

VII.4 Fuel Cell Electric Vehicle Evaluation

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Project Start Date: October 1, 2012

Project End Date: Project continuation and direction
determined annually by DOE

Overall Objectives

- Validate hydrogen fuel cell electric vehicles (FCEVs) in a real-world setting
- Identify current status and evolution of the technology

Fiscal Year (FY) 2015 Objectives

- Provide a status of FCEV durability compared with the DOE 2020 durability target
- Analyze real-world fuel economy and range
- Report on FCEV specifications as well as driving and fueling trends
- Compare performance data with relevant or past data sets (e.g., FCEV Learning Demonstration, National Household Transportation Survey (NHTS), and typical gasoline fueling trends)
- Make results available through online publication, highlights, and presentations
- Complete two publications cycles (Fall 2014 and Spring 2015).

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration (MYRDD) Plan:

- (A) Lack of Fuel Cell Electric Vehicle and Fuel Cell Bus Performance and Durability Data

Contribution to Achievement of DOE Technology Validation

This project contributes to the achievement of the following DOE milestones from the Technology Validation section of the Fuel Cell Technologies Office MYRDD Plan:

- Milestone 2.3: Validate fuel cell electric vehicles achieving 5,000-hour durability (service life of vehicle) and a driving range of 300 miles between fuelings (4Q, 2019).

FY 2015 Accomplishments

- The National Fuel Cell Technology Evaluation Center (NFCTEC) has completed two publication cycles of real-world FCEV operation. The data analyzed has come from 48 vehicles, with model years spanning 2006 to 2012.
- While the 48 vehicles analyzed do not represent all FCEVs on the road today, it is a statistically significant set of data for evaluation with 2,413,340 total miles traveled and 79,468 total fuel cell operation hours. The maximum vehicle odometer is 178,550 miles (approximately 10% of vehicles have passed 100,000 miles) and the maximum fuel cell operation hours is 5,605.
- Compared current FCEV performance with past data from the Learning Demonstration (LD) phases. The comparisons to the LD project have provided insight into the steady progress made over the last eight years, specifically in fuel cell voltage durability, fuel economy, range, and driving trends. The current values are summarized in Table 1.



INTRODUCTION

Under FOA-625, the DOE has funded projects for the collection and delivery of FCEV data to NREL for analysis, aggregation, and reporting. Multiple real-world sites and customers are included in this FCEV demonstration project. This activity addresses the lack of on-road FCEV data and seeks to validate improved performance and longer durability from comprehensive sets of early FCEVs, including first-production vehicles. NREL's objective in this project is to support DOE in the technical validation of hydrogen FCEVs under real-world conditions. This is accomplished through evaluating and analyzing data from the FCEVs to identify the current status of the technology, comparing it to DOE program targets, and assisting in evaluating progress between

TABLE 1. Current Status against DOE 2020 Targets

Vehicle Performance Metrics	DOE Target (Year 2020) ^a	Current ^b	LD2+ ^c	LD2 ^c	LD1 ^c
Durability					
Max fuel cell durability projection (h)	5,000	3,930	—	2,521	1,807
Average fuel cell durability projection (h)		2,032	1,748	1,062	821
Max fuel cell operation (h)		5,605	1,582	1,261	2,375
Efficiency					
Adjusted dyno (window sticker) range		No update planned	—	196-254 mi	103-190 mi
Median on-road distance between fuelings		119 mi	98 mi	81 mi	56 mi
Fuel economy (window sticker)		51 mi/kg (median)	—	43–58 mi/kg	42–57 mi/kg
Fuel cell efficiency at ¼ power	60%	No update planned	—	53%–59%	51%–58%
Fuel cell efficiency at full power		No update planned	—	42%–53%	30%–54%
Specification					
Specific power (W/kg)	650	240–560		306–406	183–323
Power density (W/L)	850	Planned 2015		300–400	300–400

^a Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan [1]

^b Current results are available at http://www.nrel.gov/hydrogen/proj_fc_vehicle_evaluation.html [3] (updated May 2015)

^c National Fuel Cell Vehicle Learning Demonstration Final Report (<http://www.nrel.gov/hydrogen/pdfs/54860.pdf>) [2]

multiple generations of technology, some of which will include commercial FCEVs for the first time.

The project includes six original equipment manufacturers (OEMs): GM, Mercedes-Benz, Hyundai, Nissan, Toyota, and Honda. The latter three OEMs are part of one DOE project with Electricore. Up to 90 vehicles are expected to supply data over potentially two phases, with particular attention on fuel cell stack durability and efficiency, vehicle range and fuel economy, driving behavior, maintenance, on-board storage, refueling, and safety. Previous technology validation work on FCEVs and hydrogen infrastructure was performed through the FCEV LD [2], also known as the Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project. Some of the current partners were also part of the LD. Those vehicles and technologies are not necessarily the same as the vehicles currently under evaluation even though some of the platforms are the same. Except where referenced or labeled, all of the data reported here are for the current project.

APPROACH

The project's data collection plan builds on other technology validation activities. Operation, maintenance, and safety data for fuel cell system(s) and accompanying infrastructure are collected on site by project partners. NREL receives the data quarterly and stores, processes, and analyzes the data in NREL's NFACTEC. The NFACTEC is an off-network room with access provided to a small set of approved users. An internal analysis of all available data is completed quarterly and a set of technical composite data

products (CDPs) is published every six months. Publications are uploaded to NREL's technology validation website [3] and presented at industry-relevant conferences. The CDPs present aggregated data across multiple systems, sites, and teams in order to protect proprietary data and summarize the performance of hundreds of fuel cell systems and thousands of data records. A review cycle is completed before the CDPs are published. This review cycle includes providing detailed data products (DDPs) of individual system- and site-performance results to the specific data provider. DDPs also identify the individual contribution to the CDPs. The NREL Fleet Analysis Toolkit is an internally developed tool for data processing and analysis structured for flexibility, growth, and simple addition of new applications. Analyses are created for general performance studies as well as application- or technology-specific studies.

RESULTS

The current FCEV evaluation analyses include the following categories: durability, deployment (e.g., number of vehicles included), system specifications, range, fuel economy, efficiency, fill performance, reliability, drive and fill behaviors, power and energy management, fuel cell transients (e.g., frequency of rapid increases or decreases in fuel cell power), and benchmarking against technical targets and typical gasoline vehicle operation.

As of December 2014, NREL has analyzed more than 120,000 trip data files (a cumulative data file size of nearly 11 GB). More than 4,000 analysis files (non-published results)

have been created and submitted to the individual OEMs. All of the public results are available on the NFCTEC website.

The current evaluation includes 48 vehicles with more than 2.4 million miles traveled and nearly 80,000 fuel cell operation hours. As of December 2014, 16 vehicles were retired. The durability target for fuel cell systems is 5,000 hours (equivalent to 150,000 miles), which is on par with light-duty vehicle customer expectations and conventional technologies. Two parameters used in this evaluation project to track and validate system durability are projected operation time to 10% voltage degradation and actual operation hours. Fuel cell durability results were initially published in 2006 (the first generation of the LD project). The voltage durability trend from four unique reporting periods is shown in Figure 1. FCEVs in a fleet and a reporting period are of the same generation and design. The operation time to 10% voltage degradation for each stack in a fleet is averaged to determine the fleet voltage degradation value. The average of the fleets' average operation time to 10% voltage degradation in a reporting period is shown in blue and has increased 147% since the first LD period. The maximum of the fleets' average operation time to 10% voltage degradation, 3,930 hours, has increased 118% since the first reporting value in 2006–2007.

Fuel cell durability has steadily and significantly improved over the last decade. The on-road fuel economy has also increased. The minimum and maximum on-road fuel economy is 41 and 58 miles per kilogram hydrogen, respectively (Figure 2). Overall, the current evaluation indicates an improvement of approximately 30% from the first generation LD (LD1) results (Figure 3).

Another positive trend over the last decade of NFCTEC-analyzed FCEV operation is the actual distance driven between refueling (Figure 4). The results show that the median distance between fueling events was 56 miles for 2005–2007 (light gray), 81 miles for 2007–2009 (dark gray), and 98 miles for 2010–2011 (black). The median distance between refueling in the current evaluation is 119 miles, more than twice as long as the result from the LD1.

In addition to comparisons to past FCEV results, the driving and fueling data have been compared with the NHTS 2009 [4] and typical gasoline fueling trends [5]. Those comparisons include time of day, day of week, daily distance traveled, and average speed. We've found that FCEVs are driven primarily during the work week (Monday through Friday) and have less driving on Saturday and Sunday than the NHTS data indicate. The average speed of all the FCEV trips is just over 28 miles per hour, which is slightly above the NHTS overall average of 25 miles per hour. The percentage of FCEV drive days that are 40 miles or less is 44%, compared with 68% for the NHTS drive days. Relative to the total days of driving for the vehicles in each data set, FCEVs may be driving more in a day than the NHTS vehicles because some of the FCEVs are driven on schedules aimed to accumulate high mileage and operation hours over a variety of conditions, referred to as durability vehicles in this report. Durability vehicles are driven on public roads, in conditions typical for the regions, and will typically accumulate many miles each day.

When comparing the FCEV fills with the typical gasoline fueling profile data, the distribution is most different on Saturday and Sunday. However, the weekend FCEV fills (7–8% of fills) have increased when compared with the

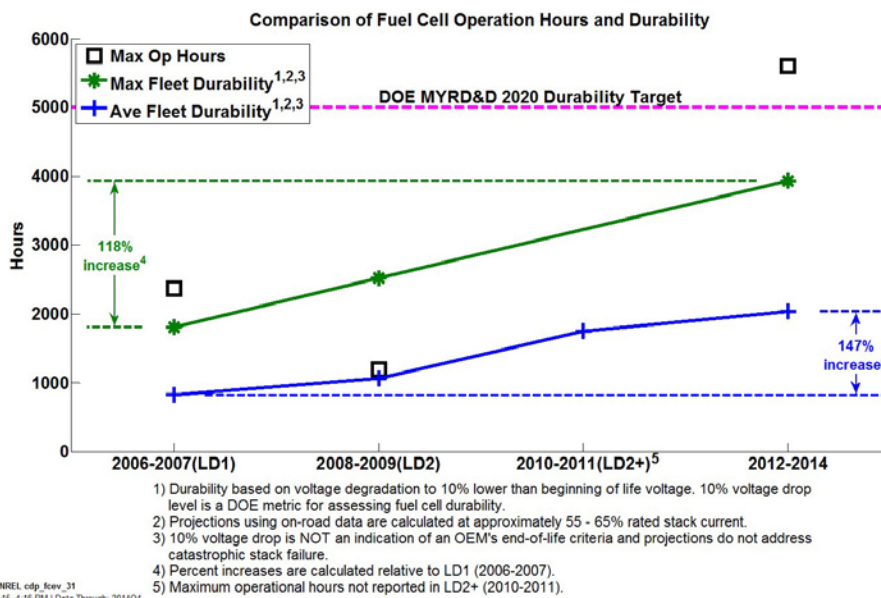


FIGURE 1. FCEV durability trend and comparison

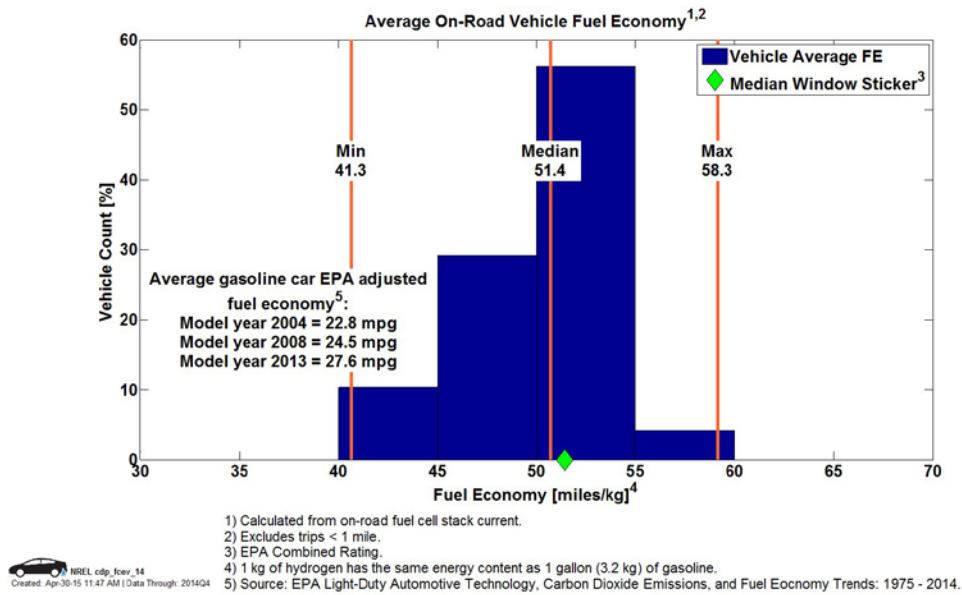


FIGURE 2. FCEV on-road fuel economy

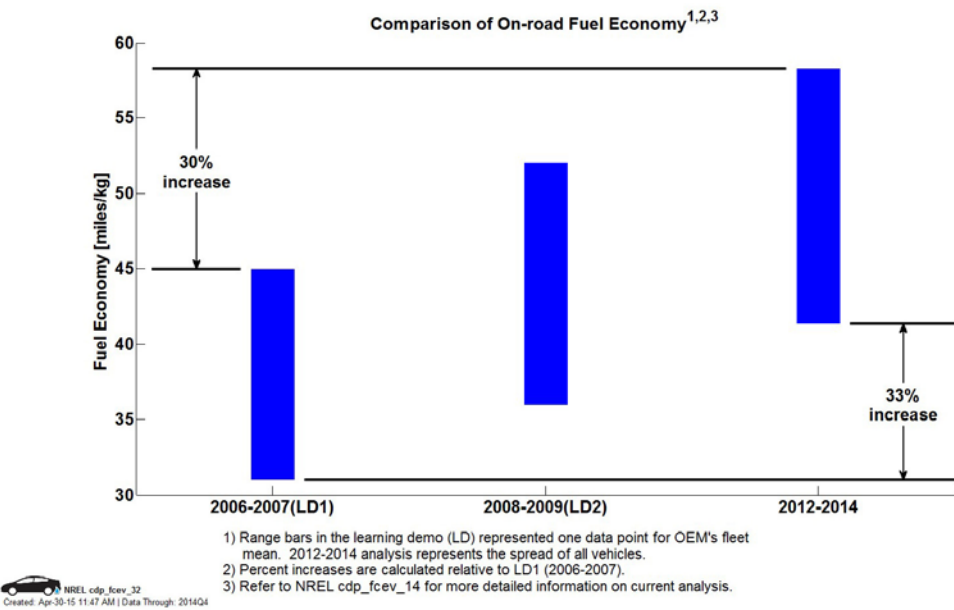


FIGURE 3. FCEV on-road fuel economy trends and comparison

LD fills, where only 2–4% of fills were on Saturdays and Sundays. Almost 80% of all the FCEV fills have occurred between 6 a.m. and 6 p.m., and the FCEV data show a much higher demand early in the day (between 7 a.m. and 10 a.m.) than the typical gasoline Friday fueling profile does.

CONCLUSIONS AND FUTURE DIRECTIONS

NFCTEC has completed two publication cycles of real-world FCEV operation. The data analyzed has come from 48

vehicles, with model years spanning 2006 to 2012. While the 48 vehicles analyzed do not represent all FCEVs on the road today, it is a statistically significant set of data for evaluation with 2,413,340 total miles traveled and 79,468 total fuel cell operation hours. The maximum vehicle odometer is 178,550 miles (approximately 10% of vehicles have passed 100,000 miles) and the maximum fuel cell operation hours is 5,605. Both driving and fueling trends have been compared with conventional gasoline trends. A few differences (like daily distance traveled and weekend fueling) have been observed

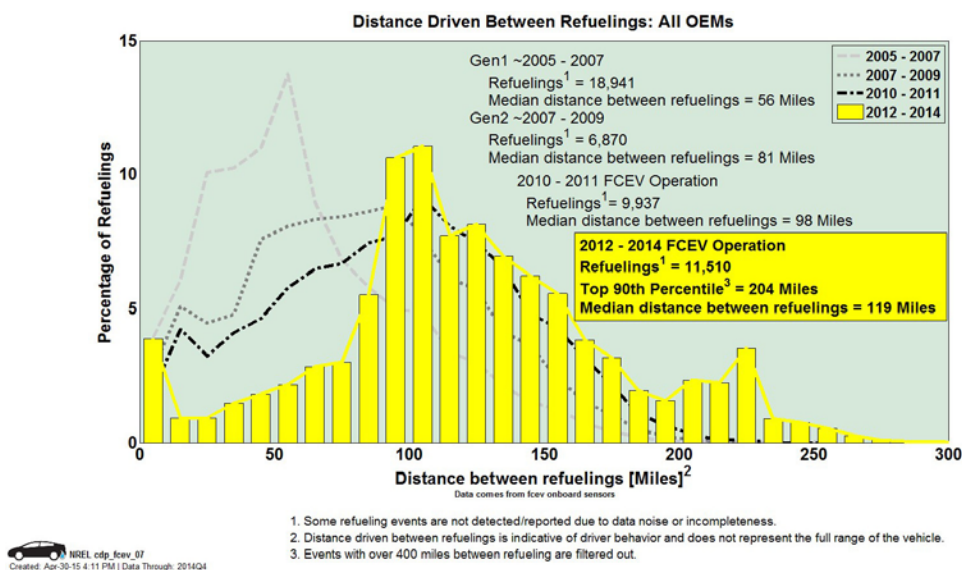


FIGURE 4. FCEV actual driving distance between refueling trend and comparison

in those comparisons. This is an indication that FCEV drivers are utilizing vehicles just as they would any other vehicle except with the advantage of a decreased carbon footprint. There are some FCEVs included in this analysis that are driven based on schedules aimed at accumulating miles and operation hours faster than a typical driver. The future work includes:

- Publish
- Continue analysis on fuel cell durability, fuel economy, and range
- Review key performance trends (durability, fuel economy, and range) over time
- Study the interdependence between FCEV and hydrogen station performance
- Quantify FCEV benefits based on real-world data
- Identify the durability FCEV data trends versus traditional customer FCEVs
- Complete a drive cycle analysis to categorize the different FCEV drive cycles for comparison with standard drive cycles and supply data to R&D community for fuel cell testing

3. Kurtz, J., Sprik, S., “Fall 2014 FCEV Evaluation Results,” Golden, CO: National Renewable Energy Laboratory, November 2014. Composite data products. (report)

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2. Wipke, K.; Sprik, S.; Kurtz, J.; Ramsden, T.; Ainscough, C.; Saur, G. National Fuel Cell Electric Vehicle Learning Demonstration Final Report. NREL/TP-5600-54860. Golden, CO: National Renewable Energy Laboratory, July 2012. <http://www.nrel.gov/hydrogen/pdfs/54860.pdf>.
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FY 2015 PUBLICATIONS/PRESENTATIONS

1. Kurtz, J., Sprik, S., “Spring 2015 FCEV Evaluation Results,” Golden, CO: National Renewable Energy Laboratory, May 2015. Composite data products. (report)
2. Sprik, S., Kurtz, J., “Technology Validation of Fuel Cell Vehicles and Infrastructure,” Fuel Cell Seminar 2014, Los Angeles, CA, November 2014. (presentation)