V.E.3 Fuel Cell Technology Status: Degradation

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Project Start Date: July 1, 2009
Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

- Conduct an independent assessment to benchmark current fuel cell system cost and price in a non-proprietary method.
- Leverage National Fuel Cell Technology Evaluation Center (NFCTEC) activities.
- Collaborate with key fuel cell developers on the voluntary data share and NFCTEC analysis.

Fiscal Year (FY) 2017 Objectives

- Receive and analyze new laboratory durability data.
- Publish aggregated, current fuel cell voltage durability status.
- Include electrolysis and updated price data.

Technical Barriers

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

(A) Durability (Lack of data for current fuel cell durability status per targets)

(B) Cost (Lack of data for current fuel cell costs and status per targets)

Technical Targets

This project is conducting an independent assessment of the current fuel cell durability test data from leading fuel cell developers. All results are aggregated to protect proprietary information and are reported on by the system application. Table 1 shows the durability targets.

TABLE 1. Fuel Cell Durability Target and Status Table

Application	2020 Durability Target	Lab Status – Average Hours to 10% Voltage Degradation
Light-Duty Automotive	5,000 h	3,700 h
Public Transit	25,000 h	6,200 h
Forklift	20,000 h Target Under Review	13,500 h
Backup	10,000 h	2,600 h
Stationary 1–10 kW	0.3%/1,000 h	11,900 h
Stationary 100 kW–3 MW	80,000 h	

Per the Fuel Cells section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan, the cost targets are as follows:

- The 2020 transportation fuel cell system cost target is \$40/kW with an ultimate target of \$30/kW.
- The 2016 fuel cell transit bus cost target is \$1,000,000 with a 2020 target of \$600,000.
- The 2020 micro-combined heat and power (5 kW) fuel cell system cost target is \$1,500/kW.
- The 2020 medium combined heat and power (100 kW–3 MW) fuel cell system cost target is \$1,000/kW for natural gas and \$1,400/kW for biogas.

FY 2017 Accomplishments

- Collected new fuel cell voltage degradation data sets from fuel cell developers (including data on proton exchange membrane, direct methanol, and solid oxide fuel cell of full active area short stacks and full stacks with systems).
- Analyzed, aggregated, and published current status of platinum loading over time.
- Analyzed, aggregated, and published current status of fuel cell voltage degradation versus DOE targets.
- Published 22 composite data products (CDPs) [1] with data from 23 domestic and international fuel cell and electrolysis developers.

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INTRODUCTION

DOE has funded significant research and development activity with universities, national laboratories, and the fuel cell industry to improve the market competitiveness of fuel cells. Most of the validation tests to confirm improved fuel cell stack performance and durability (indicators of market competitiveness) are completed by the research organizations themselves. Although this allows the tests to be conducted by the developers most familiar with their specific technology, it also presents a number of challenges in sharing progress publicly because test conditions and data analysis take many forms and data collected during testing are often considered proprietary.

NREL is benchmarking the state-of-the-art fuel cell performance, specifically focusing on durability, through independent assessment of current laboratory data sets. NREL's data processing, analysis, and reporting capitalize on capabilities developed in DOE's Fuel Cell Electric Vehicle Learning Demonstration. Fuel cell stack durability status is reported annually and includes a breakdown of status for different applications. A key component of this project is the collaborative effort with key fuel cell developers to understand what is being tested in the laboratory, study analysis results, and expand the included data sets.

APPROACH

The project involves voluntary submission of data from relevant fuel cell developers. NREL is contacting fuel cell developers for fuel cell voltage degradation, cost, and price data for multiple fuel cell types to either continue or begin a data sharing collaboration. A continuing effort is to include more data sets, types of fuel cells, quantity of units sold, and developers. The fuel cell voltage degradation data are sent from fuel cell developers performing testing and studied over time against DOE's voltage degradation targets.

Raw and processed data are stored in NREL's NFCTEC. The NFCTEC is an off-network room with access provided to a small set of approved users. Processing capabilities are developed or modified for new data sets and then included in the analytical processing of NREL's Fleet Analysis Toolkit, 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. The incoming raw data may be new or a continuation of data that have already been supplied to NREL. An internal analysis of all available data is completed annually and a set of technical CDPs is published every year. Publications are uploaded to NREL's technology validation website [1] and presented at industry-relevant conferences. The CDPs present aggregated data across multiple systems, sites, and teams 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.

RESULTS

Results published in May 2017 were the seventh update for this analysis effort. The annual voltage degradation analysis of state-of-the-art laboratory durability was completed in advance of the milestone to provide an update that could be presented at DOE's Annual Merit Review and Peer Evaluation Meeting. In the current published data set, seven applications were covered and 23 fuel cell and electrolyzer developers supplied data (more than one data set in many cases). The data sets covered proton exchange membrane, direct methanol, and solid oxide fuel cell stack testing as well as electrolyzer testing. A total of 224 data sets have been analyzed with 50 new additions from the previous year. Note that a data set may represent test data from a short stack, full stack, or system. Of the total data sets, 84% have been retired, meaning the system or stack is not accumulating any new operation hours either because of test completion, technology upgrades, or failures. The published data results include 22 CDPs, including a new CDP looking at platinum loading over time as well as a new degradation CDP showing results of only recent data sets (excluding pre-2013). The power capability illustrates the range of fuel cell power for the data sets by application from less than 2 kW to more than 50 kW. Most of the analyzed data sets are laboratory systems at less than 14 kW power.

The analyzed data sets are from laboratory testing of full active area short stacks (e.g., stacks with fewer cells than the expected full power stack) and test systems with full power stacks. The data sets also vary from one to the other in how the stack or system was tested. Data were generated between 2004 and late 2016 from different testing methods that included constant load, transient load, and accelerated testing. The variability in test conditions and test setups creates a group of data that can be difficult to compare.

Fuel cell durability is studied at a design-specific current point and measured against a target of 10% voltage drop from beginning of life. The 10% voltage drop metric is used for assessing voltage degradation with a common measurement, but the metric may not be the same as end-of-life criteria and does not address catastrophic failure modes. Figure 1 and Figure 2 are aggregated set of results separated by application; Figure 1 includes all data sets received to date, while Figure 2 includes only data sets from 2013 and after. Not all application categories have enough data sets to be included in Figure 2. For both the automotive and prime application categories, data from 2013 and on have higher durability projections than the durability projections for all

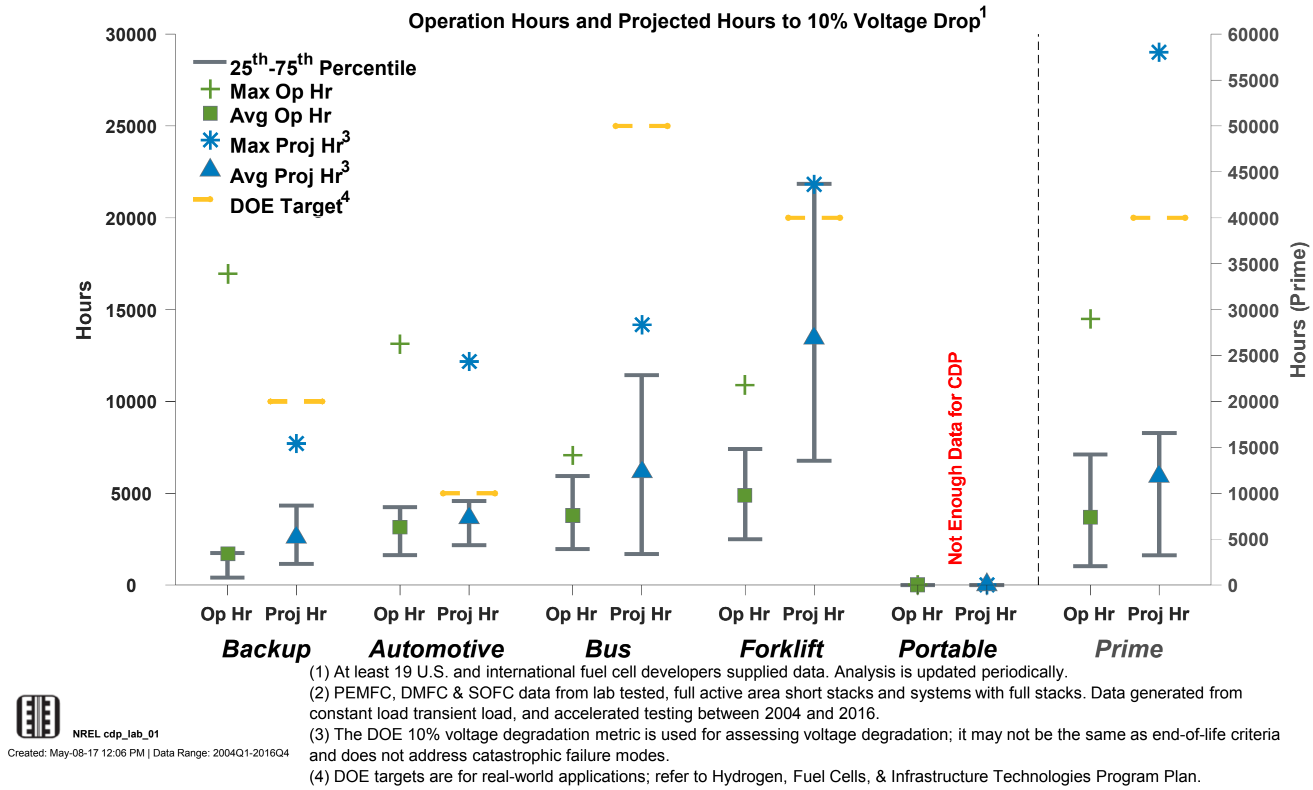

FIGURE 1. Voltage degradation results by application

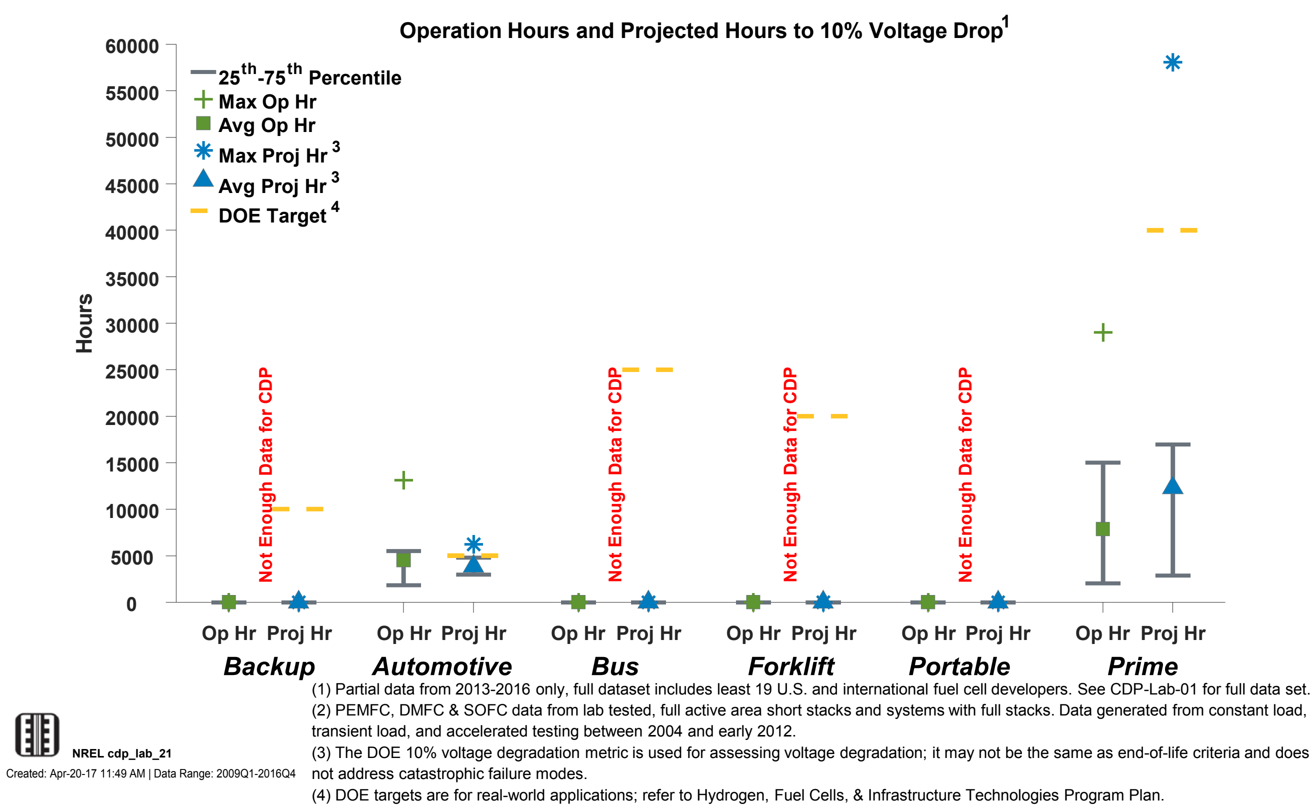

FIGURE 2. Voltage degradation, recent results (2013+)

data starting before 2009. The automotive category is 200 hours higher and the prime category is 400 hours higher. For each application, the average, maximum, and 25th and 75th percentile values are identified for the operation hours and the projected hours to 10% voltage drop. Current density variation (Figure 3) is dependent on developer-selected test protocols and objectives. NREL updated this CDP in 2017 to include several higher density bins to accommodate the variations in data. The automotive data sets are primarily in the higher current density bins because of vehicle packaging constraints for power density. More than 60% of automotive data sets were studied at ≥1.2 A/cm^2 in the 2017 results (<50% in the 2016 analysis results). A future comparison could be the study of voltage degradation at one chosen current density for all data sets within a category or type. The current density points used for the aggregated durability results are based on individual designs, and data may not be available at multiple current densities. The most variety in current density is seen in the prime and automotive categories.

The 10% voltage drop level is not necessarily a measurement for end of life or even a significant reduction in performance. Many data sets have not passed (or did not pass) the metric of 10% voltage degradation. The reason data sets operated beyond 10% voltage degradation could be because end-of-life criteria may be greater than 10% voltage degradation or because the test was designed to operate until a failure occurred. The stack configuration and test conditions can have a significant impact on the projected time to 10% voltage degradation within an application. In general, the average projection decreases with more aggressive test conditions and full systems. Not all applications have data sets in each configuration or test condition group. The test condition groups include:

- Steady—little or no change to load profile.
- Duty Cycle—load profile mimics real-world operating conditions.
- Accelerated—test profile is more aggressive than real-world operating conditions.

In a new analysis in FY 2017 NREL added a request for platinum loading based on range categories from fuel cell loading research and targets. The project team also went through all old data sets to retroactively ask for the platinum data where possible. Platinum loading is highly correlated to cost for some types of fuel cells, and a new CDP (Figure 4) looks at the trends of platinum loading over time. The platinum loading per square centimeter is decreasing on the data sets analyzed, per the trend for the mode in both 2015 and 2016. In the future NREL hopes to combine this with the degradation analysis in order to study how or if the platinum loading has affected degradation projections over time. In the automotive category, voltage durability projections are relatively stable over the years of analysis, but additional data are needed in order to look at this further.

In the automotive category, voltage durability projections are relatively stable over the years of analysis. This may

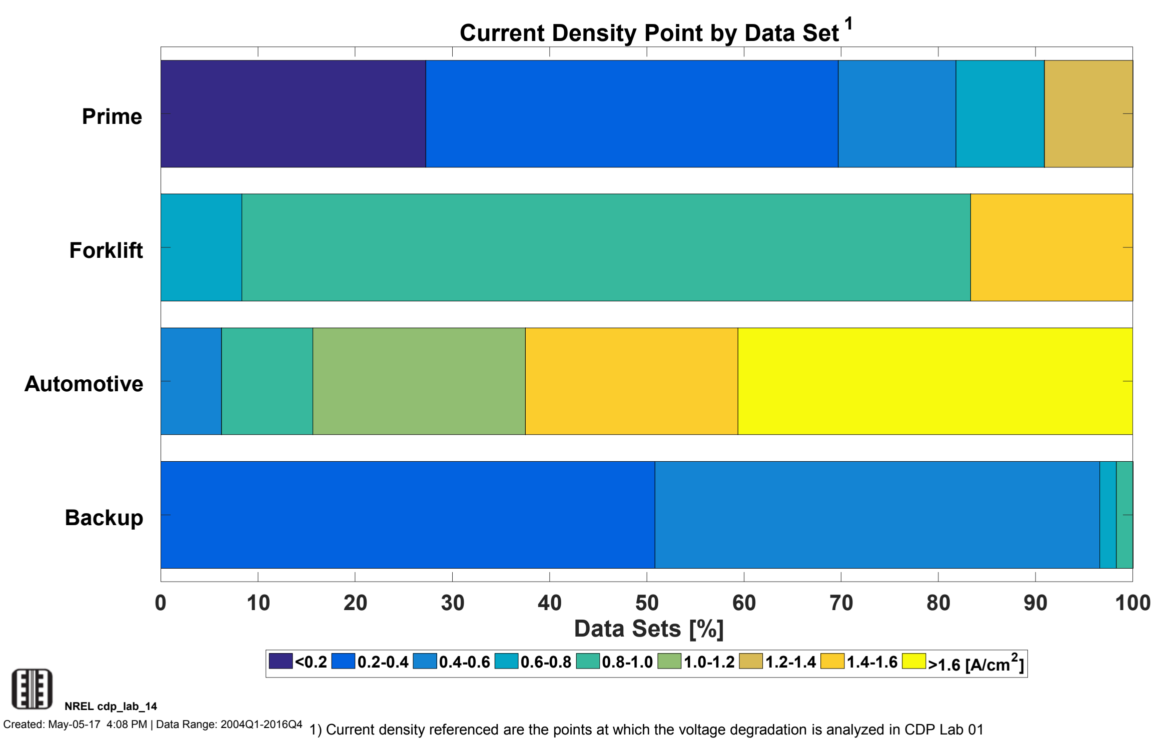

FIGURE 3. Current density variation between data sets

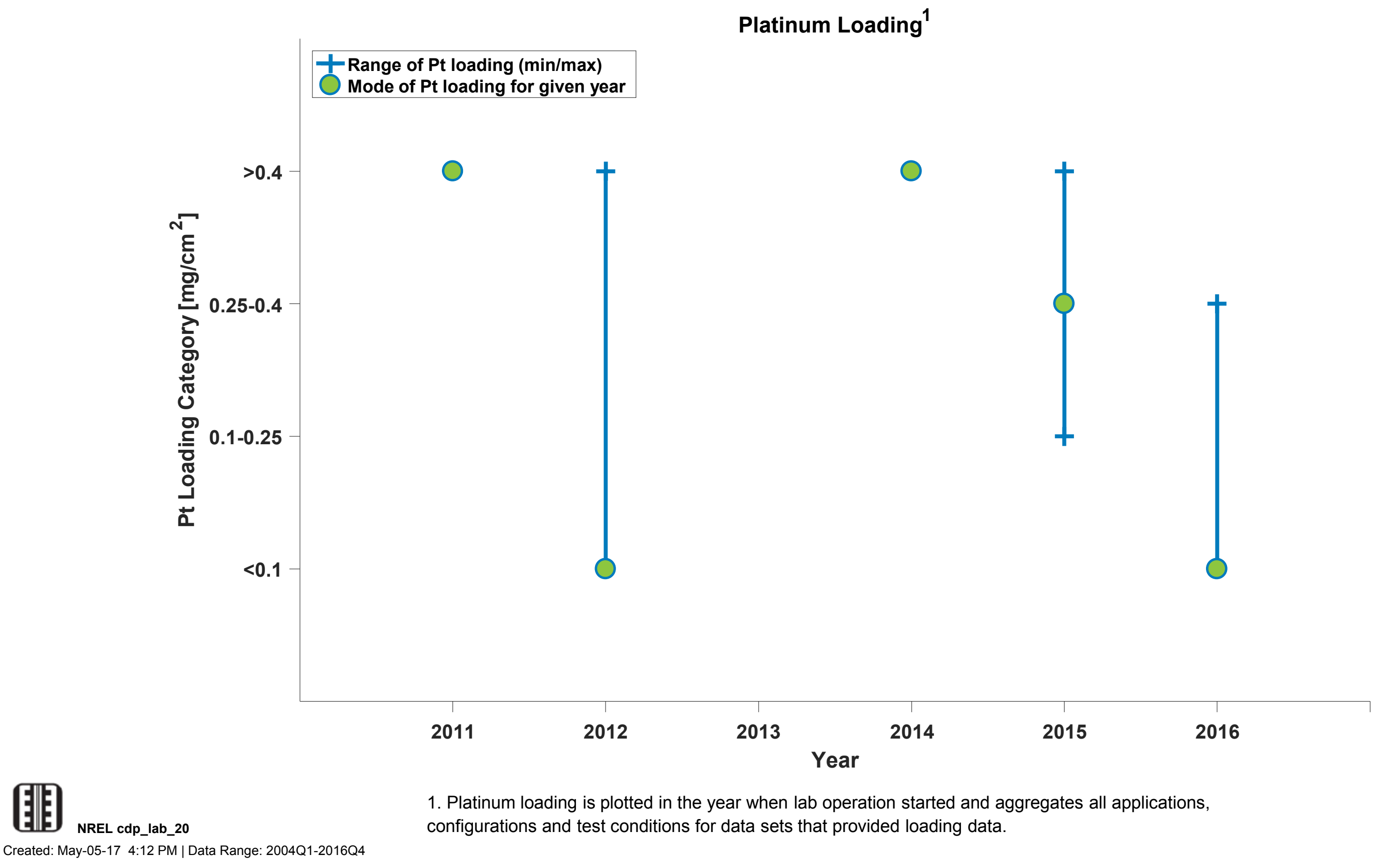

FIGURE 4. Platinum loading trend

be due in part to a shift in focus from durability to cost reduction while maintaining an acceptable degradation rate, as seen in Figure 4. There is an interdependence between cost and durability, and, depending on the economics, durability may not be the driving technical parameter at this time.

CONCLUSIONS AND UPCOMING ACTIVITIES

This project has leveraged other technology validation projects and existing industry relationships to steadily increase the quantity and depth of reporting on the state-of-the-art fuel cell durability status with a relatively low level of investment from DOE. Both U.S.-based and international developers have voluntarily supplied at least one data set, and it is an ongoing effort to include new data sets, update data sets already included (if applicable), and include new fuel cell developers, applications, and types. The voluntary participation of leading fuel cell and electrolyzer developers provides an overall technology benchmark (with the published aggregated data) and an individual developer benchmark (with the detailed data products). Additional breakdown of the data sets is an important aspect of future work and is dependent on the accumulation of more data sets to not reveal an individual data supplier's contribution to the results or proprietary data. Future work, following the path of degradation and cost/price status updates every other year, includes the following activities:

- Continue cultivating existing collaborations and developing new collaborations with fuel cell and electrolyzer developers.
- Gather, process, and report on current fuel cell product cost and/or price.
- Add analyses around accelerated testing comparisons.
- Address legacy data in several of the analyses.

FY 2017 PUBLICATIONS/PRESENTATIONS

1. Jennifer Kurtz, Huyen Dinh, Genevieve Saur, and Chris Ainscough, "Fuel Cell Technology Status – Degradation," presented at the 2017 DOE Annual Merit Review and Peer Evaluation Meeting, Washington, D.C., June 2017.

2. Genevieve Saur, Jennifer Kurtz and Huyen Dinh, "Fuel Cell Technology Status – Degradation: FC Tech Team," presented to the Fuel Cell Tech Team, May 2017.

3. Jennifer Kurtz, Huyen Dinh, Chris Ainscough, and Genevieve Saur, "State-of-the-Art Fuel Cell Voltage Durability Status: 2017 Composite Data," NREL/PR-5400-68621, Golden, CO: National Renewable Energy Laboratory, May 2017.

4. "Fuel Cell Technology Status Analysis Project: Partnership Opportunities," NREL/FS-5400-67899, Golden, CO: National Renewable Energy Laboratory, March 2017.

5. Jennifer Kurtz, Huyen Dinh, and Genevieve Saur, "Fuel Cell Technology Status – Degradation," excerpt from the 2016 DOE Hydrogen and Fuel Cells Program Annual Progress Report, February 2017.

REFERENCES

1. "Fuel Cell Technology Status Analysis," National Renewable Energy Laboratory, https://www.nrel.gov/hydrogen/fuel-cell-technology-status.html.