VII.0 Technology Validation Sub-Program Overview

INTRODUCTION

The Technology Validation sub-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 sub-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 sub-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 sub-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 sub-program are to:

- Validate a hydrogen fueling station capable of producing and dispensing 200 kg H_2/d (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 fuel cell system efficiency of 65% lower heating value and 5,000 h fuel cell durability.

FISCAL YEAR (FY) 2017 TECHNOLOGY STATUS AND ACCOMPLISHMENTS

Vehicles

Fuel Cell Electric Vehicle Evaluation

Over the last 10 years, the National Renewable Energy Laboratory (NREL) has completed analysis of 227 on-road vehicles that have accumulated more than seven million miles. Current data are supplied by three original equipment manufacturers for 42 vehicles, with model years spanning 2008 to 2016.

Fuel cell durability has steadily and significantly improved over the last decade, and on-road fuel economy and driving range between fills have also increased over the last 10 years. The maximum vehicle odometer reading is 296,300 mi (approximately 10% of the vehicles have surpassed 100,000 mi), and the maximum fuel cell operation is 5,648 hours. NREL is seeing the FCEVs operated in similar ways to traditional gasoline vehicles for driving and fueling. Analysis results show progress against key U.S. Department of Energy (DOE) metrics of voltage durability, system gravimetric and volumetric capacity, specific power, and power density. Future plans for this project include evaluating the interdependence between FCEV and hydrogen station performance, continuing to benchmark fuel cell durability and FCEV range, and developing and validating a predictive FCEV fueling demand model. (NREL)

Fuel Cell Electric Bus Evaluation

Fuel cell propulsion systems in buses have continued to show progress in increasing the durability and reliability of fuel cell electric buses and their primary components. Table 1 shows that the current technology meets the ultimate reliability target for road call frequency for both the overall bus and the fuel cell system. The fuel cell system on one bus is nearing the ultimate target for power plant lifetime, and seven additional fuel cell systems have surpassed the 2016 target. Table 1 also summarizes the current status compared to the DOE and U.S. Department of Transportation Federal Transit Administration performance targets. Transit agencies have made major progress over the last two years to transition maintenance to transit agency staff. (NREL)

TABLE 1. FY 2017 Summary of Progress toward Meeting DOE and Federal Transit Administration Targets

	Units	2017 Status	2016 Target	Ultimate Target
Bus lifetime	Years/miles	5.6/150,000[a]	12/500,000	12/500,000
Power plant lifetime	Hours	3,061–24,800[a]	18,000	25,000
Bus availability	%	75	85	90
Road call frequency (bus/fuel cell system)	Miles between road call	4,500/20,700	3,500/15,000	4,000/20,000
Operation time	Hours per day/days per week	19/7	20/7	20/7
Maintenance cost	$/mile	0.46–2.28	0.75	0.40
Fuel economy	Miles per diesel gallon equivalent	5.8–6.6	8	8
Range	Miles	220–270	300	300

[a] Accumulation of miles and hours to date—not end of life.

Fuel Cell Hybrid Electric Delivery Van Development and Deployment

This project aims to develop and demonstrate a hydrogen fuel cell hybrid electric van with a 125-mi operational range and validate the vehicle through in-service deployment in a California United Parcel Service fleet. In FY 2017, the vehicle design was finalized, including component layout and packaging details, after completing a hazard analysis with support from DOE's Hydrogen Safety Panel. Long lead time components were procured, and primary components of the fuel cell hybrid electric powertrain were integrated into the vehicle. The fueling requirements were reviewed with Linde, while fueling tests and fuel purchase strategies were discussed in preparation for the demonstration. The next step will be to validate a prototype van through a six-month demonstration in parcel delivery service, while also collecting and evaluating operating data during deployment. (Center for Transportation and the Environment)

Infrastructure and H2FIRST

Innovative Advanced Hydrogen Mobile Fueler

The design of the mobile hydrogen fueling system proposed by this project has been completed, and the team is ready to begin construction. The team solicited input from selected automotive companies and DOE to determine crucial design specifications and parameters for the mobile fueler. Air Liquide's C100 station design was selected as the base design. A safety plan was also developed. Major and long lead components are currently being purchased, including two Hydrogen Technology & Energy Corporation Power Cubes, a compressor, and the heat exchanger. In addition, the team is actively pursuing vendor quotes and purchase order agreements for the remaining equipment items. During the design process, the team identified barriers and challenges associated with the operation and site selection and developed a plan with DOE and other stakeholders to reduce risk and address the barriers identified. Planned activities include assembly, testing of sub-systems and full system, and site selection. (Electricore)

Hydrogen Station Data Collection and Analysis

Using the data reported to NREL by 26 retail hydrogen stations and 9 non-retail stations, analyses were conducted on several categories including deployment, performance, reliability, utilization, safety, energy use, and hydrogen quality. Current analysis shows that maximum daily utilization is beginning to approach station capacity at a few stations, which implies a need for larger and/or more stations to meet the upcoming vehicle demand. An increase in the amount of hydrogen dispensed each quarter results from more stations being built and more FCEVs on the road. In 2016, over 107,000 kg of hydrogen was dispensed from retail stations. A look at maintenance by equipment type shows that hydrogen dispensers are now the primary items needing maintenance both in terms of number of events and labor hours. Fueling rates average 0.83 kg/min, fueling amounts average 2.86 kg, and fueling time averages 3.6 min. Compressors use 3.65 kWh/kg and electrolyzers use 62 kWh/kg on average. There are 23 hours of maintenance at a station on average per month. (NREL)

Performance Evaluation of Delivered Hydrogen Fueling Stations

This project aims to assess the readiness level of current and state-of-the-art infrastructure technologies by collecting and reporting on operational, transactional, safety, and reliability data for five hydrogen fueling stations located in California. Two key technologies that are part of this project are a Gas Technology Institute (GTI) data acquisition system and a Linde ionic compressor. Two of the five sites are operational (West Sacramento and San Juan Capistrano), and data collection has commenced. The GTI data acquisition system was installed and commissioned at the San Ramon station, and the site will open for public use in the near future. Construction began at the Mountain View station in June 2017, with expected installation of the GTI panel likely occurring in September or October of 2017. Progress continues to be made on the installation of the final station; a site has been proposed and the major equipment have been built and are awaiting final site selection. (GTI and Linde)

Hydrogen Component Validation

This project addresses two challenges facing forecourt hydrogen stations today: particulate contamination and station components' energy consumption. The particulate contamination project was developed to collect field samples of particulate matter, determine the origin, and identify major issues impacting a high percentage of stations. Currently, 11 stations are participating and NREL is reaching out to more stations as they become operational. NREL identified metal particulates as a significant portion of particulate contamination. Using in-line filters, NREL examined the impact of three cleaning methods to remove metal particulates after tube cutting, beveling, and threading. The filters from tubing cleaned with the air and rag method showed the most contamination with the greatest filter mass change and the highest number of particles on the filter. Filters from tubing cleaned with the sonication method had the lowest filter mass change, and filters from the systems cleaned by tube brush had the lowest number of particles. Plans are to develop an outreach program for station fabricators on tube cleaning techniques.

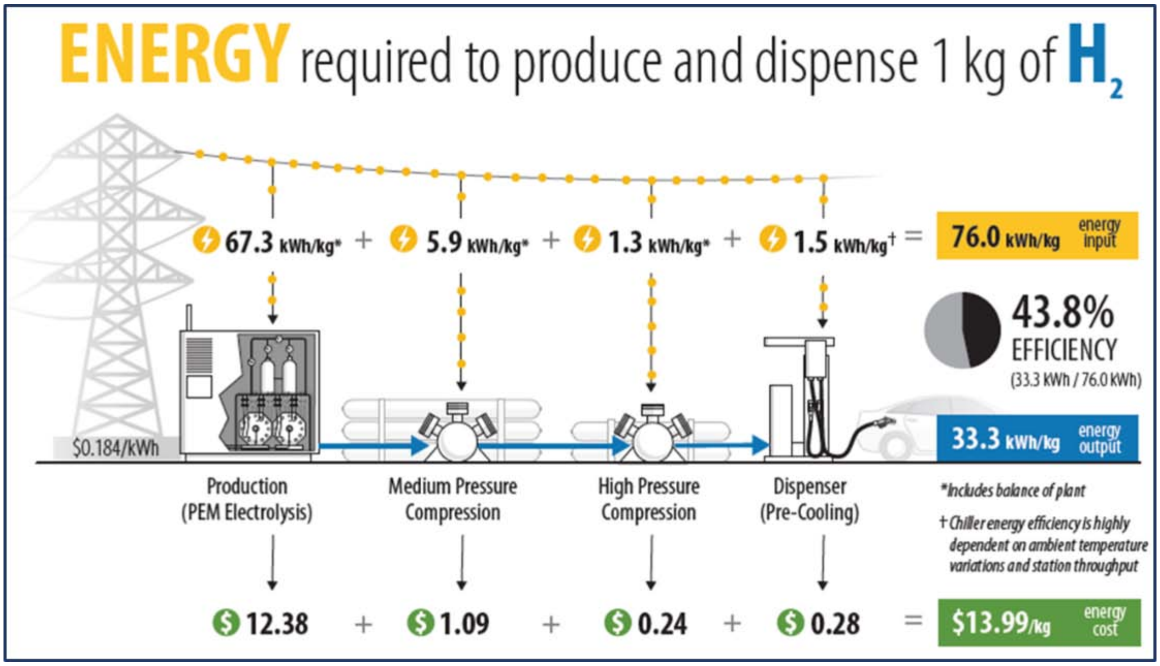
Power and energy consumption of major station components impacts operating costs at hydrogen stations. To better understand the contribution of major station components, NREL monitored the power requirements for two hydrogen compressors and the hydrogen pre-cooling system at the NREL Hydrogen Infrastructure Testing and Research Facility (HITRF) and compared the results to data from commercial fueling stations. The HITRF compressor data matched well with the retail data while the pre-cooling data comparison was found to be highly variable between HITRF and the retail stations. The primary parameters causing the variability were the ambient temperature and the mass of hydrogen chilled per unit of time. Figure 1 shows one instance of performance data, with a cost per component for each kilogram of hydrogen assuming a typical electricity rate for Los Angeles, \$0.184/kWh. (NREL)

Performance and Durability Testing of Volumetrically Efficient Cryogenic Vessels and High Pressure Liquid Hydrogen Pump

An experimental vessel was cycle tested 456 times to 700 bar with cryogenic pressurized hydrogen (before failing by developing a crack through the liner), while simultaneously measuring system performance. The liquid hydrogen pump delivered 1.65 tonnes of hydrogen to the experimental vessel during the cycle testing. The pump consistently demonstrated high hydrogen throughput (96 kg/h average and 100+ kg/h peak hydrogen flow rate). Throughput is a key parameter for reducing refueling cost per vehicle. The experimental vessel was consistently refueled in under 3 min at ~3.7 kg hydrogen per refuel. While the prototype vessel is small (65 L), these results show promise for future practical refueling times (<5 min) in larger vessels with 5–8 kg of hydrogen capacity. The pump showed low electricity consumption at an average of 1.1 kWh/kg hydrogen active power during the fill, which is considerably lower than for available alternatives. Several sources of boil-off were identified, and results indicate that the station lost 430 kg of hydrogen (25.9% of dispensed hydrogen) to boil-off during the 19-day experiment. Lower boil-off losses (16%) were measured for a typical day of operation where 300 kg of hydrogen were dispensed. Substantial reductions in boil-off to as little as 3.6% are projected for an improved delivery system where the liquid hydrogen truck is not depressurized after dewar refueling and the liquid hydrogen pump is in close proximity to the station dewar. (Lawrence Livermore National Laboratory)

Hydrogen Meter Benchmark Testing

This project aimed to design and build a laboratory-grade gravimetric standard for measurement of hydrogen flow and to evaluate the performance of three commercially available hydrogen flow meters using the gravimetric standard. High-pressure testing of commercially available flow meters (two Coriolis; one Turbine) was conducted over a range of simulated SAE J2601 fueling protocols. For the best meter, the probability that a single fill will be within 2% was found to be 82.2% for all cases, 64.6% for high flow, and 88.1% for typical flow. The probability that a single fill would fall within the 2% or 10% accuracy classes for all the data, and for high flow cases (≥2 kg/min), is shown in Table 2. (NREL)



PEM – polymer electrolyte membrane

FIGURE 1. Energy consumption for major components at the HITRF. An electricity price of $0.184/kWh, typical of Los Angeles, is assumed to show the cost of producing 1 kg of hydrogen at 700 bar and -40°C.

TABLE 2. Single Fill Performance Data

Probability a Single Fill Falls Within an Accuracy Class	All Data		High Flow Data (2+ kg/min)	
Accuracy Class	**2%**	**10%**	**2%**	**10%**
C1	46.5%	99.8%	34.1%	97.3%
C2	82.2%	100%	64.6%	100%
T1	12.6%	58.7%	35.0%	98.5%

C1 and C2 are the two Coriolis flow meters; T1 is the Turbine flow meter.

Hydrogen Energy Storage/Grid Integration

Optimal Stationary Fuel Cell Integration and Control (Energy Dispatch Controller [EDC])

This project aims to create a tool set to foster growth in fuel cell-integrated buildings by implementing an open source tool (EDC) for optimized dispatch of building components and a planning tool for optimal component selection and sizing that uses the chosen dispatch control strategy. The EDC optimization framework was demonstrated to show how varying inputs would drive different behaviors for controlling building components. Four different methods for building load forecasting (for uncontrollable loads, as input to the EDC optimization) are being evaluated. A co-simulation environment is also being established for the EDC and EnergyPlus (DOE's whole-building energy simulation engine). This co-simulation will allow the EDC to run against a building simulation, which will provide a feedback loop to which the EDC can react. The EDC and the EnergyPlus simulation are currently running separately, and the project team is working towards a functioning co-simulation environment. (NREL)

Integrated Systems Modeling of the Interactions between Stationary Hydrogen, Vehicle, and Grid Resources

This project aims to establish the available capacity, value, and impacts of interconnecting hydrogen infrastructure and fuel cell electric vehicles to the electric grid. A hydrogen–vehicle–grid integration (H2VGI) toolset is being developed to quantify and optimize the complex interactions between these energy systems. Progress has been made on developing several sub-models for the H2VGI tool set, looking at vehicle deployment scenarios, FCEV drivetrains, fueling demand from large vehicle populations, and fueling station components that demand electricity. The potential benefit to California's net load shaping from a large population of FCEVs fueled by electrolytic production of hydrogen has been modeled for the first time. Increasing overall electrolyzer capacity in megawatts (or equivalently, successively lower capacity factors) may provide some valley-filling of the net load shape. Electrolytic hydrogen production also was found to provide net load ramping mitigation. Ramp rates can be significantly reduced when the electrolyzer is slightly oversized (capacity factor reduced from 1 to 0.9), with a ramping rate reduction of about 2.85 GW/h, or about 26% from the maximum ramp rate, without hydrogen production. (Lawrence Berkeley National Laboratory)

Dynamic Modeling and Validation of Electrolyzers in Real-Time Grid Simulation

This project aims to quantify the value of electrolyzers at hydrogen refueling stations from a grid integration perspective. The anticipated value of electrolyzers stems from the fact that they are a controllable load with fast response. The test set-up involves real-time simulations of power systems at Idaho National Laboratory (INL) with hardware-in-the-loop of a 250 kW electrolyzer at NREL. In FY 2017, INL and NREL performed an aggregate of over 500 hours of testing of the 250 kW electrolyzer stack, primarily for stack characterization and front end controller (FEC) functionality. Test results demonstrated capability of the electrolyzer to provide local grid services and the ability of the FEC as hardware to control the electrolyzer. Economic optimization of the FEC also has been developed and implemented, allowing the FEC to make optimal decisions under different market rates and structures to generate hydrogen at a low cost. (INL and NREL)

Modular Solid Oxide Electrolysis Cell System for Efficient Hydrogen Production at High Current Density

This project aims to demonstrate the potential of solid oxide electrolysis cell systems to produce hydrogen at a cost of \$2.00/kg H_2 or less (excluding delivery, compression, storage, and dispensing). An additional objective involves enhancing stack endurance and imparting subsystem robustness for operation on load profiles compatible with intermittent renewable energy sources. During FY 2017, work was initiated on cell-, stack-, and system-level technology development and verification. Steady-state degradation tests of the electrolysis cells were completed over 4,500 hours of operation at 1 A/cm^2 and 2 A/cm^2, showing degradation rates of 1.3%/1,000 h and 2.6%/1,000 h, respectively, well below the 4% value as the upper limit target. A new generation of the cell design has been developed to reduce degradation rates further and is currently undergoing degradation testing. System-level investigations have focused specifically on the effects of system operating parameters and system architecture on overall system efficiency and economic feasibility. The baseline system process model has been completed and tradeoff analysis is ongoing to determine optimal system architecture and operating conditions. Future work will focus on further improvements in cell and stack endurance, forecourt system optimization, and detailed system design for the >4 kg H_2/d demonstration system. (FuelCell Energy)

H2@Scale

H2@Scale Analysis

The H2@Scale concept was presented by the national laboratory-led team during the FY 2016 Big Idea Summit and is based on utilizing hydrogen's unique ability to both support the electric grid and provide clean energy to a variety of demands. This project is focused on improving initial analysis estimates by analyzing both the technical and economic potential for hydrogen markets. The technical potential demand for hydrogen under the H2@Scale concept was estimated to be 60 million metric tonnes per year. Analyses revealed that sufficient domestic fossil and nuclear resources are available to meet the potential hydrogen demand. Assuming that hydrogen demand is supplied by water electrolysis using renewably generated electricity, the analyses indicated that fossil energy use would decrease by 15%. During the remainder of FY 2017, the team will analyze the economic potential of H2@Scale by using supply and demand curves to estimate hydrogen demand at market equilibrium. Possible work in later years could extend the analysis to consider regional analysis, storage and infrastructure development challenges, and macroeconomic impacts. (NREL)

High-Temperature Electrolysis (HTE) Test Stand

INL developed a world-class HTE laboratory and test capability that includes both a 25 kW flexible test station plus infrastructure support for up to 250 kW HTE turnkey systems. A three-dimensional computer aided design model of the 25 kW HTE system layout has been prepared, and operating specifications have been determined. Assembly of the 25 kW HTE demonstration facility will be completed during the first and second quarters of FY 2018, and full-scale testing is planned for later in FY 2018 (third and fourth quarters). (INL)

BUDGET

The Technology Validation sub-program was allocated $18 million in FY 2017 (Figure 2). This funding enabled 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), 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 Office of Energy Efficiency and Renewable Energy, major focus areas in FY 2017 were hydrogen-based energy storage and grid integration activities, including H2@Scale.

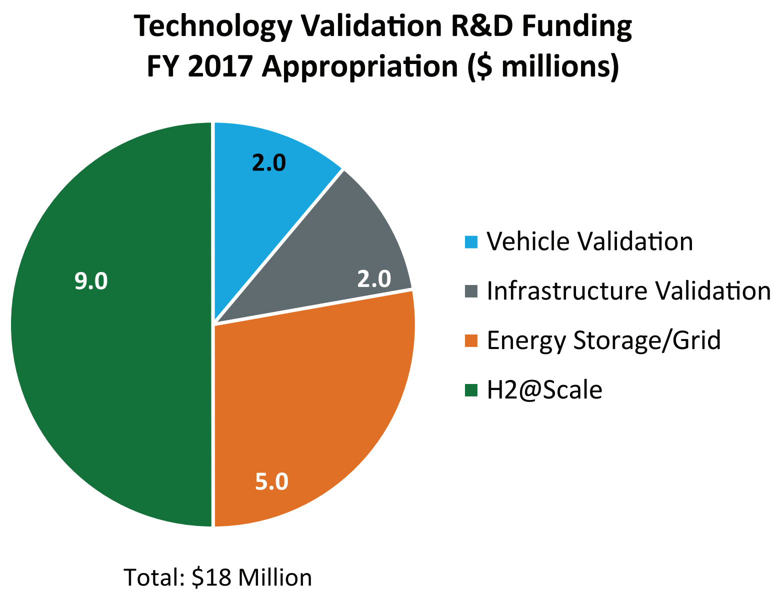


FIGURE 2. FY 2017 Appropriations

UPCOMING ACTIVITIES AND PLANS

With funding remaining from previous fiscal year appropriations, the Technology Validation sub-program will continue the following activities in FY 2018:

- Collection of performance and maintenance data from hydrogen fueling stations.
- Collection of performance data from fleets of FCEVs and fuel cell systems.
- Performance testing of high-pressure liquid hydrogen pump to 300 bar.
- Modeling and validation of electrolyzers in real-time grid simulation scenarios.
- Prototype testing and demonstration of medium-duty parcel delivery truck using a fuel cell solution for increased range.
- Construction and testing of a J2601-compliant mobile hydrogen fueler for FCEVs.
- Detailed design of a 4 kg/d modular solid oxide electrolysis cell hydrogen production system.
- Establishment of co-simulation environment for an EDC.
- Quantification of the scale of the opportunity for hydrogen–vehicle–grid integration.
- Assembly of 25 kW high temperature electrolysis test stand.

Future activities are subject to appropriations.

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