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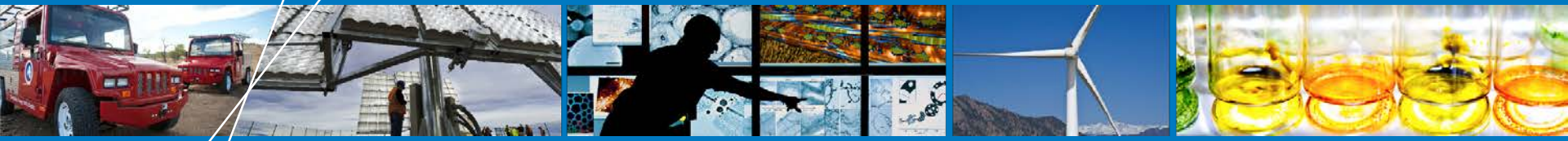
NATIONAL RENEWABLE ENERGY LABORATORY

Fuel Cell Technology Status: Degradation



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National Renewable Energy Laboratory
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Project ID FC-081

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

Overview

Timeline and Budget

- Project[1] start date: July 2009
- FY14 DOE funding: $100k
- FY15[2] planned DOE funding: $85k
- Total DOE funds received to date: $650k

Partners

- U.S. and international fuel cell developers supply data voluntarily and review published results

Barriers

- Lack of data for current fuel cell stack voltage durability

Application	2020 Durability Target[3]
Light Duty Automotive	5,000 Hours
Public Transit	25,000 Hours
Stationary 1-10kW	0.3%/1,000 Hours
Stationary 100 kW – 3 MW	80,000 Hours

[1] Project continuation and direction determined annually by DOE

[2] FY09–FY13, and FY15 project objective focused on status of fuel cell durability
FY14 project objective focused on fuel cell price

[3] Fuel Cell Technologies Office Multi-Year RD&D Plan –Section 3.4

Relevance

Benchmark state-of-the-art fuel cell durability

- Develop snapshot of state-of-the-art fuel cell durability
- Uniformly apply analysis method to **developers' voluntarily supplied data from lab testing**
- 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 FCEV Learning Demonstration and early market demonstrations)
- Compare lab and field data

Collaborate with key fuel cell developers

- Provide feedback to fuel cell developers
- Study differences between lab and field durability
- Benchmark system price

FY15 Objectives

- Receive and analyze new lab durability data
- Update and publish the durability results

Barrier/Impact

- Data on fuel cell stack voltage durability is received at the National Fuel Cell Technology Evaluation Center (NFCTEC)
- Consistent and independent source for current and legacy voltage durability

Approach: NFCTEC Analysis and Reporting of Real-World Operation Data

Fuel Cell* Technology Status Data Supply

Voluntarily supplied from fuel cell developers

Durability – voltage, current, and hours minimum data needed

Test – time frame, objective, protocol, application, and type

Market – system price, availability, and application

*Fuel cell technologies include Polymer Electrolyte Membrane (PEM), Solid Oxide (SO), and Direct Methanol (DM)

Internal analysis completed quarterly in NFCTEC

National Fuel Cell Technology Evaluation Center

Confidential

DDPs

Public

CDPs

Detailed Data Products (DDPs)

- Individual data analyses
- Identify individual contribution to CDPs
- Shared annually only with the partner who supplied the data

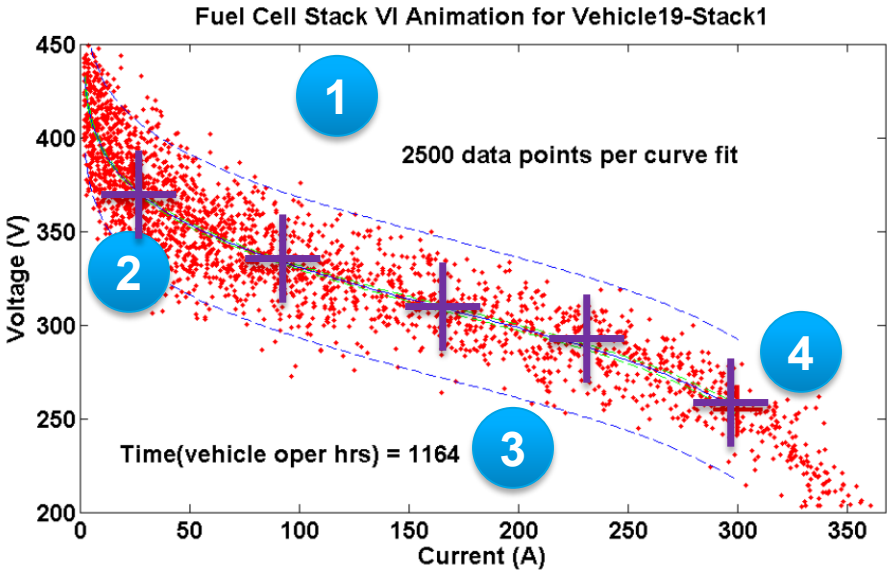
Composite Data Products (CDPs)

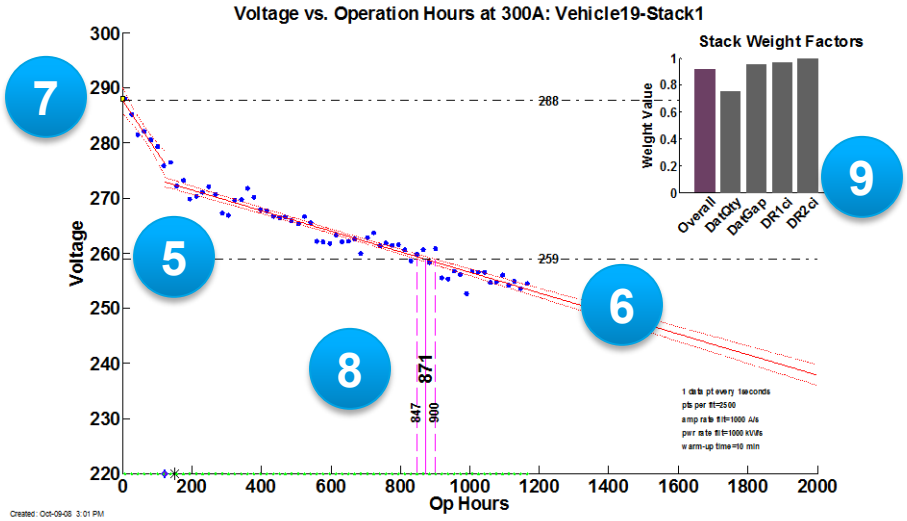
- Aggregated data across multiple systems, sites, and teams
- Publish analysis results annually without revealing proprietary data

www.nrel.gov/hydrogen/proj_tech_validation.html

Approach: Raw Fuel Cell 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





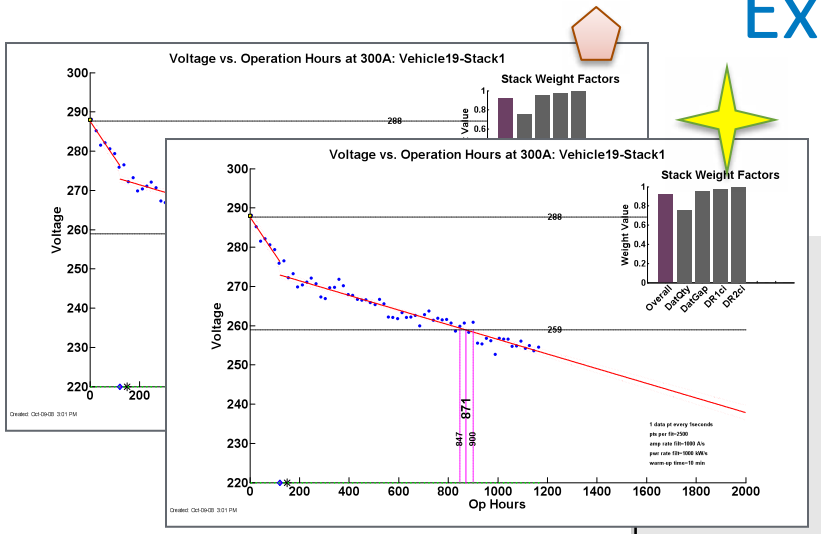
Approach: CDP and DDP Review

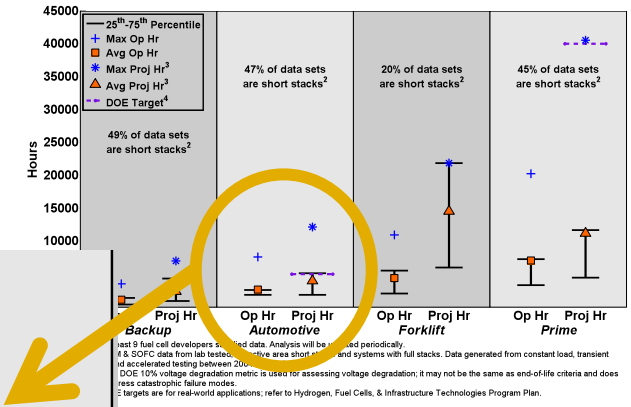
Data Process and Analysis

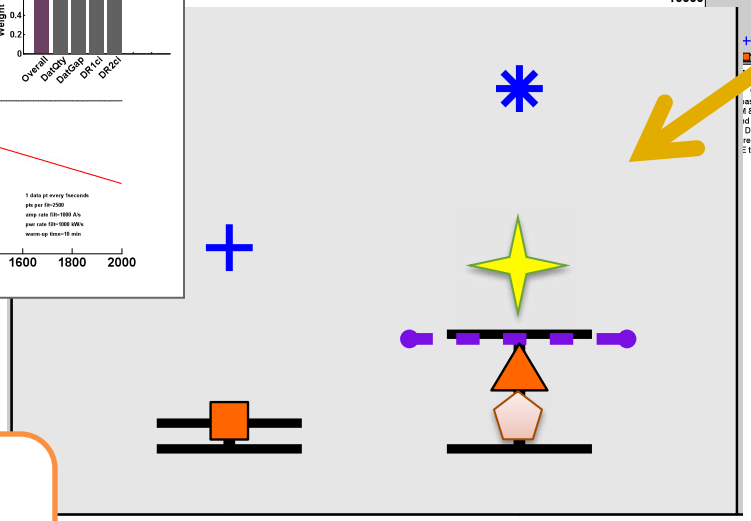
Example Data Results (if needed) → Draft CDPs → Initial Review (~1 week) → Final Draft CDPs (<1 week) → Final Review (<1 week) → Finalized CDPs (<1 week)

(~4 weeks excluding data processing and analysis)

Example DDPs







Sample Data Set 1

Sample Data Set 2

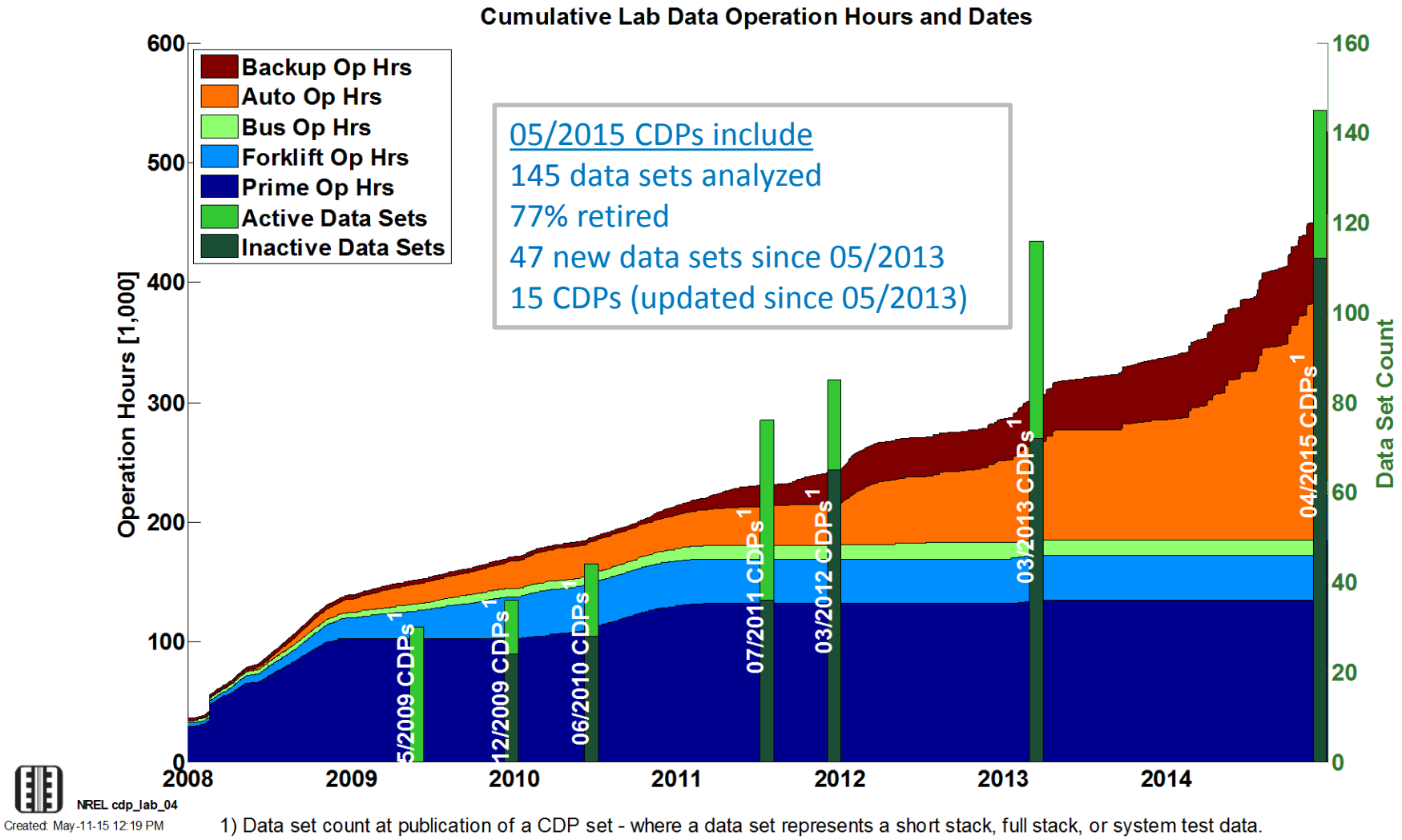
Op Hr **Proj Hr**

Automotive

FY15 Milestone

Analysis complete and updated results published by 04/2015

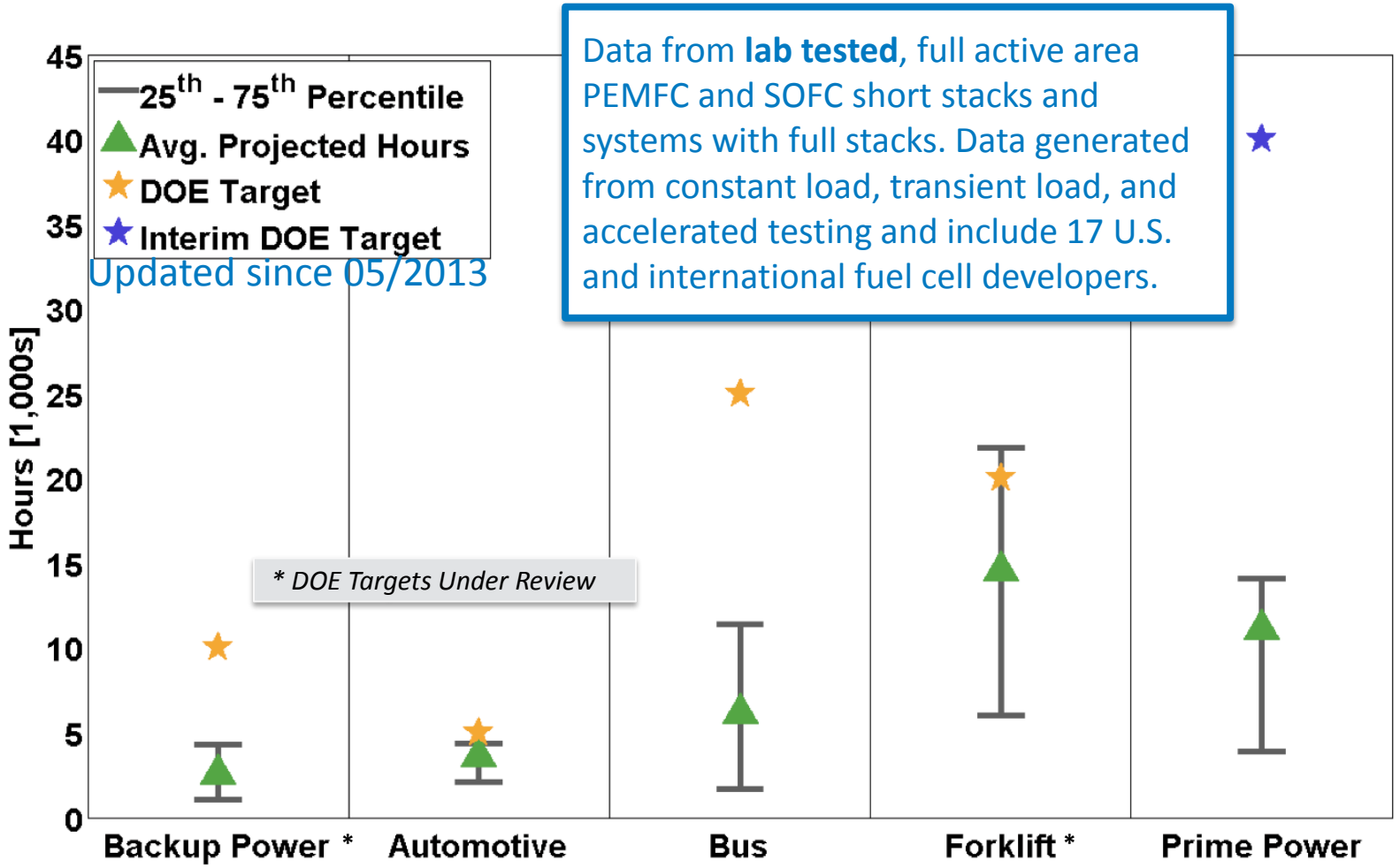
Accomplishments: Data Set Count and Operation Hours



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

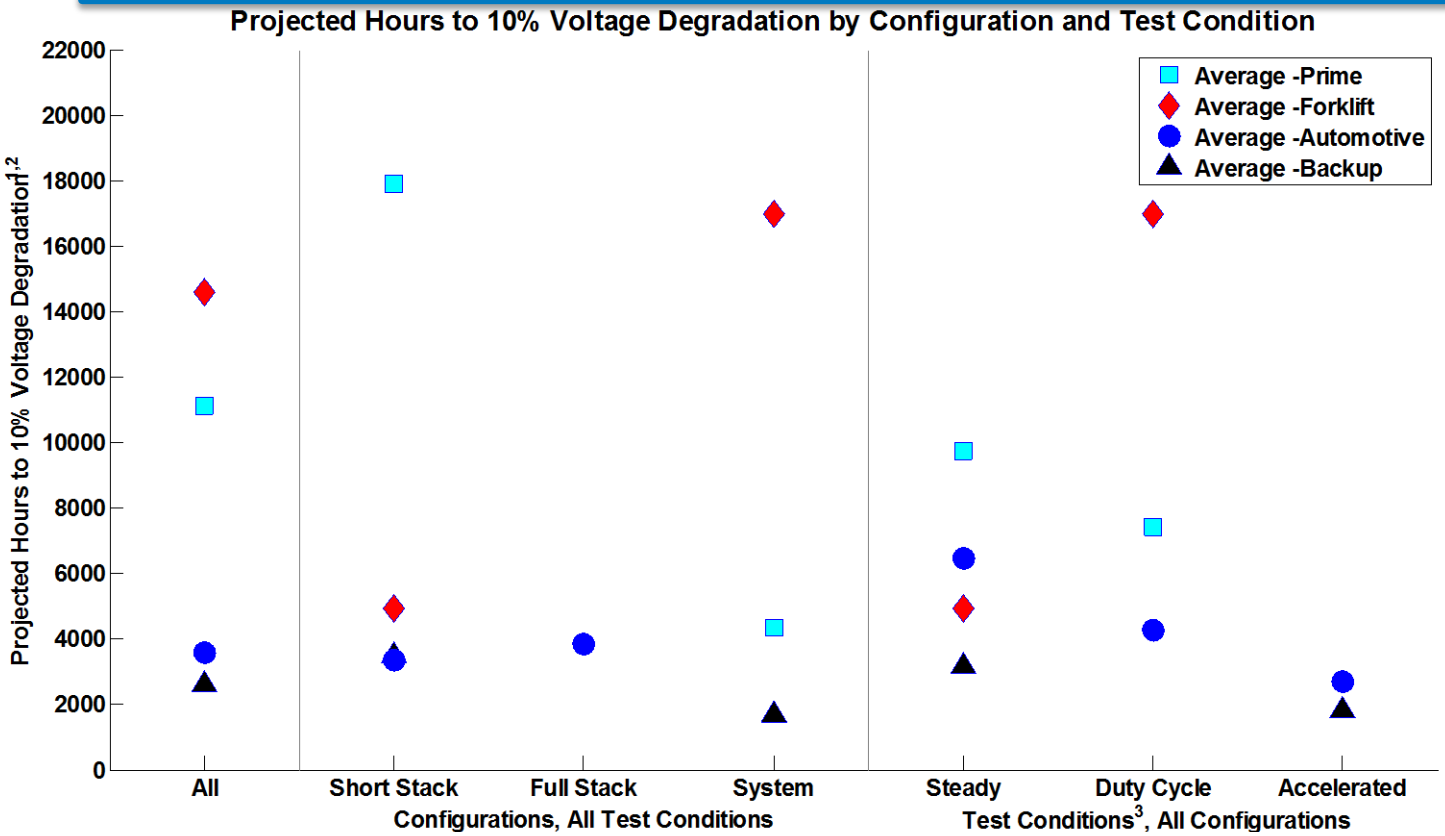
The average projected times (hrs) to 10% voltage drop are **2,500**, **3,600**, **6,200**, **14,600**, and **11,100** for **backup power**, **automotive**, **bus**, **forklift**, and **stationary** applications, respectively.



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. DMFC included but not enough data was available for publication. DOE targets are for real-world applications; refer to Fuel Cell Technologies Office Multi-Year RD&D Plan.

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 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 and data not corrected for accelerated conditions

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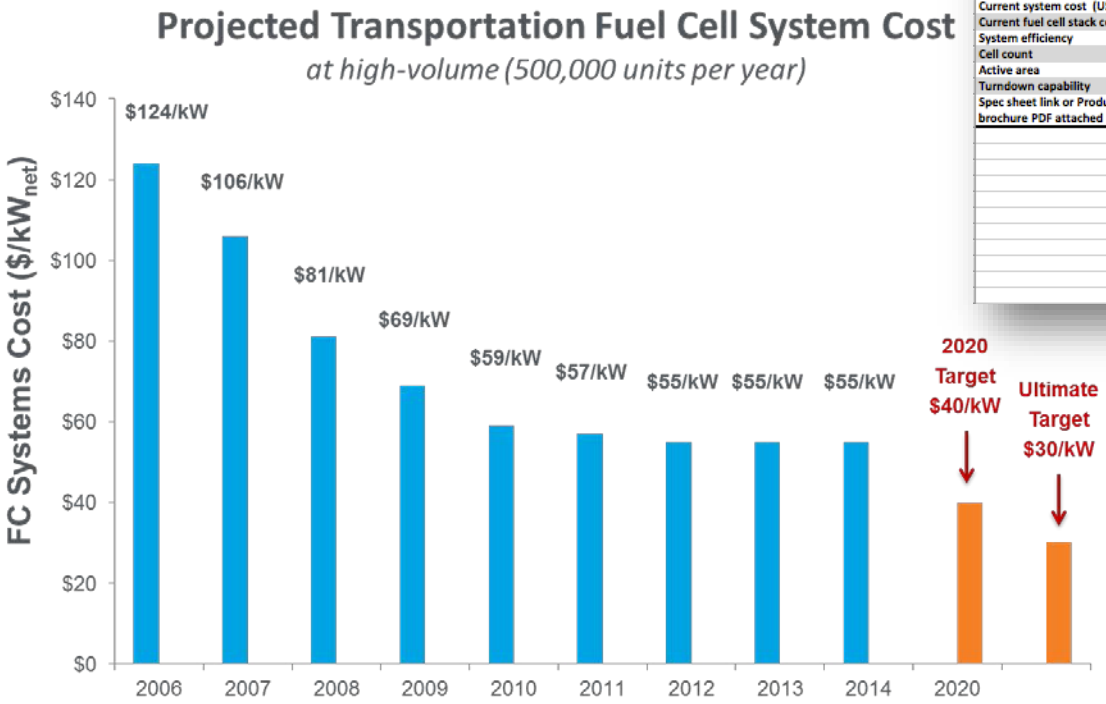
Updated

Approach: Current Status to Complement DOE Fuel Cell System Cost Based on Models for High Volume



Note: The information you provide here will be shared with the NREL National Fuel Cell Technology Evaluation Center for independent analysis and may be published as composite data products after a 2 stage review and concurrence process with the data providers. The information will be treated as confidential.

Instructions -

Please fill in applicable requested information for each available product, with each product entered as a new column. Some information may have been filled in based on an internet search of your available product. Please correct as appropriate.

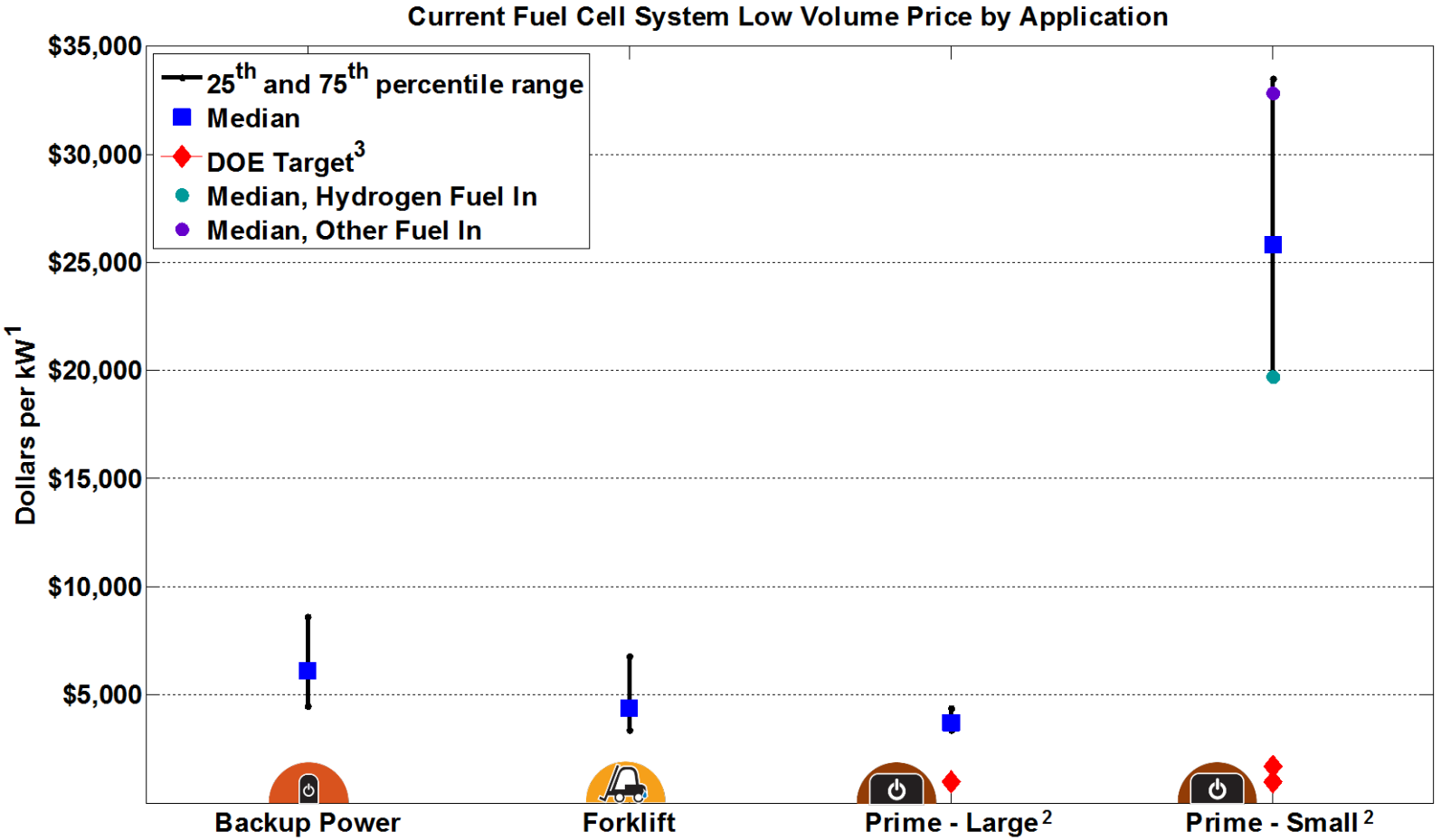
System	ProductName1	ProductName2	ProductName32	ProductName4	ProductName5	ProductName6
Current Price (US $)						
Availability						
Market						
Application						
Fuel Cell Type						
Fuel						
Comments						
Power Rating (kW)						
Other features						
# systems sold to date						
2010 Price (US $)						
2012 Price (US $)						
2014 Price (US $)						
Current system cost (US $)						
Current fuel cell stack cost (US $)						
System efficiency						
Cell count						
Active area						
Turndown capability						
Spec sheet link or Product brochure PDF attached						

	Availability	Application	Fuel Cell Type	Fuel	Other features	Markets
	Available	Stationary Prime	DMFC	Hydrogen	CHP	Europe
	Future product	Stationary Residential	PEMFC	Methanol	CHHP	Japan
	No longer available	Stationary Backup	SOFC	Reformate	Other (Please specify)	United States
	Other (Please specify)	Forklift	MCFC	Other (please specify)		All
		Automotive	PAFC	Natural Gas		Other (please specify)
		Bus	AEM	Propane		
		Portable	Other (please specify)			
		Auxiliary				
		Other (Please specify)				

Cost/Price Template

Record Source: http://www.hydrogen.energy.gov/pdfs/14014_fuel_cell_system_cost_2014.pdf

Accomplishments: Low Volume Price of Current Fuel Cell Systems



1. Data (in 2013 dollars without incentives) sources include public information, ARRA deployments, and fuel cell developers (voluntarily supplied). Includes over 35 different data points from more than 7 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 tables 3.4.5 and 3.4.6.

NREL cdp_lab_15
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Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- **This project was not reviewed last year.**

Collaborations

- **Multiple fuel cell developers voluntarily supplied data**
  - 18 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

Remaining Challenges and Barriers

- Voluntarily supplied data
- Inconsistent availability of data and status reporting
- Reporting on additional information relevant to durability
- Analyzing and reporting on the relationship between lowering cost and improving durability
- Analyzing factors that influence durability

Proposed Future Work

- Alternate between a status update on fuel cell durability and system cost/price – price status update planned for FY16
- Continue cultivating existing collaborations and developing new collaborations with fuel cell developers
- Publish a report on the durability analysis method (9/2015)
- Add electrolysis data and published updated results (9/2015)

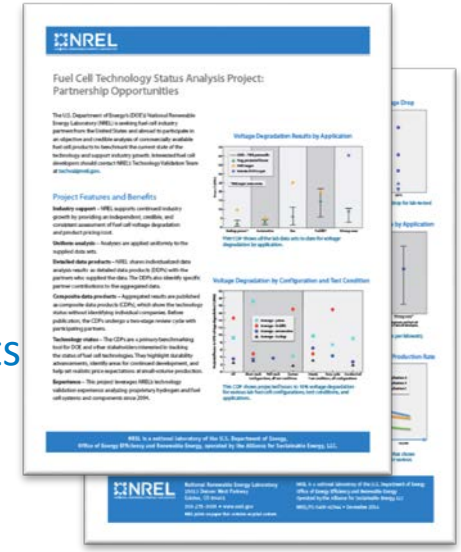
Summary

***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 NFCTEC and prioritized industry collaborations.

***Accomplishments*:** Updated sixth annual results for six applications, plus started electrolysis, and included 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



Application	2020 Durability Target	Lab Status - Ave Hrs to 10% Voltage Degradation
Light Duty Automotive	5,000 Hours	3,600
Public Transit	25,000 Hours	6,200
Stationary 1-10kW	0.3%/1,000 Hours	11,100
Stationary 100 kW – 3 MW	80,000 Hours	
Forklift	20,000 Hours Target Under Review	14,600
Backup	10,000 Hours Target Under Review	2,500

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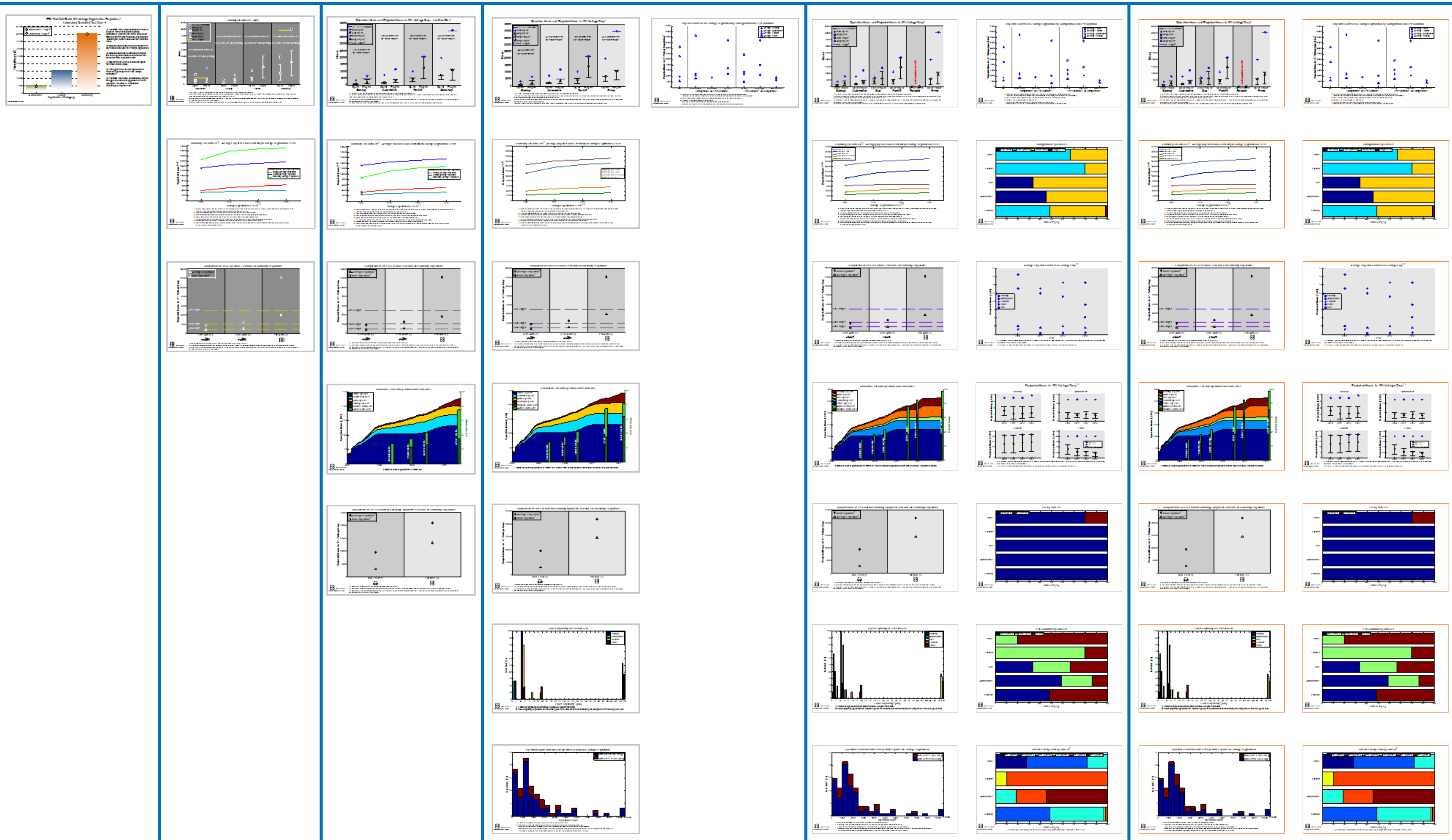
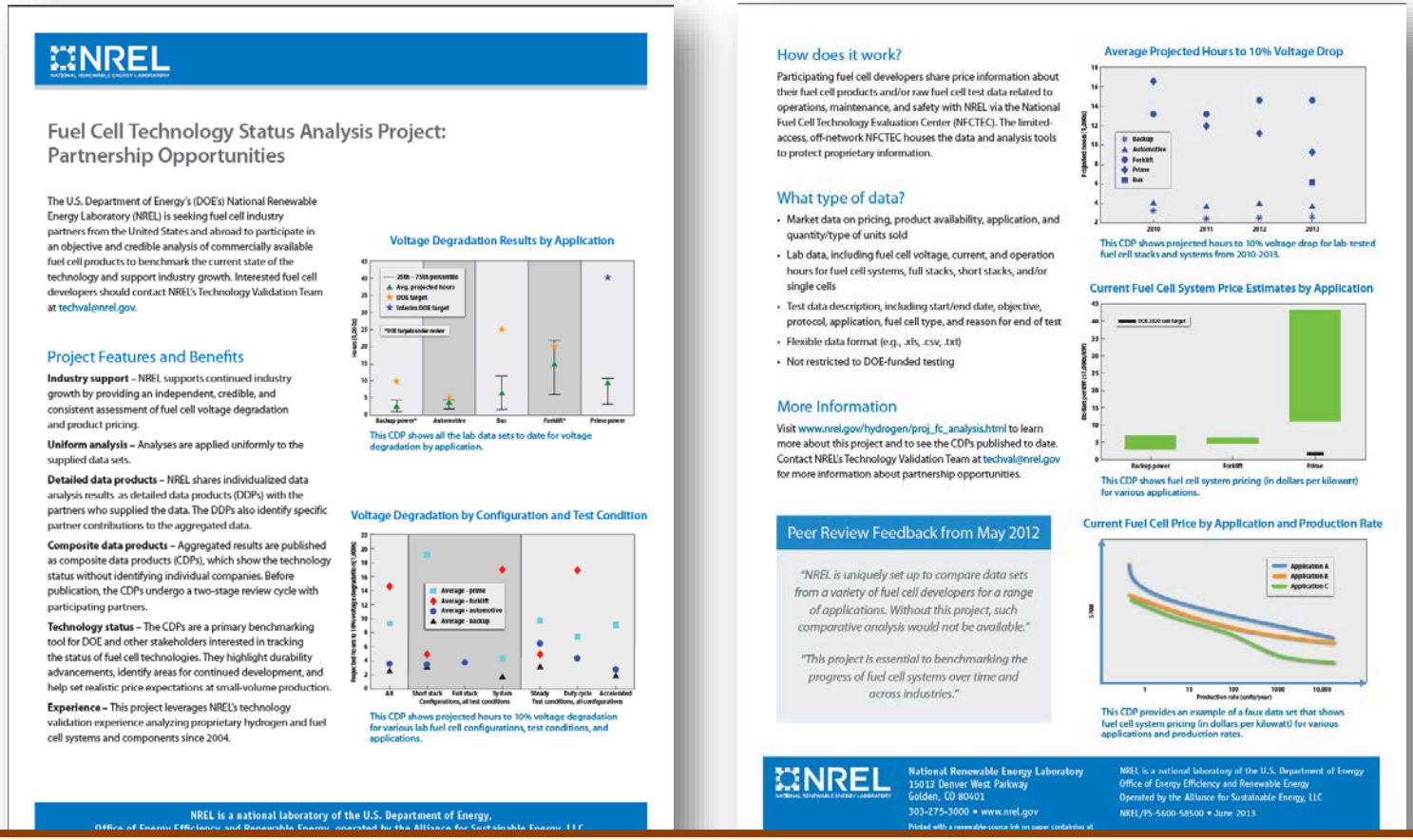
Technical Back-Up Slides

Annual CDP Updates – Durability Benchmark

FY09 FY10 FY11 FY12 FY13 FY15



Pamphlet with Participation Details and Benefits



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Fuel Cell Technology Status Analysis Project: Partnership Opportunities

The U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) is seeking fuel cell industry partners from the United States and abroad to participate in an objective and credible analysis of commercially available fuel cell products 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.

Project Features and Benefits

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

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

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

Composite data products – Aggregated results are published as composite data products (CDPs), which show the technology status without identifying individual companies. Before publication, the CDPs undergo a two-stage review cycle with participating partners.

Technology status – The CDPs are a primary benchmarking tool for DOE and other stakeholders interested in tracking the status of fuel cell technologies. They highlight durability advancements, identify areas for continued development, and help set realistic price expectations at small-volume production.

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

Voltage Degradation Results by Application

This CDP shows all the lab data sets to date for voltage degradation by application.

Voltage Degradation by Configuration and Test Condition

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

NREL is a national laboratory of the U.S. Department of Energy.

How does it work?

Participating fuel cell developers share price information about their fuel cell products and/or raw fuel cell test data related to operations, maintenance, and safety with NREL via the National Fuel Cell Technology Evaluation Center (NFCTEC). The limited-access, off-network NFCTEC houses the data and analysis tools to protect proprietary information.

What type of data?

- Market data on pricing, product availability, application, and quantity/type of units sold
- Lab data, including fuel cell voltage, current, and operation hours for fuel cell systems, full stacks, short stacks, and/or single cells
- Test data description, including start/end date, objective, protocol, application, fuel cell type, and reason for end of test
- Flexible data format (e.g., .xls, .csv, .txt)
- Not restricted to DOE-funded testing

More Information

Visit www.nrel.gov/hydrogen/proj_fc_analysis.html to learn more about this project and to see the CDPs published to date. Contact NREL's Technology Validation Team at techval@nrel.gov for more information about partnership opportunities.

Peer Review Feedback from May 2012

"NREL is uniquely set up to compare data sets from a variety of fuel cell developers for a range of applications. Without this project, such comparative analysis would not be available."

"This project is essential to benchmarking the progress of fuel cell systems over time and across industries."

Average Projected Hours to 10% Voltage Drop

This CDP shows projected hours to 10% voltage drop for lab-tested fuel cell stacks and systems from 2010-2013.

Current Fuel Cell System Price Estimates by Application

This CDP shows fuel cell system pricing (in dollars per kilowatt) for various applications.

Current Fuel Cell Price by Application and Production Rate

This CDP provides an example of a faux data set that shows fuel cell system pricing (in dollars per kilowatt) for various applications and production rates.

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