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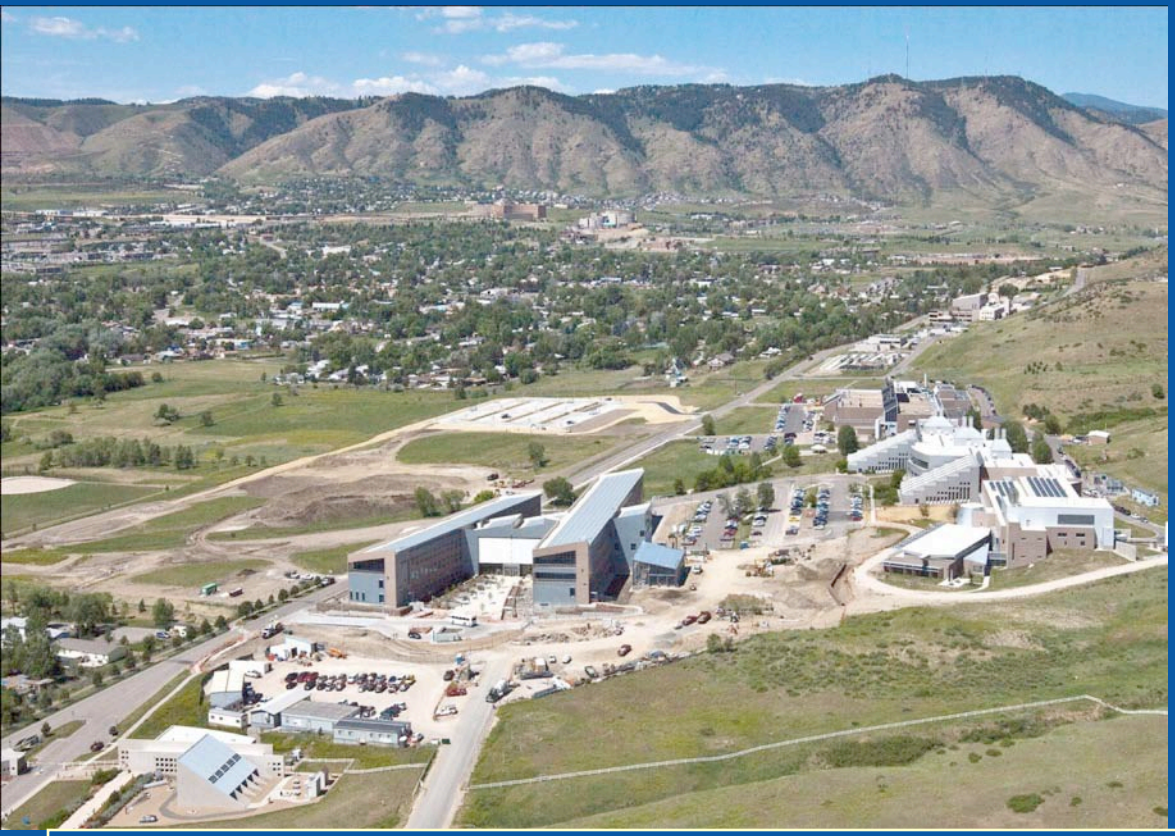
NATIONAL RENEWABLE ENERGY LABORATORY

Fuel Cell Technology Status – Voltage Degradation



2011 DOE Annual Merit Review

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5/12/2011

Project ID: FC081

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

Project Start Date: July 2009

Project End Date: October 2011*

Percent Complete: On-going

Barriers

Durability of state-of-the-art fuel cell stacks and systems

Budget

Total Project Funding

DOE share: $200k

Contractor share: $0

Funding Received in FY09/FY10: $200k

Funding Received in FY11: $0

Partners

22 Fuel Cell Developers contacted

8 Fuel Cell Developers shared data

**Project continuation and direction determined annually by DOE*

Objectives - Relevance

Benchmark state-of-the-art fuel cell durability

- Snapshot of state-of-the-art fuel cell durability
- Uniformly apply analysis method to all data accumulated in lab
- Independent assessment and status of state-of-the-art fuel cell technology

Leverage analysis experience

- Utilize analysis methods, experience, and data from fuel cell field demonstrations (e.g. DOE's FCV Learning Demonstration and Early Market demonstrations)
- Lab and field data comparisons

Collaboration with key fuel cell developers

- Feedback provided to fuel cell developers
- Factors affecting fuel cell durability
- Study of differences between lab and field durability

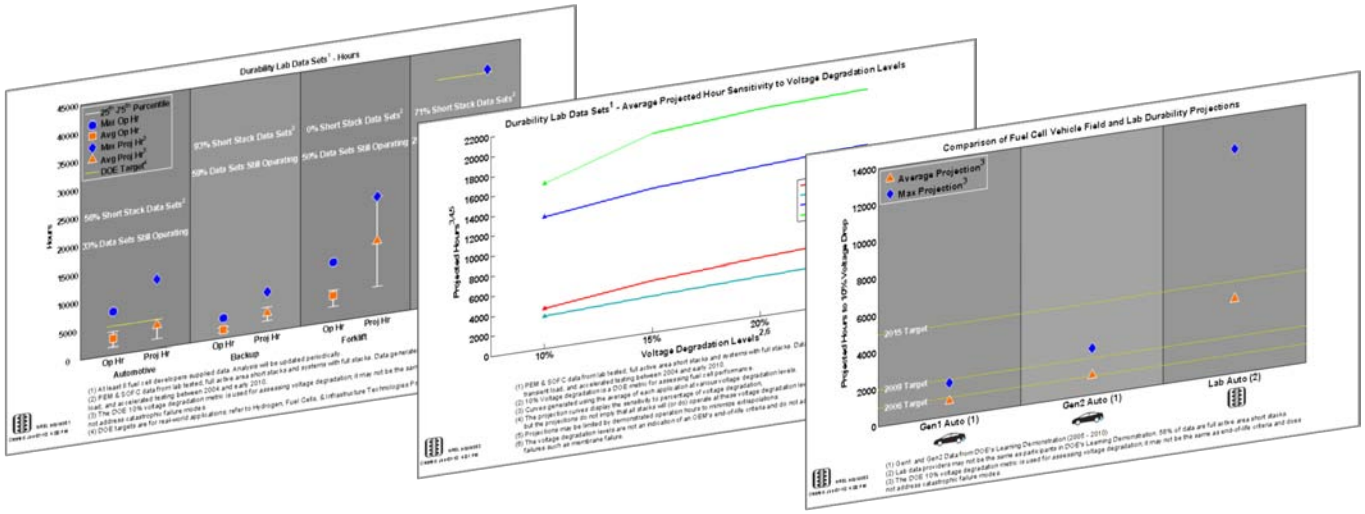
FY10 and FY11 Milestones - Approach and Accomplishments

FY10 Milestone

- Complete at least 1 Composite Data Products for review by DOE and industry (04/2010)
  - Updated Composite Data Products in 06/2010

FY11 Milestone

- Complete at least 3 Composite Data Products for review by DOE and industry (07/2011)



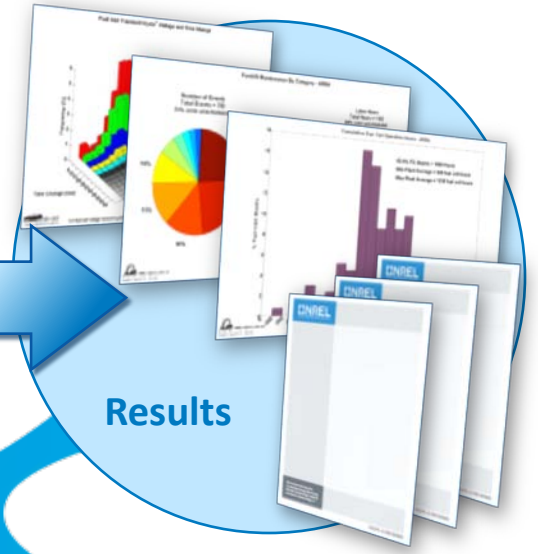
Hydrogen Secure Data Center - Approach

Bundled data (operation & maintenance/safety) delivered to NREL quarterly

Internal analysis completed quarterly

HSDC

NREL's Hydrogen Secure Data Center



DDPs

CDPs

Detailed Data Products (DDPs)
- Individual data analyses
- Identify individual contribution to CDPs
- Only shared with partner who supplied data every 6 months[1]

Composite Data Products (CDPs)
- Aggregated data across multiple systems, sites, and teams
- Publish analysis results without revealing proprietary data every 6 months[2]

1) Data exchange may happen more frequently based on data, analysis, and collaboration
2) Results published via NREL Tech Val website, conferences, and reports

Raw FC Data Processing - Approach

Establish collaborative relationships with fuel cell developers

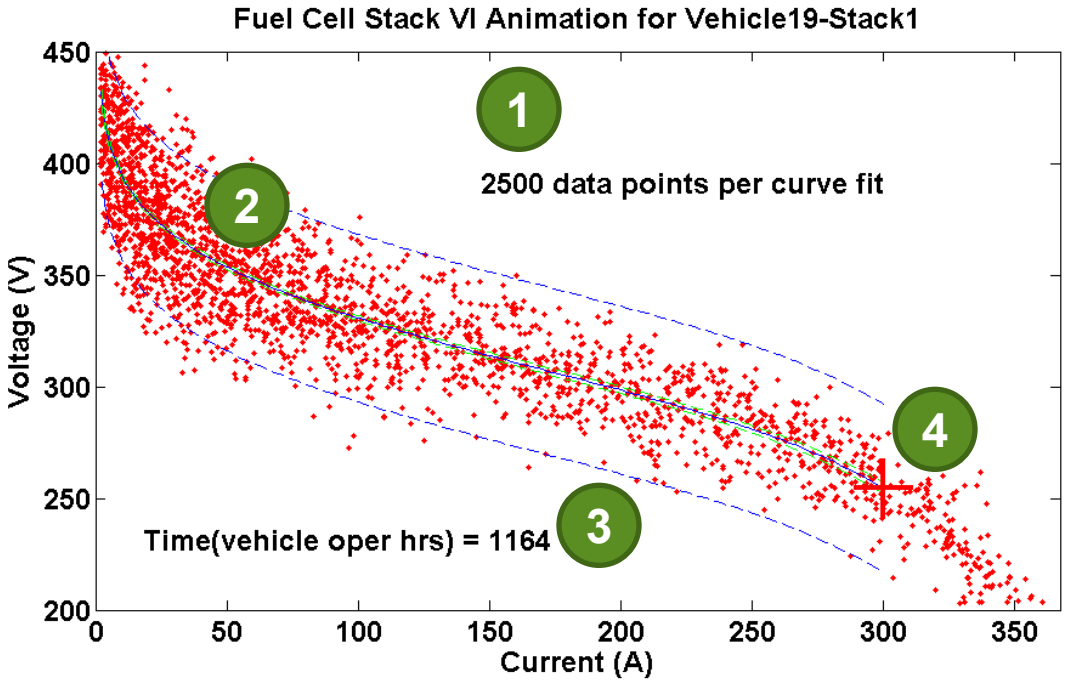
Leverage capabilities developed by the DOE's Learning Demonstration

Data sharing completely voluntary

Receive state-of-the-art fuel cell data

Store and process voltage and current data

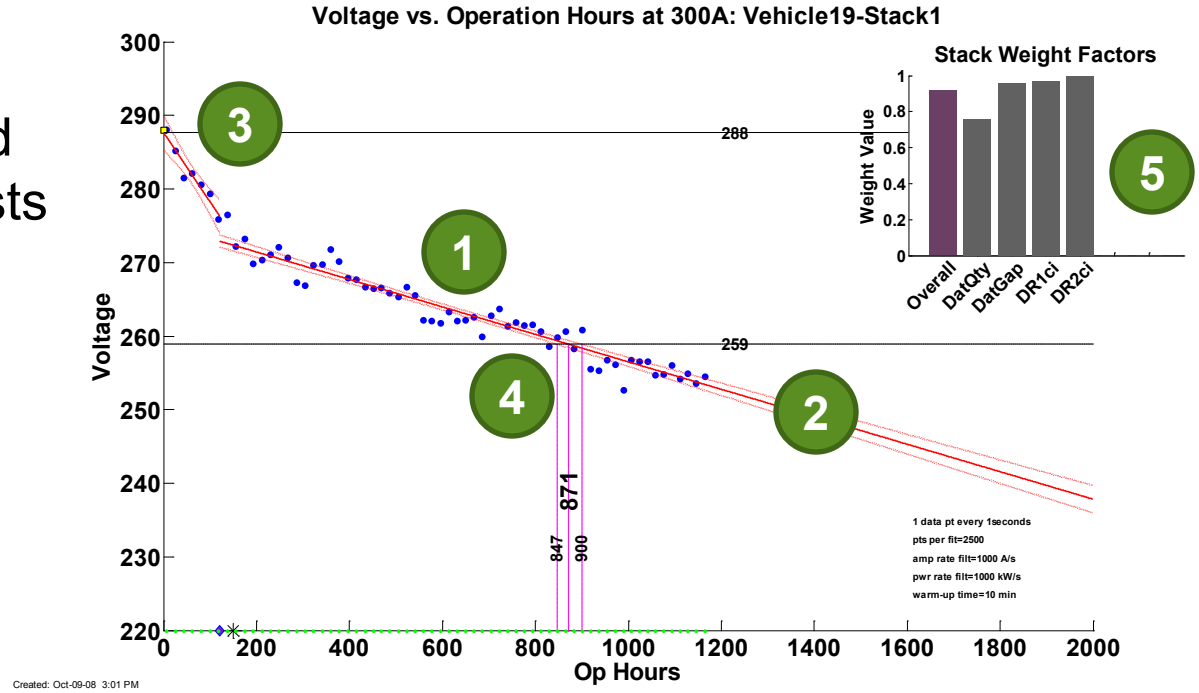
1. Segment fuel cell voltage and current data
2. Apply polarization fit
3. Record operation hour for segment
4. Record voltages from polarization fit at set currents



Processed Voltage Degradation Projections - Approach

Voltage versus Operation Hour

1. Plot polarization fit voltage at a specific voltage
2. Apply robust segmented linear fit (if trend suggests non-linear degradation trend)
3. Record fit y-intercept (nominal voltage drop)
4. Record operation hour when fit crosses 10% nominal voltage drop
5. Investigate fit quality

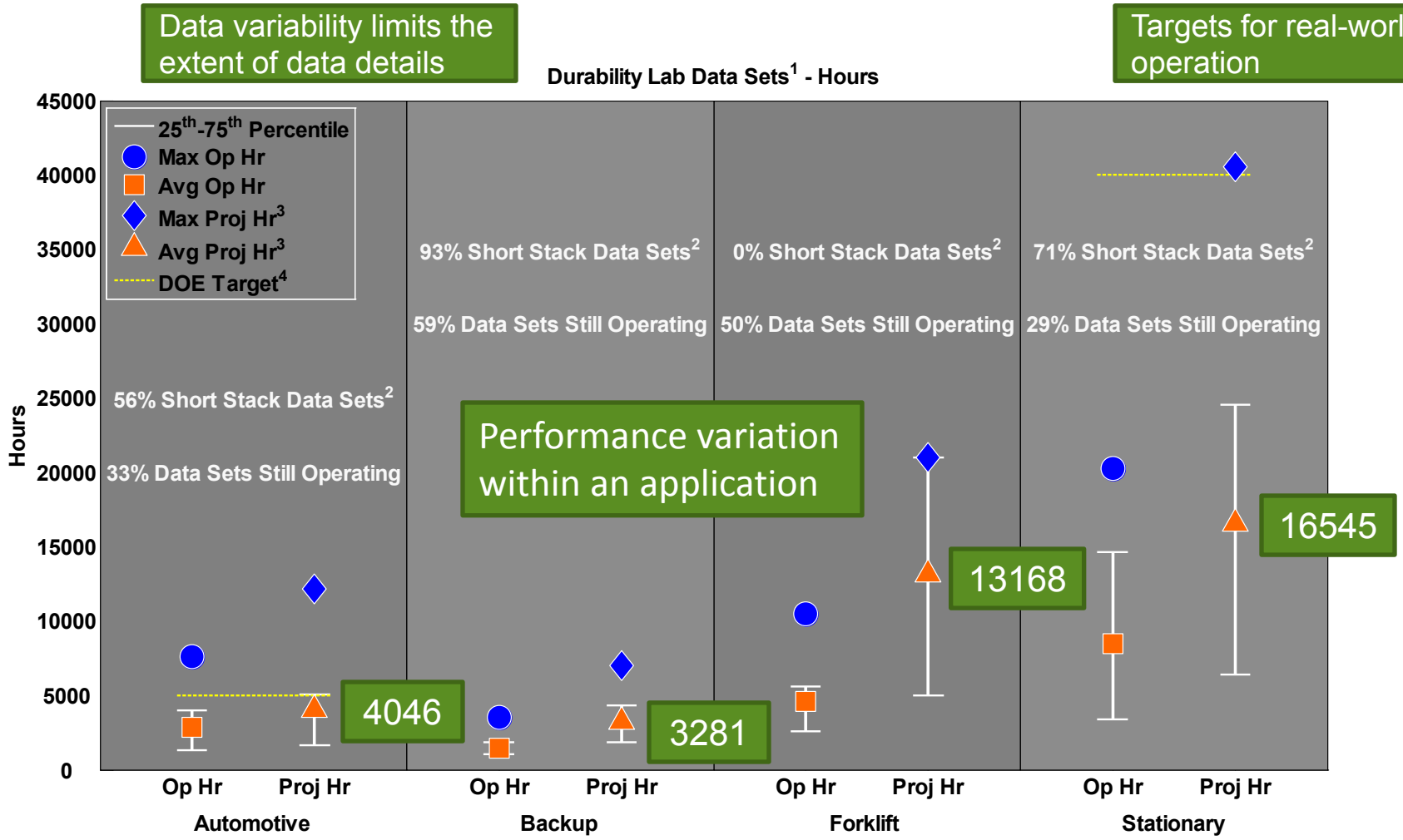


Note: 10% voltage drop is a DOE target/metric, not an indicator of end-of-life

Voltage Degradation Projections Composite Data Products - Accomplishment

- ***Fuel cell durability projections categorized***
  - Expected field application
  - Short stack or system
  - Fuel cell type
  - Test procedure
- ***Fuel cell durability projections aggregated into a composite data product (CDP)***
  - Statistics (average, max, and 25th and 75th percentiles) plotted per application
  - CDP details limited due to number of data sets in each category and the variability in the data sets
- ***Durability comparison with automotive lab and field***
  - Automotive first comparison because of FCV field results
  - Highlights progress between technology generations, positive results for current fuel cell technology in the lab, and a gap between lab and field durability projections

FC Lab Data Durability Projected Time to 10% Voltage Drop - Accomplishment



(1) At least 8 fuel cell developers supplied data. Analysis will be updated periodically.
(2) 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 early 2010.
(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.

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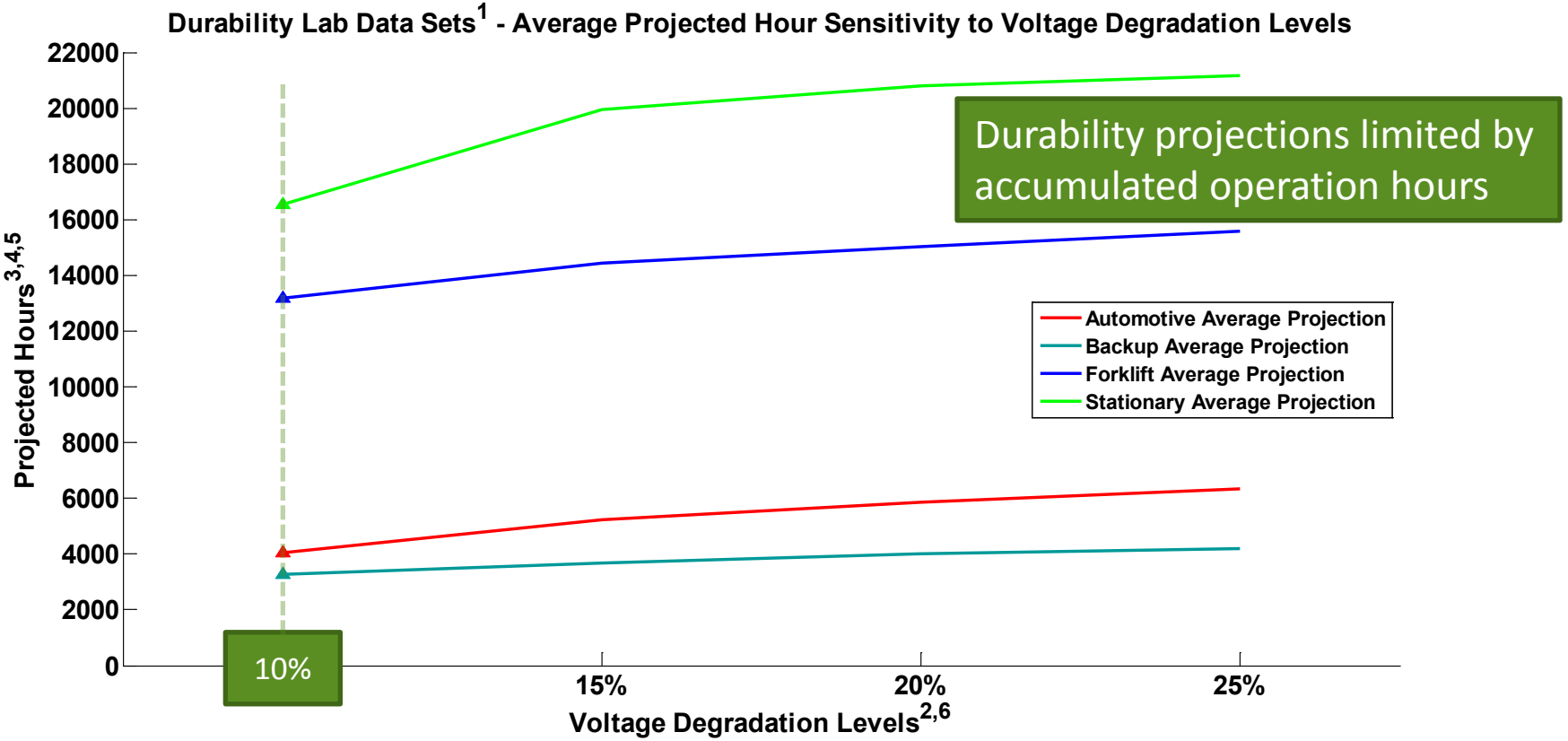
Durability Lab Data Projection Sensitivity to Voltage Degradation Levels - Accomplishment



(1) PEM & SOFC data from lab tested, full active area short stacks and system with full stacks. Data generated from constant load, transient load, and accelerated testing between 2004 and early 2010.
(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.

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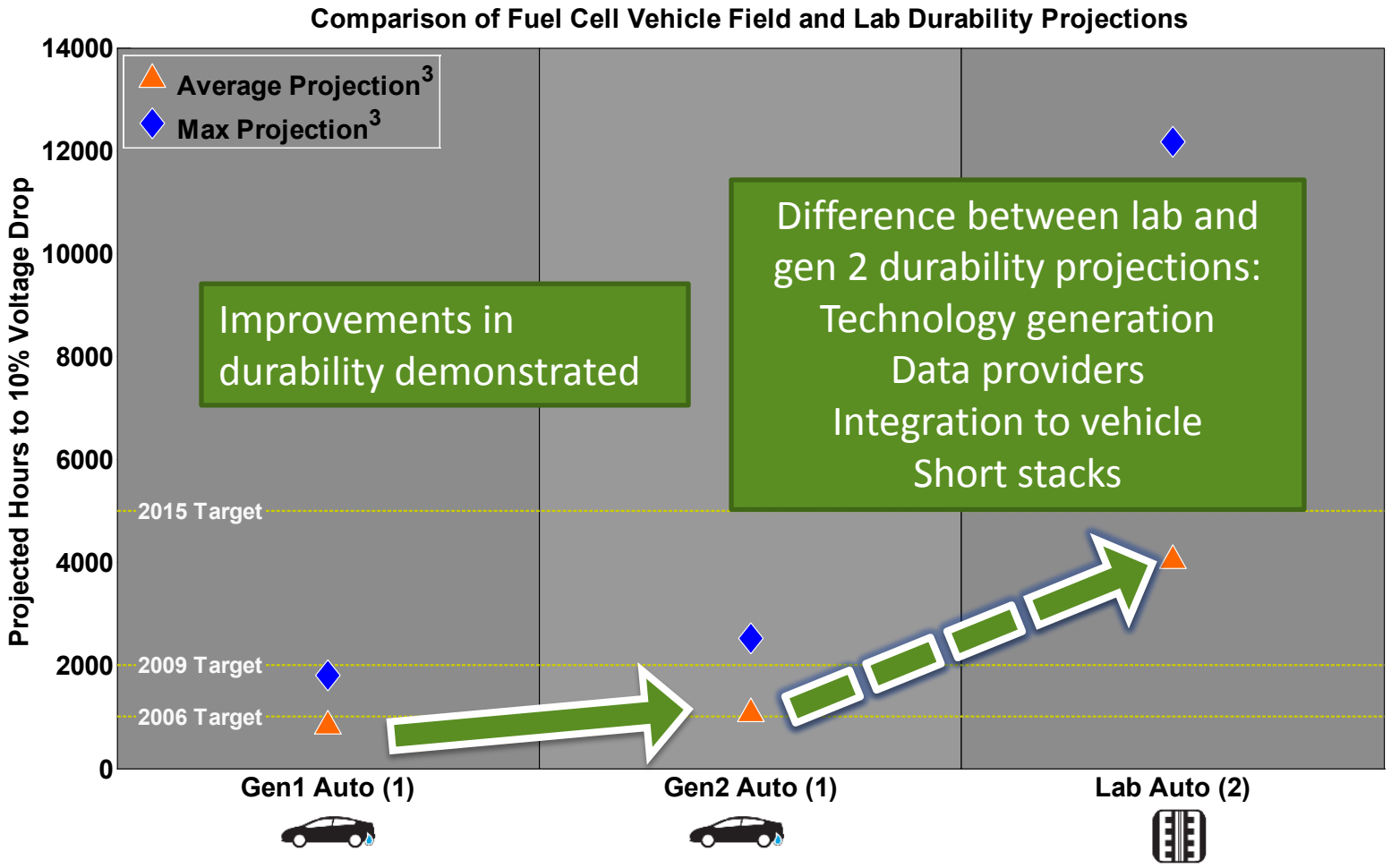
Automotive FC Durability Comparison - Accomplishment



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(1) Gen1 and Gen2 Data from DOE's Learning Demonstration (2005 - 2010)
(2) Lab data providers may not be the same as participants in DOE's Learning Demonstration. 56% of data are full active area short stacks.
(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.

CDP Additions in FY10 - Accomplishment

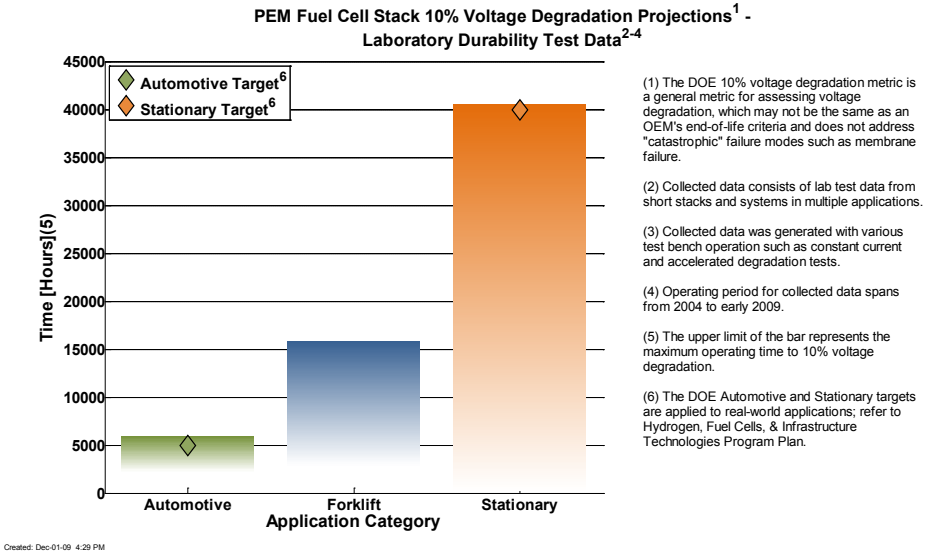
Additional Details in FY10 CDP:

Backup category

Max, Average, 25th, and 75th percentile of accumulated hours and projected hours to 10% voltage drop

Percentage of short stack data sets

Percentage of data sets still operating



(1) The DOE 10% voltage degradation metric is a general metric for assessing voltage degradation, which may not be the same as an OEM's end-of-life criteria and does not address "catastrophic" failure modes such as membrane failure.

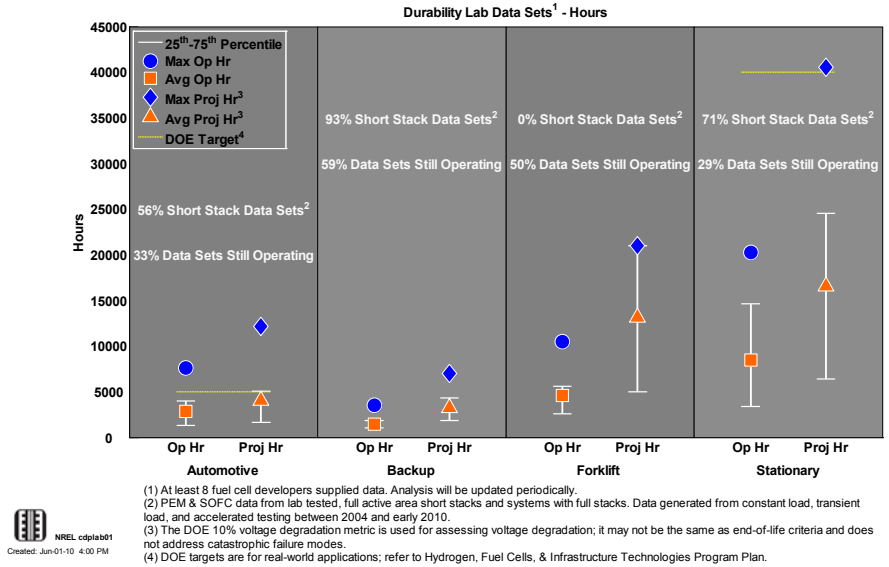
(2) Collected data consists of lab test data from short stacks and systems in multiple applications.

(3) Collected data was generated with various test bench operation such as constant current and accelerated degradation tests.

(4) Operating period for collected data spans from 2004 to early 2009.

(5) The upper limit of the bar represents the maximum operating time to 10% voltage degradation.

(6) The DOE Automotive and Stationary targets are applied to real-world applications; refer to Hydrogen, Fuel Cells, & Infrastructure Technologies Program Plan.



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FY09 CDP Version

FY10 CDP Version

Collaborations

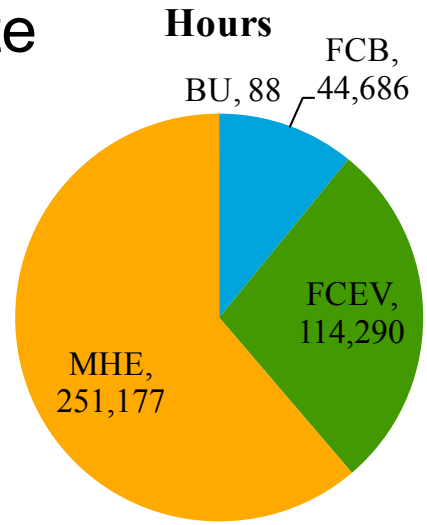
- Working with multiple fuel cell developers
  - 8 of 22 fuel cell developers contacted have supplied at least one dataset
  - Reasons for developers not providing data include concerns over voluntary proprietary data sharing, available data sets with high operation time that are a good fit to include in the analysis, and readily accessible data in the requested format.
  - Data contributors not identified yet because of limited data sets by application category.
- PEM and SOFC datasets
- Data sharing completely voluntary
- Ongoing effort with fuel cell developers to
  - Include new data sets (particularly in the stationary category)
  - Update datasets already included if applicable
  - Include new fuel cell developers

Future Work

- Continue contacting and data sharing with fuel cell developers
- Accumulate data to allow for new and more detailed CDPs
- Expand comparisons with other applications
- Study differences between lab and field durability projections and performance
- Investigate factors affecting durability

Summary

- Fuel cell data analyzed in 4 categories: automotive, material handling, backup power, and stationary power
- Data supplied from 8 fuel cell developers (PEM and SOFC)
- Analysis method applied uniformly to all data
- Durability analysis evolves as data is accumulated and trends are observed
- Publish proprietary, lab data as CDPs (update in summer 2011 Milestone 07/31/2011)
- Statistics of durability projections for each category
- Able to compare and study durability between applications, technology generations, and state-of-the-art laboratory data



FC Hours Analyzed by Application
>410,000 as of June 2010