that all stations fueling FCEVs in a retail manner report operational data for inclusion in the database and assessment.
- NREL provided a list of partners providing data on slide 31 and lists all collaborators on slide 30. Beyond slide 31, there was no discussion on who did what, if anything.

Question 5: Proposed future work

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

- The project must continue to collect data on cost versus performance. The CEC builds the stations, and the project simply collects the data. Although the number of stations in the future is somewhat unknown at this time, at least the team is identifying areas where stations should be located and raising the funds to build them.

- The reviewer is looking forward to the new stations and the separation of retail vs. demonstration.
- Thinking about future work could be broad and/or out of the box.
- NREL may be collecting a lot of data, but without considerable management overhaul, the data could be irrelevant, if not just plain wrong.
- It would have been good to see within the proposed future work an effort to continue to reach out to domestic and international stations that do not currently report data. Also, the team should communicate and exchange lessons learned from international organizations that collect similar data for stations located outside of the United States.
- It is not clear what defines "retail" vs. "demonstration" stations.

Project strengths:

- This is an important area of focus since it represents a key potential barrier to the market and one that really needs to be addressed through a collaborative effort, with public and private sector input. Therefore, this seems like an ideal project for DOE.
- Partners such as CEC and CARB are a huge plus in this project. The publishing of data every six months is excellent and should continue.
- The slides comparing the flow rates and fill times for -20°C vs. -40°C filling are very useful, justifying the additional cost for hydrogen pre-cooling to -40°C.
- Project strengths include the experience from years of data collection, analysis capabilities, and frequent data reports.
- Strengths include the large numbers of data, with more to come, and the ability to handle more.

Project weaknesses:

- One weakness is really a weakness in the hydrogen fueling market. It seems there is a very limited pool of suppliers for some of the key technologies here, making it hard to see if the problems with certain stations are likely to be fundamental problems with the station configuration and technology choice or if the problems are specific to one company's products.
- International collaboration is lacking. The number of stations within the project is a weakness, as is the types of technologies under review. There is a need for data on combined heat, hydrogen, and power (CHHP) and cryo-compressed hydrogen.
- The inclusion of previous/old-generation hydrogen station data is a weakness. Differences between data fields completed/submitted by station operators give an incomplete picture of what the real issues are.
- One trivial comment is that the word "data" is plural. In the responses to past comments, the presentation includes statements such as "data is reported."

Recommendations for additions/deletions to project scope:

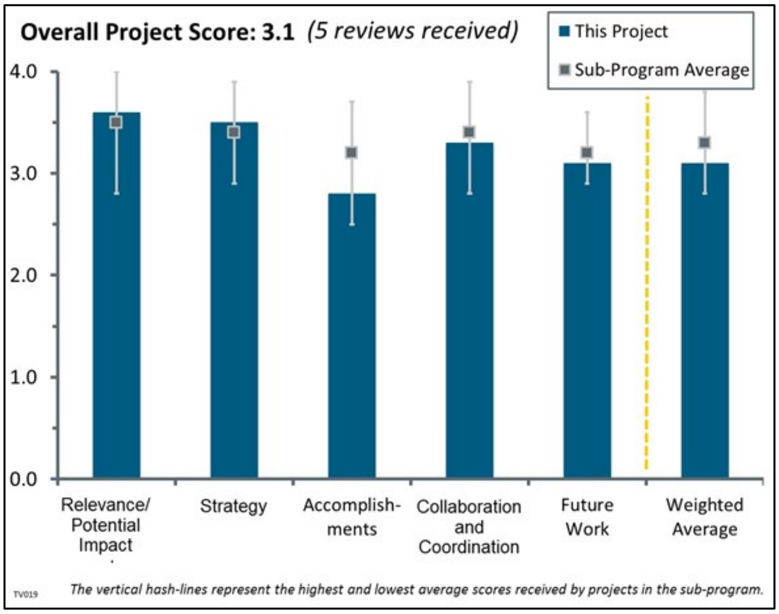
- The project should consider sharing results with the International Partnership for Hydrogen and Fuel Cells in the Economy.
- It could be interesting to assess how a station would ramp up to more hydrogen fueling events per day and how it would supply the hydrogen as the market grows.
- International collaboration for data collection and analysis should be strengthened. The number of stations within the project should be increased, as should the types of technologies under review, for instance, CHHP and cryo-compressed hydrogen stations.
- Under safety events, it would be useful to understand what "near misses" are. The project defines "near misses" as including hydrogen leaks without ignition. It would be good to know whether there were many hydrogen leaks, and, if so, what the estimated leak rates were.
- There should be a serious look at how NREL is managing the project and NREL's response to this year's shortcomings.

Project #TV-019: Hydrogen Component Validation

Daniel Terlip; National Renewable Energy Laboratory

Brief Summary of Project:

The objectives of this project are to (1) reduce fuel contamination introduced by forecourt station components, (2) improve station reliability and uptime, and (3) increase the publicly available energy and performance data of major station components. The project will focus its efforts on a contaminant library, station reliability and maintenance, and station power and energy demand.



Question 1: Relevance/potential impact on 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 was rated **3.6** for its relevance/potential impact.

- The project clearly advances and supports progress toward understanding and improving the reliability (and feasibility) of hydrogen dispensing stations. Ideally, this work would be done by industry. However, in the absences of industry work, this project serves a very useful role.
- A project of this type offering failure analysis provides critical information necessary for improvements that increase component and station reliability.
- The project is targeted at identifying key areas of failure, collaboration for common solutions, and commercial advancement of industry for hydrogen fueling.
- It is important to conduct hydrogen component validation.
- Based on the presentation, the objectives and the areas of focus are consistent with H_2USA priorities. However, it is not clear how the objectives and areas of focus address barriers identified by the U.S. Department of Energy (DOE). The presentation should show the barriers being addressed.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.5** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The general approach of working with users to log and investigate equipment failures is sound. The survey of equipment vendor concerns is quite valuable. The National Renewable Energy Laboratory (NREL) is uniquely suited to collect and analyze the data from a variety of sources. The approach of installing and testing equipment is a key component in obtaining and understanding the data.
- Collaborating with industry to identify areas of common failure at compressors, dispensers, and chillers is a sound strategy. The project should share data as appropriate and undertake outreach to identify solutions.
- Leveraging the existing projects is a positive approach for this project. The inability to find a customer base is a weakness. If the customers are sponsored in part by DOE, then they should make space available if this is important to them and to DOE. It is not clear whether the forecourt station operators are DOE-sponsored. There are no specifications of sampling techniques and anticipated contaminants. There are purity specifications for hydrogen, but it is not clear that these will be used in the study. The project will benefit

from the National Fuel Cell Technology Evaluation Center (NFCTEC). Several points are not clear: whether monthly station reports will be published, how H2Tools will benefit the project, how the Station Operational Status System will benefit the project, or how NREL composite data products will benefit the project.

- The project should focus on compressor operation and reliability, as this component has had the highest downtime and maintenance.
- Both organization and collaborations should ensure adequate information is available for failure analysis, part modification, and retest.

Question 3: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- Progress is good in terms of examining common problems associated with contaminants, valves, and seals. Thought has gone into metering to isolate problems. Posting data on H2Tools should be of value for industry collaboration.
- Contaminant library data, energy cost data, and reliability data are necessary data collection points if the industry is to improve uptime.
- The project reports initial data/samples collected and reported. The analyses have been initiated. On slide 9, it is not clear what “function group contaminant studies performed at NREL highlight” means—whether the three chemicals/compounds shown (amides, sulfur compounds, and aromatics) are present there or to be looked for. It is also not clear what “compressors and dispensers remain major maintenance burdens,” means on slide 10, since this was already known. The pie chart on side 10 indicates “electrolyzer” has the most maintenance events, but this was not discussed for reasons that are unclear. “Progress – Maintenance Reduction” may not be the proper title for slide 11, since what is presented there are more like actions initiated as a result of data analyses. Progress is not “Communicating with equipment manufacturers.” On slide 14, it is not clear whether the 900 bar compressor installation generates the data. It is not clear what the source of these data is since slide 14 comes two slides after the installation slide (slide 12), with chiller and dispenser data in slide 13.
- Progress since last year is adequate; however, at this stage, high-level recommendations on the compressor (design changes/modifications, system changes, etc.) should be given.
- The amount of data analysis and number of conclusions are disappointing approximately four years into the project. Greater understanding and more success stories were expected. For example, the monthly logging and accumulation of data on thousands of failures are very good. However, little or no analysis of the root causes of the failures is presented. This may be due to an absence of findings or merely from deficiencies in the presentation. Photographs of metal flakes and elastomer are shown, but no description of their sources or how to avoid their occurrence is included. Under “Maintenance Reduction,” it is not clear how or whether maintenance was actually reduced as a result of the project. The graphs selected for compressor performance did not illustrate conclusions from the project. For instance, presumably performance is measured to compare to expectations and/or compare estimates. Merely showing results does neither. Furthermore, the graphics raised questions as to why power decreases, why the kilogram–hydrogen curve is so jagged, and why a graphic over such a limited range of pressure increase was selected.

Question 4: Collaboration and coordination with other institutions

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

- The project seems to have a robust selection of relevant industry participants.
- The project is partnering with HydroPac and others to identify problems and solutions, which is good. More collaboration is needed, possibly through H2Tools.
- There is a good list of collaborators, although the project should consider adding Air Products and Chemicals, Inc.
- There is collaboration with five different organizations.

Question 5: Proposed future work

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

- The Venn diagram of activities and issues is an effective way of illustrating and thinking about future work.
- The future work of value is to continue with the investigation of common problems, collaboration with industry, and identification of common solutions.
- The proposed future work is too high-level. A list of activities is recommended. The drawing is not well defined. It would be unfortunate if the project work is only the area defined by the overlap of all three circles, although this is not clear.
- The project should solicit seal and gasket suppliers to join the collaboration effort.
- More details should be given to clarify the objective/focus of the proposed future work.

Project strengths:

- The project is fulfilling a need not currently being conducted by industry.
- Strengths include a streamlined process to identify common problems, collect and store data, and collaborate with industry for solutions.
- A high number of critical infrastructure suppliers are engaged collaborators.
- Strengths include the focus on validating operation and reliability of the key components affecting system downtime and maintenance. There needs to be an identification of failure modes and root causes.
- NFCTEC has well-established data collection processes.

Project weaknesses:

- The project does not identify critical contaminants that have been specified through previous DOE efforts. It is not clear how the project at Hawaii Natural Energy Institute, the project at the University of Connecticut, or codes and standards efforts contribute to this project.
- The testing location is at elevation (5,800 feet). Real assets deployed in the field are essentially at sea level. Corrections for altitude should be included. Future work should prioritize areas of research based on feedback from actual infrastructure installations.
- The project seems to have limited accomplishments, given its four-year lifetime. The viewgraphs as presented do not adequately reveal conclusions from the project; they merely cite activities.
- Lack of project completion targets is a weakness.
- There is limited interaction with industry to identify problems and solutions.

Recommendations for additions/deletions to project scope:

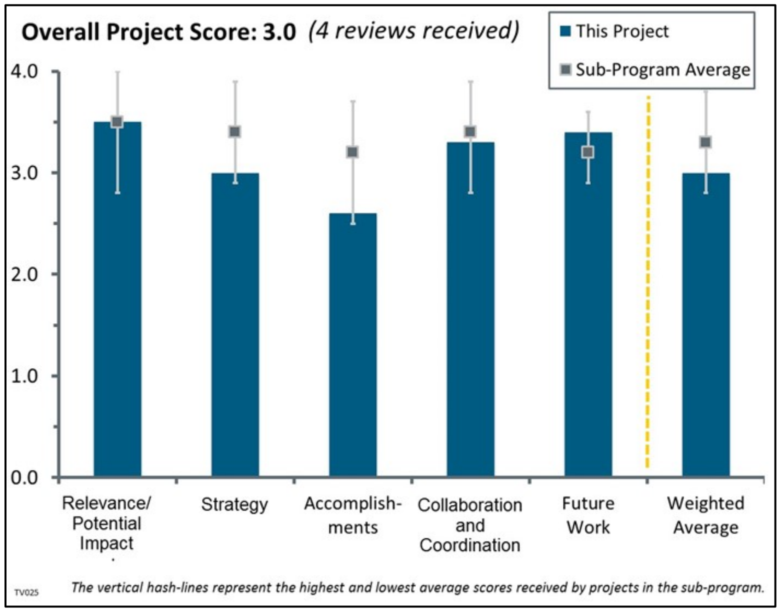
- There should be increased dissemination of aggregated data to industry, possibly promoted through H2Tools, to increase interest in identification of common problems and solutions.
- There should be more emphasis on discovering the cause of the failures and working with the manufacturers to fix them.
- The project would benefit from Air Products and Air Liquide as collaborators.

Project #TV-025: Performance Evaluation of Delivered Hydrogen Fueling Stations

Ted Barnes; Gas Technology Institute (GTI)

Brief Summary of Project:

The objectives of this project are to (1) install data collection systems at five 100-kg/day delivered hydrogen fueling stations located in California for a 24-month period, (2) submit station data specified in the National Renewable Energy Laboratory Hydrogen Station Data templates, and (3) provide useful data to accurately characterize stations' performance.



Question 1: Relevance/potential impact on 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 was rated **3.5** for its relevance/potential impact.

- As the number of fueling stations increases in the coming years, it is very important to get real-world data on the performance of delivered hydrogen fueling stations. The project aligns well with U.S. Department of Energy (DOE) research, development, and deployment objectives.
- Real-time, remote data acquisition provides an easier and faster means to determine the reliability of various station components.
- This project aligns well with DOE objectives and will provide good data from multiple sites to help validate station performance.
- It is unclear whether all the Linde Group stations are based on liquid hydrogen or whether their designs are significantly different. Therefore, monitoring five stations by the same operator may not have as much impact as having different hydrogen delivery technologies or different operators.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.0** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The project has a good plan with appropriate decision points.
- It would be helpful if the project could identify the specific technologies and performances being validated at each station, beyond just reporting number of fills per month.
- The project appears to be stuck because of permitting issues with remaining stations. Perhaps the investigator can switch to stations that are in active duty already.

Question 3: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- This project has made good progress with the first stations and expects to have more than the two years of planned data. Delays on the newer stations will result in less than two years of data. This is not unexpected because of issues with getting stations commissioned at this stage of development. Having more than two years on specific stations could provide added value by showing how the station performs over time.
- The project appears to be stuck because of permitting issues with remaining stations. Perhaps the investigator can switch to stations that are in active duty already.
- Certainly, the delay in permits has contributed to the delay in data from the three non-commissioned stations. However, the quality of data collected from the first two stations could be improved beyond just number of fills and dispensed amount. Perhaps the project should include boil-off rates, daily fill variations, etc.

Question 4: Collaboration and coordination with other institutions

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

- The team has excellent collaborations with industry and multiple station locations.
- The Gas Technology Institute (GTI) and the Linde Group appear to be strong partners.
- It is possible that there may have been practical reasons not to include other stations from different operators, but this project might as well be titled “Performance Evaluation of Linde H2 Stations by GTI.” Also, there is no need to plug an unrelated company sales pitch at the Annual Merit Review (slide 15).

Question 5: Proposed future work

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

- The future work will increase overall station data.
- Commissioning of the remaining stations should be at the top of the list. If delays continue, additional time may be needed to generate meaningful data from the new stations.

Project strengths:

- The project will provide much needed data on station performance at multiple sites. Having data beyond two years on some stations could provide insight on station durability.
- Dealing with a single operator should make communication and execution easier.

Project weaknesses:

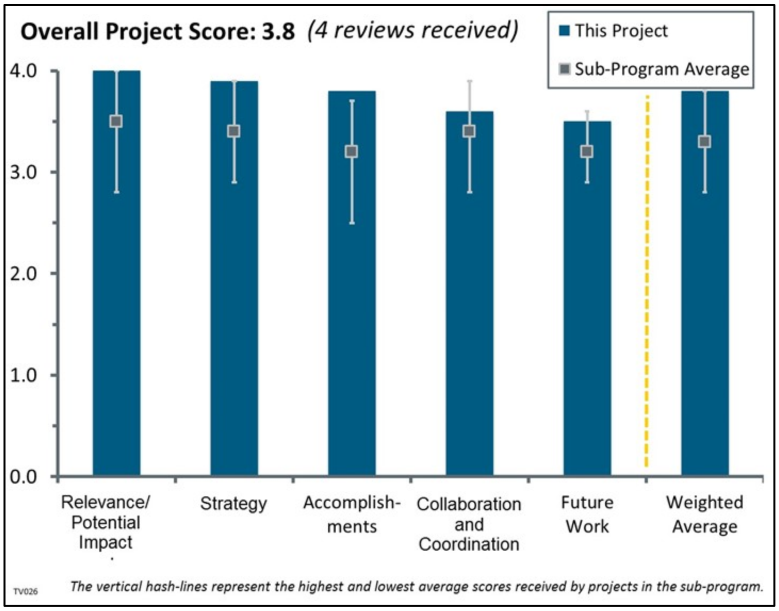
- The permitting process continues to cause delays for station commissioning. This emphasizes the need to engage code officials early in the process and to educate those with less familiarity of hydrogen.
- Dealing with a single operator can make the data quality biased.

Recommendations for additions/deletions to project scope:

- Perhaps the investigator can switch to stations that are in active duty already in order to collect data.
- The project team should focus on securing permits for the remaining three stations and catch up to the schedule. The team should also consider getting input from other delivered hydrogen vendors.

Project #TV-026: Development of the Hydrogen Station Equipment Performance (HyStEP) Device

Terry Johnson; Sandia National Laboratories



Brief Summary of Project:

The main objective of this project is to accelerate commercial hydrogen station acceptance by developing and validating a prototype device to measure hydrogen dispenser performance. Fill safety is a common goal of vehicle manufacturers, consumers, station operators, and state stakeholders. The Hydrogen Station Equipment Performance (HyStEP) device can shorten the lengthy station acceptance process.

Question 1: Relevance/potential impact on 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 was rated **4.0** for its relevance/potential impact.

- This project develops a device to test hydrogen stations without the need to use multiple original equipment manufacturer vehicles. This is of vital importance to the industry and will speed up the process of commissioning stations.
- Based on past experience with the 350 bar station testing apparatus (STA) of the California Fuel Cell Partnership (CaFCP), the development of a unit that can test and validate a station for 700 bar cold fills will be very useful in speeding up station commissioning. However, for adding to commissioning efficiency for commercial purposes, it would also be helpful to have an adapter added to the unit that can collect hydrogen samples for quality testing. Beyond commissioning, the testing unit can also be used for periodic gauging of station performance.
- The HyStEP device is likely to contribute in accelerating station acceptance process, both in time and cost, while helping standardize hydrogen dispensing safety and performance.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.9** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The only thing this reviewer would change is doing tests in the winter in conditions similar to those found in upstate New York to determine reliability under harsh conditions.
- The project has an excellent approach to developing and testing the device.
- The project appears to be well designed and well managed, both from a schedule and cost perspective.

Question 3: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- The fact that the project was successfully deployed in about a year and half is very impressive. The project management and execution should be held as an example for other projects.
- The project has come in on target for scope, costs, and schedule. The management of this project has been great.
- This project has made significant progress. The design is good for ease of movement between sites. Testing included fault detection to determine how well the stations respond to specific out of bound conditions. The device was validated at several stations.

Question 4: Collaboration and coordination with other institutions

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

- There was good collaboration with other laboratories, industry, and station providers.
- It is recommended that this project understand previous work, such as the CaFCP STA, so that it can learn from others.
- In Phase II it will be crucial to begin investigating who this device will be handed off to for future work and how that will happen. Otherwise, the investment and work to date could fall flat and not reach the stated goal.
- Overall, there is excellent engagement with partners. However, Powertech was missing from the partner and collaborator list although a chunk of the construction, performance, and safety tests was done at Powertech. Also, it is not clear why U.S. automakers were not part of this effort.

Question 5: Proposed future work

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

- The project has a good plan for follow-on work. Most future work is for other partners to put the device to work.
- This should evolve into more of a turnkey operation for station commissioning that includes hydrogen quality sampling for purity certifications and eventually flow meter certification. A company that could do all three would really simplify commissioning.
- The project needs to enlist feedback and participation of possible future users of the device (or one like it) in order to ensure (as best possible) this device will be readily picked up and used for future station testing activities. Merely developing and confirming the device will not be sufficient; project partners need to "lean into" the third party use of this device.
- The stated future work is sound. However, if the project is considered complete and the device deployed, there are questions about who will do the follow-up work and how it should be performed.

Project strengths:

- Project strengths include a robust design that can be easily moved from site to site and open source code to ensure all in the industry can benefit from the technology. The fact that an audience member during the presentation asked where he/she could acquire the device speaks volumes to the value of the project.
- The project team including Powertech with all of its experience helped to keep the project on scope and on time. Further use is guaranteed by California Air Resources Board (CARB).
- The project has a clear objective as well as excellent project design and execution.

Project weaknesses:

- *[No responses entered.]*

Recommendations for additions/deletions to project scope:

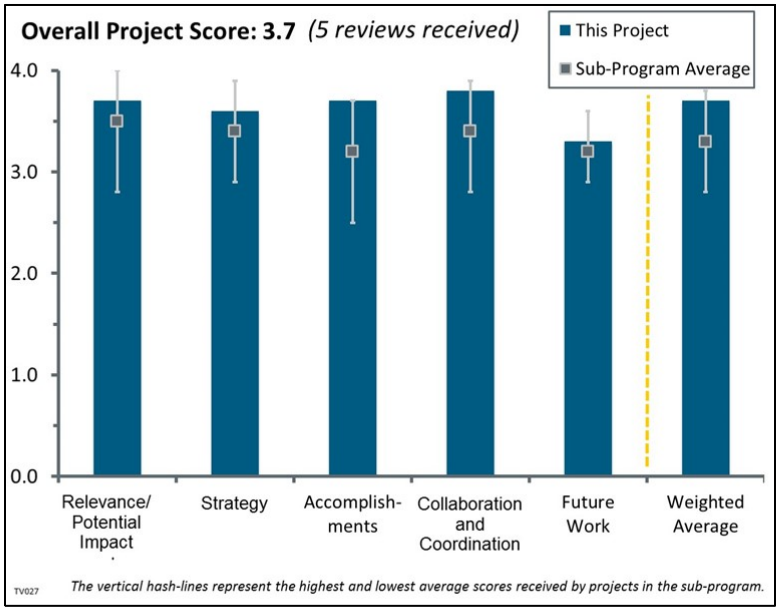
- Although it is likely out of scope, an added benefit would be to investigate the possibility of adding a hydrogen sampling device to test quality.
- It is not clear what the commercialization or deployment plan is for the HyStEP device. It is not clear who should be responsible for validating station performance: regulators (e.g., CARB), station owners, or automakers. This is outside the scope of this project, but if these questions are not addressed, the value of the device may be diminished.

Project #TV-027: Station Operational Status System (SOSS) 3.0 Implementation, SOSS 3.1 Upgrade, and Station Map Upgrade Project

Ben Xiong; California Fuel Cell Partnership

Brief Summary of Project:

The objectives of this project are to (1) consistently and reliably report hydrogen station operational status information to fuel cell electric vehicle (FCEV) customers to increase customer satisfaction and station demand and (2) provide the most recent, realistic, and accurate hydrogen station information to FCEV customers, station implementers, and authorities having jurisdiction to address stakeholder station information needs.



Question 1: Relevance/potential impact on 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 was rated **3.7** for its relevance/potential impact.

- This project has provided the U.S. Department of Energy (DOE) and project partners with valuable data and has established a customer-based information system for hydrogen station availability and liability so that an FCEV user can know if a station is available. This information system answers the question of whether the station is online or offline, a needed capability with so few stations available.
- The project strongly supports early-stage rollout of FCEVs. It would be difficult to proceed with early commercialization if a station locator tool such as this did not exist.
- This project is vital to commercialization as it promotes customer acceptance. Customers need this information during the early stage of implementation of hydrogen stations when availability is limited.
- The objectives of this project are highly relevant in advancing hydrogen FCEV deployment. One of the frustrations for owners and early market manufacturers of FCEVs remains the availability of reliable fueling stations.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.6** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- Phase I and Phase II are completed and it is an outstanding information system. Researchers are now improving the Station Operational Status System (SOSS) website so the customer can use the information easier. Data collection is fairly simple, so the customer can determine whether a station is available. Red, yellow, and green indicate the status of a station.
- The project benefitted from an excellent plan from its initial phase through continual updates to improve functionality.
- The project's approach implementing the SOSS upgrade is sound and achievable.
- Because this tool will likely be needed for the next 10 years of early market introduction, adding someone with a bit more information technology (IT) knowledge and experience is strongly encouraged to ensure

that all features needed for future growth and security are taken into consideration. For instance, IT subject matter experts from the University of California, Los Angeles; original equipment manufacturers (OEMs); Air Products and Chemicals, Inc. (APCI); or IBM Solutions can be consulted on this project to make sure that it is done right from the start as opposed to a stopgap, Band-Aid approach that leaves the tool vulnerable and inefficient. For instance, it was unclear why Amazon Cloud was selected over Microsoft Cloud, which may offer a lot more features and flexibility and has a proven track record with industry. Also, if Microsoft Cloud is adopted there is no longer any need to support a separate server, which will become obsolete in a couple of years. You can save cost on hardware and software, have the latest security features, and backup is taken care of by Microsoft. Finally, if the tool will be used for both electric and compressed natural gas (CNG) vehicles, it is imperative that all of hardware and software features/requirements be fully vetted by experts to make them as secure, cost effective, seamless, and intuitive as possible.

Question 3: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- Researchers have successfully upgraded their data to a mobile-friendly access: http://m.cafcp.org. They are developing a backup system or server in case one of the systems crashes. They are also developing a new application called implementation station map upgrade to advise of new stations coming online and their status.
- The number of stations participating in the project is commendable. DOE, the California Air Resources Board, and the California Fuel Cell Partnership (CaFCP) deserve kudos.
- There have been outstanding accomplishments over the last year, with added stations and better data collection. The project is moving to automated data collection, which can speed up the process and avoid human error. Development of a disaster recovery plan is a good addition to the project scope.
- The project has succeeded in bringing all California stations onboard its system and made good progress on the disaster recovery plan.

Question 4: Collaboration and coordination with other institutions

This project was rated **3.8** for its collaboration and coordination.

- Overall, collaboration is impressive. The project has seven car companies providing valuable input as well as station operators.
- Collaborations could not be improved; the project is working with all known stations in the state. New funding calls from state organizations require that all new projects participate and will ensure complete coverage is maintained.
- There is excellent collaboration with the right stakeholders.
- Key stakeholders are all participating, which is further validation that the project is necessary.

Question 5: Proposed future work

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

- Adding new data fields will greatly increase the functionality of the application.
- The project is supporting the development of additional stations in California and elsewhere through Air Liquide. At the moment, the database can only process four pieces of data. The team needs to develop a capability to add data.
- The goal of collecting cumulative customer and detailed station data, although extremely helpful to industry, may not be welcome by OEMs or station owners, such as APCI. Therefore, it will be another feather in CaFCP’s cap if this can be pulled off with full buy-in from the stakeholders. Also, although station locators for electric and CNG vehicles are available, having all of this information on a single platform will be helpful.

- Besides real-time reporting, the project team may also consider engaging legal or social media experts regarding sensitivities surrounding privacy and customer data collection and use.

Project strengths:

- Strengths include 100% participation in California of operating stations. The project also has good partners such as the CaFCP.
- The project provides vital data to customers, which could increase acceptance of hydrogen as a vehicle fuel. New projects funded by the state will require participation.
- The project strengths are its relevance, timing, and strong partnership with vendors.
- It provides a much needed solution for three alternative vehicle areas.

Project weaknesses:

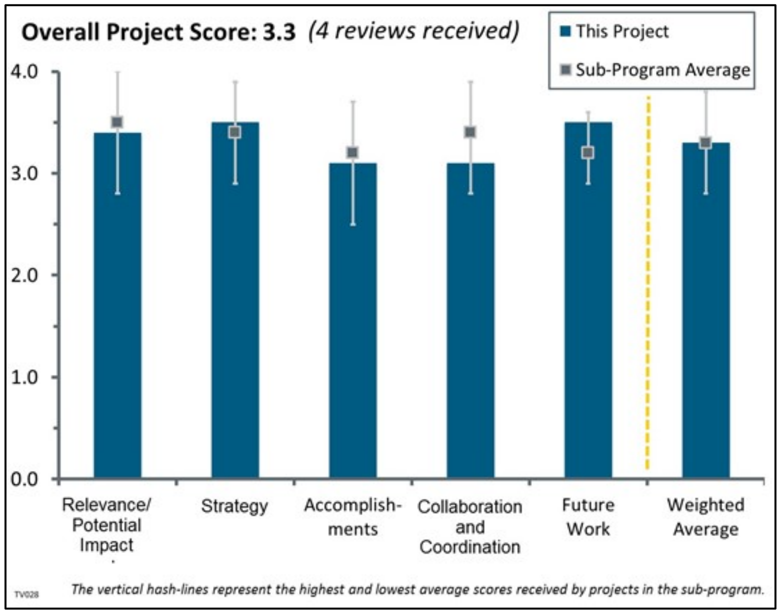
- Because this tool may be used broadly for many years, the project is encouraged to leverage multi-OEMs and station provider IT expertise, especially using those that have a lot of remote data collection experience and lessons learned. There is no need to constantly be reinventing the wheel from scratch.
- It would be helpful if the project could make a clear boundary between its effort and those of the OEMs.

Recommendations for additions/deletions to project scope:

- The team should claim victory on this project and publish the results for all to see and use.
- The project should continue work to increase data fields that can be used for analysis.
- It looks like the SOSS station status criteria considered only one tank size (which appears to be for light duty passenger cars). Therefore, the relative unit of 95% state of charge (SOC) can potentially send the wrong information for vehicles with larger tanks, such as buses. Therefore, the project team should consider adding one or more tank-size categories and calculate the 95% SOC accordingly.

Project #TV-028: Advanced Hydrogen Fueling Station Supply: Tube Trailers

John Aliquo; Air Products and Chemicals, Inc.



Brief Summary of Project:

This project supports the U.S. Department of Energy (DOE) objective of developing and validating advanced hydrogen tube trailers for the hydrogen and fuel cell market. Investigators will design, procure, construct, and demonstrate a new composite over-wrapped pressure vessel to increase the pressure capability of tube trailers. Increasing hydrogen delivery pressure to >586 bar (8,500 psig) can raise hydrogen delivery capacity, reduce the need for compression at hydrogen fueling stations, and lower overall hydrogen delivery cost.

Question 1: Relevance/potential impact on 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 was rated **3.4** for its relevance/potential impact.

- The project is very relevant. The number of hydrogen stations is on the rise, and the majority utilize delivered gaseous hydrogen.
- The project will develop hydrogen tube trailers at higher pressures. This could be a big benefit to the industry by reducing the need for compressors. At this point in development, compressors are responsible for the majority of station issues.
- There is a clear need for high-pressure tube trailers, and this project addresses the need directly. There is no fundamental technology barrier to conducting this design and fabrication project. Air Products and Chemicals, Inc., (Air Products) could do the entire effort on its own without U.S. Department of Energy involvement. However, considering that there is a national need for such a product and the economics alone have not led Air Products to pursue the project, this is an appropriate use of research and development dollars (especially considering it is almost 50% cost-shared).
- The project has the potential to minimize some of the expense associated with station compression if the U.S. Department of Transportation (DOT) allows these high-pressure trailers to move on major highways and pass through tunnels.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.5** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- Air Product's successful design, construction, and implementation of the 520 bar tube trailer provide a lot of confidence in its project plan for the 586 bar composite tube trailer.
- The approach is a good plan with adequate decision points for moving forward.
- The approach is logical, straightforward, and appropriate for the largely engineering task proposed.

Question 3: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- This is a new project, so it is not expected to have accomplished much at this point.
- The project has just begun; as would be expected, there have been no substantive accomplishments to date.

Question 4: Collaboration and coordination with other institutions

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

- The project involves good partners that are committed to the work.
- The proposed collaboration is appropriate. It is important that the project engage a vessel manufacturer.

Question 5: Proposed future work

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

- The majority of the work plan is included in the future work. This is expected of a new project.
- The future work plan is appropriate for the project.

Project strengths:

- The development of higher-pressure tanks that can be delivered to sites could be a benefit to the entire industry. Reducing the need for compression could lower cost and reduce downtime due to compressor issues.
- A project strength is the straightforward, direct work plan proposed, i.e., design, build, and test a high-pressure tube trailer truck.

Project weaknesses:

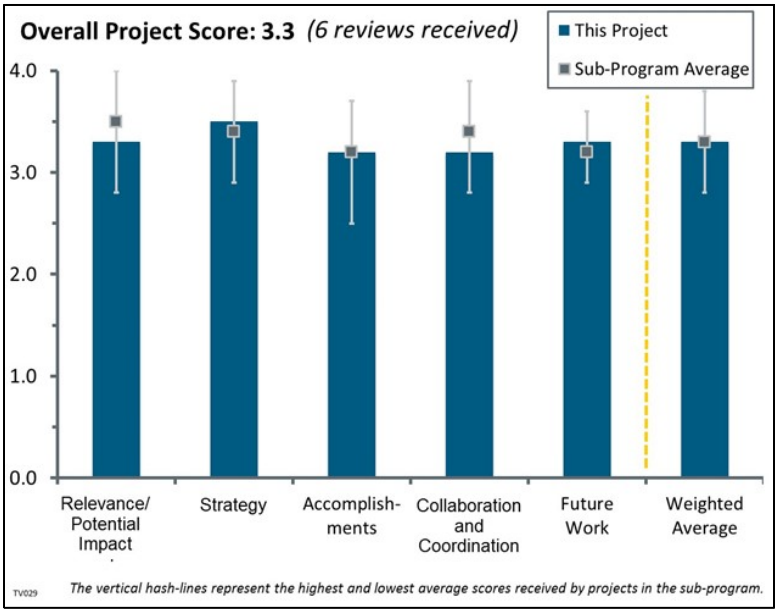
- For the project to be of most benefit, the results need to be widely distributed as opposed to being tied to patents specific to one company.
- The goals of the project are not adequately specific: the team does not have a cost goal at all, and its pressure goal is >586 bar (although it implies wanting >700 bar). Its Task 1 go/no-go is also vague, stating only that it will “prove the technical and cost viability of >586 bar,” but the project does not say how such viability will be determined.

Recommendations for additions/deletions to project scope:

- Getting DOT approval for moving the tube trailers on the road is critical to the success of the project. The team should engage DOT officials as soon as possible to ensure this process does not stall the work and result in excessive delays.
- A specific system cost goal needs to be added.

Project #TV-029: Performance and Durability Testing of Volumetrically Efficient Cryogenic Vessels and High-Pressure Liquid Hydrogen Pump

Salvador Aceves; Lawrence Livermore National Laboratory



Brief Summary of Project:

The objective of this project is to demonstrate performance limits for cryo-compressed storage and delivery technology in the most adverse conditions. The project will manufacture small, durable vessels with thin insulation refuelable to high density with a liquid hydrogen (LH2) pump. Cryogenic pressurized hydrogen storage and delivery provides safety, cost, and weight advantages over alternative approaches to long-range (500+ km) zero-emissions transportation.

Question 1: Relevance/potential impact on 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 was rated **3.3** for its relevance/potential impact.

- Cryogenic pressure vessel technology has been worked on for many years with noticeable progress, so extending it to 700 bar refueling makes a lot of sense. What is learned from the thermomechanical lifecycle and strength testing adds to the knowledge needed to improve compact vessel design, safety, and durability. If successful, this project could lead to substantially increasing hydrogen density storage and vehicle range.
- Given that fueling systems are not yet fully standardized, even for type of fuel, a discussion about LH2 storage vessels and pumps is justified and necessary.
- LH2 offers unique benefits compared to gaseous hydrogen (GH2): the commercial hydrogen industry uses LH2 for long-distance transport, the suggested technology has merits to make good progress toward U.S. Department of Energy goals, and there are very good technical parameters for storage. The use of the vacuum jacket concept is unique, but there needs to be manufacturability validation. The composite vessel design with LH2 is good.
- This technology evaluation is of high value to increase energy density storage and reduce cost for fuel cell electric vehicle (FCEV) commercialization.
- The description of barriers should be focused on those such as storage cost and not the generic barriers of storage and infrastructure.
- There does not appear to be much interest in onboard LH2 storage by automakers beyond BMW. To stay relevant, the project team should make a convincing techno-economic feasibility case for LH2 over other options.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.5** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- Based on its presentation, Lawrence Livermore National Laboratory (LLNL) is clearly and sharply focused on barriers, and it would be difficult to offer suggestions for improvement.

- The test facility at LLNL appears impressive. It would be helpful to tie explicitly the capabilities and novel/unique features of this site with the goals and objectives of the project.
- Safety is the main concern with this project, and the principal investigator, in collaboration with the Linde Group (Linde), did an excellent job in completing the hazard and operability study (HAZOP) and managing the risk, as demonstrated by the safety features designed into the hydrogen test facility.
- The project has a good technical team, and Spencer Composites and Linde make the team stronger. The recycling of GH2 at pressure and the re-liquefy strategy is unique. It can benefit more from a solid-state electrochemical compressor compared to mechanical; the 100 kg/h rate is a good and achievable goal. The finite element analysis (FEA) model approach is sound. The 1,500 bar test and data analysis approach is satisfactory.
- There is ongoing work to evaluate stress of vessel, life-cycle calculations, safety, and the cost of high value necessary for FCEV evolution.
- The technical approach is sound and logical. However, it would be beneficial to the project to get input from other automakers. The team should also assess the refueling and infrastructure cost of the technology compared to the conventional compressed gas option.

Question 3: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- Using 350 to 700 bar to get 80 g/L hydrogen seems achievable. Fatigue analysis data show fiber and metal synergistic behavior that can be economically advantageous. BMW support in FEA simulation is beneficially utilized. Plastic fatigue potential to improve design is a good finding. The team has done a good job in designing, building, and testing multiple vessels and improving them further. The hydrogen test facility and its use for safety evaluation are valuable.
- Work to extend from 350 bar to 700 bar continues with stress and life-cycle testing of the vessel and liner. The hydrogen test facility is of high value for future work associated with testing for leakage, durability, permeation, and cycling. This work occupies a limited niche but is of high value for ultimate evolution of FCEV commercialization.
- The technical accomplishment is good, especially the establishment of the test facility and the cycle testing of multiple cryogenic vessels.
- While the presenter and the presentation were clear, direct, and very well organized, the presentation only glanced upon the manufacturability of the systems discussed. The subject was brought up during the presentation, but there was no discussion or follow-up, and the question was reinforced as an issue with the discussion on slide 9 about failures due to productivity. On slide 7, there was a brief discussion of testing cryogenic storage vessels and their design for 6,400 cycles (fill/refill cycles) to provide a 4x safety factor for 1,600 cycles. Not until during or just after the question-and-answer session was it explained why 1,600 cycles was chosen (it is believed to be the target necessary to achieve 500,000 miles lifetime per vehicle). That said, the numbers presented are questionable. Given the numbers presented (a target of 500,000 miles per vehicle and a design of 1,600 fill cycles), LLNL is assuming about 312 miles per tankful, a target number consistent with a typical gasoline internal combustion engine fill-up. However, as someone with extensive FCEV driving experience, the reviewer believes that range anxiety is such that an FCEV driver will fill up the FCEV before the fuel tank is less than a quarter full, and at times a driver will want to fill up the FCEV with a tank that is half full or even fuller. Therefore, filling up at a quarter of a tank may indicate that 1,600 fills will only allow an FCEV to be designed with a 375,000-mile normal driving range, and filling up at the half mark drops the range to 250,000 miles. Laboratory testing is one thing; the real world can be a little different.
- Five cryogenic vessels have been tested with noticeable improvements in cycle life.
- The update would benefit from a table of goals and timelines vs. progress toward those goals and schedule. It is not clear whether the project is on track or behind. From slide 9, it is not clear whether the second quarter/fiscal year 2016 milestone, “Complete 1,000 accelerated thermomechanical cycles on two 65 L 700 bar, 80+% volume ratio vessels,” is completed. It appears that it is not. Slide 18 showing goals/ milestones in 2016 should go earlier, prior to Accomplishments.

Question 4: Collaboration and coordination with other institutions

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

- The team is composed of strategic partners, each bringing a unique set of skills essential to the success of the project.
- The project has a small but tight team; in this case, adding additional members would probably be counterproductive.
- The project makes good use of Linde's capability in HAZOP for the hydrogen test facility. There is a need to show benefits more quantitatively during storage, dispensing, and use.
- Work with partners, including BMW, is of high value, but additional partners are needed.
- The fact that storage and delivery technical teams are co-funding the project is positive. However, broader collaboration and buy-in from multiple automakers beyond BMW are needed for any chance of commercializing LH2 storage.
- It is good to have BMW's participation, but the work is more fundamental than just near-term automotive support.

Question 5: Proposed future work

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

- LLNL is performing a needed task and appears to be doing a good job.
- The project is of high value for testing, evaluating, and commercializing cryogenic storage. Goals are relevant for industry use. Additional work for comparison with gaseous storage is needed.
- The proposed work is sound, especially testing of the thin liner vacuum jacket. However, the quantitative value of carrying out the 1,300 bar test is not clear.
- It is not clear what the thermodynamic benefits of LH2 are relative to GH2. It will be helpful to show feedback on manufacturing input comments and BMW input on future potential, capital cost, and maintenance costs.
- Slide 15 is not really describing challenges and barriers but rather tasks and goals. More informative would be a table of goals with a column of explicit challenges and barriers for each goal. For example, it is not clear whether the key challenge is the thin liner or high fiber fraction and why that is true. It is not clear whether the failure mechanism(s) is known.

Project strengths:

- Strengths are that the project is relevant, the approach seems reasonable, and the test facility looks promising.
- A project strength is the fundamental testing of cryogenic storage for commercial use with increased energy density. BMW as a partner is a significant strength, but additional partners are needed. Development of a test facility for additional testing of applications is of value.
- A strength is the strong team, which includes a vessel manufacturer, an end user, and a pump supplier.
- The good team is a strength. LH2 may offer new solutions for FCEVs.
- Having its own LH2 test facility provides an excellent capability for hands-on learning.
- The team clearly has a strong understanding of the issues.

Project weaknesses:

- Not having other automakers on board on LH2 storage could be viewed as less attractive for large-scale deployment.
- The project needs to show more data and analysis of why LH2 was selected.
- This project may not lead to a commercially acceptable vessel design after many years of expensive research and development.
- The project needs more commercial partners for analysis and demonstration. Other weaknesses include complex technical issues regarding durability of the pressure vessel and thin liners that will require

additional time and funding to address. Also, there is a need for a detailed cost analysis and comparative analysis with gaseous storage. There is also a need for robust and repeated testing of pump, pressure vessel, and thin liners to increase confidence for commercial applications.
- The status, strategies, progress, or linkages of the various tasks are not very clear. For example, slide 7 shows “durable design modeling with safety factor of 4.” Slide 9 shows a vessel overview. It is not clear which vessel corresponds to the safety design with a safety factor of 4. It is not clear what the approach is to address the tank performance issues. It is not clear whether it is possible to correlate failures with the modeling. For the goal of “Test degradation by pumping 24 tonnes LH2,” it is not clear what the key approach/barrier is or why the team is not showing any data on this. It is not clear whether the HAZOP review was a requirement before conducting this work.

Recommendations for additions/deletions to project scope:

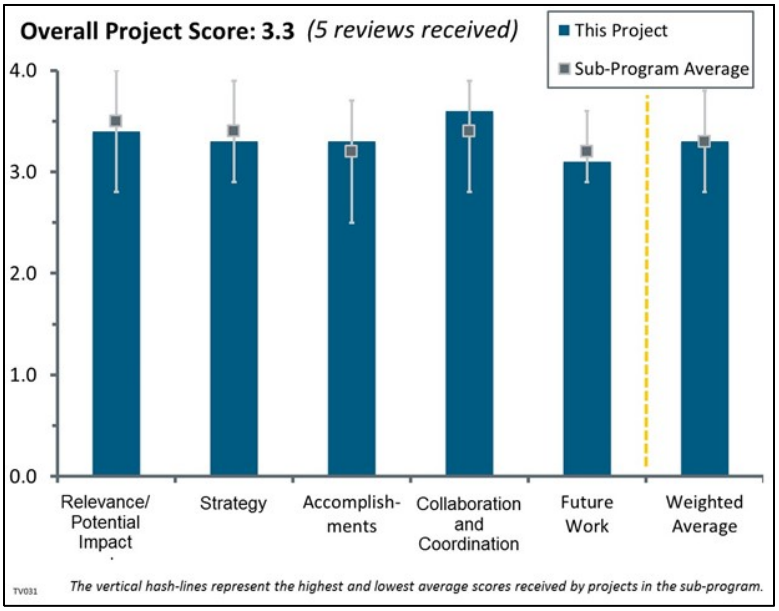
- It would be very helpful to see a more organized/structured presentation approach. Other improvements include the following: (1) specific technical goals/timeline mapped to specific progress, (2) a description of key learning and troubleshooting, and (3) a strategy and approach to move forward to address key failure modes/risk areas, plus some dispositioning of observations (high risk vs. low risk, confidence level to address issues, etc.).
- A cost analysis for commercialization and a comparative analysis with gaseous storage would both be of value. Other recommendations include repeated testing to increase confidence and increased collaboration with industry partners.
- The project should carry out infrastructure cost analysis. The project should seek out input from other automakers.
- The project should have a stakeholder workshop to share results and the deployment strategy.

Project #TV-031: Dynamic Modeling and Validation of Electrolyzers in Real-Time Grid Simulation

Robert Hovsapian; Idaho National Laboratory

Brief Summary of Project:

This project is conducting a business case analysis of electrolyzer-based hydrogen fueling stations. The purpose is to validate the use of hydrogen-producing electrolyzers as beneficial to full-scale fuel cell electric vehicle (FCEV) deployment. Researchers will use first-of-a-kind, distributed real-time simulation with hardware-in-the-loop (HIL) model validation to examine electrolyzer participation under dynamic grid conditions.



Question 1: Relevance/potential impact on 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 was rated **3.4** for its relevance/potential impact.

- The project validates electrolyzer response time data for analysis to determine the best fit of an electrolyzer in a support role to the grid.
- The relevance and potential impact of this project is resolving the application of electrolyzers for grid services and hydrogen generation.
- This project aligns well with the Hydrogen and Fuel Cells Program.
- This project addresses a key question for hydrogen generation and storage. The potential benefits for grid support are not clear since, in the future, greater amounts of renewable power may need to be curtailed.
- There appears to be a great deal of measuring occurring, but the presentation and briefing were not clear on why the measurements were necessary and/or beneficial. One example is on the chart titled "Accomplishment, Demand Response and Electrolyzer Performance." That chart provides six different graphs, but a briefing was provided for only one graph, and the graphs' importance was not provided for any of the graphs.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.3** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

> It seems that a key focus should be on future potential revenue streams with much higher levels of renewable penetration. If the economic analysis at 2015 utility rates and the 2015 California renewable profile for PV and wind is not that favorable, then it seems that this analysis is incomplete and does not tell the full story. This "future" scenario is of course uncertain in its offerings of grid support markets—perhaps some learnings from Germany could be utilized. However, one can see the value and learnings that can emerge from both a hardware demonstration and economic analysis, and the overall integration and execution approach appears well-thought-out.

- The grid modeling approach is not associated with any specific grid system. It seems most likely that not all local grids are the same. It is not clear how the grid modeling will take into account interaction with different grid systems, i.e., how the grid for California will interact with the grid for Colorado. Perhaps the project assumes one giant grid for North America will be modeled. Better definition is needed. Regarding the electrolyzer interface, it is not clear whether the project is discussing an electrolyzer or an electrolysis cell; one has balance-of-plant (BOP) hardware and controls (electrolyzer), and the other is just an electrochemical cell. They will have different response times and different vulnerability to surge currents. It is not clear what a “Utility/Aggregator” is. The presentation should at least attempt to educate the reviewer. A 500-hour demonstration does not provide reliability data, decay data, or efficiency data other than for the beginning of life. The project should consider 4,000 hours to 8,000 hours (~one year).
- The key barrier/risk (front-end controller) in this project has been identified.
- The project needs to look more at the BOP spin-up times as the electrolyzer scales to higher power output.
- Project evaluation is troubling as the use of metrics is not well explained nor was an explanation provided as to how or why results mattered or what the metrics goals should be.

Question 3: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- This category is excellent to outstanding. Good progress is reported on all fronts. It is requested that the project spell out/define RTDS next year.
- The data are very promising.
- There may be a good deal of good, if not great, work being performed under this project, but neither the oral presentation nor the written slides support that position well. The what, the why, and even the how were not well detailed. Numerous data were provided but not the managerial sense behind the data. The lack of clarity cannot support a higher grade nor does it justify a lower score.
- Progress is adequate. It is not clear how Milestone 2 will be accomplished on September 2016 with only 20% complete to date (June 2016).
- The accomplishment for the electrolyzer handling grid transients or rapid ramp-up was not for an electrolyzer but for an electrolytic cell; there is a big difference. It is concerning that the National Renewable Energy Laboratory does not understand the difference and would report information that could easily be misinterpreted.

Question 4: Collaboration and coordination with other institutions

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

- Including the California Air Resources Board (CARB) and the Pacific Gas and Electric Company (PG&E) is a very good. EnerNOC’s interest in how this technology fits into the company’s grid program future validates the need for this work.
- Given the nature of the project, there is outstanding collaboration between the two laboratories, the utilities, the universities, and CARB.
- It is excellent that the project is getting real-world and market information from utilities.
- There is collaboration with relevant industry.
- It is not clear why there is no electrolyzer company as a collaborator. It is suggested that Proton Onsite or some other electrolyzer company be considered as a collaborator.

Question 5: Proposed future work

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

- Proposed future work is well planned and addresses the key and critical areas.
- The development of a front-end controller is an acceptable future activity. There are two or three milestones on slides 9 and 10 that still need to be completed. Proposed work is ambitious.

- Perhaps there is a way to explore possible revenue streams with future, much higher fractions of renewable power. The following is from an earlier slide: “Objective: Validate the benefits of hydrogen electrolyzers through grid services and hydrogen sale to fuel cell vehicles for full-scale deployment.” There was not much discussion of the latter (hydrogen sale for FCEVs); the focus was mostly on grid support. Perhaps this objective should be dropped. It needs some further discussion.
- Obstacles or issues were recognized and stated. At the next review, feedback should be added from collaborators on the work described on slide 23.
- The oral presentation and the reviewing of the written documents generate a question as to how all the data tie together, i.e., whether the data is truly beneficial and required or is being gathered for the sake of gathering data. The presentation seems to indicate the latter.

Project strengths:

- Strengths include the demonstration, HIL-style approach, quantification of responsiveness, and calculation of economic benefits.
- This is a well-planned project with a focus on key technology barriers.
- The larger budget for national laboratories is a strength.

Project weaknesses:

- The project does not accurately assess the operation of the electrochemical cell (rather than electrolyzer) in relation to transients. It is not clear how the current controllers respond to transients—or perhaps the current controllers have been bypassed. If the latter, perhaps there are safety concerns. It is not clear how the hydrogen compression pumps respond to the different rates of hydrogen production—whether they run faster or slower and how they know to run faster or slower. If these questions cannot be answered with a high level of confidence, the project managers and DOE should re-evaluate the project.
- There is no real sense of what is trying to be presented. The project should figure out what message is desired and stick to it. Then more data should be shifted from the primary slide section to the back-up slides section.
- The weakness is in current vs. future markets; the focus on current markets is understandable but less interesting and important than future ones.
- Coordination and inputs from collaborators are project weaknesses.

Recommendations for additions/deletions to project scope:

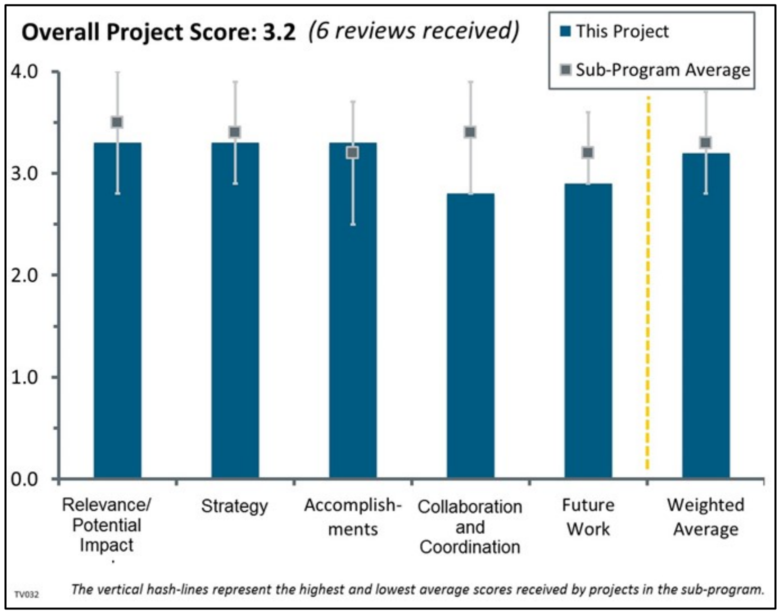
- The following is on slide 10: “Develop suitable PG&E distribution network model…” This activity does not seem trivial. Perhaps there are existing models that can be used or leveraged. More information here on approach/strategies would be good. If the electrolyzer resource would be bidding into an independent system operator (ISO) market, perhaps information from prior ISO markets can be used rather than relying on a new distribution network model.
- The project should consider evaluating the impact that the subsystems supporting the electrolyzer will have on response times. The project should determine whether the pumps, blowers, and valves spin up fast enough to match the stack response time. For example, perhaps there is an optimal size for the electrolyzer and associated BOP, i.e., banks of specific-sized electrolyzers or simply one very large electrolyzer.
- The project does not need additions; it needs focus.
- The DOE should assess the probable success of this project.

Project #TV-032: Fuel Cell Electric Truck Component Sizing

Ram Vijayagopal; Argonne National Laboratory

Brief Summary of Project:

This project aims to develop design concepts for fuel cell electric trucks (FCETs) that are functionally equivalent to conventional diesel trucks in multiple classes and functions. These prototypes will use fuel cells as the primary source for propulsion power. Onboard hydrogen storage will provide the entire energy requirements for the drive, and the battery will be used in a charge-sustaining manner. Investigators will determine fuel cell and battery power requirements, the stored hydrogen mass and total mass of the fuel cell system, and fuel economy and range. The project will conduct analysis to verify whether the concept designs meet real-world requirements.



Question 1: Relevance/potential impact on 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 was rated **3.3** for its relevance/potential impact.

- The range of truck sizes and applications is quite broad. This project uses automated vehicle analysis to examine a wide range of vehicles and applications. It provides a cost-effective analysis of a broad application space that has previously only been explored in piecemeal fashion.
- The project involved modeling to estimate the sizing for fuel cells and other components for various heavy-duty truck platforms. This is a good start for any original equipment manufacturer (OEM) wanting to develop FCETs for different market segments.
- Establishing a methodology for sizing truck components while balancing the fuel cell with the battery is critical to a successful integration effort.
- This could be the next big fuel cell market after materials-handling equipment. The project is therefore very relevant.
- This project aligns well with the Hydrogen and Fuel Cells Program.
- Relevance addresses objectives and/or questions to be resolved. Relevance does not address barriers identified by the U.S. Department of Energy.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.3** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The project has a good plan for accomplishing the work with available data on market segments. The approach of using the worst possible fuel economy to size the tanks for a 200-mile range is good because real-world efficiency is often lower than advertised.
- The effort uses the existing strengths of the Autonomie vehicle model in a transparent manner that focuses on the key design aspects of truck power system modeling. The effort captures all key aspects.
- The project has excellent approaches in selecting vehicles and developing sizing methodology.

- There is good analysis based on computer simulations of FCET performance.
- It is not clear whether the system design takes into account an inner city driving cycle with frequent stops and starts. It is not clear whether there is enough time to recharge the batteries in such a cycle.
- The four-step process given in slide 5 is at the very top level and does not identify details of how decisions on truck designs will be made. Retrofitting a fuel cell and electric power train into a vehicle is an ambitious approach. The approach is reasonable, and the execution of the approach will be very difficult and will require fuel cell design knowledge (a drop-in fuel cell would be very difficult to find or accomplish). Changes in weight distribution will need to be addressed, as will safety issues, ruggedness of the system components, fuel storage issues, and operator acceptability. It is not clear all of these aspects (and others) are considered in this project.

Question 3: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- This short project is focused and delivers good value and considerable accomplishments.
- The project was completed with all the objectives accomplished.
- Use of the Autonomie model to validate fuel economy and hydrogen needs was sufficient. Data provided detailed base weight and performance information.
- The project lays a good foundation for pursuing FCET design and building of prototype FCETs.
- The project was completed within the time period. Modeling is a great start for designing a new vehicle. The next step is to get an OEM involved in building and demonstrating an actual vehicle.
- Slide 11 identifies the targets and performance requirements as accomplishments; a164 kW fuel cell was identified for applications. It is unclear how this compares to a fuel cell bus requirement. Whether this project can learn from the fuel cell electric bus (FCEB) activities is unknown. Motor sizing is reported; it is unclear how this compares to FCEB projects. The project reports that hydrogen storage capability can be achieved for a 200-mile run. It is unclear whether this is consistent with the FedEx project.

Question 4: Collaboration and coordination with other institutions

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

- The project team has good collaboration with other laboratories.
- Collaboration is good considering the limited scope and the short period of performance of the project.
- Collaboration with other groups (other than the National Renewable Energy Laboratory [NREL]) is not apparent, but it is not obvious that additional collaboration is necessary.
- Collaboration partners noted were from the technical community. Collaborators that operate real-world truck fleets should be added.
- It is unclear why no truck companies were involved.

Question 5: Proposed future work

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

- There is no proposed future work, as the project was completed.
- Adding cost data would be valuable. However, it could be a challenge to get users to provide these data. The team should consider how data could be collected from multiple users in a way that protects anything considered sensitive.
- Taking the analysis one step further by conducting a life-cycle cost analysis that incorporates cost and durability would be of value.
- The project should add comparative greenhouse gas reduction results for the load profile and truck types evaluated.
- It is unclear whether there are any plans to build and test prototype FCETs.

- The project does not address how to prove the analyses were correct. The project moved to cost analyses assuming technical analyses were correct.

Project strengths:

- Selecting representative truck applications is quite a challenge. The team did a great job of narrowing it down to a selection that covers a wide variety of platforms. This information on what is required to meet users' needs could be valuable to the industry. The truck market is large and could help drive volume production of components.
- The project seems to have been conducted in a very professional and direct manner. The application of the Autonomie model platform is an enabling technology that covers the breadth of cases examined. Results of the project are summarized in the "FC kW vs. H2 kg Stored" graph, which shows that a ~160–200 kW fuel cell power system would have wide applicability for trucks.
- The project is well-planned and has excellent approaches in developing sizing methodologies.
- There are good computer simulations between Argonne National Laboratory and NREL.
- Analyses were performed.

Project weaknesses:

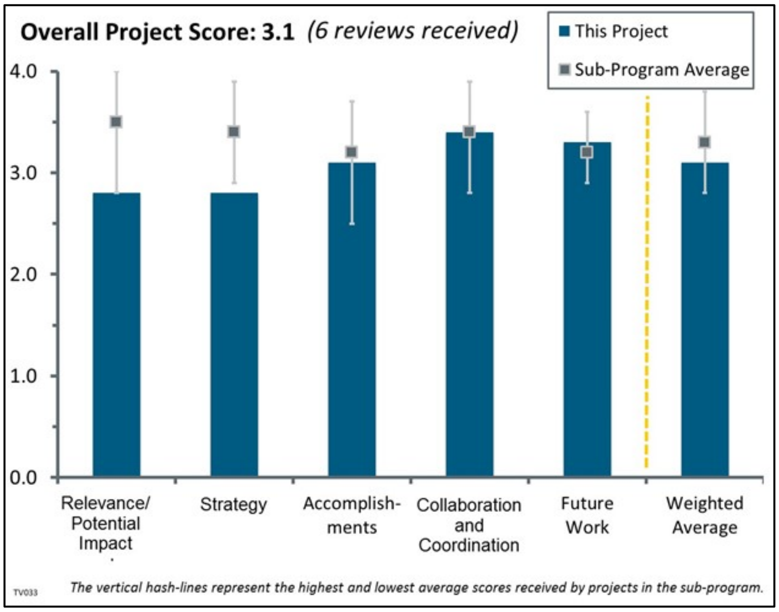
- Consideration is not given to the ambient temperature effect on the energy storage characteristics of the battery portion of the system.
- It is unclear why there was no truck OEM participation.
- Modeling is only as good as the assumptions. Real-world service will be needed to fully validate performance.
- There is no confirmation the analyses were valid.

Recommendations for additions/deletions to project scope:

- It appears that the masses of the vehicles (due to fuel cell and storage subsystem weights) were incorporated into the analysis. A sensitivity analysis should be conducted to see how alternate mass and volume scaling would affect system projections (due to weight compounding).
- Research should be added on the impact capturing regenerative energy would have on fuel consumption. The project should investigate the trade-off of the increased weight that would result from providing a slightly larger battery.
- If funds are available, the project should initiate the building of prototype FCETs.
- This project does not appear to have any capability to cross-check the analyses with real-world data. The "relevance" statement in the presentation says, "Verify whether the concept designs meet real-world requirements." However, the team did not identify verification actions in either the "approach" or the "accomplishments" discussion of the presentation. Maybe this project should be linked up with the FedEx project.

Project #TV-033: Brentwood Case Study

Carl Rivkin; National Renewable Energy Laboratory



Brief Summary of Project:

This project has undertaken permitting and construction of a hydrogen fueling station. Investigators will document lessons learned to reduce the time and costs associated with deploying hydrogen fueling technology. This work will address key barriers including lack of knowledge regarding project siting, inadequate installation expertise, and high permitting costs.

Question 1: Relevance/potential impact on 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 was rated **2.8** for its relevance/potential impact.

- This is a great project, less to provide direct research but more to support the need to provide hydrogen fuel in Washington, DC, a crucial goal.
- This project certainly aligns with the U.S. Department of Energy's goals insofar as it can help clarify issues surrounding hydrogen station deployment. It is somewhat limited in its broader applicability because of its location at a National Park Service (NPS) site, as opposed to a retail station site similar to what the industry is looking to build. That said, it is worth evaluating whether this experience suggests that building stations at government-owned or other non-retail locations could be one pathway for deploying fuel cell fleets.
- Inadequate installation expertise of contractors was mainly a barrier because of the choice of contractors without experience implementing fueling stations overall (conventional fuels and natural gas). Lessons learned from this project are mainly useful to accelerate station implementation of behind-the-fence non-retail stations.
- Many of the lessons learned related to permitting in the Brentwood Case were part of many station reports in 2004–2008. This project probably would have been a stronger presentation if the objective were to strengthen collaborations with other agencies and put a substantial load on the Proton Onsite fueling system to fully test out the technology.
- It is difficult to see how this project, being the production of a case study report in particular about the station development, will be applicable beyond the scope of the Brentwood station installation. While the physical station is useful, the location essentially self-selected to one that does not provide the opportunity to obtain substantial lessons learned outside of this particular installation. Perhaps there will be opportunities to gain lessons learned during station operation, but that does not seem to be the scope of the project. A redirection may be wise at this point. The final deliverable could still include some information about the installation of the station but would ultimately provide significantly more information about the operations.
- The project has little impact on advancing commercial hydrogen stations or even addressing the stated barriers. Part of the reason for this may be that the site selection process was pre-determined for reasons unrelated to project design. The NPS location was too ideal and simple to generate lessons for future stations. There would have been much greater relevance if the case study had been carried out for a commercial station in a busy public intersection with public hearings attended by multiple stakeholders.

Question 2: Strategy for technology validation and/or deployment

This project was rated **2.8** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- Given the nature of the challenge, barriers were identified and met with effectiveness and efficiency.
- The project seems well designed as an "add-on" to the desired goal of building a fueling station in Washington, DC, which has been lacking one. Although applicability to the broader effort to deploy hydrogen stations may be limited, the project seems to have been well designed to illuminate the issues in this environment. It makes sense as a way to provide some added value to that main goal. However, it should be made clear that was its purpose; it was not designed to highlight the most likely issues facing those building hydrogen stations in retail sites. It would be valuable to reach out to other organizations focused on building hydrogen stations to see how the Brentwood project compares to their experiences and perhaps make sure there is a cohesive message getting out about station-building. The lessons learned about the challenges of moving a modular station seem quite useful. It is a bit surprising to learn how difficult even this model is.
- The usability of lessons learned from this project can be expected to be low because of significant differences between working with a federal government agency for implementation of a station on federally controlled property and implementation of hydrogen stations at retail station sites (the presenter made reference to the National Association of Convenience Stores' (NACS's) being a target audience for the lessons learned report).
- The station's location seems to inherently limit the breadth of lessons learned that can be generated for the report. In particular, the strategy seems to be weak because it seems that there is very little guarantee that the station installation process encountered many, if not most, of the challenges that are actually encountered by developers active today and for the foreseeable future. In the end, the strategy seems like it will limit the value of the end product.
- There was no technology to validate, just a permitting process to describe.
- It might have been helpful to this project if the team had read some of the NREL (Wipke) reports related to permitting, building, and deploying stations.

Question 3: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- The project did a good job in identifying and documenting the lessons learned with respect to the various permitting agencies that can potentially be used for potential sites on park service lands.
- Given the nature of and need for this project, achievement and progress are outstanding.
- The overall fueling station project will help to better educate the U.S. Department of the Interior on fuel cell technology and potentially provide an opportunity for education and outreach with Congress.
- The project seems generally well aligned with DOE goals. The one weakness is that there are intensive efforts to create hydrogen stations in California (and elsewhere), and this one is slightly out of alignment with the goal of supporting stations that help create a viable retail market. However, it makes sense as a relatively low-cost add-on to a project intended to provide much-needed hydrogen fueling in Washington, DC.
- It was difficult from the presentation to determine just how much of the report work has been completed. It seems that there could have been some discussion at least of the material collected to date and perhaps some status on report writing (even if just at the outline, or similar, stage).
- The report should make it very clear that this was not a retail station implementation and how this station differs from other fueling station installations. The report should include a section about what unexpected items were to be considered by readers of this report (and which unexpected issues did not occur that could have occurred).

Question 4: Collaboration and coordination with other institutions

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

- The right stakeholders and partners were engaged for the chosen location.
- The collaboration so far seems to be appropriate and well-coordinated. The only comment is that, at the presentation, it was revealed during discussion that the subcontractor for installation was not an entity regularly in the business of installing fueling stations. This is not really a weakness, but it does seem like there was a missed opportunity for learning how hydrogen stations compare to stations that provide other fuels in terms of installation, as may have been revealed if the subcontractor had more prior experience with fueling installations.
- From the presentation, it appears that DOE and the National Renewable Energy Laboratory (NREL) coordinated well with each other. They hired Werken and Anderson–Burton, not so much to partner but instead to perform straight construction work. It appeared the NPS role was limited to landlord services and that the DOE–NREL partnership collaborated with Proton OnSite. To some degree, because of the nature of this project, the opportunity for collaboration might be limited.
- Collaboration seemed to be good. The project should consider coordinating messaging and public dissemination of reports on this effort with others, such as the Fuel Cell & Hydrogen Energy Association and California Fuel Cell Partnership.
- It is not clear whether interviews were done with project partners on benchmark information.
- Collaboration with the U.S. Department of the Interior, since the station is located at an NPS facility.

Question 5: Proposed future work

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

- The future plans seem good. Using this as a springboard to other NPS sites is a good follow-on as long as it is determined there is a real opportunity for those stations to be used and support a fleet of hydrogen vehicles.
- Support and planning for future requirements are outstanding.
- The proposed future work seems appropriate for the scope of the existing project and includes relatively low-risk plans.
- After completion of the lessons learned report, the team should consider expanding the scope to real-world commercial stations rather than looking for another NPS location.
- It will confuse NACS membership if lessons learned from this project are portrayed as applicable to retail gasoline station sites or that the project results could be used to benchmark for those sites. Future work presented on slides does not include outreach to the commercial fueling industry, which was identified as a barrier and a challenge. Work with NACS should be added.

Project strengths:

- The key strengths are that this is a fairly low-cost way to provide added value to an effort to build a station. It makes sense to use that opportunity to provide lessons learned. The coordination among participants seemed effective.
- Strengths include fueling in the Washington, DC, area; lessons learned about construction contractors; and lessons learned about overlapping jurisdictions.
- The simplicity of a project meeting a need is a strength.
- Some important milestones have been accomplished by the station itself on which the project is centered, including bringing a station to the Washington, DC, area and making use of a containerized (possibly even modular) station design.
- The project has engaged the right stakeholders to obtain the lessons learned.

Project weaknesses:

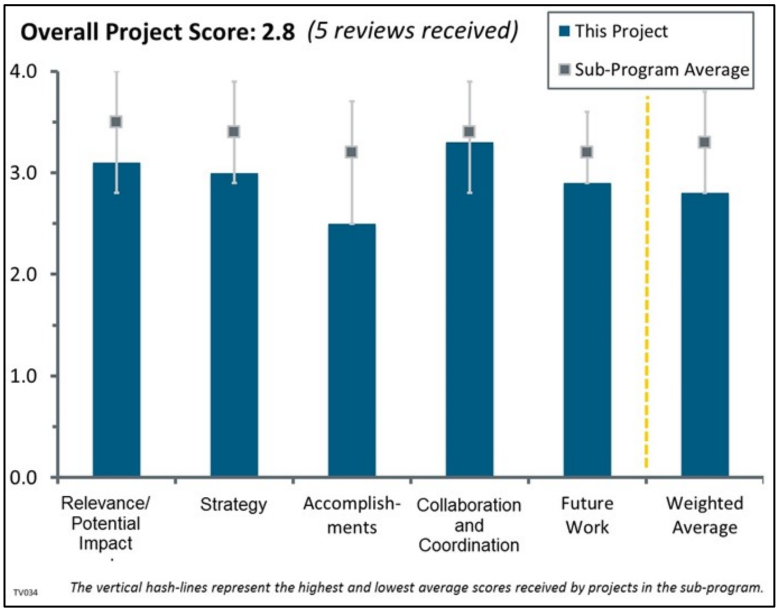
- The key weakness is seeing how this matches up with other experiences in building hydrogen stations. Some coordination with other entities around messaging is needed. It would also be good to make sure that the report does not become a "dead" document on a web portal but perhaps instead can be revised as further experience is gained through other hydrogen station deployments such as this.
- The non-retail and behind-the-fence location of the hydrogen station is a weakness.
- Poor site selection has limited the project impact.
- The final product report does not have broad applicability, and that is a definite weakness.

Recommendations for additions/deletions to project scope:

- An aspect of lessons that can be learned from operations should be added, even if this extends the project budget and timeline. This will potentially have a greater impact than the lessons learned from the installation of the station.
- The project would have been more suited to the Codes and Standards program rather than the Technology Validation program. There was no technology to validate under this project, just permitting.

Project #TV-034: Fuel Cell Hybrid Electric Delivery Van Project

Jason Hanlin; Center for Transportation and the Environment



Brief Summary of Project:

This project aims to increase substantially the zero-emissions driving range and commercial viability of electric drive medium-duty trucks. Investigators will develop and validate a demonstration vehicle to prove its viability and then build and deploy up to 16 vehicles, which will perform at least 5,000 hours of in-service operation. The project will also develop an economic and market opportunity assessment of medium-duty fuel cell hybrid electric trucks.

Question 1: Relevance/potential impact on 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 was rated **3.1** for its relevance/potential impact.

- Goals to develop, demonstrate, and deploy longer-range medium-duty zero-emissions-vehicle trucks are important, and the tasks seem extremely relevant for the U.S. Department of Energy (DOE) to support since this has been studied less than light-duty vehicle decarbonization and because biofuels are contentious and may be better applied in other areas, such as aviation. States such as California are very interested, and it is encouraging to see the California Energy Commission (CEC) as a partner.
- The potential impact of this project is outstanding. Phase 1 vehicle development and deployment needs to happen. A go/no-go decision is important, and while Phase 1 is important, if Phase 2 goes forward, this project would be amazing. The potential partners could operate multiple vehicles and collect operational and market data. This would help DOE demonstrate the marketability of these fuel cell vehicles for fleet applications. The project will also be demonstrating hydrogen fueling infrastructure.
- Extending the range and durability of fuel cell electric delivery vans will help with market transformation via advancing potential commercialization in the delivery van sector.
- This project will design, build, and test a fuel cell electric truck that could be adopted by multiple companies in the market segment. The success of this project could help reduce costs for all fuel cell applications by increasing the volume of production.
- The value of the project is good for widespread deployment of a low- or zero-emissions vehicle by a well-established commercial delivery company.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.0** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- DOE covers only the fuel cell part of the project, which totals $3 million. The project partners will raise nearly $8.5 million. This is a good deal for DOE. The overall project will cost around $13 million. Transparency of objectives is outstanding. The range will be 125 miles. Zero-emissions delivery vans are the objective. The project will use one vehicle to demonstrate at multiple sites.

- Converting existing vehicles will show how the new technology compares to the baseline, with changes only to the power train. Full commercialization will require commitment by original equipment manufacturers (OEMs) to achieve higher production volumes.
- Partner contributions from the two California agencies and the United Parcel Service, Inc. (UPS) strongly support project execution. Contractor selection and progress are of significant concern.
- It is not clear why additional funding is needed for Phase 2 (16 additional vehicles). The project could just reduce the number of vehicles and renegotiate terms to avoid delaying another one to two years. The presentation should show the new vehicle configuration that is mentioned. On slide 6 (Milestones), it is very hard to evaluate progress since only $188,000 of $2.982 million of DOE funds was reportedly spent, but it is unclear how much was spent by partners. A mapping slide showing the key project roles and project owners would be helpful since it is a large group of funders and partners.
- If project managers had more experience and were more familiar with the earlier reports related to similar validation efforts with delivery vans, for example the Sprint vans, they might have anticipated some of the issues with service providers and had a better plan to mitigate risks. For instance, identifying back-up service providers for vehicle after-market modifications during the first request for proposals might have saved a lot of time. Also, the installation of fueling stations should be completed well ahead of deploying the delivery vans. Otherwise, the project will potentially incur yet another serious bottleneck.

Question 3: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- UPS has developed a design for an existing walk-in van to be retrofitted with a fuel cell system and storage system. They have completed a lot of due diligence on the size of the fuel cell and storage system as well as the fueling infrastructure. They put out a procurement request and found a replacement partner for the fuel cell. They have done a lot of analytical work this year, but the presentation does not show this. The South Coast Air Quality Management District (SCAQMD) is a partner and has committed $980,000 to building vehicles. The project still needs more funding to complete the building of the fleet. Center for Transportation and the Environment (CTE) activity resumed in February 2016 after Unique Electrical Solutions (USL) agreed to be the subcontractor for equipment design. Complete Coach Works (CCW) out of California will be the subcontractor to USL and will modify the first vehicle. The design for the vehicle looks good.
- The project team is making progress despite early issues with a project partner pulling out. The delay in timing is unfortunate, although understandable, considering the situation. Choosing the new partner through a competitive bidding process ensures the best value and that the partner is committed.
- Progress is slow because of subcontractor changes, initial technology selection, and the need to complete funding.
- It is hard to evaluate this project. Very little to minimum technical progress was reported. The partnership with SCAQMD, as well as with UPS, is cited. It is unclear why UPS is not mentioned in the partner co-funding amounts. Given the delays, the statement "Continually search and identify additional funding sources" seems problematic. This objective does not seem to be a good use of time and funding. On slide 8, it is not clear that the amount of work is commensurate with the DOE charges for the past year. This is something DOE should assess. On slide 9, "evaluate" is used as the verb, which makes this hard to assess as a reviewer. It is unclear what the bottom line is. It is unclear how close the team is to locking in a final design and final design specifications. It is unclear what has changed from last year.

Question 4: Collaboration and coordination with other institutions

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

- The project has excellent partners (as of the addition of the new team member). The principal investigator (PI) has successfully gained additional funding from California agencies that will allow at least half of the planned trucks to be built.
- The project has high value with UPS and the California agencies as partners.

- The partners have already committed funds for this project. Having UPS as a partner is outstanding. USL is fully on board.
- This is a nice group of project sponsors, especially CEC and SCAQMD. These sponsors provide the ability for the project to access the hydrogen fueling station projects in various parts of California, which is vital to the success of the project.
- Slide 15 seems incomplete: “Identified and evaluated additional upfitter/refurb contractors to support project; will partner with CCW” and “Collaborating with DOE and Argonne National Laboratory (ANL) to validate vehicle modeling and simulation results—ANL focused on vehicle configuration, component sizes, and operating profile of potential deployment routes.” These do not seem to be shown on slide 15. A task flow showing key tasks, deliverables, and dates would add clarity, especially for design and safety standard reviews.

Question 5: Proposed future work

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

- The project has taken responsibility for getting funding in advance and developed a realistic design and solid partners in order to build the vehicle. Codes and standards are going to meet the safety standards, and this will be part of any redesign. The project has already started to determine how to finalize the retrofit of the vehicle to demonstrate it. This project needs to go forward.
- The plan is sufficient to complete the objectives. Having a go/no-go decision point for acquiring the additional funding is good.
- It would be good to see the station contracts completed.
- The goal for a 125-mile range with a hydrogen cylinder is of value, but subcontractor issues for technical build-out, lack of progress, and financial controls are concerns.
- This comment is about the following: Task 1 –Vehicle Build: Complete design and hold final design review [2Q 2016]; Order long-lead components [2Q 2016]; Build vehicle and validate battery-only operation [3Q –4Q 2016]; Task 4 –Project Management: Update and Review System Safety Plan and Hazard Analysis [2Q 2016]. It is unclear whether these tasks have been completed or if there is some other status. Without understanding the current status better, it is hard to comment on future work.

Project strengths:

- The PI has experience in putting teams together to complete the work and meet project objectives. His excellent skill in managing the unforeseen changes with partners is an asset to the team. Having a committed demonstration partner is a plus. The demonstration period of two years will allow a good data set to be collected for analysis. The trade study is of high value to inform the industry. Good variability of routes for the demonstration will help test the vehicle under many conditions.
- There are excellent project partners and advanced funding. The vehicle design has progressed and is ready to go. There is a realistic timeline for implementation of this project. The team includes fuel cell integration experience.
- Team members, including UPS and the California agencies, will make valuable contributions to judgments about project acceptance.
- Relevance is high. The two-stage process seems sensible, and the team elements seem to be there.

Project weaknesses:

- The project has certainly had its share of setbacks, which is to be expected from high-risk pre-commercial research projects. Probably having partners with greater fuel cell vehicle validation experience would have been helpful in avoiding some of the pitfalls, but the project team contributed little money while learning valuable lessons.
- The predicted range of the truck seems low, although the presenter stated it would satisfy 95% of route requirements. It would be good to know whether the use of auxiliary loads (air conditioning) will lower this range.

- Weaknesses include completion of funding, change in subcontractors, technical issues for hydrogen storage on the vehicle, and lack of progress.
- The team has not done a good job of conveying the current project status, or overall progress (not just DOE work), or progress toward goals for the overall project. Information about the progress shown by DOE's partners could be conveyed in one or two slides and would add tremendous insight into the project. It is unclear whether the project is on track to meet the stated timeline. Stating in the project slides that seeking more funding is a key objective does not build confidence and puts the project at further schedule risk.

Recommendations for additions/deletions to project scope:

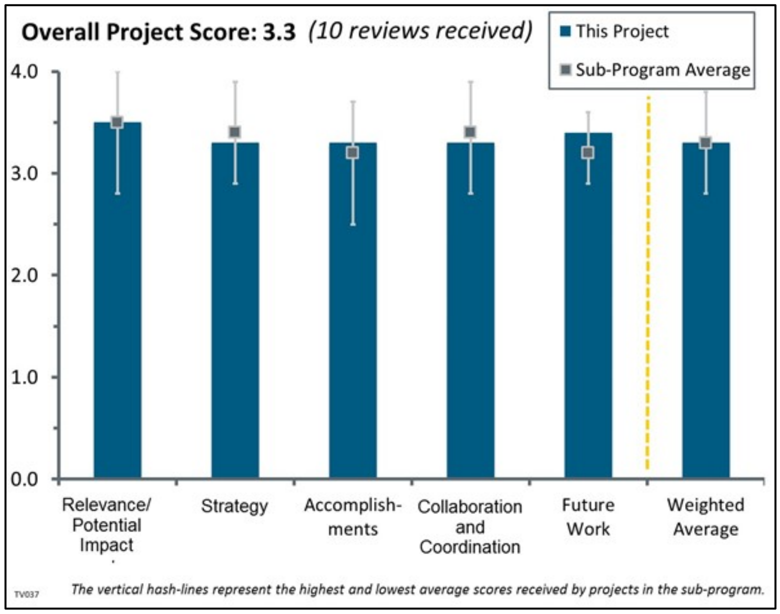
- Acquiring hydrogen tanks of the right shape and size to increase range is a challenge because of the high cost of designing and testing new tank configurations. The team might explore the possibility of teaming with a tank manufacturer that could provide cost share on the development work. This new tank design would need to be applicable to multiple vehicles to make the development worthwhile to the tank OEM.
- The project would be well served with additional project management.
- The project should not seek additional funding but perhaps just go with six trucks instead of sixteen. In addition, CTE should not seek additional funding to allow for investment into custom 700 bar tank development for Phase 2 vehicles. That objective would be nice to have but is not required. The project needs to focus its time and attention on delivering a working, safe, reliable truck with extended range. It is not clear how close the project is to this objective, and the team should not be distracted from this goal.
- Someone should inquire as to whether FedEx and DHL Express are interested in buying into this project.

Project #TV-037: Hydrogen Meter Benchmark Testing

Michael Peters; National Renewable Energy Laboratory

Brief Summary of Project:

Hydrogen flow meters are struggling to meet the 1.5% accuracy requirement for motor vehicle fuels, impeding the sale of hydrogen by the kilogram. This project will design and build a laboratory-grade gravimetric hydrogen standard; conduct high-pressure hydrogen testing of commercially available flow meters, replicating conditions specified in the SAE International J2601 fueling protocol; and report on flow meter performance against National Institute of Standards and Technology (NIST) Handbook 44 (HB44) requirements and California Code of Regulations accuracy classes.



Question 1: Relevance/potential impact on 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 was rated **3.5** for its relevance/potential impact.

- Accurate metering is one of the fundamental enablers of hydrogen fueling infrastructure deployment.
- This project is critical to meet SAE J2601 standards for refueling using commercial meters. It will directly address a barrier to technology commercialization, as it is important to know whether there is a technology that meets the 1.5% accuracy requirement.
- If done properly, this project can be very useful in progressing hydrogen fueling toward mass point-of-sale commercialization.
- The project has two overarching objectives: (1) to inform the U.S. Department of Energy (DOE) of the status of the present metering technology, and (2) to act as a kind of "innovation laboratory" to encourage development of new solutions. In the present status of fuel cell and hydrogen technologies, it will be hard to have consolidated market players to invest in this development. In other words, established companies in the field do not see accurate hydrogen metering as a valid business case. To be successful as catalyzer of innovative solutions for this technology, some plan will be needed.
- This is a critical element in enabling the deployment of a hydrogen infrastructure. It is crucial to have accurate meter technologies to be able to sell hydrogen to the consumer. The presentation says that the resolution of the scale has been enhanced to +/- 0.2 g, which would be okay if it were clear whether the accuracy is +/- 0.2 g. Enhancing the resolution says nothing about the accuracy (which is different from precision and different from the resolution of the device). The meaning of "1% relative" is that the meter must measure 1% at every flow rate; the lowest mass injected is 20 g, so the device must measure 0.2 g. This requires the system to be accurate to 0.067 g (using the factor of three or better, as stated by the principal investigator [PI]). This system will likely not deliver on what is eventually going to be needed. However, as an initial testing device to get an "idea" of where meter technology is, this will do.
- The project is addressing important needed work in metering for station validation, but the strategy could use some slight improvement: (1) it was not quite as clear as it should have been how this work will directly translate to improvements in meters in hydrogen stations, as opposed to metering methods for station validation, and (2) it presupposes that any existing inaccuracy in validation metering may be greater

than the inaccuracy of dispenser meters themselves. This may be the case, but evidence for this was not presented.

- It is important to advance an accurate and reliable way of measuring hydrogen at stations. However, the goals of this project do not seem to be well defined. It is not clear whether the goal is to improve accuracy of existing flow meters or to compare/validate the performance of commercial meters or to develop a protocol for testing the accuracy of hydrogen flow meters. Also, some of the stated barriers do not appear to be addressed by this project, at least not at this stage.
- While the low tolerances are certainly a technical challenge, it would be going too far to say they are "impeding" the sale of hydrogen, as there are (temporary) countermeasures to address this issue in the near term. There are not clear reasons to look at meters that are not in practice/use at stations. It seems that it would be more relevant to use actual meters that are in service and help improve those. A separate project can be initiated to look at potential metering technology.
- While attaining a better understanding of flow meter accuracy is a reasonable step, the limited number of flow meters being tested and the likely proprietary nature of results will result in limited project impact. If the project were geared toward developing a test "standard" or methodology to evaluate any flow meter and included some industry agreed-upon acceptance criteria for the testing, it would be of considerably higher value.
- There is still much practical work to do.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.3** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The hydrogen infrastructure testing and research facility at the National Renewable Energy Laboratory (NREL) is an appropriate testing site for the project. The team conducted an adequate preliminary assessment of flow meter technologies to down-select the Coriolis meter. The test plan, which includes the three types of tests, is adequate to test the conditions that would be experienced at hydrogen refueling stations. The system design and the pre-test are well designed to ensure that measurements are correct and can be replicated.
- The strategy appears to be well developed. In particular, the broad range of operating conditions and the inclusion of pre-testing will help ensure future confidence in the work's final determinations. The strategy is thus comprehensive and provides added value to the project.
- The approach seems to be well conceived to address the barriers.
- The approach at this stage of this work is good. This work needs to eventually get to the point at which dynamic measurements and meter validation are made under a true SAE J2601 fill profile, including initial pressure pulse (20 g) and National Fire Protection Association Hydrogen Technologies Code 2 (NFPA2) intermediate stops for leak checks, not just measurements under similar conditions. The flow meter needs to be accurate to 1.0% (acceptance) and 1.5% (maintenance) (under HB44 and Recommendation 139 [R 139] of the International Organization of Legal Metrology [also known as Organisation Internationale de Métrologie Légale – OIML]). California has temporarily relaxed this, generating additional accuracy classes, so for the immediate term, the accuracy of the validation device can be relaxed a bit to be more in line with the relaxed California accuracy classes. Operators need to be able to start and stop the fill and maintain this accuracy at every point in the fill, not just at the end, so a time-resolved real-time measurement and validation at these accuracies needs to be made; during a SAE J2601 fill, the mass flow rate—not just the end states—needs to be accurate to HB44. What is needed is a very accurate mass flow rate measurement. Arguably, the measurement of the flow rate meter validation system should be ~10 times more accurate or 0.1% relative. During the question-and-answer session (Q&A), the PI indicated he was targeting 3%. It is a start, but a factor of 10 should be a goal for this work. Also, the investigators are attempting to take mass as a function of time (mass flow rate measurement). This is a real challenge and is noted here because focus should be maintained on what is really needed. The presentation says that the resolution of the scale has been enhanced to +/- 0.2 g, which would be okay if it were clear that the accuracy is +/- 0.2 g. Enhancing the resolution says nothing about the accuracy (which is different from precision and different from the resolution of the device). The meaning of 1% relative is that the meter must measure 1% at every flow rate. The lowest mass injected is 20 g, so the device must measure 0.2 g.

This requires the system to be accurate to 0.067 g (using the factor of three or better, as stated by the PI). This system will likely not deliver on what is eventually going to be needed. However, as an initial testing device to get an "idea" of where meter technology is, this will do.

- The project is answering well to the present needs related to metering technology. Independent assessment is required. During the presentation, it was not possible to check how far work in this field that is already available has been considered and used. Probably it is too early now, but when experimental results are available for evaluation, the already available work achieved in Europe and Japan will have to be used as benchmarking.
- This is a good project, but it needs careful balance so that scientific laboratory and vehicle original equipment manufacturer perspective will not get in the way of realistic meter operation in the field (laboratory-grade gravimetric hydrogen standard vs. replicated conditions specified in SAE J2601 fueling protocol vs. testing designed to span the range of hydrogen gas conditions that would be experienced at current light-duty hydrogen vehicle fueling stations vs. noted "no pre-chilled hydrogen/testing at ambient conditions" vs. meter location in system). It is not clear how many hydrogen tanks and kilograms of capacity are in the system.
- This project does address some of the stated barriers, assuming the objective is to develop a protocol for testing commercial flow meters for a hydrogen station environment. However, the technology deployment pathway is not clear. It is not clear who the beneficiary will be: flow meter flow manufacturers, regulatory agencies, or research laboratories.
- It is great that the team is consulting with NIST, but for commercial systems, the team is encouraged to add Coriolis if the company is willing to participate so that a prime suppler can share strategic information and learn from others on the team. Ideally, such an approach will lead to timely adoption of information and improvements by industry. This may already be happening, but the discussions around manufacturer participation seemed a bit vague.
- For a flow meter to provide the most accurate measurements, several performance aspects need to be quantified:
    - Calibration. It is not clear how the meters will be calibrated (presumably simply using factory calibration curves). It is not clear against what standard they will be calibrated, but perhaps the scale system could be used for this. Along these lines, flow meter settings need to be documented.
    - Installation. Flow meters can be very sensitive to installation, including straight runs, orientation, vibration, mounting, etc. This needs to be verified with the manufacturer and reported. Station designers will likely deviate from this, and the effects are unknown.
    - Environment. Depending upon the flow meter type, environmental factors can have a significant effect on accuracy. For Coriolis meters, mounting and vibration can be a factor. For turbine meters, flow conditioning and de-swirl of inlets can have a big effect and need to be addressed.

  From a station designer's perspective, the greatest interest is in the effect of operating conditions on the ability to provide an accurate fill. For example, station designers would like to know the cumulative errors during a tank fill rather than uncertainty in measured flow rate. A simulated fill protocol with different fill rates, transients, etc., which is then reported in error over a tank fill, would be most valuable.
- It seems that one of the issues with meters is the extreme temperature cycling. It is not clear whether there are plans to do precooled hydrogen (preferably to -40°C). Presumably this has a significant impact on the final outcome(s). When asked about this topic, the presenter stated that the meters are not in the path of precooled hydrogen, and to add that hardware would have added extensive cost and time. While the SAE J2601 standard says that the startup hydrogen mass shall be less than 200 g, it seems that some providers are right up to that limit (as close to it as possible)—this may be useful information for the device-under-test pressure pulse plan. It is not clear whether the project is going to send a temperature signal to the stations (or how to fake out the station on temperatures that do not occur in Colorado).

Question 3: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- This project will provide information to domestic and international hydrogen fuel providers, helping them to understand how commercial meters perform and what corrections need to be made on the control side to

improve accuracy. This will directly help accelerate the introduction of hydrogen refueling stations and improve the customer experience.
- If the project maintains its expected schedule, the completion of the project will be very well timed to current and ongoing developments in California and the Northeast. This will help maximize the potential impact of the project. To date, progress appears to be quite rapid.
- Planning and engineering work are good, considering the very tight development timespan. Some work is still necessary to evaluate quantitatively the measuring accuracy of the facility. During the Q&A, it was stated that the facility aims at an accuracy three times better than the required maximal accuracy of the metering device (1.5%). This should be demonstrated as soon as possible because it is essential for project's success.
- This project is just getting started; progress is good. Because of delays in acquisition and permitting, the laboratory has taken longer to construct than anticipated, but delays in this area are actually commonplace.
- System design and the rationale behind it are well aligned. There is one caveat: flow measurements in selected positions 1 and 2 may not work for a dispensing facility in which a cascade storage bank branches off to more than one dispenser.
- Meter selection, system design, and system pre-testing are good accomplishments. Now actual testing has to be done and completed to make data observations.
- System design and pre-testing accomplishments are sound. However, there may not be enough time left for the planned actual test before the September end date.
- The project has an aggressive schedule (12 months), including procurement and testing. It is not surprising that storage vessels and flow meter lead times have put the project behind schedule.
- Because of the long lead time for Type 3 vessels, the project is a bit behind but appears to have some slack in the schedule to catch up during testing.
- It is not clear what the reason is for location 3 of the meter if it is out of scope and causes problems as the meter becomes a heat sink (between heat exchanger and breakaway). When asked during the presentation, the presenter said that the project will focus on positions 1 and 2 initially. Input from industry stakeholders is that there are now efforts to move meters closer to the nozzle. Pressure, volume, temperature (PVT) compensations will inevitably be an inadequate method of improving overall accuracy (90%–95% accurate at best when making a correction for 20–80 g, and that is not good enough). Therefore, station developers will continue to push to locate the flow meter closer to the point of transfer, and flow meter manufacturers will improve the accuracy of the meter with multiple (inlet + outlet) temperature compensation (accounting for temperature change inside the meter) and calibration parameters that are more highly customized and tuned for the hydrogen fueling application, instead of generic steady-state flow applications for the manufacturers' core clientele (the chemical and petrochemical industry). This returns us to the question of the reason for the choice of meter that is not in use (based on cost, per a comment from the presenter).

Question 4: Collaboration and coordination with other institutions

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

- The project appears to be coordinating appropriately with many partners. In particular, the use of a testing facility already within DOE's portfolio of capabilities was a good decision for this project. Additionally, the outreach to the international community involved in station development and testing will be particularly valuable.
- This is a good set of collaborators, but it would be good to see a dispenser manufacturer and a fuel provider as part of the team. Sandia National Laboratories (SNL) is part of the team, but no SNL materials expert is listed as a participant. It would be good to see that SNL materials expertise is at least available for occasional consultation. During the Q&A, this issue was posed to the PI, who indicated that he consults with SNL frequently, which is good. This is particularly important since some of these meters (Coriolis in particular) really require a high-strength material to enable thinner wall material, and unless it is high in Ni content, the material will have increased sensitivity to embrittlement. The investigators recognize that materials issues are an area of concern, so having access to SNL materials expertise is important.
- Established collaborations are invaluable for this project.

- While the current collaborations are good, and certainly there is much that can be learned from the experiences of the California Division of Measurement Standards, there needs to be some actual station developers in there, too—those in the field with real-world experience, dealing with this in a retail setting.
- The collaboration with NIST and researchers from national laboratories is excellent. It would be beneficial for the project team to engage the meter manufacturers more.
- There is a good mix of national and international project partners. However, adding a station operator from industry with field experience outside a national laboratory station may strengthen this project significantly.
- It would be helpful to have inputs from the station owners/designers who will need to implement these flow meters. A standard test procedure and test platform that could be used to evaluate flow meter suppliers would be a helpful outcome. In particular, flow meter manufacturers could use this test stand and test procedure to validate performance for direct comparison to other manufacturers.
- The project shows collaboration with NIST and in Europe with the Joint Research Centre. However, other players have already gained considerable experience (the Clean Energy Partnership in Germany), and how far the project has considered these achievements is not apparent.
- The only suggested addition to the list of collaborators is hydrogen producers currently operating refueling stations such as Air Products, Air Liquide, Linde, or other similar companies in the industry.
- It would be helpful if the project would more clearly identify the flow meter suppliers with whom the team is actually working.

Question 5: Proposed future work

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

- It seems this should be a continuous/longer-term project that can constantly keep up with industry and assist with progress. Industry can use this as a tool, a leg up; the project can be a real incentive for industry to keep working on the technology. It is suggested that funding be continued (at some useful level) to keep driving this progress.
- The future work is appropriate for the scope of the project. Coordination with final decision making in HB44 could potentially have a great impact on accelerating station development.
- The future work in the two-year frame of the project is excellent. It is, however, not clear whether the laboratory can be further used as a tester/enabler of developers (in the sense that there may not be very many). Perhaps the development toward a fully certified instrumentation for mass measurement could be considered.
- It is important that the team complete the stated project closeout work.
- It would be good to see a realistic SAE J2601 table or MC Method fill. It is agreed that since the meter needs to be upstream of the chiller, cooling is not necessary. However, a realistic fill without the chiller should be performed—which might not be possible while keeping the tank from over-temperature, over-pressure, or over-state-of-charge.
- Proposed future work is adequate. The only suggested improvement is to receive feedback from companies currently operating hydrogen refueling stations before testing begins.
- Proposed future scope seems adequate to meet the project objectives.
- It appears that the project is primarily focused on milder California weather conditions, hence diminishing its overall usefulness. It is recommended that the project seek additional funding to set up the system for multiple ambient weather extremes, as well as varying vibration conditions since the meters will be on working forecourts. Also, it is not clear how the flow meter components will be stressed to understand flow meter drift over time.
- It is not clear what "Provide validation testing of proposed SAE J2601 slow fill protocol for home fueling and roadside assistance" has to do with proposed future work for metering. This appears squeezed in by SAE J2601 proponents and unfit for work done in this project. This should be eliminated from this project because *if* there is metering for home fueling and roadside assistance, there is no business transaction taking place that requires accuracy applicable to retail fueling.

Project strengths:

- This project represents a first-of-a-kind instrument in the public domain and is trying to tackle a critically important problem: qualifying a mass flow rate meter to HB44 under an SAE J2601 fill. As a first attempt, this project is good.
- The project's strength is that it is helping to answer a major unknown currently being faced by today's station developers. The immediate impact and value potential are very large for this project.
- The project is developing a laboratory-grade meter benchmark and assessing viable (but to-be-conclusively-proven) hydrogen meters.
- The overall direction/intention is positive and will create an accurate benchmark/baseline meter accuracy—in industry, there is a lack of determining accuracy in a controlled environment (although it is done in the field).
- Strengths include use of the hydrogen infrastructure testing and research facility, skilled researchers, appropriate design of experiment, and the inclusion of pretesting.
- The partnership with NIST brings considerable expertise, plus some previous experience with compressed natural gas (although the reviewer may not have heard the presenter correctly about the last point).
- The main strengths are strong technical competence and an expert team, availability of an up-to-date refueling station for testing, and correct timing.
- Strengths include a strong experimental base at NREL and very strong international collaborations.
- The project has a good team and an aggressive schedule.
- The project design and the system pre-testing are well done.

Project weaknesses:

- There are no particular weaknesses in this project.
- There are no significant weaknesses. One potential weakness is that the project is looking only at the case in which each dispenser is served by an independent storage bank.
- The proposed location of the meter (location 1 or 2) is a project weakness. Even though location 3 could act as a heat sink, from a practical/realistic perspective, the meter should be as close to the nozzle as possible. The heat sink concerns will be addressed based on in-field experience by industry. However, locations 1 and 2 may be a good solution for in-laboratory benchmark testing of meters—which does not take away the technical requirements for meters installed in retail stations in location 3.
- The qualification of mass flow rate meters operating in the required pre-testing time specified by an SAE J2601-compliant fill and to accuracy of HB44 is a very challenging problem. However, validation techniques and hardware must be developed to accomplish that task. This project falls short of achieving that in accuracy over the entire range of fill parameters and in its ability to actually execute an SAE J2601-compliant fill (there is no precooling).
- Station developers/industry have moved far beyond this challenge and onto bigger ones (flow meter placement, flow meter internal temperature compensation)—the pace is fast. What is known about the metered accuracy now was not even tested six months ago. Industry may not be as thorough as the laboratories, but industry is solving the problems at free market pace; there needs to be a way for laboratories/DOE to keep up *and* do the needed research and development (R&D) for future applications (i.e., future technologies).
- The stated challenges with project permitting, logistics, and schedule may be detrimental to the project's success.
- A project weakness is the lack of a stakeholder community able to drive and optimally profit from the facility.
- There is a lack of involvement or inputs from the station designers. If this work is to be implemented, their input is needed to coordinate the deliverables to be usable in station design.
- There is a lack of detailed input from industry experts.
- Only one type of meter can meet that 1.5% accuracy requirement.

Recommendations for additions/deletions to project scope:

- The project scope appears appropriate and well designed. There are no additions or deletions recommended at this time.
- This is a first step in establishing a better understanding of flow meter performance. The project could be strengthened by the establishment of test standards or protocols that could be used across flow meter manufacturers, providing station designers with a way to do “apples-to-apples” comparisons of flow meters. Eventually, this could be expanded to create a test standard by which a flow meter could be “qualified” for the application, along with guidance on installation, operation, setup, calibration, etc.
- The objective “Provide validation testing of proposed SAE J2601 slow fill protocol for home fueling and roadside assistance” should be deleted from the project. The proposed location of system design of the developed system will be made publicly available. The project should assess at what range or number of meter units a meter could be commercially profitable. This will be valuable information to add to this benchmarking effort because the information will provide an understanding of what is needed to motivate meter manufacturers to invest in R&D to develop new or more accurate meters.
- A beneficial outcome of this or future research would be correlation factors that account for errors in traditional PVT/ideal gas or equation of state calculations *and* errors introduced by the nature of the gas temperature’s changing as it settles in the heat exchangers (often metal thermal storage, which causes dramatic temperature gradients and transients).
- This system (or project) needs to develop a mass flow rate meter validation system capable of validating an SAE J2601-compliant fill and one that is accurate per HB44. It would be good to see a system 10 times more accurate for validating the meter, but a factor of 3, as the PI has indicated, will be satisfactory. The current system does not have this capability. The investigators are working toward this but are not there yet; this objective needs to be kept in sight.
- The project should consider a scenario in which a storage system serves more than one dispenser through the same main line and priority fill panel, then branches off to individual dispensers that can be fueled simultaneously.
- The project should invite companies involved in the design and operation of hydrogen refueling stations to provide feedback.
- The project should reach out to the broader area of the metering industry, well beyond hydrogen, and organize international benchmarking exercises with similar facilities.
- The likely technology deployment pathway should be clarified.