V.A.1 Analysis of Laboratory Fuel Cell Technology Status – Voltage Degradation

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

Fiscal Year (FY) 2012 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

Technical Barriers

This project addresses the following technical barrier from the Fuel Cells section (3.4) of the Fuel Cell Technologies Program 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 expected application.

FY 2012 Accomplishments

- Analyzed fuel cell stack and system data in four application categories (backup, automotive, forklift, and stationary) and from 10 fuel cell developers
- Published eight composite data products (CDPs) on:
  - Operation time and projected operation time to 10% voltage drop
  - Projected operation time sensitivity to voltage drop levels
  - Comparison of automotive and material handling equipment (MHE) lab and field durability projections
  - Power capability
  - Data sets operated beyond 10% voltage drop
  - Durability projections by configuration and test condition.
- Projected operation time to 10% voltage drop summary by application:
  - Backup
    - Average projected operation hours to 10% voltage drop ~2,400 hours
    - Maximum projected operation hours to 10% voltage drop ~7,000 hours
  - Automotive
    - Average projected operation hours to 10% voltage drop ~4,000 hours
    - Maximum projected operation hours to 10% voltage drop ~12,200 hours
  - Forklift
    - Average projected operation hours to 10% voltage drop ~14,600 hours
    - Maximum projected operation hours to 10% voltage drop ~21,800 hours
  - Stationary
    - Average projected operation hours to 10% voltage drop ~11,200 hours
    - Maximum projected operation hours to 10% voltage drop ~40,600 hours.
- Included data on proton exchange membrane fuel cell (PEMFC) and solid oxide fuel cell (SOFC) 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 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 lab, study analysis results, and expand the included data sets.

Approach

The project involves voluntary submission of data from relevant fuel cell developers. We are 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 (NRELFAT). 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 in the number of data sets analyzed, applications and fuel cell types studied, and amount of details published. Results published in April 2012 were the fourth update for this analysis effort, and the next analysis update is scheduled for February 2013. The annual voltage degradation analysis of state-of-the-art lab durability was completed in advance of the milestone in order to provide an update that could be presented at the DOE's Annual Merit Review. In the last published data set, four applications were covered, 10 fuel cell developers supplied data (more than one data set in many cases), and the data sets covered PEMFC and SOFC stack testing. A total of 82 data sets have been analyzed, including 39 new data sets added over the last 12 months. 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

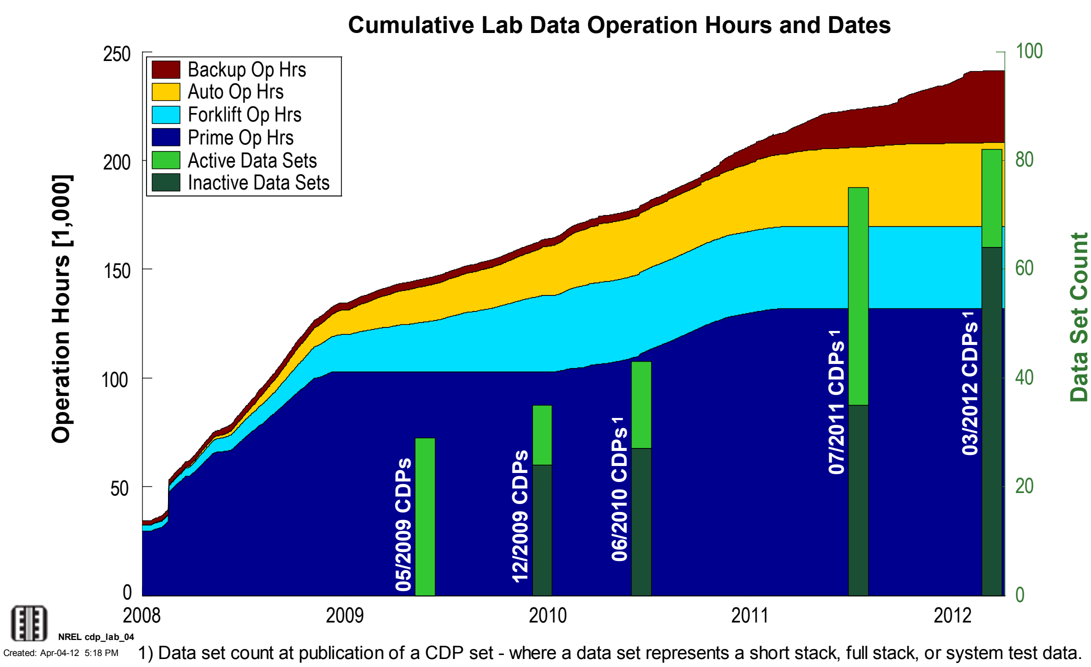

FIGURE 1. Cumulative lab data operation hours and dates

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 lab systems at less than 14 kW power.

The analyzed data sets are from lab 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 2011 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. 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. Table 1 summarizes the average values highlighted in Figure 2.

TABLE 1. Summary of Average Operation Hours and Average Projected Hours to 10% Voltage Drop by Application

Application	Average Operation Hours	~Average Projected Hours to 10% Voltage Drop
Backup	1,100	2,400
Automotive	2,700	4,000
Forklift	4,400	14,600
Stationary	7,100	11,200

The 10% voltage drop level is not necessarily a measurement for end-of-life or even 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. 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 (Figure 3). Not all applications have data sets in each configuration or test condition group. The test condition groups include:

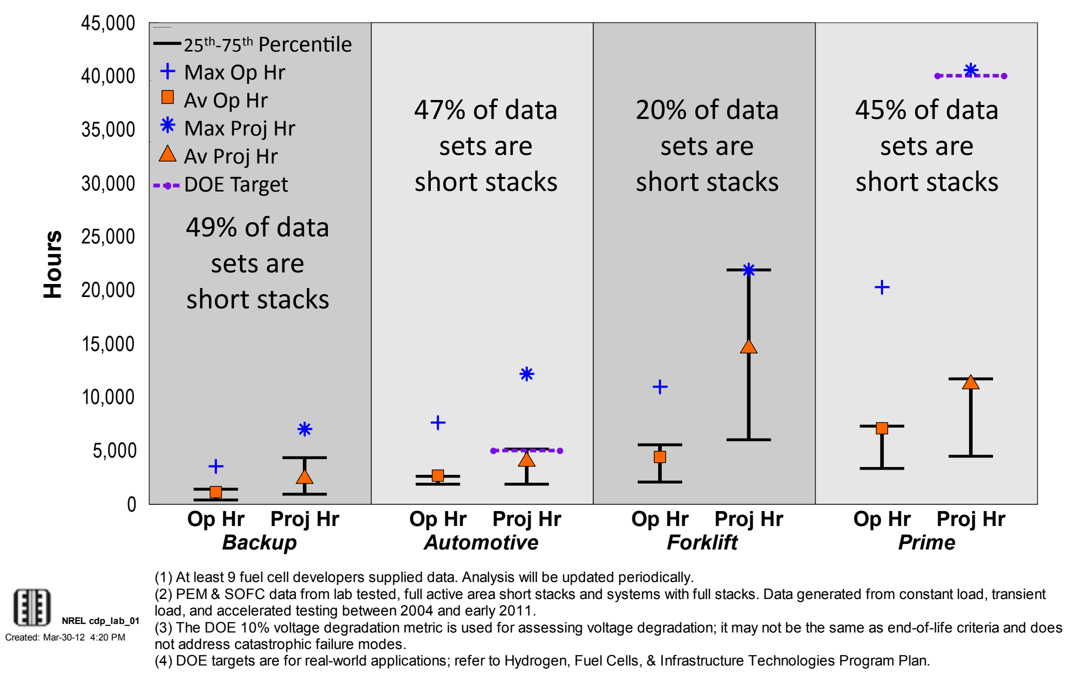

FIGURE 2. Operation hours and projected hours to 10% voltage drop by application category

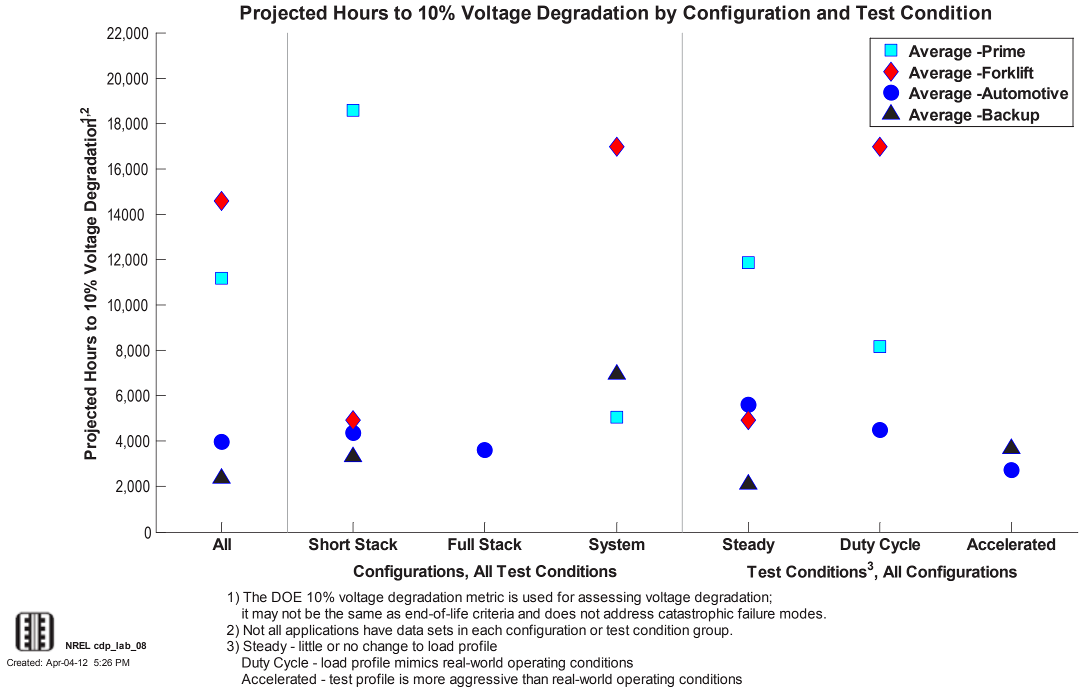

FIGURE 3. Projected hours to 10% voltage drop by configuration and test condition

- 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

Comparisons in the automotive and material handling applications indicate there are gaps between field and lab voltage durability performance (Figure 4). Possible reasons include different data providers, technology generations, operating conditions, and test procedures. Additional comparisons to investigate are projections by configuration and test conditions with field performance.

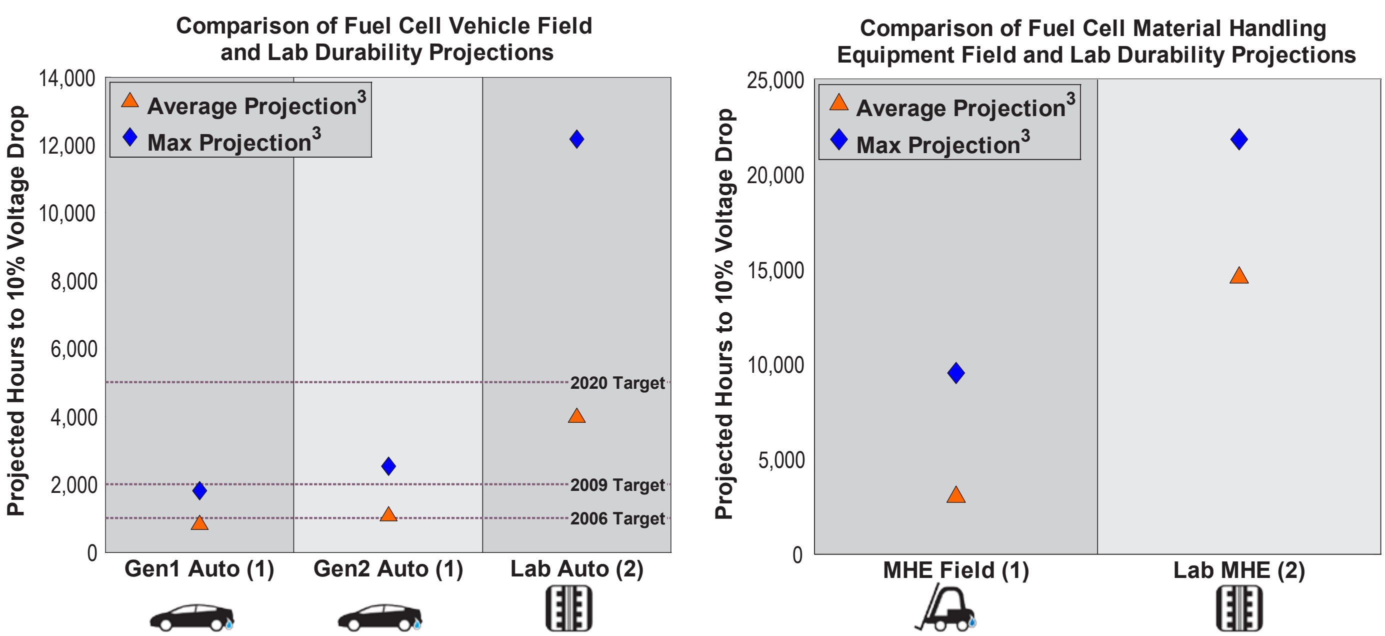

FIGURE 4. Comparison of field and lab durability projections for automotive and MHE application categories

A new website was created for this Fuel Cell Technology Status project at http://www.nrel.gov/hydrogen/proj_fc_analysis.html. The website, located with NREL's technology validation website, provides the following information:

- A project overview
- Links to more information about the Hydrogen Secure Data Center
- A contact link for developers interested in participating
- Links to all of the CDPs, publications, and reports.

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. Half of the 20 fuel cell developers contacted 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 NRELFAT and an online interface provides information on the project, contact information for interested collaborators, and all publications. The published results from April 2012 are the fourth update and were completed ahead of the milestone requirement with many new data sets and results. An annual update is planned for February 2013 and the future work includes the following:

- Continue cultivating existing collaboration and developing new collaborations with fuel cell developers
- Expand the type of testing to include single cell or short stack testing that is early in the development stage and may not have a clear path to a commercial product
- Identify results from DOE accelerated stress test protocols
- Investigate the difference between field and lab projections and data sets
- Expand results aimed at improving data comparability and statistical confidence
- Investigate other aging parameters for fuel cell durability (e.g., start/stops, soak time)
- Include other applications such as portable.

FY 2012 Publications/Presentations

1. Kurtz, J., Wipke, K., Sprik, S., Saur, G., "Fuel Cell Technology Status – Voltage Degradation," Presented at the 2012 Annual Merit Review and Peer Evaluation Meeting, Washington, D.C. (May 2012)

2. Kurtz, J., Sprik, S., Saur, G., "State-of-the-Art Fuel Cell Voltage Durability Status, 2012 Composite Data Products," Composite data products produced by the NREL Hydrogen and Fuel Cells Research team. (April 2012)

3. Kurtz, J., Wipke, K., Sprik, S., Saur, G., "Analysis of Laboratory Fuel Cell Technology Status – Voltage Degradation," Excerpt from the 2011 Annual Progress Report. (November 2011)