State-of-the-Art Fuel Cell Voltage Durability and Cost Status
2018 Composite Data Products

Genevieve Saur, Jennifer Kurtz, Huyen Dinh, Chris Ainscough, Shaun Onorato

May 2018
CDP-LAB-01: Lab Data Hours Accumulated and Projected Hours to 10% Stack Voltage Degradation

(1) At least 23 U.S. and international fuel cell developers supplied data. Analysis is updated periodically.
(2) PEMFC, DMFC & SOFC data from lab tested, full active area short stacks and systems with full stacks. Data generated from constant load, transient load, and accelerated testing between 2004 and 2017.
(3) The DOE 10% voltage degradation metric is used for assessing voltage degradation; it may not be the same as end-of-life criteria and does not address catastrophic failure modes.
(4) DOE targets are for real-world applications; refer to Hydrogen, Fuel Cells, & Infrastructure Technologies Program Plan.
CDP-LAB-02: Durability Lab Data Projection Sensitivity to Voltage Degradation Levels

**Durability Lab Data Sets**¹ - Average projected Hour Sensitivity to Voltage Degradation Levels

![Graph showing projected hours sensitivity to voltage degradation levels across different application types.](image)

---

(1) PEM & SOFC data from lab tested, full active area short stacks and systems with full stacks. Data generated from constant load, transient load, and accelerated testing between 2004 and 2017.

(2) 10% Voltage degradation is a DOE metric for assessing fuel cell performance.

(3) Curves generated using the average of each application at various voltage degradation levels.

(4) The projection curves display the sensitivity to percentage of voltage degradation, but the projections do not imply that all stacks will (or do) operate at these voltage degradation levels.

(5) Projections may be limited by demonstrated operation hours to minimize extrapolations.

(6) The voltage degradation levels are not an indication of an OEM’s end-of-life criteria and do not address catastrophic stack failures such as membrane failure.
Comparison of Fuel Cell Operation Hours and Durability

1. Durability based on voltage degradation to 10% lower than beginning of life voltage. 10% voltage drop level is a DOE metric for assessing fuel cell durability.
2. Projections using on-road data are calculated at approximately 55%-65% rated stack current.
3. 10% voltage drop is NOT an indication of an OEM's end-of-life criteria and projections do not address catastrophic stack failure.
4. Maximum operational hours: 2,375 (LD1); 1,200 (LD2); 5,648 (Current FCEV Analysis); 13,129 (Lab Status); Maximum operational hours not reported in Learning Demonstration 2 continuation (LD2+) (2010-2011).
CDP-LAB-04: Cumulative Operation Hours by Application and Number of Data Sets

1. Data set count at publication of a CDP set - where a data set represents a short stack, full stack, or system test data.
2. Renewable Energy Storage via Electrolysis
1) A data set represents a short stack, full stack, or system test data.
2) Power capability represents the maximum power for a data set but not necessarily the load profile or time at a power level.
CDP-LAB-07: Data Set Operation Hours and the Percentage of Data Sets That Have Passed 10% Voltage Degradation

Operation Hours and Data Sets Operated Beyond 10% Voltage Degradation

1. A data set represents a short stack, full stack, or system test data.
2. The DOE 10% voltage degradation metric is used for assessing voltage degradation; it may not be the same as end-of-life criteria and does not address catastrophic failure modes.

Some data sets have operated beyond 10% voltage degradation because they are able to satisfy the operating requirements at a higher percentage of voltage degradation or the test is designed to operate until a failure.
Projected Hours to 10% Voltage Degradation by Configuration and Test Condition

1) The DOE 10% voltage degradation metric is used for assessing voltage degradation; it may not be the same as end-of-life criteria and does not address catastrophic failure modes.

2) Not all applications have data sets in each configuration or test condition group.

3) 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
CDP-LAB-09: Data Set Configuration

Configurations by Data Set

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Full Stack</th>
<th>Full System</th>
<th>Short Stack</th>
<th>Single Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forklift</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automotive</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backup</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CDP-LAB-12: Data Set Fuel

Fuel by Data Set

- **Prime**: 60% Hydrogen, 40% Reformate
- **Forklift**: 100% Hydrogen
- **Bus**: 100% Hydrogen
- **Automotive**: 90% Hydrogen, 10% Reformate
- **Backup**: 100% Hydrogen
CDP-LAB-13: Data Set Test Conditions
CDP-LAB-14: Current Density Points

1) Current density referenced are the points at which the voltage degradation is analyzed in CDP Lab 01
CDP-LAB-15: Low Volume Price of Current Fuel Cell Systems

Current Fuel Cell System Low Volume Price by Application

- 25th and 75th percentile range
- Median
- DOE Target
- Median, Hydrogen Fuel In
- Median, Other Fuel In

1. Data (in 2018 dollars without incentives) sources include public information, ARRA deployments, and fuel cell developers (voluntarily supplied). Includes over 35 different data points from more than 10 domestic and international fuel cell developers.
2. Prime power data includes multiple system sizes, types, and fuels. Small prime is < 11 kW.
3. Based on DOE MYRDD Fuel Cell section 3.4 (Updated May 2017), tables 3.4.11-3.4.14, equipment cost. Bus target is total bus cost ($), others targets listed as $/kW.
4. Bus costs include total bus cost including fuel cell power plant normalized to 2018 dollars.
CDP-LAB-16: Average Projected Voltage Degradation by Year

Average Projected Hours to 10% Voltage Drop

(1) The DOE 10% voltage degradation metric is used for assessing voltage degradation; it may not be the same as end-of-life criteria and does not address catastrophic failure modes.

(2) At least 23 developers supplied data, including international. Analysis is updated periodically. Durability results were not published in 2014.
Projected Hours to 10% Voltage Drop

(1) The DOE 10% voltage degradation metric is used for assessing voltage degradation; it may not be the same as end-of-life criteria and does not address catastrophic failure modes.

(2) At least 23 developers supplied data, including international. Analysis is updated periodically. Durability results were not published in 2014.
(1) At least 3 electrolyzer test labs supplied data. Analysis is updated periodically.
(2) Full active area short stacks and systems with full stacks. Data generated from constant load, transient load, and accelerated testing between 2003 and 2017.
(3) The DOE 10% voltage degradation metric is used for assessing voltage degradation; it may not be the same as end-of-life criteria and does not address catastrophic failure modes.
# Lab Durability Summary Table

<table>
<thead>
<tr>
<th>Application</th>
<th>2020 DOE Durability Target&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Lab Status - Ave Hrs to 10% Voltage Degradation&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Duty Automotive</td>
<td>5,000 Hours</td>
<td>3,800</td>
</tr>
<tr>
<td>Public Transit</td>
<td>25,000 Hours</td>
<td>6,200</td>
</tr>
<tr>
<td>Stationary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-10 kW</td>
<td>0.3%/1,000 Hours</td>
<td></td>
</tr>
<tr>
<td>100 kW - 3 MW</td>
<td>80,000 Hours</td>
<td>11,900</td>
</tr>
<tr>
<td>Forklift</td>
<td>20,000 Hours - Target Under Review</td>
<td>11,600</td>
</tr>
<tr>
<td>Backup</td>
<td>10,000 Hours</td>
<td>2,600</td>
</tr>
</tbody>
</table>


<sup>b</sup> Current results are available at http://www.nrel.gov/hydrogen/images/cdp_lab_01.jpg (Updated 04/2018) or from on-road results (2017 Annual FCB results www.nrel.gov/docs/fy18osti/70075.pdf)

<sup>c</sup> Results are a fraction of the 2020 targets in the MYRDD.

<sup>d</sup> Stationary 100kW-3MW vs DOE target of 80,000 hrs.
Platinum loading is plotted in the year when lab operation started and aggregates all applications, configurations and test conditions for data sets that provided loading data.
CDP-LAB-21: Lab Data Hours Accumulated and Projected Hours to 10% Stack Voltage Degradation (2014–2017 data)

(1) Partial data from 2014-2017 only, full dataset includes least 23 U.S. and international fuel cell developers. See CDP-Lab-01 for full data set.

(2) PEMFC, DMFC & SOFC data from lab tested, full active area short stacks and systems with full stacks. Data generated from constant load, transient load, and accelerated testing between 2004 and 2017.

(3) The DOE 10% voltage degradation metric is used for assessing voltage degradation; it may not be the same as end-of-life criteria and does not address catastrophic failure modes.

(4) DOE targets are for real-world applications; refer to Hydrogen, Fuel Cells, & Infrastructure Technologies Program Plan.