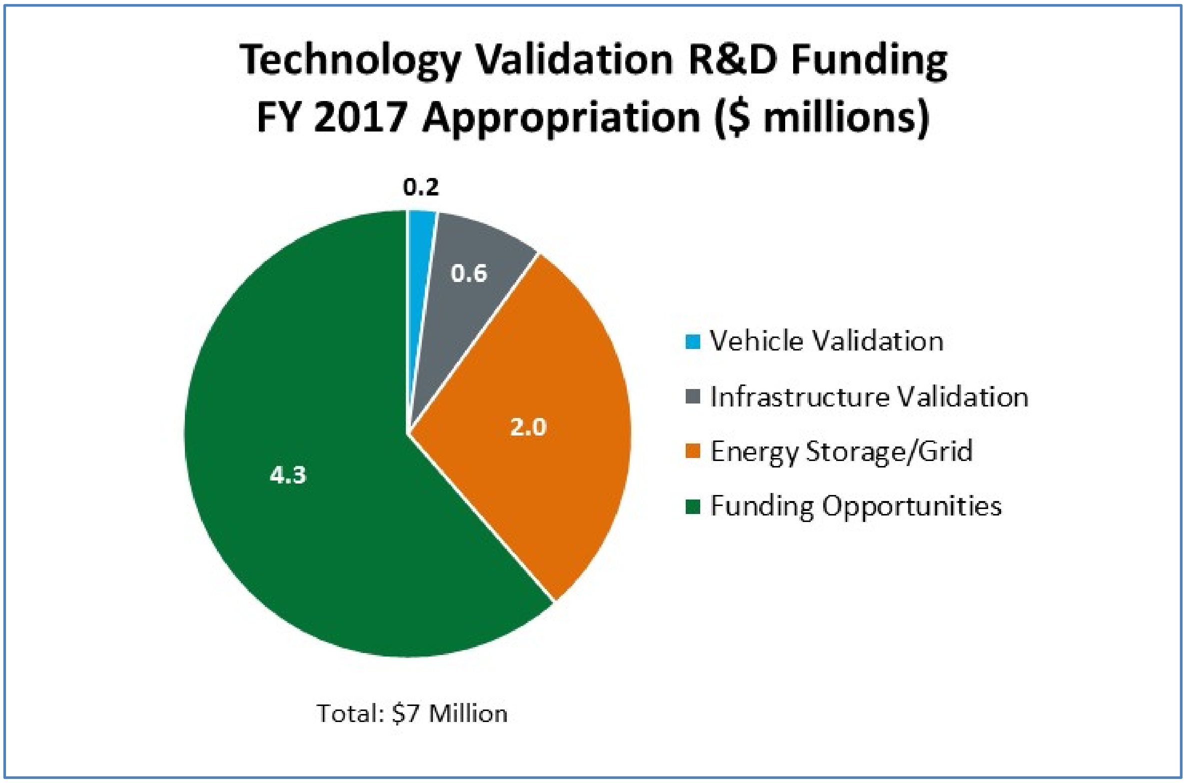
# 2017 – Technology Validation
# Summary of Annual Merit Review of the Technology Validation Sub-Program

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

In general, reviewers commented that the Technology Validation sub-program is well managed, with a balanced set of projects that is both appropriately broad and flexible enough to consider market changes. It was noted that this sub-program is well informed of real-world challenges and addresses both fundamental and practical issues. While the reviewers valued the accomplishments presented, it was noted that progress in projects was not clearly benchmarked against the past year. Reviewers further recommended that failures (and related lessons learned) should also be reported, projects that have diminished in relevance because of changes in the landscape should be pared down, and interactions with utilities should be strengthened.

### Technology Validation Funding:

The fiscal year (FY) 2017 Technology Validation sub-program funding totaled $7 million. This funding enabled the continuation of data collection and analysis from fuel cells operating in transportation applications (e.g., light-duty vehicles, medium- and heavy-duty trucks, and buses), while validating and evaluating hydrogen infrastructure (e.g., fueling stations, components, and delivery/dispensing). In coordination with the Office of Electricity and other offices in the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, major focus areas in FY 2017 were hydrogen-based energy storage and grid integration activities, including Hydrogen at Scale ("H2@ Scale"), an approach to enable the widespread use of hydrogen across multiple sectors, and the national laboratory cooperative research and development agreement (CRADA) call.



## Majority of Reviewer Comments and Recommendations:

The 14 Technology Validation sub-program projects had a maximum score of 3.7, a minimum score of 3.0, and an average score of 3.4. Key strengths identified by reviewers across the Technology Validation projects were the collaborations with key partners and the potential for the projects to contribute valuable data, enabling stakeholders to gain enhanced insights and successfully deploy hydrogen and fuel cell technologies.

**Transportation Applications:** Three projects relating to transportation applications were reviewed, with an average score of 3.5. The highest-ranked project in this grouping received a score of 3.7, while the lowest-ranked project scored 3.2.

Reviewers noted that the ***fuel cell electric vehicle data collection*** project is a well-designed project that continues to provide high-quality data. The move toward developing a predictive fueling model was praised as a progressive approach to providing the kind of information that could be most useful today. Reviewers observed that interaction with the participating original equipment manufacturers went above and beyond collecting and submitting data, but expressed concern over the age of the project and whether industry needs it as much now as it has in the past ten years.

The learnings from the ***fuel cell electric bus data collection*** project were deemed also to hold value in serving as a context for assessing the technology potential in the trucking industry. Reviewers commented that the project provides quality data to decision makers and that team members maintain good collaborations with transit agencies. The newly developed technology maintenance readiness level (TMRL) guidelines were highly praised. Reviewers recommended conducting more comparisons with battery-based buses and providing data on fueling infrastructure availability for fuel cell buses.

A well-designed truck platform and detailed simulations of actual routes and fuel requirements were considered strengths of the ***fuel cell hybrid electric delivery van*** project. However, reviewers expressed concern over the project's delayed start and uncertainty regarding remaining cost share. It was suggested that a fueling test should be scheduled and that more hydrogen tank suppliers should be involved in supplying a new "off-the-shelf" tank.

**Infrastructure and H2FIRST:** Six projects focusing on hydrogen infrastructure were reviewed, with an average score of 3.4. The highest-ranked project in this category received a score of 3.6, while the lowest-ranked project scored 3.0.

The project team involved in the ***hydrogen station data collection*** project was praised for achieving improved data quality, working well with the many collaborators, and having the ability to change and remain relevant as the industry matures. Suggestions included categorizing data based on station technology, collecting certain information more often (e.g., monthly), and working with entities deploying hydrogen stations in the northeastern United States. Reviewers also commented that they would like to see additional analysis on how station capacity utilization affects costs per kilogram for each station type, as well as hydrogen losses in the system for each station type.

While acknowledging that the ***performance evaluation of delivered hydrogen fueling stations*** project has made progress in installing and collecting data of value on two stations, reviewers expressed concern over permitting challenges and whether there was adequate time for data collection on the remaining three stations. They further suggested that the project team outline a specific plan to communicate lessons learned on subjects such as system development, network communications, and commissioning.

Reviewers saw the ***advanced hydrogen mobile fueler*** as an enabler in filling infrastructure gaps, with design features considered to be well-thought-out. Suggestions included performing Hydrogen Station Equipment Performance (HyStEP) testing to prove fueling performance per SAE J2601 requirements, engaging Northeastern U.S. Weights and Measures Association officials with their counterparts in California, and improving the user interface for the dispenser to support unattended fueling.

The test rig developed and the use of statistical methods for characterization were regarded as unique value-added capabilities of the ***hydrogen meter benchmark testing*** project. Reviewers strongly advised performing some complete J2601 fills, and they stressed that the meter manufacturers should be involved as actual project partners.

Reviewers commented that the results of the ***hydrogen component validation*** project can assist with addressing issues that deter the progress of hydrogen stations. It was suggested that a more representative cross-section of the industry (e.g., various types of station designs and automakers) could be included to provide feedback, and that collaboration with the station developers could be increased. Reviewers also suggested providing clarity around the mechanisms of component failures, investigating high-throughput stations and dispenser failures, developing best practices for evaluating power use, and expanding data collection beyond compressors to include other failed station parts (e.g., chillers).

The ***performance and durability testing of cryogenic vessels and liquid hydrogen pump*** project was praised for collaborating with experienced project partners, but concern was raised over whether the approach will offer a competitive solution. Reviewers recommended further discussion on what could be achieved to limit hydrogen losses, and also suggested conducting a more detailed well-to-wheels analysis of boil-off and energy use.

**Grid Integration and Energy Storage:** Four projects focusing on grid integration and energy storage were reviewed, with an average score of 3.3. The highest-ranked project in this category received a score of 3.6, while the lowest-ranked project scored 3.0.

The **e*nergy dispatch controller*** project was praised for having well-designed modeling to demonstrate savings and to have shown good progress in its initial year. It was stressed that the project should include input from relevant stakeholders and end users, and that these users should be consulted during the model development phase.

The ***stationary hydrogen-vehicle-grid integrated systems modeling*** project was perceived as the core of the H2@ Scale concept, and reviewers noted that the approach provides flexibility and synergies. Reviewers strongly suggested an outreach strategy and additional discussions with grid operators, station owners, and related stakeholders, especially with regard to gaining their input on underlying model assumptions.

The ***dynamic modeling and validation of electrolyzers in real-time grid simulation*** project was commended for its unique approach to integrating modeling and hardware and for its productive collaborations with a wide range of stakeholders. Cooperation with utilities in obtaining real-time electric grid data was seen as having great value, but reviewers suggested that interactions with electrolyzer manufacturers should also take place.

The ***modular solid oxide electrolysis cell system*** project was regarded as having a progressive approach and the potential to advance the understanding of high-temperature electrolysis. Reviewers highlighted that progress has been steady and suggested that there should be a third-party validation of the system performance.

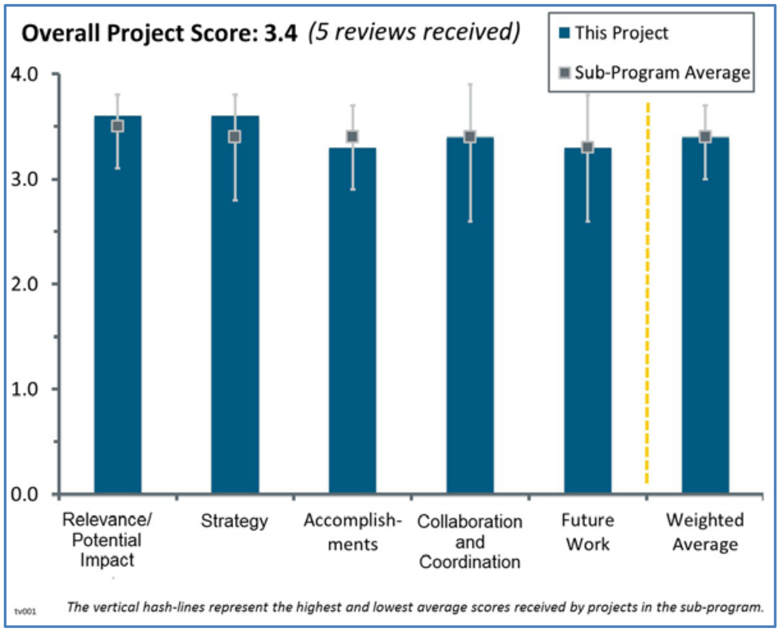
**Hydrogen at Scale (H2@ Scale):** The ***H2@ Scale analysis*** project was regarded as a comprehensive evaluation that uses well-established models. It received an overall score of 3.6. Reviewers expressed concern that this analysis might be too internally focused and thus encouraged the project team to seek additional collaborations with industry, consider a range of policy decisions that may add uncertainty about hydrogen market growth, and analyze nearer-term projects.

## 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-powered fuel cell electric vehicles (FCEVs) in real-world settings and to identify the current status and evolution of the technology. The analysis objectively assesses progress toward targets and market needs defined by the U.S. Department of Energy (DOE) and stakeholders, provides feedback to hydrogen research and development, and publishes results for key stakeholder use and investment decisions. Fiscal year 2017 objectives focus on analysis and reporting of FCEV durability, range, fuel economy, fueling behavior, and reliability.




### Question 1: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.6** for its relevance/potential impact.

- The project is relevant and has many positive impacts (existing and potential) and uses within the fuel cell transportation industries. The project is a data aggregator, reporter, and information and knowledge provider about FCEVs to the industry and research and development community. This project follows and fulfills the mission and the goals of DOE: publish results about the adoption and sustained use of FCEVs and provide information for investor decision-making. This project provides an evolutionary perspective about FCEVs. The real-world use of FCEVs is reported. Industrial players need these data to articulate and evaluate FCEV usage and other aspects about the vehicles. The provision of these data assists in hydrogen refueling station planning and rollout. This project entails working with seven partners—in many cases over a long period of time—and thus represents a fairly significant population. The data collection and internal analysis is consistent with that used in 2016. The National Renewable Energy Laboratory (NREL) team provides an independent assessment of data from multiple FCEV original equipment manufacturers (OEMs). This project addresses fuel economy, range, and consumer fueling behavior, in addition to predictability and performance according to DOE requirements and metrics. OEMs send proprietary data, including voltage data, which are evaluated quarterly. Reports are published more often.
- This project is continuing to address a critical need of the DOE Hydrogen and Fuel Cells Program (the Program) in understanding the state of development of FCEVs. The project still appears to be filling a role that could not be filled adequately in the private sector, and NREL continues to be a trusted partner for automakers. However, not having Toyota contribute at this stage is a clear weakness, given Toyota's leading role in early commercial deployments.
- The reviewer wanted to award a grade higher than 3.5, given the necessity to measure performance—something the NREL team seems to have greatly improved upon—but by definition, the 4.0 grade requires the project to have the potential to significantly advance DOE research, development, and deployment goals rather than the goal to "advance progress." The lower grade is regrettable, but the need to stay within grading guidelines is recognized; a higher grade would have been assigned if the parameters were wider.
- The project fully supports the Program goals and objectives.

- While this project has been around for some time, it is good to see that there are changes made in the primary objectives to better align with the kind of information that could be most useful today (i.e., vehicle–station interface, because customer experience is a primary topic for vehicle OEMs at the moment).

### 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.

- The strategy for technology validation in this project hinges on the technical capability of the NREL team, the need for the information when aggregated, and a reliable source of the information. The FCEV OEMs trust the computer security used at NREL to the extent that they provide car-use data. NREL aggregates the use data with the fuel economy and fueling behavior data. The project design supports regular participation, and the participation is straightforward and continued by those involved. Data are returned to the data providers. Honda, Hyundai, and Mercedes (2008–2016) all send FCEV data to NREL. At least three OEMs have to provide enough data, or the team will not publish. Now fewer vehicles are being analyzed.
- Clearly, the NREL team has applied a critical eye toward the data provided, but more importantly, NREL appears to have improved its approach to collecting data. There are no issues on this subject.
- The project continues to focus on critical barriers in an effective manner and seems well thought out. The proposal to shift toward developing a predictive fueling model is intriguing and demonstrates the project's continuing relevance.
- The project data collection and analyses are well designed.
- The once-a-year publication (down from twice a year) seems reasonable, given that fewer vehicles are analyzed (fewer partners).

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

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

- There are 7.1 million miles worth of data. DOE targets are not fully met, but great progress has been made. It is definitely nice to have these data compiled somewhere and to be able to access them and tell the story.
- The team has made good progress toward the project objectives; however, it is not clear how the analysis and data are used to improve technology progresses/advancements.
- Per slide 11 (the spider chart), several DOE targets are addressed: efficiency and so forth. The FCEVs have made progress toward DOE targets, but future work remains in some areas. The fueling data are used to develop a model to predict fueling demand (this is useful for hydrogen refueling station rollout).
- Against DOE goals and performance indicators, NREL progress appears to be fairly complete, i.e., NREL has done what DOE asked it to do, and its presentation of the data this year is clearer than it was in the past. However, there are a few issues:
    - NREL claims the slide 10 chart analyzes FCEVs and miles traveled since 2006, but neither the chart nor the work behind it seems to analyze anything, and in fact the NREL chart and work do nothing more than provide a year-by-year count of vehicles and miles. The chart seems to do little more than raise the presentation's slide count. Conversely, the slide 11 spider chart provides a much better view of various specifics. Slide 11 analyzes, not slide 10.
    - A number of slides discuss fuel station activities, and while it is understood why FCEV OEM data are hidden, especially when fewer than three providers are available given the nature of the competition between FCEV providers, it is much less clear why station identification data are not provided, given the absence of competition and the completely different funding model for the stations.

## Question 4: Collaboration and coordination with other institutions

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

- There seems to be very good interaction with the participating OEMs (over and above just sending them data).
- Collaboration with OEMs has been excellent.
- While the grade for relevance/potential impact was lowered based on the definition of the grades, the recognized inability for NREL to do much about coordinating with partners did much to ensure that the NREL grade for this category was not lower. From the presentation and a review of the documentation, it appears that manufacturing an FCEV qualified an organization as a partner, but the reality indicates that for this project, NREL performed almost all the work (while the partners did get to review the reports).
- The project is an excellent partner for OEMs, but not having Toyota as a partner is a real drawback.
- The collaboration does not include the one OEM that sells FCEVs, and one of the OEMs included has reported plans for new models (but does not sell or lease the new models).

## Question 5: Proposed future work

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

- The direction of the future work is thinking outside the box (operating a station to reduce costs). It should keep going in that direction.
- The idea to use the data collected to develop a predictive fueling model is a real step forward and shows good creative thinking by the project team on how to provide maximum value from the data collection.
- Future work includes a plan for publishing results of the number of on-road FCEVs in May 2018. Additionally, the future work includes developing and validating predictive FCEV fueling demand based on fill and drive data to decrease operations and maintenance costs, which currently exceed an average of $10,000 per month. It is not clear whether the station use can be optimized so the cost to operate a station goes down. Other future work is to include durability of the fuel cell stack (voltage degradation/drop).
- It is not clear that this project has a decision point.
- The future work is for routine results.

## Project strengths:

- The dissemination of FCEV metrics is important to vehicle acceptance. A major project strength is the fact that the data and information originate from a neutral party (NREL) with no ownership of stock in the station component providers or the vehicle providers, and that data and information are disseminated. Information about how to better operate the stations based on their use is very important to the financial solvency of the hydrogen refueling industry. The value and strength of this project are clear. The output from this project is strong, and the experts who work on this project are strong; therefore, the work is used by both public and private sectors. The approach is one in which the data are shared with those who provide the data in the first place, and aggregated data are used by public and industrial groups and organizations.
- Project strengths are the high-quality data collection and the project team’s ability to track progress over a long period. The project’s value as an independent validation of FCEV progress and continued weaknesses is high.
- The project helps with business intelligence in that it can validate the information and/or provide new or different data. There is a robust procedure for securing data. The team has a long history of data collection and analysis. Jennifer Kurtz is really working to redefine the project and come up with new and innovative outcomes. It has improved over the previous year.
- The data collection and analysis are well designed.

## Project weaknesses:

- A project weakness is the limited number of OEMs, which is largely a function of limited vehicle availability and thus not a "fault" of the project, but practically speaking, it means that there is less public access to the data results where the data cannot be sufficiently anonymized.
- The only weakness is that Toyota is not presently involved (apparently).
- A potential downside is the age of this project and whether the industry needs it as much now as in the past 10 years (even though not all DOE targets are met). The fact that there are fewer participants may be a testament to this fact.
- The project activities seem to be going on without decision points or endpoints.
- The project amounts to little more than a report; the report may be necessary, but it is still a report. This may not be NREL's fault.

## Recommendations for additions/deletions to project scope:

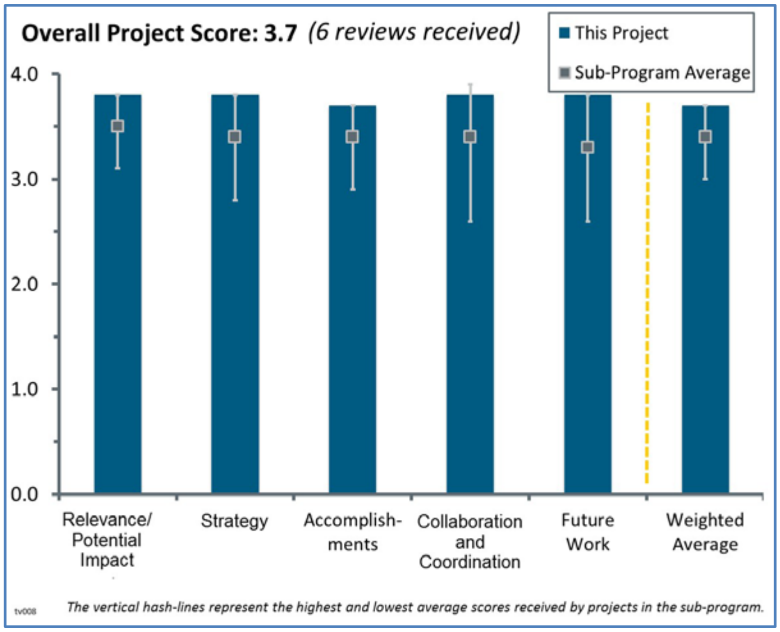
- It is recommended that the project add a customer experience element. This would have to be voluntary, but because this is still in the early market, it might be doable. It could tie in with customer/user social media. Maybe Sandia National Laboratories could make a Facebook, Instagram, or Pinterest page for FCEV users and collect data such as vehicle use frequency, fueling frequency, and where people are going in their vehicles (for input for station locations).
- The project could have been a much better project if there had been more analysis. The slide 11 spider chart demonstrated that the NREL team can analyze, and its "Remaining Challenges & Barriers" and "Proposed Future Work" sections advise that NREL wants to analyze. It would have been nice to see more analysis in this presentation.
- The project should add metrics that the NREL experts want to add to the "Summary of Key FCEV Metrics" (slide 23). The team should also add a built-in learning capability to the approach so the NREL experts can change this evaluation from year to year (if not already included and used).

## Project #TV-008: Fuel Cell Bus Evaluations

Leslie Eudy; National Renewable Energy Laboratory

### Brief Summary of Project:

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




### 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 is highly relevant to the data analysis about the deployment of FCEBs, and it supports and advances the progress toward the DOE Hydrogen and Fuel Cells Program (the Program) goals and objectives for zero-emission vehicles. Analysis based on actual operating FCEBs is needed to provide a perspective for suppliers, transit agencies, and policymakers as they consider long-term commitments to deploying/using FCEBs, which are capital-intensive. The relevance and potential impact of this third-party review (neutral) is important because the upfront costs of capital equipment and the operating costs of buses are high, and from a planning perspective, people need this information so they spend their funds correctly to obtain the greatest amount of greenhouse gas emission reductions possible. In some cases, transit investments are "one-time shots," and neutral, mathematically grounded reviews and "walk-throughs" prior to investment are integral to sound directions. This project advances Program objectives; it is based on DOE and DOT metrics (i.e., the life of the power plant). This project discusses sharing components with conventional buses and is based on comparisons with the existing diesel and compressed natural gas (CNG) bus infrastructure.
- With the advent of fuel cell electric trucks under consideration as a potential alternative for limited-range battery electric trucks, the operational data collection and lessons learned documented about FCEBs in revenue service is even more essential than before. Not only will transit agencies rely on a neutral party to collect and analyze this data, the trucking world will now also need this as context to assess technology potential. On the fueling infrastructure side, because of lack of published (anticipated and/or modeled) cost information from hydrogen suppliers on medium- and heavy-duty vehicle fueling (including FCEBs), this effort is needed even more to support progress.
- Buses have been, and will continue to be, an important platform for fuel cell system commercialization. Tracking progress toward achievement of targets and comparisons with performance of conventional technology buses are valuable for fuel cell and related technology developers, bus manufacturers, and transit fleet managers. On slide 3, relevance is stated succinctly and is easily understood. The table nicely summarizes the targets/metrics for FCEBs.
- The project fully supports the Program goals and objectives, especially regarding deployment of FCEBs.

- The presentation did an outstanding job explaining why the study is important. The slide 3 chart, "Relevance," clearly presents relevant facts on one slide.
- This continues to be a valuable project for providing insight into development of FCEBs, a key goal. It does seem as though the current crop of buses has reached the limits of insights to be gained from its analysis at this stage, so it is good that analysis on them will be closing out in 2017.

### 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 approach to identifying data elements, collecting information, analyzing data, and reporting has been well refined over a number of years. The strategy is straightforward; success in implementing the strategy is dependent on establishing and maintaining solid working relationships between the National Renewable Energy Laboratory (NREL) and the various providers of data. The ongoing and potential future involvement of transit agencies and other data providers indicates that NREL's team has continued to build credibility. The approach, which results in efficiently translating raw data into reports that have value for decision makers, contributes significantly to effective communications and trust among project partners and contributors.
- The strategy for technology validation is to compare buses with the industrial guidelines, i.e., features and functions. For example, FCEBs have accumulated an average of over 14,000 hours of use per FCEB power plant. The output is a real-world review of the features and functions. The project is well designed and can be integrated with alternative fuel deployment efforts.
- The approaches regarding information and data collection are well designed for this project.
- The processes in this project have been fine-tuned based on feedback from transit agencies, but they would benefit from the inclusion of additional bus projects, both FCEBs and battery buses (for comparison of zero-emission options).
- The project is well designed and continues to provide quality data as well as maintain good collaborations with transit agencies. It would be improved by doing a comparison against battery buses as well as the baseline diesel or CNG, because batteries are the main competitor to fuel cells in the zero-emission bus space. Agencies will want to see what the comparative benefits are.
- The approach is crystal clear, both in the verbiage and also in the charts.

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

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

- This project results in a very clear picture of the progress being made by FCEBs relative to DOE and other stakeholder targets and how the performance of FCEBs compares to that of conventional, mainstream bus technology. Nine "Accomplishment and Progress" slides are outstanding. Ms. Eudy's superb presentation highlighted and summarized both project accomplishments and FCEB progress. Information was provided that demonstrates achievement of project objectives (as stated in the "Relevance" slide); documents FCEB performance; and details maintenance costs by bus type, system, and sub-system. Comparative information on maintenance costs is included in response to a prior review comment; the detail serves to indicate that the number of data elements associated with the project is extensive. Taking the initiative to develop a draft technology maintenance readiness levels (TMRL) guideline is commendable (slide 14).
- The targets/performance indicators are clear, so by measuring the correct data points, it appears that progress has been made for the technology. The TMRL guideline stands out as a gem that has been undervalued by government, but it is highly appreciated by industry (both transit agencies and heavy-duty vehicle manufacturers) as a tool to assess the status of vehicle technology and what to focus on next.
- This project includes comparisons of performance at the existing sites of FCEBs. Additionally, this project addresses the expected growth in FCEBs. Results include the following:
  - The top fuel cell power plant exceeded expectations for the 2016 targets.
  - The bus availability improved over 2015 and 2016.

  - The miles between a road call increased over the last four years.
  - The aging buses and their need for increased maintenance is addressed.
  - The TMRL is discussed (developed with fleet and original equipment manufacturer [OEM] partner input).
- The project has done an excellent job providing facts as well as an analysis. There is quite a bit of data and solid analysis.
- Progress has been good. The TMRL guideline is appreciated. It is important to make sure that it is clear to anyone reviewing this analysis that the increased labor time for these buses is because of the shift from maintenance being performed by the technology company to transit agency. This is an important and necessary step, but the team just needs to be careful that it is explained as such.
- Excellent progress has been obtained regarding data on cost and reliability/maintenance.

### Question 4: Collaboration and coordination with other institutions

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

- It seems NREL has maintained an excellent working relationship with data providers. The transit agencies that operate the majority of FCEBs in the United States are project partners. Continuous communication is required for efficient inputs of agreed-on data elements to NREL and review of NREL's products by its project partners. Information is shared with other U.S. and international organizations that have a stake in the evolution of bus technology (slide 16). While not specifically mentioned under "Collaborations," the project-funding support by the Federal Transit Administration and California Air Resources Board (slide 23) is another factor in the reviewer's score of "Outstanding."
- This project includes collaboration with both national and international organizations to validate bus performance and cost. Additionally, the TMRL guideline was developed in collaboration with fleet and OEM partner input.
- This project continues to be a model for collaboration with private-sector partners and public agencies.
- Many different projects and entities come together in this project, including hydrogen infrastructure and other vehicle applications.
- Given the conditions, there is perfect collaboration.
- Collaboration is excellent with transit agencies and bus/fuel cell manufacturers.

### Question 5: Proposed future work

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

- Collecting data for FCEB projects that are coming online will provide the comparison data needed to get a better overview of what a significant difference in climate may have on the performance of FCEBs.
- Expectations about tracking FCEBs coming into service underscore the value of the project. NREL continues to work on bringing in additional transit agencies in order to collect data on new FCEB designs and systems. As long as new FCEBs are being acquired and they are not yet comparable with other bus types regarding performance and cost, it seems appropriate that the project be continued. Proposed future work (slides 18 and 19) is clearly and succinctly articulated.
- The most important aspect of NREL's planned future work is that the work is consistent with past actions.
- The addition of buses in colder climates and with battery-dominant systems is pleasing to see. It is not clear how the battery-dominant FCEBs will be evaluated and how the evaluation be different from the benchmarking assessment for a fuel-cell-dominant system.
- The proposed work is well planned to address identified barriers/issues.
- The plan is to present the TMRL guideline to a broader group of transit agencies (via a public conference).

## Project strengths:

- The NREL project team, led by Ms. Eudy, is providing superior returns for a relatively small investment by DOE. Having managed the project for an extended period, the NREL staff has great experience and superior knowledge of bus technologies. The project approach is well tested and refined. NREL staff is aware of what needs to be done in order to achieve continual improvement in project value (slide 23). Documentation of bus performance, comparative analyses, etc. is excellent. Timely reports on results are published by NREL for use by those with an interest in FCEBs, advanced bus technology, and transit/ energy policy. Presentations are also made at bus workshops and conferences.
- The project strengths include the following:
  - Unbiased data collection and analysis
  - Data variables that align with industry practices on what to collect data on
  - Long-running data collection process with international recognition by industry
- There are good collaborations with transit agencies and technology companies. The comparison to baseline buses provides valuable insights.
- The project approaches are well designed, and collaboration with transit agencies and bus/fuel cell manufacturers is excellent.
- The completeness of the work, obvious professionalism, and thoroughness of the team are project strengths.
- Public transit is often misunderstood, and this presentation does a decent job at showing the business nature of public transit. The project addressed maintenance (cost per mile) and hinges on collaboration with transit agencies, OEMs, and policymakers.

## Project weaknesses:

- No project weaknesses are noted.
- None are noted.
- Limited funding is a project weakness.
- Some slides could be redone into more slides with fewer concepts, but this is a minor issue.
- A key weakness is just the age of the buses being analyzed, but that should be resolved with the conclusion of the current bus fleet assessment. Another weakness is that the FCEBs are compared only to existing diesel and CNG technology and not to their most likely competitor for agencies looking to move to zero emissions: battery buses.
- As part of the Program Annual Merit Review process, the presentations were handed in early this year, so the data collection reporting ended in December 2016; it would be good to see more current information. The differences between 2016 and the "ultimate target" could be explained for those not experienced in this area. Also, a slide on the definition of a commercial bus could be added, e.g., Commercial bus: sold in large quantities, and major OEMs sell them. Perhaps refueling cycles for the sites could be added as well, e.g., average volume of hydrogen used in refuel. The summary slide would be a great "explainer slide." Perhaps the summary slide could be broken down, item by item. This would be very valuable. It is not clear how to continue to collect data as the quantity of buses increases.
- International collaboration is weak.

## Recommendations for additions/deletions to project scope:

- Full funding is recommended.
- The team should publish the TMRL guideline separate from a large report so that the transit industry can use the guideline in a manner similar to the 2012 Fuel Cell Bus Technical Targets, i.e., as a benchmark and assessment tool for the status of the context that supports optimal performance of FCEBs. The TMRL guideline concept also applies to new vehicle technologies in the trucking sector. The TMRL guideline should be considered and reworked to apply to fuel cell electric trucks as well (as a separate project). The project should include numbers for overall bus availability of conventional buses in the host agency's fleet—to make the benchmark even stronger. The team should add numbers for infrastructure availability for FCEBs fueling at each of the project locations.

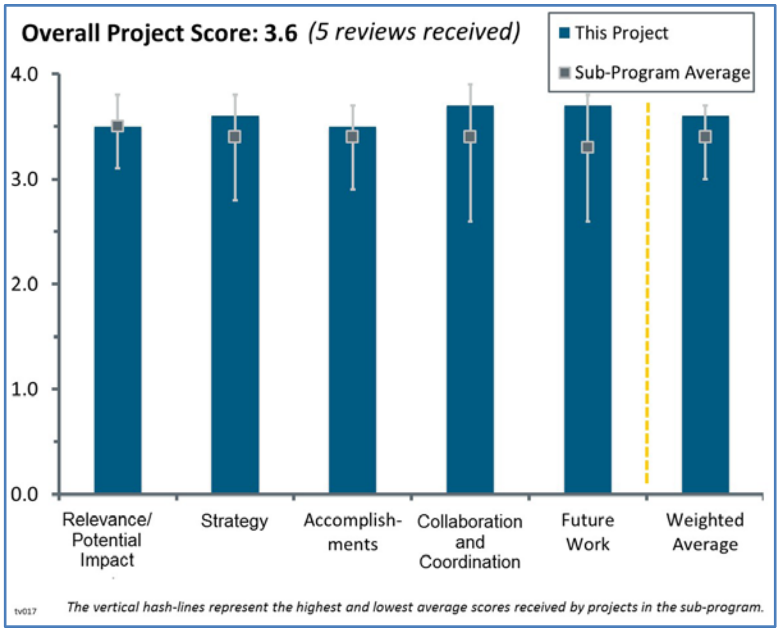
- The project would be improved by coming up with a way to compare the FCEBs to battery electric buses, to inform transit agencies considering both options.
- If success is achieved in bringing additional transit agencies and buses into the project, and funding is not increased, the focus on data collection should be on the new buses and most current designs—for both FCEBs and other bus types. (This does not suggest a change in project scope.) Funding is recommended that is sufficient to support data collection, analysis, and reporting for as many currently operational FCEBs as possible.
- There is an issue of air conditioners that are a new design; these are expensive. It is not clear why. Perhaps future work can be done here. Another issue is that the buses are out of warranty and parts are in need of replacement. Perhaps information can be added here as to how this is resolved. Of course, the obvious questions concern how NREL can collect more data on more buses and work on parts pooling as a partial answer to the parts supply issue.

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

Sam Sprik; National Renewable Energy Laboratory

### Brief Summary of Project:

This project evaluates hydrogen infrastructure performance, cost, utilization, maintenance, and safety. Data analysis supports validation of hydrogen infrastructure, identifies status and technological improvements, provides feedback to hydrogen research, and provides results of analyses 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.

- This project is to collect, sanitize, and produce analyzed results suitable for public consumption. This is extremely valuable to understanding how stations are improving, identifying areas in need of improvement, etc. The approach taken by the National Renewable Energy Laboratory (Sam Sprik) is very good. Clearly, as this technology matures, the data collection, analysis, and analysis deployment will need to be modified. This project has a history of being receptive to these needs and providing the data and analysis that is most valued. This is excellent.
- Data collection and validation are of high importance for the further development of the U.S. Department of Energy (DOE) Hydrogen and Fuel Cells Program (the Program). Therefore, the approach is excellent for improving the knowledge regarding hydrogen stations.
- Independent data collection on hydrogen stations is absolutely critical to understanding progress, costs, issues, and challenges associated with deploying the fueling networks that will support fuel cell electric vehicles.
- This project is clearly making progress toward removing the barrier outlined by DOE: “Lack of Hydrogen Refueling Infrastructure Performance and Availability Data.” However, no goals/objectives in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan were called out in the slides or the presentation.
- It is a well-organized approach.

### 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.

- The output from this project is excellent. It remains resilient to the current data and analysis needs of this community in its infancy stage of development.
- This project is addressing barriers by providing accessible information and analysis of station data to the community and the public. The work plan is feasible. Future areas for integration include installation of data collection devices, such as the ones outlined in the Program Annual Merit Review 2017 TV-025 presentation, if they are not already installed.

- The project has an excellent approach to collect data from stations and integrate further stations that are not part of the funding.
- The strategy includes good parameters for hydrogen station performance.

### 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 summary of stations and their performance is very good.
- Further expansion of collected data and inclusion of non-funded stations give additional benefit.
- The goals outlined in the slides include using the existing stations as a guide for future innovations and issues for research. The slides and data provided are of great quality and interest, but the presentation would be improved by providing a summary and emphasizing the specific issues or research areas identified from the data collection. However, it is clear that these results will influence research directions (e.g., identifying causes of dispenser failures).
- The data acquisition, analysis, and distribution are critically important to help guide the maturity of this embryonic technology.

### Question 4: Collaboration and coordination with other institutions

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

- Coordination with station operators as well as station deployment in California shows a comprehensive approach in cooperation with relevant stakeholders.
- Collaboration appears to be great for getting necessary data.
- The group appears to be working well with the many collaborators to obtain the data.
- The project has a strong team and good interactions.
- The reviewer scored it a "3" principally because there was no real discussion about who collaborators might be; instead, a very broad statement with no specificity was provided. The principal investigator (PI) simply noted that the project works closely with industry and government, but it is not clear whom. Presumably, the principal government collaborator is DOE (which is a funding entity, not really a collaborator); the California Energy Commission, which is the entity funding stations in California, is a non-DOE government agency, which is very appropriate. Also, some industry collaborators can be the stations providing data. These collaborators will help the project understand the data needs of these stations as both retailers and station operators, which means that these operators should be keenly interested in component behavior. Hence, there likely are a large number of potential entities that are contributing to this work. This requirement was not really addressed by the PI.

### Question 5: Proposed future work

This project was rated **3.7** for its proposed future work.

- This project has already demonstrated the flexibility to be responsive to the data needs of this nascent industry as hydrogen fueling stations (HFSs) are deployed. This is excellent.
- The plans for the future are to continue to achieve the proposed goals, with more of an emphasis on the analysis and publication. It is important that the team clearly communicate its recommendations for future research or development needs from this data collection activity. It may be beneficial to separate data based on technology as more stations in each category come online.
- Enhancements of data collection show a learning curve and improve data quality and availability of relevant information.
- The work plan built on current results is very good.
- There are only 35 stations with data. Obviously, the project needs to continue to collect data as the fueling network grows.

### Project strengths:

- The project is providing relevant data as HFS deployment continues. The PI has demonstrated the ability to change and remain relevant as the deployment and the industry mature.
- The project clearly addressed a DOE barrier, and it covers a large number of stations. Future plans are appropriate with a focus on continued data gathering, analysis, and reporting of the data gathered.
- The comprehensive information availability for the evaluation of hydrogen stations and further project development are strengths.
- The project is very relevant to current industry needs.
- The project team is a strength.

### Project weaknesses:

- No major weaknesses are detected.
- To collect (some) information more often (e.g., monthly) might be interesting.
- It would be good to see additional analyses, including (1) how station capacity utilization affects actual costs per kilogram for each station type and (2) assessment of hydrogen losses in the system for each station type.
- There was no concrete plan to work with the entities deploying HFSs in the Northeast. The funding (ownership) model in the Northeast is very different from the one in California. This fact makes the ability to get data from those stations very different. It would be beneficial to see an aggressive plan to get those agreements in place. The PI did comment that "they are working" to get the data, but that demonstrates a desire rather than a plan. Developing relationships with the station provider (Air Liquide, Shell, etc.), potential operators, and the governments in the Northeast would be beneficial.

### Recommendations for additions/deletions to project scope:

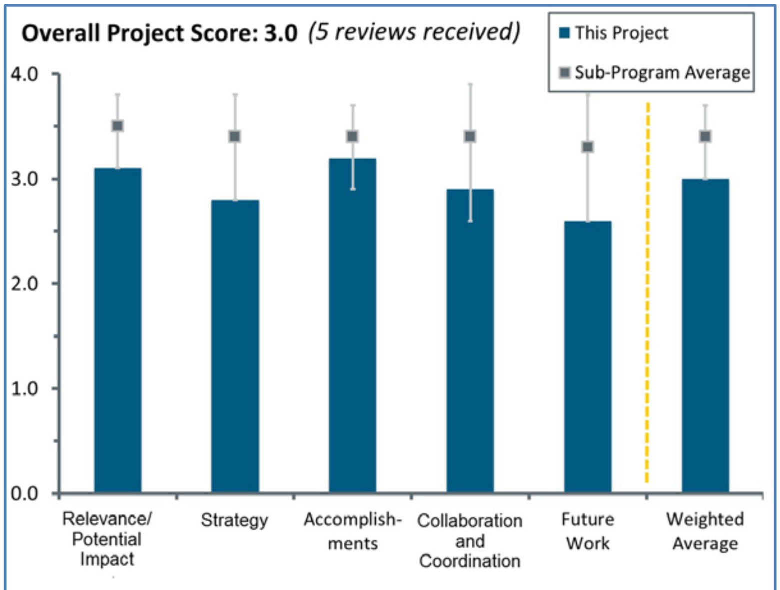
- The project should keep up the excellent work. This project is working hard on solving the data acquisition issue from stations going into the Northeast. Also, it is recommended that the PI work with the Pacific Northwest National Laboratory (PNNL) to investigate putting the database into the PNNL portal so that the industry and public can easily gain access to these data.
- The project scope is appropriate; no changes are recommended.
- The project should continue the California focus and identify a strategy on increasing station usage/ capacity factors.
- A supply of relevant information for hydrogen station users/customers might be of additional value. This might also lead to live information for station availability/price/etc.
- The project needs to continue to add stations as they come online.

## Project #TV-019: Hydrogen Component Validation

Daniel Terlip; National Renewable Energy Laboratory

### Brief Summary of Project:

The objectives of this project are to (1) reduce fuel contamination introduced by forecourt station components, (2) improve station reliability and uptime, and (3) increase the publicly available energy and performance data of major station components. The project is focusing its efforts on understanding common component failures and sources of particulate contamination at hydrogen stations, while quantifying the related costs incurred when operating a hydrogen station.




*The vertical hash-lines represent the highest and lowest average scores received by projects in the sub-program.*

### Question 1: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.1** for its relevance/potential impact.

- The project has high relevance and a high potential impact on the hydrogen refueling industry. The project supports the goal of advancing the use and efficiency of the use of hydrogen as a transportation fuel by using the facility/equipment at the Hydrogen Infrastructure Testing and Research Facility (HITRF) at the National Renewable Energy Laboratory (NREL). The facility is configured for 700 bar refueling, which is up to par with most of today's refueling stations. By addressing contaminants in hydrogen, this project looks at a key point of today's hydrogen refueling infrastructure. The research entails collecting samples from station operators. The concern with today's stations is how much testing is needed to "be as good as" in situ testing. The issue is that in situ testing costs too much (as much as $300,000), and this additional cost is not feasible for today's station operators. The project can provide assistance with the question of how many tests are necessary (for contaminants). By addressing power use, this project looks at another key point: how much power is needed for the compressor and the polymer electrolyte membrane electrolyzer and how this can be decreased. Overall, the cost of stations continues to be affected by energy consumption and reliability (contaminants). The industry needs answers as to how to better design stations to address both. It should be noted that from January 2016 to today, the overall reliability of stations (nationwide) has stabilized, but the compressor reliability and energy consumption continue to be problems with some station developers without resources to counteract. This research assists in both areas, which are likely to change over time.
- This project directly addresses the barrier outlined by the U.S. Department of Energy (DOE): "Lack of Hydrogen Refueling Infrastructure Performance and Availability Data." It is likely that the results will be of interest to the community and will affect decisions made as hydrogen fueling infrastructure is designed. It is somewhat unclear from the slides which goals/objectives in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan are being addressed, although it seems that the project does address some key goals.
- The project fully supports the DOE Hydrogen and Fuel Cells Program (the Program) goals and objectives.
- This project is relevant to the extent that results can assist with documenting and addressing issues that deter progress in achieving hydrogen station objectives. The "Relevance" portion of the presentation (slides 3 and 4) was not particularly helpful in clarifying the focus of and rationale for the project. During

discussion at the poster session, however, the project manager stated the focus is on sources of hydrogen station costs and how to reduce them.

- Using $758,000 to identify the power consumption of obsolete production, compression, and cooling technologies along with high-school-level assessment of cleaning procedures is not a wise use of funds. The impact is limited because there are no clear innovations, no transfer to industry, and no industry-led efforts. It is not clear why DOE is allowing this project to proceed with 0% industry cost share. Industry cost share of 50% or greater would ensure that DOE dollars are spent appropriately. The facility at NREL appears very capable of providing high-value work; the potential impact is the only redeeming feature of this project.

### Question 2: Strategy for technology validation and/or deployment

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

- The strategy for technology validation of the hydrogen compressors (outreach to three compressor manufacturers and seven station operators) to review maintenance events, develop best practices, and review existing materials that degrade fuel cells is both appropriate and sustainable. The use of the NREL test station (HITRF) is reasonable. Although this is a test station and not a commercial station, and it does not serve customers (non-commercial), the station encounters similar or the same "major maintenance burdens." The research team reviewed both the research station and the HITRF station and showed data expressing similarities. The NREL team tested the valve failures and the valve seals (with wide temperature ranges), and the same (or similar) failures were exhibited.
- Analysis of collected data and information is excellent.
- The project is addressing barriers, is feasible, and is well integrated with other efforts. Failure analysis may be improved by providing a comparison to non-failed parts and perhaps by doing more to understand/describe how these particles contribute to the ultimate failure.
- Having clarified that the overall focus is on hydrogen station costs and cost reduction, each of the three topics in the "Approach" portion of the presentation (slides 5 through 7) seems appropriate for inclusion in the project. However, no information is provided about a general strategy or approach to determining the priorities for using project resources. It appears that the varied topics being addressed within the project may be determined by the interests of one or a few stakeholders.
- Technology validation should ensure relevance to industry and technology transfer, or in this case, acceptance of suggestions for industry best practice should have been the objective. It is not clear how the article and presentation at a conference in Europe affects DOE objectives and relevant U.S.-based best practices.

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

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

- This project outlined three goals, which were to (1) understand common failures at hydrogen stations, (2) understand the source of particulate contamination in hydrogen stations, and (3) quantify the costs incurred when operating a hydrogen station. The progress made addresses all three goals. The work done to investigate cleaning of pipes is particularly practical and useful, although more could be done to test whether properly cleaned equipment or intentionally dirty equipment does lead to fewer failures or more failures, respectively. Also, it might be helpful to consider other sources of particulates besides cleaning.
- Good progress has been made toward addressing the barrier (lack of hydrogen refueling infrastructure performance and availability data).
- The "Accomplishments" portion of the presentation indicates the following:
    - The HITRF at NREL is providing relevant information, e.g., on station energy measurements and cost.
    - Particulates, which have an impact on component failure, can be affected differently by selection of tube cleaning methods.

It is assumed that the accomplishments documented in the presentation were achieved since the previous Program Annual Merit Review (AMR). Because DOE funding was $47,000 carry-over in fiscal year (FY) 2016 and zero in FY 2017, it would be helpful to have information on the timeframes associated with the accomplishments, confirmation that work is ongoing, and the sources of funding for the continuing activity.

- This test process responded to the 2016 reviewer's comments about broadening the types of compressors and the routine data collection for each. The number of hours for this testing were increased, and the failures are documented. The most hours were spent testing the valves/filters in the dispenser and the hydrogen pre-cooling process. The testing includes the number of car fills and the power and energy demand for the components. For the maintenance and reliability of the station components, the NREL team plans to continue collecting data.
- The accomplishments and progress by the researchers are good, given the project objectives. However, it is not clear why the researchers and DOE Program management did not scope a more aggressive technical challenge. There is very limited value in this assessment; no one learns anything from a detailed description of power consumption and particulates. Anyone operating a hydrogen station is well aware of these issues and could have provided this insight.

### Question 4: Collaboration and coordination with other institutions

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

- The "Collaborations" slide (slide 14) suggests that a number of organizations that have a stake in hydrogen station design and operation are working with NREL on quantifying performance metrics and resolving issues related to station cost. The institutions listed indicate NREL's credibility and outreach.
- Collaboration is excellent with various appropriate organizations.
- It appears the partners are participating in the project and there are no issues with gathering data.
- The number of gas companies involved with this work could be purposefully increased. Likewise, the collaboration with the station developers could be increased. Also, at least one additional transit agency could be contacted and collaborated with.
- Collaboration and industry cost share would resolve the issue of relevance. This project is off track and needs significant realignment with the capabilities and value of national laboratory involvement in industry activities.

### Question 5: Proposed future work

This project was rated **2.6** for its proposed future work.

- The plans for tube cleaning communication and outreach are great. It is also good to investigate high-throughput stations, as scaling up throughput will likely bring the costs down. It is unclear what impact investigating the variable suction pressure might have. It is also unclear what the outreach for more failed parts entails, and a clearer plan would be helpful. Finally, the project might also consider investigating dispenser failures, as this becomes the most common maintenance issue with time (see the TV-017 presentation in the 2017 AMR).
- Although this project started in 2012, the team proposes continuation in the future. The areas proposed are needed: conducting research into linking station failures to contaminants (increases are planned in the number of participating members of the contaminant library) and pursuing new ways to predict failures. Root cause analysis for failures will also be studied to decrease the quantity of replacement with like parts "because one did not know the cause and that seems to be the logical solution." For the energy and power demand of stations, the team plans to increase the data-sharing with modeling projects.
- The proposed future work is well planned.
- Presumably, NREL and selected stakeholders have reasons for the entries on slide 16 of the presentation, addressing proposed future work. There is some concern that the topics selected are not the result of an overarching approach to determining project priorities. In response to a question posed to the project manager during the poster session about how he would spend $100,000 per year, he stated that he would focus the resources on particulate studies. The second bullet on slide 16 ("Outreach program for station

fabricators on tube cleaning techniques") is questionable as an activity for support by the Technology Validation sub-program. If future DOE funding is provided, it seems appropriate to focus on compressor operation and reliability, as proposed by a previous reviewer.
- The future work will not lead to any new information within the industry and, therefore, will add no value to addressing barriers and challenges.

### Project strengths:

- The strengths of this project include how the project is grounded in the test facility already at NREL and the technical NREL staff. This test system is not disturbed by a commercial use for the station, and test setups can be, therefore, more efficient. Further, the understanding of contaminants, reliability, and power use at NREL is excellent, and this understanding makes for a strong project.
- The project strengths are the very practical, relevant findings—particularly the tube cleaning—and the good future plans for communication.
- The project uses excellent approaches for data collection and analysis.
- NREL collaborates with multiple stakeholders having an interest in the project; information, advice, and failed parts are received from them. To the extent that there is a clear focus on reduction of hydrogen station costs, that is also good.
- The researchers have good technical strength.

### Project weaknesses:

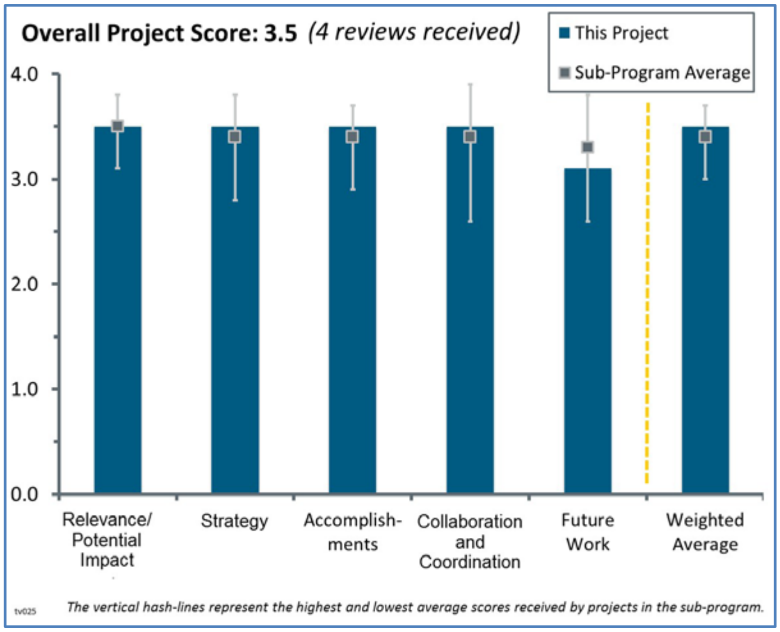
- None of the weaknesses are significant.
- The project weaknesses include the need for more participants in the contaminant- and component-testing category. Additionally, a more representative section of the industry should be sought—various types of station designs, for example—and potentially the automakers could be included to provide feedback on the impact of contaminants on vehicles.
- The failure analysis lacks some clarity as to how the particles are causing the failure. The tube cleaning data in the presentation seem to have high error, and the interpretation is difficult because of this.
- There seems to be no overarching approach or strategy for the project. There should be a framework or process for determining how best to apply available resources. Based on the lack of DOE FY 2016 and 2017 funds, there is an implication that this project will be low-priority, particularly in a reduced overall budget environment.
- The project is very poorly aligned with DOE objectives.

### Recommendations for additions/deletions to project scope:

- While the project has some great activities and scope change is not necessary for success, more detailed and systematic failure analysis and understanding may be considered, because it may lead to other preventative measures in addition to careful tube cleaning.
- The project should increase the focus on the installation of power meters and their use in evaluating energy demand and use by the various station components. Also, the project should provide the following: practical best practices for evaluating power use; overall case study impacts of the relationships of contaminants with station component reliability; and a collection of information and data about the failed station parts, i.e., chillers (other than compressors). This is asking a lot.
- Absent a positive reassessment of this project's approach, focus, and priorities, a renewal of DOE funding is not recommended. Such an assessment should be done in conjunction with a study on how best to utilize the HITRF. The concern about funding for this project should not be construed as applying to support for the HITRF.

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

Ted Barnes; Gas Technology Institute (GTI)




### Brief Summary of Project:

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

### Question 1: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

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

- This project directly addresses the barriers outlined by the U.S. Department of Energy (DOE) and outlines specific DOE technical objectives. The data gathered will be useful in estimating hydrogen fuel demand and the need for more stations.
- Data collection is an important part of measuring station maturity and advances toward the Fuel Cell Technologies Office's (FCTO's) goals. Lower-cost stations that meet efficiency and reliability targets can be enabled by this project.
- The technical objectives in the "Relevance" portion of the presentation (slide 3) reflect the objectives and directly address the barriers associated with hydrogen refueling infrastructure, as discussed in the FCTO Multi-Year Research, Development, and Demonstration Plan (MYRDDP). The table in slide 3 defines project objectives and goals succinctly and well.
- This project fully supports the DOE Hydrogen and Fuel Cells Program goals and objectives.

### Question 2: Strategy for technology validation and/or deployment

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

- The strategy for validation and deployment appears sound. While the data are aggregated, DOE will still have some idea where additional research and development might be needed and what gaps remain. The data can also be used to encourage other stakeholders and private industry to continue or start investment in certain types of stations.
- The project is well designed to address the barriers regarding hydrogen refueling infrastructure performance and availability data.
- While the data collection design and related systems are relatively sophisticated, the project approach is straightforward. The approach is articulated well in presentation slides 4 through 7 and is readily understood. An important and positive aspect of the project is the collection and transmission of component, performance, and cost data to NREL's National Fuel Cell Technology Evaluation Center (NFCTEC).

- The project is directly addressing the barrier of providing performance data. It is integrated with efforts to post information publicly in the same format. It is somewhat unclear how the work relates to the barrier of "Codes and Standards" directly.

### 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.

- Excellent progress toward data collection has been made to date.
- The initial phase of the project went well, with two stations completed. The team did have to adapt its strategy regarding the data collection board; however, the biggest challenges remain around permitting, which this project cannot change.
- The status of each of the five stations in the project, and data collection for the two operational stations, are nicely summarized in presentation slides 8 through 12. Consistent with project plans and goals, data are being collected and provided to NREL for the sites located at West Sacramento and San Juan Capistrano. The project transitioned to Budget Period 2 nearly two years ago. Based on the material presented in the slides and on the poster display, it is clear that two years of data collection from each station will not be accomplished prior to the stated end point for the project (January 2018). This was discussed with Tony Lindsay of the Gas Technology Institute (GTI) during the poster session. He stated that because of delays in permitting of three stations, the current intent is to provide 10 "station-years" of data. In that circumstance, it seems data provided would be primarily from the two currently operational stations. It is recommended that FCTO and the project managers collect at least four quarters of data for each of the five stations; such a requirement would necessitate a no-cost extension, which is evidently in the works. At the poster session, the reviewer suggested including a spreadsheet with more specific information on the data being collected and sent to NREL. Slide 5 has some information, but Mr. Lindsay agreed with the suggestion.
- Progress has been made, as equipment has been installed at another site and complete data sets have been gathered. One of the goals is to collect "high-quality data"; however, it is unclear what is considered high-quality. A list of pros/cons of this particular data-gathering system would also be helpful. Permitting continues to be an issue, but it is great to have data on stations that have gone through the process.

### Question 4: Collaboration and coordination with other institutions

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

- The combination of GTI and the Linde Group produces a strong, experienced project team. Their respective project responsibilities are reasonable and appropriate. Good coordination between them is required. Collaboration with NREL's NFCTEC is an important aspect of the project, and it has evidently been successful.
- The project team appears to be well coordinated, and team members are working well together.
- There is good collaboration between Linde and GTI. Data collection had to be split between the two entities based on individual capabilities and then compiled for the data collection process.
- There is collaboration with Linde.

### Question 5: Proposed future work

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

- Future work appears on track with the continued two years of data collection. The biggest challenge is around the last of the five stations, which still needs permitting approval and construction before the data collection equipment can be installed and used. The Foster City station should have more support from project stakeholders outside of GTI and Linde, where possible.
- The plans for the future are a logical extension of the work already conducted, and those plans and work will likely result in a successful project. One suggestion for improvement is to outline a specific plan to

communicate lessons learned to, or even develop case studies for, the community on the topics outlined in the slides such as system development, network communications, and commissioning. Strategies for this enabling of communication while remaining sensitive to intellectual property can be developed or at least discussed internally.

- The presentation materials and poster do not mention plans for a no-cost extension and do not address the issue of providing data from stations for differing periods of time. It would have been helpful if the project had cited alternative approaches to dealing with the delays in permitting new stations and included a selected alternative for proposed future work.
- It is not clear how the data will be analyzed.

### Project strengths:

- Project strengths include the following:
    - Experience and capabilities of the project team
    - Collaboration with, and submission of data to, NREL's NFCTEC
    - Strong linkage between project goals and the objectives/barriers included in the Technology Validation sub-program portion of the MYRDDP
- The data acquisition systems appear to be successful, and more sites are being installed. The team has good experience and connections.
- Effective communication and data manipulation by the partner companies are project strengths.
- The project has well-defined plans and well-designed approaches.

### Project weaknesses:

- The lessons learned should be communicated more specifically and more broadly.
- A potential weakness is the limited period during which data are collected and submitted to NREL for up to three of the five stations in the project.
- Weaknesses include the challenge of developing a project dependent on permitting and other aspects that are outside of the team's control.
- Planned analysis of collected data is lacking.

### Recommendations for additions/deletions to project scope:

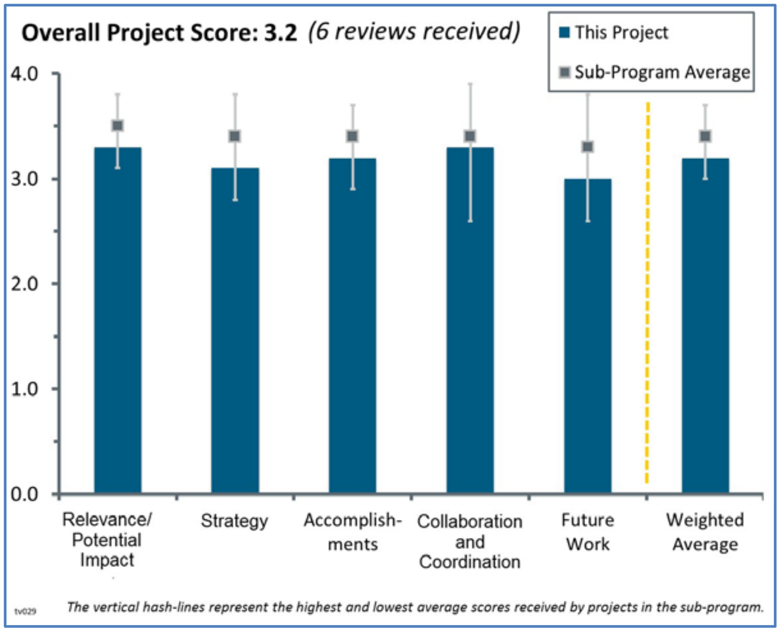
- The project scope is appropriate as long as the permitting issues are solved. The plan for a no-cost extension may be appropriate in this case.
- The project should add an additional station if the Foster City station cannot be completed in a timely manner. It is also recommended that the project add no-cost extensions where required, and it should ensure that follow-up continues and data are shared.
- The reviewer has no recommendations for additions or deletions but has concerns about severely curtailing data for some of the five stations under a "10 station-year" plan. It is recommended that at least four quarters of data be provided for each station.

# 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 explores the potential for reaching high volumetric (50 g $H_2$/L target) and gravimetric (9% $H_2$ weight fraction target) storage performance within a small (63.5 L internal volume), high-aspect-ratio (34 cm outer diameter and 100 cm length) cryogenic pressure vessel with long durability (1,500 thermomechanical cycles) refueled by a liquid hydrogen ($LH_2$) pump to be tested for degradation after delivery of 24 tons of liquid hydrogen. Cryogenic pressurized hydrogen storage and delivery provides safety, cost, and weight advantages over alternative approaches to long-range (500+ km) zero-emissions transportation.




## Question 1: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.3** for its relevance/potential impact.

- This project fully supports the U.S. Department of Energy (DOE) Hydrogen and Fuel Cell Program (the Program) goals and objectives.
- The project has high relevance because it looks at one possible solution to a key set of challenges for hydrogen-fueled vehicles—fuel storage density and storage system cost. If these problems can be solved in a meaningful way, the impact is high. Whether the approach being studied will offer a commercial solution is an open question.
- The presentation is outstanding.
- The project is aligned with Program goals and has made progress. However, without a more detailed full well-to-wheels analysis, there are concerns about overall efficiency. Boil-off is being investigated at the pumping station, but there is still a significant loss. Moreover, trucking from the hydrogen generation facility is not addressed.
- Research, development, and analysis prior to this project have indicated advantages for cryogenic pressurized hydrogen storage, transportation, and dispensing. Based on the presentation (slide 4, "Relevance"), this project has focused on the issue of $LH_2$ pump performance and durability. While this issue is important, it is one of multiple challenges that must be successfully addressed before $LH_2$ can be considered commercially viable and competitive as an automotive fuel.
- At the moment, the relevance of the project regarding market uptake might be low because most of the carmakers are pushing compressed hydrogen. With a view on future large-scale deployment of hydrogen, $LH_2$ might get a further push.

## Question 2: Strategy for technology validation and/or deployment

This project was rated **3.1** for its project design, approach to addressing barriers, feasibility, and integration with other efforts.

- The approach looking at vessel durability and hydrogen pump performance and durability is excellent.
- The project has an excellent approach for the evaluation of $LH_2$ vessels.
- The approach allows two components of the project to be tested at once. (The vessel has been cycled in temperature and pressure using the cryo-pump, so both are being tested.) This also allows system interactions between the two parts to be considered.
- The project approach—cycle testing of a prototype pressure vessel using the $LH_2$ pump—seems reasonable as a means to determine storage vessel and pump performance. However, if one is not familiar with the rationale and alternatives for the project approach, it is unclear whether any alternatives could have resulted in more performance and durability data. For a $4.7 million project with a duration of 3 years and 9 months, the 456 cycles, 19 days of data collection, and 1,650 kg of hydrogen dispensed seems limited. It would be good to know more about what accounted for the time and funds.
- The project focused on improving storage cylinder and pumping station losses in a very applied manner. Progress was made on the storage cylinder, but much more is necessary on improving pumping station efficiency. Also, to be effective, it would need to integrate with the entire $LH_2$ transportation infrastructure system, which was not shown.
- While boil-off and venting losses, as well as how to manage these losses, were discussed, the cost of liquefying hydrogen and a comparison with the compression of hydrogen were not as well addressed.
- Boil-off for fuel cell electric vehicles not in use was discussed and appeared to have been deemed acceptable, but it is not clear whether consumers will accept the loss of their fuel dollars. Venting losses associated with delivery truck depressurization was discussed, and while the audience was advised that the problem would be addressed, there was no indication of how.

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

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

- Excellent progress has been made, especially regarding collecting data from $LH_2$ pumps.
- The “Accomplishments” portion of the presentation (slides 6 through 13) provides excellent information resulting from 19 days of storage vessel and pump cycle testing performed during May 2016. Some results (e.g., pumping rate) were positive. Other results indicate a need for further technology development and testing. The project demonstrated that significant work remains to be done on topics such as $LH_2$ storage vessel design and excessive venting of hydrogen to the environment. However, there are concerns about minimal documented accomplishments, given a relatively large project budget and nearly four-year duration.
- $LH_2$ might have a growing relevance in future hydrogen deployment. Therefore, the results contribute to future technology development, although basic research is needed.
- The testing cycles were completed as noted. Perhaps the most eye-opening finding from this is the amount of hydrogen lost to boil-off and venting.
- The project is effective, the Lawrence Livermore National Laboratory team must be working on barriers, and the presentation did advise that boil-off losses were being addressed; however, there was inadequate discussion on what could be achieved to limit system and consumer losses.
- The project has made progress on advancing storage cylinder cycling on simulated operational cycles and high refill rate capability. However, there are concerns about efficiency at 1.1 kWh/kg hydrogen and 1.5 kVAh/kg hydrogen electric consumption. While claimed to be low consumption, it appears to be a high energy penalty. What it is being compared with is unclear. More concerning is boil-off by the pumping station demonstrated at 26% of pumped hydrogen. This is unacceptably high. Projections claim this can be reduced to 3.6%, but this is still significant and ignores boil-off in the trucking transport of $LH_2$ to the pumping station and other overall losses.

## Question 4: Collaboration and coordination with other institutions

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

- No collaboration weaknesses were noted; collaboration is significantly better than for most other presenters.
- The project has excellent collaboration with industries.
- Collaboration is good in the pump and tank parts of the overall fuel value chain. It would be useful to include more technical detail and cost analysis of the interface parts of the system. For example, it is likely that this technology still requires a cryogenic fueling hose, but the principal investigator (PI) did not seem able to answer that question during the review. There are also concerns that the energy of liquefaction and the amount of boil-off and venting throughout the entire hydrogen production, transport, storage, dispensing, and use chain are too high to be viable (the 3.6% loss number cited is likely only for a very small part of the chain).
- Collaboration with BMW is appreciated, especially with the next phase of testing of the BMW prototype vessel. Other collaborations should be considered with market players that look into $LH_2$.
- The project is partnering with BMW, the Linde Group, and Spencer Composites.
- Slide 15, addressing collaboration with industry leaders, provides information only on the three project partners. Nothing in the slide set or the oral presentation indicated collaboration or communications outside the project team. The reviewer agrees with a previous reviewer comment about conducting a stakeholder workshop (slide 14). The project team could benefit from recommendations and input provided by those who are skeptical about the use of $LH_2$ as a vehicle fuel.

## Question 5: Proposed future work

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

- The proposed future work is consistent with work completed and challenges recognized.
- Testing of the BMW prototype and the extension of testing parameters are highly appreciated.
- The future work is on increased cylinder cycling durability and improving filling station infrastructure, but greater focus is needed on improving pumping efficiency and decreasing boil-off.
- The current project is scheduled for completion in September 2017. Future work, as outlined in slides 17 and 18, seems to be more of the same, i.e., demonstrating performance/durability of a cryogenic vessel prototype and a pump. The Program Annual Merit Review presentation and project results have not made a convincing case for the future work described. The issue of $LH_2$ feasibility should be addressed by DOE before any further investment in similar testing and validation. $LH_2$ may have potential advantages, as suggested by the project team. However, an objective, hard-nosed, and comprehensive assessment of the current state of the technology, and technology prospects, should be done prior to making another significant investment in validation of selected components. In response to a question, the presenter noted that some fundamental research is still needed, e.g., on storage vessel design.
- The project needs a more thorough understanding of vehicle fueling process and equipment. Also, the project needs a metric for comparing technologies—maybe energy per kilogram delivered to the car—and it needs to include the energy of liquefaction (even if called an investment). Also, the project needs to understand vehicle fuel tank latency—it is likely that an order-of-magnitude improvement (something like a 10% loss in 30 days) in vehicle loss/boil-off is needed. The PI wants to use a “typical driver only loses x% of [hydrogen] in normal use” metric for latency. It is not clear whether this would work from an automotive industry perspective where typically things have to be designed to accommodate 98th or 99th percentile uses and situations.
- It is not clear how the “slow and complex” manufacture of vacuum vessels will be addressed.

## Project strengths:

- Cycle testing using an $LH_2$ pump seems reasonable as a means to determine storage vessel and pump performance. The involvement of Linde and BMW as project partners is a plus. They have relevant expertise and a commitment to $LH_2$ technology.

- The project has well-planned and well-designed approaches, especially regarding $LH_2$ pumps.
- The project has a good plan to test the specific elements included in the scope and good collaboration to achieve that testing/data.
- This is interesting work on a technology with some opportunities that were not previously evaluated in comprehensive research projects. The project might show important advantages if it can get vessel manufacturing and losses in the whole chain under control.
- The aggressiveness of the effort is a project strength.
- The project has demonstrated high cycling capability and fill rate for $LH_2$ storage cylinders.

## Project weaknesses:

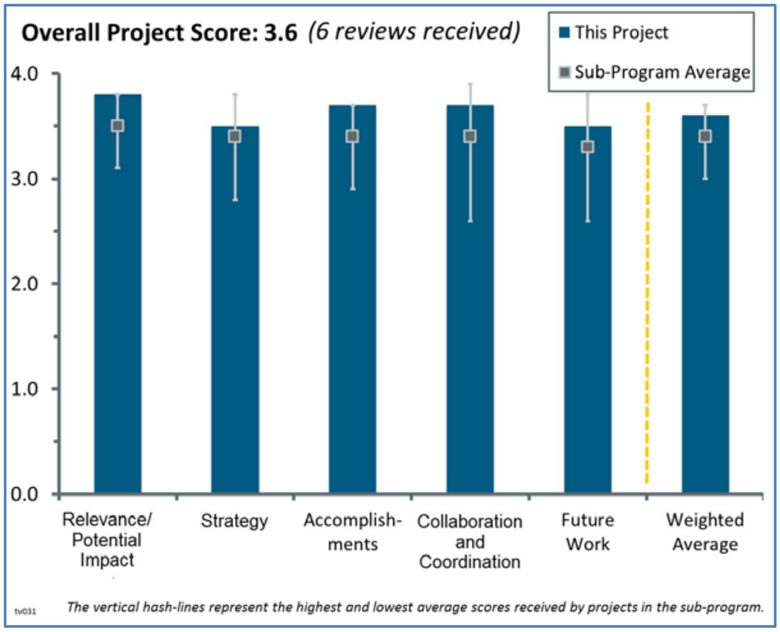
- The shortcomings were not always explained.
- Significant boil-off needs to be addressed as well as improving cycle efficiency.
- The future work needs more details and definition.
- The project does not really address whether the whole $LH_2$ system from production to power generation can be economically viable (e.g., cradle-to-grave boil-off, energy per mile driven, cryogenic fueling hose, etc.).
- Market relevance of $LH_2$ is not a given at the moment. It is unclear whether $LH_2$ will increase in relevance in the future. Results of the project show opportunities but also point out some challenges in $LH_2$ storage.
- The project has limited results for a significant expenditure of resources. A basic premise linked to the project seems to be that $LH_2$ is the most viable approach to hydrogen distribution and vehicle fuel storage (see slide 14). However, the results of the project fail to provide evidence that supports the premise, even though the presenter stated that performance (presumably of the pump) was consistent with Argonne National Laboratory analysis. Including a spreadsheet that compares selected metrics for $LH_2$ and other hydrogen vehicle-fueling options, and provides context for this project, could have been helpful in evaluating project focus, relevance, and approach.

## Recommendations for additions/deletions to project scope:

- It would really be good to see the whole system energy use and boil-off losses needed to implement this type of storage, as well as more consideration given to defining acceptable tank latency.
- The project should address well-to-wheels efficiency: boil-off and electric consumption.
- Further stakeholders should be included.

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

Rob Hovsapian; Idaho National Laboratory




### Brief Summary of Project:

This project is demonstrating the fast-reacting performance of electrolyzers and characterizing the potential and highest economic value of their installation to enable participation in energy markets and demand response programs. A novel approach of distributed real-time simulation is used, with electrolyzer hardware at the National Renewable Energy Laboratory (NREL), used in conjunction with power system simulations at the Idaho National Laboratory (INL).

### 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.

- Grid integration is very important for increased renewable energy and more rapid deployments of fuel cell electric vehicles by providing lower-cost hydrogen. This foundational work will meet Fuel Cell Technologies Office goals and accelerate the deployment of electrolyzers while increasing grid reliability.
- This project is directly aligned with the goal of demonstrating grid energy storage and hydrogen production from potentially renewable resources. The interactions with the electrical grid are quickly becoming recognized as one of the largest unknowns with the most urgent need for insight and clear understanding within this space. This project is essentially the only work looking to demonstrate real-time capabilities of hardware systems that will need to be placed in the field in the near future and validated for the intended two-pronged purpose of hydrogen production and grid services to enable increasing implementation of renewable electricity on the grid.
- This project clearly addressed U.S. Department of Energy Milestone 3.9, related to Systems Analysis and Technology Validation. The impact of this project is far-reaching, and it identifies areas for future development that make good economic sense, as well as the possibilities for what can be done today to implement hydrogen technology.
- The project basically explores the possibility of cross-linking hydrogen production (cheap and renewable) with the power sector. It addresses the capacity of electrolyzers to balance the electricity grid, namely owing to the fluctuating electricity production from renewable sources and variations in demand. This entails the need for fast response for real-time adaptation to production and grid conditions. Production of hydrogen through electrolysis when electricity is in over-supply (hence “cheap” according to supply–demand trends) should allow the production of low-cost hydrogen, thus allowing for feeding low-cost hydrogen to the user, namely, users in the transport sector. Furthermore, increasingly “low-carbon” hydrogen can be produced if the grid renewables content is increased.
- Grid balancing and grid services can be some of the advantages of electrolyzers as part of the energy system. These can also contribute to a business case for the operation of electrolyzers (and therefore the deployment of the technology) and support the integration of the growing share of renewables in the electricity system.

- The project provided a clear description of its relevance and objective, including statements of how the objective will be met. However, it is not clear how this will reduce hydrogen costs. It is not clear that there is a reduction in the cost of the electric power used for the electrolyzer because it benefits the grid.

### Question 2: Strategy for technology validation and/or deployment

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

- The excellent approach from the high level of grid signals and hardware response from the electrolyzer clearly shows the capability and goes into intricate details that are often missed with other studies. The 500-hour test with the electrolyzer and the Real-Time Digital Simulator (RTDS) are uniquely set up to show stakeholders the value, capability, and reliability resulting from close integration.
- This project to date has addressed the barriers of a lack of data in real-world operation and also hydrogen–electricity co-production and the milestones/goals are well-thought-out. The integrated approach between modeling and the use of real hardware is very good, and it makes the economic results relevant and convincing. Future work will address the barrier of hydrogen from renewable sources, and it should be interesting to see how this affects the cost of delivered hydrogen.
- The project combines tests with real-life data from grid operators. Therefore, the relevance regarding the transferability of the results for the operation of electrolyzers is high. The early interaction with grid operators is crucial for the further awareness of the technological advantages.
- The project does an exemplary job of addressing the noted barriers to renewable hydrogen and electricity co-production. However, other barriers that were listed include the implementation of stationary fuel cells in real-world operation. There does not appear to be any inclusion of a fuel cell in the test system. None were mentioned in the methods or in the remaining challenges and scope for future work. While an electrolyzer is similar to a fuel cell, and the merits of the electrolyzer work on its own are significant enough validation of the need for this project, it appears to be that the project does not address one of the claimed barriers at all.
- This is essentially a modeling project based on the simulation of an existing electricity grid (in California) interconnected with hydrogen refueling stations (although the stations themselves are not integrated in the model). A real (experimental) electrolyzer is connected to the model grid, and its response to impulses and effect on the grid is monitored. The point of view is essentially from the grid standpoint. It looks at what improvement on grid stability can be provided by the electrolyzer while also monitoring the derived effect on hydrogen production costs. No detailed information is given on the electrolyzer itself (250 kW—presumably a polymer electrolyte membrane electrolyzer, but nothing else is disclosed), and hence, the electrolyzer-improvement lessons cannot be drawn from this project. The project appears well designed and feasible.
- The project provided detailed identification of the components used in the experimental setup under the approach and an explanation of the testbed configuration. There was a good explanation of the components and functions of the front-end controller. It is not clear how the front-end controller yields fast response because of dependence on balance-of-plant (BOP) response time. Identification of metrics is at a top level; e.g., it is not clear what "safe operation" entails. The explanation of optimization of BOP does not provide a comparison describing the improvements or what was changed.

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

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

- The unique capability that this project demonstrates is how to use physical HIL in response to real-time electric grid data, which is on its own a unique and major achievement. Additionally, the demonstration of grid support capabilities, while not unique or a first, makes significant contributions to the growing body of knowledge regarding real-world expectations of electrolyzer performance. The business case analysis is also among the highlights of accomplishments for this project. The ability to translate highly technical capabilities of the electrolyzer into the opportunities and limits of real-world application is one of the greatest information needs in the area. The particular approach this project takes toward that end adds confidence to these results and is highly valuable.

- The grid modeling results from Pacific Gas and Electric Company (PG&E), with the map of regions and locations of electrolyzers with actual load profiles, gives an excellent view and provides education to those who might not understand the use and capability of electrolyzers and grid integration. The clear example of a fault situation and how electrolyzers can respond rapidly shows the clear value of the project. This is especially important when traditional generation with “grid inertia” support (reactive power) is gradually declining with increased solar and wind generation. The efficiency results were clearly demonstrated as well as grid simulation capabilities. All of these results can be fed back to research and development efforts on electrolyzers, fed to the grid integration and modernization efforts, and—most critically now—passed forward to grid stakeholders so appropriate policy frameworks can be implemented.
- The project’s great success in showing the positive effects of the front-end controller and pointing out the advantages of electrolysis for grid operations contributes highly to a positive perspective for future electrolyzer deployment. The excellent approach and the high quality of work regarding verification and validation of the results are highly appreciated.
- Good progress has been made on all goals outlined, except Milestone 2, but it is expected that the milestone will be complete by the new deadline. While potentially outside of scope, it would be interesting to investigate the effect of electrolyzer and system scale on the economics with the model. Generally, scaling the systems up has resulted in lower cost per kilogram of hydrogen.
- The milestone table gives the status of recent and past accomplishments. Chart 14, “Summary of Accomplishments,” is more of a shopping list and does not fully explain what the barriers or accomplishments are. Subsequent charts yield additional information explaining benefits. Electrolyzer data provides a basis for improving the controller and optimizing electrolyzer performance. It is not clear what the benefit of demonstrating HIL capability is and how it moved the project forward. It is not clear whether charts 16 through 19 include an electrolyzer with BOP or just a stack. It is not clear how the electrolyzer response is determined. The business case analysis reduces the cost of hydrogen by 50%, which is extremely good. This should be cross-checked by an independent third party. It is not clear whether the analysis includes the delivery of hydrogen to the user. The economic benefit for a U.S. state assumes a demand for hydrogen. It is not clear whether utilities go into competition with the gas industry. It is also not clear who the owner/operators of the electrolysis systems are and whether the cost includes delivery to the user.
- The presentation was very difficult to follow owing to the wide use of acronyms and the technicalities related to unfamiliar grid operations. The results presented demonstrate the relevance of electrolyzers for stabilizing the grid against frequency and voltage peaks, while at the same time producing hydrogen in a more or less efficient manner, depending on the power feed and according to grid needs. In parallel, the perspective of electrolyzer cost and revenue optimization are also modeled in the optics of producing hydrogen using cheap electricity at times of favorable supply–demand conditions (high supply, low demand) while attempting to maximize electrolyzer operations. A comparison across the U.S. states is made according to utilities’ rates. The project is progressing steadily toward its goals, albeit with some delay. It is expected to reach the 500-hour operation milestone by end of 2017, somewhat late compared to the project plans. Initial results are encouraging, showing the swift response and beneficial effect of electrolyzer “intervention” in case of simulated faults in specific locations (nodes) of the grid, be it in terms of voltage or frequency peaks/troughs.

### Question 4: Collaboration and coordination with other institutions

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

- Because of the nature of the work, there was extremely tight collaboration with INL, with the RTDS and grid signals, and also NREL’s support and management of the electrolyzers, monitoring of individual components, and capability to respond to variable operation. The highlight and most important collaboration is the early input from end-user stakeholders: PG&E, California Independent System Operator (CAISO), Xcel Energy, and EnerNOC. The input from Humboldt State University and Florida State University is very important for workforce development and encouraging the knowledge and capability expansion outside of California. The California Air Resources Board is an important stakeholder,

and the business case evaluation will further push this project forward with electrolyzers and lower-cost hydrogen coming into the market.
- The direct collaboration for this project, with utilities in particular, and the ability to use real-time data based on their system performance and knowledge are accomplishments that several other projects have not previously been able to achieve. These partners and their contributions are a key part of this project's usefulness and success. All other project partners present a wide range of knowledge bases and end uses for the information produced by this project. Engagement with the state of California is likely to be a boon to faster implementation of this project's goals, given the state's current efforts in renewable energy and hydrogen.
- The efforts would seem well distributed among the project partners where roles and tasks are effectively respected. A wide range of stakeholders from various fields (utilities, environmental boards, DOE laboratories, and academic research) is taking part in the project, and the collaboration appears constructive.
- The team is well organized and well qualified, and all parties appear to work well together.
- Including real grid data and the grid operators already in the early stage of the project emphasizes the relevance of the topic for operations.
- Collaborations include key energy producers but do not include electrolyzer manufacturers. It is not clear how chart 22 got the electrolyzer cost reduction without having an electrolyzer manufacturer collaborating with the project. The power production industry is heavily regulated and does not have a reputation for innovation. It is not clear where the rest of industry is for this project. Subsystem characterization for stack is reported, but the feedback comment does not address BOP response time. Direct electrolyzer response time should be fast, but BOP hardware will be slower. The question addressed BOP. The project managers are attempting not to answer reviewer questions. This type of response reduced the rating in question 7.

### Question 5: Proposed future work

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

- The proposed future work hits all the key points. The ability of the grid-controlled electrolyzer to reduce the cost of produced hydrogen is the key underlying question. The front-end controller and cost analysis are very important to enabling the electrolyzer integration. The real challenge and success will be when grid rules and requirements can be adjusted for full electrolyzer integration into electricity markets in California and then in other states.
- The plans for the future are to continue to achieve the proposed milestones. The focus on renewable energy is appropriate. The plans to communicate the findings through a webinar and papers are excellent.
- Further work items, including validation and verification, show the excellent approach to facilitating the integration of electrolyzers in real-life grid environments.
- The only concern is the time left for the future work to be completed. The work is logical, and risk mitigation is planned, but it seems like it will take longer than the remaining project time, especially considering any documentation time that may be required.
- This is not really addressed in the presentation, and in fact, the project is virtually finished (ending in September).
- It is not clear where and when the response time of the BOP (not the stacks) will be reported.

### Project strengths:

- The direct applicability of the project and the imminent and significant knowledge gap that it addresses are core strengths. Additionally, the unique approach, collaborations, and tie to real-world business case analysis will prove extremely powerful in the project's outcome.
- The project addresses multiple barriers and specifically addresses a DOE milestone. Progress has been mostly on schedule, and the results and tools delivered so far are useful for understanding the role of electrolysis with the technology available today. Plans will also likely deliver data that has high impact, and the plans to share results are notable.
- The project has an excellent approach, with comprehensive grid modeling based on real-life data. Collaboration with grid operators is also a project strength.

- Projects strengths are the collaboration and well-thought-out design of experiments and equipment integration.
- The project has a well-organized approach and an acceptable team, except that an electrolyzer manufacturer is needed.
- The project has powerful modeling work capable of illustrating the mutual benefits of water electrolysis for grid services and hydrogen production for an effective cross-linking of the two sectors.

### Project weaknesses:

- No major weaknesses are detected.
- The project would benefit from a better roadmap and explanation of how the project information can be directly input into an electricity market formulation so that electrolyzers can be treated as being as capable as batteries.
- The only weakness is that the project approach allows only for evaluation of the possibilities provided by present-day electrolyzer technology. Electrolyzer hardware is rapidly evolving, and there are expectations for significantly greater operational capabilities in the not-too-distant future. Although projections of future capabilities are beyond the core scope of this project, it would have been favorable to see some of this added to the project.
- The project has not fully demonstrated that the BOP response time will be acceptable.
- The main weakness does not address the science but rather its dissemination; the project could benefit from a clearer presentation and illustration of the benefits from both the grid and the hydrogen production standpoint, using terms that both sectors are able to understand. It was difficult to follow the grid standpoint because of a lack of familiarity, and this was not helped by the wide use of acronyms. For the electrolyzer part, there appeared to be no statement on the technology addressed and other specificities, while presumably this must play a significant role in some of the results.

### Recommendations for additions/deletions to project scope:

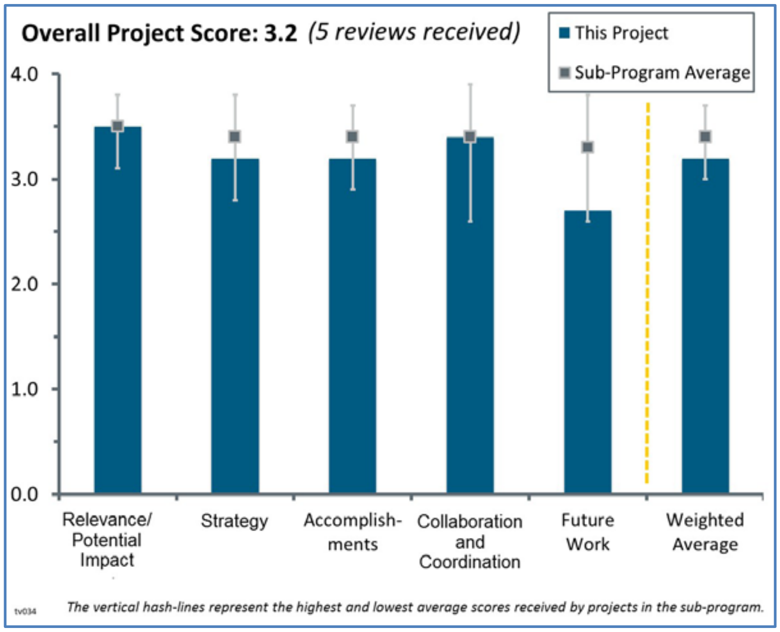
- The project scope is appropriate as long as the delay in the 250 kW testing does not delay other milestones. It did seem it would not pose any issues.
- Where scope and budget are available, the project should look for further meetings with CAISO, the California Energy Commission, and the California Public Utilities Commission to discuss how these results can inform electricity market updates and to start discussions with the Federal Energy Regulatory Commission.
- A good addition would be some way to project differences in the grid-integration-level possibilities for future electrolyzer technology. This is simply in acknowledgment of the rapid pace of development in that field currently and the potential for this project’s results based on current electrolyzers to under-predict the benefits of such a system by the time it could be implemented in the real world.
- It is recommended that the project bring in an electrolyzer manufacturer that will guarantee the response time of a commercial electrolyzer. The project should explain why the BOP response time was not specifically given, because previous years’ work assumed an electrolyzer stack response. An independent third party should analyze the business case.
- Future work may also include the integration of different electrolysis technologies to see whether any of them can show further advantages for grid services.
- The project is about to finish, so no recommendations appear to be relevant at this stage.

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

Jason Hanlin; Center for Transportation and the Environment

### Brief Summary of Project:

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




### Question 1: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

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

- The project scope is relevant in that it aims to validate, in real-life conditions, the combined use of battery electric drive with hydrogen fuel cell electricity generation for extended-range versus battery-only electric motors, combining the best of both worlds in the quest for effective zero-emission solutions in United Parcel Service (UPS) parcel delivery vans. The project has the potential to bring evidence that the technology is ready, competitive, and effective in practice, with the elimination of battery-only limitations such as range.
- The fuel cell hybrid delivery van has the potential to reduce operating costs, reduce fossil fuel use, and commercialize the application of fuel cells for medium-duty transportation. Fleets of zero-emission delivery vehicles provide enormous market potential, and this project will showcase the capability and is a potential key to convincing industry and other players to invest. Fossil fuel reduction and zero emissions at the community level will be a visible end result to prove the value of the technology.
- This project has enormous potential to address a critical need in terms of viable medium-/heavy-duty commercial vehicles using fuel cells and in long-range applications. Unfortunately, funding gaps suggest it may end up being of less value than it could have been.
- The project fully supports the U.S Department of Energy Hydrogen and Fuel Cells Program goals and objectives, especially for fuel cell vehicles.
- There is a high potential impact owing to the limited range that comparably sized battery-powered electric medium-duty delivery trucks have been shown to deliver.

### 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 and system validation are well planned and will provide the critical element of performance and durability data. By using the system in real-world applications, the market acceptance barrier can be overcome and help educate decision makers regarding the economic value gained from using low-carbon transportation. User experience from driving these vehicles and managing infrastructure will be key to providing know-how and the opportunity for improving and optimizing the system with future improvements. Funding should not be a barrier and speaks to the design of the state and federal demonstration programs and the need for better coordination, which is outside of the control of the industry project partners.

- The project has some excellent components, such as developing an option for longer-range delivery services (which lack good zero-emission vehicle options) and an opportunity to work closely with a shipping concern such as UPS to ensure fuel cell system integration meets UPS's needs. It is understood that dual-port fueling will be performed for practical reasons, but it is noted that it makes the viability of this technology less clear.
- Regarding project design:
    - The project foresees the initial development of one prototype vehicle and test-driving that vehicle for six months before making a go/no-go decision for the development and further testing of up to 15 additional vans. The project design appears sound, although the criteria for the decision to move to Phase II are not clear.
    - With respect to implementation, it seems to have slipped more than one year without explanation. The presentation suggested that delays are due to a modification of the consortium, although this remains vague. Further problems appear to be due to funding, which is not yet secured, so that the number of additional vehicles to deploy in Phase II may be reduced considerably in comparison to the 15 originally planned.
    - Surprisingly, a fueling problem is described in which the fueling stations to be used for the project are not configured for fueling 10 kgs of hydrogen in a single operation; two tanks will be refueled separately through different ports (one at each side of the van). This will inevitably increase the refueling time but is a viable solution at this stage. Ultimately, UPS would, if the technology is widely adopted, install its own refueling station.
- The project activities are well planned and well designed.
- The go/no-go decision point is February 2017, an apparent typo as the Phase 1 demonstration had an estimated completion date of January 2018. The approach is good, but there is a very tight timeline considering the vehicle build status in June 2017 and the goal of collecting six months of operational data. It is not clear whether the arrangement (fueling contract and payment card) is in place to fuel vehicles at a hydrogen station (West Sacramento or elsewhere). Fueling may also require a number of fueling tests, as it appears the assumption is that this vehicle can be fueled without any challenges.

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

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

- The project has an outstanding platform design and went into significant detail to model and simulate actual routes, fuel requirements, and the difficult challenge of sizing batteries and the fuel cell. With 50% of the project complete, the real test will be how much data is collected and to identify a clear path around the challenges of refueling infrastructure. The delayed start due to funding issues may result in fewer metrics or less progress.
- The project demonstrates improved progress in this past fiscal year, although it still has a long time horizon and seems to be struggling to keep pace with that. There is a concern that while this project is working to get off the ground, other technology developments will be occurring that will make the results of this analysis less relevant.
- Satisfactory progress has been made to manufacture the first vehicle, showcasing the chassis and components at the Advanced Clean Transportation Expo in Long Beach in May 2017. It would be good to hear that a fueling contract is in place and that fueling tests are scheduled.
- The project seems to make steady, albeit slow, progress, and it would seem that the first vehicle will finally be deployed in the coming months. Currently, and at least until the first vehicle is demonstrated, it is difficult to decide whether the design will work or drawbacks will emerge. In any case, learning could be drawn even from problematic setbacks, so steps toward DOE goals will still be made, albeit more in terms of what not to do.

- There have been delays in the demonstration vehicle build.

### Question 4: Collaboration and coordination with other institutions

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

- The collaboration required for route simulation and vehicle component sizing between UPS and the integrator is a difficult challenge that was satisfied. The design and tank development require close collaboration, and perhaps more suppliers could be brought in to compete for supplying a new “off-the-shelf tank” choice, or looking at a new design shared among multiple customers.
- There is excellent collaboration among several organizations, especially UPS.
- There is little information about this in the presentation, but there is no reason to doubt good collaboration now that the consortium is confirmed.
- It appears that the right partners are on board and actively contributing now. Insufficient cost-sharing commitments have put the project’s go/no-go decision point at risk.

### Question 5: Proposed future work

This project was rated **2.7 f**or its proposed future work.

- This project should include fueling tests, as a single-tank system (times two with independent receptacles to get to the 10 kg total vehicle capacity) falls within the 35 MPa SAE J2601 fueling standard; dispensers at California retail hydrogen stations may respond differently for multiple-tank systems from the single-tank systems on passenger fuel cell electric vehicles. It should not be a problem, but with the current schedule, additional delays cannot be afforded.
- The main decision point is the go/no-go decision to be taken after deployment of the first vehicle.
    - This makes perfect sense, although the criteria to be used to determine whether the project should be continued are unclear. The bottleneck of vehicle construction should nevertheless be addressed since it took more than three years from the project’s start to completion for the first van; it seems important to ensure that the following vehicles are produced significantly more rapidly so as to be deployed in time to produce relevant performance data by project end. There are doubts that a 5,000-hour operation time per vehicle (apart from the first prototype van) will be possible by the end of 2020.
    - The go/no-go decision (scaling from 1 to 16 vehicles) was initially intended for February 2017, yet even the first vehicle is not yet deployed, and the decision seems to be now scheduled for “early 2018.” At the submission deadline for the AMR presentation, the first vehicle was still only 50% constructed, so it is hard to believe that in the first quarter (Q1) of 2018 the vehicle will have been on the road for the intended six months to allow for an informed decision to scale up the demonstration fleet. Furthermore, the principal investigator mentioned that the prototype van would not be deployed over the Christmas period, so the utilization period will be further reduced. Currently, the project could be ready for a go/no-go decision no earlier than April–May 2018, assuming that the first vehicle is deployed this fall (it is unclear if it will really be ready by September). It is difficult to be confident of the scheduling indicated for Q1 2018.
    - Should a “go” decision be taken, it is uncertain that the project can secure the funding for all 16 vehicles originally foreseen. Phase II vehicles would then need to be built, placed into service (with possibly one year required for production), and operated for two years to comply with the project plans. This may not be feasible within the current project end date in November 2020.
- While future work appears logical, the shifting target on remaining cost share did not appear promising. The most critical elements will be to finish the vehicle build and vehicle operation in order to collect data. There does not appear to be a risk mitigation option if the funding is not available. Training and education are also important and should be straightforward after the vehicles are complete.
- Unfortunately, this project is suffering from elements outside its control, namely funding availability. It appears that the Phase II development of pre-commercial volume may not happen; this is a real limitation on the project’s real value to move fuel cell technology forward in this application. It appears that it may be up to the private sector partner to carry this forward.

- Details for the proposed future work are lacking.

### Project strengths:

- The project has strong collaboration between partners, including a thorough review of component requirements needed to advance the DOE Fuel Cell Technologies Office (FCTO) roadmap goals. The project team provided detailed modeling and simulation results required for system sizing. This will ensure the results are accepted by industry and that regulatory agencies see the technology potential needed to ensure a higher chance of commercialization, which is the ultimate goal of FCTO in bringing new technologies to market. An important strength was the clear collaboration between multiple project partners and sponsors to share the data and knowledge from the publicly funded project. Detail-oriented safety hazard and operability analysis, including operator training, will be vital to ensuring the smooth introduction of the new technology and gaining acceptance from the public, the industry operator, and communities where the trucks will be used.
- The project has the potential to bring high visibility to fuel cell technologies owing to the relevant vehicle fleet operator (UPS). The presence in the media since spring 2017 will hopefully allow the technologies to reach a wider public and feed into the goals of the “Education and Outreach” technical plan, namely on technology awareness and acceptance. This could result in increased market uptake, at least in markets with favorable infrastructure density, such as California.
- This addresses a real gap among current technology solutions for low-/zero-emission delivery vans. Collaboration with UPS is a plus. The vehicle appears to have been designed largely to meet real-world delivery needs.
- There is potential of a fuel cell drivetrain in the project’s truck vocation. Partners and component suppliers are a strength.
- The activities of the project are well designed and well planned.

### Project weaknesses:

- There seems to be a high uncertainty as to what the project will eventually develop into, namely the total number of vehicles deployed (in the case of a “go” decision). In addition, the schedule presented appears unrealistic and will lead to a non-completed project unless the timeframe is extended beyond 2020.
- The need to use public fueling is unfortunate in the impacts it had on vehicle configuration. Clearly the biggest weakness is the potential for this not to move to Phase II. That is a risk with this type of project configuration, but it does seem as though the project may end in “stranded” vehicles that do not move to a commercial phase.
- Funding, or lack of funding, coordination between local, state, and federal agencies is a project weakness.
- Project delays and lack of details (including risks and risk mitigation) for proposed activities are weaknesses.
- A funding shortfall, the cost of 70 MPa tanks, and (external) fueling protocol limitations are weaknesses.

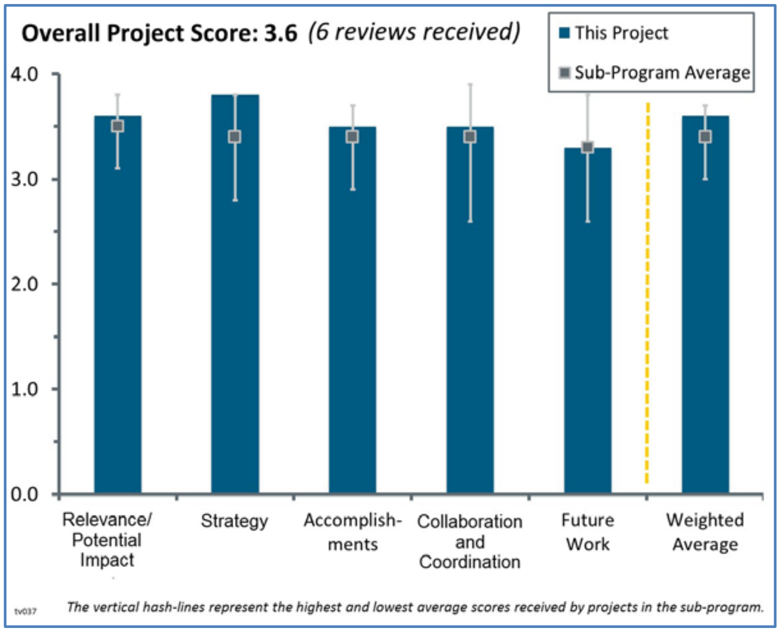
### Recommendations for additions/deletions to project scope:

- The project should consider using 70 MPa tanks similar to those used for Toyota Portal truck or passenger car tanks and purchase through car manufacturers to take advantage of scale contracts with tank suppliers. The project should explore larger batteries or battery systems (from existing passenger vehicles such as BMW or Nissan; BMW battery systems are showing up in other applications as a reliable supplier-supported system) to deal with challenges of fueling protocol limitations at 70 MPa. Relying on passenger vehicle battery systems may also aid in reducing overall costs, including cost reductions that can be achieved by using/acquiring smaller fuel cell systems—possibly 16 or 20 kW. For future marketing of developed systems and focus on “kit approach,” the project should consider approaching an entity such as Freightliner Custom Chassis.
- In the light of all information available in the presentation, there should be a more realistic plan and strict implementation management to avoid further delays. This should also include specific, measurable, achievable, relevant, and time-bound criteria that will be used in the critical go/no-go decision step so as to be able to apply them promptly and objectively to take the appropriate decision. In case of a “go” decision,

given the uncertainty on the total number of vans that can be funded, partners should make relevant scenarios according to ultimate deployment numbers. The plan should also include preparation for the building of the additional vans in view of minimizing the time needed for further deployments.
- Funding should be increased for storage development for 10 kg modules that could be used across multiple fleet applications, not just for UPS. The project should develop an explicit off-ramp for the project and criteria needed for actual adoption by industry for zero-emission, medium-duty delivery trucks.

## Project #TV-037: Hydrogen Meter Benchmark Testing

Michael Peters; National Renewable Energy Laboratory




### Brief Summary of Project:

This project designs and builds a laboratory-grade gravimetric hydrogen standard for measurement of hydrogen flow; conducts performance testing of commercially available flow meters, replicating conditions specified in the SAE International J2601 fueling protocol; and reports on flow meter performance against National Institute of Standards and Technology (NIST) Handbook 44 (HB44) requirements and California Code of Regulations accuracy classes.

### Question 1: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.6** for its relevance/potential impact.

- This project is highly relevant to the support and advancement of the progress toward reaching the U.S. Department of Energy Hydrogen and Fuel Cells Program goals and objectives. The metering in a hydrogen refueling station is integral to designing, building, commissioning, and operating a hydrogen refueling station, which is often required by regulation to undergo testing and certification to sell the fuel. The development of a robust supply of accurate flow meters is essential to the proliferation of stations. The development and production of accurate flow meters that the public can rely on to output reliable, repeatable, systematic, and trustworthy data so both the hydrogen refueling station operator and the consumers that drive the fuel cell electric vehicles (FCEVs) are charged equitably is a cornerstone of the retail sale of hydrogen, and this is part of the project relevance.
- This project is highly relevant because it addresses real-time gaps in knowledge and potentially even equipment design that are affecting the real-world deployment of hydrogen fueling stations and hydrogen-fueled vehicles today. Meter accuracy is considered a key enabling technology in jurisdictions where hydrogen fueling stations are currently being installed because the ability to accurately meter dispensed hydrogen qualifies a station for retail sale of fuel. Without retail fuel sales, hydrogen FCEVs and stations will not be able to proliferate, and essentially the goal of demonstrating station capabilities is lost in real-world applications.
- The coordination with the California Division of Measurement Standards is excellent and absolutely necessary. The fact that one of the meters is a Coriolis that is in development is very good; perhaps it should be a prerequisite for this project that meters to be tested are not be commercially available or used.
- This project is important to benchmarking state-of-the-art metrology technologies and to doing so under actual filling protocols currently established (SAE J2601). The measurements performed are important and clearly quantify the accuracy shortfalls of the meters tested. The measurement test method is good, and the accuracy of the test facility is good enough for this application (+/-2.5 gm out of 4.0 kg). There is some concern, however, that some critical elements specified in J2601 were not tested. The test protocol included a start-and-stop sequence, but it did not include the sequence specified for leak testing (National Fire Protection Agency), which is a sudden stop, followed by a short time of zero flow, followed by a return to the pressure ramp specified in J2601. It is anticipated that this leak test sequence will result in significant

error, particularly because all the meters have a delay in measurement as identified by this project, and no known meter will measure accurately if the frequency of the data is infinity (sudden stop and start have frequency responses of infinity). Also, it would be beneficial to see the testing done across an entire J2601 fill process. This project was dinged on approach principally because only parts of the fill protocol were tested. The project should either test across the entire J2601 protocol or provide convincing reasons why that is not necessary.
- The project contributes to the understanding of metering devices and the relevant parameters that need to be addressed in regulations, codes, and standards.
- Three units were benchmarked: two Coriolis meters and one turbine meter. One of them is commercially available. A number of variables were changing during the fill: flow rate, temperature, pressure, readout response, etc. No attempt was made to remove a variable to determine individual effects. For example, if the fuel density range during the fueling process was reduced by 50% by controlling the meter inlet pressure and temperature, it is not known how this would affect the measurement accuracy. Expecting a meter to be accurate over a 15,000 psi pressure range and a 100°C temperature range may be unrealistic.

### 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 first major highlight of the approach is the test rig that was developed for this work. This appears to be a unique capability and is providing data that no other entity currently seems to be investigating. In addition, the use of statistical methods for characterization in this work was an intelligent choice and adds power and meaning to the results. Presentation of probabilities of meters to meet tolerances is a clear advance in the ongoing conversations in this area and is a necessary addition. It is encouraging that this project presents its results in this manner.
- The strategy for technology validation and the deployment of flow meters developed and presented in this project is reasonable and logical. The project is well designed; it started with data collection. The project analyzed station data, including efficiency, downtime, maintenance cost/time, capital cost, integration, and controls of stations in the field. The strategy also included engaging industry stakeholders to find solutions to meter benchmarks.
- The project has an excellent approach to contributing to awareness for improvements in metering accuracy as well as the understanding of critical parameters for metering.
- It is pleasing to see that the project is working to meet the +2%, because it is necessary for station deployment.
- The progress made to date is excellent, but it needs to go further.
- The test results support the concern on the measure range (pressure and temperature). During the process, it is not clear whether the researchers thermally choked the flow in the meter. The issue with vibration is interesting, but it is not clear whether it was from an external source or was flow-induced. If the vibration was from an external source, it is not clear whether there were ideas on how to isolate the meter from the source. If it was flow-induced, it may be an artifact of the meter or the installation. It is not clear whether the meter is experiencing vortex shedding or periodic thermal choking. It is not clear whether the meter is installed correctly. For example, the flow is usually disturbed for 5 to 10 pipe diameters after a component that might disturb the flow. Perhaps the meter was too close to a fitting or a device was located immediately upstream.

### 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 project has numerous accomplishments:
    - The station layout is complete.
    - The station components are purchased and installed (including a chiller and dispenser). Quality testing is complete.

  - The station flow diagram is complete.
  - Vehicles are on site.
  - An on-site electrolyzer is installed.
  - Power supplies are installed.
  - The Hydro Pac compressor is installed.
  - Low, medium, high pressure are installed.
  - In this two-year project (ended in 2016), there is a flow meter that works for compliance with HB44 (5% accuracy) and 2% meter accuracy. This project tested three flow meters, including one flow meter that is commercial.
  - The project simulated SAE J2601 fills and typical fueling conditions for FCEVs (0.5 kg to 1.2 kg fills). To simulate fills in the field, the project used +/-2%. This project tested the probability that the fill falls within a 2% accuracy. High flow rates (the meter did worse), pressure ramp rates, and the position of the meter were tested. The project observed false readouts under conditions of vibration. The time between when the flow stopped and when the meter stopped incrementing changed with the various meters.
  - The overall goal is to charge the customer the "right amount" and also charge the station the "right amount." This project made substantive progress to achieve this goal.
- This, in particular, is an area where the project has improved over the past year. The project's intent is now absolutely clear and is in the correct direction for meeting the needs of demonstrating the viability of a hydrogen fueling station. To that end, this project is providing much-needed insight that will enable deployment, use, and long-term viability of the types of hydrogen fueling stations that are part of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan goals.
- Metering is one of the crucial issues in the future deployment of hydrogen in the market. This project contributes to improving the accuracy of metering and, therefore, the market readiness of hydrogen as a transport fuel.
- The project has a lot of good information/learnings, but it would be nice to know which of the two Coriolis meters had the 73 g add with the 8-second delay and vibration (the one currently in use or the pre-commercial one). Either way, the project provides excellent information for station developers, meter manufacturers, and weights and measures officials.
- The work done to date may transfer to the dispenser product safety testing protocol.
- Meter accuracy is critical to the selling of hydrogen to the public. Current meters are not sufficiently accurate to satisfy the eventual accuracy of the needs of metrology (the relaxed accuracy classes currently used in California will sunset soon). This work should help meter manufacturers improve their devices.

### Question 4: Collaboration and coordination with other institutions

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

- The collaborators and coordination with other institutions are appropriate for this activity. This team consists of appropriate players in the field. Indeed, the Joint Research Centre Institute for Energy and Transport, which is well established as doing excellent work on understanding the fill physics, and NIST are both key partners. It is an excellent team.
- Collaboration included many stakeholders and end users. It is excellent across the board.
- There is great collaboration with producers of metering devices.
- The collaborative partners seem appropriate and complete. However, of concern are the noted difficulty with data confidentiality and, more important, the lack of clarity for a proposed solution to this issue. The ability to share the project's data and insights as closely as possible with equipment manufacturers will likely be the key to this project's ultimate impact. Additionally, there is noted collaboration with equipment manufacturers, but it could be preferable to have them as actual partners.
- Equipment suppliers, manufacturers, and regulatory agencies in California were included.
- The collaborators make sense. The issue is that none of the collaborators make flow meters.

### Question 5: Proposed future work

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

- The development of a control scheme to improve accuracy is an excellent path forward; it would be nice to do some complete J2601 fills.
- The proposed future work is necessary and seems reasonable, although it might be a bit ambitious for the remaining time of the project (especially development of a controls scheme). One addition that could prove useful is to develop design suggestions of best practices based on the insights gained from this work.
- The proposed future work needs to also include filling over the entire J2601 fill protocol. The notion of developing a "calibration" algorithm to develop a correction for these meters is good. It will be good to see whether one can be developed using the "station" certification process to improve the accuracy of these devices.
- Inclusion of further metering devices and further parameters for testing is highly appreciated.
- Although this two-year project ended, the author proposes the following future work: power to gas, vortex tube, MC method fueling, tube trailer consolidation, and tests with new chiller technologies.
- The proposed future work might not be cost-effective. However, the following paths might be:
  - Working with a meter supplier
  - Generating testing protocols for measuring accuracy of dispensers and supplying them to the CSA Group and the International Organization for Standardization (ISO)
  - Looking at other technologies such as mass flow meters
  - Considering system design changes for dispensers to enable the meters to be more accurate

### Project strengths:

- Significant strengths include the immediate applicability of this work, as well as its critical role in developing an enabling technology for hydrogen fueling station deployment. Additionally, the statistical characterization of meter performance is one of the strongest portions of this project because it moves the national conversation around meter accuracy forward with a needed degree of insight and nuance that has been lacking.
- The project is technically superior. From a presentation point of view, it used graphics well. The project tested numerous conditions and sets the stage for best practices to help station developers/operators to use the right meter, which is not necessarily the cheapest meter or the meter that is the easiest to get.
- Project strengths include the excellent test capability, very qualified principal investigator, and excellent collaborations and team.
- The project covers an extremely relevant field of research that affects acceptance of hydrogen for users as well as stations.
- The project ruled out some technology (or at least confirmed that it is not good for retail hydrogen stations). It also got useful information about vibration and its effects on the meter and accuracy. The project can potentially be a great service to the industry.
- The partners are a project strength.

### Project weaknesses:

- The project may need control schemes for FCEVs containing different amounts of fuel (half full and completely full). It may need to develop a control scheme for each dispenser on the market.
- The project might formulate recommendations for future metering technologies as an outcome of the test results.
- This is not so much a weakness, but it is unfortunate that the project is not able to do a full J2601 filling event. Maybe the partial fill is fine, but it would be nice to confirm this by comparing the partial to the complete fill.
- An expansion of the number of different meter designs may be necessary in the future for this or a follow-on project. Inclusion of equipment manufacturers as full project partners may be a strategy to enable this expansion. Additionally, the project did not make it clear what types of information, insights, etc. would be passed along to manufacturers once the confidentiality issues were resolved.

- The project should fill out the test methods to include a more complete J2601 fill.
- There are no meter manufacturers.

### Recommendations for additions/deletions to project scope:

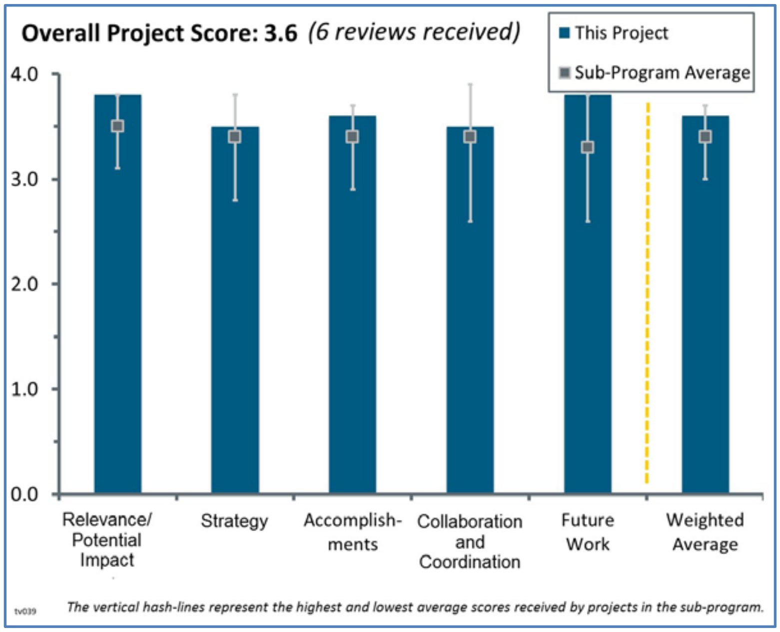
- If the project continues to test commercial meters as well as pre-commercial/prototypes, perhaps there should be two separate “arms” of the project. If a meter is already in use at hydrogen stations, the extent of testing may not be the same as ones that are prototypes. The pre-commercial ones, it would seem, have more opportunity for tweaks to improve them over the ones already out on the market.
- It is recommended that the project determine the probable causes for the inaccuracies and develop tests to verify that the deficiencies are addressed. The project team should work with CSA, ISO, and NIST to generate test methods to address these issues. The project needs an end game (goal).
- The project should add, as a project outcome, a technical brief that provides insight into potential solutions for the problems that have been identified by this project.
- This project term is over; the team is working on a National Renewable Energy Laboratory publication to disseminate. In the next phase, the team should implement a control scheme in the Northeast hydrogen refueling stations and get more manufacturers involved.
- Including further meters as well as test parameters can contribute to a growing understanding of metering issues.
- The project should fill out the test methods to include a more complete J2601 fill.

## Project #TV-039: Innovative Advanced Hydrogen Mobile Fueler

Sara Odom; Electricore

### Brief Summary of Project:

The objective of this project is to design and build an advanced hydrogen mobile fueler (AHMF). The developed mobile fueler will be deployed to support a network of hydrogen stations and vehicles, and fueling data will be gathered for analysis by the National Renewable Energy Laboratory Technology Validation Team. To reduce risk, the mobile fueler is based on an existing conventional station design, and project efforts are coordinated with station providers and automotive manufacturers.




### 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.

- The project is very relevant to the goals of petroleum reduction and collecting data to show market potential and enabling zero-emissions transportation. Objectives were clearly outlined with milestones for the design and build of the mobile fueler. The project will also increase the network of refueling stations to allow a network effect and accelerate customer acceptance. The data collection is important to prove technical capability and show safe operation.
- A 70 MPa, SAE J2601-compliant mobile/temporary fueler has not been built and operated in the United States before. This helps with understanding the gaps in the codes and standards framework. Population in the Northeast has limited awareness about hydrogen fuel cell vehicles, even less so about hydrogen fueling infrastructure. This mobile fueler will help educate and lay the foundation to understand the technology.
- The project has high relevance in that it allows gaps in the hydrogen refueling station (HRS) network to be filled and can contribute to the education, outreach, and acclimatization of authorities having jurisdiction and the public in areas (e.g., the U.S. Northeast) where there are few or no HRSs. In addition, resolving the U.S. Department of Transportation (DOT) issue with transporting charged storage systems can have significant impact. However, it seems like others have potentially already received this approval (One$H_2$, Hydrogen Frontier).
- This project supports and advances progress toward the Hydrogen and Fuel Cells Program goals and objectives: reduced petroleum use, improved air quality, and the commercialization of fuel cell technologies. This project hinges on the perceived need of mobile refueling and, should that need come to pass, is highly relevant. An issue is that the industry cannot afford to wait, and if it waits too long, the opportunity window may shut.
- The mobile fueler option is a key to help bridge the infrastructure issue in case a station is down or a car is stranded. As an enabler, it could likely have a higher cost and still be attractive as an interim solution.
- The approach for this project is excellent, giving this project an excellent chance of successful completion. Reliance on existing design reduces the risk of failure.

### Question 2: Strategy for technology validation and/or deployment

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

- Challenges and barriers are well laid out, with mitigation plans/solutions proposed. Discussion included safety considerations and the needs of users. Permitting considerations are also pointed out as a common opportunity that other suppliers can leverage. The project also leverages existing technology where possible to be consistent with existing stations.
- The mobile fueler is an option to start infrastructure to get over the hurdle of mass market required for profitability. Barriers related to transporting hydrogen, unattended refueling, retail sales experience, and component lead times are all barriers being partially addressed. Hydrogen transport and DOT permits with unattended retail sales will be key to working toward commercial viability.
- This is a new project (a little less than one year old), and progress to date is very good. The design is complete, with many of the long-lead-time items purchased. The project is poised to start assembly.
- The approach is straightforward. The design is a modification of an existing station design. It seems like the major hurdle is the total cost (approaching that of a permanent station) and the lead time. Using an existing design allows good specs and allows the focus of the project to be on solving the two significant hurdles.
  - Phase 1: Design and build.
    - Specs: 15 kg/hr., 100–120 kg/day, 70 MPa, pre-cooling temperatures of -30ºC (T30) or -40ºC (T40), dispenser human–machine interface at point of sale (HMI/POS) same as retail stations.
  - Phase 2: Test and deploy.
    - Fuel delivered to the mobile fueler using power cubes. It can be bump-filled or swapped out and taken back to a hub and filled. Also, one can hook into an off-board hydrogen (compressed hydrogen gas) supply.
    - The team is using a low-emission diesel generator that can plug into 480 V power.
    - SAE J2719 hydrogen fueling standards will be achieved.
- This is an effort to resolve known barriers, but at the same time, the project is most likely to identify new, unknown barriers.
  - Regarding vehicle grounding, there is a need for a grounded concrete fueling pad (blacktop/asphalt is not allowed for fueling operations). No alternative solutions are proposed, and considering the mobile nature of the device, this should be considered. Possibly there could be electrically conductive interlocking tiles or a mat onto which rear wheels have to be driven (to create a similar solution as grounded concrete fueling pad). Adding a grounding cable would change the steps a vehicle driver must take to fuel a vehicle, so that is not a good alternative.
  - For critical assumptions and issues, Option 1, without a DOT special permit, involves a high-pressure bank storage vessel. It is unclear why it would need to be purged, while "medium-pressure" DOT-rated tanks can be transported at ~50 MPa. It is not clear if this is an alternative solution to be discussed with DOT if the project is not receiving a special permit for 100 MPa.
- Permitting and the large footprint of a Class 8 truck need to be addressed. Many of the existing HRSs that this fueler would augment are too small for a Class 8 truck. The approach does not address permitting and fire codes. The approach does not address the footprint issue. The project team has completed an initial hazard analysis and will repeat the analysis in a future project. The AHMF is based on the Air Liquide C100 hydrogen station and will fill a vehicle in three to five minutes on a 25ºC day.

### 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 design was completed, and the design report has been submitted, which is good. It is unclear whether one can transport with both lower- and higher-pressure banks charged to lower levels and whether that will allow for faster set-up and avoid the need to purge high-pressure storage banks.

- The final design is completed, and the design report was submitted. Long-lead items were ordered. Initial hazard analysis was completed, together with a review by the Hydrogen Safety Panel. It is not clear how many long-lead items, such as a compressor and high-pressure storage vessels, were ordered.
- The collaborators and the coordination with other institutions are appropriate for this activity. There is a well-established gas supplier, consultants working with a major original equipment manufacturer and performing economic analysis, and entities well qualified for system design. This is a good team.
- Accomplishments include the completion of the fueler design (meeting current fueling protocol standards) that includes two Hydrogen Technology and Energy Corporation (HTEC) “power cubes” and provides an HRS on wheels. The next step is to build. The project milestone chart is complete. The project managers plan to send station data (from those vehicles to be fueled) to the National Renewable Energy Laboratory Technology Validation Team, and this data collection is very important to the overall refueling network. The plan is to be capable of refueling three fuel cell electric vehicles (FCEVs) in the first hour (~15 kg) and 20–24 FCEVs (~100–120 kg) per day.
- The project is just finishing the design phase, but design features were well-thought-out and included a review by the Hydrogen Safety Panel. There are still some uncertainties on permitting and what capabilities will be allowed on the fueler (such as transportation of high-pressure hydrogen or a need to purge the tanks before moving the fueler).
- The project is relatively new and will go through the most difficult phase with actual system builds. The cross-region applicability and critical path technology transfer activities are all in close alignment with DOE goals and show preliminary progress toward DOE goals of fossil fuel reduction and technology transfer to commercial applications.

### Question 4: Collaboration and coordination with other institutions

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

- When successful, this project will provide a critical capability to accelerate the deployment of hydrogen fueling station (HFS) infrastructure. A critical need exists for coverage, and soon capacity, to support the growing HFS infrastructure. Equally important is the critical need to improve station reliability. It is well recognized that HFS redundancy is needed to improve reliability and coverage. The AHMF will help solve this critical need.
- The project has five different partners that are all working in close collaboration. The complicated design and mix of technology and regulatory barriers speaks to the strength and need for tight collaboration. Involvement with local universities or other additional workforce development opportunities would be a possible addition.
- There is a good line-up of collaborators, with the hydrogen gas company as the main partner. The capacities/experience of HTEC with 100 MPa storage vessels (in pods), an area in which few entities have experience, are not completely clear. The project should consider engaging the California Department of Food and Agriculture – Division of Measurement Standards for introduction to the Northeastern Weights and Measures Association through gas company partners and/or a California network of contacts.
- The project partners are logical for gathering the components needed for the project. There are unconventional/unique partners that could be engaged to support/resolve the two key barriers (transport of charged storage and hydrogen metering).
- The project includes collaboration with vehicle companies and other stakeholders. The team is also pursuing permitting with DOT that would enable better station utility.
- The team began collaborating with others, developing fueling systems after the design was complete (it may or may not have been better to collaborate at the beginning of the design).

### Question 5: Proposed future work

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

- The next stages are basically to procure components and build and test the mobile fueler. The team has addressed most of the barriers, but the potential impact of any issues that would change the design should be resolved before the components are purchased.

- It is time to execute. It seems like the project will be highly successful if it can build the AHMF and resolve the two key barriers.
- It is not clear whether this AHMF could serve as an early fueling solution before officially opening at Northeast stations selected and funded for implementation (Air Liquide stations). This could develop early demand in the region and prove operational capabilities of the fueler until more vehicles are available in the Northeast. Sales of FCEVs have not started in this region and may still not be available by the second fiscal quarter of 2018.
- The presenter did not discuss future work, but the presentation includes future work: building the fueler and starting the tests in the Northeast (for commissioning new stations). Other future work includes certifying the mobile fueler to sell hydrogen, subsystem testing, and safety testing.
- The future work described is simply build it, test it, and deploy it in suitable regions (California) to test and sell hydrogen to the public.
- The next steps will be the most difficult for the project. Hardware and safety testing often carry the greatest risk. The project partners will need to work very closely to ensure successful completion.

### Project strengths:

- The strength of this project is that it addresses the issues of unattended fueling. The project managers have already purchased a compressor, which shows commitment to the project. Another strength is that the project is based on already existing hardware design and equipment (i.e., the Air Liquide C100 hydrogen station and the Kobelco heat exchanger). The fueler will have an HMI/POS.
- The project has strong integration and collaboration components. The technical challenge of fitting 700 bar fast-fill equipment on a truck is very demanding. The project has a good team, and the design appears functional.
- The design is self-contained but still provides the ability to use stationary storage and off-site power. The proposed design is patterned after a well-established and used design; this reduces the risk of execution.
- The project had good assessments of the potential risks and mitigation plans for dealing with them. A review of the design was completed by the Hydrogen Safety Panel.
- Strengths include the project partners, the use of existing stationary fueling station components, and a mobile fueler capable of meeting J2601 fueling protocol requirements.
- There are clear goals, and the barriers/hurdles are well defined.

### Project weaknesses:

- On-board power with a diesel generator is a weakness. The project should consider replacing this with an alternative fuel. The size is a drawback (the fueler will not fit in many HRSs), but the fueler can fit into larger areas. The fueler “weighs a lot” (the speaker did not give the weight).
- The physical size/dimensions of the mobile fueler are a weakness. It is not clear what the countermeasures are with regard to the adaptation of stationary station components or a trailer to withstand vibration from transport over the road.
- No clear economics of mobile fuelers were shared. It is unclear how much public funding is required to make a sustainable business case, even at $15/kg.
- There are still some uncertainties on siting and transportation considerations with the fueler that should be resolved.
- The team does not seem to have fully researched innovative solutions to the barriers that others may have found.

### Recommendations for additions/deletions to project scope:

- It will be a significant accomplishment to reach the goals of the project as currently planned.
- The project should clarify the nature of “unattended fueling requirements” or develop the requirements comparison table between unattended fueling and attended fueling. It is unclear what the network of secure card lock fueling stations is. The team should investigate whether 24/7 fueling is possible in all locales with the generator in operational mode (the fueler not connected to on-site 480 V). Hydrogen Station Equipment Performance testing should be used to prove fueling performance per J2601 requirements.

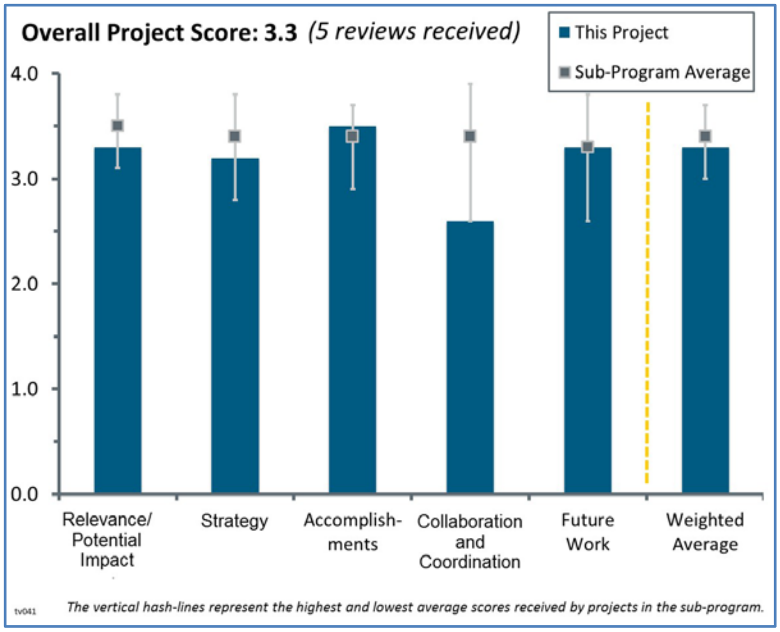
- Alternative fuel (instead of diesel) should be used for on-board power. The team needs to work on regulations for the retail sale (metering) of hydrogen for this fueler. As an option, the team could adopt the California regulations for this. The team should work on the user interface for the dispenser to support unattended fueling. The team is doing excellent work.
- The economics of mobile fuelers, including lessons learned and the current pace of technology development, should be evaluated.

# Project #TV-041: Modular Solid Oxide Electrolyzer Cell System for Efficient Hydrogen Production at High Current Density

Hossein Ghezel-Ayagh; FuelCell Energy

## Brief Summary of Project:

This project seeks to demonstrate the potential of solid oxide electrolysis cell (SOEC) systems to produce hydrogen at a cost less than $2 per kilogram, exclusive of delivery, compression, storage, and dispensing. Project activities aim to (1) improve SOEC performance to achieve greater than 95% stack electrical efficiency based on lower heating value (LHV) of hydrogen, resulting in significant reduction in cost of electricity use for electrolysis; (2) enhance SOEC stack endurance by reducing its degradation rate; (3) develop an SOEC system configuration to achieve greater than 75% overall (thermal and electric) efficiency; and (4) improve subsystem robustness for system operation compatible with intermittent renewable energy sources and their load profiles.




## 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.

- SOEC systems at 90% electric efficiency with an ability for intermittent operation is very relevant to U.S. Department of Energy (DOE) goals and long-term cost targets. High-temperature electrolysis is more efficient and needs more development to get a better understanding of future cost reduction potential. A total of 1500 kg $H_2$/day is the right size for a hydrogen refueling station. The big challenge will be onsite storage, use profiles, and actual installed capital costs/durability.
- This technology could represent a significant step change in our ability to meet the hydrogen needs for the medium and long terms. If the project can meet the $2/kg targets, it would essentially replace the existing steam-methane-reformer-based infrastructure in the industrial hydrogen sector as well as scale to meet the needs of hydrogen energy for mobility.
- The project is indirectly relevant to the hydrogen production goal "research and develop technologies for low-cost, highly efficient hydrogen production from diverse renewable sources," although the project basically focuses on the solid oxide electrolysis technology widely, irrespective of electricity origin. The DOE Fuel Cell Technologies Office objective directly targeted is the costs from electrolysis (<$2.30/gge, exclusive of delivery, compression, storage, and dispensing) mentioned in terms of $2/kg $H_2$ in the project. Related objectives concern electrical efficiency of the stack (95%) and electrolyzer (90%). The degradation rate (<1%/1000 hours at cell level, <2% at stack level) and robustness in operations are linked to intermittent power sources (i.e., renewables).
- The project has the potential to advance our understanding of high-temperature electrolysis technology, especially with respect to stack energy efficiency of SOECs.
- This project seems to be a technology development project and not a technology validation project. The researchers are testing new materials and fabrication methods. Maybe the project should be moved to the Hydrogen Production sub-program area.

### 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 milestones were met, and hardware has been built. This shows initial progress and builds confidence. Upcoming milestones toward 1000 hours and 95% efficiency by LHV look challenging and should meet or exceed DOE targets. Cost and operational targets are most difficult to meet, and looking at start–stop and long-term operation will show technology capability. Cell degradation is a difficult barrier, and the project has shown very positive initial results with less than 3.5% degradation in 1000 hours for 2400 hours. The full demonstration will prove how well the barriers were actually addressed.
- The approach is a progressive one. Research is first to be conducted at the cell level to optimize working conditions versus performance (including degradation). Then, scaling up is performed gradually up to 4 kg $H_2$/day at the stack level, with further design of components for the additional scale-up to 38 kg $H_2$/day for the system, and, further still, technoeconomic considerations to reach 1500 kg/day. This rather academic approach appears very relevant here since cell-level testing and characterization are intended to allow for optimal material design. The project includes two go/no-go decisions that are well defined: first for stack performance after 1000 hours, and then during the system configuration leading to the design of the 4 kg $H_2$/day system (45 cells).
- The approach of developing a full-size stack baseline module for a scale-up concept and then validating stack components at subscale is sound. Using a breadboard system demonstration approach to test the milestone metrics is also a good idea.
- There are many questions around the technology related to the robustness of the solution (degradation issue) and in the economics of the solution. In the project, addressing these two topics needs to be moved to the forefront. To date, significant testing has been completed on the existing technology, but it is not clear what will be done to address degradation. Testing shows that degradation remains an issue, but it is unclear how it will be addressed in this project. Regarding the technoeconomic analysis (TEA) of the overall system, it is not clear what is meant by operating efficiency, what the boundaries are for this, and what the impacts on the cost of hydrogen are if this efficiency is not met. It is unclear if it includes the energy for the steam production and how it would be integrated into an existing power generation structure.
- The strategy for validation and/or deployment comes at the end of the project and is very poorly defined.
    - The technology transfer activities are poorly defined.
    - The demonstration needs to be defined.
    - The parametric studies are well-thought-out.

### 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.

- It is not clear how many of the accomplishments were carried out after project kick-off or funding availability, but given that the project is only few months in, much has been accomplished. The progress on systematic isolation of multiple parameters (temperature, pressure, inlet concentration, steam usage) and their effect on stack performance was impressive.
- Hardware has been tested, and hydrogen is being produced with limited degradation. There is a good description of remaining challenges and exploration of operation range with multiple parameters: pressure, temperature, steam utilization, etc.
- Results to date are very impressive with respect to the amount of testing completed. It is not clear how many of the results shown were for this project exclusively and how many are leveraging previous results and related programs. Project leads should be careful to clearly delineate when work is directly a result of this funded project and when results are from previous work or from related programs.
- To date, the eight-month-old project has essentially focused on cell- and stack-level observations including the variation of working conditions such as current density, steam use and concentration, pressure, temperature, and oxygen concentration. Correlations are made between variations in operating conditions and efficiency, lifetime, and downstream requirements in the purification step. The actual reporting of a

cost indicator, which is the ultimate project objective, is still missing and will be tackled at a later stage. Similarly missing is a scientific description of the systems, materials, and set-ups tested or the changes implemented for improving their behavior. Residual base work is still needed concerning degradation before upscaling.
- The accomplishments are all on developing the technology and not on technology validation. The parametric studies are important to understanding how the technology should be operated.

### Question 4: Collaboration and coordination with other institutions

This project was rated **2.6** for its collaboration and coordination.

- Little is explained concerning the distribution of tasks in the partnership between the National Energy Technology Laboratory (NETL) and Versa Power Systems (VPS)/FuelCell Energy (FCE) within the project other than in slide 17. Overall, there is no doubt about the good collaboration and coordination between the two partners, although it is somewhat confusing that VPS is mentioned throughout the presentation while the heading mentions parent company FCE.
- The role of the partners (VPS and NETL) is not clear. It appears that all project work to date has been with FCE exclusively. Given the broad questions around the system performance, it would be particularly valuable to have a third party complete the TEA and validate the performance, efficiency, and economics of this solution.
- The VPS collaboration is confusing since FCE owns VPS; it is unclear if this is really an external collaboration. The NETL collaboration is to "support development of solid oxide fuel cell (SOFC) technology for power generation." It is unclear how this helps with an electrolyzer that consumes power. The project needs to define the roles better.
- Although there is value in understanding the performance and cost of SOFCs, the role of the collaborators appears to be solely on the fuel cell development aspect, not the electrolyzer.
- There is limited outreach with industry and end users, who would be most likely to purchase these systems, or low-cost electricity providers.

### Question 5: Proposed future work

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

- Overall, the stated future work sounds reasonable. Early cell and stack fabrication and durability testing of high-temperature components is critical. The performance model development followed by system demonstration is the logical approach.
- Future work consists of a clear path through continued degradation characterization and high-efficiency system demonstration. This should include more details on total energy in and hydrogen produced with cost of electricity or a spread to show some parametric analysis toward meeting the target of $2/kg of hydrogen produced. All assumptions should be transparent. More explanations should be given toward intermittent operation verification and test cycles.
- Good stage gate milestones are defined for the project in 2018. It will be interesting to see progress against these in the near future. It is not clear what tasks will be undertaken to improve the degradation. A plan or potential areas of focus for this would be valuable.
- It seems that the project is well managed and followed with clear milestones, targets, and reviews of progress towards each of them, and a plan for future work.
- The demonstration takes place late in the project and does not seem to be the focus of the work.

### Project strengths:

- The technology leverages work done previously in NETL and other programs. There is significant potential to change the industry if the targets are met.
- This is good initial work and data collection of actual hydrogen production.
- The previous experience and background of FCE with SOFC development is a strength.
- The project is well managed and is making steady progress.

- The researchers have a good technology. They are well funded.

### Project weaknesses:

- The project would be strengthened by independent evaluation of the TEA results. Many questions from reviewers on the technical validity of the results in the areas of energy integration and overall process efficiency could be addressed by the addition of a partner to complete/validate this independently. It is not obvious what roles the partners are playing in the project.
- There is little mention of state-of-the-art or competing technologies that would ascertain the relevance and comparative advantage of the current work.
- Optimistic assumptions are a weakness. The team needs to address the source and availability of "waste heat" for vaporization of water.
- More details are needed on cost analysis and how the technology will be brought to the market.
- The technology validation and technology transfer plans are poorly defined. The partner roles are poorly defined.

### Recommendations for additions/deletions to project scope:

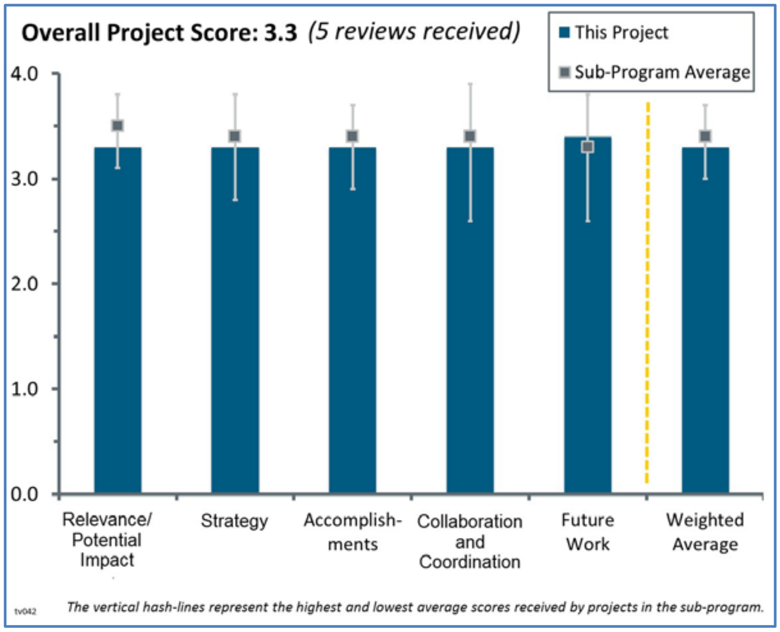
- The project should account for the impact of integration with renewable and intermittent power (one of three stated barriers to address) on the system performance and cost. It is suggested that the project add this factor to the operating window exploration (slide 11). The same is recommended for the impact of operating in reverse SOFC mode.
- A review of the state of the art to position this research versus competing technologies or research groups worldwide is recommended.
- It is not clear that this project really is a technology validation. It seems to be more of a technology development project.

## Project #TV-042: Optimal Stationary Fuel Cell Integration and Control (Energy Dispatch Controller)

Genevieve Saur; National Renewable Energy Laboratory

### Brief Summary of Project:

Current control strategies for building systems tend to be simplistic. The objective of this project is to create an open-source, novel energy dispatch controller to optimize the dispatch of different building components such as combined heat and power, storage, and renewable generation systems. Such a controller, which will incorporate improved forecasting capabilities and model predictive control strategies, would enable these building systems to participate in grid ancillary services markets. A planning tool for sizing building components utilizing simulated dispatch will also be developed.




### 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.

- Grid modernization is a recent element of the U.S. Department of Energy (DOE) Fuel Cell Technologies Office (FCTO) but is key to showing the full value cycle of using hydrogen for both transportation and supporting the grid with additional variable generation sources (wind and solar). The three main impacts include new energy management, grid modernization, and the fuel cell vehicle market. Stationary fuel cell integration enables all three topics and will have a significant impact on reaching the FCTO's Hydrogen and Fuel Cells Program (the Program) goals. The model development and predictive controls are required when anticipating variable electricity generation, which may have a mismatch with supply and demand timeframes. Both the graphical user interface (GUI) and building design framework are needed to ensure the output can be adopted by end users outside of the national laboratory environment where these tools are needed most.
- This project has excellent potential to help fuel cells capture some of the interest in combined heat and power and dispatchable energy.
- Regarding relevance, the impact statements support the goal of optimizing fuel cell systems for energy management and control of buildings. The reviewer is not fully appreciative of issues with energy management and control of buildings and has difficulty fully understanding the benefits of this project.
- The project supports the Program goals and objectives. It appears this project supports energy management and the control of buildings, not vehicles.
- It handles part of grid control only.

### Question 2: Strategy for technology validation and/or deployment

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

- The project utilizes the expertise of the team to address a very complicated issue and builds on existing technology to develop solutions. The project is broken down into components for addressing technical issues.
- The approaches are feasible and well designed.
- The project appears to be well designed, but it is not clear how difficult it will be to get the knowledge and solutions out of the laboratory and into real-world adoption. Some of the control strategies will be completely dependent on the local market and its ability to provide ancillary services. The heating and cooling examples show how these can be energy buffers and support decisions toward deployment. However, cost and relative magnitude of advantages versus savings were not initially obvious beyond moving in the right direction for saving energy and money.
- The grid needs both round-trip excess and shortage in energy, power, and other services.

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

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

- The load forecasting for buildings looked to be complete and to match actual data collected from real-world applications. The work to ensure the forecast uses the right mix of models was encouraging and shows a high level of technical competence. The barrier to using this modeling in different regions or markets may be high. The visual feedback and GUI design may help with education, showing how the system is running and what might be saved, but there may be significant cost to adopting the approach to a new system or building. By using Energy+, the project team may have better adoption, but Energy+ appears to be used mostly by national laboratories and DOE rather than commercial building owners or other end users. Technology providers are well represented, but end users and other stakeholders were not obvious.
- Very good progress has been made in the first year.
- Progress has been made on the development of the electrically driven compressor (EDC).
- Chiller issues were identified and solutions proposed. Fuel cell set-points are set depending on the price of natural gas. The high cost of fuel cells typically suggests that the economic value of fuel cells can be achieved by running the fuel cell continuously. For FuelCell Energy molten-carbonate fuel cells (MCFCs) and Doosan phosphoric acid fuel cells (PAFCs), the fuel cell cannot be shut down because of heat-up (startup times) and must be run continuously at partial power. It is not clear that the project has addressed this characteristic of these fuel cells.
    - Pre-cooling consumes energy while cooling is not fully needed. It is not clear how big the battery must be to offset electricity from the grid when the price of grid electricity is increased.
    - For heating, the fuel cell does not go from zero output since MCFCs and PAFCs must be in stand-by condition to maintain electrolyte temperature. No analyses of stand-by power consumption were reported.
    - Chart 13 was not understood. The fuel cell as a heater (i.e., output determined by the heating load) is not considered an efficient device. If excess power is generated at partial load, it is unclear whether it can be returned to the grid or could have another use.
    - The whole-building forecast appears to anticipate load requirements. The reviewer is not familiar with Naive, so a better explanation is needed to comment on this approach.
    - Forecast methods appear to distinguish an autoregressive integrated moving average (ARIMA) approach as the best fit, but with less error in ARIMA. The reviewer requires a better explanation.
- The economic parameters relationship is not realistic. There should be input from a real-life group that makes money doing this. Fuel cells do not load-follow as well as assumed.

### Question 4: Collaboration and coordination with other institutions

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

- There is excellent collaboration with appropriate organizations.
- Once the model is released, it will be important to find additional end users. The pursuit of open-source solvers may allow for broader distribution, depending on the complexity and effort needed to populate the model with inputs.
- The project does not have a company that builds and markets energy management controls for buildings, and this is a weakness. Other collaborations are very good.
- The collaboration team should include real-life stakeholder input to make a good study.

### Question 5: Proposed future work

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

- The proposal to use the algorithms in an actual commercial building is the best step forward to ensure other users can adopt the information and resource through a clear example. The additional development of the co-simulation environment will be needed to ensure broader use, and the dual operating system capability as part of the optimization will help. Completing the GUI will be needed before the model can be adopted, in addition to including sample use cases and the Open Studio design interface. The most important gap is finding key stakeholders, which can ensure completion of the significant effort required so the software can be adopted and used outside of the national laboratories or DOE working space.
- Future work for the project has been well planned to address identified barriers/issues.
- The project's remaining challenges and barriers are listed. There should be a detailed list of proposed future work. Because of the reviewer's lack of experience in this area, it is not clear that all barriers are addressed.
- The project should consider a utility or the Electric Power Research Institute (EPRI) to help guide what is needed. This work so far is of only academic importance.

### Project strengths:

- The strongest project aspect is the detailed modeling and efforts to make the information accessible to building owners by showing what savings are available.
- This is a good team that builds on previously developed expertise. The project appears well organized with understanding of pathways to resolve barriers.
- There are well-designed approaches for the development of an EDC.
- Some considerations of expected parameters and use of models are good.

### Project weaknesses:

- There are no significant weaknesses.
- The project's biggest challenge may be to ensure that the project can move from the laboratory to actual end users, if those stakeholders are not consulted during development, to ensure it can mesh with existing tool sets. The positive aspect is that once initial results are available and the effort matures, this input can be provided before decisions are finalized that limit options or changes that would facilitate use outside of the laboratory.
- The project should include the industry partner with expertise in energy management and control of buildings.
- There is a lack of real-life stakeholder input.

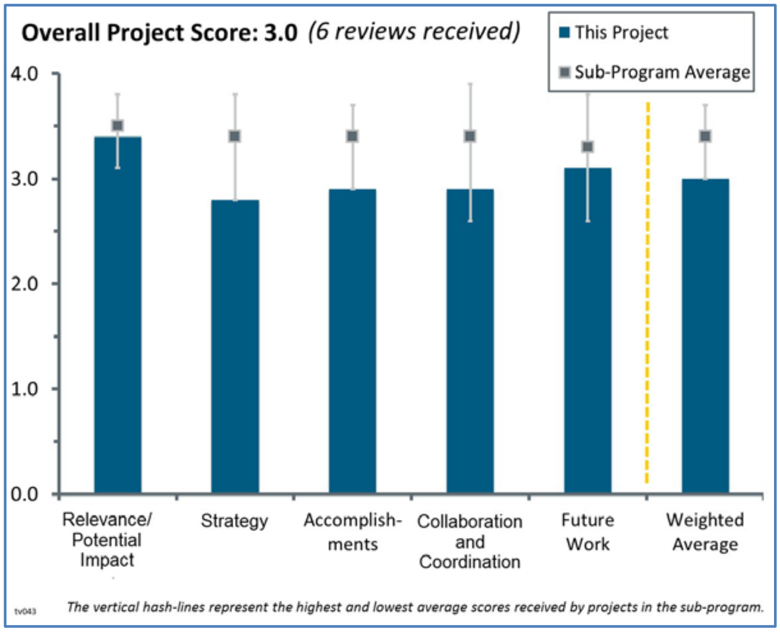
### Recommendations for additions/deletions to project scope:

- The project should find stakeholders early in the project to ensure GUI usability, metrics, and outputs are compatible with what a majority of building owners need to make a decision for incorporating and using the model.

- The solution must be what the customer needs. Input from a real-life consumer of the solution should be included. An aggregator, utility, or EPRI may be better to have on the team to make good progress.
- The project should involve industry for energy management and control of buildings. Reviewers with expertise in energy management and control of buildings should be identified.

## Project #TV-043: Integrated Systems Modeling of the Interactions between Stationary Hydrogen, Vehicle, and Grid Resources

Samveg Saxena; Lawrence Berkeley National Laboratory




### Brief Summary of Project:

Hydrogen technologies offer the unique ability to simultaneously support the electricity and transportation sectors, but the value proposition for such systems remains unclear. This project is developing an integrated modeling capability to establish the available capacity, value, and impacts of interconnecting hydrogen infrastructure and fuel cell electric vehicles (FCEVs) to the electric grid. The potential to support the grid and to balance resources from flexible hydrogen systems, such as dispatchable production of hydrogen by electrolysis, are quantified. Methods to optimize the system configuration and operating strategy for grid-integrated hydrogen systems are also developed.

### 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.

- This project is very relevant, given the uncertainty around grid changes and economics of grid services that may be provided by electrolyzers. The grid is rapidly evolving, with increased renewable energy coming into the grid. If this shows an economic case and sustainable business due to the integration of multiple resources and demand centers, policies can be developed to accelerate the integration and optimization with existing electricity markets.
- The relevance is potentially huge; this is the crux of the H2@ Scale concept for leveraging renewables into grid support and transportation. Modeling is an excellent start. Next, the project should examine how this can lead to demonstration of the concepts that can attract commercialization and private investment.
- The Lawrence Berkeley National Laboratory (LBNL) team seems to have a clear understanding of the task before it, the importance being that its project advances fuel cell deployment and the maximization of renewable resources.
- This project is very relevant to the benefits of hydrogen economy. It will be important to make objective decisions with regard to the Hydrogen Vehicle-to-Grid Integration Model (H2VGI Model). Slide 5 does a good job capturing relevance to multiple stakeholders groups.
- Although the project does not specifically address Fuel Cell Technologies Office (FCTO) Multi-Year Research, Development, and Demonstration Plan (MYRDDP) stated objectives, its scope and goals are certainly valuable in advancing the implementation of U.S. Department of Energy Hydrogen and Fuel Cells Program objectives. The potential flexibility and synergy that can be realized from integration of stationary hydrogen sources, FCEVs, and the grid are worth exploring.
- The “Relevance” portion of the presentation (slides 3, 4, and 5) indicates that the focus of this project is on development, validation, and implementation of the H2VGI Model. This initiative may have merit for the overall FCTO. However, it does not support and advance progress toward achieving the goals and objectives associated with the Technology Validation sub-program. The barriers listed in slide 2 of the presentation are not among the barriers included in the Technology Validation sub-program portion of the

MYRDDP. The barriers cited for the project are also not specifically cited among those in the Systems Analysis sub-program portion of the MYRDDP. Were this project's relevance evaluated solely with respect to the Technology Validation sub-program, it would receive an "unsatisfactory" grade. Because the project may have benefits in the context of the Systems Analysis sub-program goals and objectives, a rating of "fair" was assigned.

### Question 2: Strategy for technology validation and/or deployment

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

- The project addresses key questions needed to launch/commercialize key elements of large-scale, economical green hydrogen production. This approach provides an important first step and guidance as to what needs to be demonstrated in this space. Any additional clarification/modeling of the economics of the approaches modeled would be helpful. The approach cuts across many stakeholders—providing data to drive collaborative best decisions for policy, original equipment manufacturers, station owners, etc. The approach is to integrate many existing modeling components. For example, it expands the vehicle-to-grid (V2G)-Sim tool from the battery electric vehicle (BEV) model to include FCEVs. This feeds into the dynamic station model, etc. The project will then look at key case studies (e.g., the California duck curve issue and central vs. distributed hydrogen production). It is not clear whether this will offer needed resources such as grid transmission capability. There is a go/no-go plan at the end of 2017, but it is not clear whether there will be a plan for clear economic impact output by then (the project is pushing this with the Revenue Operation and Device Optimization [RODeO] model and fuel model, and also pushing on duck curve work). The project needs reports and good communication for this to be recognized quickly as the key data that can underpin policy and investment decisions. "Pathway to use" of data/reports is critical (there was a question from another reviewer about influencing grid operation rules/standards/policies). This emphasizes the need for hydrogen advocates to reach out to the California Independent System Operator (CAISO).
- The approach looks comprehensive, but it could use additional feedback from a broader industry perspective beyond transportation. However, this could be done in a Phase II because transportation may have the highest value and the greatest demand. Heavy-duty hydrogen vehicles may be more easily integrated than light-duty hydrogen vehicles.
- The approach appears to be good. It would be good to see more about the validation plan, as well as more information about how each of the variables are accounted for (for instance, station hydrogen storage did not appear to be addressed).
- The "Approach," slides 6 through 8 of the presentation, describes a plan for integration of multiple existing models and national laboratory initiatives to create a sophisticated H2VGI Model. The results would be applied for analysis of hydrogen-related issues, questions, and case studies. The project phases outlined in slide 8 seem reasonable—for a Systems Analysis sub-program project. Objectively, rating this project on "Strategy for Technology Validation and/or Deployment" would result in an "unsatisfactory" score. However, because of its potential benefit as a contributor to Systems Analysis sub-program goals, a rating of "fair" is assigned.
- A concern is the information presented on the slide 6 chart "Approach – H2VGI Model Structure" because if the chart is indicative of the end product, the end result may look complicated but not be a usable tool. The slide 7 chart "Key planned case studies" and slide 8 "Approach: Project Phases and Selected Milestones" indicate LBNL plans to perform a great deal of modeling and data review, but they do not mention that LBNL will examine existing renewable-grid electric-hydrogen systems such as Hawaii Natural Energy Institute's megawatt-sized battery systems supporting the grid in Kona (Hawaii County) and Honolulu, Hawaii, or the Navy's hydrogen station at Joint Base Pearl Harbor–Hickam. It is recommended that LBNL use the existing systems coupled with the use of models rather than perform a model-only review.
- The project's technical validation approach appears to rely heavily on the existing Vehicle Grid Integration (VGI) model, which is based on BEVs. However, the project needs to specify how this model would be different from VGI; for instance, it is not clear whether there is any interface between FCEVs and the grid similar to VGI's two-way integration to enable BEVs to provide grid services. Moreover, unlike utility-

scale solar or wind, it is not clear how multiple and much smaller stationary hydrogen stations (with expensive reverse electrolyzer configuration or added stationary fuel cell units) or FCEVs are supposed to be coordinated and satisfy smoothing the demand and supply curves. Ultimately, because of the added energy conversion step in the case of hydrogen, the peak-shaving or valley-filling prospect or justification for this project to resolve California's net-load or duck curve issue may not be as strong as presented.

### 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.

- The case studies were well developed and important to show the capabilities and impact of the chosen approach. The modeling of FCEVs' hydrogen demand as an aggregated demand may need finer fidelity, unless additional hydrogen storage is used as a buffer.
- The preliminary results and baseline scenarios for hydrogen demand, dynamic power consumption, and prices are a good start. The early result on electricity consumption and the grid support model presented should be helpful in fully understanding the station's energy management and revenue assumptions.
- It would be helpful to see specific pointers to things that can be implemented and demonstrated so that stakeholders can see hardware and get energized around investing. This can help set priorities on what the work suggests as the first/highest-impact part to implement/demonstrate. Some notes and accomplishments from the presentation follow:
    - So far, the project has some sub-models for vehicle activity and resulting hydrogen demand.
    - The Scenario Evaluation, Regionalization, and Analysis (SERA) model has generated scenarios for the geographic location of vehicles and hydrogen demand.
    - The project is quantifying the value of hydrogen production facilities to help mitigate the California duck curve. The project is reducing peaks, filling valleys, and reducing ramp rate.
    - Hydrogen station electricity consumption and grid support models (time-of-day analysis) represent opportunities to reduce the cost of operation/demand charges.
    - The National Renewable Energy Laboratory (NREL) RODeO model application and integration with the U.S. Utility Rate Database represents progress.
- The "Accomplishments and Progress" portion of the presentation (slides 9 through 15) provides evidence of significant activity and results in the development and validation of sub-models, implementation of models and sub-models, scenario development and analysis, and analysis of the potential for hydrogen production facilities. For the project's contribution to overall project and FCTO goals, the reviewer's rating is "satisfactory." However, if the standard is accomplishments and progress relative to Technology Validation sub-program goals and objectives, the rating would be "unsatisfactory."
- There are many problems with information presented in the "Accomplishments" section:
    - On slide 9, "Accomplishments and Progress: Sub-models for vehicle activity initializer and individual vehicle models," LBNL uses the term "initializer" but does not explain what values are being set, why, or who is doing the setting. LBNL lists a category as "Development of preliminary mobility hydrogen demand sub-models," but it did not advise on the difference between models and sub-models, why the data is preliminary, or why the emphasis is on preliminary. LBNL uses the term "Calibrated fuel cell vehicle models" but does not explain what calibrated FCEV models are, what the models are calibrated against, or why. It is completely unclear what the initialization data for travel itineraries for large collections of vehicles using national household travel survey data is or why it is necessary as a first step. LBNL provides a chart showing hydrogen consumption over 40 days for 2,094 vehicles, but the chart is a waste of time and space because the data could be communicated more effectively by simply stating that 2,094 vehicles consumed about 16,000 kgs of hydrogen over a 40-day period and that consumption was at a steady rate. The right half of the slide 9 chart is no better, but further criticism seems redundant if not also overkill.
    - From the slide 10 chart, LBNL advises that the SERA model has been used to generate self-consistent FCEV adoption and hydrogen demand scenarios, and while the follow-on points are understandable, it is not clear why the term "self-consistent" applies.
    - Slide 11 "Quantifying the value of hydrogen production facilities..." proudly claims that centralized electrolysis to provide grid peak shaving valley support for California has been

modeled for the first time, but something seems missing if LBNL does not acknowledge that actual peak shaving and valley filing has been performed elsewhere outside the state of California.
  - The RODeO model discussion on slides 14–15 is unclear to the point that the chart and graphs appear to be little more than filler to add to page count.

### Question 4: Collaboration and coordination with other institutions

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

- The project represented good collaborations with NREL and the Idaho National Laboratory (INL); however, additional discussions with grid operators, station owners, and related stakeholders (CAISO, California Public Utilities Commission [CPUC], and California Energy Commission [CEC]) would lead to more relevant results. This should happen later in the project to ensure a better chance of the knowledge being incorporated into new electricity market rules for electrolyzers.
- Slide 17 "Collaborations" provides information on the roles of LBNL's project partners, NREL and INL. Presumably, there is good collaboration and coordination among the three laboratories. While stakeholder categories are mentioned on slide 5, no information is provided on plans for collaboration and communication with the many parties having an interest in the project's activities and results. However, the need for an outreach and engagement strategy is recognized on slide 18 on remaining challenges and barriers.
- Having NREL and INL on station and grid topics shows good collaborative effort. At some point, the project team should consider getting input from station owners and grid operators, especially on underlying model assumptions.
- Any collaboration with partners that could provide validation of any of the elements of the model would be a very helpful addition to the project. NREL is leading model integration. INL is leading the electrolyzer operation/application load dispatch model.
- While NREL and INL seem to be working well together, there appears to be no collaboration with any other organization.
- Outreach strategy and involvement of key stakeholder groups still need to be developed.

### Question 5: Proposed future work

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

- The proposed future work is very sound, especially the scope involving model testing/validation, building case studies, and plans to seek stakeholder input.
- With the future work, it is important to get early input from other stakeholders, especially those who set the rules for electricity markets. The technical capability and the demand are there; however, the actual mechanisms for market integration are missing and skewed toward batteries for now.
- The future modeling work is well founded. It is not clear whether there are any opportunities for validation of the model results. Any integration/validation of economic models would be very helpful.
- It appears that NREL and INL have a lot more to do than what is listed in their future work chart. They need to tighten up their effort.
- Proposed future work, as described on slide 19, seems reasonable and appropriate for the project. My recommendation is that FCTO's Systems Analysis sub-program team should ensure that the work of this project does not duplicate or overlap other modeling and analysis efforts being funded by FCTO and other organizations. If actions to provide such assurance are already underway, that is good. To reiterate prior comments, Technology Validation sub-program resources should not be used to fund this modeling and analysis project. The project is not relevant in the context of the Technology Validation sub-program portion of the MYRDDP.

### Project strengths:

- Project strengths include detailed and comprehensive modeling as well as the use of existing resources and capacities, e.g., models from other laboratories.
- The project's strengths include the collaborative effort among the three laboratories with complementary skill sets. The approach of leveraging the existing VGI model could also be a plus.
- The project relevance is important. The approach is good and has stayed current despite grid demand changes.
- Project strengths include the modeling and analytical expertise resident in the three national laboratory project partners. The project approach and phasing seem logical and should lead to achieving objectives—as a Systems Analysis sub-program project.
- The project offers a first look at key elements of H2@ Scale concepts.
- No strengths were noted.

### Project weaknesses:

- It would be beneficial to understand more about how the project is accounting for variables and validation steps.
- The project seems to take a "top-down" approach to developing the model, such as quantification of economic benefits based on California-based average net load profile. Perhaps a model based on a "bottom-up" approach, building up from typical hydrogen station capacity and operations, may be more realistic and valuable.
- The project could use some elements to validate model results and to include economic modeling.
- The project needs early and frequent input from the main organizations responsible for market barriers to integrating electrolyzers with the grid: CAISO, CPUC, and CEC.
- There is need for a stakeholder engagement plan and follow-through in implementing the plan. In response to a question, Dr. Wei indicated that the project team is aiming to publish initial project reports by the end of this year. There is a need to establish the relevance of the project for stakeholders in government (public policymakers) and industry, e.g., electric utility and automotive.
- The NREL–INL team needs to couple its modeling efforts with real-world activities, even if those activities do not perfectly match exactly what the team is challenged with accomplishing. After that, the team needs to work on messaging so that whatever they are really trying to say is clear as crystal rather than clear as mud.

### Recommendations for additions/deletions to project scope:

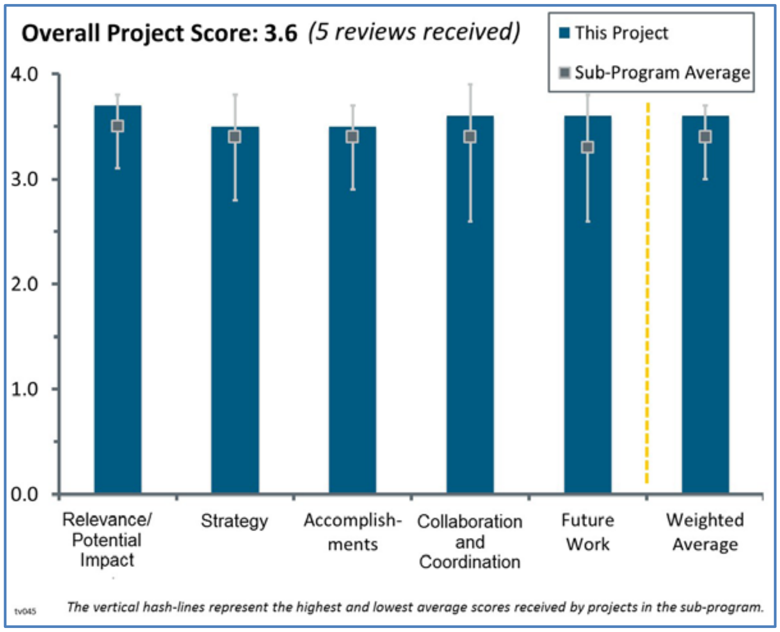
- The economics example for device optimization is a good start. However, going forward, more specific station configuration and realistic assumptions of capital cost (e.g., reverse electrolyzer or a separate stationary fuel cell) and grid support scenarios should be considered.
- The project should expand the scope for reporting feedback and requests from grid management and planning stakeholders for how electrolyzers can be more rapidly integrated.
- No scope changes are recommended, except accounting for hydrogen storage.
- The project may be scoped adequately, but the means of accomplishment and presentation need improvement.

# Project #TV-045: H2@ Scale Analysis

Mark Ruth; National Renewable Energy Laboratory

## Brief Summary of Project:

H2@ Scale is a concept that explores the potential for wide-scale hydrogen production and utilization in multiple energy sectors in the United States. The objective of this project is to improve the fidelity of the H2@ Scale value proposition. The analysis seeks to quantify the potential economic, resource, and emissions impacts from wide-scale hydrogen production and utilization. In addition to nationwide analysis, regional opportunities and challenges will also be identified. H2@ Scale analysis integrates many transportation, industrial, and electrical sector analyses and tools.




## Question 1: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

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

- This project is extremely relevant in supporting DOE's goals in the Hydrogen and Fuel Cells Program. The recent increase in interest in hydrogen, not only as a transportation fuel but as a prospect for an energy source of the future, makes the H2@ Scale analysis fundamental to understanding the challenges and potential impact on the economics, resources, and emissions, as stated by the presenter.
- H2@ Scale is a real backbone initiative for the U.S. Department of Energy (DOE). The project potentially has impacts on industry across all spectrums of energy but specifically relative to hydrogen and its enormous potential.
- This analysis is highly relevant to the integration of multiple sources and users of hydrogen within an integrated network. The staged analysis includes theoretical, technical, and economic potential, and therefore, the project scope is broad. Economic externalities are among the remaining analysis.
- Arguably, the analysis portion of the H2@ Scale project is the most important component, as it has deliverables enabling actions and deliverables to the hydrogen energy community.
- It is appropriate to follow the steps outlined in the approach to assess the technical and economic potential. However, the market potential is being overestimated by double-counting hydrogen needs in some of the categories and assuming a high growth in hydrogen demand, particularly light-duty vehicles (LDVs). Further, although the concept is good and relevant, industry would prefer to see near-term projects.

## Question 2: Strategy for technology validation and/or deployment

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

- The strategy taken by the project leader and team is very sound and well-thought-out. The presenter clearly identified the main gaps in the analysis and the approach to be taken to address these (slide 8). In addition, this project will integrate well-established models and tools for performing the analysis proposed.

- The strategy of producing and using hydrogen as an energy carrier with a quantitative, in-depth analysis is followed. The strategy includes quantitative analyses for economics, resources, and emissions. The strategy includes frameworks and integrates the transportation, industrial, and electrical sectors. The Regional Energy Deployment System (ReEDS) tool is an example of the models and tools included in the strategy (grid buildout). This project uses the strategy of evaluating the volume of existing hydrogen and applying existing tools to estimate the impact on infrastructure and emissions. Notably, this is a "first-pass" effort.
- The staged analysis is very organized and helps to reduce "noise" and potential confusion.
- The goal of the project with respect to green hydrogen production needs to be clarified. Originally, the project did not include (or at least did not show on the concept schematic) natural gas production and, to date, does not show coal production or whether the project team thinks coal will be a player in the future energy grid. If we are focused on only green energy, then why is natural gas included? Does it require carbon capture and sequestration?
- It would be more useful to validate this concept with a near-term project instead of doing analysis for long-term hypothetical hydrogen demand. Granted, it is necessary to understand whether this concept will be feasible in the future, but it is unclear what to do in the meantime. It is also unclear how to start building up the H2@ Scale idea now. It is recommended that the strategy also incorporate more tangible projects in collaboration with industry.

## Question 3: Accomplishments and progress toward overall project and DOE goals

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

- The analysis is very comprehensive and really shows the enormous potential of hydrogen in the "big picture." Renewable hydrogen and its role in grid stability really needs to be highlighted and reported. People in the industry should get the word out to get utilities to start investing.
- Significant progress was presented, especially given that the project just recently started early in 2017. Progress was mainly on the impact on emissions and fossil use through the use of renewable electrolytic hydrogen.
- This project is at the beginning, and it is probably too early to comment on progress, other than to say that, to date, the project has had high visibility and has the potential to have a significant impact.
- The accomplishments include setting strategies and boundaries. The visualization of the stakeholders and ecosystems is drafted. The plan for the future (pending funding) has started. The attraction of participants has started. The evaluation of the demand for hydrogen is articulated; 60 MMT/year (total market/technical potential) begs the question of how many resources this took. This presenter quantified the technical potential. Total demand, including hydrogen, is satisfied by approximately 6% of wind, <1% of solar, and approximately 100% of hydrogen (required to get up to 60 MMT of hydrogen).
- The technical potentials for hydrogen demand are inflated. The inflation is partly because of double-counting, overestimation of LDVs in the market, and the hydrogen blended in natural gas pipelines. Regarding the latter, it is unlikely that blending hydrogen with natural gas will be feasible in the near term, given the price differential in the United States, the lower British thermal unit content of hydrogen, and the potential embrittlement damage of pipelines not designed to handle hydrogen.
    - In measuring whether resources will be sufficient, it is important also to consider transmission build-out and what is expected. High-voltage, direct-current (HVDC) transmission is being built, but it is expensive. It is not clear what is realistic to expect in the future.

## Question 4: Collaboration and coordination with other institutions

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

- The extensive collaboration with other national laboratories is very strong and is key for the significant progress of this work. The engagement with industry via external workshops is of extreme value as well.
- This project team collaborates and coordinates with other institutions. They held workshops to provide input and information from numerous sources: national laboratories, academia, and the private sector.
- The early incorporation of stakeholders and outside experts is excellent, and of course, so is the involvement of the national laboratories across the board.

- For the current work, collaboration is appropriate. However, the team should seek additional collaborations with industry, looking for synergies between supply and demand to start building the concept. It would be good to see where there is cheap, excess hydrogen capacity and whether it is close to demand areas. This project could really make strides by kick-starting this kind of action.
- The biggest concern with this project is that it is very internally focused to deliver insights and direction to the technical community within the national laboratories. While it is clearly important to provide guidance and direction to the technical stakeholders, it is not clear how this project will influence industry or policy decision makers. It is unclear what an industrial hydrogen supplier expect might out of this project or whether a hydrogen supplier should be using it to make technical investment decisions or marketing decisions. If so, the deliverables do not really help very much in these decisions. To address this, a stronger tie into industry and decision makers is needed.

### Question 5: Proposed future work

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

- The proposed future work (pending funding) includes drafting the strategy, the cost reductions in electrolyzers (for electrolytic reduction in hydrogen from wind or solar resources), and cost reductions realized from grid mix changes to determine price points, increased need for research and development (R&D) advances, and future work in the economic potential (bottom-up cost estimate used to estimate the potential). This project's future work will also include identifying price requirements and supply options (market-dependent price-point changes). Other future work includes looking at production costs such as steam methane reforming, nuclear, and curtailed electrical power with a focus on "what are people/ companies willing to pay." The plan is to present the roadmap and propose future R&D in September 2017.
    - Future work will help guide how the technical potential can meet the demand. Perhaps more policy makers need to be integrated. As new applications are included, the bottom-up summation will "move" and become summarized.
- The workshop with outside experts to prioritize the economics is excellent. It is good that the project is reaching across all areas of expertise, from the laboratories to industry, and incorporating all input.
- The proposed work on scenario generation and the planned review by the external experts' panel are key for the successful continuation of this analysis work.
- As far as analysis goes, the project has a good plan, but it would be even better to add uncertainty/ variability to the hydrogen market potential numbers and analyze additional near-term projects.
- It is concerning that the future work does not take policy scenarios into consideration. It appears that the analyses are based upon assumptions about future states of power, demand, and supply as inputs to determine what effect this will have on hydrogen supply. There is no mention of how policies will enable us to get to that state. The project should include a range of policy decisions as input to determine the effects on supply and demand in order to drive the technology needs to be included. Without this, it will be left to speculation to determine what decisions need to be made to enable the vision.

### Project strengths:

- The strengths of this project include a focus on making the grid more efficient, reductions in greenhouse gas emissions, and the efficiency of using electricity required to produce an increased amount of hydrogen. This project also evaluates the amount of transmission needed to store and distribute power and conducts county-by-county analyses. Another strength of this project includes determining how placing resources near areas of heavy potential hydrogen use and demand affects the use, cost, and resource.
- The project is very well organized and looking at a variety of aspects such as demand, economics, and technical possibility. The project pulls in experts outside of (but in addition to) the laboratories, which is key to truly understanding all the elements of each topic.
- Strengths of this project are the analysis expertise provided by the project leader and the interactions with the other national laboratories.
- The team has strong analytic capabilities and good access to data, resources, and models.
- This is a highly visible project with broad input from across DOE.

### Project weaknesses:

- There are no apparent project weaknesses.
- The team should be cautious that considerations such as those raised by reviewers (subsidies and incentives, for example) are not left out, which could have a significant effect on the outcomes. This is a complex thing to manage, and the team will surely be successful.
- The project is internally focused on DOE laboratories regarding the priority and direction of technology programs. Industry is on the outside looking in at this project, not sure how to engage or what to expect. Analysis does not have a policy impact component to drive timelines and roadmaps.
- The project has inflated long-term demand numbers, and there is a lack of realistic projects.

### Recommendations for additions/deletions to project scope:

- In measuring whether resources will be sufficient, it is important to also consider transmission build-out and what is expected. HVDC transmission is being built, but it is expensive. It is unclear what is realistic to expect in the future. The team should add variability to the market's potential numbers. The current numbers for refineries, natural gas, and LDVs are inflated, given their low likelihood. For instance, refineries are not likely to uptake so much hydrogen from excess capacity generated elsewhere unless mandated by law or heavily subsidized. Natural gas pipelines are not likely to blend in 10% hydrogen, given the price differential, potential embrittlement, and decrease in energy contents. The near-term assessment is to approach utilities and companies that produce excess hydrogen, match them with the demand side, and help them with the technoeconomic analysis to start building a business case.