Validation of Hydrogen Fuel Cell Vehicle and Infrastructure Technology

The GM/Shell partnership that produced this fuel-cell vehicle and fueling facilities for it is one of four such partnerships that the U.S. DOE is cost-share funding and for which NREL is collecting and analyzing extensive performance data to validate hydrogen fuel cell vehicles and infrastructre technology.

Highlights

With U.S. DOE cost-share funding assistance, four automobile manufacturer-energy company partnerships are building small fleets of fuel cell vehicles and hydrogen fueling facilities to fuel them.

To validate hydrogen fuel cell vehicle and fueling technology, NREL is collecting and analyzing extensive data on the operation of these fleets.

Results of this data analysis are available on a public Web site www.nrel.gov/hydrogen/cdp_topic.html

National effort is under way to make hydrogen-powered fuel cell vehicles a key element of future transportation systems. How do we determine if technological progress is meeting goals for key factors for consumer acceptance?

Hydrogen-powered fuel cell vehicles could play a central role in future transportation systems. They produce only electricity, heat, and water at point of use. They could also use predominantly domestic—potentially renewable—energy supplies instead of imported oil to help meet one of our most pressing energy needs. Consequently, there has been great interest in hydrogen as a primary "energy carrier" displacing petroleum-based fuels.

Moving to extensive use of hydrogen and fuel cells would involve complex and substantial developments and investments in hydrogen production, hydrogen distribution and storage, fuel cell technology, vehicle technology, and other aspects of energy and transportation infrastructure. The U.S. Department of Energy (DOE) has a major program for research and development of hydrogen and fuel cell technology. A key element of that research and development is the five-year, $175-million industry-cost-shared "Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project."

Through a 2003 competitive solicitation, DOE selected four automobile manufacturer/energy company teams to participate in the project— Chevron/Hyundai-Kia, DaimlerChrysler/BP, Ford/BP, and GM/Shell. DOE is cost-share funding those teams to build small fleets of fuel-cell vehicles plus fueling stations to demonstrate their use in five regions in the United States. The five test regions are in Northern California, Southern California, Southeastern Michigan, the Mid-Atlantic, and Central Florida, covering a range of temperature and humidity conditions.

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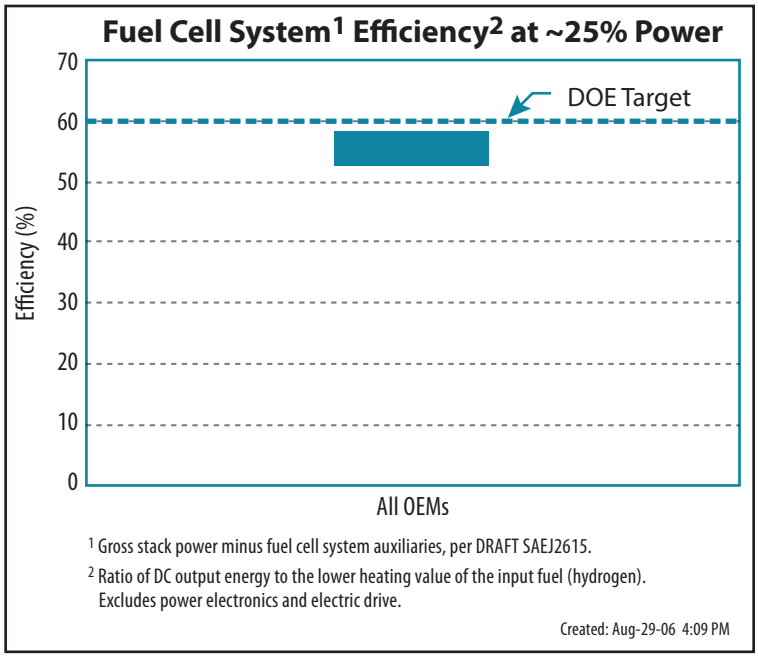
Vehicles from three of the automobile manufacturer/automobile company partnerships for which NREL is validating performance. Top to bottom: Ford/BP, DaimlerChrysler/BP, and Chevron/Hyundai-Kia.

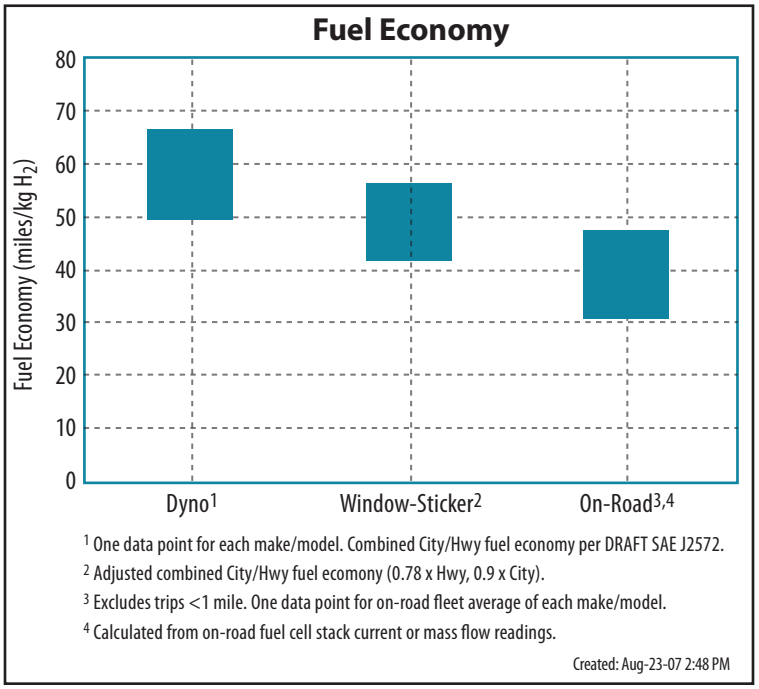
All of the teams are using polymer-electrolyte membrane fuel cells. Most of the vehicles have 350-bar (5,000-psi) compressed-hydrogen storage tanks, but a few have 700-bar (10,000-psi) or cryogenic liquid-hydrogen tanks. The fueling stations include a mixture of hydrogen delivered as a liquid and as compressed gas and on-site generation both by reformation of natural gas and by electrolysis.

DOE's National Renewable Energy Laboratory (NREL) has set up a data-collection and analysis system with the teams for the project. The system collects extensive data on the demonstration fleets and infrastructure. NREL researchers use the data to validate progress toward meeting DOE objectives for hydrogen and fuel cell technology and help guide future research and development. A key feature of the NREL validation project is that it provides multiple outputs to different stakeholders. Aggregated general results are reported publicly as "composite data products." Detailed data specific to the individual team efforts are reported only to those teams, so as to provide valuable feedback, but avoid any potential risk to the intellectual property development of the individual teams.

As of 2007, two years into the project, 77 "first-generation" fuel-cell vehicles and 14 fueling stations are in service under the program. Project vehicles traveled 1,321,000 km (821,000 mi) on 30,000 kg (66,139 pounds) of hydrogen. On the basis of progress toward interim 2006 goals, as demonstrated by validation data collected during 2005 and 2006, NREL



Fuel cells are highly efficient, capable of productively using more that half of the energy in hydrogen fuel, roughly double the conversion efficiency of most internal combustion engines running on gasoline. The fuel cell systems in the validation project vehicles averaged 53% to 58%, already very nearly meeting the long-term goal of 60% efficiency.



Fuel cell vehicle fuel economy compares quite favorably to that of gasoline-powered vehicles. Because there is about the same amount of energy in a kilogram of hydrogen as in a gallon of gasoline, these mi/kg figures for validation-project fuel cell vehicles are comparable to mpg figures. The middle "window-sticker" column is most comparable to current published automobile fuel-economy ratings. Ranging from 42 to 56 mi/kg, the fuel cell vehicles met the goal of 50% improvement over gasoline-engine cars. [The first "Dynomometer" column is actual test data before adjustment and the third "On-Road" column is what was demonstrated in actual usage. (The current rating system will be adjusted by EPA to more accurately reflect actual performance starting in 2008.)]

recommended that DOE proceed with funding additional "second-generation" vehicles to reach a planned full complement of roughly 120 vehicles and 20 fueling stations (some vehicles also refuel at pre-existing stations). Second-generation vehicles with new fuel cell stack technology, and seeking to meet more ambitious 2009 goals, are expected to become available late in 2007 and 2008.

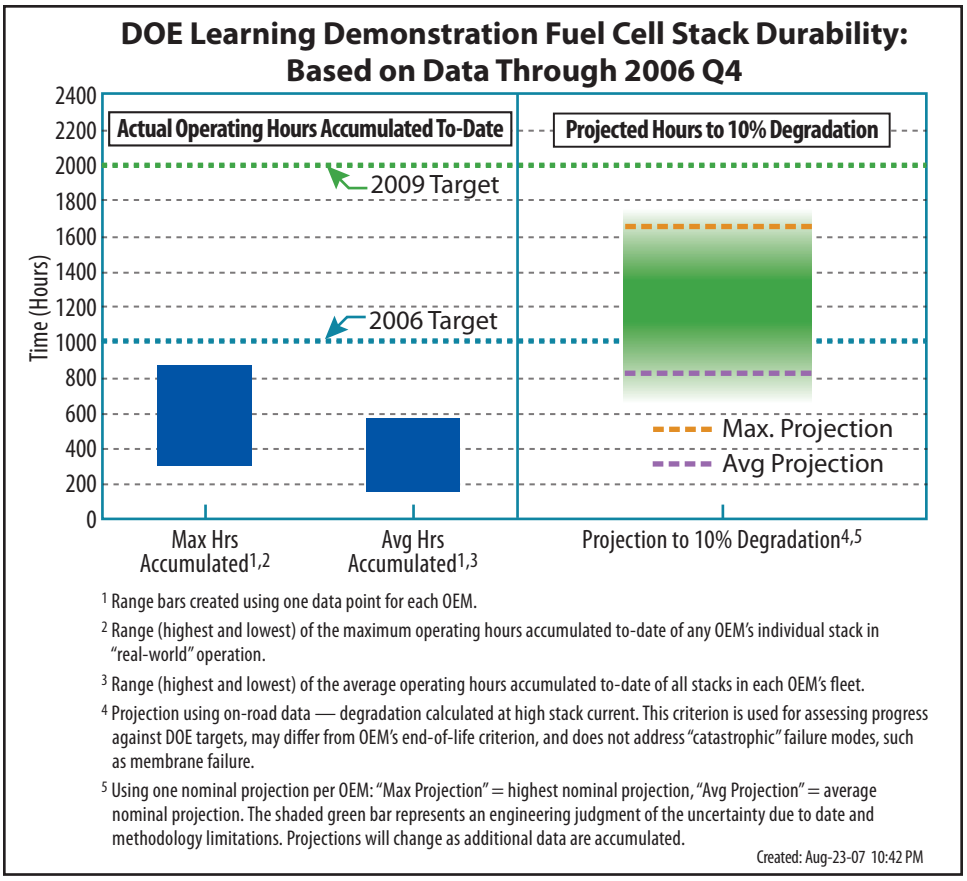
Key DOE targets for the program for 2009 at the end of the initial validation project, and for 2015 to meet objectives believed adequate for consumer acceptance include:

Performance Measure	2009	2015
Fuel Cell Durability	2,000 hours	5,000 hours
Vehicle Range	402 km (250 miles)	483 km (300 miles)
Untaxed Fueling Cost at Station	$3/gallon gasoline equivalent	$2-3/gallon gasoline equivalent

5,000 hours is equivalent to about 161,000 km (100,000 miles) for an average vehicle. Other important parameters that the validation project is tracking include refueling time, dynamometer and on-road fuel economy, cold-weather starting, safety incidents, fuel impurities, and storage tank capacity per volume and weight.

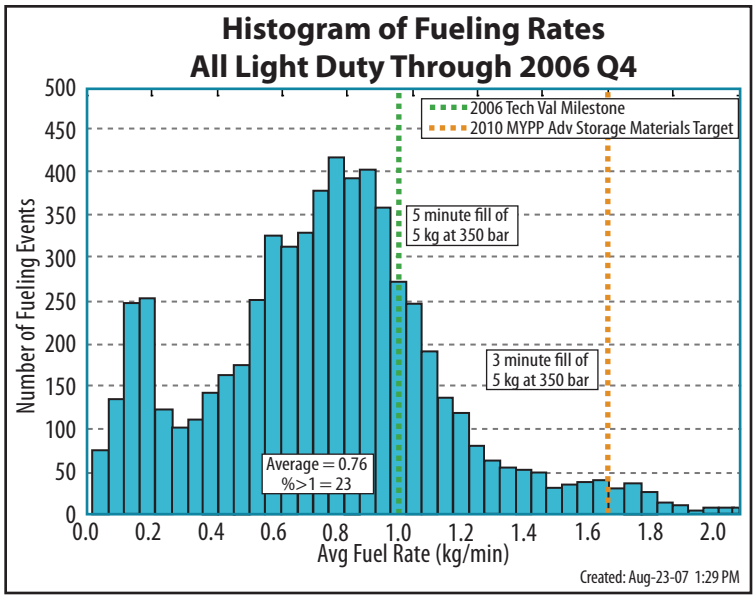
Initial assessments from the first two years of the project include:

- Fuel-cell vehicles in the demonstration fleet averaged 68 km to 91 km (42 mi to 56.5 mi) per kilogram of hydrogen. With the energy content of a kilogram of hydrogen being about equivalent to 3.9 liters (1 gallon) of gasoline, this exceeds the 50% greater fuel economy per unit energy goal DOE set for the project.
- Driving range calculated on the basis of these fuel economies and usable hydrogen storage for the vehicles ranged from 161 km to 306 km (100 mi to 190 mi). The 2009 target is 402 km (250 mi), but the great majority of the vehicles were using 350-bar (5,000-psi) compressed hydrogen storage tanks and a move to 700-bar (10,000-psi) tanks is anticipated.
- Fuel-cell system efficiency for the vehicles (measured at about one-quarter power) ranged from 53% to 58%, very nearly meeting DOE's long-term target for the fuel cell systems.
- NREL projected fuel-cell durability for the project vehicles (measured as the projected time to 10% voltage degradation) averaged a little more than 800 hours. One of the teams, however, has an average projection of more than 1,600 hours, well in excess of the 2006 DOE target of 1,000 hours. Second generation vehicles will be evaluated against the 2009 target of 2,000 hours.
- Refueling at the various station/vehicle combinations averaged 3.66 minutes and 0.76 kg (1.7 pounds) per minute. 85% of the refueling events took less than the 5-minute target and 23% exceeded the 1-kg-per-minute target.



Fuel cell life is a key technological objective for consumer acceptance of fuel cell vehicles. The DOE and industry long-term goal of 5,000 hours fuel cell stack durability correlates to engine life of about 100,000 miles. The projected average "life" (defined for this project as hours to 10% voltage degradation) for the validation project fuel cell stacks was over 800 hours, not far from the 2006 goal of 1,000 hours, and NREL projected one team's stacks to achieve more than 1,600 hours, well above the goal.

The Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project includes several different hydrogen fueling station technologies. Top to bottom: fuel delivered as compressed gas, fuel generated on-site by natural gas reformation, fuel generated on-site by electrolysis, and fuel delivered as liquid hydrogen at cryogenic temperature.



Fueling infrastructure performance is an important part of introducing hydrogen vehicles. One kilogram/minute (enough to provide 5 kg of fuel in five minutes) was chosen as a 2006 goal for consumer acceptable fueling rate. About 23% of the project fueling events exceeded that rate.

- While hydrogen used for the demonstration generally met the 99.99% purity objective, levels of certain impurities sometimes exceeded targets and better and less expensive impurity sampling is needed.
- There were no major safety concerns identified and only one safety report classified as an incident.

Collecting second-by-second data from the demonstration vehicles, NREL processes immense amounts of information (more than 149,000 trip reports for the first two years). NREL analysts have developed sophisticated data processing and analysis tools to automatically process the data and prepare desired analysis results, while maintaining necessary security for individual team data. An NREL-developed innovative "Fleet Analysis Toolkit" software allows the analysts easy access to the data and a wide range of outputs from that data. A publicly accessible Web site www.nrel.gov/hydrogen/cdp_topic.html has been established, currently displaying 41 graphic representations of data collected thus far by the project, with new and updated results posted every 6 months.

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