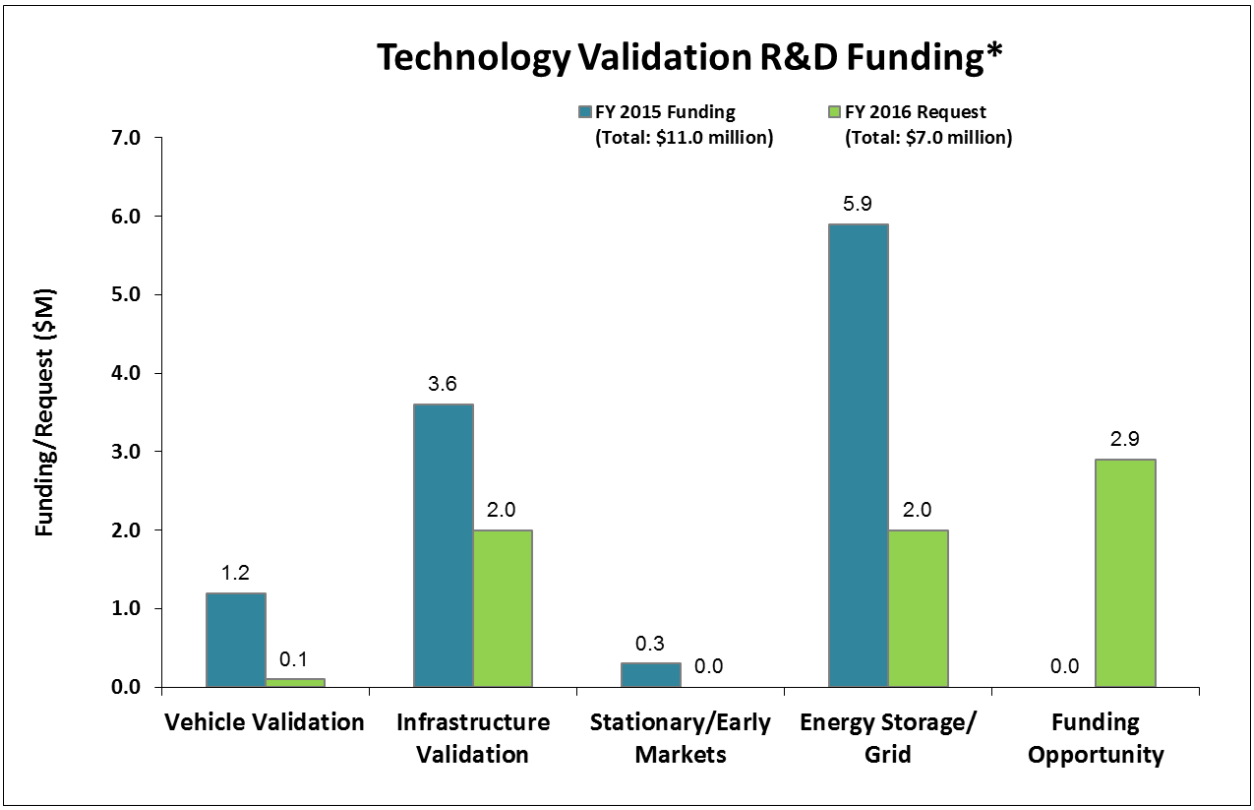
2015 — Technology Validation
Summary of Annual Merit Review of the Technology Validation Sub-Program

Summary of Reviewer Comments on the Technology Validation Sub-Program:

In general, the reviewers believed that the objectives and metrics of the Technology Validation sub-program were clearly stated, and that the role of the sub-program within the structure of the Fuel Cell Technologies Office was clearly identified. They believed that effective collaboration with partners and successful management of large amounts of data were key strengths of the sub-program and furthered its goals and objectives. Reviewers stated that progress related to projects and near-term plans of the sub-program were adequately presented, but they suggested increasing the emphasis on longer-term plans and comparison of recent progress to that of the previous year. Reviewers also suggested that the sub-program focus more attention on cost data and consumer acceptance.

Technology Validation Funding:

The Technology Validation sub-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-duty trucks, and buses), stationary and early market applications (e.g., material handling), and hydrogen infrastructure activities (e.g., fueling stations and components). In coordination with the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy and Office of Electricity, a key focus in fiscal year (FY) 2016 will be hydrogen-based energy storage and grid integration activities. The FY 2015 appropriation was $11 million. The FY 2016 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 11 Technology Validation sub-program projects that were reviewed had a maximum score of 3.9, a minimum score of 3.0, and an average score of 3.4. Key strengths identified by reviewers in all of the Technology Validation projects were (1) the collaboration involving key partners and (2) the potential for the projects to contribute valuable data to allow stakeholders to gain enhanced insights and successfully deploy hydrogen and fuel cell technologies. Reviewers also observed that the National Renewable Energy Laboratory's (NREL's) approach for collecting, securing, and analyzing data is well established and trusted by project collaborators.

Fuel Cell Electric Vehicles (FCEVs): Reviewers stated that this project has served as the main global source for reporting on the status and progress of FCEVs, and that the project has been conducted with well-defined goals and methodologies. Reviewers praised the project team for maintaining the cooperation of several automotive companies, and they suggested that these automotive original equipment manufacturers continue to provide data during increased rollout and commercialization. The reviewers also offered some suggestions for improvement, including segmenting data based on vehicle model year, disaggregating vehicle classes, collecting data for fuel efficiency at one-quarter and full power for newer model vehicles, looking more closely at fuel cell stack vintage, and evaluating the effects of climate on vehicle performance.

Fuel Cell Electric Buses (FCEBs): Reviewers found this project to be valuable for a variety of stakeholders, and to feature consistent data collection and evaluation efforts. Reviewers noted that consistent, long-term collaboration between NREL, data providers, and data users has proven to be very effective. Reviewers suggested that the project team compare FCEBs with more technologies and under different circumstances, explore the potential application of a Technology Readiness Level–like concept for maintenance personnel's level of experience, and consider combining the different results to date into a bigger-picture evaluation.

Material Handling Equipment: Reviewers viewed this project as having the potential to identify optimization for the commercialization of fuel cells in key early markets, and as providing insights into user behavior, which in turn helps guide design requirements. NREL staff's background knowledge and practical experience with the material handling equipment industry was seen by reviewers as a key strength. The reviewers noted that steady cooperation of industry has allowed a significant data set to be built.

Hydrogen Refueling Stations: Reviewers noted that data collection and evaluation efforts for hydrogen refueling stations have provided a long history of reliable information, and that the maintenance data was especially valuable and relevant in deriving preventive operations and maintenance schedules. Reviewers recommended that the researchers start identifying next-generation "open" retail stations in data reporting separately from previous generation non-retail stations, as well as evaluate the correlation between station usage and compressor failure events. Reviewers noted that the Proton hydrogen station project has provided useful insights that help stakeholders assess whether advanced hydrogen production technologies will advance efforts to reach DOE hydrogen cost goals. Reviewers articulated that the GTI hydrogen station project involves capable partners, and that good progress has been made to date. They noted that having data from five stations will help validate the technology, and that project partners should document lessons learned to aid the industry in overcoming barriers for future hydrogen station installations.

Compressor Performance Evaluation: Reviewers viewed NREL's compressor performance evaluation project as important in the deployment of commercial hydrogen stations. While they acknowledged the project has generated useful data and made significant progress in the evaluations, they also noted that there has been limited operational data and run time. Reviewers suggested performing more hours of compressor testing, evaluating other compressor types, investigating the impact of start-up mode and frequency on compressor performance and failure modes, and adding a separate mass flow sensor to confirm the calculation of the mass flow.

Cryogenic Hydrogen Storage and Liquid Hydrogen Pump: Reviewers remarked that this project has the potential to boost hydrogen density to meet DOE targets. They found the safety analysis conducted by the project team to be very thorough and capable of serving as a model plan. Reviewers commented that the project partners possess complementary expertise and are well chosen for their ability to contribute. Reviewers suggested that the project team obtain further input from vehicle manufacturers, more fully specify performance benchmarks, identify

the cost of the system, and analyze the economics and pressure excursions during dormancy. Reviewers also noted that more emphasis should be put on collaborating with institutions outside the consortium.

Station Operational Status System (SOSS): Reviewers found the SOSS interface to be well designed and functional. They noted that integration with all stations is essential for the success of the project. They suggested that it would be useful to include (1) customer feedback on the app design to gauge customer satisfaction and obtain feedback for enhancements, and (2) a count of app usage and daily visits to measure its effectiveness.

Hydrogen Station Equipment Performance (HyStEP) Device: Reviewers found that this project effectively links the DOE research and development objectives related to the Safety, Codes and Standards and Technology Validation sub-programs, accelerating the validation process of hydrogen refueling stations. They noted that the mobile device is well engineered, and they praised collaborations with various organizations involved in the project. Reviewers encouraged caution with the potential changing of standardization requirements (e.g., CSA HGV 4.3 – Test methods for hydrogen fueling parameter evaluation) and the revision of SAE International J2601 (Hydrogen Fueling Protocol), and they remarked that it may be prudent to synchronize completion of this project with the publication of the revised standards.

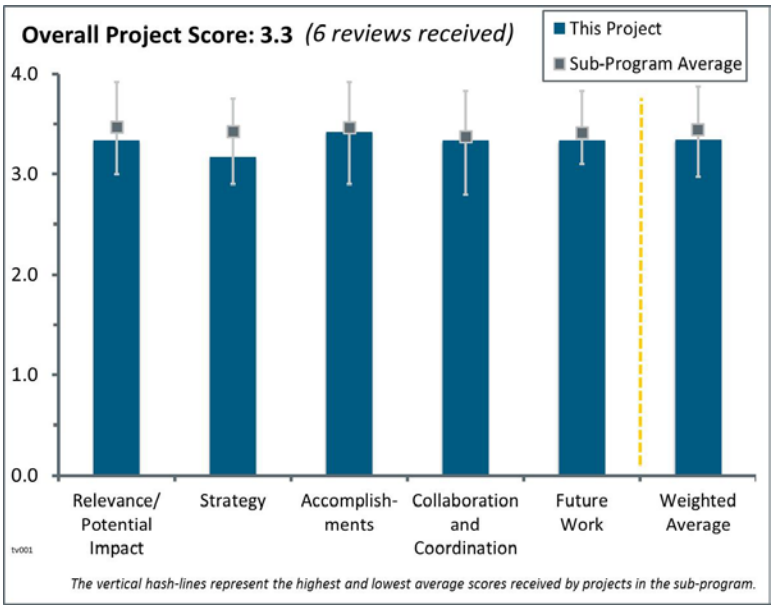
Hydrogen Energy Storage/Grid Integration: Reviewers stated that this project has demonstrated how both hydrogen and fuel cell technologies are part of a broader clean energy system and linked to a very current topic of global interest. They noted that project results have the potential to stimulate clean energy expansion. They commended the amount of progress the project has demonstrated in a short time frame on both electrolyzer technology and communications. Reviewers advised that the project could be enhanced by including utilities and Independent System Operators in order to obtain feedback on their experiences in incorporating renewables and their needs.

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 2015 objectives focus on analysis and reporting of FCEV durability, range, fuel economy, vehicle specifications, and driver experience.



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.

- One cannot manage what one cannot measure. This project is one of the most critical for the Fuel Cell Technologies Office (FCTO) because it measures progress against DOE targets in real-life conditions. This project can determine when a project can be shelved in favor of something more promising. The project will also help determine when DOE programs are not supporting pre-commercial technologies anymore.
- Continuing to validate the current state of fuel cell vehicle technology durability and overall performance compared to technical targets remains essential to the FCTO Multi-Year Research, Development, and Demonstration Plan. The aggregated data are useful to policymakers, as well as fleet managers, manufacturers, and other potential consumers. It is exciting to see that one of the vehicles has 6,500 hours on a single fuel cell stack and that the average on-road vehicle economy is 51.4 miles/kg.
- Data collection to measure progress toward goals is always important. When original equipment manufacturers (OEMs) start commercialization, there should be a consideration about not including/collecting data anymore for specific OEMs.
- The project aligns well with DOE Hydrogen and Fuel Cells Program goals and objectives.
- Grading this project is tough; the material is a very necessary requirement, but the presentation of the material could have been improved greatly. The project is critical, but actual performance is tough to assess. The National Renewable Energy Laboratory (NREL) states that an objective is to validate FCEVs in a real-world setting, but little is presented beyond some limited refueling data, when other data exist and are regularly provided to users (e.g., monthly data about General Motors FCEVs are provided to the U.S. Navy and Marine Corps).

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 is well designed and is being conducted according to plans.

- There is a need to aggregate data, given confidentiality issues, but it would be very useful if the aggregated data could be provided in an Excel spreadsheet and if the results were categorized by vehicle class. It would be much more useful to get the actual numbers instead of trying to guess. It would be interesting to test vehicle range on partial fills, particularly at p-50.
- The presenter recollected no problems encountered during the project; a quick review of the hard copy does not find a similar discussion. If the project is integrated with efforts beyond the efforts of OEMs to place FCEVs onto the roadways, it was not discussed. The project presentation seemed limited to a presentation of highlights.
- The current data set appears to be a bit limited, with between 28 and 48 vehicles, whereas the funding is for up to 90. With the expansion of vehicles in California, it is important to have firm plans for the Office of Energy Efficiency and Renewable Energy's participation in data collection and analysis.

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

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

- The project is not finished. Reporting is outstanding at this point in time. Work needs to continue at this same high level, addressing the issues outlined in the project thus far.
- Significant accomplishments have been achieved in assessing FCEV on-road performance. Some key caveats, assumptions, or key points, if any, may need to be included with composite data products (CDPs).
- The number and variety of CDPs provide for easy historical trending. Also, the data show much progress toward meeting the DOE targets.
- There are more vehicles being tested every report period, which is a great accomplishment.
- Because the focus is on meeting stack targets, slide 11, which describes improvements in on-road fuel economy, should be considered—i.e., whether the reported improvements in fuel economy also included hybridization improvements. (Miles per kilogram may not be due to the fuel cell [including improvements] only.) There was a good point about looking into peaks of onboard fuel pressure at the end of fills. Perhaps analysis of the results shown in the graph on slide 15 could also be an indication of other observations with regard to the temperature limit.
- Apart from collecting and promulgating data, the project seems like an administrative requirement.

Question 4: Collaboration and coordination with other institutions

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

- Maintaining the continued cooperation of six automotive companies is no small feat.
- Collaborating with U.S. partners is great. It would be even better if the data could be compared with data from other OEMs outside of the United States.
- This project is based on collaboration with six OEMs and industry working groups.
- It appears that NREL performed all the work for this project. The partner activities listed were conducted by the automotive OEMs. Once they manufactured the car and their FCEV hit the road, it is not clear what they did for this project. There was one partner that assisted NREL, but that partner was not listed in the presentation. Otherwise, it seemed that all project work was performed by NREL and nobody else.
- It is unclear what the expectation is going forward regarding OEM involvement in providing data during commercialization.

Question 5: Proposed future work

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

- The proposed future work is consistent with plans and schedules.
- The elements for future analysis work look fine. However, it would be nice to substantially increase the number of vehicles in the study by establishing contracts with the automotive OEMs and the state of California for data collection and analysis services for the rollout of the commercial vehicles, especially

those that will be purchased as part of the state fleet. It would also be good to include collection of data for fuel efficiency at one-quarter and full power for newer-model vehicles. Also, there should be some data segmentation based on model year so that the performance of later models can be fully appreciated.
- The project is underway. The team has a great handle on what needs to be reported, has a great relationship with the OEMs, and is adjusting subtask focuses as needed to address areas that need review as they surface from the data collected.
- It is not clear whether the data is being fed back to U.S. DRIVE Partnership Technical Teams to adjust model assumptions.
- It is not clear whether NREL/DOE is communicating with potential new OEM market entrants.

Project strengths:

- This project represents the main global source for benchmarking and reporting status and progress of FCEV durability.
- Data collection and analysis remains strong and relevant.
- Fill pressure anomalies were captured as something that needed explanation.
- The project has been conducted with well-defined goals and methodologies.
- Stakeholder engagement and project planning are strengths.

Project weaknesses:

- There are no significant weaknesses.
- The fill data metrics appeared to show that the market has a conservative approach to the fill process. Those data were reported to the safety side for possible changes to the process. The question is what can be done to show the changes in benefits due to reduced fill time and range.
- The vehicle configurations, the extent of hybridization, the size of vehicle, etc. are unclear.
- If the number of vehicles gets to a certain minimum, then the usefulness of the data collection effort should be reconsidered.
- The format of results is not very useful for analysis.

Recommendations for additions/deletions to project scope:

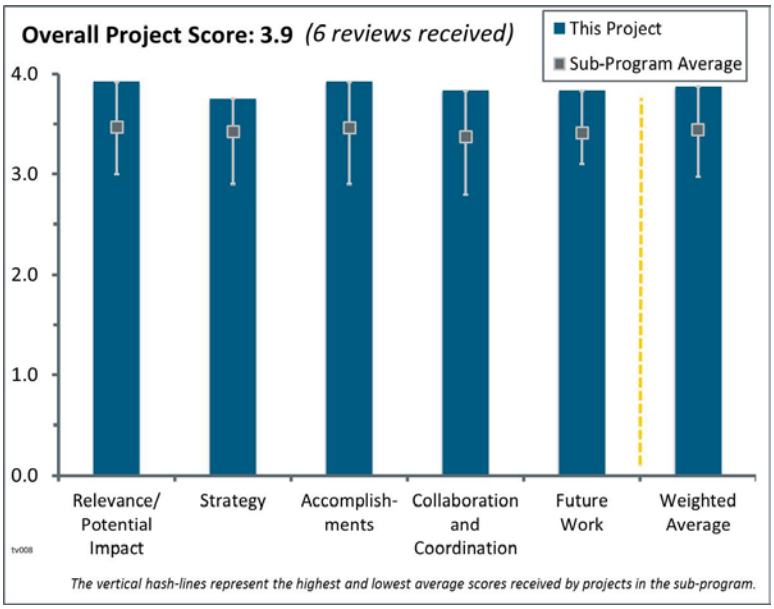
- DOE should recommend that presenters include references to posters on the same topic from previous years. A one-letter difference in file names of documents made available to reviewers (in this case, 2014 and 2015 file names) could cause confusion for reviewers and possible negative feedback.
- Stack vintage within a car's manufacturing cycle should be somehow included in the project. Most stacks are still somewhat handmade. As stack production improves, consideration should be given to how to capture that repeatable process to evaluate life changes. Early cars were demonstration platforms used at shows, ride and drives, and other events. As such, distance between refills should be low compared to cars actually placed in service with fleets and consumers. Segregating those data will go a long way to showing the actual user experience versus the demonstrator experience. When reporting the miles per gallon gasoline equivalent (MPGe), the project should look at whether drivers used the onboard displays to adjust pedal movement. Driving an FCEV the same way one would drive a gas car results in lower MPGe. Retraining the driver's pedal actions using the display can result in significant MPGe improvement. As more cars deploy, a note on the ambient environment will become appropriate—cold-weather climate versus warm-weather climate, southern California versus the Northeast. Another metric to consider will be the impact the mechanic will have on the vehicle: his training, his tools, etc.—i.e., considering who is taking care of the car and whether the mechanic is at a factory location or a dealer.
- The project should improve public reports to disaggregate vehicle classes and provide numbers in spreadsheets. International OEMs should be engaged.

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 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 **3.9** for its relevance/potential impact.

- This project has been funded in one form or another for 13 years. The results of the project speak for themselves. These are the only data collected from public transit buses using fuel cells, electric batteries, and diesel engines. The impact on the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan (MYRDDP) has been revealing.
- Because buses are important to DOE and are a DOE target for fuel cell deployment, it is necessary to measure the deployment of fuel cells on buses, and the National Renewable Energy Laboratory (NREL) team appears to be doing a thorough and complete job of gathering, measuring, interpreting, and providing the necessary metrics.
- Third-party validation is important to setting standard protocol to assess where technology really is and how it compares to conventional/commercial technologies. Studying fuel cell buses individually is important because they have different potential models from light-duty vehicles (e.g., depot model and specific range).
- The project enables learning from early adopters for larger populations of transit agencies and the Federal Transit Administration.
- The work is most valuable for different government agencies and is being used accordingly.
- The project clearly and directly supports the Hydrogen and Fuel Cells Program's (the Program's) goals and the objectives delineated in the MYRDDP by analyzing the performance of in-service fuel cell transit buses.
- The activity reports on components, service programs, and performance metrics to show the interconnection between them. It is not perfect, but it identifies the issues and areas that should be addressed to allow the technology to meet and exceed long-term goals.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.8** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The strategy is excellent and aimed at analyzing and summarizing in-service performance data supplied by fuel cell bus operators. Results are compared to DOE targets. It is a very useful technology validation project.
- The project has outstanding evaluation and coordination with transit companies to collect and evaluate key data on real-world performance and maintenance of fuel cell buses. The design of this project has not varied from the beginning and provides consistent data collection over time.
- Analysis was across several different metrics. Some could be better tied to conventional vehicles, although samples may not be available in all cases, while others are directly tied. Regarding the discussion of baseline vehicle selection, the presenter did a good job of describing the challenges (e.g., the team would like to have at least five vehicles but cannot always get them from the transit agencies) and approaches to overcome limitations. The project team talked to vehicle drivers to learn anecdotal things a data sheet cannot provide. On a similar note, passenger surveys were performed. These activities are very important because technology adoption is not solely about cost and performance—if the customers do not like something, they still will not buy it.
- Consistency in data collection and analysis is a great strength.
- It is difficult to suggest improvements to the NREL presentation, which appears complete and thorough.
- To the extent that bus users allow, comparisons between the types of bus technologies are good. Data collection is good. Additional reporting should extend to show the effect that larger numbers of fuel cell buses at a single site can have when compared to a two- or three-bus user site.

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

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

- The presenter provided a good description of the caveats around the analysis and why differences are expected (e.g., comparing Technology Readiness Level [TRL] 9 conventional technologies to TRL 6–7). It is good to see that in the assessment of power plant life, AC Transit exceeded the 2016 target (>19,000 hours). There was a good breakdown of downtime to explain the delta between actual availability of 70% versus the target of 85% (which was mainly due to bus issues, not the fuel cell, which only accounted for 10%–15% of the reason for unavailability). In addition, it is important to point out that propulsion is the most costly, even if it occurs less often (but again, this is typically not due to the fuel cell but mainly because of cooling issues). The fuel analysis is good as well; it shows the fuel economy is significantly better than the diesel equivalent and has passed 2016 targets on miles between fuel cell service.
- Much progress has been made since the project started in fiscal year 2003. A large amount of data has been received and analyzed relative to near-term and ultimate DOE targets. While most of the targets have not quite been met, the results seem to be quite promising relative to standard diesel and compressed natural gas (CNG) vehicles. This project has gone a long way in convincingly showing that fuel-cell-based bus operating performance will ultimately be competitive with present fossil-fueled buses. The principal investigator is also getting some important verbal input from drivers. Fuel cell buses are very popular with drivers and riders.
- The Program can rest easy knowing that valuable data are being collected on public bus transits in a consistent manner and evaluated with transparent and accurate methodologies to evaluate the Program's technical targets. The project clearly shows the reliability targets of miles between road calls (MBRC). Cost of maintenance per mile is just one of the ways to evaluate the data collected, and this metric was explained well. Maintenance cost per mile by system is another example of how to evaluate the data collected. DOE reaps the benefit of the detailed data collected.
- It is impressive that the 2016 target is exceeded by one FCEB and that the average hours for most FCEBs is beyond 8,000 hours. The presentation included a solid explanation of the graphs and data, including reasons for observed changes in data. Maintenance cost per mile is an incredibly valuable parameter for

transit operations, so inclusion of this in the reporting is very valuable for DOE. It would be good to know how much of a propulsion system can be considered "shared" with other technologies from buses with the same manufacturer. In response to a 2014 reviewer comment/question, the presenter made a good point about bringing up the average MBRC number for the transit bus industry.
- Data collection does identify spare power plants. The reporting of spare power plants in combination with in-service power plants offers a challenge in interpreting what the real stack life is.
- It would have been nice to know whether NREL had difficulties with the project. NREL did a nice job of detailing the challenges that bus service providers faced, but it did not really describe the challenges, if any, it faced while performing the project. This category grade was almost a 3.5, and it would not be difficult to change downward from the grade assigned.

Question 4: Collaboration and coordination with other institutions

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

- DOE is fortunate to have someone like Leslie Eudy establishing such excellent partnerships with so many bus transit companies over the years. This consistent long-term collaboration has proven valuable to evaluating the performance of fuel cells in real-world conditions.
- Collaboration and coordination with other institutions has been excellent. Collaborations include data from fleet operators, drivers, bus and fuel cell manufacturers, and fuel suppliers. In a few cases, data flow has been interrupted when there are management changes within the collaborating organizations. This is unavoidable and has not been a major problem.
- Working with transit authorities in different regions is challenging. This group has done an outstanding job with that effort.
- Given the nature and scope of the project, NREL did a very commendable job of working with collaborators, such as transit agencies, manufacturers, or other agencies. The project is doing a nice job.
- The collaborations are excellent, and the project should keep it up. The team could potentially include hybrid diesel technology buses, where possible, for comparison.
- Interaction with transit agencies (input and output) and manufacturers (testing consistency and realism) was clear. Feedback from/connection with state and international organizations, other than data sharing, was not as clear.

Question 5: Proposed future work

This project was rated **3.8** for its proposed future work.

- This excellent work should continue and expand according to the future work outline. It is very important to add battery-electric buses to diesels and CNG for comparison. Battery research and development (R&D) is probably exceeding fuel cell/hydrogen R&D at the moment. The great future technological battle in electric vehicles will be fuel cell versus battery.
- Because it is necessary to monitor and measure deployment activities, it is very difficult to find/determine improvement.
- Other geographic areas could be considered. Other fleets with various power configurations should be considered, as the presenter suggested. These potential transit companies should be included in the future. This would help broaden the data collected.
- The proposed future work is mainly the completion of reports—this section went by pretty fast. Perhaps there is a way to tie together the different reports and draw bigger-picture conclusions once there is more of a critical mass, or perhaps this is just more of the same, or perhaps one can draw conclusions on advancements based on studies of later versus earlier buses. It is not totally clear what the additional data were going to provide.

Project strengths:

- This project represents the only consistent source of FCEB data in the United States. The analysis and conclusions are neutral.

- There is good context and knowledge around bus maintenance—the project is clearly not just mining data from a computer.
- The project has outstanding data collection and detail in all areas. It is very easy to start drilling down on those areas that will contribute to life goals.
- This is excellent real-world operation analysis.
- The consistent data collection and evaluation is a strength.

Project weaknesses:

- Comments from transit operators, the bus operators themselves, the maintenance people, and the riders should be added to the project, allowing for comparison between the various technologies. Climate impacts—hot versus cold, wet versus dry—were not evident.
- It would be better to also include the average on the right of slide 12. It is somewhat misleading to have only high and low versus CNG (and it is not clear how the information ties to slide 13).

Recommendations for additions/deletions to project scope:

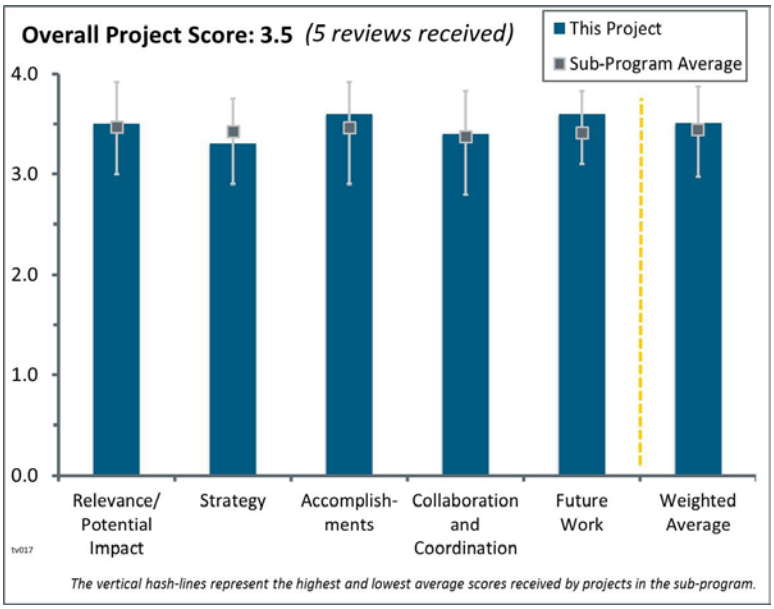
- Road call values are increasing toward the target, but it is not clear why (e.g., whether it is better preventative maintenance programs that are preemptively solving problems or better parts being used for the fix). It was noted that quick change batteries have improved and may start to give fuel cell buses a run for their money. Climatic comparisons should be considered. Battery buses in the Northeast have been reported to have range issues during the winter, causing some rerouting (e.g., in Worcester, Massachusetts).
- A comment was made that the key driver is policy (zero emissions). How this can be leveraged further should be considered. (This is not really in the scope of the project, but we should consider what recommendations can be made to other groups to drive policy.) The scope could be expanded to include the impact of regulations on the number of fielded buses.
- Additional funding should be provided to increase data from the baseline fleet vehicles. The project should explore the application of a “TRL”-like concept for maintenance personnel’s level of experience to maintain FCEBs and its relation to the availability of FCEBs.
- The project should add new transit companies in different geographies.

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

Sam Sprik; National Renewable Energy Laboratory

Brief Summary of Project:

The goal of this project is to evaluate hydrogen infrastructure performance, cost, utilization, maintenance, and safety through independent analysis. 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 **3.5** for its relevance/potential impact.

- The project supports the Hydrogen and Fuel Cells Program in the area of hydrogen refueling stations (HRSs) by collecting useful data on station capacity/utilization, fueling, maintenance, costs, and timing. Such data collection is worthwhile, and resulting analysis brings significant knowledge to HRS players (e.g., owners, utilities, and users) to focus on critical elements so that HRSs are more reliable and easier to operate.
- The National Renewable Energy Laboratory (NREL) team is doing a very good job in working to meet U.S. Department of Energy (DOE) goals and requirements.
- These data are essential for evaluating station performance, following the previous NREL endeavors in collecting and analyzing data from fuel cell electric vehicle (FCEV) field testing.

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.

- This is an extremely complete performance by the NREL team to address critical barriers and advance fuel cell vehicle fueling; the work could be valuable to improving infrastructure deployment.
- The bundled data (manually and automatically collected data) are delivered quarterly to the NREL researchers, who process the data and return both internal and public data products every six months around nine categories of interest (e.g., maintenance and refueling). Despite the fact that templates were produced, the level of details and harmony of data between stations is having an impact on the conclusions that follow from the NREL analysis. One can sometimes regret that the analysis is given with no indication of the data set's representatively.
- Ideally, data are collected automatically and not entered manually by station operators into the forms described. The project should (1) start identifying next-generation "open" retail stations in data reporting separately from previous-generation non-retail stations (e.g., behind fence, non-retail, and non–SAE International J2601 compliant) and (2) consider using the "open" definition as developed by the California

Fuel Cell Partnership and California infrastructure stakeholders (e.g., vehicle original equipment manufacturers, station providers, and state government).

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

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

- The project managed to gather data from 7–9 HRSs, which accounts for nearly all public HRSs in the United States. Significant results were obtained for the benefit of the involved parties. Maintenance data are particularly relevant to deriving preventive operations and maintenance schedules so as to maximize a station's availability and reduce the operating expenses.
- This is outstanding. The collection and presentation of fueling data provides an interesting and useful story.
- It would be good to know whether composite data products (CDPs) will have separate data for 70 MPa fills colder than -30°C in the future. Based on collected data, NREL should evaluate the correlation between station usage and compressor failure events, because compressors have fewer issues when running continuously.

Question 4: Collaboration and coordination with other institutions

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

- All HRS stakeholders (e.g., state agencies, institutes, and HRS operators) are contributing to the project. A wider benchmark including station data from other continents would astutely complement the landscape of the data set.
- Without collaboration, there are no data to share, so collaboration is an essential aspect of this project. It is good to have a memorandum of understanding with the California Energy Commission (CEC) for collection of data from CEC-funded hydrogen stations. The question is whether data collection will continue after the first six months the station is operational and/or after the first three years of funding (the required operational time to receive funding).
- Collaboration appears to consist mainly of partner organizations providing data rather than an effort to develop a greater role for partners.

Question 5: Proposed future work

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

- The project was successful in demonstrating its technology and economic value. Its continuity is mandatory; continuing the data feed without DOE funding is under consideration.
- The project and the work performed are necessary, and NREL did a commendable job of presenting the data as well as the challenges and issues that can be addressed in the future.
- The project should keep up the good work.
- There is no indication as to whether NREL can manage, or needs to prepare for, data processing and analysis for reporting from 40+ additional California hydrogen stations and 10+ Northeast stations.

Project strengths:

- This project has a long history of reliable data collection, analysis, and report-out activities. A large amount of data are included in CDPs. The data collection process is anonymous.
- NREL has excellent experience in collecting and analyzing data from the hydrogen and FCEV space.
- The knowledge of HRS characteristics has greatly progressed.

Project weaknesses:

- The project sometimes contemplates its CDPs, and the value of its conclusions is delivered with limited recommendations on exploiting the data for research and development policy or seeding other projects. For example, the maintenance analysis allows prediction of an estimated duration of HRS downtimes as a function of the type of issue and parts to repair. Such dynamic information could be used in project TV-027 Station Operational Status System,(SOSS) in which the application currently shows only static information about HRS status (i.e., offline, online, or limited) with 15-minute refresh; the application does not tell when the station would work again in the case of offline status. TV-017 has the potential to tell that.
- No collaboration is equal to no data or fewer data.

Recommendations for additions/deletions to project scope:

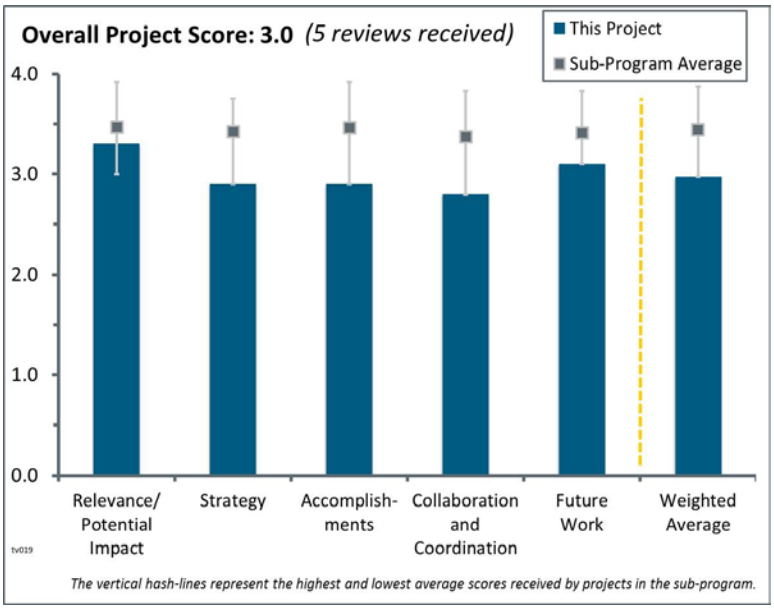
- Products should start distinguishing between data from early generation stations and currently implemented next-generation stations, of which a larger number of the same design are built. This is especially important for understanding the new generation of compressors (where data indicate there is a high failure rate). The following should also be added to the project scope:
    - Expand the project to collect data for fuel cell bus refueling, measuring fueling time, state of charge, average fill, etc.
    - Indicate which stations fill other vehicles (medium and/or heavy duty) and devices, which will affect data if included.
    - Collect more detailed information about reported downtime/failures/issues with compressors.
- A workshop should be organized with all projects using HRS data so that better links and deeper exploitation of the data would emerge.

Project # TV-019: Hydrogen Component Validation

Daniel Terlip; National Renewable Energy Laboratory

Brief Summary of Project:

The goal of this project is to generate data and study compressor operation to determine common failure modes (approximately one-third of maintenance hours at stations) and performance in variable conditions. Through data collection and analysis, the project will provide information to help improve compressor operation and reliability, highlight compressor failures and consequences, and assist original equipment manufacturers (OEMs) in improving design and increase 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 **3.3** for its relevance/potential impact.

- Small-scale hydrogen compressors are relatively new, and reliable data on their performance and failure modes are not widely available. This project aims to gather operational data on failure modes under different conditions, which is critical for the deployment of commercial hydrogen stations.
- The project is highly relevant because compressors remain high-cost items with poorly documented maintenance requirements. On one level, the industry partners should have done this long ago. The fact that they have not (at least not adequately) shows that this project is necessary.
- The main hydrogen component validation effort in this project is commercial mechanical hydrogen compressors. This is certainly one of the objectives delineated in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.
- This project aligns well with Hydrogen and Fuel Cells Program goals and objectives.
- There is a clear need to better understand and improve compressor reliability; however, the approach used by this project will not significantly add to the body of knowledge.

Question 2: Strategy for technology validation and/or deployment

This project was rated **2.9** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The project has been well planned and well performed to date.
- The National Renewable Energy Laboratory (NREL) approach is to acquire a number (four) of commercial hydrogen compressors (diaphragm and piston) and to monitor their operation on the NREL site. In particular, failures and downtimes are quantified, and attempts will be made with manufacturers to redesign for improved reliability. All this is obviously useful for the validation of compressors within hydrogen fueling stations. Mechanical hydrogen compressors are well known to be problematical. There must be significant literature and anecdotal information that can be added to this operational study.
- This project gets detailed operating data into the public forum, but it is limited in the number of operating run hours, especially on those higher-pressure compressors.

- The approach is straightforward: test compressors to understand failure modes, time repair, and identify potential design improvements. It is not clear how much cost share the industry partners are contributing. A separate mass flow sensor should be added to confirm the calculation of the mass flow.
- Although there is a need to better understand the performance of compressors, this is not the way to do it. First of all, at a real station, the repairs will be done in a timely fashion by individuals who have the time and are well trained at repairing the parts. The amount of downtime due to the NREL principal investigator simply not having the time to work on the issue is unacceptable and badly skews the results.

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

This project was rated **2.9** for its accomplishments and progress.

- Significant progress has been made in the evaluation of compressor failure.
- Useful data have been generated so far—but not as many as could be expected so near to the end of the project. Reliability and downtime results seem to be somewhat discouraging. There is a need for increased interaction with compressor manufacturers to solve some obvious reliability problems. It would seem that industrial hydrogen compressors (e.g., in oil refineries) cannot be so troublesome.
- It took too long to complete readiness verification—six months, or a quarter of the project time. There may not be enough time to gather meaningful data on DUT 2–DUT 4 before the projects ends in October.
- There is not much to see in terms of accomplishments. The operating hours are low as a result of a lack of time to do necessary repairs. The failure modes may be due to the person doing the repairs as much as the actual compressor, especially because the time between failures seems to be excessive. What is attempted here could have been better obtained from the technology validation station data. There are also no notable changes made by PDC Machines Inc. as a result of the findings in the study to date.
- The project has only one of four compressors operating continuously. It is not clear how the other compressors, marked with a duty cycle of “as needed,” are being used.

Question 4: Collaboration and coordination with other institutions

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

- Industry cooperation is vital to the project because any identified suggested changes have to be implemented by the manufacturer. The participation of NREL and industry is a good marriage of modeling and industrial process.
- There is excellent collaboration with several companies/organizations.
- There are a few good collaborations, but there should be more with compressor OEMs and industrial users (e.g., refineries).
- Collaboration is limited to only one compressor manufacturer. The lack of extensive collaboration could potentially introduce some bias toward the partner’s equipment.
- It does not appear that PDC Machines Inc. plays a role beyond being a supplier of the compressor.

Question 5: Proposed future work

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

- The proposed future work on the impacts of contaminants is appropriate.
- The proposed work is sound, although the scope will require renewal of the current project.
- All suggested work is needed, but the project is nearing its end. It is not clear that much more can be done to solve the compressor reliability problems.
- Comparison of several different types of compressors would be quite useful. It is not clear what types of compressors the project team has in mind.
- In general, this project should be re-thought.

Project strengths:

- Unbiased, clear data collection always expands understanding.
- The project is well planned and has been conducted according to plans.
- The relevance of the project objectives to current operational challenges is a strength.
- The project provides important in-house test data.

Project weaknesses:

- There are no significant weaknesses.
- The project needs to put results in broader terms, such as mean time between failures, listing of failure modes, approximate time for repairs, and expected annual downtime.
- There is not enough survey of industrial operating data and not enough effort on practical solutions of the operational problems unearthed.
- The limited operational data and run time is an area of weakness.

Recommendations for additions/deletions to project scope:

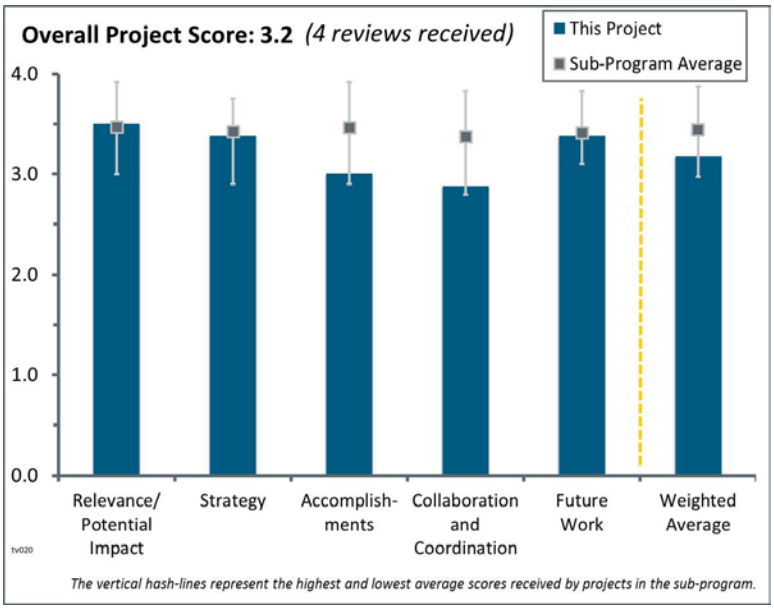
- The hydrogen flow rate should be measured directly as a check on the computed value. More hours of compressor testing and more compressor types should be added. The project should consider testing ionic compressors and Hydro-Pac piston compressors. The team should also reveal efficiency maps for the compressors to enable realistic projections of performance.
- This project must be continued, with acceleration, beyond the project end date. The problems discovered do not bode very well for fueling stations.
- The impact of start-up mode and frequency on compressor performance and failure modes should be added to the proposed work.

Project # TV-020: Validation of an Advanced High-Pressure Polymer Electrolyte Membrane Electrolyzer and Composite Hydrogen Storage, with Data Reporting, for SunHydro Stations

Larry Moulthrop; Proton OnSite

Brief Summary of Project:

The goals of this project are to meet (1) pricing targets for delivered hydrogen through developing advanced polymer electrolyte membrane (PEM) membrane electrode assemblies (MEAs) and water electrolyzers; (2) hydrogen storage targets with advanced composite containers that double usable storage per unit volume; (3) codes and standards requirements for safety, location, footprint, and costs; and (4) performance data needs through collection and reporting of 24 months of SunHydro station performance data.



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.

- It is well known that electrolysis is a more expensive hydrogen production pathway than steam methane reforming at this point in time, but electrolysis has the potential to reduce life cycle greenhouse gas emissions, depending on the source of electricity and the energy requirements. Electrolyzer performance at medium-large scale is a showstopper for this pathway, so it is necessary to transition from research and development (R&D) to commercial scale. However, it is well known that this technology is expensive and will not meet the Fuel Cell Technologies Office's (FCTO's) cost targets. It will be interesting to see whether the new storage tanks make a difference. The project directly tackles four major FCTO challenges for the electrolyzer pathway, which will provide interesting data to engineering models that focus on near-term market penetration.
- The project is well aligned with U.S. Department of Energy (DOE) objectives. Lowering the cost of hydrogen is extremely important to furthering the commercialization of fuel cell technology in various applications. Depending on the application, the high cost of hydrogen is a huge barrier to adoption of fuel cell technology.
- The goal of the project supports the need to build hydrogen infrastructure and explore better, more cost-effective ways to build electrolyzer-based stations that can generate hydrogen on-site and potentially do so renewably.
- It is good to have actual station experience.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.4** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The project includes several advances to potentially lower hydrogen cost. The project is well designed to meet objectives.

- The strategy was good, although the proposed system for hydrogen generation did not meet the energy savings demonstrated in the laboratory. However, the project did validate fabrication of the MEA.
- The project has a very long timeline, which is understandable given its size and scope, but the timeline does raise the concern that the industry or the technology will move beyond the solutions being developed during the course of the project. It is also not entirely clear how broad the benefit of this project will be, beyond helping one company build two stations.

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

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

- Over the last year, the project team has made excellent progress toward meeting goals. The project has contributed considerable data to show improved station performance (for SunHydro station #1 [SH1] with 57 bar hydrogen input).
- It seems that Proton OnSite was able to fabricate, install, and test the proton exchange membrane (PEM) without major glitches. The fabrication and installation of the storage system took longer than expected, but the project seems that it is now on target. Buffer tank optimization was not in the plan because it was not initially identified as a bottleneck in the process. It is good that the team identified the issue. It remains to be seen whether improving the buffer tank will really increase efficiency.
- The project has made progress overall, but the cost projections are still a concern, and it looks like the project will not demonstrate significantly lower-cost hydrogen generation. That is a legitimate outcome to a project, but it will be interesting to see whether any further progress is made with the second station. The development of the composite tubes seems to be a useful outcome.
- There seems to be good progress, but it would be good to have estimated hydrogen costs now, as well as projected costs for higher station deployment levels.

Question 4: Collaboration and coordination with other institutions

This project was rated **2.9** for its collaboration and coordination.

- The collaboration with Air Products and Toyota is essential to test actual vehicles, but Proton OnSite/ SunHydro have all the in-house expertise to carry out this demonstration project.
- The collaborations with partners are as expected for this project.
- The industrial partnerships seem appropriate. It would be good to see additional collaborations with U.S. DRIVE Partnership technology teams, including Codes and Standards and Hydrogen Production. Also, the data collected from this project should feed into engineering models such as the Macro-System Model (MSM) and Hydrogen Analysis (H2A) model to provide early market cost and performance data.
- It would be good to see discussion of how the project is supported by, and will support, automakers that are introducing fuel cell vehicles on the East Coast—at the very least, to show that the stations will be used and will not remain demonstration projects.

Question 5: Proposed future work

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

- The project plan for future work is reasonable. The presenter reports that the second station might be moved from the original planned location to the Washington, DC, area. That could be good for increasing station use and providing a source of hydrogen for new projects in that area. The move could increase public awareness of hydrogen and fuel cell technology by demonstrating applications in an area with a high number of visitors.
- The proposal to build the next station in Washington, DC, rather than Braintree is an interesting one. It would be good to see more detail about the plan for this to ensure that the station will be effectively utilized and will not go the same way as the Shell station that closed down. The reporting on the station activity, especially on costs, will be a critical outcome of this project.

- The proposed future work seems appropriate.

Project strengths:

- This is a good project team with a solid plan to reduce the cost of hydrogen through a combination of increasing efficiency and standardizing packaging of station components.
- The project has been able to overcome some challenges with the technology development and stay on track, and the work has provided useful insights into whether those technologies will make progress toward DOE hydrogen cost goals.
- The project team already has experience from the operation of SH1. Fabrication and installation of components have provided the team with significant experience to transfer R&D to real-world conditions.
- The team has excellent real-world experience in building stations and dispensing hydrogen.

Project weaknesses:

- The project's weakness lies in the possibility that these stations and the technology developed will not end up moving the hydrogen infrastructure market forward when the fuel cell vehicle market is at a critical juncture and needs to find pathways to deploy stations cost effectively and quickly.
- Collaborations with U.S. DRIVE teams could improve. The concept of PEM electrolysis for hydrogen generation is an expensive proposition, which is no surprise.
- The project provides little or no detail about station costs, nor is there a roadmap on how to drive costs down to the $4/kg range.
- The project could benefit from increased station usage to more fully test capabilities.

Recommendations for additions/deletions to project scope:

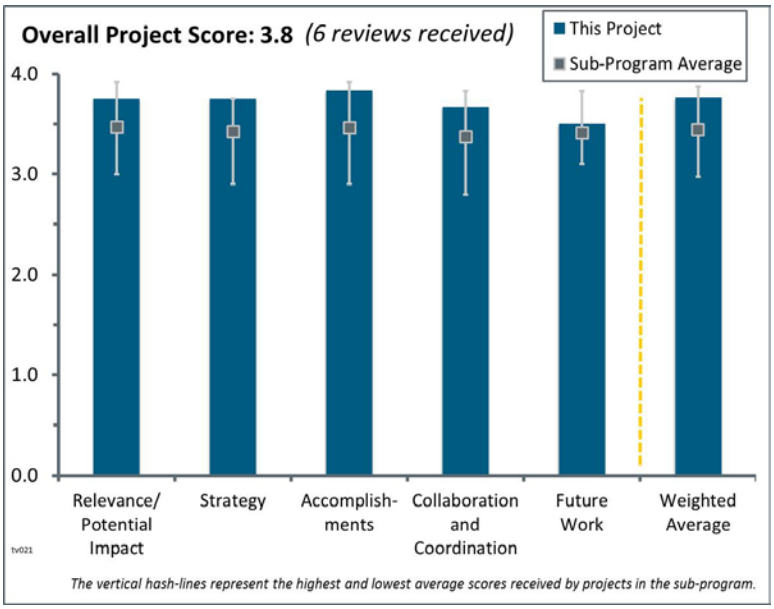
- It would be good to see a scale-up plan for how this technology could meet the need for an application with a larger throughput of hydrogen (e.g., material handling equipment or buses). It would also be valuable for the team to document the lessons learned with siting and approvals to leverage accomplishments and aid the industry with future station deployments.
- The project should add a task to estimate station costs for "N" stations and determine how many stations must be installed to reach hydrogen cost targets.
- There should be additional collaborations with U.S. DRIVE Partnership's Technical Teams.

Project # TV-021: Material Handling Equipment Data Collection and Analysis

Chris Ainscough; National Renewable Energy Laboratory

Brief Summary of Project:

The overall objectives of this project are to assess fuel cell and hydrogen technology status in real-world operations, establish performance baselines, report on the technology, and support market growth by evaluating performance relevant to the markets' value proposition. The National Renewable Energy Laboratory (NREL) will perform an independent technology assessment in real-world operation conditions and performance and report on technology status to fuel cell and hydrogen stakeholders.



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.

- This project demonstrates the success of U.S. Department of Energy (DOE) programs and the real-world performance of systems in different operating environments. It includes measurement of hydrogen infrastructure usage and showcases the first commercial-scale fuel cell vehicle (forklift) and hydrogen infrastructure deployments. The project establishes technology baselines in the field and represents a valuable use of public funds.
- NREL's data analyses, composite data products (CDPs), and detailed data products have significant benefit for fuel cell providers, investors in fuel cell technology, and anyone else with an interest in the progress of fuel cell technology. Specifically, this project provides information that is valuable to any organization that uses material handling equipment (MHE) and desires to investigate the value proposition for equipment powered by fuel cells.
- While the analysis projects do not directly advance technology toward DOE objectives, the projects provide third-party validation, which is very important in convincing decision makers. This project also provides insights into user behavior, which can help guide design and requirements. Chris Ainscough, in particular, brings a good deal of context to the analysis, which increases the value.
- This project has advanced the collective understanding of real-world performance for the fuel cell used for transportation purposes. The data collected in this project will become more valuable as they are referred to and utilized repeatedly going forward.
- The project fits well with DOE's goals and can help to identify optimization potentials for commercialization of fuel cells in key early markets.
- Data reporting is complete, concise, and relatively easy to understand. The project provides an excellent level of detail; it can be used to identify technical progress and areas that need attention.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.8** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The commercialization of fuel cells will occur because of the data collected during this project. The data collected from fuel cell forklifts on a voluntary basis represent incredible leveraging of DOE funds to collect actual data in real-world conditions. As the project comes to a close, the value added from this project will lie in the final written reports. How the infrastructure is used and performs and the 2 million vehicle hours achieved are the heart of the accomplishments. These are very impressive accomplishments. Partners are voluntarily providing outstanding data sets for the total evaluation of data collected directly by the project. Operation times, study of fueling pressure, and fast fuel are all impressive accomplishments.
- The data sets resulting from this project have shown the feasibility of fuel cells for forklifts and the value of hydrogen refueling. The project will try to continue collecting data on American Recovery and Reinvestment Act (Recovery Act) projects that have now ended. The addition of new data sets from non-Recovery Act-funded projects will allow data collection to continue beyond the life of the project and continue to support demonstration of vehicles that are operating beyond their designed lifetimes.
- This project contains large data sets that provide opportunities for further breakdown of the data, leading to deeper conclusions about what might be happening in the field. This was presented to a degree but perhaps could be more extensive. It is difficult to tell because some of the more specific conclusions are not releasable to the general public. For example, breakdown by class would be helpful; this is done internally but cannot be presented. However, it is impressive that suppliers are still voluntarily providing data, which proves they find the compiled results useful. The metrics and interpretation have good relevance, and the project features good discussion of what the classes are and how this affects the fuel cell life, even if all the data are not provided directly.
- NREL's approach to data collection, analysis, and reporting has been continuously refined by the National Fuel Cell Technology Evaluation Center (NFCTEC). All elements of the project are logical, well tested, and efficiently executed. There is a disciplined approach to publication of reports and project results.
- NFCTEC analysis and reporting of real-world operating data of material handling fuel cell systems will contribute to the commercialization of fuel cells in early markets.

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 data show clear improvement compared to batteries —one strength of this project is the people working on it and the context around material handling. It is very clear that the project is not just collecting data from a computer; there is a good deal of background knowledge and interaction in the field. Interesting observations include the fact that lumping the three classes together handicaps some of the forklifts because some are not designed for 10,000 hours, so the average lifetime for the population is decreased—but 50% are making it to 10,000 hours anyway. A full 20,000 hours is still needed for the economic case; it is not clear how many trucks have actually run that long.
- The project results have demonstrated a large payback to end users, with a refueling time of 2.5 minutes, which beats current industry standards and technologies. The inclusion of fueling times and operation times adds value to the data set. The results also show how the demands of MHE are evolving with respect to supporting infrastructure.
- The excellent continued progress in the overall project is reflected in the ninth published set of CDPs on performance, operation, and safety for MHE.
- The partners' cooperation in providing and evaluating the data is a key component for this project's great success.
- Continued updating of CDPs for fuel cell MHE and fueling infrastructure is noteworthy. The presentation slides included information about multiple metrics that are relevant in determining fuel cell progress and performance in MHE use. The substantial reduction in sites being reported on, following the completion of Recovery Act-funded projects, is a concern. The increase in total operation hours was noted. However, the

dramatic decrease in the number of operation hours being reported on per quarter seems to jeopardize the project's continued ability to provide statistically significant results for the MHE portion of the NFCTEC's work.

Question 4: Collaboration and coordination with other institutions

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

- There is some impressive collaboration with at least nine different companies, such as Air Products, FedEx, and Plug Power. The collaboration with these companies provides a high level of results and verification of data.
- The partners are clearly engaged, because they are providing data voluntarily, and they are essential to the project; there seems to be good back and forth for inputs and outputs.
- This group deserves kudos for its ability to negotiate and continue data collection past the original funding provided to MHE deployment projects.
- The project seems well coordinated and has excellent cooperation with relevant industrial partners such as users and suppliers of MHE.
- The project has shown excellent coordination with a variety of partners. The steady cooperation of industry has allowed a significant data set to be built. Other institutions could have been involved toward the end of the project to create new pathways of information dissemination.
- Slide 17 provides a list of data-sharing and analysis partners. It is unknown whether these organizations are all currently reporting. If they are, it is unclear why the number of operation hours being reported on has dropped so much in recent quarters. If they are not, then the appropriate metric for this evaluation criterion is whether current fuel cell providers and fuel cell MHE users return to reporting status.

Question 5: Proposed future work

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

- The project should continue collecting data on fueling behavior, including compressor performance. Allegedly the value proposition for MHE with a 20,000-hour life for a stack is important to reach. So far, the average is only 4,000 hours, with only one that lasted 16,000 hours.
- Future work includes ongoing data collection and analysis, beyond the scope and duration of the project, and a final report to showcase the project's accomplishments. Based on these data, the team could recommend a target for MHE life.
- Every task of the proposed future work is effective and important—especially the plans to access a much larger data set that includes many non-Recovery Act sites.
- Based on slide 19, NREL evidently recognizes the importance of working with industry to access a larger data set. This is viewed as critical to successful continuation of the project.
- This project goes year to year, which forces some ambiguity on future work; however, it would be good to see some kind of survey, workshop, or dialogue on what the partners are getting out of this and what they feel the gaps are—some kind of roadmap for possibilities for future analysis or ways to focus what is tabulated and reported.
- Future target areas beyond just stack life should be expanded.

Project strengths:

- NREL has developed a time-tested, well-designed, and effectively managed system for collection and analysis of fuel cell and hydrogen infrastructure data. The quality of NREL management and staff associated with the project is a project strength. The project presents excellent results and benefits for a DOE expenditure of $70,000–$100,000 annually.
- This is an excellent demonstration of DOE technology that has evolved commercially and successfully. This is a way to measure the performance and value of early hydrogen vehicles and fueling.
- Project strengths include the NREL staff's background knowledge and practical experience with the units, as well as the amount of data available to analyze.

- The voluntary data provided to NREL are outstanding and will continue to allow evaluation of critical MHE. This project does a good job of leveraging the evaluation of voluntary data collected.
- The project's strengths are the excellent research conducted and the close cooperation with fuel cell and hydrogen developers and end users.
- The level of detail is outstanding.

Project weaknesses:

- There has been a major reduction in data being reported subsequent to completion of the Recovery Act-funded projects. This results in questions about the project's ability to continue reporting on fuel cell MHE. Responses to questions following the project presentation indicated that information cannot be provided on the number of sites for which data are being reported to NREL, or on what percentage of total sites with fuel cell MHE operations are represented in the data being reported. No details were provided on DOE and NREL efforts to increase industry participation in future data reporting. Information was not provided to indicate the probability of success for such efforts.
- The project team needs to (1) provide an easy rubric to identify which report covers what topic and (2) match up in the presentation the areas of need to extend stack life.
- There is no assurance of how results will be disseminated beyond being posted on a website.

Recommendations for additions/deletions to project scope:

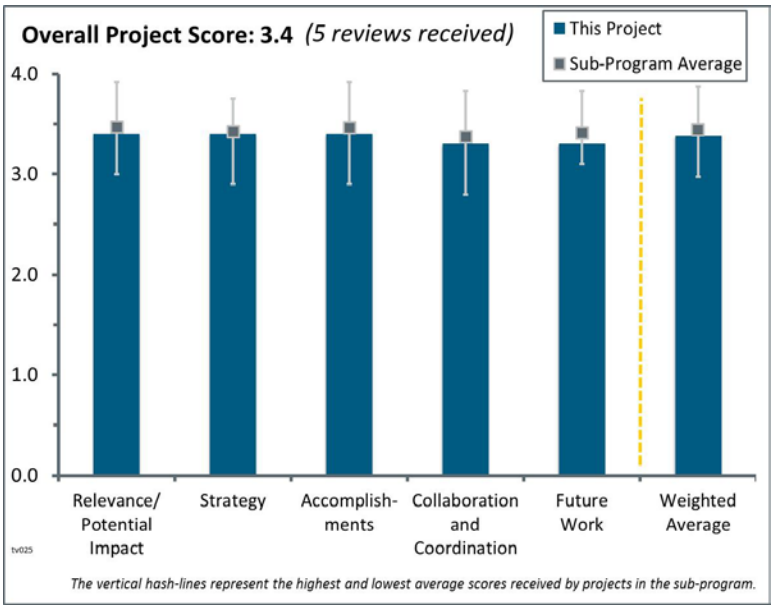
- The only recommendation is to convince companies with fuel cell MHE, fuel cell and MHE providers, and fueling infrastructure providers to participate in data reporting.
- The U.S. Postal Service would be an ideal data provider because the organization is government-funded anyway, so there should be no restriction on providing information. Also, it would be good to have a comparison of fast charge versus fuel cells.
- Continuing the data collection until 20,000 hours of operation should be considered.
- This project should consider how the resulting information will be disseminated. A partner, such as an MHE trade association or publication, could be brought in to assist.
- Technology changes have occurred on dispense pressures. The suggestion is to differentiate the old and new data and then reset the performance metrics accordingly. For example, the higher pressure may require a longer fill time, which would allow the MHE to be operated for a longer time before the next refill. It is unclear whether that combination equals what is being done today or whether the fuel cell product is outlasting the MHE equipment leases.

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

Ted Barnes; Gas Technology Institute

Brief Summary of Project:

The goals of this project are to (1) collect performance data of real-world hydrogen delivery systems through data collection tools installed at California stations, (2) use the National Renewable Energy Laboratory (NREL) Hydrogen Station Data Templates to build aggregated data products and secure confidential data with the National Fuel Cell Technology Evaluation Center, 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 **3.4** for its relevance/potential impact.

- Current and accurate data on hydrogen fueling infrastructure performance and costs is considered to be an important component of a comprehensive, complete fuel cell and hydrogen program. This project is expected to make a key contribution to the hydrogen station data sets developed by the U.S. Department of Energy (DOE) and NREL.
- This project will provide data from five stations that will help in validating the hydrogen infrastructure needed for fuel cell electric vehicles. Data from five stations is a significant addition to the current data set for validating the technology.
- Collecting actual, real-world fueling experience with liquid hydrogen delivery and gaseous hydrogen dispensing is essential.
- The project aligns well with the Hydrogen and Fuel Cells Program (the Program) barriers, namely the lack of real data availability.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.4** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The project approach is straightforward, logical, and readily understood. The distribution of work to be accomplished by the Gas Technology Institute (GTI) and Linde was described well. Acquisition of data that conform with NREL's reporting requirements and templates is vital to project success. This seems to have been taken into account in the data acquisition planning. The presentation would have benefitted from a current timeline, showing the two budget periods and the go/no-go decision point.
- The project is well designed. The timing has been good to ensure that data collection will start when the stations begin operations. Further, there are enough data acquisition systems throughout the station to meet project objectives.
- The approach is well planned and reasonable for meeting goals and addressing barriers.

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

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

- The project has made good progress since the last Program Annual Merit Review (AMR). The charts on slides 7 and 8 are excellent and clearly show the current status of each station. Data are now being provided from the first station, and the second station is nearing completion. The project team is applying the lessons learned from the first station to improve the system and installation of the second station. This will, one hopes, speed up the process for the remaining three stations so that the data can be provided to NREL.
- The progress is on target. It seems that the communication between GTI and the stations has been very positive; the equipment has been installed without major incidents. The real accomplishment will be during the data acquisition process—ensuring that the equipment is well calibrated, works effectively, and provides reliable data without major downtime.
- The progress is good; the project seems to be a well-thought-out and well-implemented data collection regime.
- Slides 7 and 8 aid in quickly understanding the status of the five stations included in the project. However, it would have been helpful to add a date to slide 7 and to include a slide with information on the accomplishments since the previous AMR. After delays in permitting for multiple stations and commencing installation of the first station, there were significant project accomplishments: completion of the West Sacramento site data acquisition system and submission of initial quarterly data. There is evidence of real progress. However, it also seems clear that the project team needs to focus intensively on working with permitting authorities for the final three project sites.

Question 4: Collaboration and coordination with other institutions

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

- The project has excellent partners with well-defined roles.
- It is difficult as an outsider to assert that collaboration has been smooth, but it has been good enough to get the equipment installed and ready for data collection.
- GTI and Linde have significant expertise and experience that can be expected to result in a successful project. The description of the work to be done by each organization, as shown on slide 15, is helpful. Slides 13 and 14 each have some information that is not particularly relevant to the project being presented. GTI and Linde could likely cite other work in their portfolios that demonstrates capabilities more directly related to this effort. A slide showing the partnership/linkage with NREL would be appropriate for inclusion in the package and presentation.

Question 5: Proposed future work

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

- The future work plan is reasonable. It would be good to see all five stations up and running by the end of 2015. The project team should apply early learnings to speed up the process.
- What remains to be accomplished during the remainder of budget period 1 and budget period 2 is clear. For this criterion, however, a projected timeline would be useful, as would a graphic describing the potential impact of continued permitting delays. On slide 18, the statement “Installation at remaining 3 station sites possible before the end of 2015” is rather imprecise. It does not seem consistent with statements made during the presentation about the challenges of getting approvals for station construction.
- The proposed future work is fine. There is not very much to it—just finish installing the equipment in the new stations and start collecting data.

Project strengths:

- Project strengths include the experience and expertise of the project partners, GTI and Linde; coordination with NREL's National Fuel Cell Technology Evaluation Center; and 50% cost share. Excellent results and benefits are anticipated for total DOE funding of $400,000.
- The project is on target, has good technical expertise, and has good communication with stakeholders. It is difficult to improve anything here.
- The project has good partners with proven ability. Data from the five stations add to the performance database and help validate the technology. The project expands the station network for better coverage.
- The project has a good, experienced data collection team.

Project weaknesses:

- The project does not appear to address cost barriers. Partners should document lessons learned for the industry to help with other station installations.
- Permitting issues have resulted in an extension of the project period. The project manager's attention is recommended to anticipate and resolve any issues that could result in further delays in project completion.

Recommendations for additions/deletions to project scope:

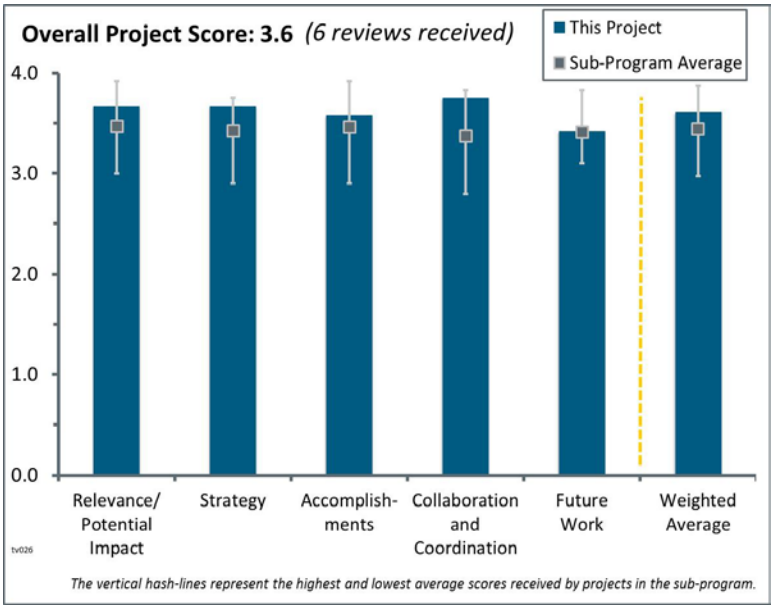
- There are no recommendations.
- The project partners should produce a report documenting the lessons learned to aid the industry in overcoming barriers for future hydrogen station installations.
- Perhaps data could be collected on liquid hydrogen boil-off rates, if the project is not already doing so.

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

Terry Johnson; Sandia National Laboratories

Brief Summary of Project:

The overall objective of this project is to eliminate the need for multiple vehicle test fills by original equipment manufacturers (OEMs) to validate station performance through the use of a surrogate device operated by a testing agency. Development and implementation of the Hydrogen Station Equipment Performance (HyStEP) device will accelerate the lengthy commercial hydrogen station acceptance process and allow multiple levels of testing through a single mechanism.



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.

- The project astutely links the U.S. Department of Energy (DOE) research, development, and demonstration objectives on codes and standards and technology validation in accelerating the validation process of hydrogen refueling stations (HRSs). The current HRS validation process is carried out in a serial fashion by the different OEMs, and HyStEP proposes to design, construct, and validate a device to measure hydrogen dispenser performance in a one-stop-shop manner for all OEMs, saving crucial time. In addition, the device is mounted in a trailer and can thus be moved as new stations are constructed.
- There is sound rationale for government support of this project. Objectives that contribute to the project's relevance include the following:
    - The design, prototype development, and validation of a device that can be used by government and independent testing organizations to ensure compliance of hydrogen stations with codes, standards, and protocols.
    - Achieving a reduction in the time required to measure hydrogen dispenser performance and complete requirements for acceptance of commercial hydrogen stations.
    - Assuming project success, a mobile device such as the one being developed could also be utilized for periodic checks on the performance and standards compliance of operational stations.
- This project addressees a critical barrier to successful deployment of fuel cell electric vehicles (FCEVs): readily available hydrogen infrastructure that can meet the needs of an FCEV fleet. While the project is quite limited in scope, it is addressing a key piece of the puzzle for the FCEV market. Indeed, the limited scope is somewhat of an advantage because it makes it easier to judge the project's success.
- If successful, the project will help shorten station acceptance and commissioning time. By aligning with SAE J2601 and CSA HGV 4.3, the project will also help standardize dispenser testing procedures.
- The project aligns very well with DOE Hydrogen and Fuel Cells Program goals and objectives.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.7** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The project approach/work flow, as presented on slides 5 and 6, is straightforward, logical, and easy to understand. National laboratory personnel, government agencies, hydrogen fuel providers, and a fuel cell vehicle manufacturer are all contributing to the design of the test equipment. The one-year schedule for completion of project work, from equipment design through validation testing at the National Renewable Energy Laboratory and field testing in California, seems demanding (which is positive). However, a case could be made to hold off validation testing of the device until revision of the CSA HGV 4.3 test method is completed later in 2015.
- The project follows a logical sequence of tasks, starting with design development and review (go/no-go decision), fabrication of the device, and testing and final validation in two HRSs (one identified). The team did a good job of analyzing the critical issues and thinking through ways to overcome those issues. The future of the project after funding from DOE expires is advanced; a task force for technology transfer was put in place, and the final trailer will validate stations in California for two years starting in the fourth quarter of 2015.
- This project seems to have been very well designed to tackle this issue in a very short time frame. The timeline has been very aggressive but appears to have mostly been successful, although it seems highly unlikely the project will meet the August milestone. If anything, the schedule should be allowed to slip a small degree if needed because of delays from the fabrication stage, rather than rushing through the milestones needed to prove out this design.
- The project has a well-defined approach. The project shows good flexibility for ease of system modification as new standards evolve.
- The project has been well planned and conducted.
- One challenge is the CSA HGV 4.3 is not finished, but the MC Formula fill is going to be part of SAE J2601—they do not have to be identified separately, but can be.

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

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

- A good amount of work was accomplished in the first six months—project halftime. Initial specifications, components and equipment lists (mechanical and electrical), and the software development are progressing quickly, in accordance with a rather ambitious calendar. The robustness of the hardware is key for the mobility of the device. The team is developing a user-friendly and highly automated software interface so that its operation by technicians is simple. Scheduling may become an issue. The team must catch up quickly following the two-week delay or the final validation at HRSs will be at severe risk. In addition, the concurrent definition of the standard may lead to last-minute adjustments to the device, and there is limited cushion time in the project Gantt chart.
- The accomplishments, as presented in slides 7 through 12, indicate that design considerations, safety issues, equipment options, components, and software have all been thoroughly and efficiently addressed. Backup slides provide additional evidence of significant accomplishments in a relatively brief time period. In compliance with an aggressive schedule, the go/no-go criteria for moving on to device fabrication were met in March 2015.
- The project's milestones, schedule, and status checks are clear and show it is on track. The team has made good use of failure mode, effects, and criticality analysis to identify risks and mitigation options.
- The project has been well designed, and progress overall seems to be very impressive.
- Significant progress has been made, especially on the design and safety evaluation of the device. It is not clear how much progress the team has made on acceptance criteria.

Question 4: Collaboration and coordination with other institutions

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

- The project partners have significant expertise and experience, which can be expected to result in a successful project. The description of each organization's role, as shown on slide 14, is helpful. Powertech Labs seems well qualified to accomplish fabrication of the HyStEP device. Slide 27, a reviewer-only slide, notes that ultimate success of the device will require its acceptance as a "surrogate FCEV" by hydrogen station providers and FCEV OEMs. DOE and the project team are encouraged to engage other stakeholders as soon as possible, as also indicated on that slide. Minimal cost share is provided for this project by industry stakeholders.
- The project includes partnerships with all actors involved with HRSs: an OEM, utilities, an HRS constructor, a regional agency, and a tank manufacturer. That gives reassurance on the project's soundness and continuity beyond the formal contract duration. The design will be public and available at no cost so that similar teams can replicate and use the device.
- The project features an excellent mix of national laboratories, state agencies, OEMs, standardization groups, and private funding.
- The project features excellent collaboration with appropriate organizations/companies.
- Overall, the collaboration and coordination appear to be good. It was concerning that it was not clear if all the automakers were engaged with this process, because only Toyota was listed as a partner, but from subsequent conversations, it appears the other OEMs are involved. Obviously having OEM buy-in is critical.

Question 5: Proposed future work

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

- Slide 16 succinctly and clearly summarizes the steps required to complete the project, the month associated with the completion of each step, and the responsible organizations. In a reviewer-only slide and in his presentation, Mr. Johnson noted that making the remaining go/no-go decision by August 31st is an issue; in response to a question, he stated it will probably occur at the end of September. As long as an extension is at no cost, it may be prudent to synch completion of this project with publication of the revised CSA HGV 4.3 test method. A task force is working on a plan for acquiring and operating the HyStEP device in California beginning in the last quarter of 2015. There is no indication in the presentation that funding will be requested from DOE to support this continuing effort.
- The project team is well aware of the challenges ahead, which mostly relate to the schedule and software. However, the uncertainties on the final version of the standard may push the project outside the initial calendar. The contingency plan is so far to keep the tool "flexible" so that the final development of the standard will be quickly exchanged to the project, because some of the partners are members of the CSA committee. A project extension for a few (maximum of two) months may be needed to get a functional and updated device.
- The project timeline is very tight and is likely to slip. It would seem wise to allow some small slippage rather than rush the testing and validation. Also, there is a need to ensure this device will indeed be accepted by the parties responsible for the safety of the dispenser. Work is being done on this, but it would be helpful to know more about the proposed pathway to having this device used and accepted as stations are being built out. In addition, it is not clear what the plan is if the device simply fails to work in the predeployment testing. It is not clear whether there is funding to go back to work out why, and to possibly make some tweaks with the design or refabricate the device.
- It is not clear whether the project team has a backup station for testing the device at a hydrogen station. Station implementation is typically delayed—Anaheim may not be an exception. The device can also be used for medium-duty FCEV testing with capacities up to 9.3 kg—a DOE-funded vehicle class.
- Completion of the remaining proposed tasks is important, although it may be difficult to meet the tight schedule.
- The team understands the risks with the aggressive schedule.

Project strengths:

- The project team has done an excellent job of utilizing the appropriate standards to design this device and appears to have done a good job of ensuring the device being built will work and be accepted by the OEMs. It has also kept on a very tight timeline, apparently without affecting the quality of outcomes.
- A project strength is that a well-engineered test device for station performance is being worked on by a collaboration of stakeholders. In addition, the design of HyStEP will be made publicly available.
- The experience, expertise, and varied perspectives of the project partners are areas of strength. The project team has a track record of on-time project accomplishments to date.
- Strengths include the project's clear goal and outstanding collaboration. The project team appears to have the right people and skill sets in place.
- This project has been well planned and features an excellent and experienced team to design, manufacture, and test the HyStEP device.
- Project strengths include the excellent consortium and ownership and a good technical approach.

Project weaknesses:

- The project has no significant weaknesses.
- The biggest remaining concern is that it is not clear who bears responsibility for anything that goes wrong with the dispenser at the station. This is important because the responsible party must be comfortable with whether the HyStEP device is acceptable as a means to validate the station. This is being addressed by stakeholders in the FCEV sector, but it does leave open the possibility that this device will not be accepted, no matter how valid it appears from the project tests. The other major weakness involves what would happen if the fabricated device fails in predeployment testing. It is not clear what the plan is if the device simply does not work.
- There is no commercialization plan for the HyStEP device. It is not clear what the demand for such a device is or who would buy it, besides maybe the California Air Resources Board.
- Weaknesses include the potential changing standardization requirements (CSA HGV 4.3) and revision of SAE J2601 with the MC Formula fueling protocol.
- Minimal cost share is being provided by industry stakeholders.
- The schedule is a weakness.

Recommendations for additions/deletions to project scope:

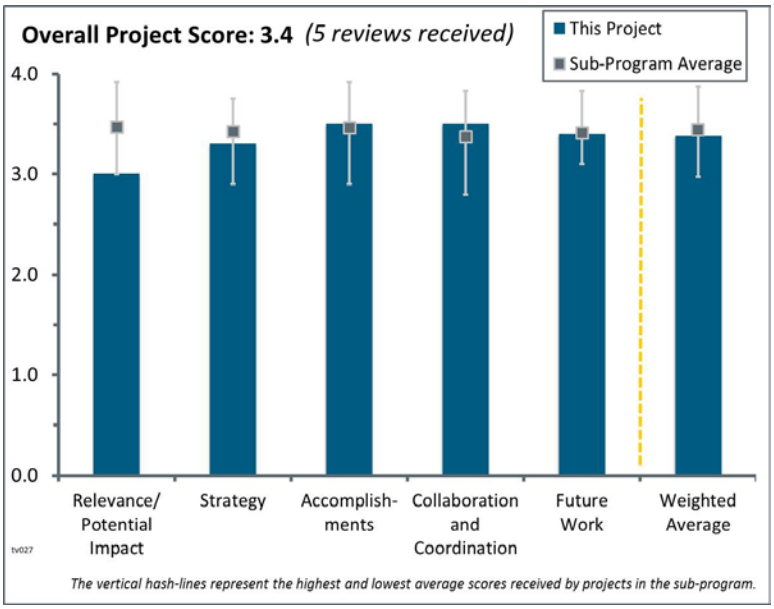
- Funding should be considered toward the building of a second HyStEP device—with one on-road accident, there is no station performance testing device available in the United States. The team should consider how this device can be used without equipment modifications to test stations for fill performance of medium-duty FCEVs with capacity of up to 9–10 kg.
- A case could be made to hold off testing until revision of the CSA HGV 4.3 test method is completed later in 2015. Mr. Johnson stated, however, that completing the project in advance of final determinations on the test method should not be an issue, because personnel working on the project are also involved with the test method development. A reviewer-only slide indicates that flexibility will be built into the device's software. No additions or deletions to the project scope are recommended.
- It would be good to see the plan for ensuring this device is in fact used in station deployment once it is handed over to state agencies.
- This project should be given a contract extension to ensure the delivery of a functional and updated device.
- The team should ensure other OEMs are in the loop regarding project progress, perhaps through SAE.

Project # TV-027: Station Operational Status System (SOSS) 3.0 Upgrade

Ben Xiong; California Fuel Cell Partnership

Brief Summary of Project:

The overall objective of this project is to upgrade the Station Operational Status System (SOSS) data system to improve user interfaces and data quality and to increase data transmission intervals between stations and data sharing capabilities. The SOSS will enhance access to hydrogen fueling station status information as well as the frequency and quality of the data available, ultimately to allow real-time access to stations' operational data.



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 **3.0** for its relevance/potential impact.

- The project supports the Hydrogen and Fuel Cells Program in the area of hydrogen refueling stations (HRS) by making the fuel cell electric vehicle (FCEV) refueling a better experience for the drivers by informing them of the station status (i.e., online, limited, or offline) at both 350 and 700 bars.
- The project addresses the barrier of public acceptance. A mobile app makes it easier to plan for fueling vehicles, which is extremely important for customer satisfaction. The data is consistent across all stations, which makes it easier for a customer to understand where to go for fuel.
- As the number of operational FCEVs grows, the value and importance of readily accessible information on hydrogen refueling availability will increase. This initiative could have a key role in development and refinement of a system that provides accurate and current information for FCEV users. In the overall context of the Fuel Cell Technologies Office (FCTO) Multi-Year Research, Development, and Demonstration Plan, this project will not contribute to achieving FCTO targets and goals for fuel cell and hydrogen infrastructure technologies. However, it could contribute to the more rapid acceptance of developed technology by vehicle consumers, particularly early adopters. It seems that the potential impact of this initiative may be competing to some extent with activities being undertaken in parallel by other organizations (e.g., individual original equipment manufacturers [OEMs]) that have similar and/or related objectives.
- The project will help improve the customer experience when refueling, but this does not seem to be non-commercial work. Automotive manufacturers and hydrogen station owners should be paying for the development of the system. The role of the U.S. Department of Energy (DOE) is to accelerate the introduction of alternative vehicle technologies, but at the point when users need a system to tell them where they can refuel their vehicles, it seems that the vehicles and the stations are already at the commercial stage.

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 approach is reasonable and steps up to add more functions as each phase is completed. The SOSS is well designed and easy to understand—it uses colors and shapes to help users identify a station's status quickly. Integration with all stations is essential for the success of the project. The consistency of the reporting and definitions is excellent.
- The project approach is good. With time passing, the first HRSs are now equipped with data loggers/transmitters to make the app active and representative of the HRSs publicly available (90% of all public HRSs adhere to the project). The project is now focusing on early planning and integration of the additional equipment from design and construction of the new HRSs deployed in the territory.
- The phased approach to the SOSS project is logical and straightforward. The overall objectives of the current Phase 2 (e.g., reporting interval of 15 minutes or less) are clearly stated on slide 4. The presentation did not include details associated with a Phase 2 work plan, a list of work elements, or a time line for completion of project activities.
- The system does address the barriers outlined by the presenter—namely, integration of complex systems and the lack of hydrogen refueling infrastructure performance and availability data. However, much of the information still needs to be put into the system manually.

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.

- Noteworthy accomplishments are documented in the slides and were discussed during the oral presentation. These include the (1) improved user interface (slide 7) and (2) additional information on hydrogen station operational status (slide 8). During his presentation, Mr. Xiong stated that 90% of the operating hydrogen stations (presumably those in California) are providing data to the SOSS. This was confirmed in his response to a question.
- The project managed to gather data from nine HRSs, which accounts for nearly all public HRSs in the United States. All FCEV manufacturers have opened their customer interface for onboard screen integration. The app is functional, easy to use on phones, and includes location features with Google Maps.
- The project is making excellent progress with the development and improvements of the SOSS. Each improvement builds on the base and adds functionality. The team is working with most stations to add real-time data that is automatically updated. This is critical to make the tool useful for drivers.
- It is good that the principal investigators (PIs) were able to get >90% of station owners to participate in the program. However, with so few stations out there, it is important to get everyone on board. That is the only way this project can be effective, particularly for people who live or work near one of the stations that is not participating. The other issue is that the PI mentioned that some car companies will develop their own status system—this indicates that the issue is no longer pre-commercial, and that perhaps station owners will be asked to choose one system over another or to implement more than one reporting system.

Question 4: Collaboration and coordination with other institutions

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

- This project is supported by members of the California Fuel Cell Partnership. As indicated on slide 11, many are providing inputs—such as criteria, requirements, and definitions development—for SOSS design and improvement.
- All HRS operators and FCEV car manufacturers collaborated in the project. The app has the potential to cover all HRSs worldwide, acting as a unique repository.

- The team is working closely with fuel providers, station owners, and customers to develop the tool. Using customer feedback to further improve functionality is a great feature of the project.
- The stakeholder engagement seems adequate.

Question 5: Proposed future work

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

- The project features an excellent plan for future improvements to the SOSS. Real-time reporting is essential for the accuracy of information on station status. Moving to an actual app should also improve functionality.
- The project was successful in demonstrating its technology and economic value. Continuing the project should be mandatory, and continuing the data feed without DOE funding should be considered.
- Slide 13 suggests that significant additional work (Phase 3) will be required to fully achieve SOSS objectives.
    - Slides 14 and 15 outline a number of future work elements and activities. However, specific information is not provided on project duration (for the remainder of Phase 2 and Phase 3) or projected costs.
    - Evidently, the portion of Phase 2 work supported by DOE funds has been completed (see slide 2). During the presentation, there was no mention of additional DOE funds for continued activity.
- The proposed future work includes the logical steps to continue the project—engage new stations, improve the software, etc. The project should also include getting the OEMs and station owners to pay for the system.

Project strengths:

- The project has been supported, through both financial resources and partner inputs, by the members of the California Fuel Cell Partnership. Results from the project should provide useful information for FCEV operators, leading to reduced anxiety about the availability of hydrogen fuel. DOE's expenditure of $155,000 is reasonable, given the expected benefits.
- Creating a mobile website or app to provide real-time station status data is an excellent way to increase station use and customer satisfaction, and to help the industry commercialize FCEVs. The project lead is committed to gaining access to all public stations.
- Project strengths include the system's adaptability to different HRS configuration and its integration to existing HRS equipment, as well as the project's early planning for HRSs under development.
- The project features good engagement of station owners, although this could be improved by integrating 100% of station owners because there are so few stations.

Project weaknesses:

- A project weakness is the lack of specificity (e.g., work plans, work elements, or timelines) associated with the project approach and proposed future plans. The project could potentially be duplicating, or at least insufficiently coordinating with, other initiatives. (This observation is based on a brief discussion after the presentation.)
- To fully reflect the hydrogen coverage available in the area, all public stations should be included. The team needs to do everything possible to gain access to all stations. There may be difficulties in doing this that are beyond the project scope (e.g., adding equipment to a station to allow real-time monitoring).
- The project is focusing on getting real-time data, whereas other interesting information on waiting time for hydrogen availability or the typical busiest refill times may help drivers decide where and when to refuel.
- The system still relies on a lot of manual input.

Recommendations for additions/deletions to project scope:

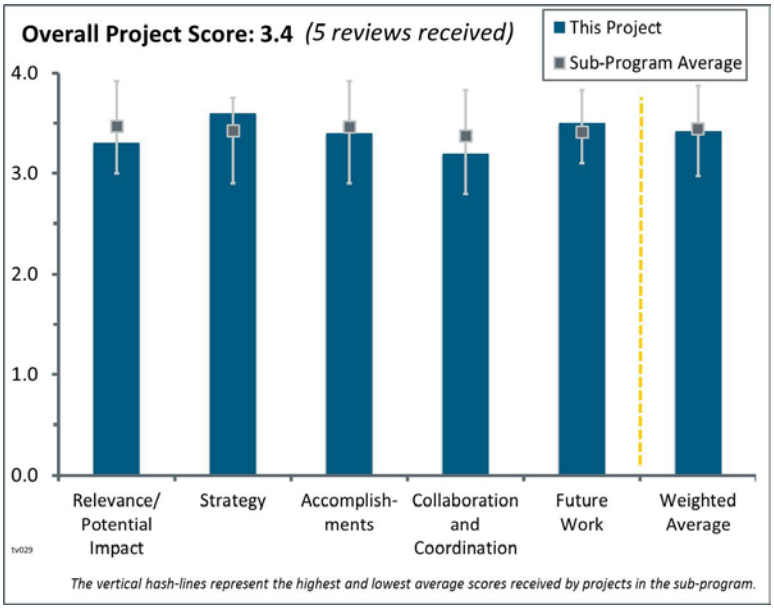
- The team should include customer satisfaction feedback on the app design, the level of information, and the assessment of new data to be included (customer satisfaction and recommendations). The project should also include a count on app usage and daily visits to allow the app's effectiveness to be measured.
- In the event that funding from DOE is requested for further SOSS development, such as Phase III, FCTO should consider funding no more than 25% of the requirement. DOE is one of many California Fuel Cell Partnership members; future SOSS funding should be divided more evenly between government and industry members.
- The project team should address any issues with stations that cannot be added. If new equipment is needed, the team should reach out to funding organizations to cover these expenses.
- The project should get OEMs and station owners to pay for the development of the system and develop an app.

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:

This project is testing a new generation of cryogenic pressure vessels equipped with liquid hydrogen pumps to develop compact, lightweight systems with long-term durability and high refuel density. Cryogenic pressurized storage has the potential to meet challenging U.S. Department of Energy (DOE) goals for improving long-term hydrogen storage while building infrastructure performance data.



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 project certainly supports the Technology Validation sub-program efforts, Hydrogen and Fuel Cells Program goals, and objectives delineated in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan (MYRDDP). In particular, the effort supports research and development on high-pressure gas storage. The project is "hybrid" in nature because it is a combination of efforts supported by technology validation, storage, and delivery.
- Advances in cryogenic pressure vessels that can increase 700 bar (liquid) hydrogen storage for increased driving range while decreasing overall weight are part of the MYRDDP goals.
- This project has the potential to boost hydrogen density to meet DOE targets.
- The project fully supports progress toward DOE goals in terms of onboard hydrogen storage. The MYRDDP targets 5.5 wt.% hydrogen by 2020, while the system under development aims for 9%, thus surpassing the 2020 target much earlier. The impact is hampered because this accomplishment is shared with ST-111, which has roughly the same scope and achievements.
- The project is a logical extension of a storage concept that has been under development for many years. The goals of the project are relevant but may be obsolete if industry (beyond BMW) does not pick up the technology.

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.

- This approach is a very useful attempt to obtain higher tank volumetric capacity than commercial ambient temperature tanks by using cryogenic gas containment. The effort centers on building, testing, optimizing, and validating a newly designed working tank. Work will also be done on an innovative liquid hydrogen pump. In summary, the approach and project results will be useful to DOE and fuel cell electric vehicle (FCEV) manufacturers.

- All the right steps have been taken to ensure the safe development and testing of both the cryo-compressed tank and the refueling facility. The innovative liquid hydrogen pump has been developed outside the project and is being integrated in the dispenser and tank system in the context of this project.
- The project approach is good. Coupling the performance test of the high-pressure vessel and the liquid hydrogen pump makes good use of resources and expertise.
- The project features a nice approach to designing and applying high stress to the thin-lined cryogenic pressure vessel.
- The project approach is logically laid out and has an excellent chance of successful completion.

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

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

- The project team deserves praise for all of the work it did to get the approvals for the cryogenic hydrogen pressure vessel test facility with the American Society of Mechanical Engineers (ASME)-rated containment vessel for non-certified vessels.
- The project is well advanced in surpassing DOE goals. Important testing facilities have been built and are ready for operation for this or future tests.
- Results from testing the 700 bar vessel with liquid nitrogen shows the team has made progress. The team made good use of the mass flow meter with the pump to get data on boil-off rates.
- With the project halfway through its three-year planned duration, the team has made much useful progress and generated a substantial amount of operational data. Cryogenic storage offers 10% volume and 20% weight improvements over conventional compressed hydrogen storage. A very nice test facility has been built at Lawrence Livermore National Laboratory (LLNL). It will surely be useful for other DOE tank testing activities. The safety analysis of the test facility has been very thorough and is a model for the required DOE safety reporting. It would be desirable to have estimates of the increased cost of the cryogenic tank and data on dormant retention time. In response to a question, the principal investigator indicated that a full tank would start venting in about one day (worst-case scenario).
- The achievements to date are good but should be accelerating now that the safety plan and (some) of the project has been completed. While a 100-page safety plan may be comprehensive, there is a possibility that it can create an unnecessarily high bar for others seeking to do similar work. While one cannot be too safe, one can be too cautious and unnecessarily costly.

Question 4: Collaboration and coordination with other institutions

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

- The project features an excellent mix of partners representing vehicle, industrial gas, tank supplier, and national laboratory entities. The Safety Plan review by the DOE Safety Panel, resulting in a request for use as a sample plan, demonstrates the quality work done by the project team.
- The work clearly demonstrates that all of the partners (e.g., Spenser Composites, Linde, and BMW) are working closely together with LLNL. Also, all or most of them were represented at the presentation.
- The collaborative partners on the project are very well chosen for their relevance and ability to contribute.
- There are three important partners: Spencer Composites, Linde, and BMW. They seem to be contributing very well to the overall effort. More vehicle original equipment manufacturer input would be desired, in particular to answer the question of whether the increased volumetric hydrogen density is really worth the added cost and complexity of a cryogenic system.
- No information was provided in terms of any collaboration with institutions outside the current consortium.

Question 5: Proposed future work

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

- Cryogenic cyclability is key and will be tested for 1,500 cycles. Also, the durability of the liquid hydrogen pump will be tested and verified. The proposed future work includes a clear list of valid milestones.
- The future tasks are well defined and have a clear go/no-go decision point.
- The future work outlined is fine and certainly needed. There are some desirable additions that can be made to the planned future work.

Project strengths:

- The project team appears to have a good understanding of the challenges and the tasks needed to overcome these challenges.
- A project strength is the complementary expertise of the project partners that work closely together.
- This is an excellent hands-on testing and safety effort.

Project weaknesses:

- The present effort is to establish hydrogen refueling stations dispensing gaseous hydrogen at 350 or 700 bar. The dispensing of liquid hydrogen would need additional investments that would be difficult to expect in the short term. Niche markets within the hydrogen FCEV (already) niche market would need to be found.
- The convincing demonstration for the need for cryogenic storage is not evident. It is not clear whether 10%–20% is adequate to justify the additional cost and complexity of cryogenic containment.
- A project weakness is the lack of a broader liquid hydrogen research community and stakeholders to share and build knowledge to advance the technology.

Recommendations for additions/deletions to project scope:

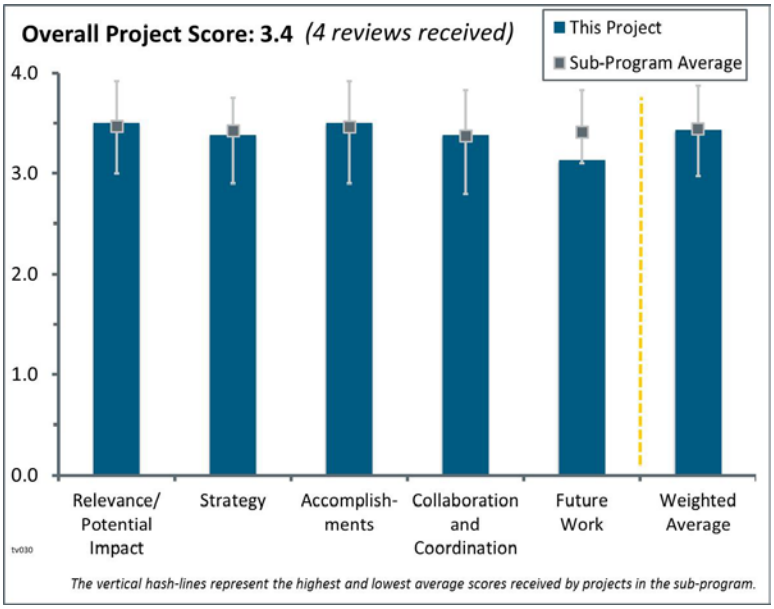
- The differences in scope and achievements of this project and ST-111 are not at all clear; a number of them appear in both PowerPoint presentations. DOE should make sure that work performed is not charged twice (i.e., in both projects). More emphasis should be put on collaborating with institutions outside the consortium.
- The specific performance benchmarks can be more fully specified. For instance, cryo pump degradation over a time period is not specified, and acceptable/anticipated heat leaking into the thinly insulated vessel is not specified. In addition, the cost of the system is not addressed.
- As long as the vessel the project team is preparing to test is not certified by any independent method, standard, or known body, any references to a vessel not certified by organizations such as ASME, the U.S. Department of Transportation, and the International Organization for Standardization should be removed.
- There should be more detailed analyses of economics and pressure excursions during dormancy.

Project # TV-030: Fuel Cell Technologies Office INTEGRATE Stack Test Bed and Grid Interoperability

Kevin Harrison; National Renewable Energy Laboratory

Brief Summary of Project:

The Integrated Network Testbed for Energy Grid Research and Technology Experimentation (INTEGRATE) project studies megawatt-scale electrolyzer systems that can provide hydrogen for numerous end uses as well as energy storage and grid ancillary services. The goal of the project is to improve grid stability and enable higher penetrations of renewable electricity sources.



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.

- Analysis of the new grid that incorporates distributed generation and renewables is very relevant both to the Hydrogen and Fuel Cells Program (the Program) and other U.S. Department of Energy (DOE)/Office of Energy Efficiency and Renewable Energy programs. New communications protocols can significantly advance the United States in this area. This project is also timely because many public utility commissions are rethinking the way that power is generated and transmitted, and they are considering distributed generation, stabilization, and efficiency. The project has the potential to create better understanding of how different systems perform in the new grid environment.
- This short project clearly supports progress toward the Program's goals and the objectives delineated in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan. In particular, it represents a unique effort to adapt large electrolyzers to the grid in an efficient and synergistic manner, thus paving the way for better utilization of time-variable renewable energy sources (e.g., wind and solar).
- The project aligns well with the Program—especially with the research, development, and demonstration (RD&D) needs, which was pointed out at the 2014 Electrolytic Hydrogen Production Workshop—and it has the potential to advance progress toward DOE RD&D goals and objectives.
- This project aligns well with the Program's goals and objectives.

Question 2: Strategy for technology validation and/or deployment

This project was rated **3.4** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The approach is well thought-out. The main idea is to construct a testbed for large electrolyzers (open to industry) and to test electrolyzers relative to variable performance and regulation to the grid. The ability to achieve long-distance communication and monitoring is studied via a connection to Idaho National Laboratory (INL).
- The approach to build up an accessible, open, megawatt-scale testing laboratory seems to be an effective tool for testing the next-generation electrolyzer stacks and for optimizing balance-of-plant components.

- The approaches to performing the work are well conceived and defined.
- The project integrates electrolyzers into grid technologies to enable higher penetration of renewables, grid optimization, and efficiency improvements. It also seeks to improve communications for better controls and data, bringing together electricity, fuels, thermals, and data. While the information passes through utilities, there is no utility partner directly involved to enhance the project's focus and provide feedback.

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 team made excellent progress by building up an electrolyzer stack testbed and establishing a real-time digital simulators (RTDS)-to-RTDS communications network between the National Renewable Energy Laboratory's (NREL's) Energy Systems Integration Facility and INL.
- The testbed was completed in a relatively short period of time, and large (i.e., 120–250 kW) Giner, Inc. and Proton OnSite electrolyzers were tested relative to the variable requirements for grid integration. Long-distance, rapid communication and monitoring were clearly demonstrated via a wide-area network. Many other useful details (e.g., hydrogen purity) were studied.
- Considering this is the first year of the project, it is impressive that the researchers have already demonstrated results in both electrolyzer technology and communications.
- The team has made excellent progress, especially in the development of a communications network.

Question 4: Collaboration and coordination with other institutions

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

- The project seems to be well coordinated and has excellent cooperation with relevant industrial partners and institutes.
- There have been excellent collaborations with Giner, Inc.; Proton OnSite; and INL.
- The project features excellent collaboration with two companies and one national laboratory.
- The project has some current partners within the industry. The researchers will interface with other programs to continue testing RTDS. The researchers could enhance this project by directly including a utility and an Independent Systems Operator to obtain feedback on what these entities are currently experiencing regarding incorporating renewables and what would be useful to them.

Question 5: Proposed future work

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

- The establishment of the communications network and data architecture, as well as the service analysis, potentially has the greatest value outside DOE. While the presentation slides focused on the future electrolyzer work, the presenter described additional RTDS work linking to other DOE projects and a utility.
- The proposed future work is good and important—especially the establishment of a megawatt-scale testbed for polymer electrolyte membrane (PEM) electrolyzer stacks.
- The proposed demonstration of control of the 120 kW electrolyzer stack testbed is appropriate for this project.
- The future work list is fine. It is not clear, however, whether that work can be completed with the remaining contract time. It is perhaps time to get other industrial organizations (e.g., utilities) involved in using the test facility.

Project strengths:

- This topic is closely linked to a very current topic of global interest—how energy is produced and delivered. It therefore has great potential impact. It also demonstrates how both hydrogen and fuel cell technologies are part of a broader clean energy system.
- The project features good, practical orientation. The results should help to stimulate the incorporation of variable alternative energy sources into the grid.
- The project features excellent research and good cooperation with industrial and institutional partners.
- The project has been well conducted and has achieved several significant accomplishments.

Project weaknesses:

- The project has no significant weaknesses.
- It is not clear the extent to which future funds will focus on electrolyzer technology versus data and communications.

Recommendations for additions/deletions to project scope:

- The project scope should include a utility partner and perhaps other entities outside DOE involved with energy generation and distribution. The scope and funding of the project should be increased to provide a broader impact.
- DOE should provide support to NREL to increase the opportunity of the test platform for large-scale testing in the real megawatt scale.
- It would be of value to continue the contract beyond the project's October 2015 close.