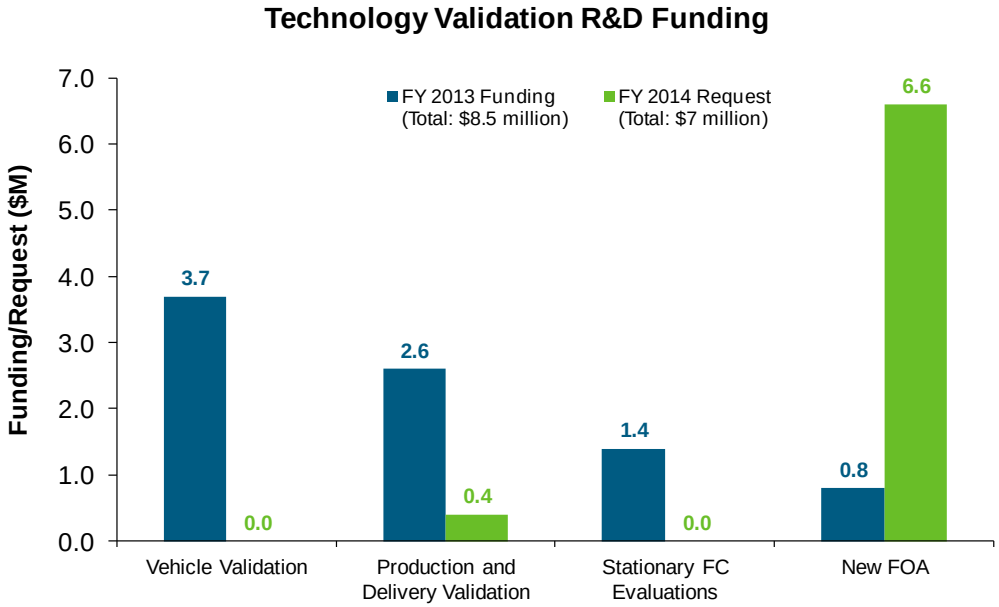
2013 — Technology Validation
Summary of Annual Merit Review of the Technology Validation Program

Summary of Reviewer Comments on the Technology Validation Program:

In general, the reviewers believed the program area was adequately covered. The role of the Technology Validation program within the structure of the Fuel Cell Technologies Office was clearly identified. Progress relating to projects was clearly presented and plans were identified for addressing issues and challenges. The partnership with the National Renewable Energy Laboratory's (NREL's) data collection/analysis team was seen as key to the success of the program's efforts, and to achieving its goals and objectives. Given the high failure rate observed with compressors, reviewers suggested that further attention should be given to their validation. Suggestions were also made for the program to consider the evaluation of 700-bar dispensing, along with related components such as gas pre-cooling refrigeration systems and flow meters. Reviewers also recommended that the program's funding decisions should reflect analysis that identifies technologies capable of providing a significant portion of the demand for hydrogen and that address a robust market for fuel cells.

Technology Validation Funding by Technology:

The Technology Validation program's funding portfolio will enable it to continue to collect and analyze data from fuel cells operating in transportation and stationary applications, as well as from hydrogen production and delivery technologies. Analysis of several new hydrogen refueling stations and fuel cell vehicles in California and the Northeast will be the main focus of the data collection activities. Data from fuel cell buses, forklifts, and backup power systems will continue to be evaluated. The fiscal year (FY) 2013 appropriation was $8.5 million. The majority of the FY 2014 funding is likely to be focused on projects resulting from proposals submitted in response to a funding opportunity announcement that was issued for a variety of application areas. The FY 2014 request of $7 million is subject to congressional appropriations.



Majority of Reviewer Comments and Recommendations:

The reviewer scores for the six Technology Validation program projects that were reviewed had a maximum of 3.8, a minimum of 3.3, and an average of 3.5. A key strength identified by reviewers in all of the Technology Validation projects was the excellent participation from collaborators—this has been critically important to the success of the

projects. Reviewers also observed that NREL's approach for collecting, securing, and analyzing data is well established and trusted by project collaborators.

It was noted that the fuel cell bus data collection project is critical to the wide-scale adoption of fuel-cell-powered buses, providing valuable insights for both U.S. Department of Energy (DOE) project managers and transit fleet operators. It was suggested that performance and reliability comparisons with previous-generation buses, as well as bus deployments already performed or underway in Europe, should also be considered. Reviewers remarked that the results of the stationary fuel cell evaluations should be compared not only to DOE targets, but also to results for other conventional and emerging prime power technologies. In addition, reviewers suggested that it would be valuable to evaluate stationary fuel cell deployments in other states, even if it included only those that provide incentives for stationary fuel cells.

While recycling of hydrogen could be an attractive business proposition for a subset of industrial hydrogen users, uncertainties exist regarding how much of the future demand for hydrogen could be met by this method, and reviewers felt that the potential is limited.

The electrolyzer hydrogen station evaluation project was seen as having the potential to significantly reduce costs for small hydrogen stations utilizing renewable hydrogen via electrolysis. Evaluation of components by NREL was seen as needing more aggressive marketing to industry so that component developers may take advantage of NREL's testing prior to demonstrating their new products with customers in order to assess performance under "real-world" operating environments.

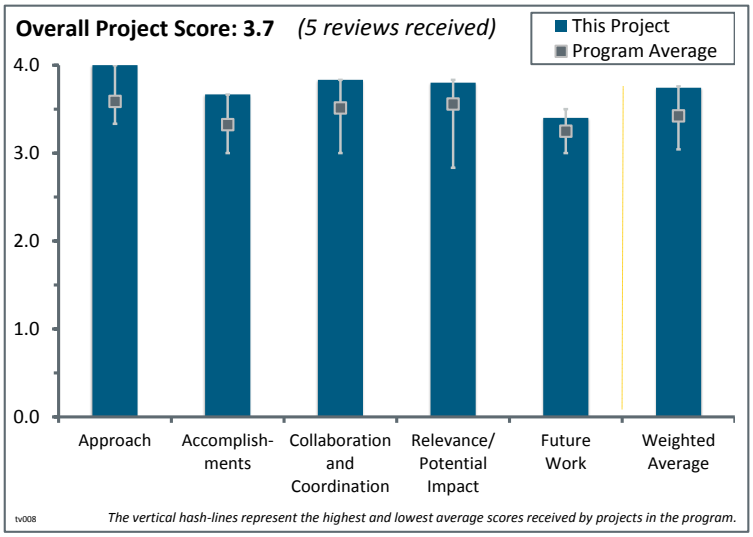
The reviewers believe that NREL's business case analysis of the economic and operating performance of fuel cell forklifts and backup power systems has contributed to the commercial ramp-up of these systems, delivering high value and impact to fuel cell system suppliers and DOE. Reviewers recommended the continuation of the data collection and analysis activities for early market fuel cell (forklifts and backup power) projects, with the purpose of establishing a long-term performance record for these systems and to portray trends over several years.

Project # TV-008: Technology Validation: 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 costs and to document progress and lessons learned on implementing fuel cell systems in transit operations to address barriers to market acceptance. The project collects data from transit partners to develop reports on individual site performance and annual FCEB status reports, including crosscutting analysis and projections for continued success.



Question 1: Approach to performing the work

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

- The data collection project is well designed and organized.
- The National Renewable Energy Laboratory's (NREL's) data collection and reporting are of high importance to the bus program.
- This project is well focused on the key technology validation issues for FCEBs.
- This project has done a nice job of comparing current technology to project work. This is well-balanced work that is well thought out, especially in terms of the inclusion of technology readiness levels (TRLs).
- The approach, as summarized in slide 4, is straightforward and time-tested. It has evolved and proven successful during the years of NREL's working with transit partners to collect data, conduct analysis, and document progress.

Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- Bringing credible TRL levels is a good additional step in terms of the data included in the reporting.
- The principal investigator should consider performing comparisons with past data in order to show the technology's progress.
- This project has made a significant amount of progress in the past year. The fuel economy numbers for the FCEBs are impressive in comparison to the diesel bus numbers. It is unclear why the AC Transit buses are not running in the 2012–2013 timeframe.
- This project has made good progress. If possible, NREL should identify the cause of the large increase in fuel economy and higher availability of the American FCEBs at Sunline Transit (SL AFCB) compared to the earlier bus (SLAT).
- This project has done an outstanding job tracking progress. There are real problems with reliability when first discussing availability; the justification for why FCEB reliability rates were so low did not seem to fully address the problem. If the average availability is 57%, and 47% of the non-availability problem is fuel cell-related, there are some real reliability issues that need further, more open discussion, and not doing so does not help the case for FCEBs.
- Slide 3 provides metrics, targets, and the current status for the performance and cost of FCEBs. These can be understood, and progress toward targets can be determined, at a glance. Slide 21 summarizes progress toward the targets as of 2013. With slides 5–16, an exceptional job was done conveying information about

the bus fleet, for which data have been (and will be) collected and analyzed. Displays and graphs, such as those on slides 8–16, are packed with information. The results during the year since the previous DOE Hydrogen and Fuel Cells Program Annual Merit Review are clearly identified. For relevant metrics, the performance of buses and transit fleets is compared to targets. The reasons for unavailability of FCEBs are detailed and provide valuable insights for both DOE project managers and transit fleet operators. The performance of FCEBs is compared to that of other bus types, including conventional, those with diesel hybrid propulsion, and ones fueled by natural gas. The conclusion stated on slide 14, a 56% increase in fuel cell system miles between road call (MBRC), is a bit misleading. The MBRC for April through August 2011 were evidently higher than that for January 2013 (the most recent month on the chart). An explanation of this apparent anomaly would have been helpful.

Question 3: Collaboration and coordination with other institutions

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

- The key collaborations are in place.
- This project has outstanding team collaboration.
- There appear to be strong working relationships among the stakeholders and NREL.
- NREL's project managers maintain continuous communication with transit agency management, FCEB manufacturers, state and local government agencies, universities, and other organizations with an interest in bus fuel economy and emissions. The project managers maintain contacts both nationally and internationally. NREL's work and approach have enabled it to earn the confidence of many organizations with an interest in advanced bus technology. NREL acquires data, analyzes the data, and provides reports on all fuel cell buses operating in the United States.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

This project was rated **3.8** for its relevance/potential impact.

- This information is critical to the wide-scale adoption of FCEB and will help to accelerate the adoption process.
- The data collected and presented by NREL should be a major selling point to convince other transit agencies to convert to FCEBs.
- The principal investigator has done a great job coalescing the data from various bus deployments. As mentioned previously, the investigator should consider performing performance comparisons with past bus deployments in order to show technology progress.
- For 20 years, since the start of DOE's support for vehicle fuel cell research and development (R&D), transit buses have been an important target opportunity for fuel cells. Given the focus on FCEB development, both in the United States and internationally, and the public resources devoted to buses, tracking the performance and cost is key to determining progress and making decisions about the merits of further development.
- The availability reports provide great data in terms of understanding the performance and identifying components that require improvement, especially since the failures appear to be caused by components other than the fuel cells. It is recommended that more be done to compare the different technologies and, if applicable, also compare new generations of vehicle technology with the previous generation of vehicle technology. This would provide data that show to what extent the technologies are improving from one generation to the next.

Question 5: Proposed future work

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

- The future work is well planned.
- It is essential to keep recording these data to provide a long history of FCEB performance.

- Consider comparing performance and reliability data with other bus deployments already performed or under way in Europe, such as the past Clean Urban Transport for Europe (CUTE) program or the current Clean Hydrogen in European Cities (CHIC) program.
- Slide 19 clearly displays the future plans, which include technology validation for a variety of FCEB types operated by transit agencies in Illinois, Texas, Alabama, New York, Ohio, and Massachusetts, in addition to California and Connecticut. Slide 20 highlights the work to be done during the remainder of fiscal year 2013 and fiscal year 2014. The products will be consistent with the pattern that has been established in prior years.
- It would be helpful if the reporting discussed in more detail the differences in generations of buses to better inform the direction in the performance of the products. It appears the newer generations are performing better than the previous generations. It is recommended that more be done to compare the different technologies and, if applicable, also compare new generations of vehicle technology with the previous generation of vehicle technology. This would provide data that showed to what extent the technologies are improving from one generation to the next.

Project strengths:

- The level of detail in the reports is a strength.
- This is a very well-planned and executed project. This is an excellent set of results.
- As indicated above, buses have been an important target for fuel cell R&D for 20 years, both in the United States and internationally. NREL's approach to data collection, analysis, and reporting has steadily resulted in building solid, productive working relationships with all parties having an interest in advancing bus technology. The bottom line is that NREL's people and systems are the foundation of this project's success. There are multiple reports, publications, and presentations by NREL on the results of FCEB data collection and analyses. Both DOE and the U.S. Department of Transportation's Federal Transit Administration support this project.

Project weaknesses:

- The inability of NREL to access warranty costs continues to be an issue affecting the assessment of progress in reducing the operating cost of FCEBs. This limitation was noted during the presentation.
- The lack of discussion on performance of the newer-generation buses versus the previous-generation buses is a weakness. There should also be data analysis to compare the different technologies among the buses.

Recommendations for additions/deletions to project scope:

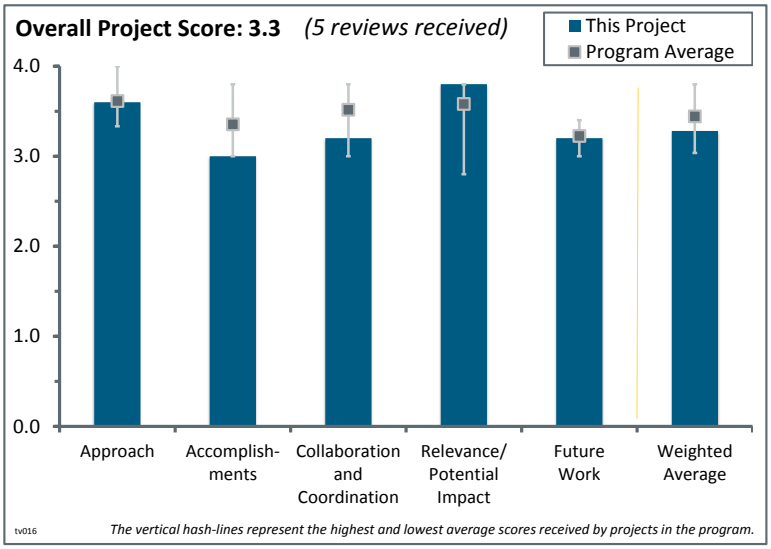
- There are no recommendations. This is a vital contribution to DOE's support of FCEB, and NREL is doing an outstanding job. NREL should just keep it up.
- This project should have generation-versus-generation comparisons of performance and technology comparisons.
- One reviewer did not have any recommendations at this time.

Project # TV-016: Stationary Fuel Cell Evaluation

Chris Ainscough; National Renewable Energy Laboratory

Brief Summary of Project:

The objectives of this project are to independently assess, validate, and report stationary fuel cell system performance under real operating conditions. Validating the performance and cost of technologies in stationary fuel cell systems under real-world conditions supports market growth, product awareness, and technology growth. This project addresses a gap in data for stationary fuel cell systems, leveraging capabilities established through previous research activities.



Question 1: Approach to performing the work

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

- The approach appears to be solid with technical data products, analysis of operation and maintenance data, and close collaboration with system vendors. It would be helpful to split out data by fuel cell technology type, but perhaps the number of installations is too low.
- The technologies have finally moved from pre-commercial to commercial stages of technology readiness. Accordingly, these stationary fuel cells will need to compete on price and value with heat engines and the grid. The availability of data and the reporting of economic and operating performance data should help boost the pace of commercialization for stationary fuel cells.
- The National Renewable Energy Laboratory's (NREL) approach to evaluating stationary fuel cells builds on the systems established, and experience gained, during implementation of similar projects for other fuel cell applications. As shown in slide 6, the approach includes analyses, which resulted in detailed data products and composite data products. Data are received by and processed in NREL's Hydrogen Secure Data Center. Thus, this relatively new addition to the Technology Validation (TV) portfolio takes advantage of previously developed elements of similar projects.
- There seems to be a little more emphasis on how to analyze the study data, as compared to actually acquiring the study data.

Question 2: 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.

- An extensive set of accomplishments is portrayed and documented in slides 9–21. Two types of accomplishments are identified: (1) installation, operation, and results for stationary fuel cells in California and (2) NREL's accomplishments in collecting data and analyzing and reporting the results. Except for slide 19 on installation costs, there is no reference to DOE goals or targets. Thus, the accomplishments generally do not include reporting on progress relative to targets. This is the first review year for this project on systems providing prime power, so it is expected that progress toward performance targets (reliability, durability, availability) will be documented in future reviews. This observation is supported by slide 23's indication of intent to expand project analysis to include maintenance and degradation data. NREL has disseminated results through publications and a website.

- Data have been obtained on the different types of fuels that power stationary fuel cell systems. However, few data are given about the operations of the systems themselves.
- There is a lack of data on stationary fuel cell systems in real-world applications being addressed. There was not much talk about codes and standards. Perhaps the technology is not sufficiently mature or in high-enough volume to make useful inputs for this. The data span a large set of power levels, combined heat and power (CHP)/non-CHP and other various technologies, so it is a bit hard to see trends, draw conclusions, etc. It is not clear if there is any reliability data. This could be a critical barrier/concern and cost issue.
- The data are limited to California. It would be good to bring in other states, even if it included only those that provide incentives for stationary fuel cells. The data also need to be better interpreted because the substantial changes in regulations could have an impact on the cost of the fuel cell deployments. As an example, if the regulations changed from allowing directed biogas to not allowing directed biogas, this change alone could have a substantive impact on the cost of the deployments. This could explain, at least partly, why the costs have been increasing.

Question 3: Collaboration and coordination with other institutions

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

- This project appears to have a solid set of partners including California, vendors, and research support.
- To date, work on this project has been focused on installations in California. More characterization of the interactions and communications with partners would enhance the presentation. It seems that NREL is still in the process of establishing the working relationships needed to achieve robust collaboration and the desired benefits of a stationary fuel cell validation data project. This is supported by slide 22, which indicates that communications are under way with other organizations about agreements for sharing data.
- It would be good to bring in more states as collaborators.
- This project would benefit from more collaboration on the acquisition of the data it needs to analyze. For example, there is no mention of the Bloom solid oxide stationary generation systems that are in place and operational.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

This project was rated **3.8** for its relevance/potential impact.

- There is a need for assessment data on stationary fuel cell power generation.
- Economic and performance data are very important, and this effort should be expanded. The pre-commercial days are over, so stationary fuel cells will need to compete with heat engines and the grid on cost and value.
- The real-world data collection is essential to understanding barriers to greater commercialization, deployment issues, and technical limitations. Thus, high value and impact is delivered to fuel cell system suppliers and to DOE.
- Fuel cell manufacturers and the government have made, and continue to make, substantial investments in the development of fuel cell systems for stationary applications. Customers of fuel cell power systems, supported by government incentives, are investing in installations. Hydrogen infrastructure is not an issue. Given this situation, data collection and analysis of stationary fuel cell installations are vital components of a complete TV portfolio. The DOE Hydrogen and Fuel Cells Program Annual Merit Review (AMR) presentation could include more emphasis on the importance of this work and address DOE's goals and objectives for stationary fuel cell power.

Question 5: Proposed future work

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

- This project should bring in comparisons with heat engines and data from other states.

- This project needs to put more emphasis on developing more sources of stationary fuel cell operational data.
- It would be good to be more specific in terms of the partnerships being pursued/the plans for collecting maintenance and degradation data.
- Slide 23 provides general statements about future plans. Expanding analysis to include fuel cell maintenance and degradation data is key to a completely successful project. In future AMRs, more details on future work plans with some selected milestones and targets for expansion of data sources would make the presentation more complete.

Project strengths:

- NREL's deep skills in data collection, analysis, and reporting are a strength of this project.
- This is the first assessment of installed and functioning stationary fuel cell industrial systems.
- This project explores an important emerging market application area and samples a wide range of system sizes and technologies. This project presents time-trend data, which is very informative.
- The ability to leverage the capabilities established by NREL for its implementation of other technology validation projects is a strength of this project. These instances include the Hydrogen Secure Data Center and the NREL Fleet Analysis Toolkit. The experience of NREL's management and staff in creating and implementing similar data collection, analysis, and technology validation projects is also a plus.

Project weaknesses:

- This project is in the early stages of completion, and there is much more work to be done.
- There are not a lot of data generated yet on stationary fuel cell industrial systems.
- The presentation does not include a listing or summary of DOE's metrics and related targets for stationary fuel cell systems. The performance and cost targets should be identified so they are readily understood and can be compared to the results achieved by current installations. If metrics and targets have not been sufficiently developed, that should be done in collaboration with those responsible for this project.
- It is hard to draw conclusions from the data shown. There is a mix of different technologies and end-use deployments. In slide 18, it is unclear which are CHP installations and if this confounds the data. The other presentation from NREL on forklifts seems to have a greater scope of data collection. It is unclear if this is because of less forthcoming vendors or different data collection methodology. More information on uptime, reasons for delayed starts, and operational issues/limiters would be helpful.

Recommendations for additions/deletions to project scope:

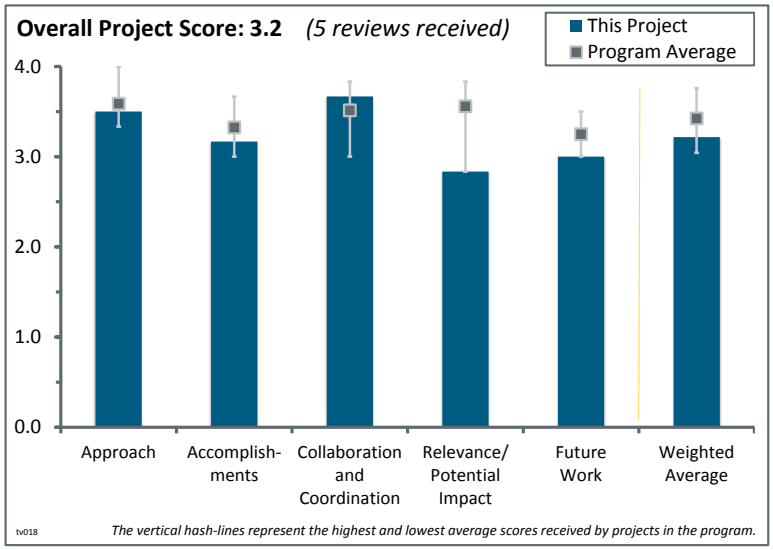
- There are no recommendations.
- This project should bring in other states and other stationary distributed generation technologies.
- Maintenance/operation/performance degradation data are needed for this type of study. Since this project scope of system sizes and technology types is large, it might make sense to focus on deeper data collection on a smaller emerging market segment (e.g., system sizes below 500 kW).
- NREL, in conjunction with fuel cell interests such as the Fuel Cell & Hydrogen Energy Association (FCHEA), should strive to expand this project to include coverage of all stationary fuel cell installations throughout the country. Sufficient funds for this should be provided by the TV program. This project should have an increase in funding (e.g., from $200,000 to $300,000 annually). This project should have a higher priority than activities contemplated in the funding opportunity announcement discussed during the TV overview presentation. NREL should aggressively work to acquire, analyze, and report on fuel cell system performance, maintenance, durability, operating costs, etc. (as indicated in slide 23 on proposed future work). The fuel cell system analysis results could be compared not only to DOE targets but also to results for other conventional and emerging prime power technologies.

Project # TV-018: Hydrogen Recycling System Evaluation and Data Collection

Rhonda Staudt; H2Pump

Brief Summary of Project:

The objectives of this project are to demonstrate the product readiness and quantify the benefits of H2Pump's Hydrogen Recycling System (HRS-100™) by installing and analyzing the operation of eight pre-commercial 100 kilograms per day systems in real-world customer locations. H2Pump will install, track, and report on multiple field demonstration systems in industrial heat treating, light-emitting diode (LED) fabrications, and semiconductor applications. The demonstrations will be used to develop case studies and showcase the benefits of the technology to drive market adoption.



Question 1: Approach to performing the work

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

- The approach is sound and follows logical progression.
- This project just started, but it is off to a good start. It is on time and within budget.
- This is a very good approach for the demonstration of their hydrogen recycling system under real-world industrial conditions.
- A creative approach was described to utilize waste stream hydrogen. The pilot approach and corresponding data collection and analysis are appropriate.
- The approach to the project, as depicted in slides 10 and 11, is straightforward and logical. The discussion of the approach could be enhanced by augmenting it with a chart that shows the time period (from project start or calendar month) during which each task/work element will be accomplished.
- Further developing a system that will reclaim hydrogen from industrial waste is a technology that warrants validation. This project is starting with metal processing industries before moving to the more lucrative, but perhaps more complex, semi-conductor and LED processing industries. Utilizing multiple metal processing industries with various gas components reduces risk by ensuring the H2Pump system has wide utility. It is not clear how sharply focused this effort is on critical barriers. The industrial processes do not appear to be negatively affected by the price of hydrogen. The source development of renewable hydrogen is an important U.S. Department of Energy (DOE) goal. The barrier this effort seeks to overcome (hydrogen infrastructure) does not appear to be much of an issue in the applications it is addressing. A question was raised about whether online monitoring of CO was taking place at the installation sites. The principal investigator (PI) said no. This may or may not be needed. The sequential approach of site visits for gas sampling, system build, installing and commissioning, data collection, and monitoring and operation/maintenance is sound.

Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- The project has figured out where to deploy the system and is on schedule.
- The project began in January 2013, and three site installations have already been established.

- The progress to date is good, especially considering this is a new project that began a few months ago.
- This project would be outstanding, but the go/no-go in April is past due, and data collection is behind schedule. The range of installations is impressive, from LED fabrications to reduction furnaces and specialty mills. This adds weight and credibility to the technology pilot.
- After only four months since the start date, it is difficult to render an opinion on progress, but the project appears to be off to a good start with Ulbrich Systems almost in place and systems three and four 100% complete. The data collection has begun, and the PI stated that the H2Pump system has had difficulty getting data automatically.
- The installation and commissioning of three systems, within four months of the official project start date, is impressive. With the benefit of funding from other sources, H2Pump was evidently prepared to move quickly on accomplishing project tasks. It would have been preferable for Task 1, data collection and reporting tool, to progress as expeditiously as equipment installation and start-up. The data plan, and collection of data from operating units, is on the critical path in terms of achieving Technology Validation (TV) program objectives. Providing background information on H2Pump's history and its technology, at the beginning of the presentation, was helpful for the reviewer.

Question 3: Collaboration and coordination with other institutions

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

- There are very good collaborations with the industrial partners.
- There appears to be a solid team with analysis, engineering, and customer hosts in place.
- The collaborations with demonstration sites are very good. This is critical for completing work and collecting data needed for assessment.
- This project has great collaboration with its partners. They already know where they will be deploying all eight systems, and they know why they need to install two in Rome, because the system demand is huge.
- The working relationships with the metals industry host sites seem to be well established and productive. Cooperation and commitment of the host site companies are key to the project's success. The roles of the engineering firms listed on slide 17 were not discussed or identified during the presentation. Slide 12 states "select a supplier" in the context of Task 1. The involvement and roles of those associated with Task 1 were not sufficiently clear from the slides or presentation.
- The New York State Energy Research and Development Authority (NYSERDA) involvement is important. This could encourage the use of more reclaimed hydrogen processes. National Renewable Energy Laboratory (NREL) involvement in data collection will ensure it is an objective and intellectual-property-protected data dissemination product. Twelve to eighteen months of data collection appears sufficient. Because this is a single supplier of a single application, it is questionable how much information NREL will be able to share without giving away the source. The industrial partners cover multiple industries.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

This project was rated **2.8** for its relevance/potential impact.

- This project needs to do a better job of explaining the cost per kilogram of hydrogen supplied.
- This project is aligned with DOE's goal of reducing hydrogen costs and using renewable sources. This appears to apply to industrial use only. It is unclear how the lower cost for this use will affect the cost of hydrogen overall.
- The recycling of waste hydrogen from various industrial operations can have a significant impact on the cost of hydrogen for fuel cell applications, provided that enough waste hydrogen is recovered economically.
- It would be good to try to quantify or estimate what kind of overall impact this could have, estimating the number of sites and some percentage of penetration, for example. It is not clear if there is any possibility of integrating the hydrogen stream into an onsite fuel cell system.
- The principal investigator estimated annual projected customer savings of about $40,000, but based on the responses to reviewer questions, this appears to be a very rough estimate and will need to be validated as

part of this effort. Given the significant need for electricity to conduct this hydrogen reclamation process, this may have limited utility in areas of high electricity costs (e.g., California). The local area is home to a growing semiconductor industry, a significant user of industrial hydrogen, and success in this effort could lead to large sales of this application. There may be other renewable hydrogen reclamation technologies informed by this effort.

- Recycling hydrogen could be an attractive business proposition for a subset of industrial hydrogen users. However, no information was provided on how much of our future demand for hydrogen could be met by recycling hydrogen-rich exhaust/waste streams. The reviewer estimates that the potential is limited. This is not a criticism of the project and how it is being conducted, but an issue about whether the technology's potential as a source of hydrogen is sufficient to justify priority in terms of DOE support over other projects. It would be helpful to have information on the cost per kilogram of pure hydrogen produced by H2Pump's technology. This is a common metric used by DOE's Fuel Cell Technologies Office.

Question 5: Proposed future work

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

- This is a good plan that follows a logical progression with checks in place.
- The researchers have just begun on the project, and they need to complete this before this question becomes relevant beyond the current scope of work.
- The proposed future work looks reasonable. There should be a better description of the new sites to be established, and also a more detailed account of the future timeline.
- It is assumed that there will be a fuller and more detailed cost-of-ownership model and a fuller description of what type of pre-treatment or site-specific engineering work or costs are required in next year's update.
- There seems to be an inconsistency between the information on slide 10 (Task 1 is 30% complete) and that on slide 16 (database online in April 2013). During the presentation, the reviewer concluded that the months shown on slide 16 are not accurate, and that the work cited on the slide will be completed later than shown. For example, the statement was made that the go/no-go decision meeting has not yet occurred.
- This question is not applicable, as this project is just getting under way.

Project strengths:

- This is a very well-focused project.
- There is good project management and oversight.
- This project addresses renewable hydrogen and creates it onsite. It is too early to discuss the strengths of the project execution effort.
- The goal of lowering hydrogen cost using a renewable source could facilitate adoption of hydrogen technology.
- This is an innovative technique that appears to be cost-effective. This project has diverse pilot sites and good partnerships in place.
- This project involves a contractor (H2Pump) with an entrepreneurial team committed to development and commercialization of a technology that represents a different and possibly unique approach to providing hydrogen for industrial customers. Other strengths include the willingness of companies to provide host sites for installation of H2Pump's equipment and to participate in data collection; participation of NREL, with its expertise in data collection, handling and analysis; cost share and support from NYSERDA; acquisition of "real-world" operating data; and use of those data in preparing case studies for reference by companies that could benefit from the H2Pump technology.

Project weaknesses:

- There are no weaknesses.
- The cost data need to be more transparent.
- It is too early to evaluate project execution impact.
- It would be good to see how this source of hydrogen could be used for other applications.

- This project is a bit behind schedule, and this was acknowledged. Some plan to recover the schedule is needed.
- Ideally, a data collection plan should have been completed and approved prior to a go/no-go decision on proceeding with the expense of site preparation and installing equipment at multiple sites. (The validity of this comment could be influenced by a better understanding of the extent to which particular tasks are being funded by DOE, and whether tasks other than data collection would be done solely with funding from other sources.) Insufficient information on data collection plans, data elements, and related metrics was provided, suggesting that significant work remains to be done on Task 1, which is vital to project success.

Recommendations for additions/deletions to project scope:

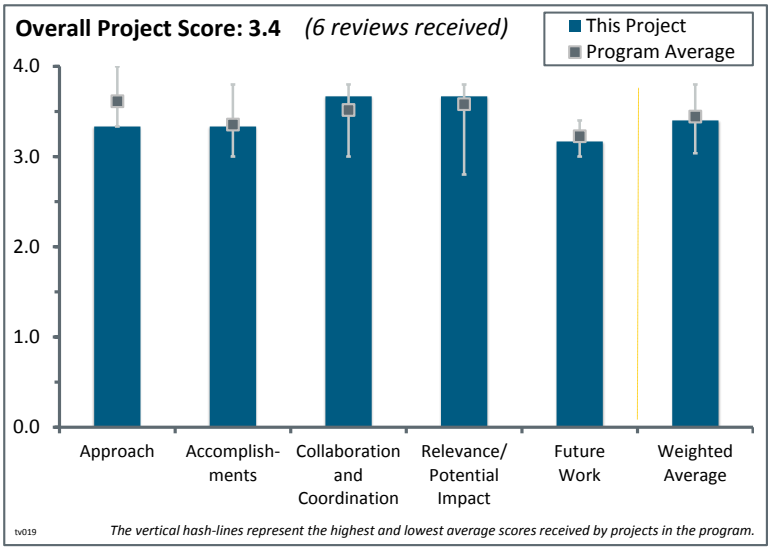
- The cost per kilogram for hydrogen should be supplemented by each system.
- More non-proprietary descriptive information about the hydrogen recycling system would be useful.
- The addressable size of this segment in industry or volume of hydrogen recovery is unclear. It would be very good to get detailed customer feedback and impressions next year; the PI is probably planning to do this.
- It is unclear if DOE has analyzed how much hydrogen could potentially be recycled/re-used. It is assumed that the amount is small compared to the current hydrogen demand and very small compared to the projected demand in a "hydrogen economy." If this analysis has not been done, it should be considered for inclusion in the analysis program and accomplished before more funds are committed to hydrogen recycling projects. While H2Pump's technology is interesting and has a possible benefit for a niche industrial market, DOE's funding decisions should reflect analysis that identifies technologies capable of providing a significant portion of the potential demand for hydrogen.

Project # TV-019: Hydrogen Component Validation

Kevin Harrison; National Renewable Energy Laboratory

Brief Summary of Project:

This project provides fully integrated system-level testing to address barriers that include a lack of performance data, instrumentation, sensor accuracy, technology transfer, and integration with renewable sources including wind and solar. The project performs operational reliability and performance testing, advances instrumentation and technology transfer, and focuses on system integration and advanced grid integration. The National Renewable Energy Laboratory (NREL) works closely with industry to understand and improve compressor reliability and hydrogen mass flow limitations and to exercise NREL's existing test platform.



Question 1: Approach to performing the work

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

- This project has utilized its funding well. These technologies are being tested and moving closer to market reality. Keeping the costs down on new compressors and running electrolyzers through rigorous testing and data collection are essential. It is a first-come–first-served basis in terms of what equipment is tested. Readiness safety and hazard operations on reliability are important to this project.
- The approach enables equipment, such as compressors and electrolyzers, to be tested while operating within an integrated hydrogen production, storage, and dispensing facility. The integrated facility allows the National Renewable Energy Laboratory (NREL) to efficiently test selected components and gather data on their performance at a relatively low cost.
- The approach is very good; it appears to be very customer-focused, flexible, and highly capable of testing and validation. The capability to provide unique testing is a real highlight. It is not clear how much the approach is going to support incoming requests versus building capacity for key or emerging test validation areas. Doing more of the latter with U.S. Department of Energy and stakeholder input could perhaps be a further enhancement of the capacity.
- The strategic direction or focus of the project needs to be clearly defined and articulated. The overall effectiveness could be significantly improved if results and efforts were coordinated with data from existing deployments.
- It would be helpful to know more specifically what work at the integrated test facility is funded by the Technology Validation program. The presentation and responses to questions did not address sources and the total amount of funds associated with the various activities identified in slides 4 and 5. That information would provide better awareness about the leveraging of the DOE contribution.
- The strategic value of this effort to the DOE Hydrogen and Fuel Cells Program is indirect but valuable. The funding provided by the Program to NREL enables this facility to be used to do testing for the fuel cell and hydrogen industry. NREL's testing and analysis is a valuable service to the companies that provide their near-commercial products to NREL for testing. This service should accelerate commercialization and the robustness of commercialized products. All this being said, it would have been good to have seen more cooperative research and development agreements (CRADAs) with companies to test their products. This is the primary reason for a "good" rating versus an "outstanding" rating. As a suggestion, NREL testing could

be a strategic step prior to the products being demonstrated in real-world operating environments by the customers.

Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- More CRADAs would have been good.
- This project is collecting data on equipment performance. Compressor reliability is an issue. The researchers are running electrolyzers in variable modes. They are running a variety of electrolyzers and comparing their performance and reliability.
- This project has very good flexibility and capability. It appears to be somewhat unique in this output. Technical capability and the span of various components being tested appear very strong. The output of this work can be an essential part of market validation and perhaps the basis for a larger effort for flexible and responsive testing and validation.
- Slides 6 through 12 provide evidence of excellent results and the ability of the test facility to generate useful data and test results. Accomplishments include lots of data and the results of data analysis. While slides 6, 10, and 11 provide a sense of progress in achieving test results, for this reviewer, complete understanding of the information contained in the slides requires more than a 30-minute session. Discussion in response to a question on slide 6 highlighted the need for work on simplifying/clarifying the message. On slide 11, a succinct statement on the practical conclusions and implications of the work accomplished would be useful. The reviewer assumes that not all the accomplishments presented (e.g., slide 12) have resulted from the $265,000 provided to the project by the Technology Validation program. If this is correct, it would be nice to identify the specific accomplishments linked with the DOE project being reviewed. In preparing for the next review, attention should be given to comparing results (for example, on compressor reliability and performance) with DOE goals and addressing indicators of performance progress.

Question 3: Collaboration and coordination with other institutions

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

- The collaborations are good; it would be good to see more of them.
- The project has good collaboration with various electrolyzer companies and compressor manufacturers.
- It is amazing to see how many CRADAs are involved; it is excellent. There should be more of these.
- NREL could expand components to other manufacturers and types; for example, they should seek to test conventional piston compressors.
- Again, the flexibility of collaboration and the demonstrated partnership with industry, utilities, universities, and CRADAs are impressive.
- Collaborations that have been established provide evidence that some manufacturers of key hydrogen system components have confidence in working with NREL. They have determined that using NREL's facility, testing capability, and analytical expertise is beneficial and cost-effective. Giner Electrochemical Systems is mentioned as a partner in slide 2, but it is not shown on slide 13. Providing summary information on the value of equipment donated and time committed by collaborators could move the mark for this criterion to "outstanding."

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

This project was rated **3.7** for its relevance/potential impact.

- NREL's component validation is a highly valuable strategic tool.
- The potential impact on early market adoption for these technologies is significant. Only through testing will anyone know the potential market application.

- The potential impact and relevance can be significant since few of this type of capability exist, and this type of CRADA agreement can certainly be a model for public–private partnership moving forward.
- The work around improving compressor reliability is important to improving the growing number of hydrogen fueling stations. It would be great to see more linkage with stations deployed in both problem analysis and problem resolution.
- For a relatively small expenditure, this project provides valuable information leading to better understanding of issues related to the performance of hydrogen system components. A particular focus is on compressors. Acquiring and analyzing test data on compressors can help determine progress toward related objectives, as well as priorities for research and development attention. The slides/presentation should include a few relevant DOE goals that are associated with the project's validation activities.

Question 5: Proposed future work

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

- Having large-scale electrolysis up to 1 MW is a great idea.
- Compressor reliability is a key area and appropriate to highlight for future work.
- Testing and validation of compressor technology, design, and materials seem to be an appropriate target on which to focus future efforts supported by the Technology Validation program. This is consistent with the information in slide 14.
- It appears that future work is driven by customer requests. A more proactive approach could be to develop a strategic plan and identify focus areas; this would make future planning easier. This would also make decision making easier.
- It would seem that an aggressive recruiting effort aimed at industry would bring in more CRADAs. The recruiting could target companies with products in the near-commercial stage of the pipeline. It could also target products or components where improvements of performance are critical to the successful implementation of the project plan. It may be desirable to more aggressively market to industry so that industry can take advantage of NREL's testing prior to demonstrating the new products or components with customers in order to assess performance under "real world" operating environments.

Project strengths:

- NREL's testing and reporting capabilities are a strength.
- This project has good collaboration and excellent partners.
- This project has great facilities and experience with renewable hydrogen equipment.
- Uniqueness, flexibility, potential to scale up scope, and the number of components under testing are good. The fully integrated system-level testing is also a strength.
- NREL's fully integrated hydrogen system test facility, which enables efficient testing of components with multiple types and designs, is a strength. NREL has significant experience in utilizing mechanisms, such as CRADAs, to structure and implement agreements with industry for the testing of equipment. NREL has built credibility with equipment manufacturers through its operation of the integrated test facility, as well as its capability to handle and protect data.

Project weaknesses:

- This project has no weaknesses.
- This is not necessarily a weakness, but it would be helpful to poll stakeholders or have an industry listening session to better focus key activities and capabilities for testing and validation.
- This project needs to better position NREL testing as a strategic step toward product commercialization. The concept would be a "pre-commercial" demonstration in a controlled environment as an intermediate step prior to a demonstration at a customer site.
- No evidence was provided to show that project results are being used to track the progress of hydrogen system components in terms of achieving specific DOE goals and objectives. This is likely being done, but the linkage should be clear as part of the DOE Hydrogen and Fuel Cell Program Annual Merit Review. If the objectives are not a focus of the project, they should be.

Recommendations for additions/deletions to project scope:

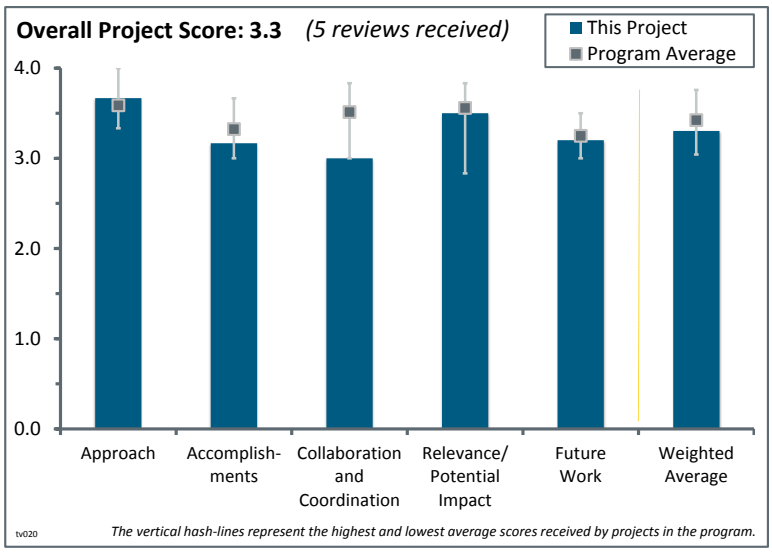
- This project should publish the results widely.
- Accelerated testing at the component/systems level and/or related data collection or development of testing methodology is critical and an area of focus.
- If possible, NREL should seek to test the Linde ionic compressor, which might significantly reduce the compression energy required and possibly achieve lower cost and higher reliability, which is the main motivation to get third-party validation of ionic compressor reliability.
- In the reviewer-only slide on publications, it was noted that the most recent publication listed was done in 2010. If there have been no publications on work related to this project since 2010, attention should be devoted to disseminating information on results of the testing/validation work. If there have been publications since 2010, the list should be updated.

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

Larry Moulthrop; Proton OnSite

Brief Summary of Project:

This project seeks to validate an advanced high-pressure polymer electrolyte membrane (PEM) electrolyzer and composite hydrogen storage for SunHydro hydrogen stations, addressing costs, hydrogen storage, codes, and lack of hydrogen refueling station performance data. The project validates hydrogen fueling infrastructure performance gains of an advanced 57 bar PEM water electrolyzer, next-generation 87 MPa composite storage tanks, and skid-mounted compact refueling component arrangements with an updated SunHydro #1 station and a fully containerized SunHydro #2 station.



Question 1: Approach to performing the work

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

- The approach for each task is solid.
- The project is utilizing storage vessels, compressors, and fuel cell stacks that the project has worked on at a smaller scale. The researchers are trying to keep the footprint small and create a container with the goal of making it portable. SunHydro #1 has been successful. They hope to increase the efficiency of the PEM stack. They also have composite storage tanks they are validating from 280 to 870 bar. The compressor is also being tested. Their unit, the SunHydro #1, looks good. They are going to instrument the system and start collecting data up to 24 months, which will include reliability data. Sunhydro #2 will be installed in 2013 in Massachusetts.
- The potential to save up to 12 kWh/kg by utilizing 57 bar (vs. 30 bar) pressure and doubling the usable storage per unit volume could help lead to competitively priced hydrogen utilizing electrolysis. The advanced composite hydrogen storage that has been identified by DOE is a key enabler. The effort provides two years' worth of station data that can inform codes and standards as well as performance. Novel component arrangements enable a maximum location of equipment away from the classified zone with firewalls in between. This effort will validate voltage reduction at full scale. Part of this effort includes participating in NFPA 2 revisions and "bringing authorities having jurisdiction (AHJs) onboard" throughout the process to inform codes and standards and speed the permitting process.
- The investigator should assess cost and determine what cost reductions are needed to meet hydrogen cost targets.

Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

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

- Progress is as expected, considering it is a new project that began a few months ago. The tasks appear to be on schedule.
- The project has been recording data for two years and hopefully will publish these data in the future. The researchers are building a new cell stack, and they have an ambitious goal for the next-generation fuel cell stack.

- Cost is probably the main obstacle in deploying electrolyzer-based fueling stations. More emphasis needs to be placed on cost-reduction efforts.
- The project is only 12% complete, so it is difficult to ascertain progress this early in the effort. Combining the two projects into one is a good idea and will eliminate administrative redundancies. Long-lead-time materials have been ordered. Ten fuel cell electric vehicles (FCEVs) have been secured from Toyota and will be used as part of the demonstration.

Question 3: Collaboration and coordination with other institutions

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

- This project has good collaborations with component suppliers and users.
- For SunHydro, Toyota has provided 10 FCEVs. Air Products is providing some components also.
- Ideally, this evaluation should be expanded to include other fueling stations, organizations, and technologies.
- Working with Air Products brings expertise on hydrogen storage and dispensing technology to the project. Partnering with Toyota, which has a planned FCEV commercialization launch in 2015, increases the chances of a successful implementation. SunHydro LLC, a builder of hydrogen fueling stations, rounds out the project team nicely.
- SunHydro LLC and Proton OnSite share the same ownership. This could restrict the transfer of technology to other electrolyzer and hydrogen station original equipment manufacturers (OEMs). Data will be sent to the National Renewable Energy Laboratory (NREL) Secure Data Center. Having NREL be part of the team will enhance objectivity and transparency in reporting of results.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

This project was rated **3.5** for its relevance/potential impact.

- This project is trying to address hydrogen costs and reduce energy usage with some measured success.
- This project fits well with DOE's goals and is expected to lower costs with improved and more efficient components. Data will go into existing DOE analysis for hydrogen stations, which builds on the current body of knowledge and allows further comparison to other sites. A station with a smaller footprint is good and could speed up the process of installation and approvals at multiple sites.
- The potential of this effort is to speed up AHJ approvals by packaging a fueling station in an ISO container with 24 months of data to validate its safe operation. The potential is for significant reduced costs for small hydrogen stations utilizing renewable hydrogen via electrolysis. With only a 50% increase in hydrogen tubes, Task 3.0 (composite storage) could realize dispensing capacity increases from 16 kg/hr to 30 kg/hr. This would allow more vehicles to be refueled at a single station and lower the cost of hydrogen.
- The cost and price need greater emphasis.
- The relevance and impact are limited since this project evaluates one design and one set of components (e.g., just one type of hydraulic compressor and one electrolyzer).

Question 5: Proposed future work

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

- This project is on schedule.
- The future plans are sound and well outlined.
- This question is not applicable, as this project has been underway for only approximately five months. It is premature to discuss future work.

Project strengths:

- This project has solid project partners.

- This project improves efficiency to lower the cost of hydrogen. A station with a smaller footprint could be useful in multiple locations where space might be an issue. This will help with the ability to increase the adoption of the technology.
- This project is renewable hydrogen-oriented and addresses technology barriers with a logical plan to overcome them. All the barriers appear to have a solid technical approach toward achievement. It is too early to make a judgment on project execution. The emphasis on involving AHJs from the start is indicative of an OEM (SunHydro LLC) that wants to commercialize the results of this technology immediately upon completion of the effort.

Project weaknesses:

- There are no apparent weaknesses, but the project is too new to determine this at this point.
- It is too early to make a judgment on project execution.

Recommendations for additions/deletions to project scope:

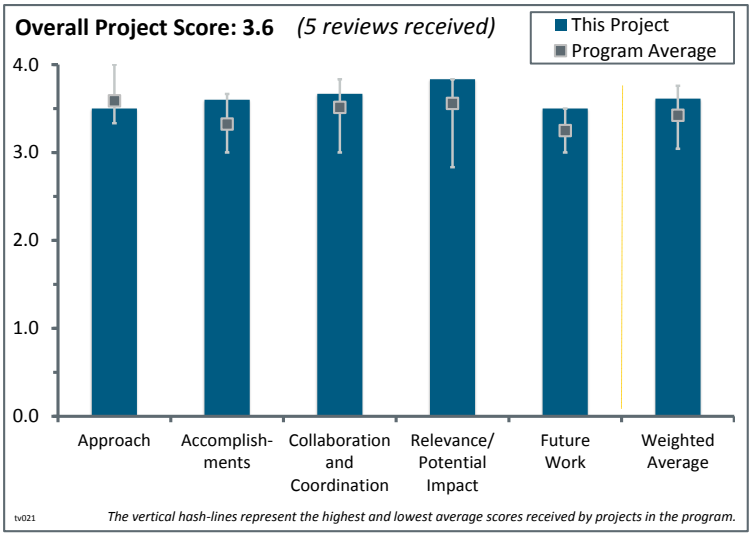
- Two reviewers noted that they had no recommendations for this project.

Project # TV-021: Forklift and Backup Power Data Collection and Analysis

Jennifer Kurtz; National Renewable Energy Laboratory

Brief Summary of Project:

The objectives of this project are to assess forklift and backup power technology status in real-world operations, establish performance baselines, report on fuel cell and hydrogen technology, and support market growth by evaluating performance relevant to the markets' value proposition. Technology will be reviewed through independent assessments, focusing on fuel cell systems and hydrogen infrastructure. Market growth will be supported through analyses of market value and reporting on technology status to fuel cell and hydrogen communities.



Question 1: Approach to performing the work

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

- This project has a solid approach on analysis.
- The approach should have more focus on the key technology-restraining issues.
- The approach appears to be solid with technical data products, an analysis of operation and maintenance data, and close collaboration with system vendors.
- The National Renewable Energy Laboratory's (NREL's) business case analysis of the economic and operating performance of fuel cell forklifts has contributed to the sharp commercial ramp-up of fuel cell forklifts. NREL shares a key role in one of the "success stories" for commercial fuel cells.
- A draft report is due soon, and data are reported on a secure basis to NREL. The detailed product is shared with the data provider, and all information is published on NREL's website. The project also has a toolkit and leverages the data analysis work. So far, 1,302 fuel cell systems have been deployed, most in the form of backup power systems.

Question 2: 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.

- This project has had excellent success with many units, and safety and reliability have been demonstrated.
- An excellent set of data was presented for fork lift systems, but there was less information provided for backup systems. Slide 18 with failure modes for infrastructure was very informative.
- NREL has successfully brought economic analysis, such as cost of ownership comparisons that feature textured comparisons of fuel cell systems versus incumbent systems, into its reporting.
- Slide 13 comparing the costs of battery lift trucks versus fuel cell lift trucks should be a major selling point to encourage more warehouses and factories to convert to fuel cells.
- This project is significantly adding to the value proposition to the user for reliability and safety. The evaluation of the maintenance and reliability categories is helpful to demonstrate a reason for industry to determine the commercialization of these technologies.
- This is a noteworthy discussion of start-ups, reliability requirements, and the deltas and explains the cause of the deltas between requirements and actual performance. There is significant and valuable discussion on

the cost of ownership in comparison to battery forklifts. This project is an outstanding discussion of refueling and mean time between failure (MTBF).
- It is not immediately obvious what results have been obtained from the current project and what results were due to the previous American Recovery and Reinvestment Act (Recovery Act) project.

Question 3: Collaboration and coordination with other institutions

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

- This project has a solid combination of team members and users.
- This project has outstanding data collection, analysis, and dissemination.
- The economic analysis could not have been as robust without NREL's ability to enlist the cooperation of its collaborators. This reflects an atmosphere of mutual respect, transparency, and trust among the collaborators.
- A wide variety of system providers are included that increase the validity of the data and conclusions. There appears to be some lack of data collection response from some vendors, but this is not the fault of the research team.
- The distinction between confidential and public results may mask some important insights that have been revealed only on a confidential basis.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

This project was rated **3.8** for its relevance/potential impact.

- This project contributes to the goal of improving the reliability of fuel cells and hydrogen infrastructure, and will help define the value proposition for backup power. The compressor breakdowns are a red flag, and performance could be improved.
- The real-world data collection is essential to understanding barriers to greater commercialization, deployment issues, and technical limitations. Thus, high value and impact are delivered to fuel cell system suppliers and to DOE.
- It is unclear how the results of this study will be employed to help strengthen the expansion of fuel cell applications.

Question 5: Proposed future work

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

- The quarterly reports and final reports are still to come. It is important to try to continue to improve compressor reliability.
- It is hoped that every demonstration program receives the same quality of analysis and reporting that NREL has provided for backup power fuel cells and fuel cell material handling equipment (MHE).
- This is a reasonable plan that outlines complete tasks, data sharing, and reporting key findings. It is not clear if there is a way or a plan to continue data collection with some installations to provide capabilities for trending data over several years.
- Every effort should be made to continue this project beyond June 2014. The continued collection of these data is very important to establish the long-term performance of fuel cells. Stopping now would effectively be throwing away an opportunity to establish a long-term record of lifetime. Some other entity would have to start over with a new fleet of systems to set up another long-term trial of fuel cell lifetime performance.
- The project is 60% complete and will end in fiscal year 2014.

Project strengths:

- A significant amount of information about fuel cell systems has been obtained.
- This was a very complete presentation and a thorough project that identified systemic weaknesses.

- This project has good data collection, evaluation teams, and protocol. This project has good connections to end users, thanks to the implementation of the previous Recovery Act project.
- This is a good national approach to fuel cell analysis. There are early warnings of commercial problems, such as compressors. The project partners are happy to validate their equipment. The lessons learned from forklifts were very good.
- This project has an excellent roster of partners and a detailed data set for important emerging fuel cell system applications (MHE, backup power). Slide 13's stack-up of annualized costs is very informative and highlights key areas for improvement. This could be the basis for instructive sensitivity analysis as well.

Project weaknesses:

- This project has no weaknesses.
- Many important observations may be held on a confidential basis.
- The point about compressor failures as the problem was not identified/ discussed in the presentation.
- There are much more detailed drill-down data for forklifts than backup power.

Recommendations for additions/deletions to project scope:

- There are no recommendations for this project
- This project should continue the data collection.
- As noted in last year's feedback, a cost-of-ownership stack-up plot similar to slide 13 for forklifts would be a valuable addition for the backup power systems.
- It would be helpful to depict time-dependent performance trends, a risk-assessment of key issues and possible resolution paths for the identified issues. This work seems to be more of a snapshot, which is very informative, but depicting trends over several years would be even more salient. It is understood that funding is a limitation.