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 activities. The Technology Validation sub-program has been focused on conducting learning demonstrations that emphasize co-development and integration of hydrogen infrastructure with hydrogen fuel cell–powered vehicles to permit industry to assess progress toward technology readiness. As the vehicle and infrastructure demonstrations are coming to a close, the sub-program is increasing its focus on other areas, such as combined hydrogen, heat, and power (tri-generation or CHHP) as well as stationary power applications.

Goal

Validate–under real-world operating conditions–the status, relative to Program targets, of hydrogen and fuel cell technologies that will be used in both the initial market entry and early market periods of fuel cells for transportation and stationary power generation.

Objectives[1]

- **2014:** Validate a stationary fuel cell system that co-produces hydrogen and electricity at 40% efficiency, with 40,000-hour durability.
- **2019:** Validate fuel cell electric vehicles (FCEVs) achieving 5,000-hour durability (service life of vehicle) and a 300-mile driving range between fueling.

Fiscal Year (FY) 2011 Technology Status

National Learning Demonstration

In 2011, the National 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 technology status with respect to fuel cell durability, driving range, and power park demonstrations. Six years of the seven-year project are complete. A total of 155 vehicles have been deployed through the first quarter of FY 2011, with 23 currently in operation. Thus far, more than 3 million miles have been traveled by the FCEVs in the project and 140,000 kg of hydrogen has been either produced or dispensed, with some of this hydrogen being used in vehicles outside the Learning Demonstration. New durability results will be available in autumn 2011; however, 2010 durability results indicate fuel cell durability exceeded 2,500 hours. Fuel cell vehicles have met or exceeded the 250-mile driving-range goal and fuel cell system efficiency data at 25% net power is 53–59%, which is close to the DOE target of 60%. Figure 1 shows all of the major key performance metrics that have been reported in the National Hydrogen Learning Demonstration.

- **General Motors (GM) Hydrogen Vehicle and Infrastructure Demonstration and Validation:** GM has deployed 60 vehicles, demonstrating two generations of GM's proprietary fuel cell technology. GM continues to operate and maintain 10 baseline Phase 2 FCEVs through 2011 or until failure. In 2010, GM inserted ten additional Phase 2 FCEVs equipped with technology developed during the initial part of Phase 2 to extend learnings (Figure 2). GM has also established retail and retail-like hydrogen stations for public fueling: Six fueling stations are in operation across the Eastern and Western regions, with various types of hydrogen generation and delivery––such as delivered compressed gas and on-site electrolysis. Two stations are infrared capable and able to fast fill more than three vehicles back-to-back. Hydrogen quality testing has been completed, and stations have been tested at 700 bar.
- **Mercedes-Benz North America:** Over the course of the project, the Mercedes Team has deployed 30 Gen-1 vehicles into customer hands for real-world operations in various climatic regions of the United States. The Mercedes Team has transitioned FCEV activities from research and development to mainstream

[1] Note: Targets and milestones are under revision; therefore, individual progress reports may reference prior targets.

commercial activities, and they have now begun customer operations of production-level Gen-2 vehicles. (The first Gen-2 FCEVs were delivered to external customers in December of 2010.) B-Class F-CELL vehicles have been incorporated into Mercedes' standard business processes within departments such as Warranty, Customer Assistance, Parts & Distribution, as well as Roadside Assistance and Sales.

Learning Demonstration Key Performance Metrics Summary

Vehicle Performance Metrics	Gen 1 Vehicle	Gen 2 Vehicle	2009 Target
Fuel Cell Stack Durability			**2,000 hours**
Max Team Projected Hours to 10% Voltage Degradation	**1,807 hours**	**2,521 hours**	
Average Fuel Cell Durability Projection	821 hours	1,062 hours	
Max Hours of Operation by a Single FC Stack to Date	2,375 hours	1,261 hours	
Driving Range	**103-190 miles**	**196-254 miles**	**250 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%

Infrastructure Performance Metrics			2009 Target
H_2 Cost at Station (early market)*	On-site natural gas reformation **\$7.70 - \$10.30**	On-site Electrolysis **\$10.00 - \$12.90**	**\$3/gge**
Average H_2 Fueling Rate	0.77 kg/min		1.0 kg/min

*Outside of this project, DOE independent panels concluded at 500 replicate stations/year:
Distributed natural gas reformation at 1500 kg/day: **\$2.75-\$3.50/kg** (2006)
Distributed electrolysis at 1500kg/day: **\$4.90-\$5.70** (2009)

FIGURE 1. Summary of Key Performance Metrics for the Learning Demonstration

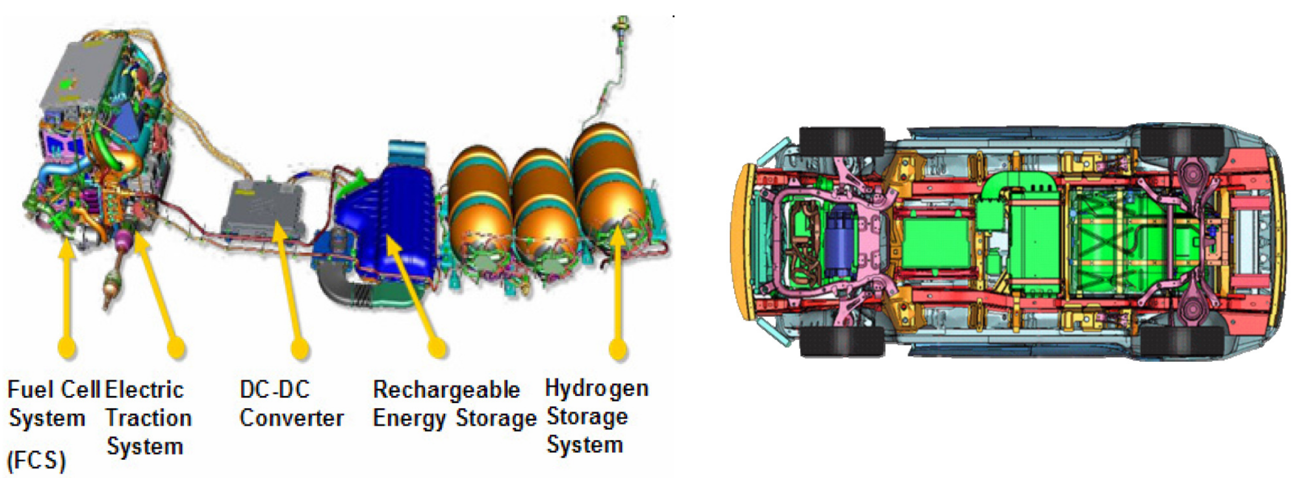


FIGURE 2. Gen-2 Chevrolet Fuel Cell Electric Vehicle with Technology Insertion

FY 2011 Accomplishments

National Learning Demonstration

The National Renewable Energy Laboratory (NREL) verified that Gen-2 learning demonstration vehicles maintained high fuel cell efficiency (53-59%). GM has concluded that FCEVs fully meet all functional needs for day-to-day customer use, FCEVs are fully functional in sub-freezing and cold weather conditions, and GM FCEVs exhibited very fast cold-start/drive-away times under sub-freezing temperatures. Mercedes-Benz demonstrated that A-Class F-CELLs exceed the 2,000-hour stack durability target. Initial test results show Gen-2 fuel cell stacks will most likely meet the 2015 DOE target of 5,000-hour durability. Engineers validated the 250-mile range and cold-start capability down to -17°C while reaching 50% of maximum power within 30 seconds (Figure 3). Hydrogen Infrastructure has been demonstrated to be customer-friendly in daily use by individual and fleet vehicle operators in a "retail-like" self-service mode.

FIGURE 3. Mercedes Engineers Validated Cold-Start Capability Down to -17°C while Reaching 50% of Maximum Power within 30 Seconds

Fuel Cell Bus Evaluation

By the end of April 2011, NREL had documented a total of 1.5 million miles of operation for three fuel cell bus (FCB) systems, with each operating in excess of 6,000 hours with no major repairs. One of these systems has logged more than 9,000 hours of service (Figure 4). Based on in-service fuel economies of 5 to 7 miles per kilogram of hydrogen, hybrid FCBs can achieve a range between 250 and 350 miles per fill, with no loss in cargo and passenger space (however, the added weight of the hydrogen storage system limits the number of standing passengers allowed on the bus). Fuel cell buses compared to baseline buses at three locations showed a fuel economy improvement ranging from 48% to 123% over diesel and compressed natural gas (CNG) baseline buses, respectively. Transit routes are unique for each location, so the duty cycles varied between the locations.

FIGURE 4. In FY 2011, NREL completed their first report on a next-generation fuel cell bus. The bus, which is in service at SunLine Transit Agency in Thousand Palms, California, is a New Flyer 40-foot bus with a Bluways hybrid system, Ballard fuel cells, and lithium-ion batteries. The bus has accumulated more than 9,000 miles and 818 hours on the fuel cell, with an average fuel economy of 5.75 miles per kg. This is nearly two times higher than the fuel economy for the baseline CNG buses.

California Hydrogen Infrastructure Project

In early 2011, construction was completed on the world's first fueling station supplied by a hydrogen pipeline (Figure 5), which was partially funded through a prior year congressionally directed project. This project aims to demonstrate a low-cost, reliable supply of hydrogen. The station, which is located in Torrance, California, close to an existing Air Products hydrogen pipeline, was developed by Shell Hydrogen. A 4-kg/hr compressor skid has been installed, along with storage for 100 kg of hydrogen at 7,777 psig and

FIGURE 5. The Dispenser Area at Shell's Torrance, California, Fueling Station, which is Supplied by an Air Products Pipeline

FIGURE 6. HF-150 Mobile Refueler at the District Office of the U.S. Forest Service in Placerville, California

20 kg of hydrogen at 15,000 psig. This station dispenses hydrogen according to SAE International technical information report 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. Two dual dispensers for both 350- and 700-bar hydrogen have been installed, and four vehicles can be filled simultaneously. Based on a 50% compressor on-stream factor, the station will have the capacity to dispense 48 kg/day, enough to refuel approximately 12 cars per day. When starting with full storage, six cars can be filled in succession. Vehicle test fills were completed in March 2011.

In December 2010, Air Products completed a nine-month deployment of an HF-150 mobile refueler at the district office of the U.S. Forest Service in Placerville, California (Figure 6). 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.

Energy Station at Fountain Valley[2]

The Hydrogen Energy Station was installed at the Orange County Sanitation District (OCSD) in Fountain Valley, California, and became fully operational in FY 2011 as the world's first fuel cell energy station that produces electric power and hydrogen from wastewater treatment gas (Figure 7).

- The first co-production of hydrogen (using natural gas) at the Hydrogen Energy Station in OCSD took place in October 2010.
- Over 1,000 hours of operation in power and (power + hydrogen) modes has been completed during the performance period. The hydrogen produced has met all quality standards.
- The unit achieved nominal 54% efficiency (power + hydrogen) when operating in hydrogen co-production mode.
- In February 2011, the first hydrogen from the Hydrogen Energy Station at OCSD was sent to the hydrogen fueling station. Initial test fills of fuel cell vehicles at the hydrogen fueling station were completed in March 2011.
- In May 2011, operation on biogas from the wastewater treatment facility began.

[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, power, and hydrogen or tri-generation) system. The station uses a high-temperature fuel cell to co-generates electricity, heat, and hydrogen. 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.

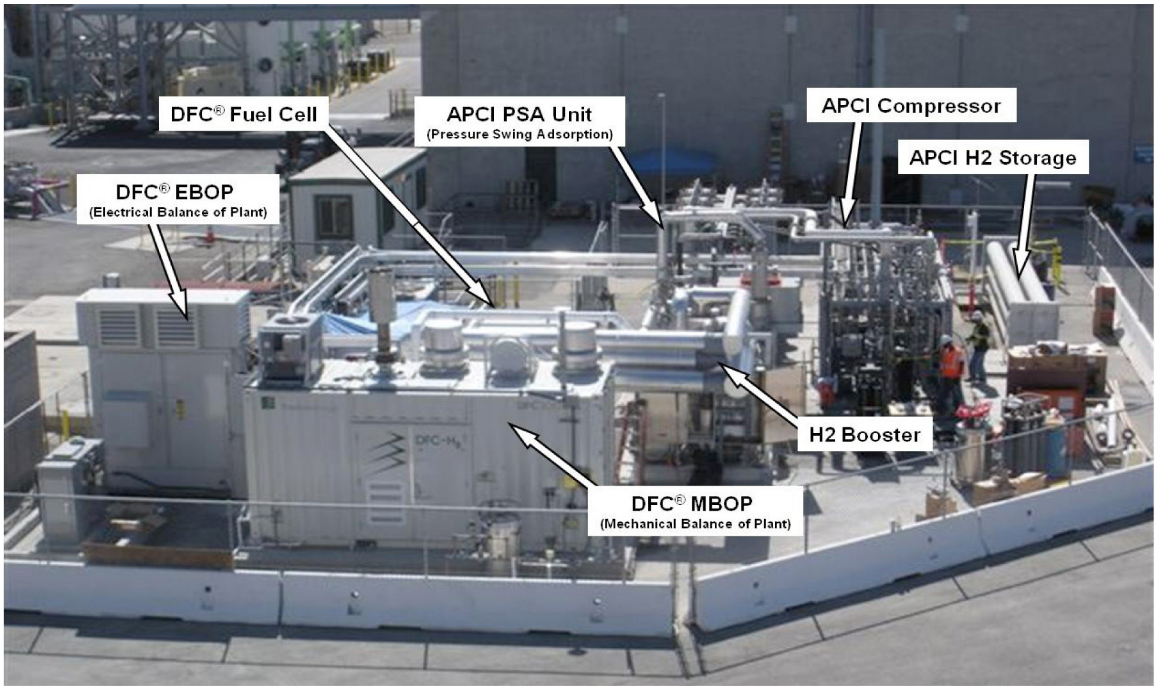
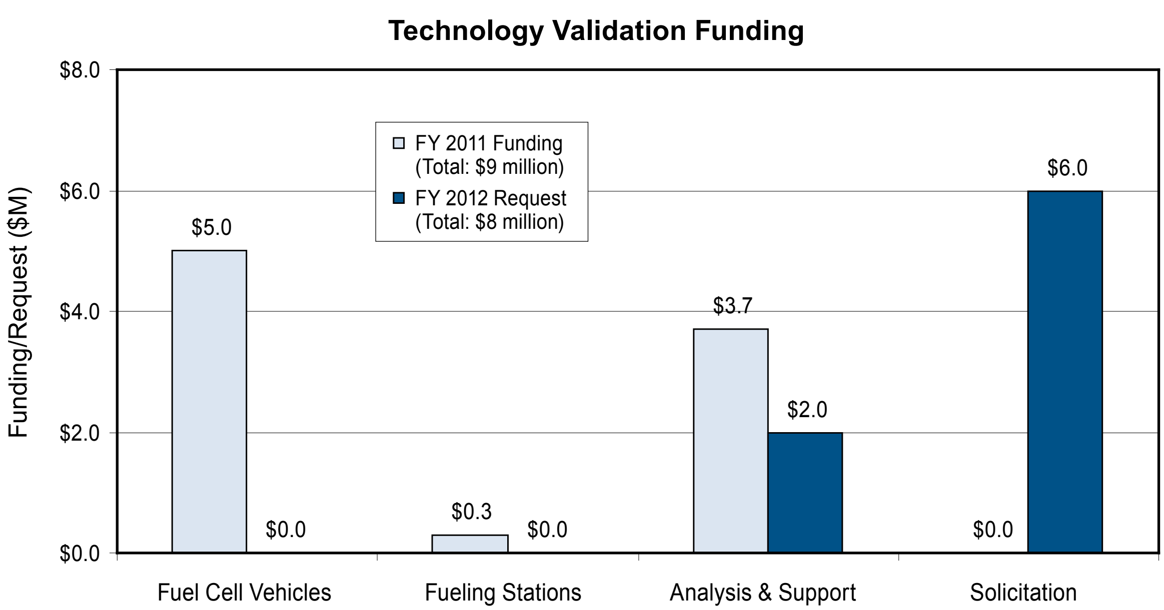


FIGURE 7. Energy Station at Fountain Valley, California (dispensing area not shown)

Budget

The funding portfolio for Technology Validation addresses the need to validate integrated hydrogen and fuel cell technologies for transportation and electric power generation in a systems context, under real-world operating conditions. In FY 2011, $9 million in funding was appropriated for the Technology Validation sub-program. The President's FY 2012 request includes $8 million for Technology Validation activities.



FY 2012 Plans

A set of composite data products (CDPs) based on data collected through June 2011 ("Fall 2011 CDPs") will be created for publication and reporting in November 2011. In the first quarter of FY 2012 the final two National Learning Demonstration projects (GM and Mercedes-Benz North America) will conclude and final reports will be prepared.

The Technology Validation sub-program will continue to collaborate with the Department of Transportation to validate fuel cell and hydrogen technologies in transit bus demonstrations conducted by the Federal Transit Administration. Efforts will also continue to harmonize data collection with other FCB demonstrations worldwide. Future FCB projects will include:

- Collecting, analyzing, and reporting on performance data for next-generation hydrogen-fueled vehicles in California, including AC Transit, SunLine, the City of Burbank, and additional sites as funding allows.
- Investigating the reliability and durability of FCBs as a part of ongoing evaluations; these efforts complement the DOE light-duty FCEV demonstrations
- Coordinating with Federal Transit Administration to ensure harmonized data-collection efforts for the National Fuel Cell Bus Program

The Integrated Hydrogen Energy Station will continue to be operated on anaerobic digester gas from the wastewater treatment facility. Data will be provided to DOE for the first six months of operation under a three-year program sponsored by the California Air Resources Board and the South Coast Air Quality Management District.

The Technology Validation sub-program is planning a funding opportunity announcement for FY 2012, subject to appropriations. Potential areas of interest may include: medium-scale (50- to 500-kW) CHHP production; medium-scale (50- to 500-kW) hydrogen and power production; on-site hydrogen generation for back-up power and specialty applications (e.g. material handling); fuel cell-powered ground support equipment for ports, terminals, and distribution hubs; and polymer electrolyte membrane fuel cells for stationary power. Final topics will consider input from the request for information that was issued to the stakeholder community and the public in FY 2011.

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