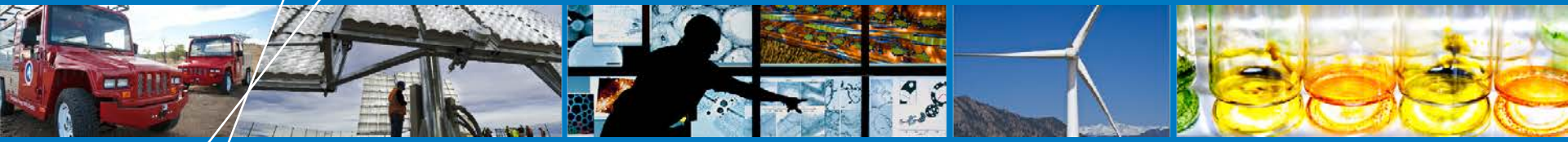
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Fuel Cell Technology Status
Voltage Degradation



2013 DOE Annual Merit Review

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May 14, 2013

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 2013*

Percent complete: On-going

Barriers

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

Budget

Total project funding

DOE share: $450k

Contractor share: $0

Funding received in FY13: $150k

Funding received FY09–12: $300k

Partners

68 fuel cell developers contacted

15 fuel cell developers shared data

*Project continuation and direction determined annually by DOE

Relevance: Objectives

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
- System price benchmarking

All data is supplied voluntarily and published results are updated annually.

Approach: Analysis and Reporting of Real-World Operation Data

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





Internal analysis completed annually in HSDC

NREL's Hydrogen Secure Data Center

Results

DDPs

Confidential

Public

CDPs

Detailed Data Products (DDPs)

- Individual data analyses
- Identify individual contribution to CDPs
- Shared once a year only with the partner who supplied the data[1]

Composite Data Products (CDPs)

- Aggregated data across multiple systems, sites, and teams
- Publish analysis results once a year without revealing proprietary data[2]

1) Data exchange may happen more frequently based on data, analysis, and collaboration
2) Results published via NREL technology validation website, conferences, and reports (http://www.nrel.gov/hydrogen/proj_learning_demo.html)

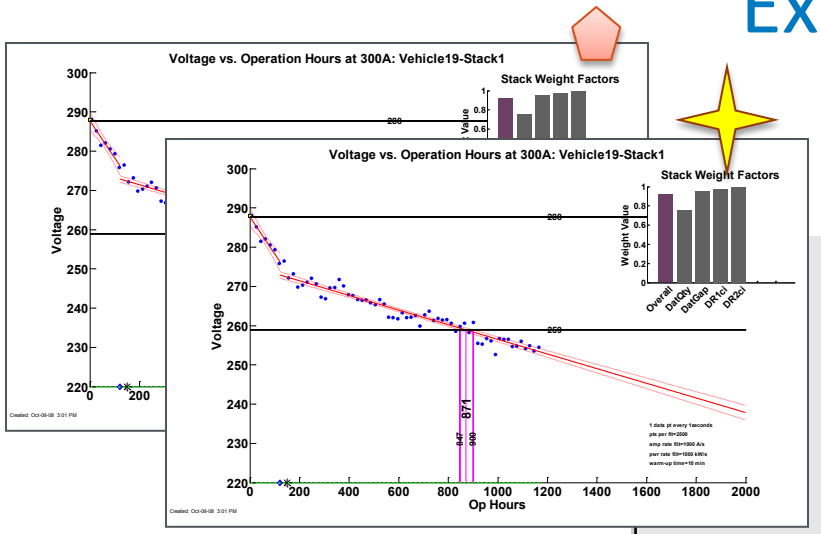
CDP and DDP Schedule

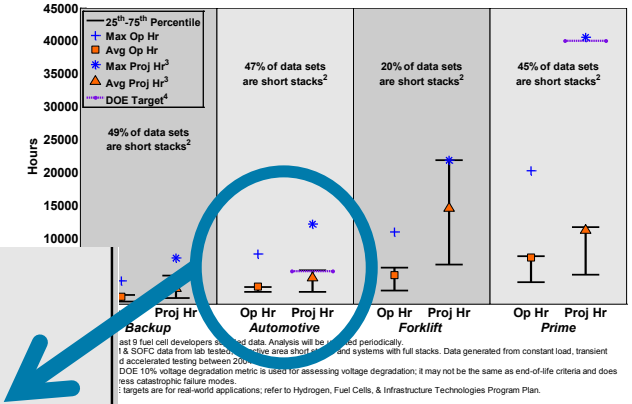
Data Process & Analysis

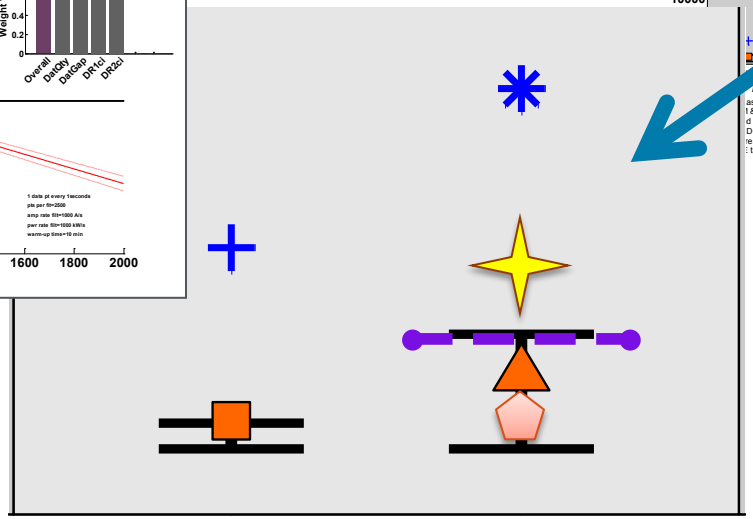
Example Data Results (if needed) → Draft CDPs → Initial Review (~1 weeks) → Final Draft CDPs (< 1 week) → Final Review (< 1 week) → Finalized CDPs (< 1 week)

(~4 weeks excluding data processing and analysis)

Example DDPs







Op Hr Proj Hr

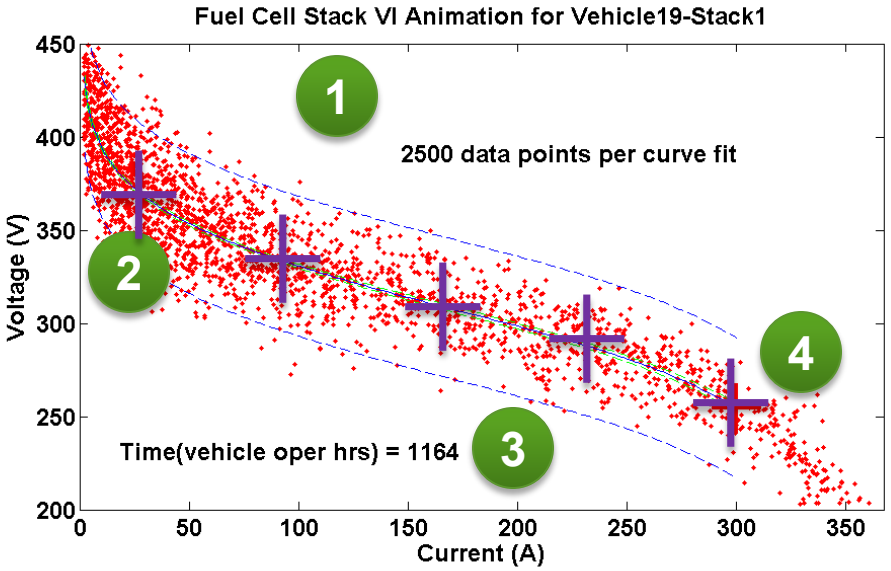
Automotive

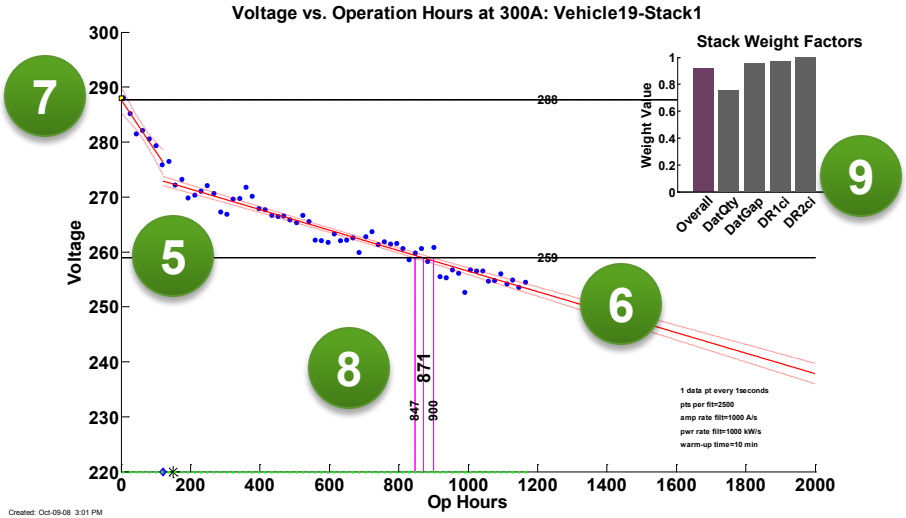
Sample Data Set 1

Sample Data Set 2

Approach: Raw FC Data Processing Example Data

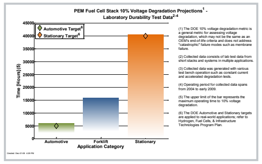
1. Segment fuel cell voltage and current data
2. Apply polarization fit
3. Record operation hour for segment
4. Record voltages from polarization fit at set currents
5. Plot polarization fit voltage at a specific current
6. Apply robust segmented linear fit (if trend suggests non-linear degradation trend)
7. Record fit y-intercept (nominal voltage drop)
8. Record operation hour when fit crosses 10% nominal voltage drop
9. Investigate fit quality



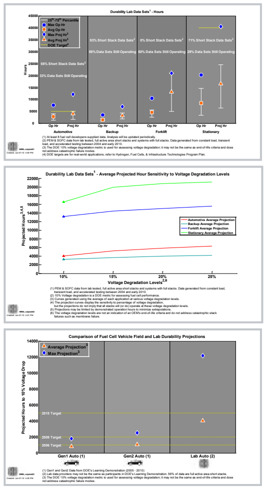


Accomplishment: Annual Update Completed

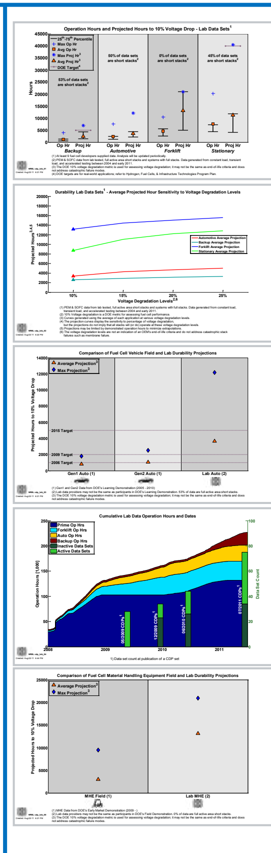
FY09



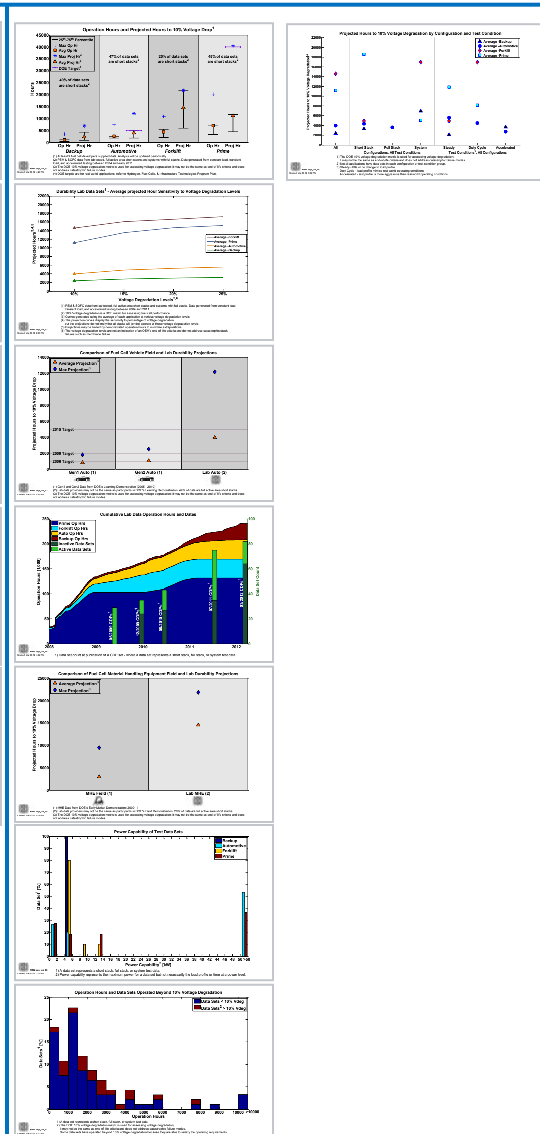
FY10



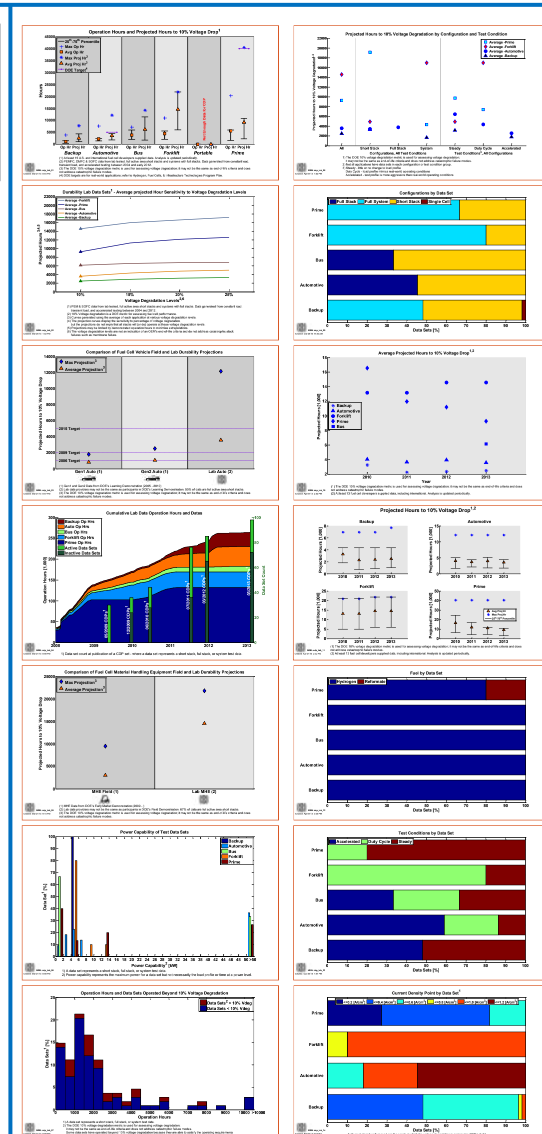
FY11



FY12



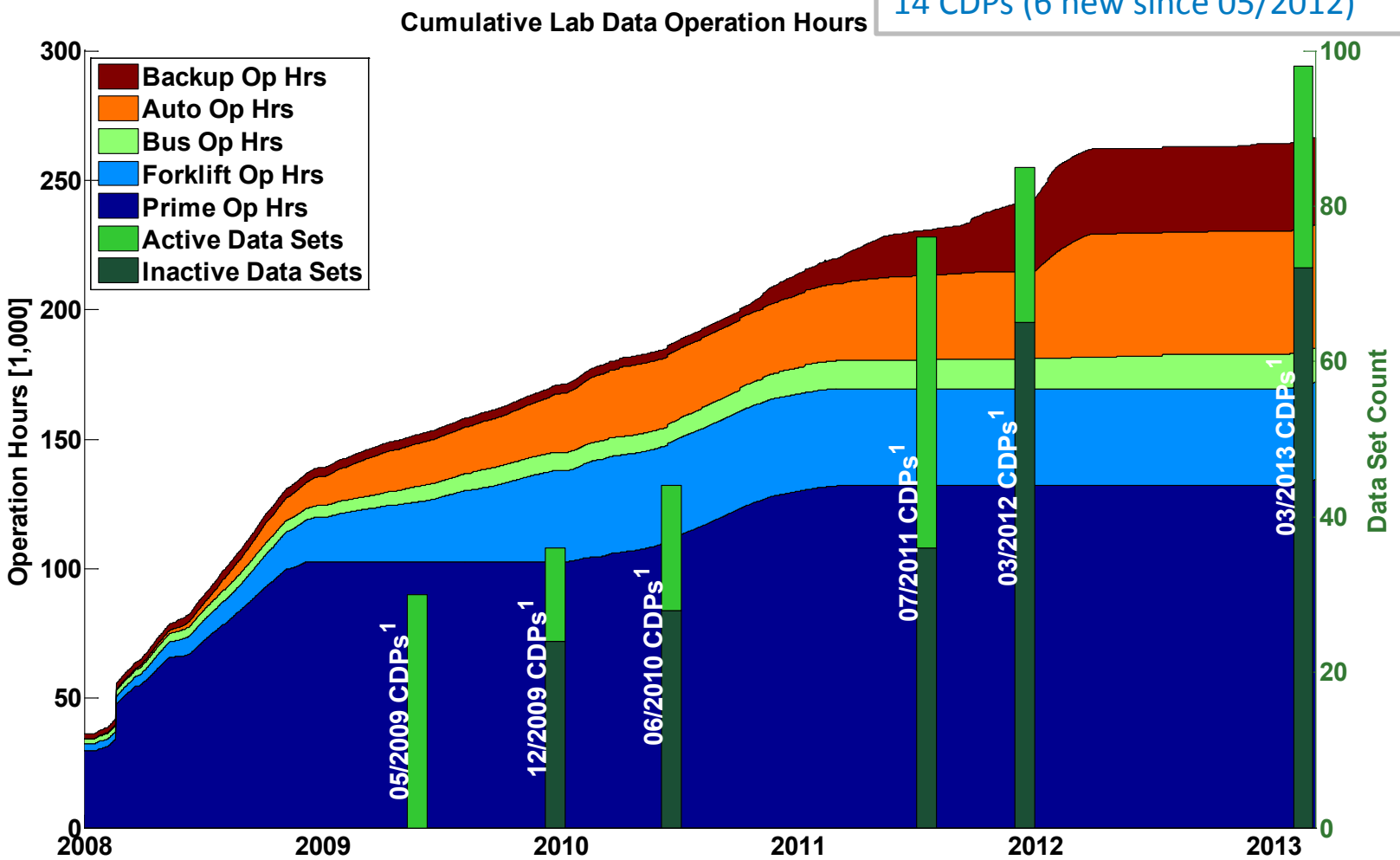
FY13



The current analysis set is the 5th annual update. The number of data sets, participants, and results have increased each year.

Accomplishments: Data Set Count and Operation Hours

04/2013 CDPs include
98 data sets analyzed, 78% retired
16 new data sets since 05/2012
14 CDPs (6 new since 05/2012)



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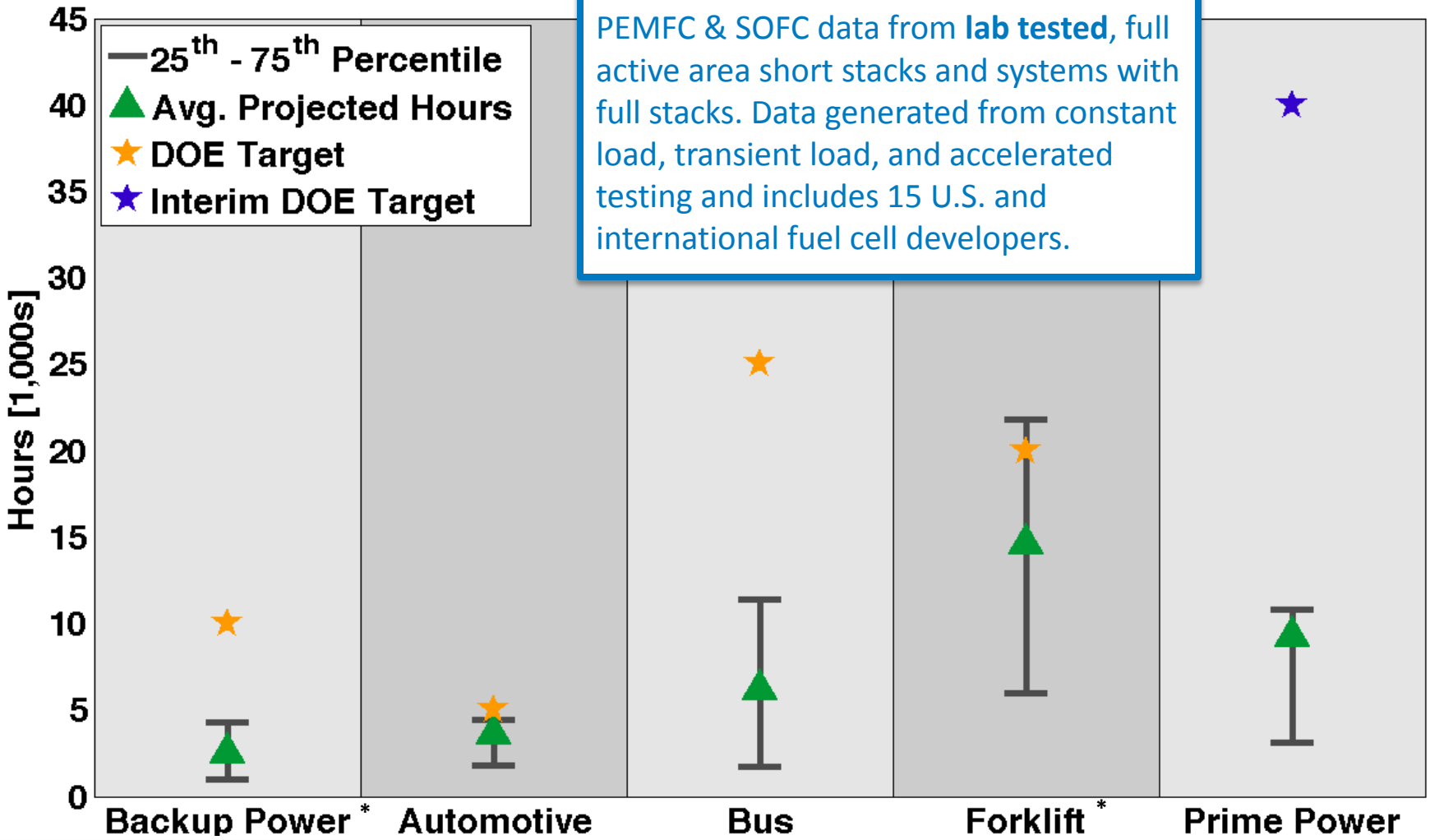
1) Data set count at publication of a CDP set - where a data set represents a short stack, full stack, or system test data.

Accomplishments: Voltage Degradation Results by Application

The average projected times to 10% voltage drop are **2,500**, **3,600**, **6,200**, **14,600**, and **9,300** for **backup power**, **automotive**, **bus**, **forklift**, and **stationary** applications, respectively.

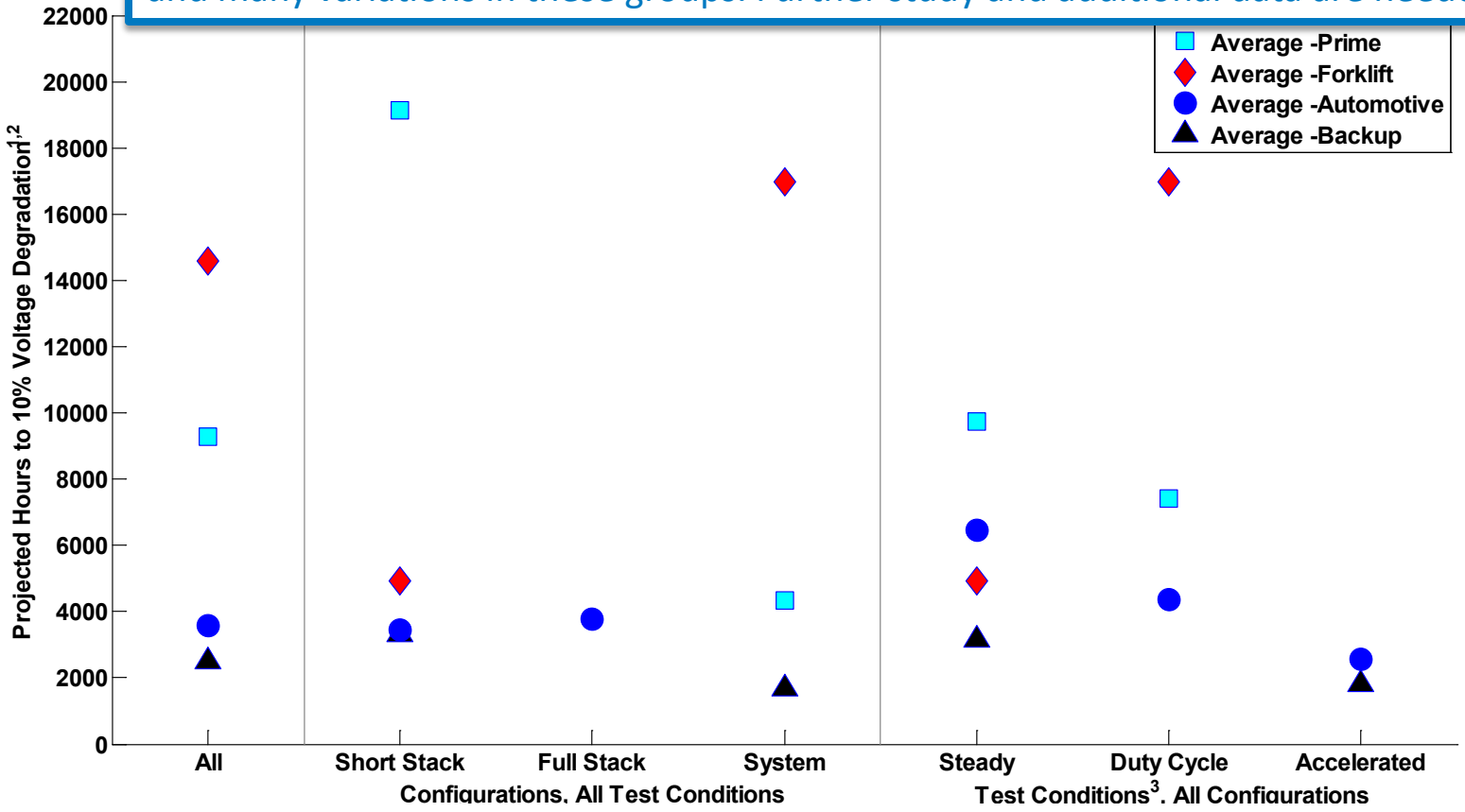


PEMFC & SOFC data from **lab tested**, full active area short stacks and systems with full stacks. Data generated from constant load, transient load, and accelerated testing and includes 15 U.S. and international fuel cell developers.

** DOE Targets Under Review*

Accomplishments: Voltage Degradation by Configuration and Test Condition

Grouping by configuration and test condition is important because of influences on degradation projects. Conclusions are still difficult to identify because of limited data and many variations in these groups. Further study and additional data are needed.



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

Updated since 05/2012

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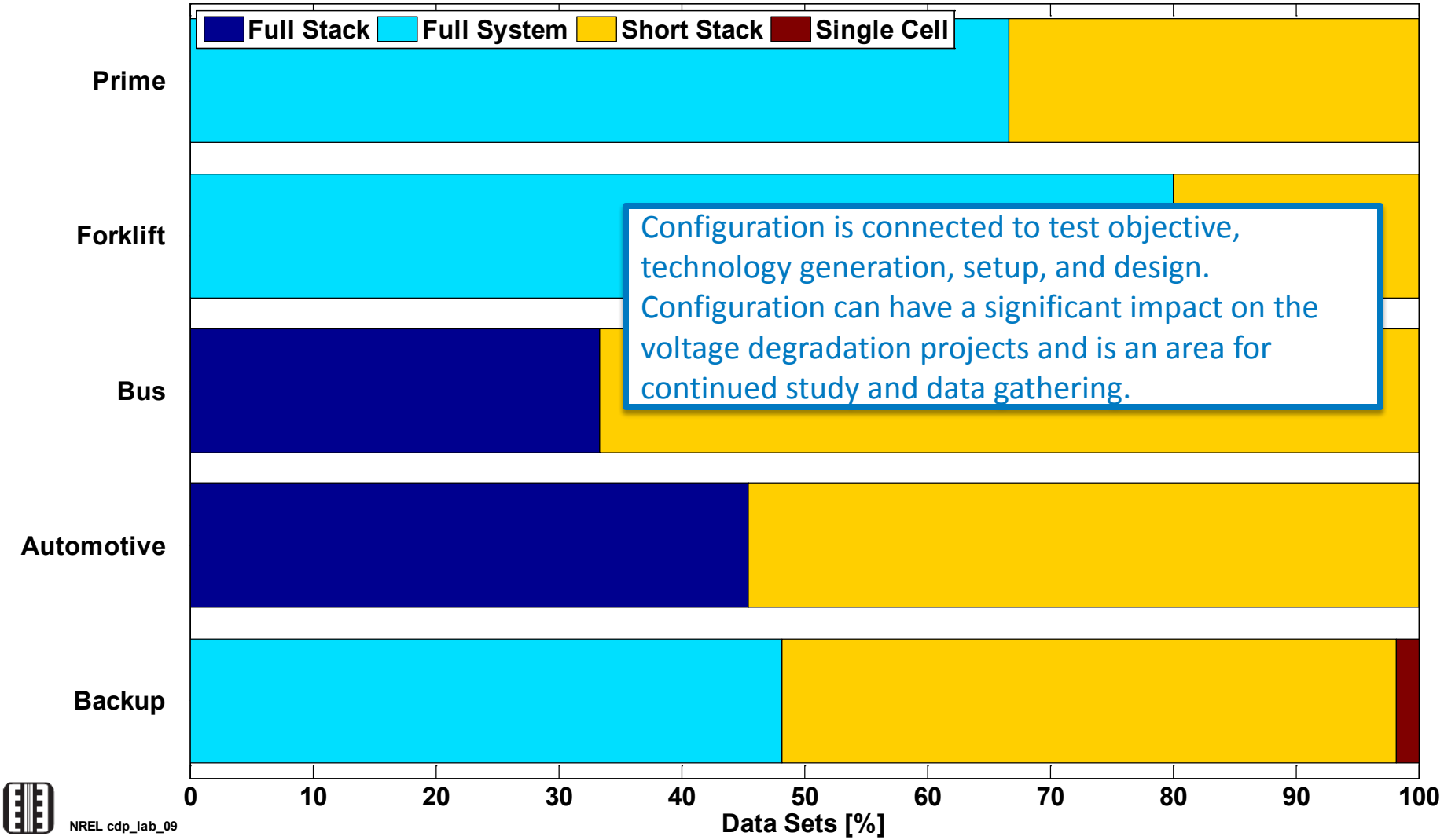
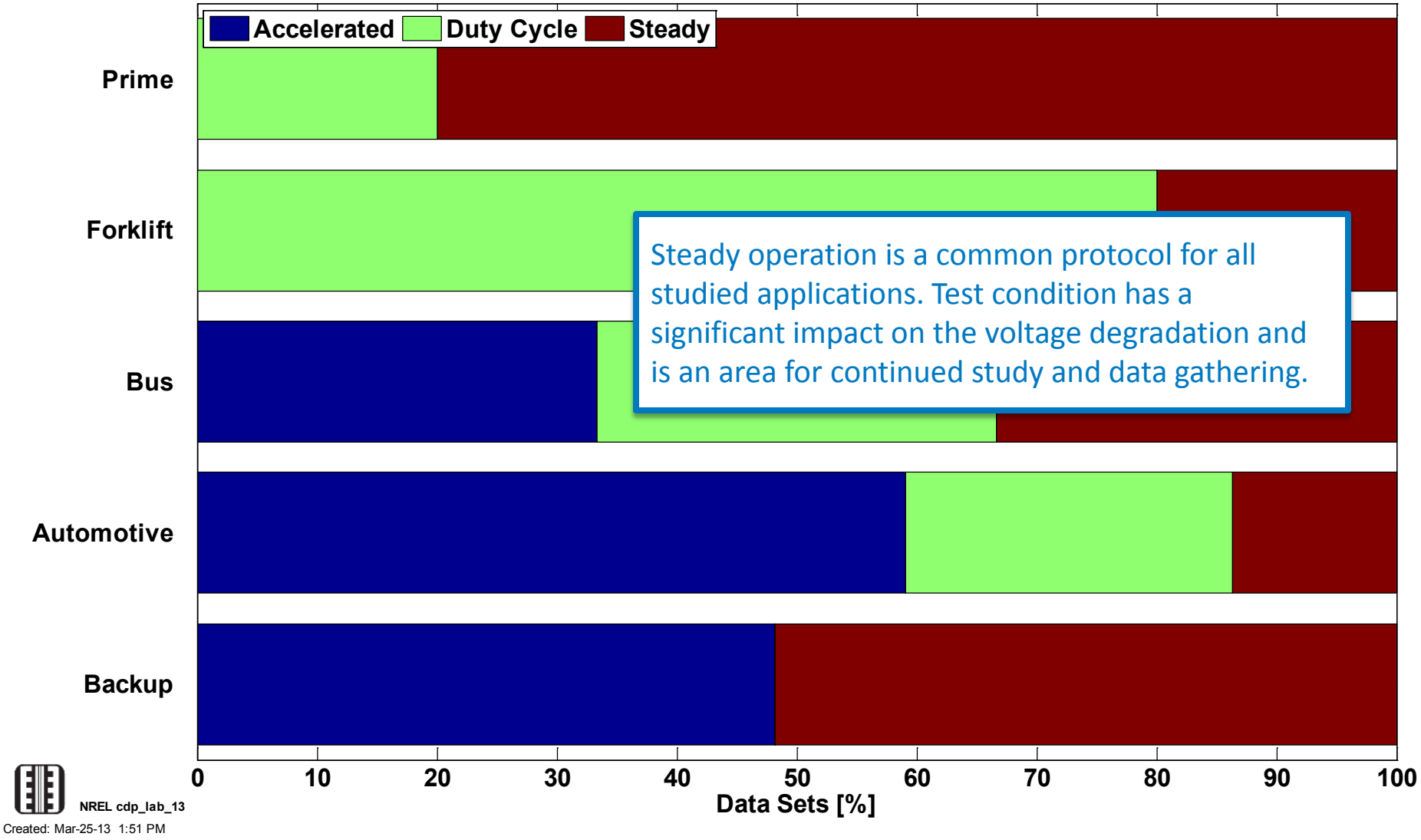
Accomplishments: Breakdown of Data Set Configuration Used for Voltage Degradation Results



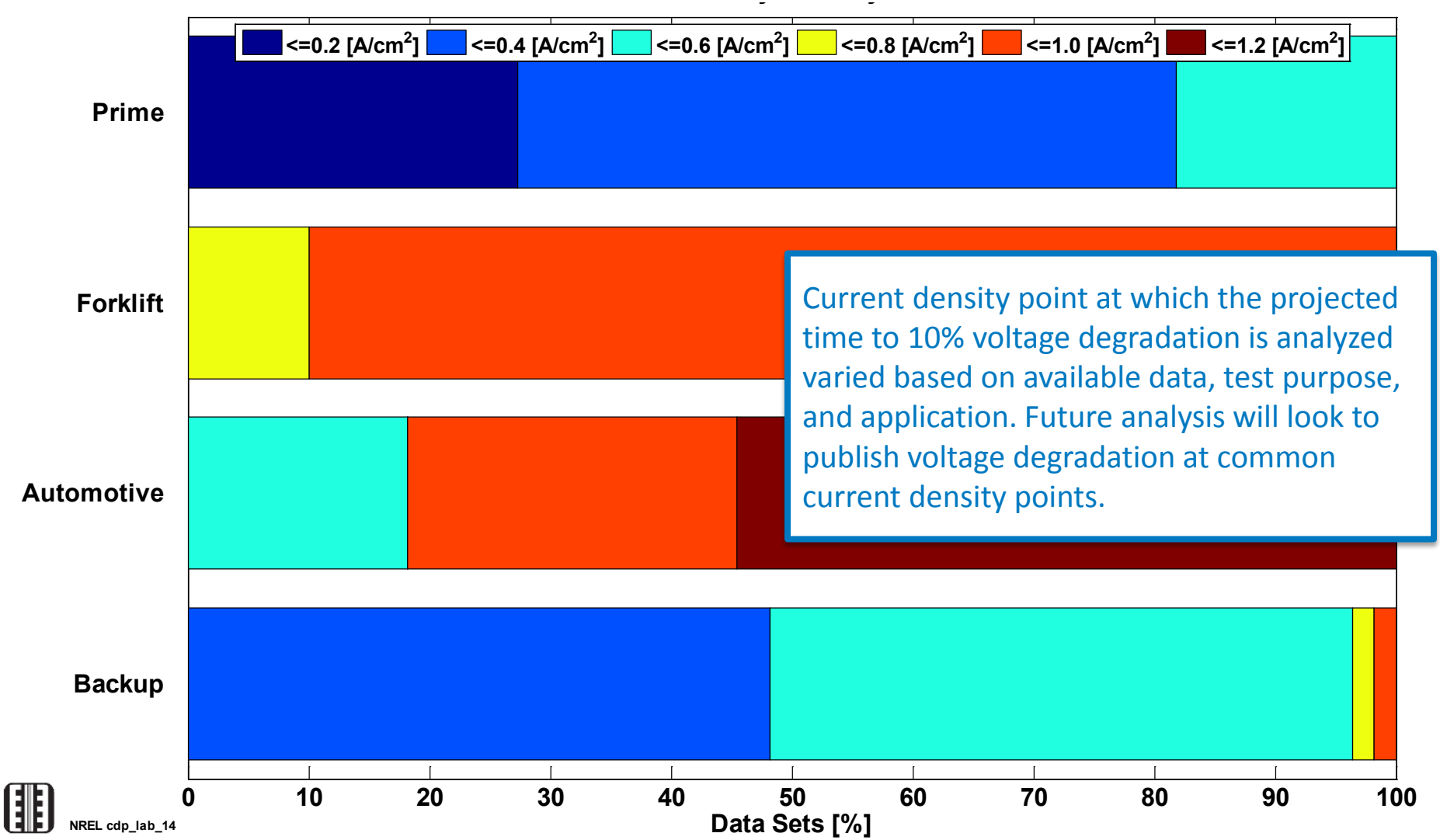
Configuration is connected to test objective, technology generation, setup, and design. Configuration can have a significant impact on the voltage degradation projects and is an area for continued study and data gathering.

Accomplishments: Breakdown of Data Set Test Conditions Used for Voltage Degradation Results



Steady operation is a common protocol for all studied applications. Test condition has a significant impact on the voltage degradation and is an area for continued study and data gathering.

Accomplishments: Breakdown of Current Densities Used for Voltage Degradation Results



Current density point at which the projected time to 10% voltage degradation is analyzed varied based on available data, test purpose, and application. Future analysis will look to publish voltage degradation at common current density points.

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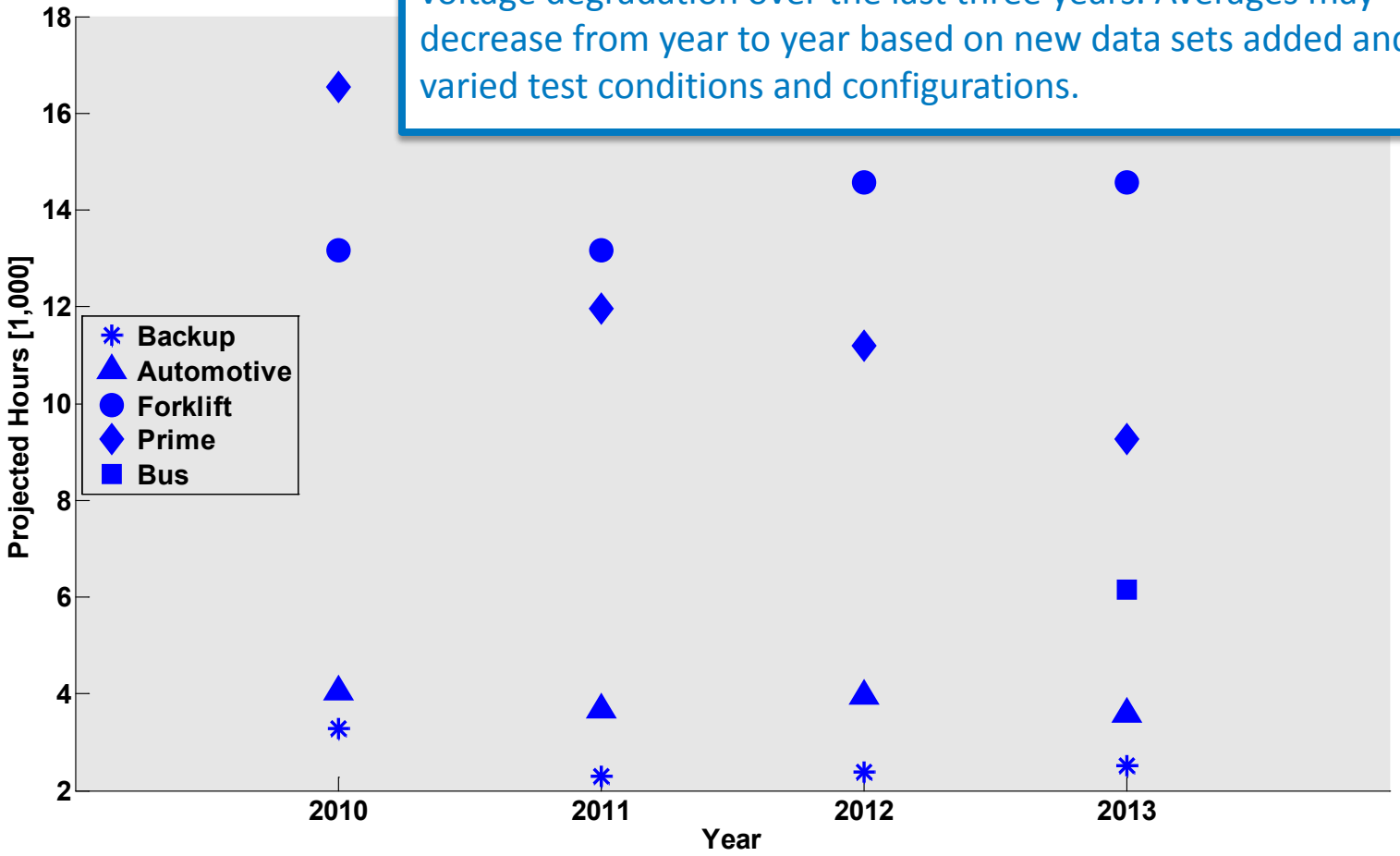
New since 05/2012

Accomplishments: Average Projected Hours to 10% Voltage Degradation by Year

Most applications have seen an increase in average time to 10% voltage degradation over the last three years. Averages may decrease from year to year based on new data sets added and varied test conditions and configurations.



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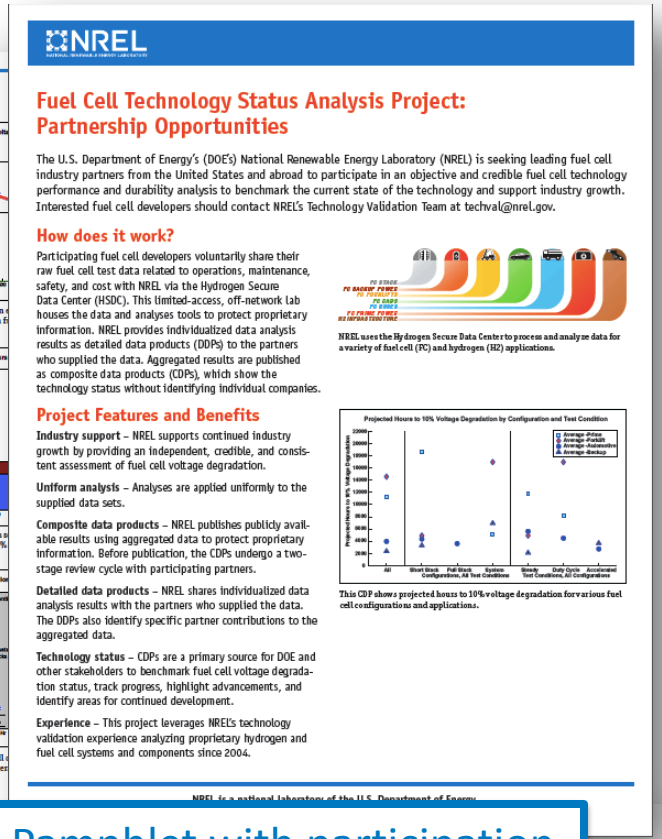
(1) The DOE 10% voltage degradation metric is used for assessing voltage degradation; it may not be the same as end-of-life criteria and does not address catastrophic failure modes.
(2) At least 13 fuel cell developers supplied data, including international. Analysis is updated periodically.

Accomplishments: Project Information Package


NREL

Fuel Cell Technology Status Analysis Project: Partnership Opportunities

The U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) is seeking leading fuel cell industry partners from the United States and abroad to participate in an objective and credible fuel cell technology performance and durability analysis to benchmark the current state of the technology and support industry growth. Interested fuel cell developers should contact NREL's Technology Validation Team at techval@nrel.gov.

How does it work?

Participating fuel cell developers voluntarily share their raw fuel cell test data related to operations, maintenance, safety, and cost with NREL via the Hydrogen Secure Data Center (HSDC). This limited-access, off-network lab houses the data and analyses tools to protect proprietary information. NREL provides individualized data analysis results as detailed data products (DDPs) to the partners who supplied the data. Aggregated results are published as composite data products (CDPs), which show the technology status without identifying individual companies.

NREL uses the Hydrogen Secure Data Center to process and analyze data for a variety of fuel cell (FC) and hydrogen (HZ) applications.

Project Features and Benefits

Industry support – NREL supports continued industry growth by providing an independent, credible, and consistent assessment of fuel cell voltage degradation.

Uniform analysis – Analyses are applied uniformly to the supplied data sets.

Composite data products – NREL publishes publicly available results using aggregated data to protect proprietary information. Before publication, the CDPs undergo a two-stage review cycle with participating partners.

Detailed data products – NREL shares individualized data analysis results with the partners who supplied the data. The DDPs also identify specific partner contributions to the aggregated data.

Technology status – CDPs are a primary source for DOE and other stakeholders to benchmark fuel cell voltage degradation status, track progress, highlight advancements, and identify areas for continued development.

Experience – This project leverages NREL's technology validation experience analyzing proprietary hydrogen and fuel cell systems and components since 2004.

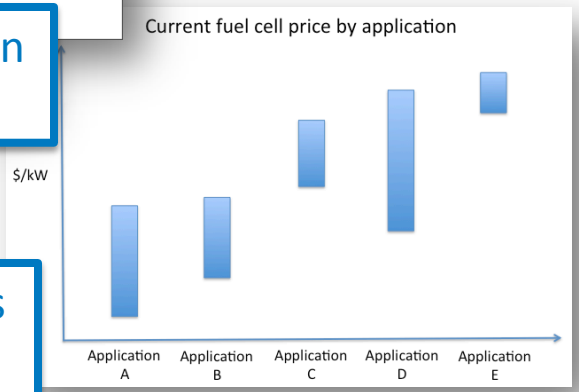
Projected Hours to 10% Voltage Degradation by Configuration and Test Condition

This CDP shows projected hours to 10% voltage degradation for various fuel cell configurations and applications.

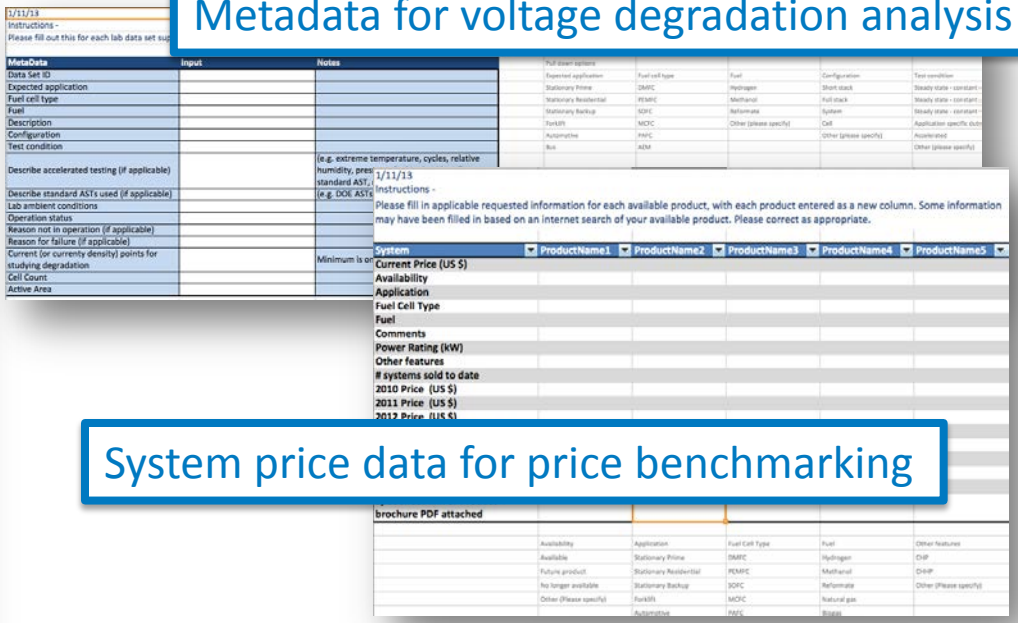
Pamphlet with participation details and benefits

New since 05/2012

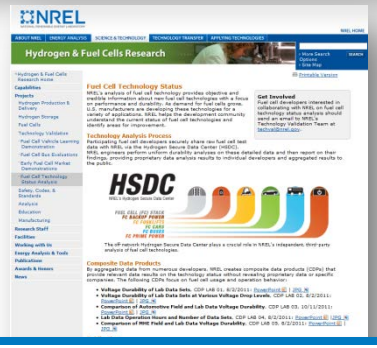
Example CDP results for price data



Metadata for voltage degradation analysis



System price data for price benchmarking



Website with published results and presentations

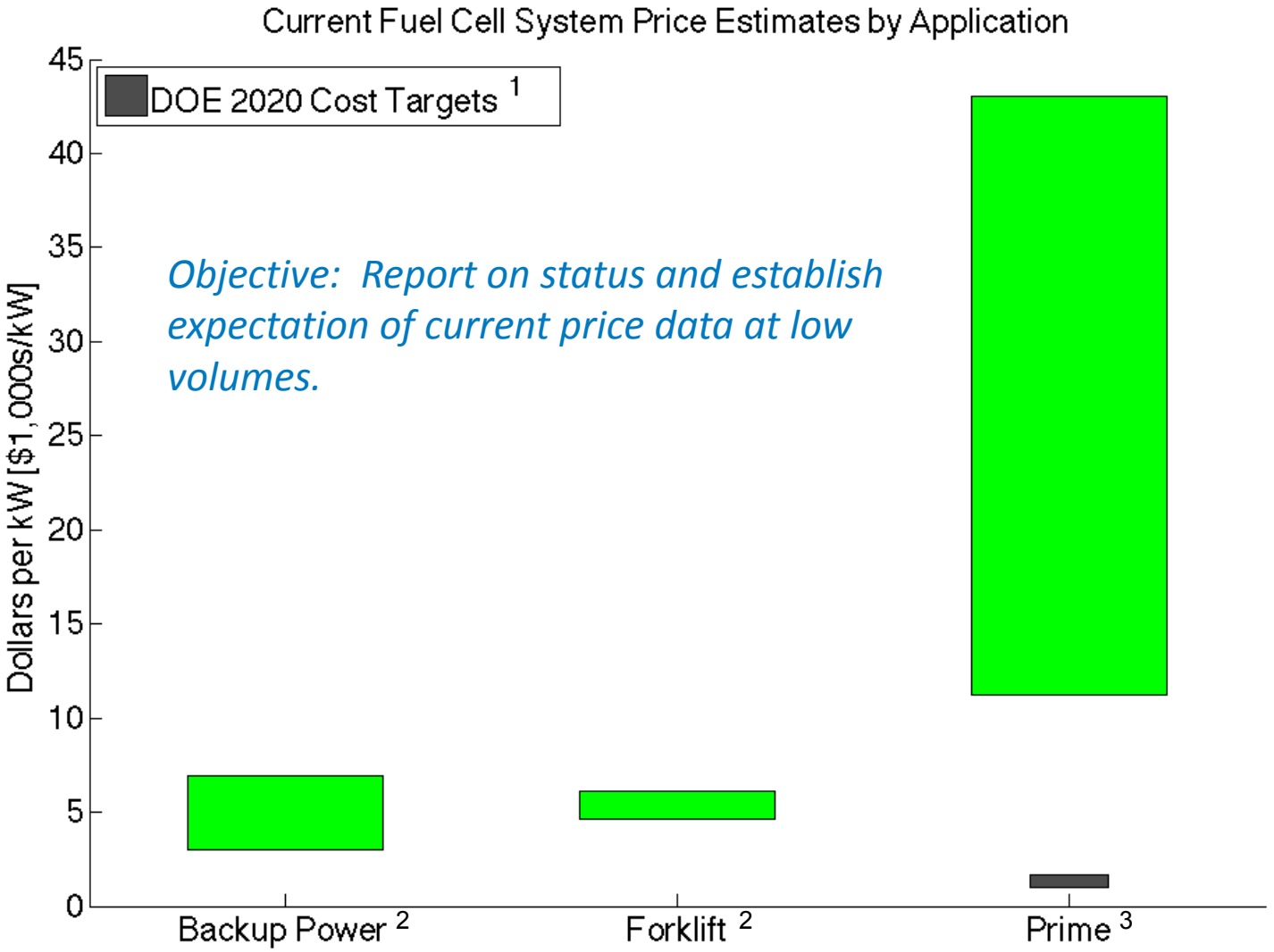
Collaborations

- **Working with multiple fuel cell developers**
  - 15 of 68 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 PEMFC, DMFC, and SOFC datasets**
- **Data sharing is completely voluntary**
- **Participation in DOE durability working group and presentation of status to fuel cell tech team**
- **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

- Publish report on durability analysis method
- Add price information to the project collaboration pamphlet
- Continue cultivating existing collaborations and developing new collaborations with fuel cell developers.
- Next planned update is 03/2014
- Possibilities that may be included in the next update are:
  - Expand results aimed at improving data comparability and statistical confidence
  - Voltage degradation at common and multiple current density points and power points
  - Price benchmarking
  - Results by testing protocol
  - PEM, SOFC, & DMFC
  - Single cell
  - Investigate other aging parameters for fuel cell durability (e.g. start/stops, soak time)

Future Work: Price Data



Objective: Report on status and establish expectation of current price data at low volumes.

1) DOE cost targets for 1 – 10 kW residential (http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/fuel_cells.pdf)
2) Data estimate source is from ARRA installations in 2012 dollars.
3) Data estimate source is from public information in 2012 dollars for US and international companies and multiple fuel cell types (≤5kW).

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*:** Fifth annual results were updated for 5 applications plus started portable and include new details based on metadata and durability trends over time and international developers. The data are fully integrated into NRELFAT and an online interface provides information on the project, connection for interested collaborators, and all publications. Improved project information material for details and benefits of participation.

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

Technical Backup

Relevance - Benefits of Lab Fuel Cell Durability Analysis

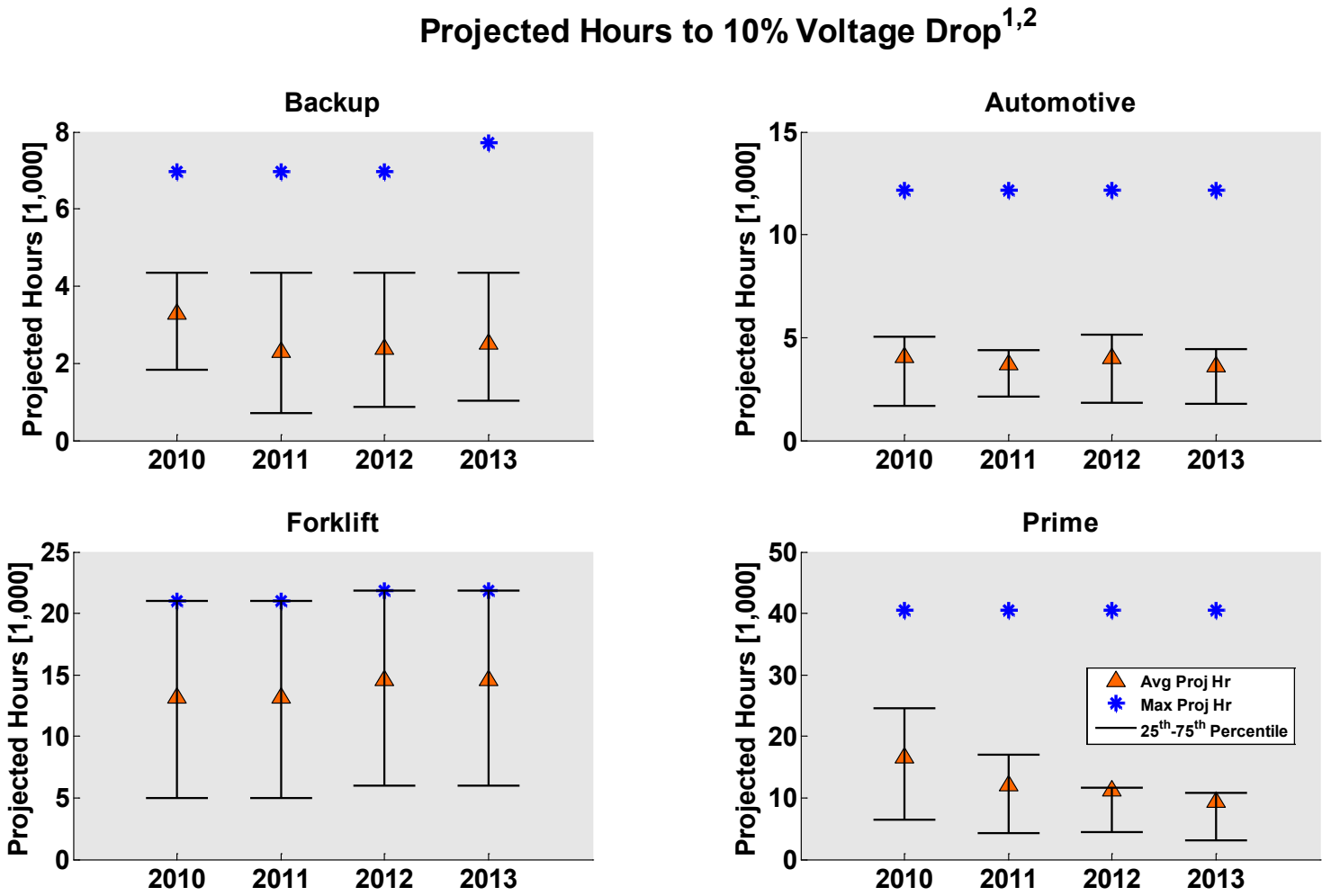
External

- One source of durability status for DOE from the leading fuel cell developers
- Independent technology assessment with uniform analysis on proprietary data
- Highlights technology successes
- Helps adoption of fuel cell technology
- Identifies areas for continued development
- Possible to study differences between field and lab performance

Internal

- Benchmarking against CDPs
- Analysis method may provide a new way to study fuel cell durability
- Collaboration with NREL's technology validation team; dedicated analysis team with experience in multiple fuel cell applications
- Provide information that is very useful for external partners (e.g. DOE) without revealing proprietary information
- Possible to study differences between field and lab performance

Accomplishments: Voltage Degradation by Year



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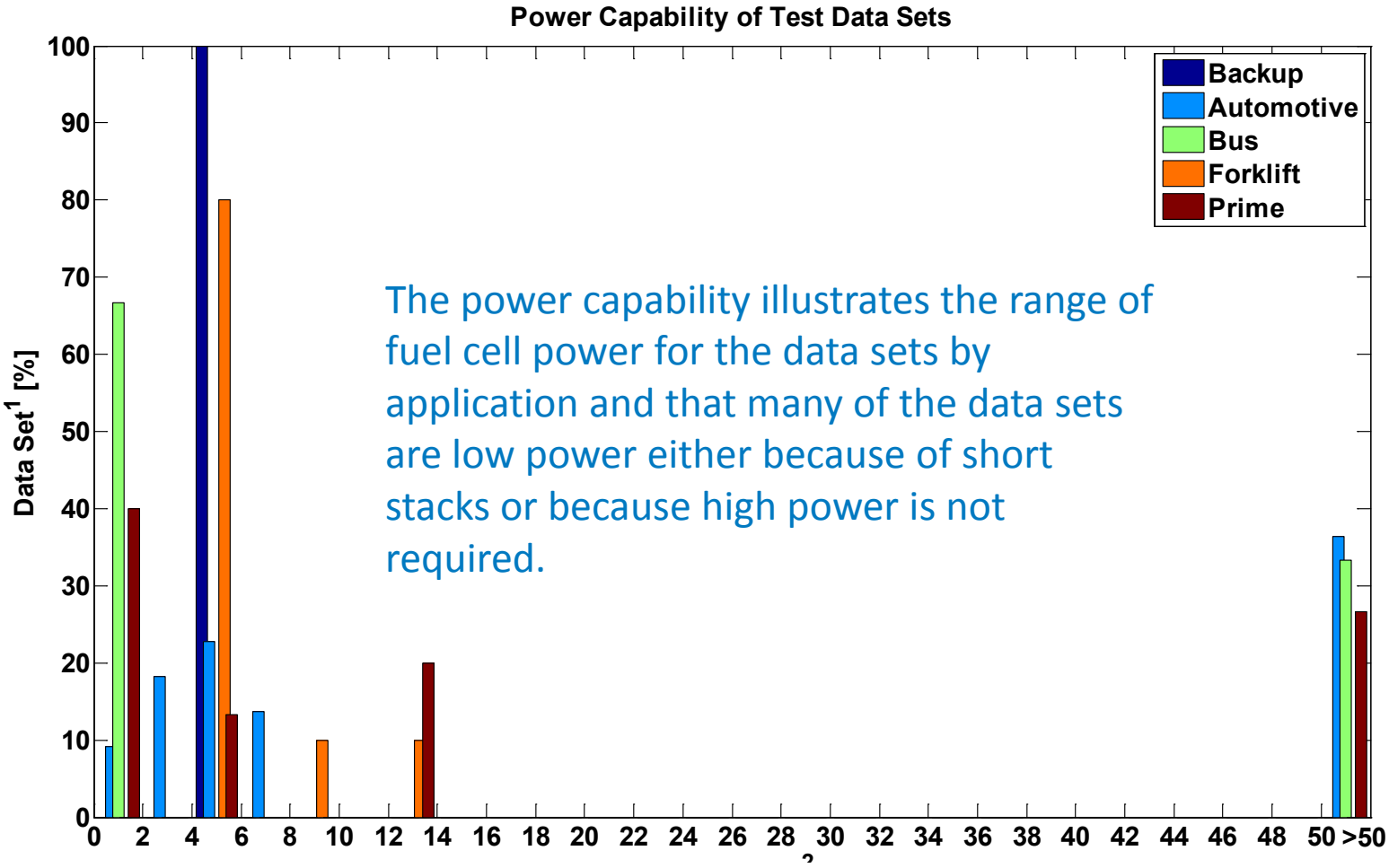
(1) The DOE 10% voltage degradation metric is used for assessing voltage degradation; it may not be the same as end-of-life criteria and does not address catastrophic failure modes.

(2) At least 13 fuel cell developers supplied data, including international. Analysis is updated periodically.

Accomplishments: Data Set Power Capability



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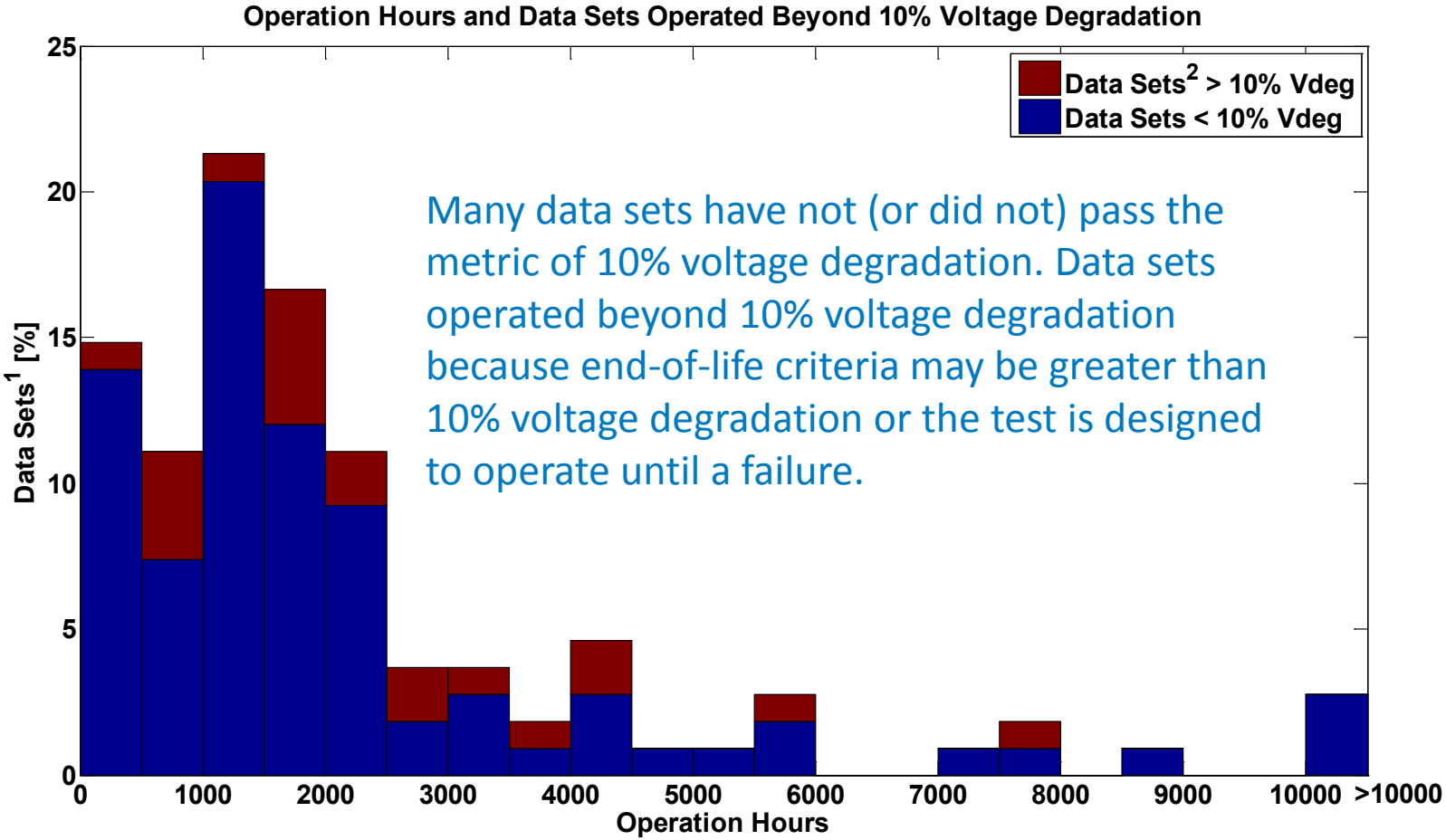
1) A data set represents a short stack, full stack, or system test data.
2) The power capability represents the maximum power for a data set, not the load profile or time at a power level.

Accomplishments: Data Set Operation Hours and the Percentage of Data Sets That Have Passed 10% Voltage Degradation



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.