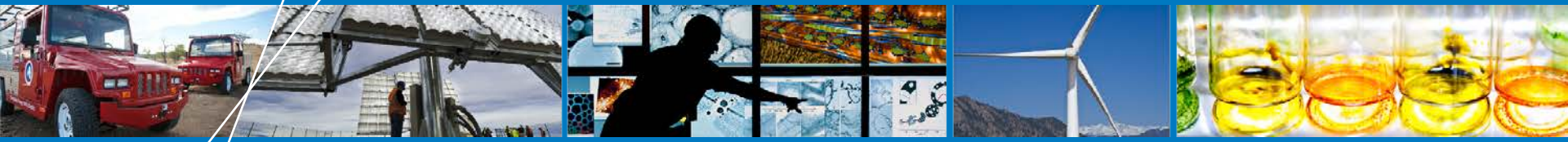
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Fuel Cell Technology Status – Voltage Degradation



2012 DOE Annual Merit Review

Jennifer Kurtz, Keith Wipke, Sam Sprik, Genevieve Saur

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NREL/PR-560-54473

Project ID# FC-081

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

Overview

Timeline	Barriers
Project start date: July 2009 Project end date: October 2012* Percent complete: On-going	Durability of state-of-the-art fuel cell stacks and systems
Budget	**Partners**
Total project funding DOE share: $300k Contractor share: $0 Funding received in FY12: $100k Funding received in FY11: $0k Funding received FY09–10: $200k	20 fuel cell developers contacted 10 fuel cell developers shared data

*Project continuation and direction determined annually by DOE

Objectives – Relevance

Benchmark state-of-the-art fuel cell durability

- Develop snapshot of state-of-the-art fuel cell durability
- Uniformly apply analysis method to data accumulated in lab
- Obtain independent assessment and status of state-of-the-art fuel cell technology

Leverage analysis experience

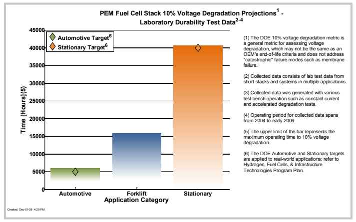
- Utilize analysis methods, experience, and data from fuel cell field demonstrations (e.g., DOE's FCV Learning Demonstration and Early Market demonstrations)
- Compare lab and field data

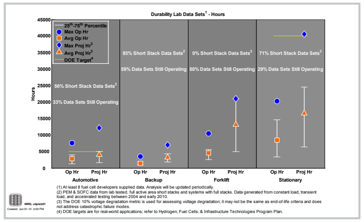
Collaborate with key fuel cell developers

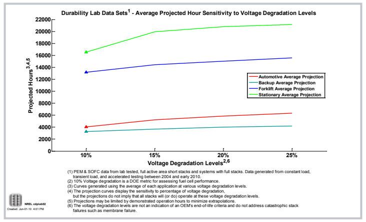
- Provide feedback to fuel cell developers
- Investigate factors affecting fuel cell durability
- Study differences between lab and field durability

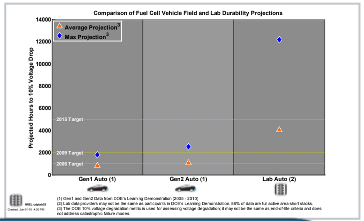
Milestones – Approach and Accomplishments

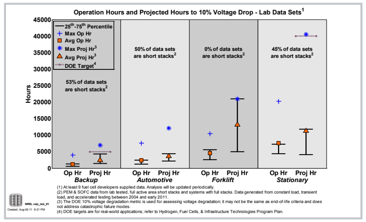
FY09 FY10 FY11 FY12

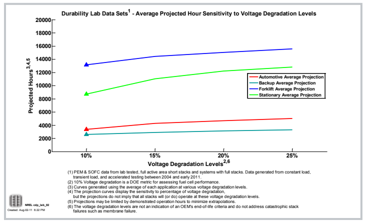


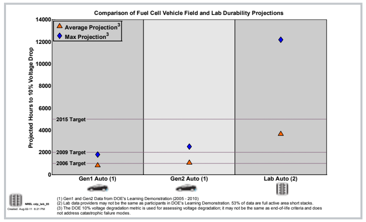


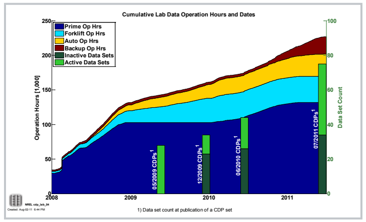


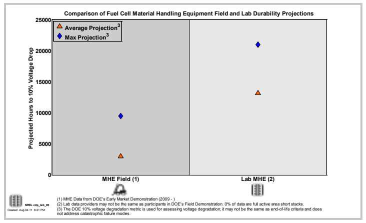


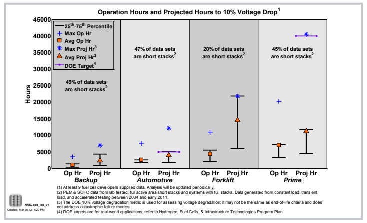


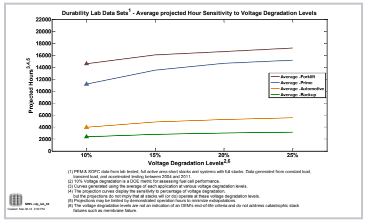


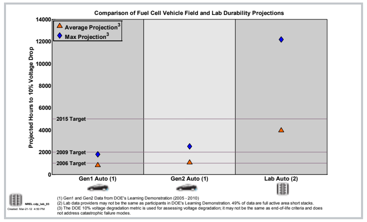


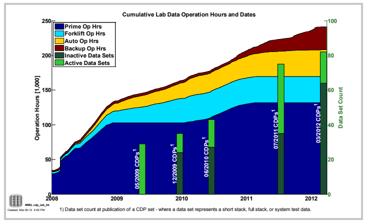


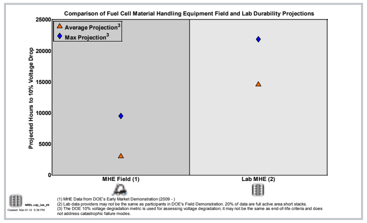


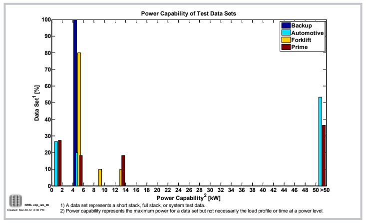


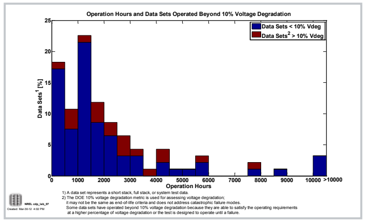


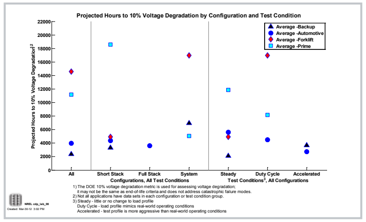












Project milestones are for annual updates of analysis results which has been completed four times. Each update has had more data, results, and details than the previous update.

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

Confidential

Public

CDPs

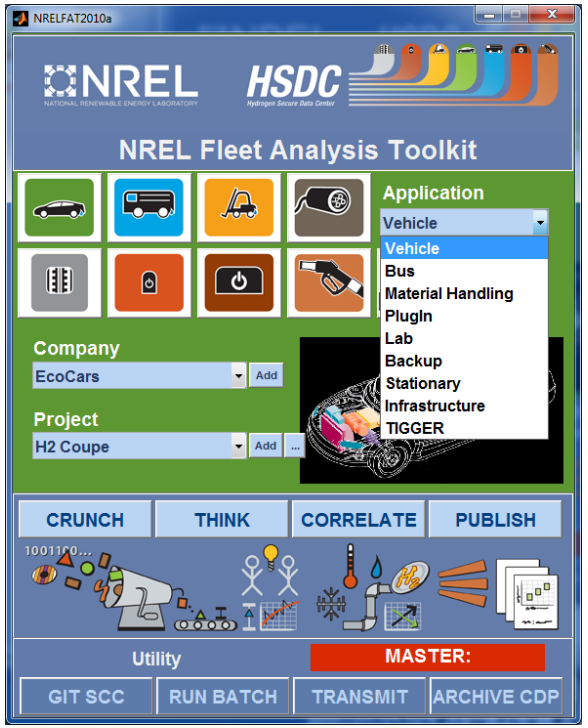
Detailed Data Products (DDPs)
- Individual data analyses
- Identify individual contribution to CDPs
- Only shared with partner who supplied data every 6 months[1]

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

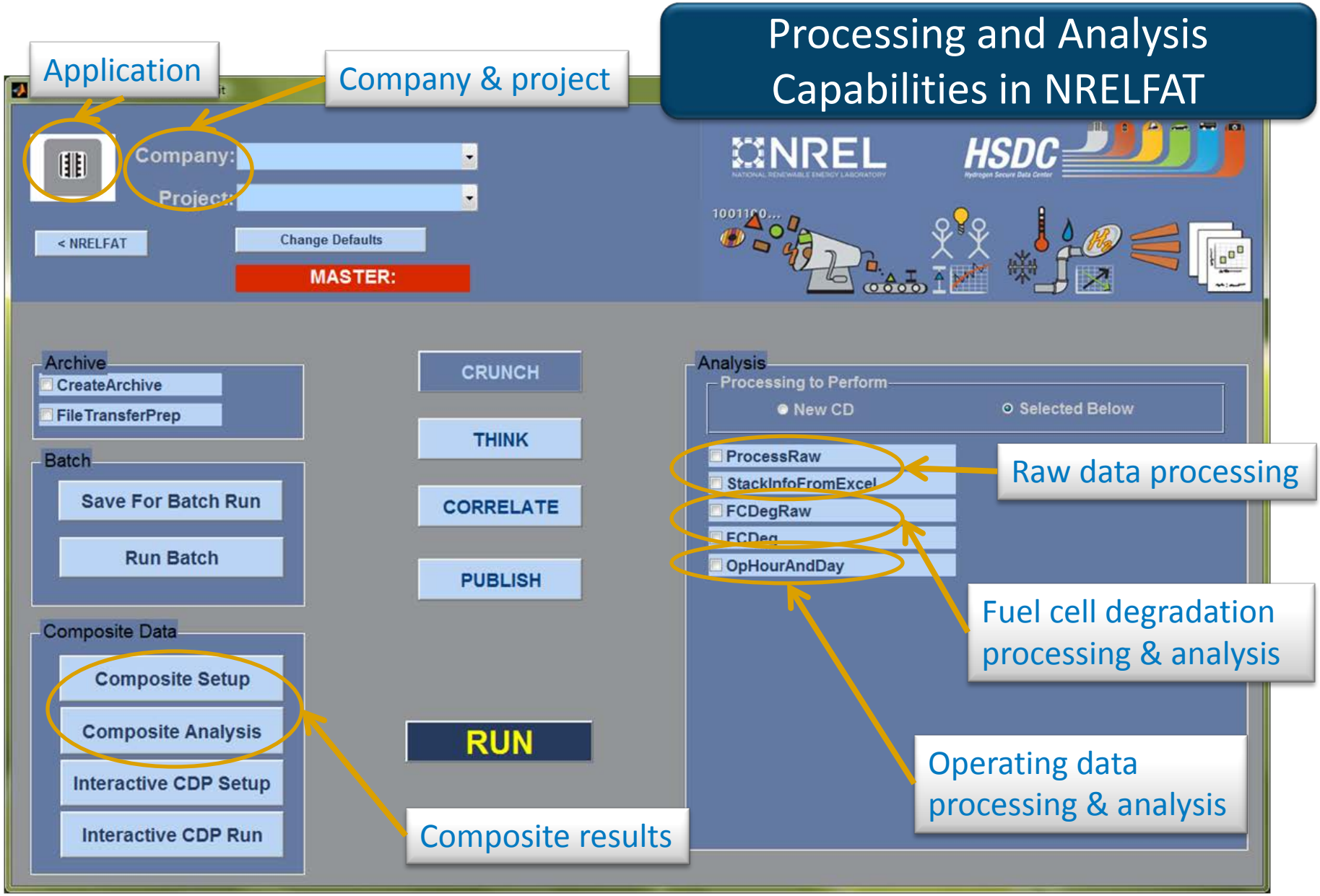
1) Data exchange may happen more frequently based on data, analysis, and collaboration
2) Results published via NREL Tech Val website, conferences, and reports

Analysis – Approach and Accomplishment

- **NREL Fleet Analysis Toolkit (NRELFAT)**
  - Developed first under fuel cell vehicle Learning Demonstration
  - Restructured architecture and interface to effectively handle new applications and projects and for analysis flexibility
  - Leverages durability analysis already created
- **Data sharing, storing, and processing**
  - Voluntary data sharing
  - Data from many different stacks, systems, and test conditions
- **Publish results**
  - Detailed and composite results
  - Target key stakeholders such as fuel cell and hydrogen developers and end users



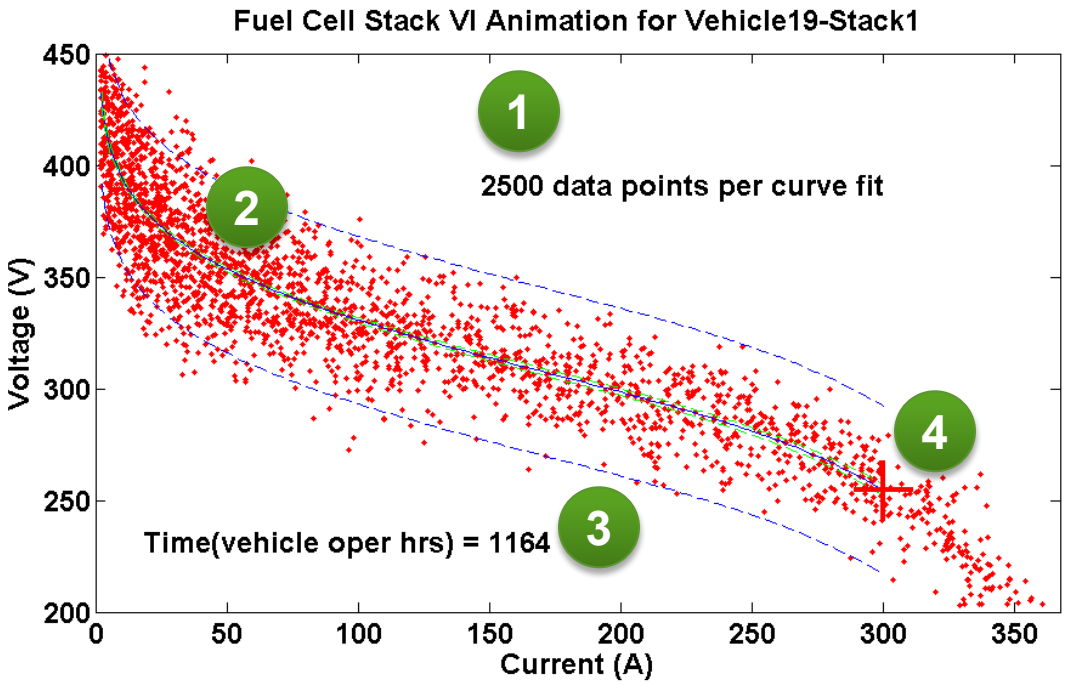
Lab Fuel Cell Processing – Approach and Accomplishment



Raw FC Data Processing – Approach

Store and process voltage and current data

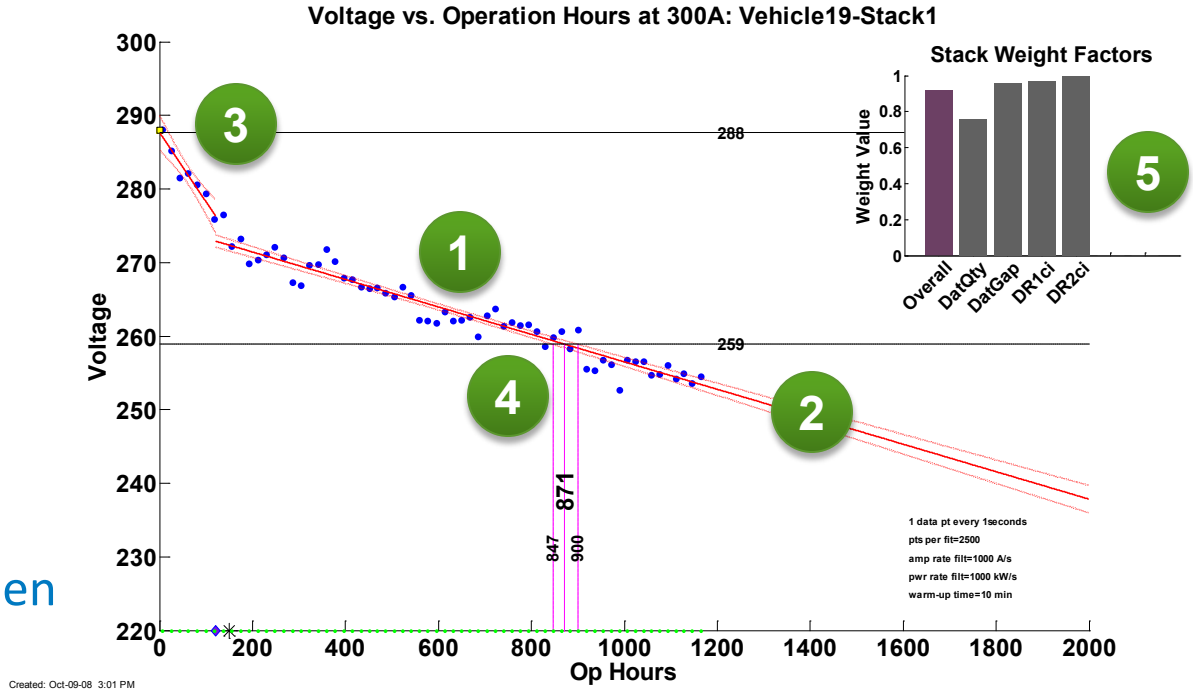
1. Segment fuel cell voltage and current data
2. Apply polarization fit
3. Record operation hour for segment
4. Record voltages from polarization fit at set currents



Processed Voltage Degradation Projections – Approach

Voltage versus operation hour

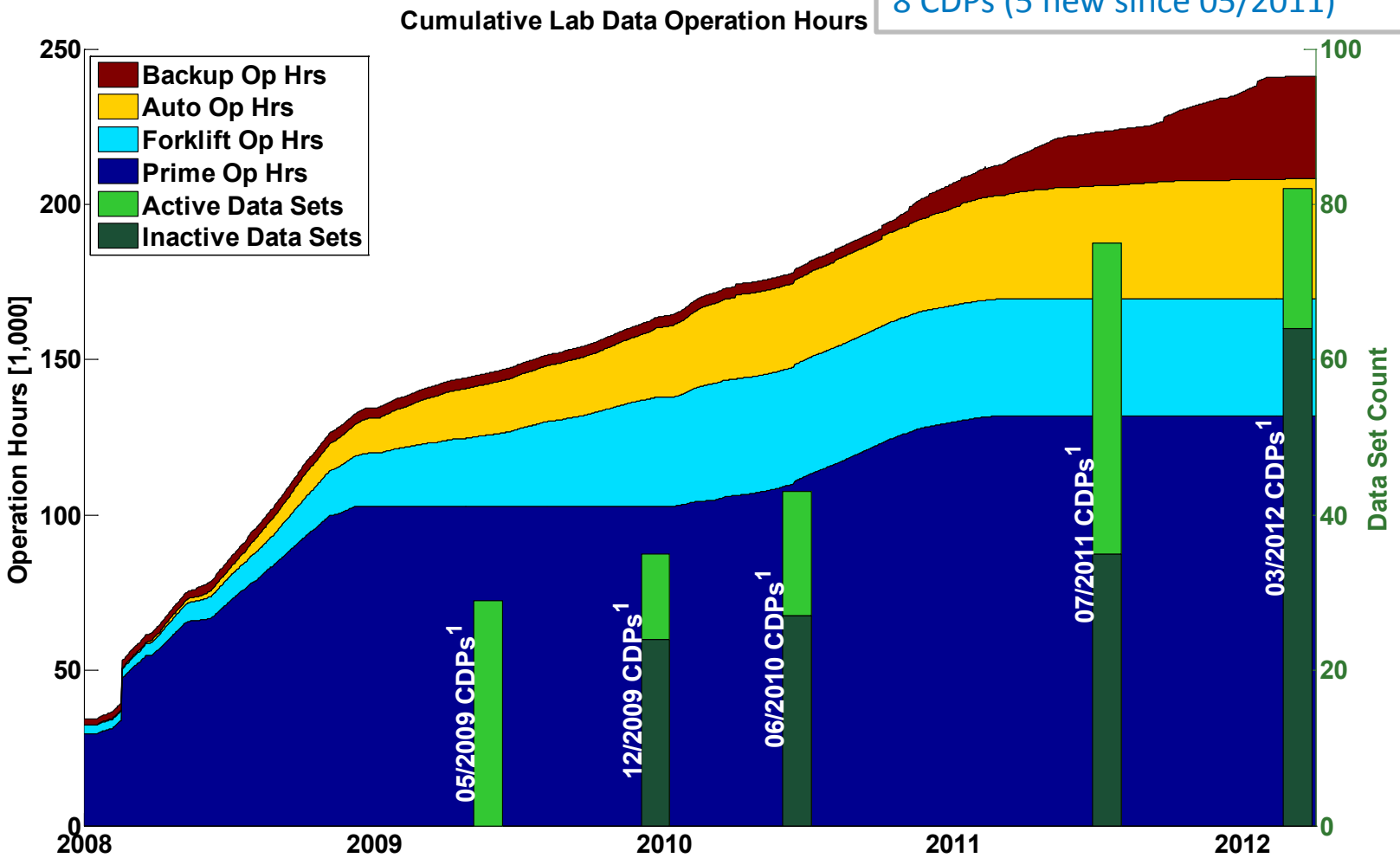
1. Plot polarization fit voltage at a specific current
2. Apply robust segmented linear fit (if trend suggests non-linear degradation trend)
3. Record fit y-intercept (nominal voltage drop)
4. Record operation hour when fit crosses 10% nominal voltage drop
5. Investigate fit quality



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

Data Set Count and Operation Hours – Accomplishment

04/2012 CDPs include
82 data sets analyzed, 78% retired
39 new data sets since 05/2011
8 CDPs (5 new since 05/2011)



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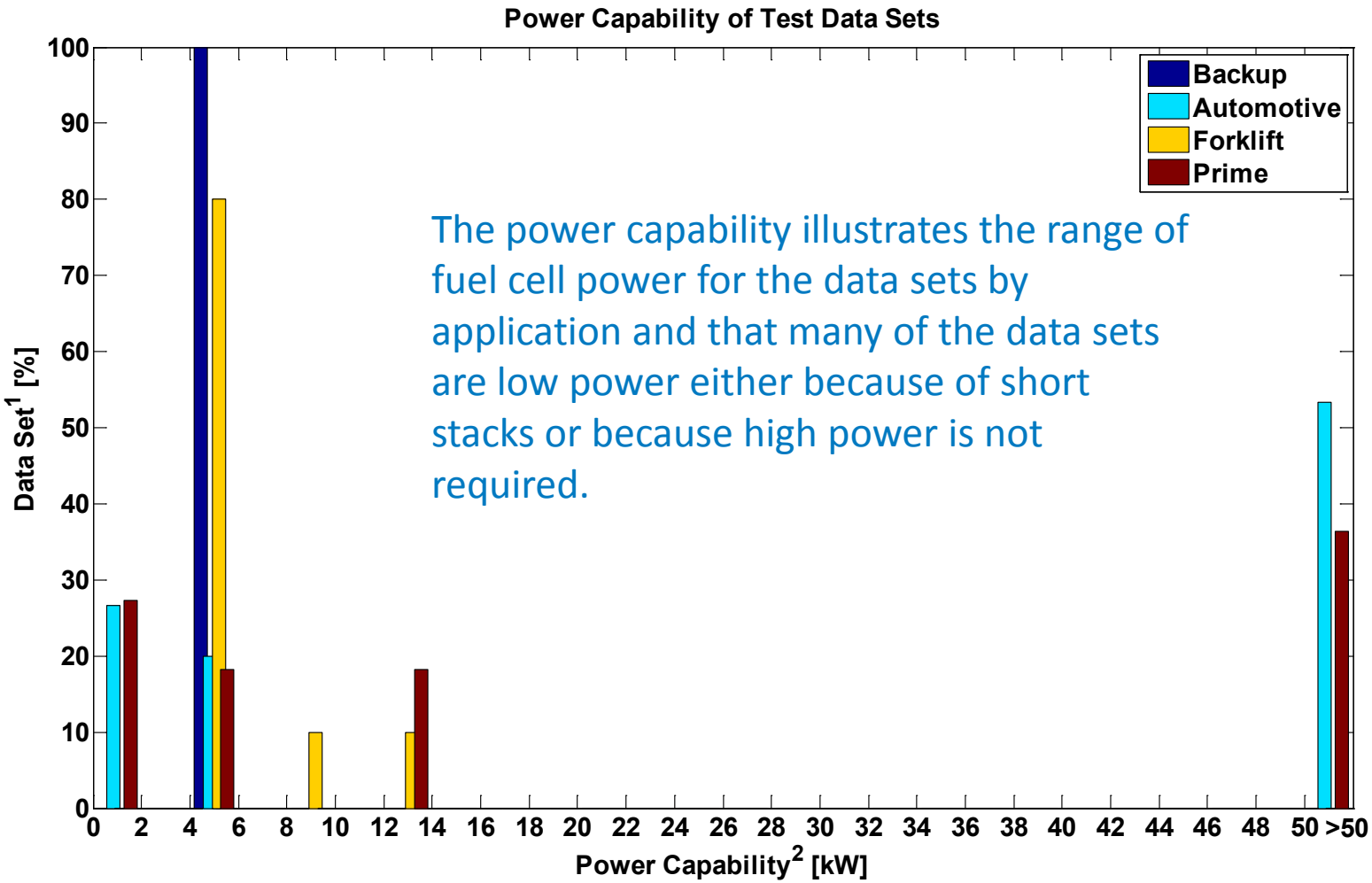
1) Data set count at publication of a CDP set - where a data set represents a short stack, full stack, or system test data.

Data Set Power Capability – Accomplishment



The power capability illustrates the range of fuel cell power for the data sets by application and that many of the data sets are low power either because of short stacks or because high power is not required.

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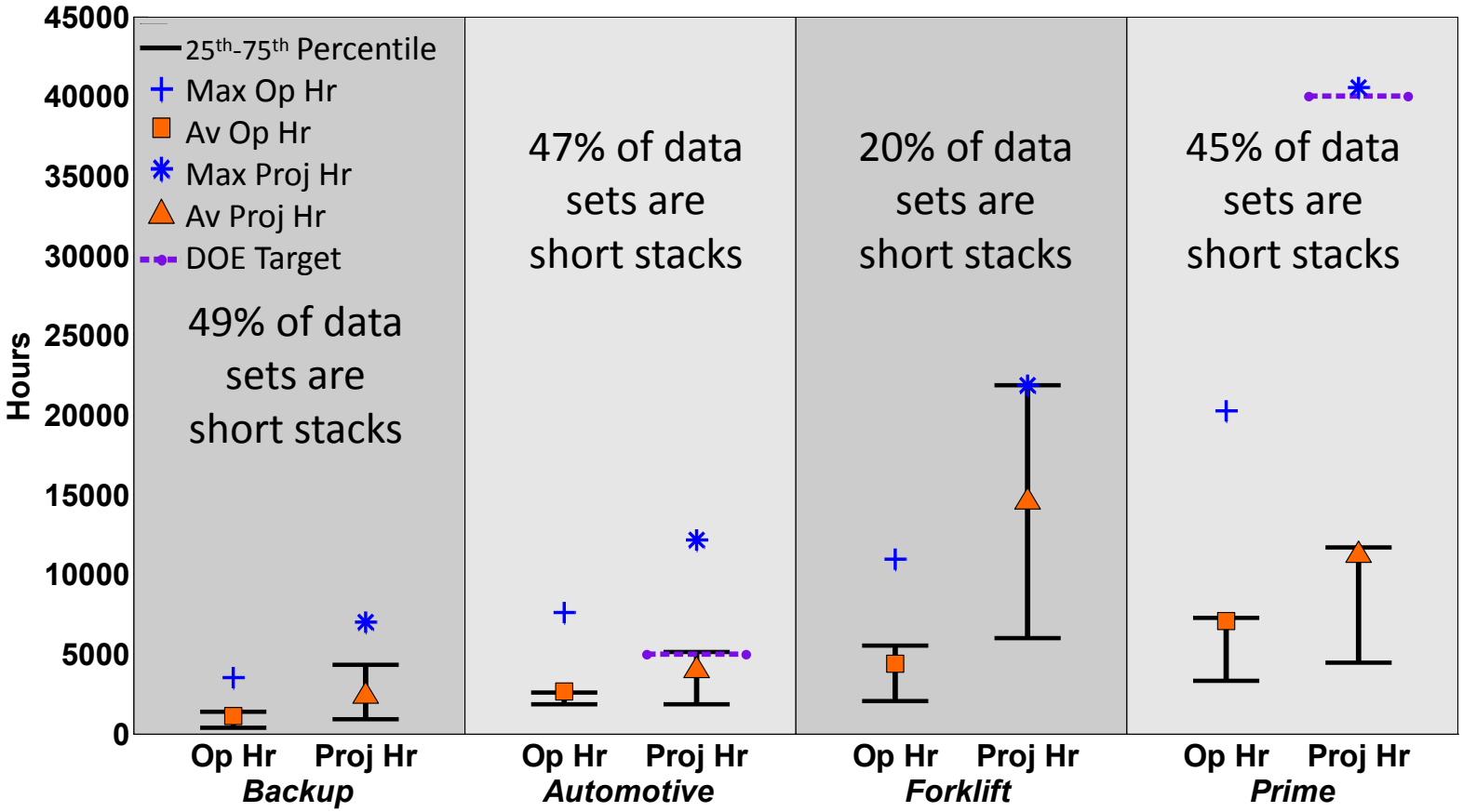
1) A data set represents a short stack, full stack, or system test data.
2) The power capability represents the maximum power for a data set, not the load profile or time at a power level.

Voltage Degradation Results by Application – Accomplishment

The average projected times to 10% voltage drop are **2,400**, **4,000**, **14,600**, and **11,200** for **backup power**, **automotive**, **forklift**, and **stationary** applications, respectively.



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 and includes 10 fuel cell developers.

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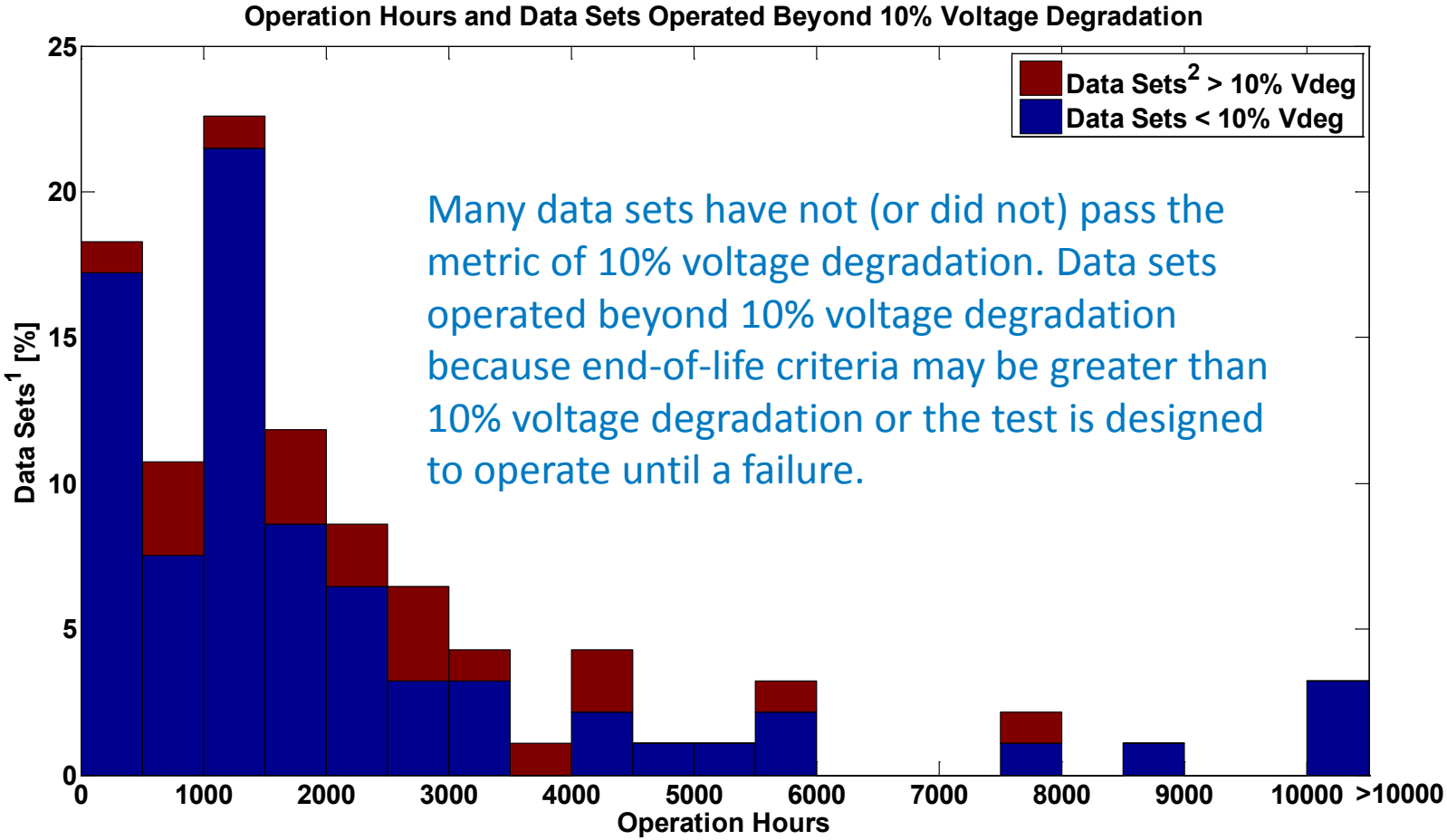
Data Set Operation Hours and Identification of Data Sets That Have Passed 10% Voltage Degradation – Accomplishment



Many data sets have not (or did not) pass the metric of 10% voltage degradation. Data sets operated beyond 10% voltage degradation because end-of-life criteria may be greater than 10% voltage degradation or the test is designed to operate until a failure.

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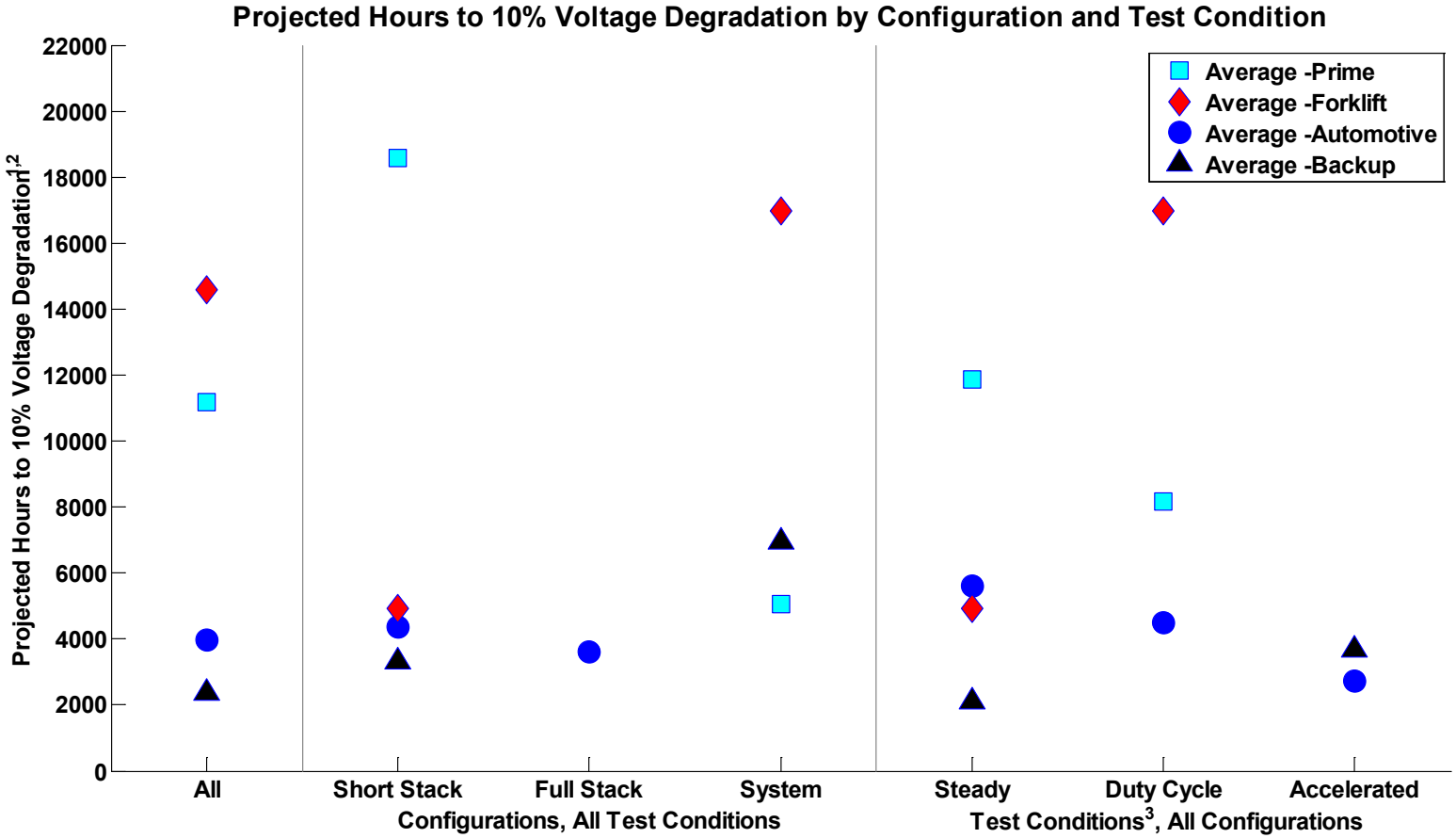
1) A data set represents a short stack, full stack, or system test data.
2) The DOE 10% voltage degradation metric is used for assessing voltage degradation; it may not be the same as end-of-life criteria and does not address catastrophic failures.

New since 05/2011

Voltage Degradation by Configuration and Test Condition – Accomplishment

The groups of configurations and test conditions highlight the impact of configuration and test condition on the projected time to 10% voltage degradation by 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.

Steady – little of 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

New since 05/2011

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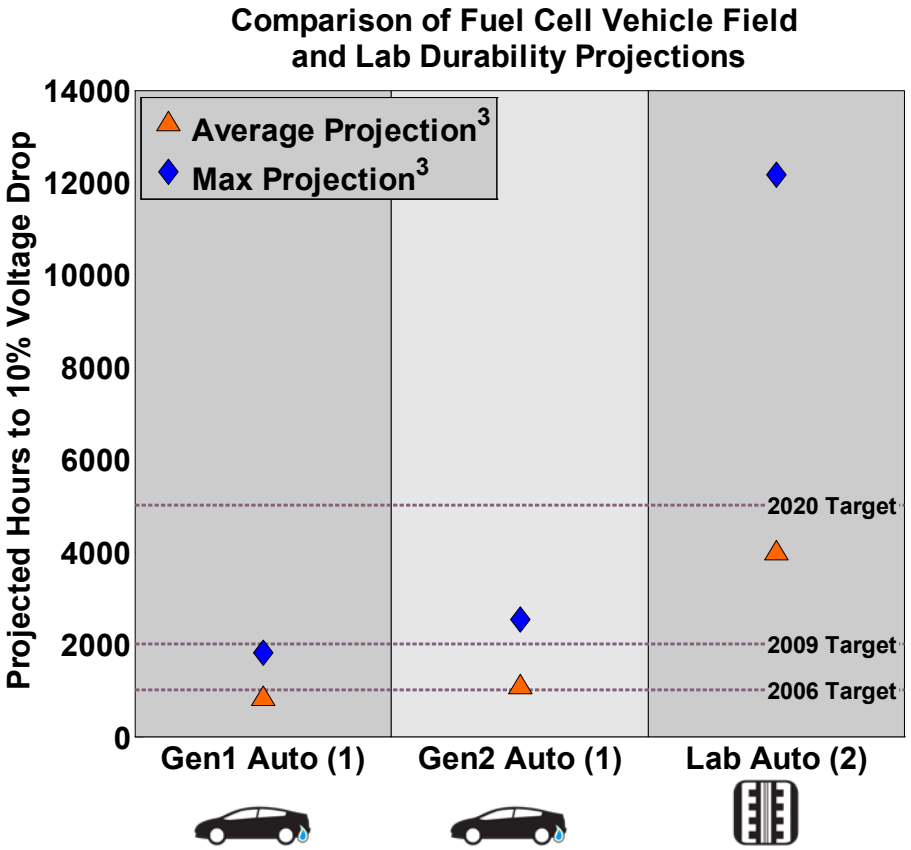
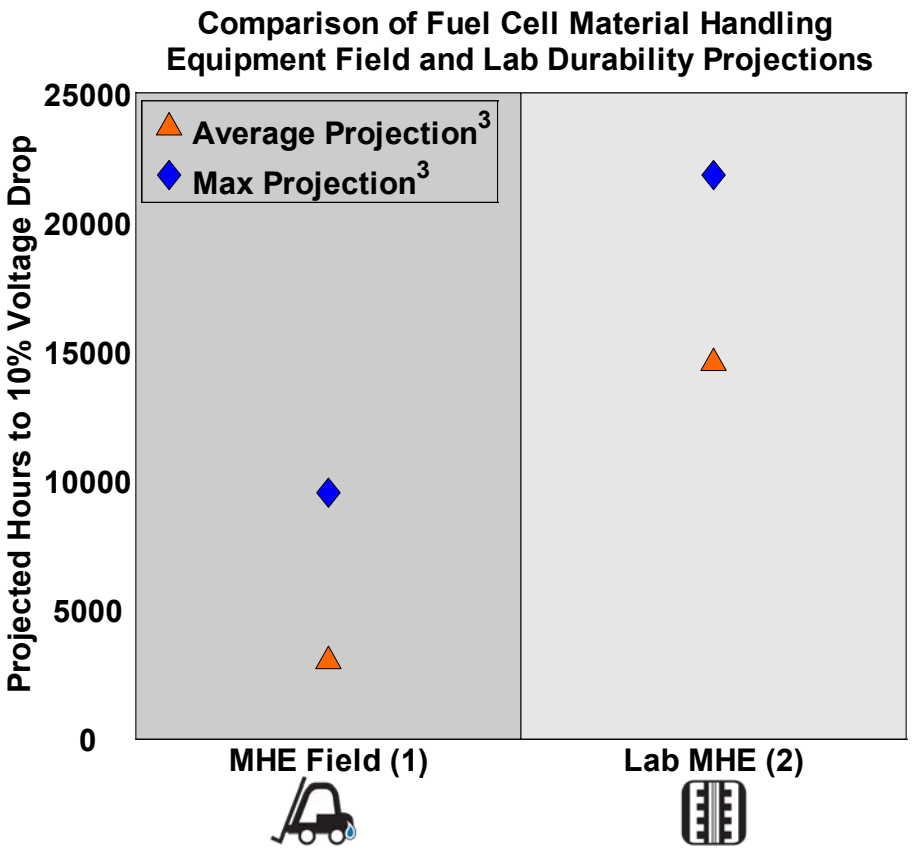
Lab and Field Voltage Degradation Comparisons – Accomplishment



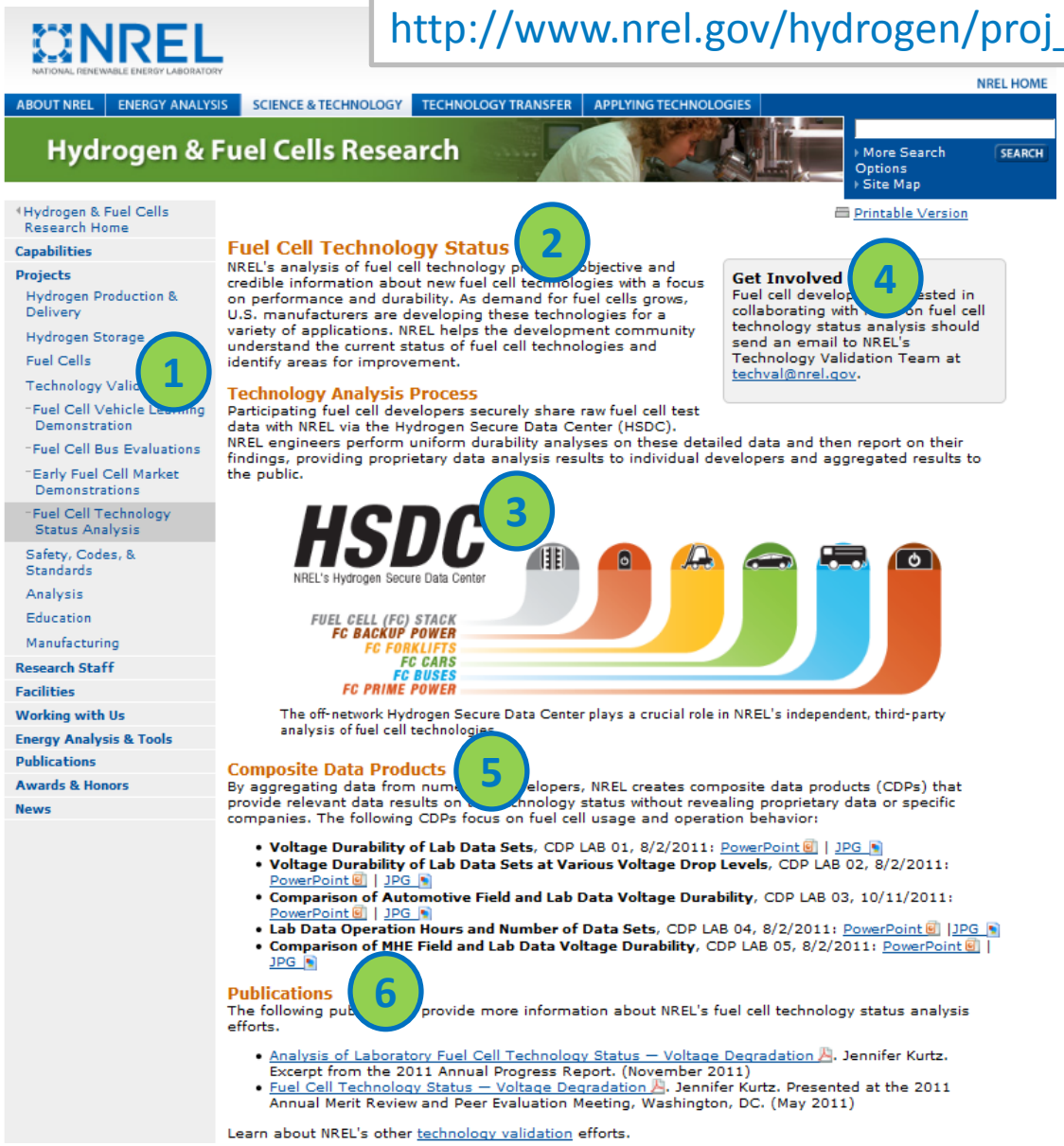


Comparisons in the automotive and material handling applications indicate there are **gaps between field and lab voltage durability performance**. Possible reasons include different data providers, technology generations, operating conditions, and test procedures. Additional comparisons to investigate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

Updated since 05/2011

Website for Fuel Cell Technology Status – Accomplishment

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



Fuel Cell Technology Status website

1. Included under technology validation
2. Provides a project overview
3. Link for more information about the HSDC
4. Contact link for collaboration
5. Composite data products
6. Publications

New since 05/2011

Collaborations

- **Working with multiple fuel cell developers**
  - 10 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, availability of 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 are not identified yet because of limited data sets by application category.
- **Gathering PEM and SOFC datasets**
- **Data sharing is 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 cultivating existing collaborations 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 protocol testing.
- 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).

Summary

***Relevance*:** Independent assessment of state-of-the-art fuel cell technology provides one location for fuel cell durability status from leading fuel cell developers with a uniform analysis and reporting method on a variety of proprietary data.

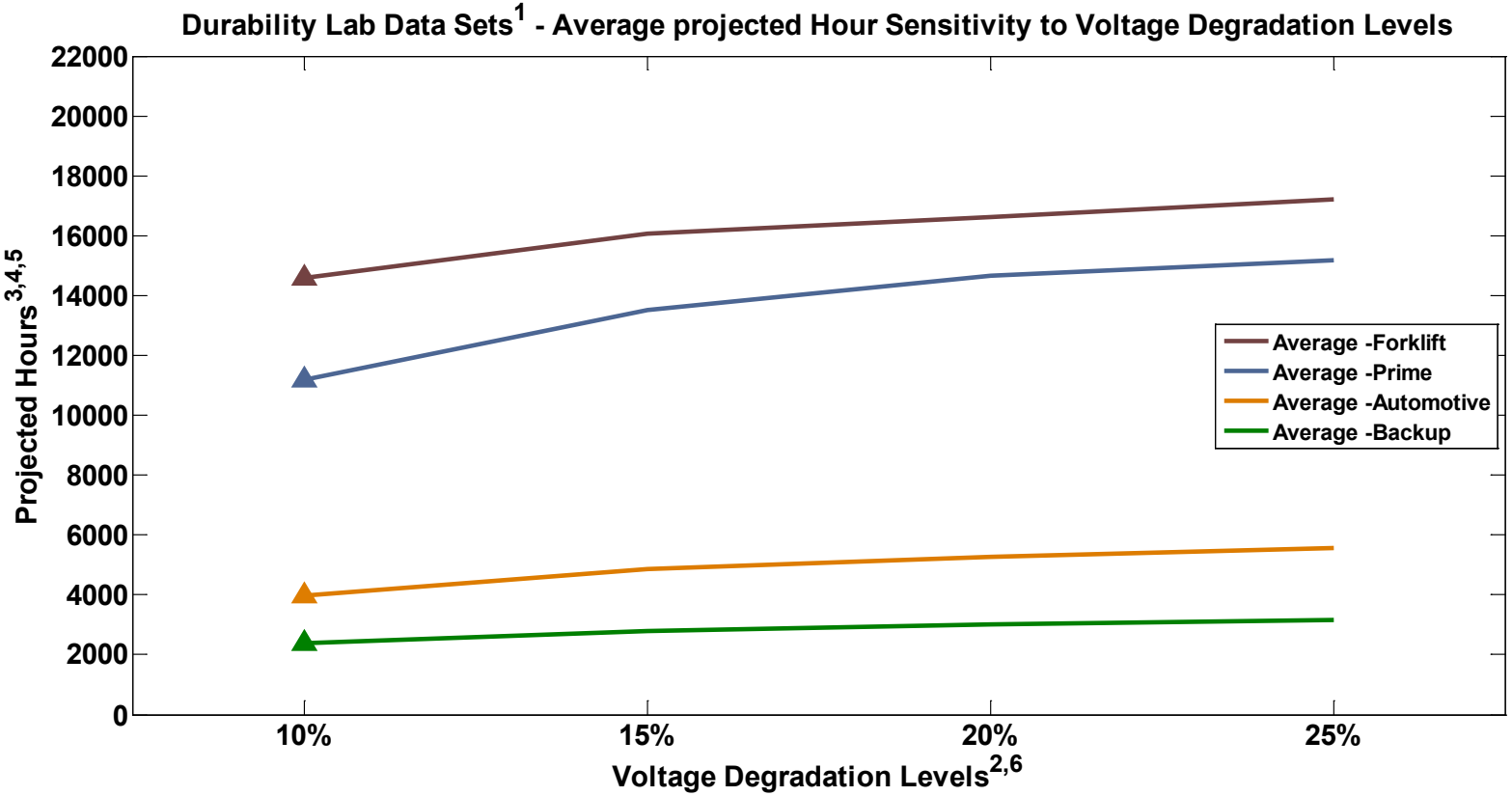
***Approach*:** Leverage capabilities established under other technology validation activities (NRELFAT) and industry collaborations.

***Accomplishments*:** Fourth annual results were updated for 4 applications and include new details based on data set configuration and test condition. The data are fully integrated into NRELFAT and an online interface provides information on the project, connection for interested collaborators, and all publications.

***Collaborations and Future Work*:** Continue expanding analyzed data sets, included fuel cell developers, and results.

Technical Backup

Durability Lab Data Projection Sensitivity to Voltage Degradation Levels



(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 2011.
(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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Reviewer Only

Response to Reviewer's Comments

"Data conditions may vary and add to uncertainty."

- New result (CDP-Lab-08) is the first result to group data by configuration and test condition.
- Additional detail breakdowns are expected as the project continues.

"The project should not lump together different technology types (i.e., PEM fuel cells and SOFCs). A linear decay assumption for projected life may not be sufficient for all stacks or systems."

- There are not yet enough data sets of different fuel cell types to separate out the results while maintaining data provider anonymity on the proprietary data, but getting enough and more fuel cell types included is a goal of this project.

"Execution relies on data, and developers gain no utility from comparing data at widely different conditions."

- Voltage degradation analysis is designed to accommodate many different types of data and study durability with a common method.
- Developer benefits include detailed individual fuel cell degradation analysis results, benchmark their systems with the rest of the data sets, and participation in the independent assessment and reporting of state-of-the-art fuel cell technology.