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 Program's research and development (R&D) activities. This year, the sub-program concluded the National Fuel Cell Electric Vehicle Learning Demonstration, the principal emphasis of the sub-program over the past decade, which encompassed the co-development and integration of hydrogen infrastructure with hydrogen fuel cell–powered vehicles, allowing industry to assess progress toward technology readiness. In addition, the Technology Validation sub-program completed a project on combined hydrogen, heat, and power (tri-generation or CHHP). Continuing efforts include the real-world evaluation of fuel cell bus technologies at various transit authorities, and monitoring performance of fuel cells in stationary power, backup power, and material handling applications. The sub-program solicited proposals for a new data collection effort, which will continue to track technological progress in the performance, durability, and reliability of refueling stations, advanced refueling components, and fuel cell electric vehicles (FCEVs).

GOAL

Validate the state of the art of fuel cell systems in transportation and stationary applications as well as hydrogen production, delivery, and storage systems. Assess technology status and progress to determine when technologies should be moved to the market transformation phase.

OBJECTIVES[1]

- By 2012, publish the final report on the National Hydrogen Fuel Cell Electric Vehicle and Infrastructure Learning Demonstration.
- By 2014, validate durability and efficiency of stationary fuel cell systems against fuel cell targets (40,000-hour durability, 40% efficiency).
- By 2017, complete the validation of commercial fuel cell combined heat and power systems target (50,000-hour durability).
- By 2017, validate durability of auxiliary power units against fuel cell systems target (15,000-hour durability).
- By 2019, validate hydrogen FCEVs with greater than 300-mile range and 5,000-hour fuel cell durability. Validate a hydrogen fueling station capable of producing and dispensing 200 kg H_2 per day to cars and/or buses.
- By 2020, validate large-scale systems for grid energy storage that integrate renewable hydrogen generation and storage with fuel cell power generation—operating for more than 10,000 hours, with a round-trip efficiency of 40%.

FY 2012 TECHNOLOGY STATUS

National Fuel Cell Electric Vehicle Learning Demonstration

In 2012, the National Fuel Cell Electric Vehicle Learning Demonstration—a government-industry cost-shared project initiated in 2004 with four automobile and energy company teams—continued to provide data for evaluating the status of the technologies, including key metrics such as fuel cell durability, driving range,

[1] Note: Targets and milestones were recently revised; therefore, individual project progress reports may reference prior targets. Some targets are still currently under revision, with updates to be published in Fiscal Year (FY) 2013.

and efficiency. The project is now complete and the final report has been published. Data has been collected on a total of 183 fuel cell vehicles and 25 hydrogen fueling stations during the learning demonstration, with 13 stations still in operation as of 9/30/2011. FCEVs in the project traveled 3.6 million miles, and 151,000 kg of hydrogen was either produced or dispensed (with some of this hydrogen being used in vehicles outside the Learning Demonstration). Durability results indicate fuel cell durability exceeded 2,500 hours (~75,000 miles). FCEVs met or exceeded the 250-mile driving-range goal, and fuel cell system efficiency at 25% net power was 53–59%, which is close to the DOE target of 60%. Table 1 shows all of the key performance metrics that have been reported in the Learning Demonstration.

TABLE 1. Summary of key performance metrics for the Learning Demonstration. Outside of this project, DOE independent panels estimated that producing hydrogen from distributed reforming of natural gas would cost approximately $2.75-$3.50/kg H2 (2006 study) and producing hydrogen from distributed electrolysis would cost approximately $4.90-$5.70/kg H2 (2009 study)—both analyses assume a build-out rate of 500 stations/year, with stations producing 1,500 kg of H2/day.[1]

Vehicle Performance Metrics	Gen 1 Vehicle	Gen 2 Vehicle	2009 Target	2010 – 2011 Results
Fuel Cell Stack Durability			**2,000 hours**	
Maximum Team Projected Hours to 10% Voltage Degradation	**1,807 hours**	**2,521 hours**		--
Average Fuel Cell Durability Projection	821 hours	1,062 hours		1,748 hours
Maximum Hours of Operation by a Single FC Stack to Date	2,375 hours	1,261 hours		1,582 hours
Driving Range			**250 miles**	
Adjusted Dynamometer (Window Sticker) Range	**103-190 miles**	**196-254 miles**		--
Median On-Road Distance Between Fuelings	56 miles	81 miles		98 miles
Fuel Economy (Window Sticker)	42 – 57 mi/kg	43 – 58 mi/kg	no target	--
Fuel Cell Efficiency at ¼ Power	51 – 58%	53 – 59%	60%	--
Fuel Cell Efficiency at Full Power	30 – 54%	42 – 53%	50%	--

[1] Distributed Hydrogen Production from Natural Gas: Independent Review, NREL, October 2006, http://hydrogen.energy.gov/pdfs/40382.pdf; and Current (2009) State-of-the-Art Hydrogen Production Cost Estimate Using Water Electrolysis: Independent Review, NREL, 2009, http://hydrogen.energy.gov/pdfs/46676.pdf.

FY 2012 KEY ACCOMPLISHMENTS

National Fuel Cell Electric Vehicle Learning Demonstration

The National Renewable Energy Laboratory (NREL) completed the data collection and analysis portion of the Learning Demonstration project and published a comprehensive Final Report in July 2012. Throughout the project, over 500,000 individual vehicle trips were analyzed, and 99 different composite data products (CDPs) were produced by NREL to validate the current status of FCEV technology (see Table 1 for the status of specific performance metrics). The Final Report represents the last of a number of significant and groundbreaking accomplishments by NREL during the project, including the establishment of the Hydrogen Secure Data Center (HSDC), the methodology of securely aggregating business sensitive

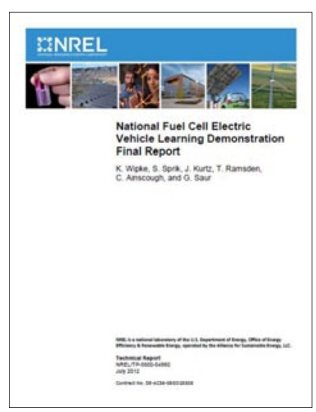


FIGURE 1. The final report of the Fuel Cell Electric Vehicle Learning Demonstration (http://www.nrel.gov/hydrogen/pdfs/54860.pdf)

performance data into useful public data, and the development of many unique and innovative data products for FCEVs and hydrogen fueling stations.

Fuel Cell Bus Evaluation

NREL began collecting and analyzing data from 17 second-generation fuel cell buses from three transit agencies (SunLine, AC Transit, and CTTRANSIT) in 2010. Transit agencies are increasing the number of scheduled miles per day: buses are operating as many as 19 hours per day and over 1,500 hours per month, with some weekend service. The second-generation bus designs have twice the fuel economy (7.78 miles per diesel gallon equivalent) of diesel buses, and the latest data show an increase in availability—9 of 17 buses are over 70% available and overall availability is 62%. NREL categorizes the reasons for unavailability and has found that the unavailability is not typically due to fuel cell issues, but relate to accident repair, air conditioning problems, and materials compatibility. Hybrid system issues were primarily software related, and battery issues have diminished in comparison to previous designs. The mean time between road calls (MBRC) for the fuel cell system (8,158 miles) improved 38% compared to first-generation systems. The target MBRC for the propulsion system is 10,000 miles. The fuel cell powerplant with the most hours of operation exceeded 12,000 hours of operation by August, 2012. Three of the powerplants exceeded 6,000 hours of operation without repair. Fuel cell bus targets vs. status are list in Table 2.

TABLE 2. Performance, Cost, and Durability Targets for Fuel Cell Transit Buses

	Units	2012 Status	2016 Target	Ultimate Target
Bus Lifetime	years/miles	5/100,000[1]	12/500,000	12/500,000
Power Plant Lifetime	hours	12,000	18,000	25,000
Bus Availability	%	60	85	90
Fuel Fills	per day	1	1 (<10 min)	1 (<10 min)
Bus Cost	$	2,000,000	1,000,000	600,000
Road Call Frequency (Bus/Fuel Cell System)	miles between road calls	2,500/10,000	3,500/15,000	4,000/20,000
Operation Time	hours per day/days per week	19/7	20/7	20/7
Scheduled and Unscheduled Maintenance Cost	$/mile	1.20	0.75	0.40
Range	miles	270	300	300
Fuel Economy	miles per gallon diesel equivalent	7	8	8

[1] Status represents data from NREL fuel cell bus evaluations. New buses are currently projected to have 8 year/300,000 mile lifetime.

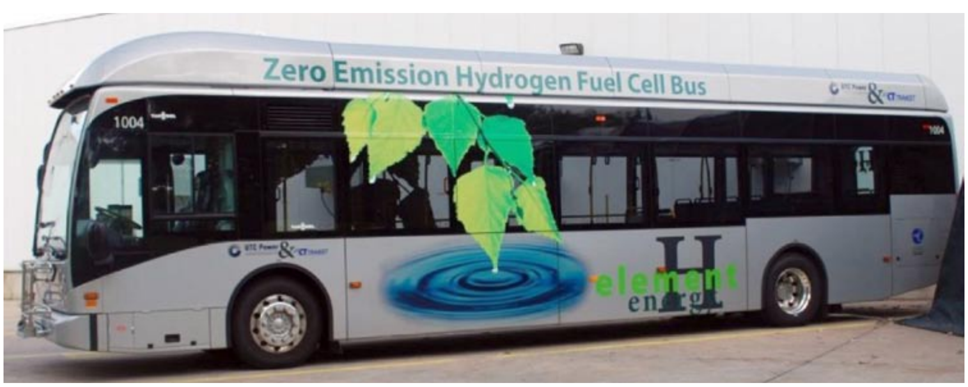


FIGURE 2. The bus pictured, which is in service at CTTRANSIT in Hartford, Connecticut, is a fuel cell dominant Van Hool 40-foot bus with a UTC Power Fuel Cell System, Siemens ELFA hybrid system using lithium-based batteries

California Hydrogen Infrastructure Project (CHIP)

The California Hydrogen Infrastructure project, a congressionally directed project from 2005, concluded in December 2011. The project developed, constructed, and operated three permanent hydrogen stations in California, described below in more detail. In addition, Air Products completed temporary deployments of HF-150 mobile refuelers at the district office of the U.S. Forest Service in Placerville, California, and at a City of Long Beach facility in Long Beach, California. The Air Products HF-150 maintains about 150 kg of gaseous hydrogen at 6,600 psig. It can dispense approximately 80 to 90 kg before needing to be refilled. It is ideal for small fleet fueling and offers the advantage of being an automated, highly reliable, cost-effective fueling system that can be easily installed.

The University of California, Irvine station is supplied with liquid hydrogen and operates at 350 or 700 bar, has 25 kg/day capacity with actual demand approaching 50 kg/day and is to be expanded to 100 kg/day. The station has completed over 8,000 fills since starting up in August 2006.

The Torrance Pipeline Station, developed by Shell Hydrogen and shown in Figure 3, uses an Air Products industrial-grade hydrogen pipeline, and the station can dispense 350- or 700-bar hydrogen for $4.50 to $5.00 per kg. It has a 48-kg/day capacity (enough to fill 12 cars per day) and is expandable to 96 kg/day with additional compression. When starting with full storage, six cars can be filled in succession. It has completed over 2,000 fills since April 2011. The station includes a 4-kg/hour compressor skid, along with storage for 100 kg of hydrogen at 7,777 psig and 20 kg of hydrogen at 15,000 psig. The station can dispense hydrogen according to SAE TIR-J2601, and it includes the first example of hydrogen purification technology for production of an ultra-pure hydrogen stream from an industrial-grade pipeline supply.

FIGURE 3. The dispenser area at Shell's Torrance, California, fueling station, which is supplied by an Air Products pipeline

The Fountain Valley Renewable Hydrogen Station[2] also supplies hydrogen at 350 and 700 bar. This installation, located at the Orange County Sanitation District (OCSD) in Southern California, is the world's first tri-generation energy station and hydrogen refueling station, producing hydrogen and electric power from wastewater treatment gas, using a molten carbonate fuel cell, with a capacity of 100 kg H_2 per day. The Integrated Hydrogen Energy Station will continue to be operated on anaerobic digester gas from the wastewater treatment facility until May 31, 2014, under sponsorship of the California Air Resources Board and South Coast Air Quality Management District.

- The first co-production of hydrogen (using natural gas) at the Hydrogen Energy Station in OCSD took place in October 2010.
- In February 2011, the first hydrogen from the Hydrogen Energy Station at OCSD was sent to the hydrogen fueling station. Initial test fills of FCEVs at the hydrogen fueling station were completed in March 2011.
- In May 2011, operation on biogas from the wastewater treatment facility began.
- Over 1,000 hours of operation in power and power-and-hydrogen modes have been completed during the performance period. The hydrogen produced has met all quality standards.

[2] This station is based on a technology that co-produces power, heat, and hydrogen. This type of system is referred to as a CHHP (Combined Heat, Hydrogen, and Power or Tri-generation) system. The station uses a high-temperature fuel cell to co-generate heat, hydrogen and power. The fuel cell can use a diversity of hydrogen-rich fuels, including digester gas, natural gas, landfill gas, and syngas. This technology is expected to provide a source of cost-competitive hydrogen, which can be renewable when digester gas or landfill gas is used as the feedstock.

- Over 5 million standard cubic feet of digester gas has been processed to produce over 5,000 kg of hydrogen and over 1 million kWh of power.
- The unit has achieved nominal 54% efficiency (power + hydrogen) when operating in hydrogen co-production mode.

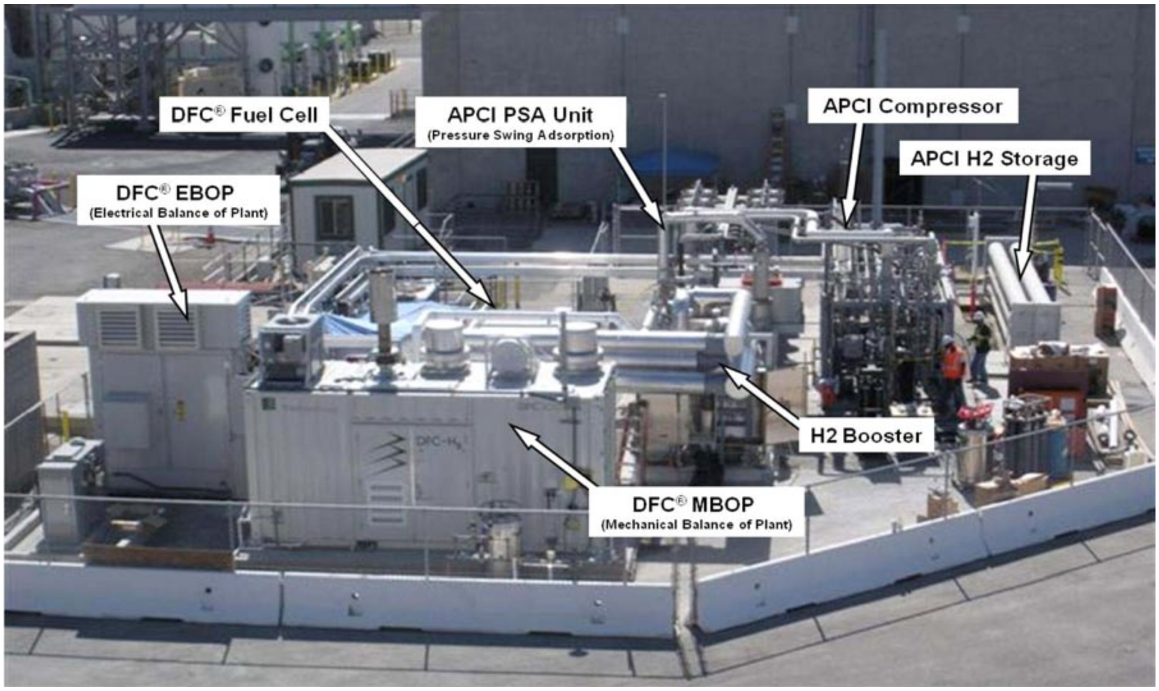


FIGURE 4. The Energy Station at Fountain Valley, California (dispensing area not shown)

Next Generation Hydrogen Station Analysis

The objective of the Next Generation Hydrogen Station Analysis project is to collect data from state-of-the-art hydrogen fueling facilities, such as those funded by the California Air Resources Board, to enrich the analyses and CDPs on hydrogen fueling originally established by the Learning Demonstration project. NREL's analyses provide valuable feedback on sensitive data from hydrogen infrastructure for industry and DOE. NREL works with facility owners/operators to benchmark performance of the fueling events relative to current SAE International procedures. Data templates were updated and the Fleet Analysis Toolkit code was updated to accept data from stations in the new templates for processing and analysis leading to CDPs. A set of 12 CDPs was created from data reported from four stations in early 2012. NREL continues to maintain an accurate database (location and status) of all online hydrogen stations in the United States, providing periodic updates to other online resources, specifically NREL's Alternative Fuels Data Center station locator, the Fuel Cell and Hydrogen Energy Association, the California Fuel Cell Partnership, and FuelCells.org.

Stationary Fuel Cell Evaluation

The analysis of stationary fuel cell operation includes systems providing primary power to a site. Operation, maintenance, and safety data are collected on site by project partners for fuel cell systems and infrastructure. NREL receives the data quarterly and stores, processes, and analyzes the data in the Hydrogen Secure Data Center. A key step in this project is the identification of locations and end users operating stationary fuel cells, as well as stationary fuel cell developers. The California Stationary Fuel Cell

Collaborative provides a strong partnership for NREL, because it involves multiple developers, end users, fuel cell technologies, and fuel cell system sizes.

Sustainable Hydrogen Fueling Station

The College of Engineering, Computer Science, & Technology at California State University, Los Angeles, as part of its energy curriculum, is building a sustainable hydrogen station to teach and demonstrate the production and application of hydrogen as the next generation of fully renewable fuel for transportation. In FY 2012, installation of all station equipment was completed and the station was commissioned, capable of fills at both 350 and 700 bar. The project was completed.

Hawaii Hydrogen Power Park

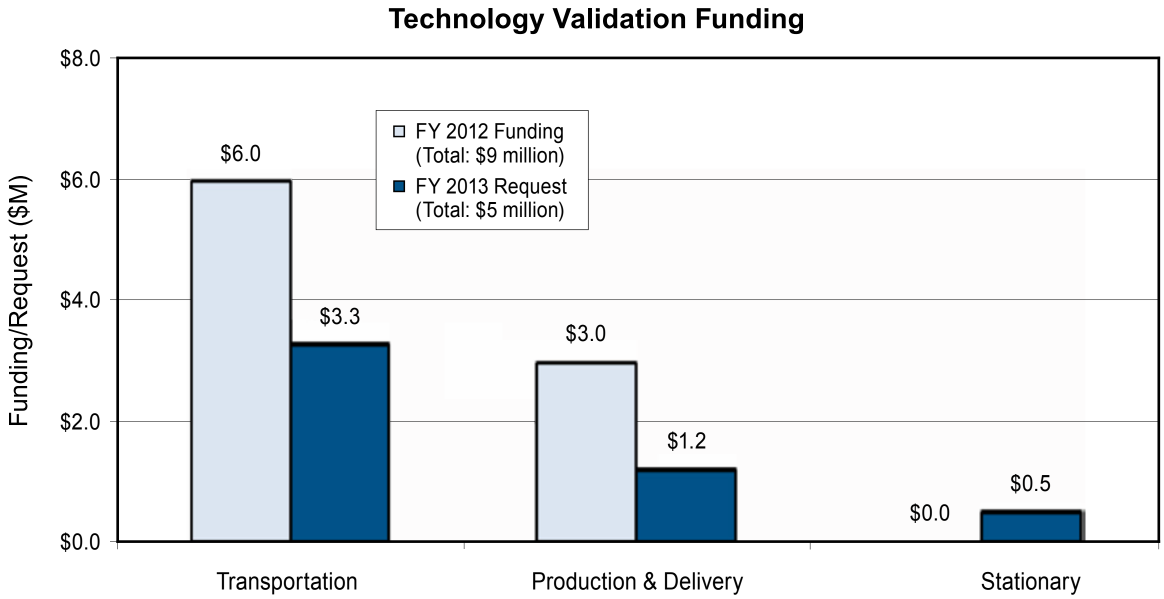
The Hawaii Hydrogen Power Park integrates a broad scope of technologies and activities funded by DOE as well as the State of Hawaii, the National Park Service, and the Office of Naval Research. The project addresses barriers to the widespread deployment of hydrogen vehicles in Hawaii and includes the deployment of hydrogen infrastructure, including 700-bar fast-fill and novel cascade non-compressor fueling systems, the installation of hydrogen fueling infrastructure at Hawaii Volcanoes National Park, and the operation, education and outreach, and economic and operational analysis of Hawaii Volcanoes National Park hydrogen shuttle bus service. The station supports the General Motors Equinox FCEV demonstration on Oahu and leverages the DOE and Naval Research Laboratory 60 kg/day geothermal-to-hydrogen grid management project to produce hydrogen.

Wind-to-Hydrogen Project, NREL/Excel Energy

NREL is demonstrating commercially available low-temperature electrolyzer technologies (proton exchange membrane and alkaline electrolyzers) to evaluate their response to commands to increase and decrease stack power (which enable them to shorten frequency disturbances on an alternating current microgrid). Results show that both the proton exchange membrane and alkaline electrolyzers are capable of adding or removing stack power to provide sub-second response that reduced the duration of grid frequency disturbances. The integrated renewable electrolysis system brings together wind turbines, solar panels, electrolyzers, compressors, storage, fuel cells, and power control components. The quick response and precise control offered by variable electrolyzer stack operation has been shown to be superior to the control capabilities of many conventional generators. NREL is demonstrating that electrolyzers can perform repeated high cyclic power variations (20–100% of rated stack power) to model performance with wind and solar power. To date, NREL has completed 7,000 hours of operation to help quantify performance differences between constant and variable stack power operation.

BUDGET

The funding portfolio for Technology Validation addresses the need to validate integrated hydrogen and fuel cell technologies for transportation, under real-world operating conditions. In Fiscal Year (FY) 2012, $9 million in funding was appropriated for the Technology Validation sub-program, and $5 million was requested for FY 2013.



FY 2013 PLANS

In FY 2013, the Technology Validation sub-program will continue its detailed evaluations of hydrogen and fuel cell technologies in transit buses, next generation hydrogen fueling stations, and stationary power applications. The sub-program will also award several new projects resulting from its funding opportunities issued in February and March 2012. The light-duty FCEV validation projects will supply dynamometer and real-world vehicle data to the HSDC at NREL for analysis and aggregation into CDPs for a minimum of five vehicles of the same model. Projects validating hydrogen refueling station performance will also supply data to the HSDC for analysis and aggregation into CDPs. A high-pressure electrolyzer and high-capacity hydrogen tanks will be installed at one or more refueling station for validation of performance and durability improvements in these advanced station components. Further funding opportunities will also be developed in FY 2013, subject to appropriations.

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