VII.A.1 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) 2017 Objectives

- Analyze FCEV fueling events and driving range between fueling.
- Make results available through online publications, highlights, and presentations.
- Complete one publication cycle (Spring 2017).

Technical Barriers

This project addresses the following technical barrier from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

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

Contribution to Achievement of DOE Technology Validation Milestones

This project contributes to the achievement of the following DOE milestone from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration 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 2017 Accomplishments

- Completed one publication cycle of real-world FCEV operation data. The data analyzed have come from 42 vehicles, with model years spanning 2008 to 2016.
- While the 42 vehicles analyzed do not represent all FCEVs on the road today, it is a statistically significant set of data for evaluation with 2,377,000 total miles traveled and 72,780 total fuel cell operation hours. The maximum vehicle odometer is 296,300 mi (approximately 10% of vehicles have passed 100,000 mi) and the maximum fuel cell operation is 5,648 h.
- Since 2006, driving and fueling data from 227 FCEVs over 7 million miles have been analyzed.

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INTRODUCTION

Under Funding Opportunity Announcement DE-FOA-0000625, the U.S. Department of Energy 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 that status to DOE program targets, and assisting in evaluating progress between multiple generations of technology, some of which will include commercial FCEVs for the first time.

The project includes six original equipment manufacturers (OEMs): General Motors, Mercedes-Benz, Hyundai, Nissan, Toyota, and Honda. The latter three OEMs are part of one DOE project with Electricore, which has been completed as scheduled. 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 learning

TABLE 1. Current Status Against DOE 2020 Targets

Vehicle Performance Metrics	DOE Target (Year 2020)[a]	LD3[b]	LD2+[c]	LD2[c]	LD1[c]
Durability					
Max fuel cell durability projection (hours)	5,000	4,130	--	2,521	1,807
Average fuel cell durability projection (hours)		2,442	1,748	1,062	821
Max fuel cell operation (hours)		5,648	1,582	1,261	2,375
Efficiency					
Adjusted dyno range (miles) (window sticker)		200–320	--	196–254	103–190
Median on-road distance between fuelings (miles)		122 miles	98	81	56
Fuel economy (mi/kg) (window sticker)		52 (median)	--	43–58	42–57
Fuel cell efficiency at ¼ power	60%	57% (average)	--	53%–59% (max)	51%–58%
Fuel cell efficiency at full power		43% (average)	--	42%–53%	30%–54%
Specs					
Specific power (W/kg)	650	240–563	--	306–406	183–323
Power density (W/L)	850	278–619	--	300–400	300–400
Storage					
System gravimetric capacity (kg H2/kg system)	5.5%	2.5%–3.7%	--	--	2.5%–4.4%
System volumetric capacity (kg H2/L system)	0.04	0.018–0.054	--	--	0.017–0.025

[a] Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan [1]
[b] Current results are available online [3] (updated May 2017) from Learning Demonstration 3 (LD3)
[c] National Fuel Cell Vehicle Learning Demonstration (LD) Final Report [2] which included two more phases Learning Demonstration 2 (LD2) and Learning Demonstration 2+ (LD2+) that had different generation vehicles and number of participating OEMs

demonstration [2], also known as the Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project. Some of the current partners were also part of the learning demonstration. 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 National Fuel Cell Technology Evaluation Center (NFCTEC). The NFCTEC 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 annually. 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 of individual system- and site-performance results to the specific data provider. Detailed data products 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), emissions, and benchmarking against technical targets and typical gasoline vehicle operation. All of the public results are available on the NFCTEC website.

The current evaluation includes 42 vehicles with more than 2.3 million miles traveled and more than 72,000 fuel cell operation hours. As of December 2016, seven vehicles were retired. Many of the OEMs are retiring legacy vehicles because commercial product vehicles are on the road or are soon to be on the road. The durability target for fuel cell systems is 5,000 h (equivalent to 150,000 mi), which is on par with light-duty vehicle customer expectations and conventional technologies. In FY 2017 the number of OEMs supplying data from on-road FCEVs for analysis decreased to three (Honda, Hyundai, and Mercedes-Benz). The vehicles are a mixture of pre-commercial and commercial vehicles, operated within fleets and by individual drivers. The reduction in data sharing partners was a combination of award completion and vehicle production phases. Some data are voluntarily supplied and not consistent across all OEMs, therefore not all analysis results were published. Our analysis in 2017 has focused on tracking progress and fueling performance that helps to inform capabilities, needs, and gaps at the interface between the FCEV and hydrogen station.

Newer-generation vehicles have been added to the current set of FCEVs analyzed, where the most recent model year included is 2016. More than 7 million miles of vehicle travel by 227 FCEVs have been analyzed at NFCTEC. Figure 1 presents results that demonstrate the trend over time for six key DOE metrics. The FCEV performance and specifications have made good progress since NREL started studying the technology in 2006, without sacrificing efficiency and capability. Figure 1 also depicts gaps with the targets. For instance, the voltage durability projections have increased by more than 160% since 2006, when durability results were initially published (the first generation of the learning demonstration project). The durability results were not published in May 2017 because there was not sufficient data to aggregate per the CDP process.

The fueling time of day, day of week, and amounts follow the trends that NREL's results have shown in the past and have a similar trend to the Chevron profile from the "Hydrogen Delivery Infrastructure Options Analysis" published in 2008. There are a few gaps in this comparison. For instance, fueling times peak around 9 a.m. and 4 p.m. for FCEV fills in NREL's analysis, but they only peak around 4 p.m. in the Friday Chevron profile (Figure 2). And there are fewer FCEV fills on the weekend than in the sample gasoline station profile. This may be driven in part by fleet operation instead of individual drivers. More than 16,000 fills have been analyzed and can be used for the development of data-

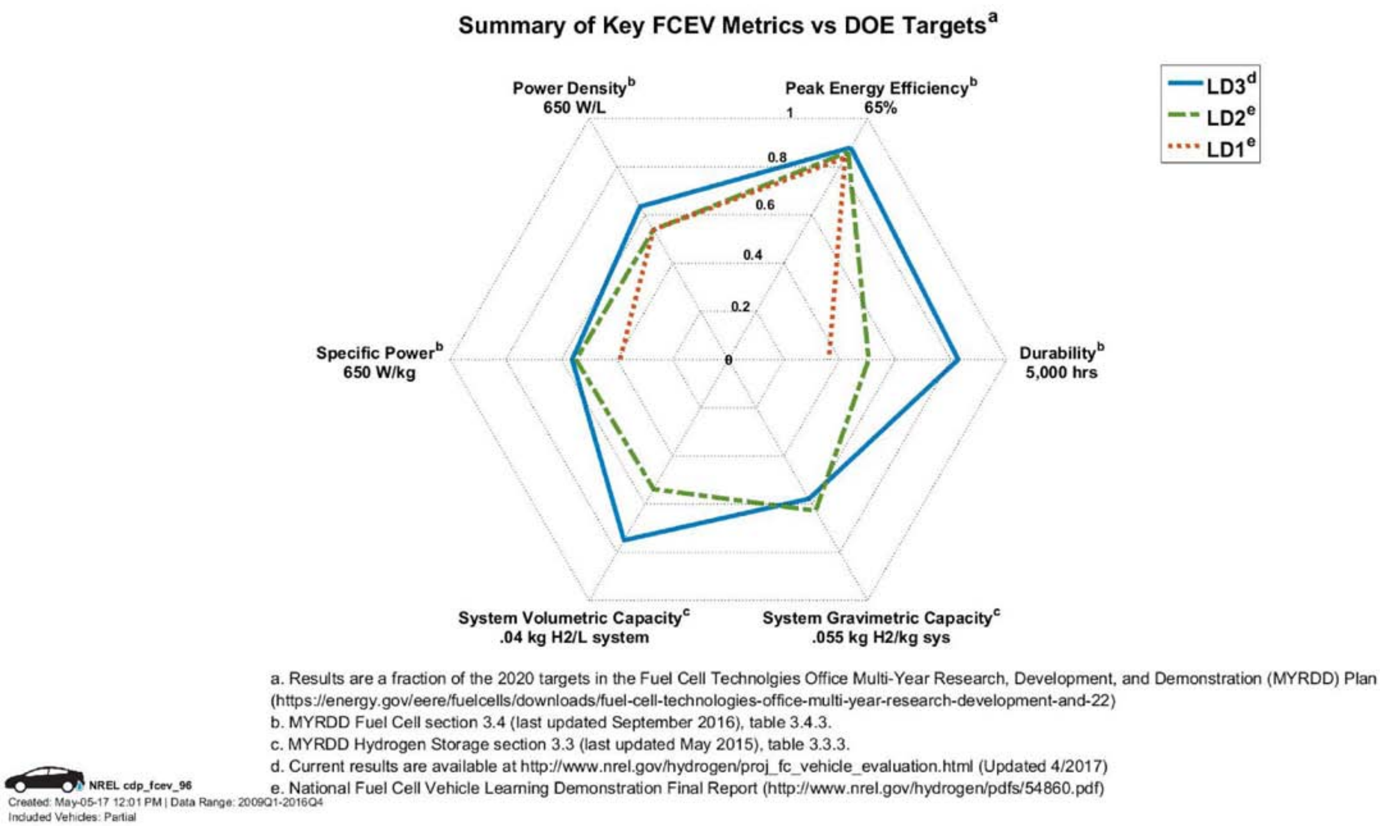

FIGURE 1. FCEV progress toward targets

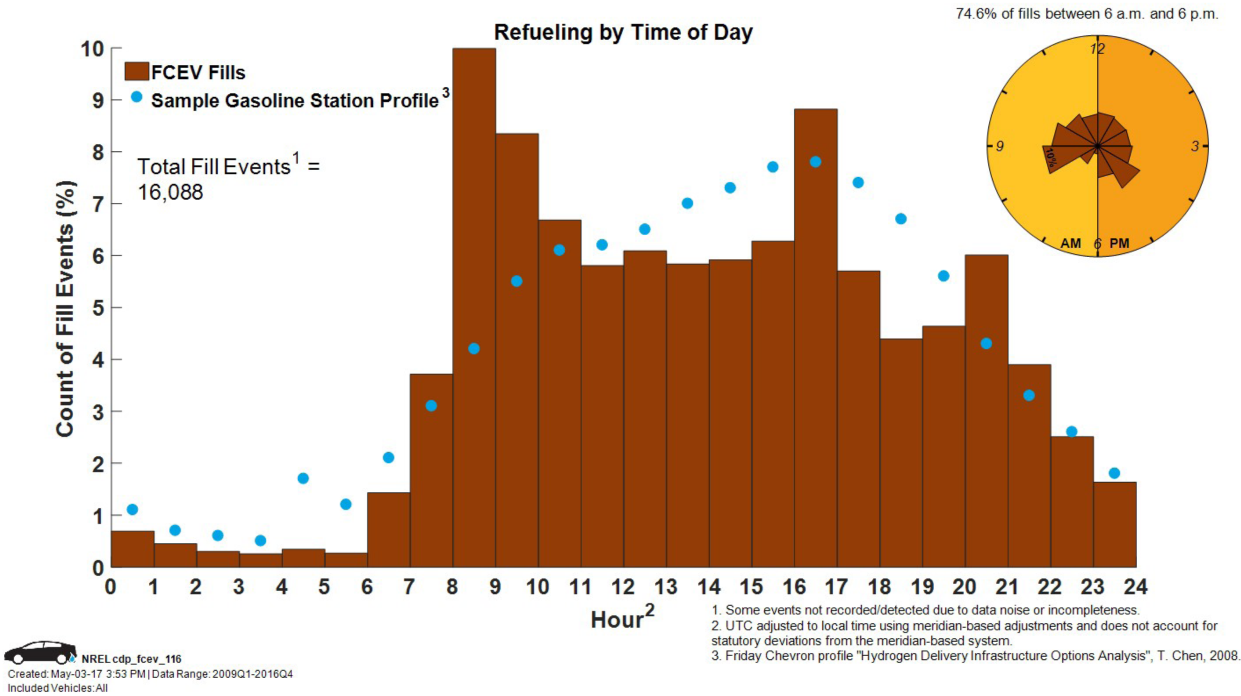

FIGURE 2. FCEV refueling by time of day

based fueling demand profiles. NREL is using the driving behavior to inform fueling behavior. For instance, the driving time of day closely follows the driving time according the National Household Transportation Survey results (Figure 3). These data can be used as a quality control of predictive hourly fueling demand profiles, just as driving range between fueling can be used to check demand profiles. The median, actual driving range of the FCEVs is ~120 mi, which is much less than the window sticker range. Fill frequency and amounts will likely change as the number and availability of hydrogen stations changes.

This predictive fueling demand model (built on both FCEV and hydrogen station fill data) can be integrated with hydrogen station operation for optimized controls. An example of the station operation control optimization based on fueling demand is storage level management and when to operate high-energy-consuming equipment such as compressors and chillers. A predictive fueling demand profile, which should improve as new fueling data are used to update the model, may also inform the best times for maintenance with the least amount of impact on the revenue-providing fills.

Figure 4 depicts the final temperature and pressure limits of more than 16,000 35-MPa and 70-MPa hydrogen fills. The highest concentration of fills was in the preferred (that is, fastest fills within acceptable safety limits) region (shown in green), and the SAE J2601 pressure and temperature limits were not exceeded for any fills. The temperature and pressure measurements were all taken from the vehicles' on-board storage systems.

CONCLUSIONS AND UPCOMING ACTIVITIES

Over the last 10 yr, NREL's NFCTEC has completed analysis of 227 on-road vehicles that have accumulated more than 7 million miles. The current data analyzed come from 42 vehicles and three OEMs, 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 actual driving range between fills have also increased over the last 10 yr. NREL is seeing the FCEVs operated in similar ways to traditional gasoline vehicles for driving and fueling, yet there are some behaviors that are more representative of fleet FCEV operation instead of use by individual drivers. Analysis results show progress against key DOE metrics of voltage durability, system gravimetric and volumetric capacity, specific power, and power density. The future work includes the following:

- Study the interdependence between FCEV and hydrogen station performance.
- Continue benchmarking fuel cell durability and FCEV range.
- Develop and validate a predictive FCEV fueling demand model.

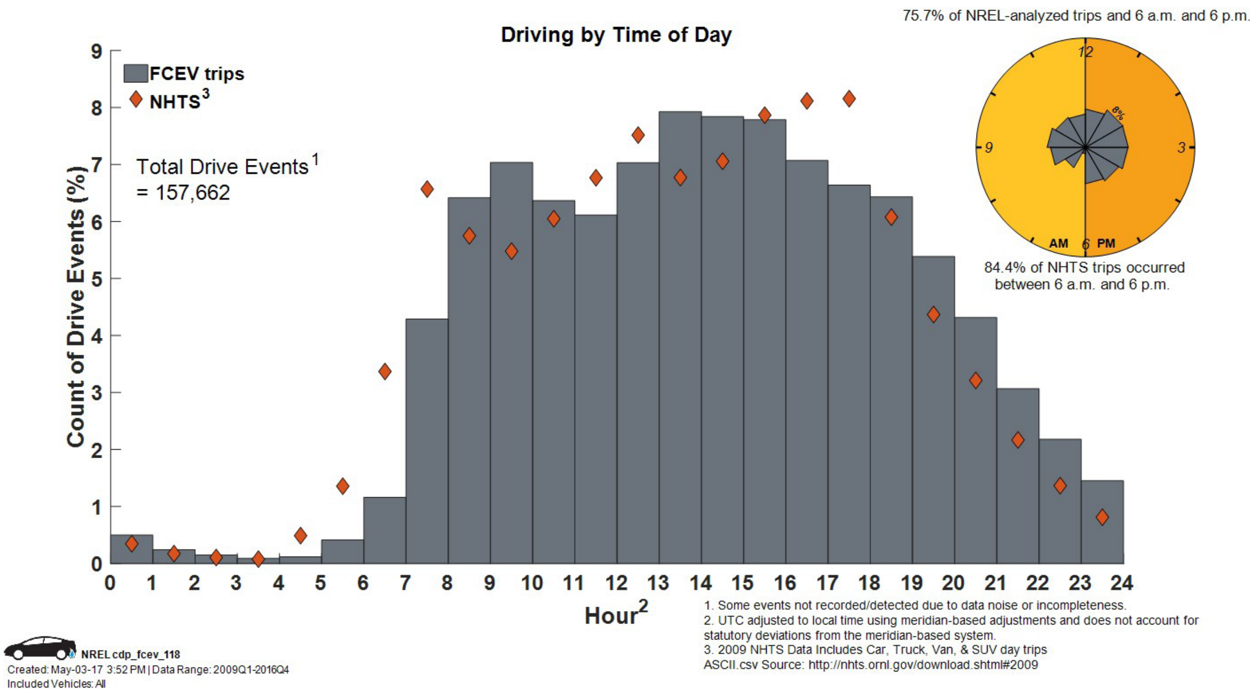

FIGURE 3. FCEV driving time of day

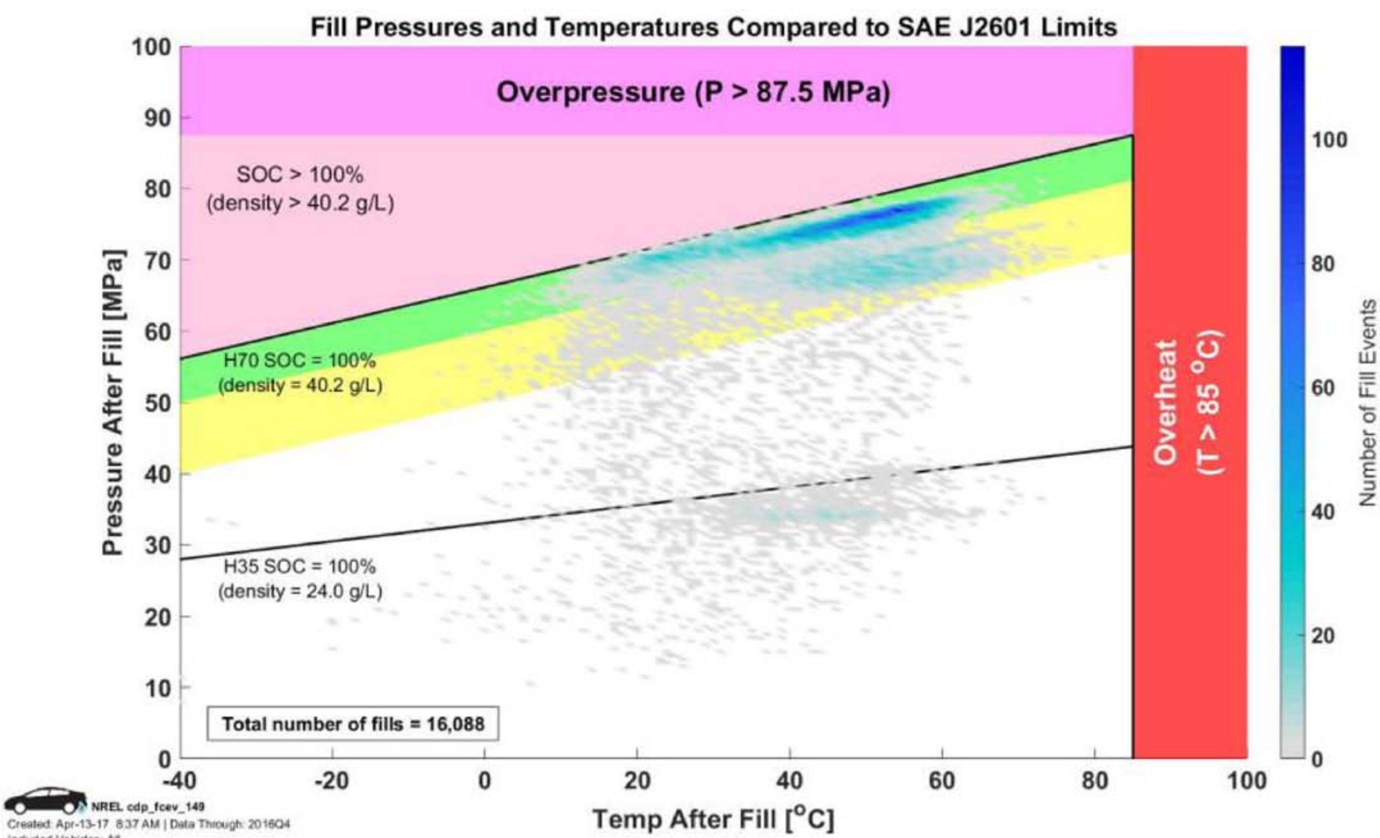

FIGURE 4. FCEV fill comparison to SAE J2601 temperature and pressure limits

FY 2017 PUBLICATIONS/PRESENTATIONS

1. J. Kurtz, S. Sprik, C. Ainscough, and G. Saur, "Fuel Cell Electric Vehicle Evaluation," Presented at the 2017 DOE Annual Merit Review Meeting, June 2017.

2. J. Kurtz, S. Sprik, C. Ainscough, and G. Saur, "Fuel Cell Electric Vehicle (FCEV) Performance Composite Data Products: Spring 2017," NREL/PR-5400-68647, May 2017.

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1. *Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan*, Fuel Cells chapter, Table 3.4.3 Technical targets for automotive application, Washington, D.C.: U.S. Department of Energy, 2012, accessed October 13, 2014, http://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22.

2. K. Wipke, S. Sprik, J. Kurtz, T. Ramsden, C. Ainscough, and G. Saur, *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.

3. "Fuel Cell and Hydrogen Technology Validation," National Renewable Energy Laboratory, https://www.nrel.gov/hydrogen/technology-validation.html.

4. T. Chen, *Hydrogen Delivery Infrastructure Options Analysis*, Nexant, June 2008, https://energy.gov/sites/prod/files/2014/03/f11/delivery_infrastructure_analysis.pdf.