V.D.4 Analysis of Laboratory Fuel Cell Technology Status – Voltage 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 state-of-the-art fuel cell durability in a non-proprietary method
- Leverage analysis experience from the Fuel Cell Electric Vehicle Learning Demonstration project
- Collaborate with key fuel cell developers on the analysis

Fiscal Year (FY) 2013 Objectives

- Complete the annual update on status of the voltage degradation analysis for publication, including new data sets and partners since the FY 2012 update
- Establish price data templates and pursue gathering current price data for fuel cell developer products

Technical Barriers

This project addresses the technical barrier of understanding the durability of state-of-the-art fuel cell stacks and systems currently developed in a laboratory setting, as well as a lack of consistent reporting on the durability of these systems. This project addresses the following technical barrier from the Fuel Cells section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(A) Durability

Technical Targets

This project is conducting an independent assessment of the durability of current laboratory fuel cell stacks and systems. The analysis, applied uniformly on all data sets, studies the projected operation time to 10% voltage drop. All results are aggregated to protect proprietary information and reported on by the expected application.

FY 2013 Accomplishments

- Analyzed fuel cell stack and system data in six application categories (backup, automotive, bus, forklift, portable, and stationary) and from 15 fuel cell developers (U.S. and international developers)
- Published 14 composite data products (CDPs) [1] on:
  - Operation time and projected operation time to 10% voltage drop
  - Projected operation time sensitivity to voltage drop levels (Table 1)
  - Comparison of automotive and material handling equipment laboratory and field durability projections
  - Power capability
  - Data sets operated beyond 10% voltage drop
  - Durability projections by configuration and test condition
  - Test configuration and condition breakdowns
  - Time series variation of results

TABLE 1. Projected Operation Time to 10% Voltage Drop Summary by Application

Application	Average Projected Time to 10% Voltage Drop (Hours)	Average Operation (Hours)
Backup power	2,500	1,100
Automotive	3,600	2,200
Bus	6,200	3,800
Forklift	14,600	4,400
Prime	9,300	5,600

- Included data on proton exchange membrane, direct methanol, and solid oxide fuel cell of full active area short stacks and full stacks with systems
- Shared all detailed data analysis results with data providers

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INTRODUCTION

The U.S. Department of Energy (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.

The National Renewable Energy Laboratory (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 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, and developers.

Raw and processed data are stored in NREL's Hydrogen Secure Data Center. Processing capabilities are developed or modified for new data sets and then included in the analytical processing of NREL's Fleet Analysis Toolkit. The incoming raw data may be new stack test data or they may be a continuation of data that have already been supplied to NREL. After the raw data are processed, the results are analyzed with particular attention to durability and operating conditions. Each individual data set has a set of data figures that are shared with the data provider and used to create the CDPs. CDPs are designed to report on the technology status without revealing proprietary information.

RESULTS

This fuel cell stack durability analysis expanded the number of data sets analyzed, applications and fuel cell types studied, and amount of details published. Results published in April 2013 were the fifth 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 the DOE's Annual Merit Review. In the current published data set, six applications were covered, 15 fuel cell developers supplied data (more than one data set in many cases), and the data sets covered proton exchange membrane, direct methanol, and solid oxide fuel cell stack testing. A total of 98 data sets have been analyzed. Note that a data set represents a short stack, full stack, or system test data. Of the total data sets, 78% have been retired (Figure 1), 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 eight CDPs. The power capability illustrates the range of fuel cell power for the data sets by application from <2 kW to >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/system was tested. Data were generated between 2004 and late 2012 from different testing methods that included constant load, transient load, and accelerated testing. The variability in test conditions and test setups created a group of data that can be difficult to compare. Additional breakdown of the data sets is an important aspect of future work and is dependent on the accumulation of more data sets in order to not reveal an individual data supplier's contribution to the results or proprietary data.

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 2 is an aggregated set of results separated by application and identifies the percentage of short stacks and how many data sets are still operating (at the time of the results) for each application. Each application has the average, maximum, and 25th and 75th percentile values identified for the operation hours and the projected hours to 10% voltage drop.

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,

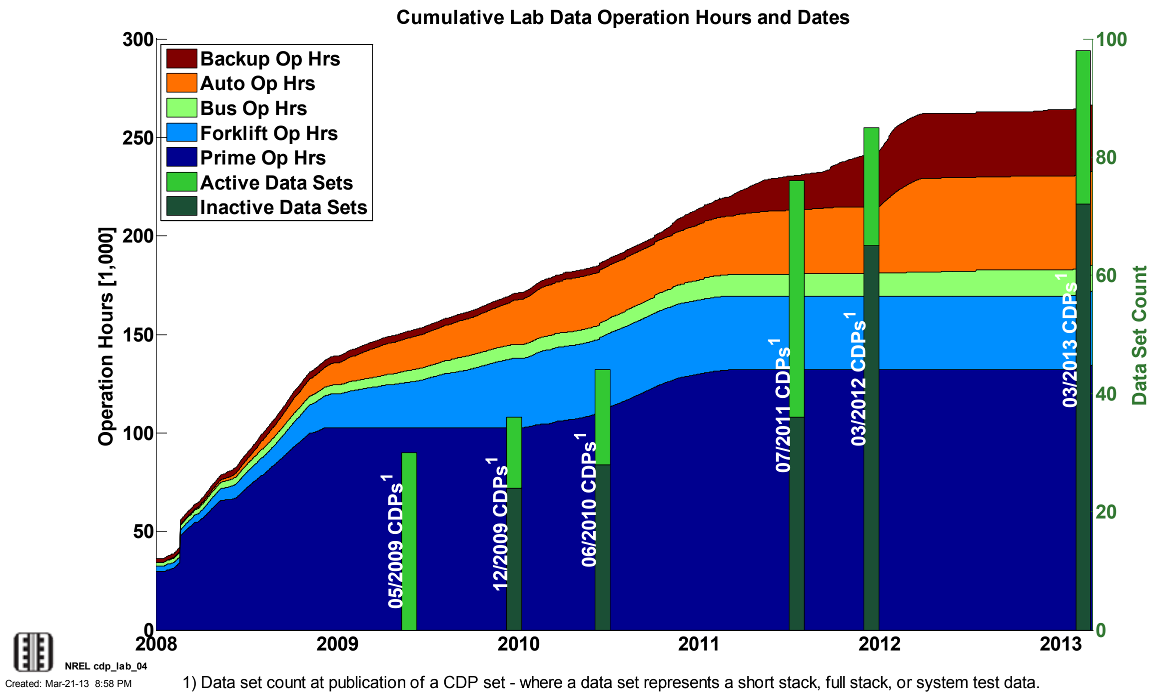

FIGURE 1. Cumulative Lab Data Operation Hours and Dates

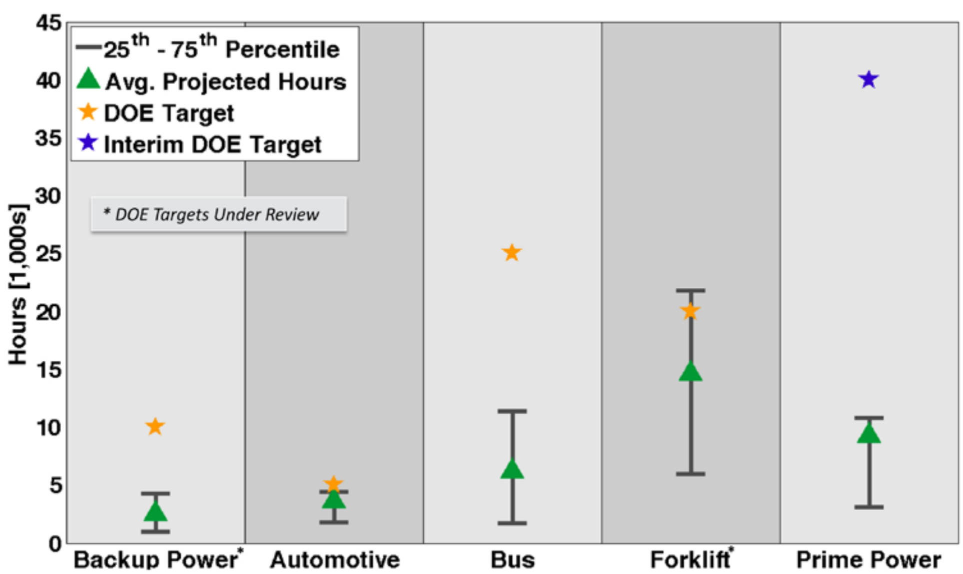

FIGURE 2. Operation Hours and Projected Hours to 10% Voltage Drop by Application Category

the average projection decreases with more aggressive test conditions and full systems (Figure 3). 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.

Most applications have seen an increase in average time to 10% voltage degradation over the last three years (Figure 4). Averages may decrease from year to year based on new data sets added and varied test conditions and configurations. Another possible reason for changes year-

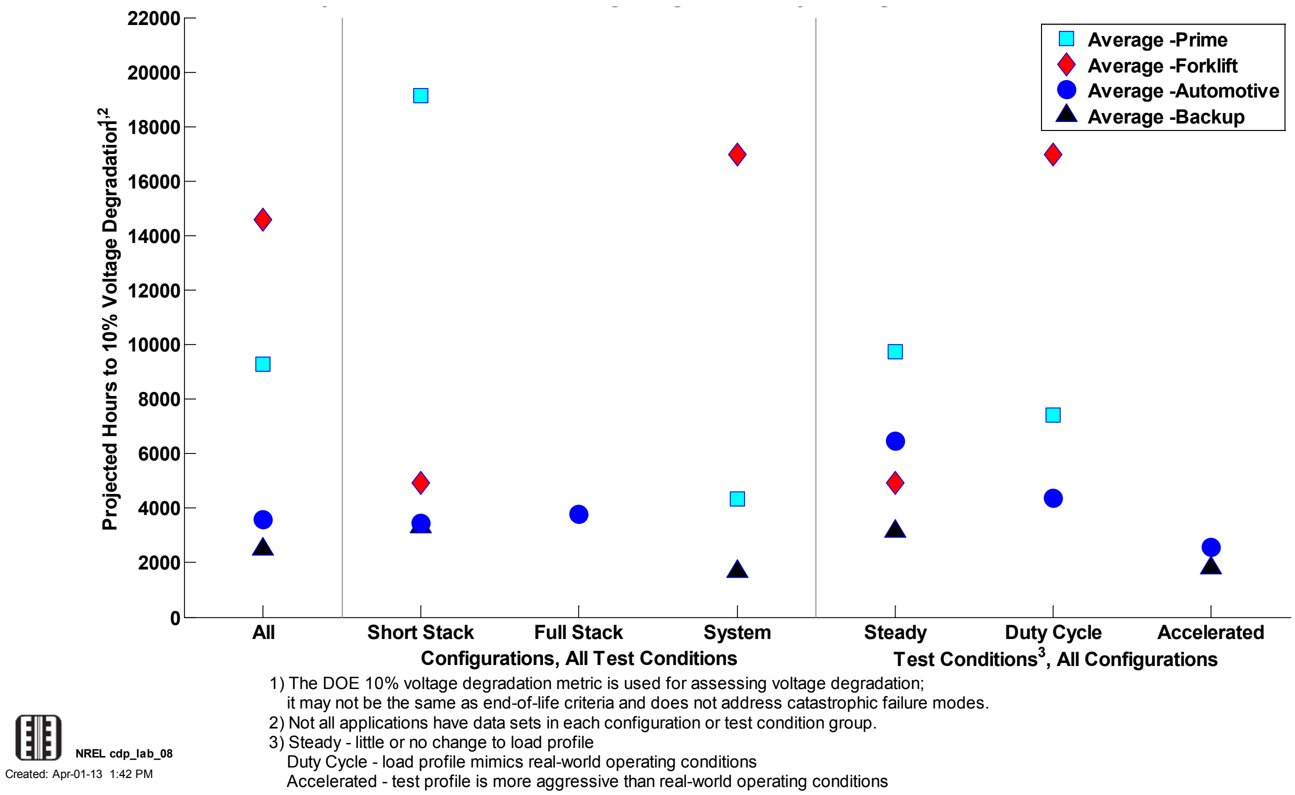

FIGURE 3. Projected Hours to 10% Voltage Drop by Configuration and Test Condition

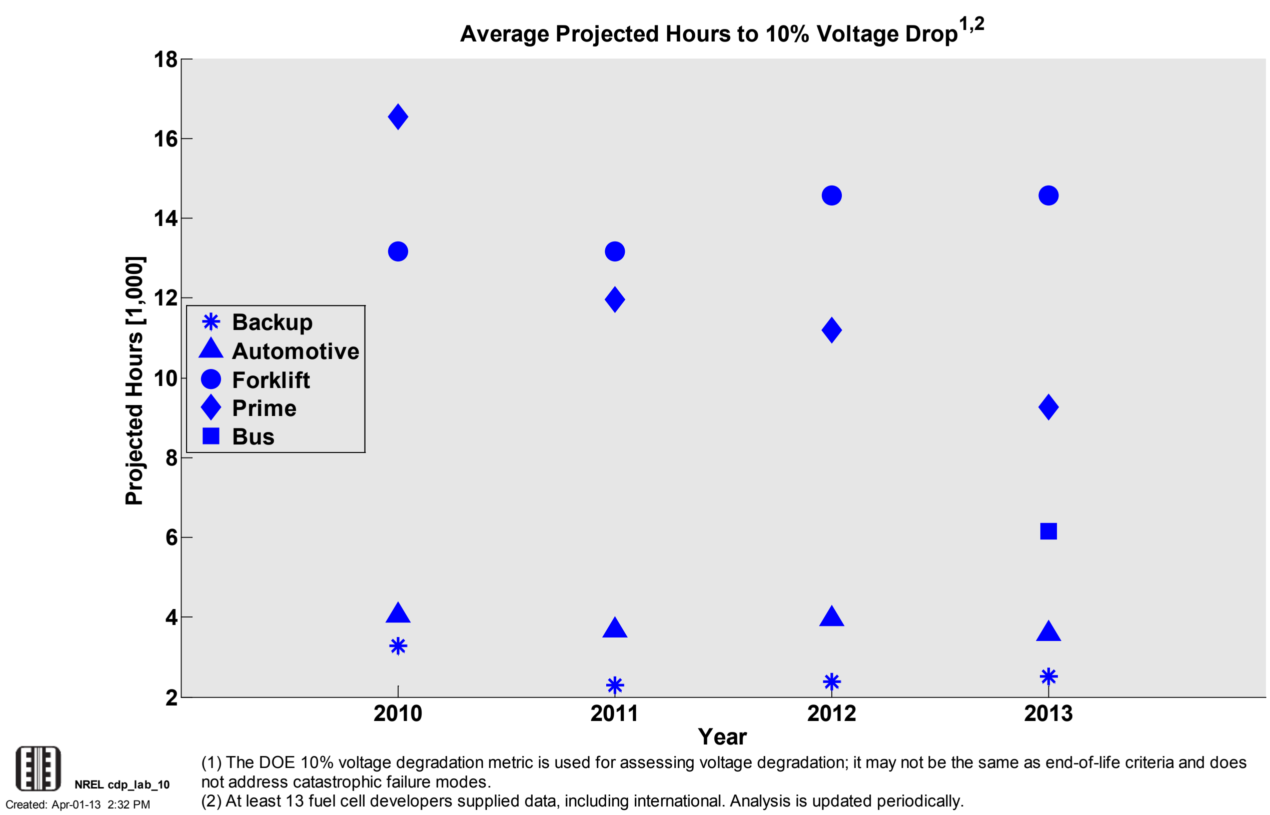

FIGURE 4. Average Projected Hours to 10% Voltage Degradation by Year and Application Group

to-year (particularly when the average decreases) is fuel cell development is focusing on multiple performance metrics that include durability, cost reduction, and efficiency. A test configuration may have been based on improvements in an area other than durability, with a small negative impact on durability. Development that focuses on more than one area (such as durability and cost reduction) is actually a statement on how far the technology has progressed. The research is not just focused on durability solutions. An up and down trend of average durability in an application from the past few years represents the degree of integration amongst the highest priority research topics. In addition, there are continued needs for the technology that is capable of meeting both cost and durability targets.

CONCLUSIONS AND FUTURE DIRECTIONS

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 investment from DOE. U.S. 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 developers showcases the fuel cell durability improvements with the current technology and provides an overall technology benchmark (with the published aggregated data) and an individual developer benchmark (with the detailed data products). The data are fully integrated into Fleet Analysis Toolkit, and an online interface provides information on the project, contact information for interested collaborators, and all publications. The published results from April 2013 are the fifth update and were completed ahead of the milestone requirement with many new data sets and results. Future work includes the following:

- Continue cultivating existing collaboration and developing new collaborations with fuel cell developers
- Gathering, processing, and reporting on current fuel cell product cost and/or price

FY 2013 PUBLICATIONS/PRESENTATIONS

1. Kurtz, J., Dinh, H., "Fuel Cell Technology Status Analysis Project: Partnership Opportunities," Fact sheet describing opportunities for industry to participate in NREL's fuel cell technology performance, durability, and price analysis. (June 2013)
2. Kurtz, J., Dinh, H., Sprik, S., Saur, G., Ainscough, C., Peters, M., "Fuel Cell Technology Status – Voltage Degradation," Presented at the 2013 Annual Merit Review and Peer Evaluation Meeting, Washington, D.C. (May 2013)
3. Kurtz, J., Dinh, H., Sprik, S., Saur, G., Ainscough, C., Peters, M., "State-of-the-Art Fuel Cell Voltage Durability Status: Spring 2013 Composite Data Products." (May 2013)

REFERENCES

1. http://www.nrel.gov/hydrogen/proj_fc_analysis.html