VII.0 Technology Validation Program Overview

INTRODUCTION

The Technology Validation program demonstrates, tests, and validates hydrogen and fuel cell technologies and uses the results to provide feedback to the Fuel Cell Technologies Office's research and development (R&D) activities. Continuing efforts include real-world evaluation and data collection associated with fuel cells operating in transportation applications (e.g., light-duty vehicles, medium- and heavy-duty trucks, and buses) and with hydrogen stations. The program is also implementing projects that support the advancement of hydrogen infrastructure by developing and validating a prototype device to measure hydrogen dispenser performance; validating infrastructure components; implementing and validating advanced hydrogen storage, delivery, and dispensing technologies; and creating tools to enhance access to hydrogen station status information. Activities of the program have expanded into examining hydrogen-based energy storage, where electrolyzers may be used as a controllable electrical load that can provide real-time grid services.

GOAL

The goal of the Technology Validation program is to validate the state-of-the-art of fuel cell systems in transportation and stationary applications, as well as hydrogen production, delivery, and storage systems, and assess technology status and progress to determine when technologies should be moved to the market transformation phase.

OBJECTIVES

The objectives of the Technology Validation program are to:

- Validate a hydrogen fueling station capable of producing and dispensing 200 kg hydrogen/day (at 5 kg/3 min; 700 bar) to fuel cell electric vehicles (FCEVs) by 2019.
- Validate large-scale systems for grid energy storage that integrate renewable hydrogen generation and storage by operating for more than 10,000 hours with an electrolysis system efficiency of 60% lower heating value by 2021.
- Validate hydrogen FCEVs with 65% lower heating value fuel cell system efficiency and 5,000 hours fuel cell durability by 2023.

FISCAL YEAR (FY) 2016 TECHNOLOGY STATUS AND ACCOMPLISHMENTS

Vehicles

Fuel Cell Electric Vehicle Evaluation

Over the last 10 years, National Renewable Energy Laboratory (NREL) has completed analysis of more than 220 on-road vehicles, which have accumulated more than 6.4 million miles. The current data analyzed come from 55 vehicles and six original equipment manufacturers, with model years spanning 2006 to 2012. Fuel cell durability has steadily and significantly improved over the last decade, and on-road fuel economy and actual driving range between fills have also increased over the last 10 years. Current analyses performed include driving behavior, fueling behavior, fuel economy, emissions, range, and reliability. While the 55 vehicles analyzed do not represent all FCEVs on the road today, it is a statistically significant set of data for evaluation with 3,052,000 total miles traveled and 101,400 total fuel cell operation hours from on-road trips analyzed since 2014. The maximum vehicle miles traveled is 190,300 miles (approximately 10% of vehicles have passed 100,000 miles), and the maximum fuel cell operation hours is 5,605. NREL also assessed the carbon dioxide (CO_2) and greenhouse gas emissions of FCEVs versus two baseline vehicles (passenger car and light-duty truck) and found that, on average, FCEV greenhouse gas emissions are 23% lower than that of a baseline gasoline passenger vehicle when using gaseous hydrogen produced from natural gas at a central steam methane reforming plant (without carbon sequestration), and 95% lower when using a 100% renewable hydrogen production pathway. (NREL)

Fuel Cell Electric Bus (FCEB) Evaluation

Fuel cell propulsion systems in buses have continued to show progress in increasing the durability and reliability of FCEBs and the primary components, and current technology meets the ultimate reliability target for road call frequency of both the overall bus and fuel cell system (Table 1). During FY 2016, NREL collected and analyzed data on 17 FCEB demonstrations at two transit agencies in the United States and Canada. Eleven fuel cell power plants with operation hours in excess of 12,000 hours were documented, and one of these systems has logged more than 22,600 hours in service, while three additional systems have surpassed 16,000 hours each. Based on in-service fuel economy of 6.8 miles per diesel gallon equivalent, the hybrid FCEBs currently in service can achieve a range of approximately 270 miles per fill. Moreover, the fuel economy of FCEBs was found to be 1.6 to 2.1 times higher than that of diesel and compressed natural gas buses (operating under the same conditions), respectively. Reliability has shown a marked increase over time, reaching the ultimate targets for both bus miles between road call and fuel cell system miles between road call, and fuel cell-related issues made up only 15% of the road calls during the period. (NREL)

TABLE 1. Progress in Meeting FCEB Targets

	Fleet Min	Fleet Max	Fleet Average	2016 Target	Ultimate Target	Target Met
Bus lifetime (years)	0.7	5.4	3.9	12	12	
Bus lifetime (miles)	8,351	131,203	91,381	500,000	500,000	
Powerplant lifetime[1] (hours)	2,013	22,203	11,462	18,000	25,000	2016
Bus availability (%)	40	92	73	85	90	
Roadcall frequency[2] (bus)	4,374	4,513	4,492	3,500	4,000	Ultimate
Roadcall frequency (fuel cell system)	19,085	23,261	22,532	15,000	20,000	Ultimate
Maintenance cost ($/mi)	0.53	2.06	1.61	0.75	0.40	
Fuel economy (mpDGE)	5.81	7.48	6.85	8	8	
Range (miles)[3]	221	345	271	300	300	

mpDGE – miles per diesel gallon equivalent

[1] Fuel cell hours accumulated to date from newest fuel cell power plant to oldest fuel cell power plant. Does not indicate end of life.

[2] Miles between road call: average for current designs.

[3] Estimated range based on fuel economy and 95% tank capacity. Transit agencies report lower real-world range.

Fuel Cell Electric Truck Component Sizing

This study examined the suitability of converting a representative sample of medium- and heavy-duty diesel trucks into fuel cell electric trucks, while ensuring similar truck performance in terms of range, payload, acceleration, speed, gradeability, and energy consumption. Models for 12 medium- and heavy-duty vehicles from various classes and vocations were developed. The component power requirement for fuel cell, battery, and electric machine to be used in these applications, and the onboard hydrogen storage requirement, were estimated. While cost will be addressed in the future, the analysis demonstrated that there are no major technological hurdles to meeting the performance and range requirements for trucks with hydrogen and fuel cell systems. (Argonne National Laboratory)

Fuel Cell Hybrid Electric Delivery Van Development and Deployment

This project developed and demonstrated a hydrogen fuel cell hybrid electric van that provides fleet operators with a zero-emission vehicle capable of meeting route range requirements while matching the performance characteristics of existing fleet vehicles. The vehicle will be validated through in-service deployment in a California United Parcel Service (UPS) fleet. Modeling activity and a component trade study performed during Phase 1 of the project showed that a 32 kW fuel cell module, 49 kWh battery energy storage, and 10–15 kg of hydrogen are required to meet the 125-mile driving range objective on actual UPS delivery routes. The proposed propulsion system configuration will allow the van to outperform existing battery–electric vans in UPS's fleet, with double the battery–electric mile range. (Center for Transportation and the Environment)

Hydrogen Fueling Stations

Hydrogen Station Data Collection and Analysis

In this evaluation period, data from state-of-the-art hydrogen fueling facilities that receive funding through DOE awards, California Energy Commission awards, and other sources were collected and analyzed by NREL. Working with codes and standards stakeholders and fueling facility owners–operators, NREL benchmarked performance of the fueling events relative to current SAE procedures. For fills greater than 1 kg with pre-cooling at -40°C, the average fueling rate was 0.87 kg/min, time to fill was 3.7 min, and the average amount dispensed was 2.8 kg. Hydrogen compressors were found to be the primary items needing maintenance both in terms of number of events and in terms of hours. Dispenser maintenance, entire system inspections, safety items (e.g., false alarms and sensors), and storage were found to have the next highest number of maintenance events for hydrogen stations. (NREL)

Performance Evaluation of Delivered Hydrogen Fueling Stations

This project aimed to integrate data collection systems at five 100 kg/d delivered liquid hydrogen fueling stations located in California for a 24-month performance period and to provide useful data to accurately benchmark and characterize station capacity, utilization, maintenance, and safety. Data on monthly dispensed hydrogen, energy used in compression and precooling of the hydrogen, maintenance and safety logs, and hydrogen quality control results were collected from operational sites (San Juan Capistrano and West Sacramento stations). A root cause failure analysis was completed, and a permanent solution was found for a data logger error that was caused by network issues. The solution has allowed for continuous data collection. All of the equipment required for data collection was ordered and assembled for installation at a third station, Bishop Ranch, which began construction on June 20, 2016. (Gas Technology Institute and Linde)

Brentwood (Washington, D.C.) Hydrogen Station Case Study

A modular hydrogen fueling advanced technology demonstration station was successfully sited, constructed, installed, and permitted in Washington, D.C., at the National Park Service Brentwood facility (Figure 1). This enabled the world's first commercially available fuel cell vehicles to become part of the DOE and National Park Service fleets (through no-cost loans). The goal of this project was to capture the lessons learned from the siting, construction, installation, and permitting process of a hydrogen station and to publish a report to document those findings, which can inform future station implementation. Some major takeaways include the following: conduct an initial environmental audit, improve coordination between multiple authorities having jurisdiction, and investigate the site for previous safety issues or limited documentation. Overall, the study provided valuable lessons learned that can be used to improve the process for creating hydrogen fueling stations. Hydrogen station data will also be collected as part of this effort. (NREL)

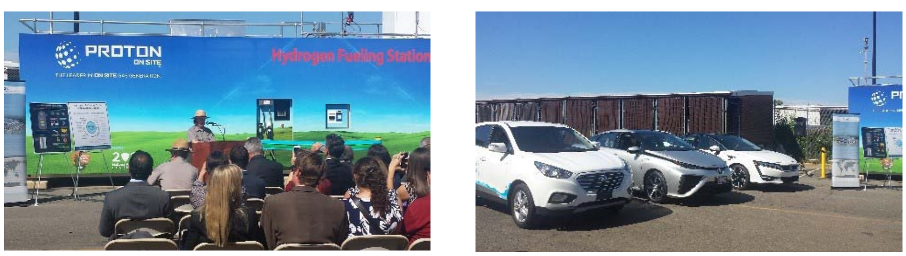


FIGURE 1. Brentwood hydrogen station opening (July 11, 2016)

Hydrogen Infrastructure Support

Hydrogen Component Validation

The goal of this project is to address the challenges associated with fuel contamination, reliability, and energy consumption related to major station components. Sample kits were provided to nine hydrogen stations to collect contaminants from failed parts. Results showed shards of metal and elastomer material likely from tubing and failed seals, along with the buildup of lubricant. Through data collected at both the NREL test facility and nine stations in industry, this project showed that the hydrogen compressors and dispensers are large contributors to downtime and system maintenance. Future work will utilize detailed maintenance and performance logs to investigate the power and energy consumption of different station components from NREL's hydrogen station, the Hydrogen Infrastructure Testing and Research Facility. (NREL)

Hydrogen Station Equipment Performance (HyStEP) Device

Currently, each automotive manufacture independently tests the performance of a hydrogen station for use with their vehicles, and this leads to a long commissioning process before opening the station for business. The HyStEP device (Figure 2) was developed to accelerate commercial hydrogen station acceptance and commissioning by measuring hydrogen dispenser performance against SAE J2601 protocols. The device has been used at three stations including at NREL, California State University, Los Angeles, and South Coast Air Quality Management District, along with a training session at the Santa Barbara fueling station. It provided consistent, reliable performance tests for over 45 fills, including leak checks, sensor and instrument checks, Infrared Data Association communications checks, and original equipment manufacturer test fills. The California Air Resources Board is leading the deployment of the HyStEP device for commissioning hydrogen stations in California. (Sandia National Laboratories)

FIGURE 2. HyStEP device

Advanced Hydrogen Tube Trailers

In order to reduce the compression needs at hydrogen fueling stations, this project aims to design, procure, construct, and demonstrate a U.S. Department of Transportation approved composite tube trailer capable of 8,500 psi delivery pressure. The project is still in the early stages, but a cost model has been developed, and the team has begun work. Experience is being leveraged from existing 7,500 psi trailers that are in operation in California and Europe for the distribution of hydrogen. (Air Products)

Cryogenic Vessels and High-Pressure Liquid Hydrogen Pump

Larger quantities of hydrogen are often transported as a liquid because of its high density. The density of liquid hydrogen has advantages during bulk transport and when storing hydrogen at the forecourt station when there is enough demand at the hydrogen station to mitigate the cost of liquefaction and avoid boil-off. If liquid hydrogen becomes available at the stations, then high-density liquid hydrogen can also be leveraged in vehicles. The objectives of this project are to demonstrate high volumetric and gravimetric (50 g hydrogen/L and 9% hydrogen weight fraction) hydrogen storage performance of cryogenic pressure vessels while achieving durability of 1,500 cycles. The performance of the liquid hydrogen pump will be measured after reaching 6,000 fueling events. In FY 2016, the cryogenic hydrogen test facility was built and commissioned, and seven total pressure vessel designs were tested for durability. After falling short on the durability tests for developed pressure vessels, the project is focusing on testing tanks provided by BMW in conjunction with hydrogen pump performance testing. The Technology Validation program is coordinating with the Hydrogen Delivery and Hydrogen Storage programs on this project. (Lawrence Livermore National Laboratory)

Hydrogen Meter Benchmark Testing

Accurate measurement of dispensed fuel is necessary for commercial sale of hydrogen to ensure fair transactions between the fuel provider and customer. At NREL, three different commercial meters are being tested to determine the performance accuracy according to the gravimetric flow standard. A test stand was constructed to allow for testing of J2601 protocols for two Coriolis and one turbine flow meter. The test results will show whether the commercially available meters are able to meet the ±1.5% accuracy required during dispensing according to National Institute of Standards and Technology standards. (NREL)

Station Operational Status System (SOSS)

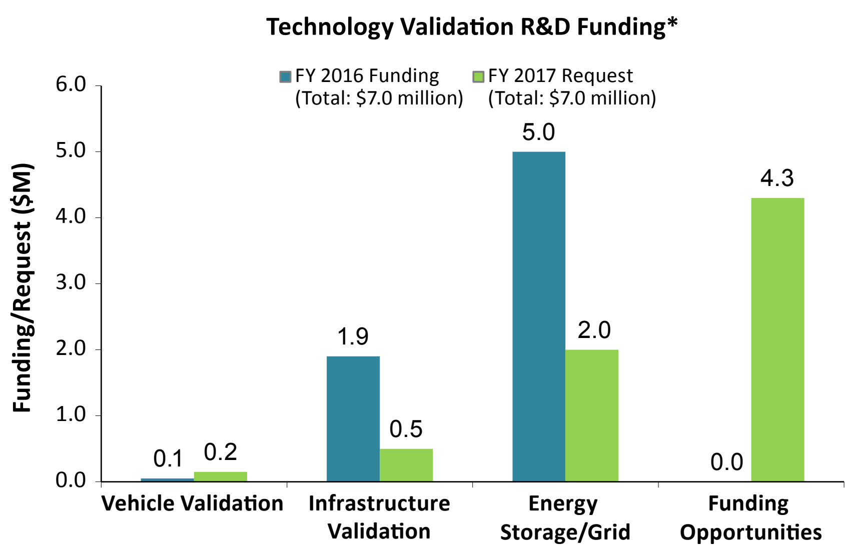
In the initial stages of station deployment, limitations in geographical coverage, station reliability, and station capacity, as well as station and component supply chain and technical support, can lead to customers arriving at a station which is unavailable for fueling. To mitigate this early-stage problem, the SOSS is designed to consistently and reliably report the status of current hydrogen fueling stations to customers through a client app for their phone or vehicle dashboard electronics. Customers can see which stations are operational, and they can be directed to the closest available hydrogen fueling station to ensure they can refuel with convenience. During FY 2016, sorting capabilities were added, and more information about the stations is now available to users. Another 20 open retail stations have been added to the existing seven for a total of 27 stations that are currently participating in SOSS. The team will continue to add new stations as they come online and improve the functionality for users. (California Fuel Cell Partnership)

Hydrogen Energy Storage/Grid Integration

As renewable energy sources penetrate the electric grid at a larger scale, the variability in the supply of this power has a greater impact on the stability of the overall power supplied to the grid. Electrolyzers can quickly ramp up and ramp down their demand to help balance the grid while utilizing extra hydrogen energy storage to ensure hydrogen energy demand is met for vehicles and other applications. This project aims to validate the benefits of hydrogen electrolyzers to the electricity grid and characterize the potential and highest economic value that they can provide. Utilizing real-time digital simulators at Idaho National Laboratory and a 120 kW electrolyzer stack as power hardware in the loop at NREL, 200 hours of operation were demonstrated and provided valuable performance data. A utility-scale network based on the Pacific Gas and Electric distribution network has been created in real-time digital simulators in order to accommodate future hydrogen refueling stations in the Bay Area. Future work will study the potential deployment of fueling stations and establish the multiple value streams for the stations. (Idaho National Laboratory)

BUDGET

The Technology Validation program's funding portfolio (Figure 3) will enable it to continue to collect and analyze data from fuel cells operating in transportation applications (e.g., light-duty vehicles, medium- and heavy-duty trucks, and buses), hydrogen infrastructure activities (e.g., fueling stations, components, and tools), and grid integration/hydrogen energy storage activities. The FY 2016 appropriation was $7 million. The FY 2017 request of $7 million is subject to congressional appropriations.



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

FIGURE 3. FY 2016 appropriations and FY 2017 budget request for the Technology Validation program

FY 2017 PLANS

In FY 2017, the Technology Validation program will continue its detailed evaluations of FCEVs, FCEBs, hydrogen fueling stations, advanced hydrogen refueling components, and infrastructure support activities. Potential future funding opportunities may emphasize hydrogen refueling station and components validation, subject to appropriations. The fuel cell hybrid electric delivery van being developed by Center for Transportation and the Environment will be fully built and validated in real-world conditions through demonstration in the UPS fleet, and its performance data will be collected and evaluated. A stakeholder workshop is planned to help develop targets for medium- and heavy-duty fuel cell trucks.

In coordination with the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy and Office of Electricity, a key focus in FY 2017 will be hydrogen-based energy storage and grid integration activities. A related workshop is planned to gain industry feedback. Support will also continue for four projects within the Grid Modernization cross-cutting effort. Two of these projects are foundational—Lawrence Berkeley National Laboratory is developing a siting and optimization tool for distributed energy resources, while Idaho National Laboratory is implementing smart technology solutions to enhance the reliability of the Idaho Falls Power distribution network. The other two projects relate more specifically to the Fuel Cell Technologies Office— Lawrence Berkeley National Laboratory is developing a tool to quantify and optimize interactions between hydrogen stations, vehicles, and the grid; NREL is developing optimal dispatch and control strategies to improve the management of fuel cell-integrated building systems.

Another area of coordination will be the Hydrogen at Scale effort, which seeks to enable deep decarbonization of industrial, transportation, and power generation sectors through wide-scale deployment of hydrogen. The Technology Validation program will coordinate with several other programs in this effort, including Hydrogen Delivery, Systems Analysis, and Market Transformation.

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