

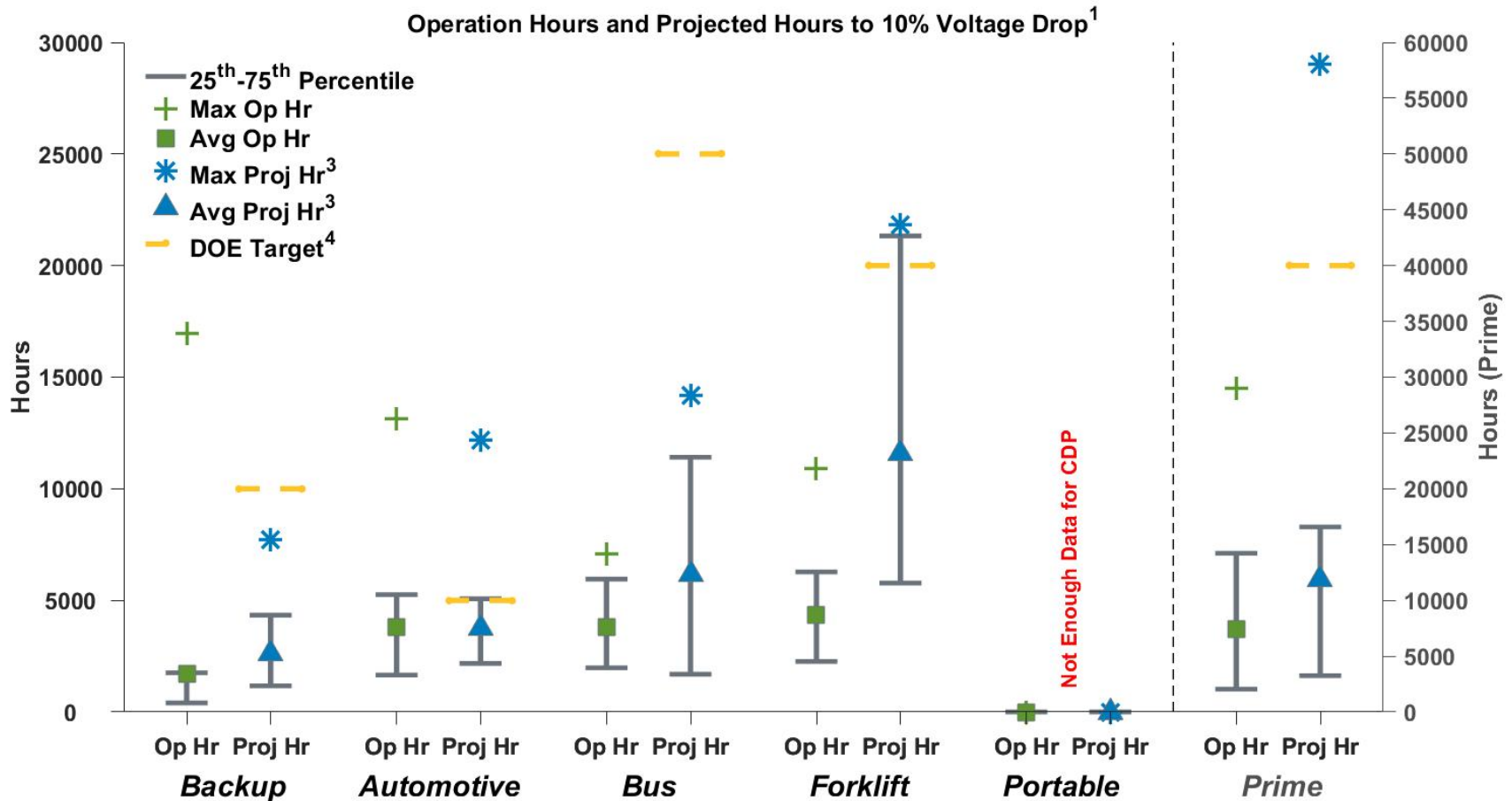
State-of-the-Art Fuel Cell Voltage Durability and Cost Status

2018 Composite Data Products

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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.

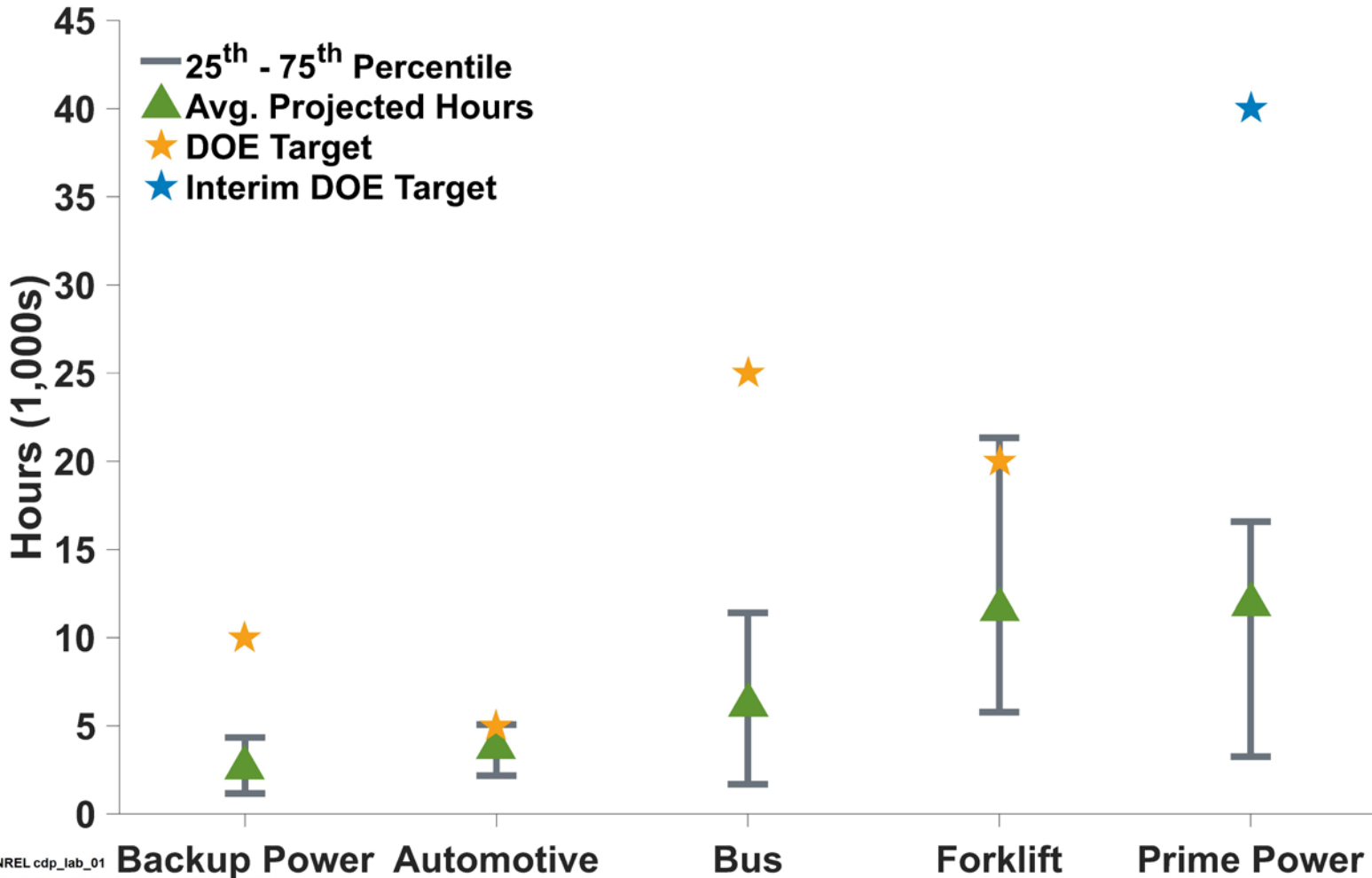
(2) PEMFC, DMFC & SOFC data from lab tested, full active area short stacks and systems with full stacks. Data generated from constant load, transient load, and accelerated testing between 2004 and 2017.

(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.



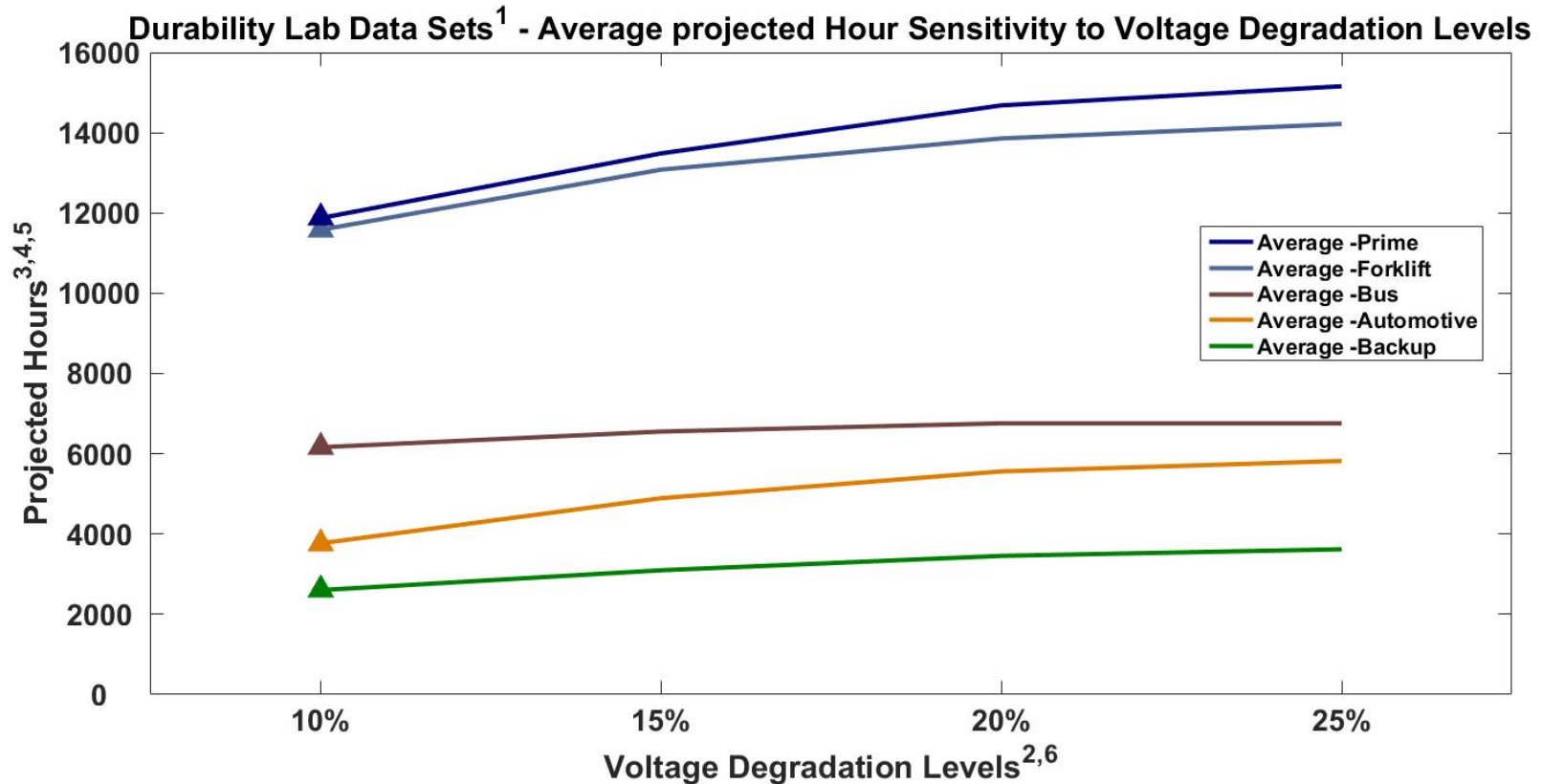
CDP-LAB-01: Lab Data Projected Hours to 10% Stack Voltage Degradation—Simplified



NREL cdp_lab_01

Created: May-23-18 3:20 PM | Data Range: 2004Q1-2017Q4

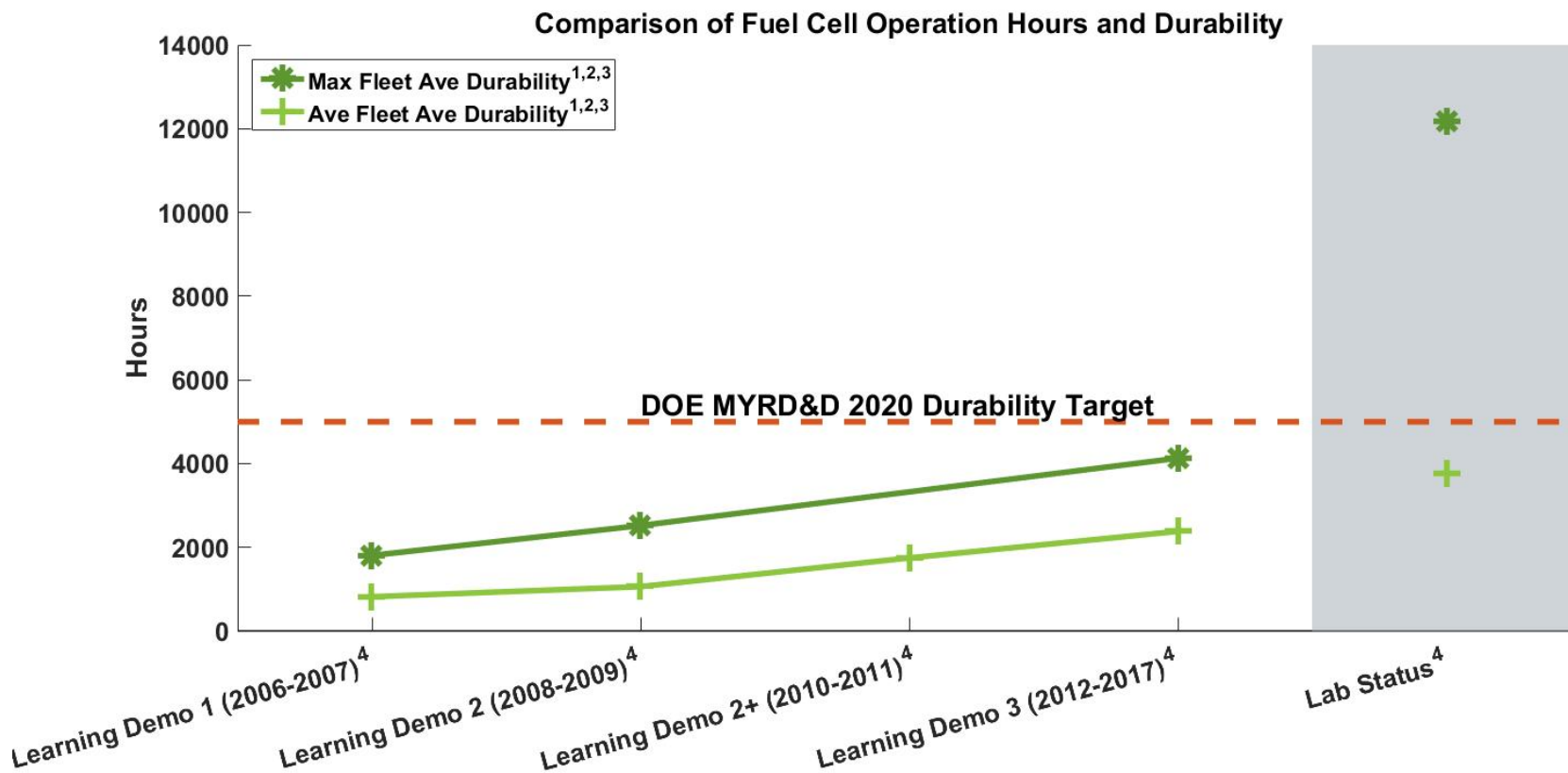
CDP-LAB-02: Durability Lab Data Projection Sensitivity to Voltage Degradation Levels



- (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 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.



CDP-LAB-03: Field and Lab Durability Projection Comparison CDP for Automotive Category



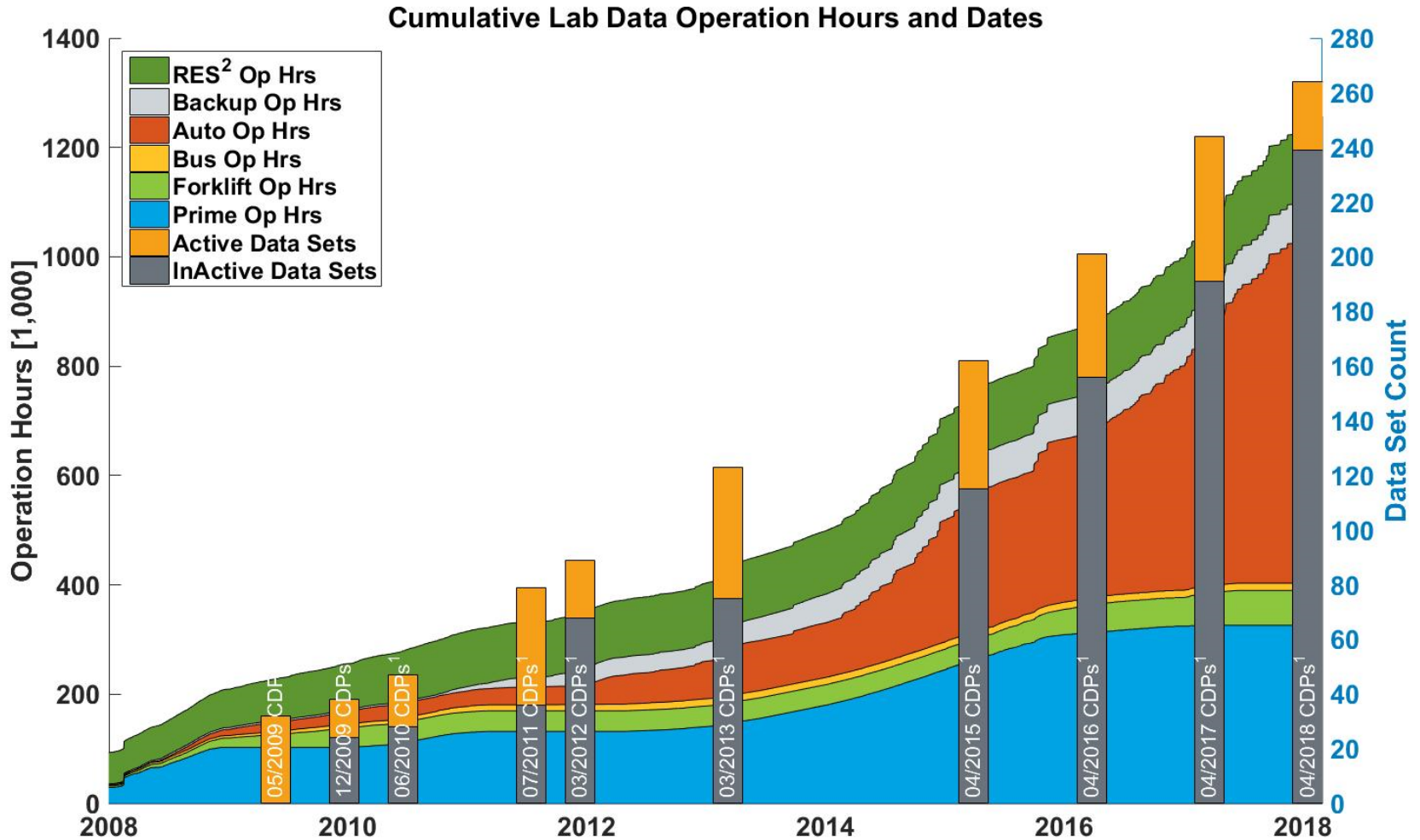
1. Durability based on voltage degradation to 10% lower than beginning of life voltage. 10% voltage drop level is a DOE metric for assessing fuel cell durability.
2. Projections using on-road data are calculated at approximately 55%-65% rated stack current.
3. 10% voltage drop is NOT an indication of 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).



NREL cdp_lab_03

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CDP-LAB-04: Cumulative Operation Hours by Application and Number of Data Sets

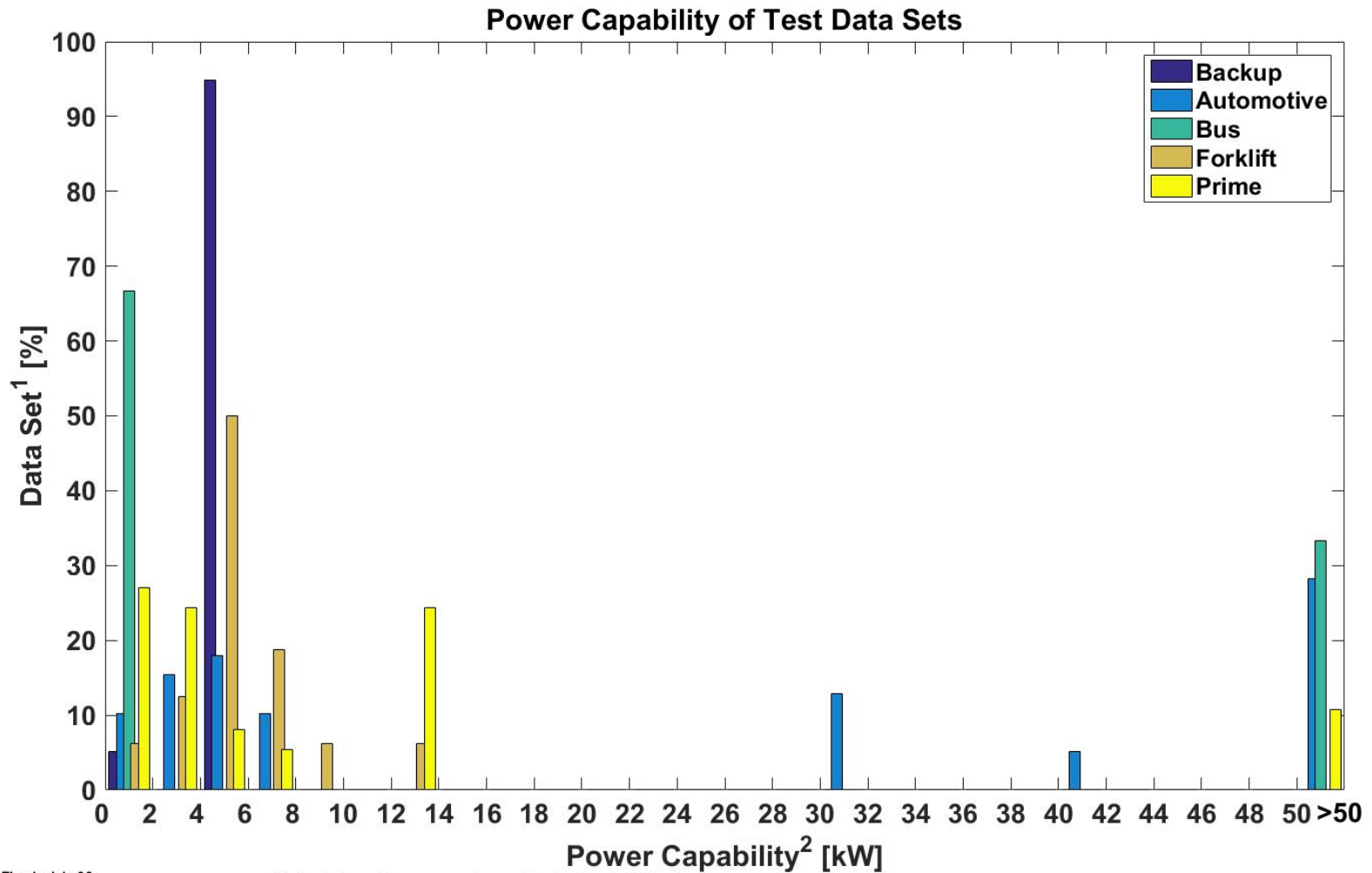


NREL cdp_lab_04

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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.
2. Renewable Energy Storage via Electrolysis

CDP-LAB-06: Data Set Power Capability



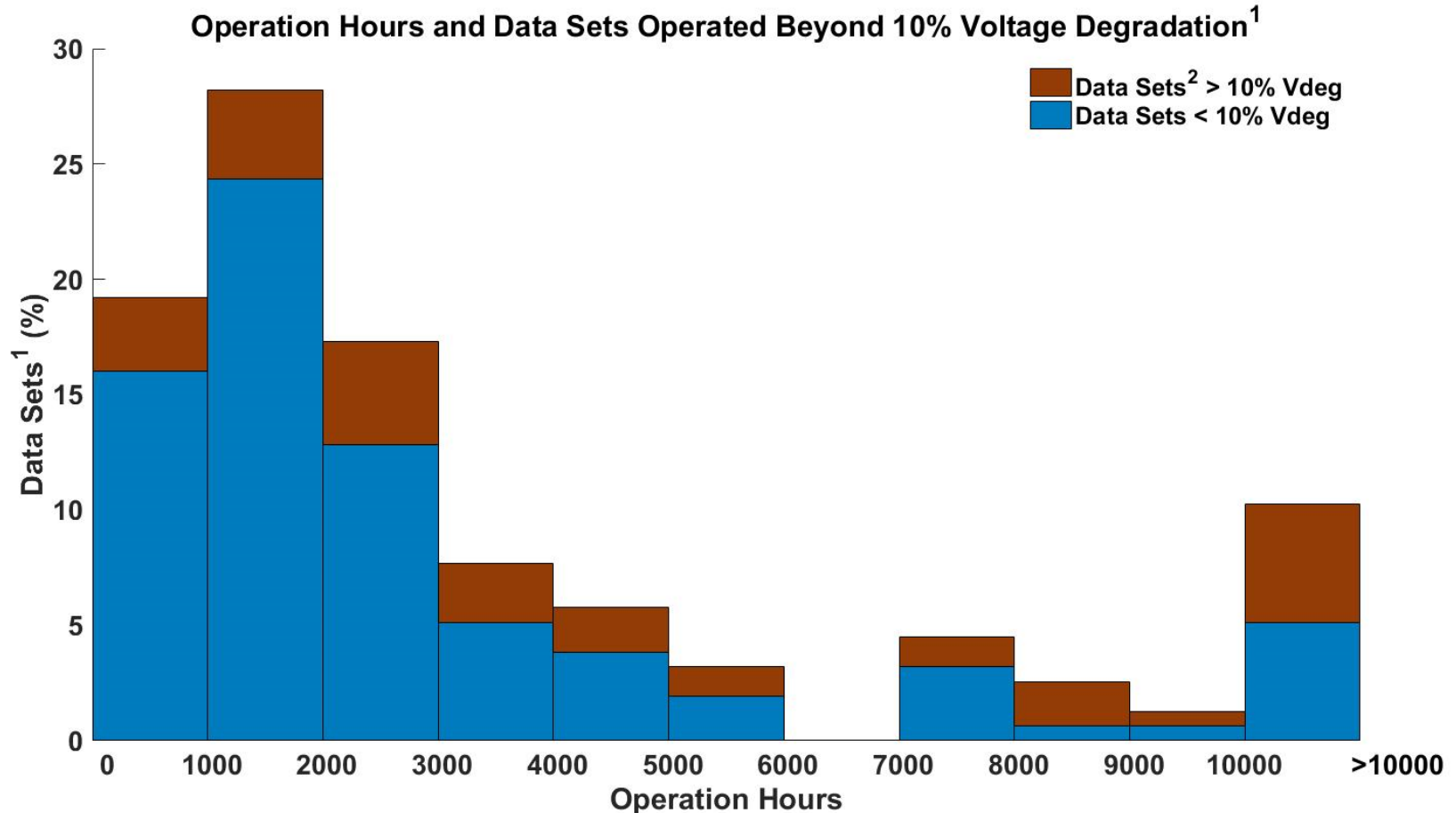
NREL cdp_lab_06

Created: May-23-18 3:35 PM | Data Range: 2004Q1-2017Q4

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



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.

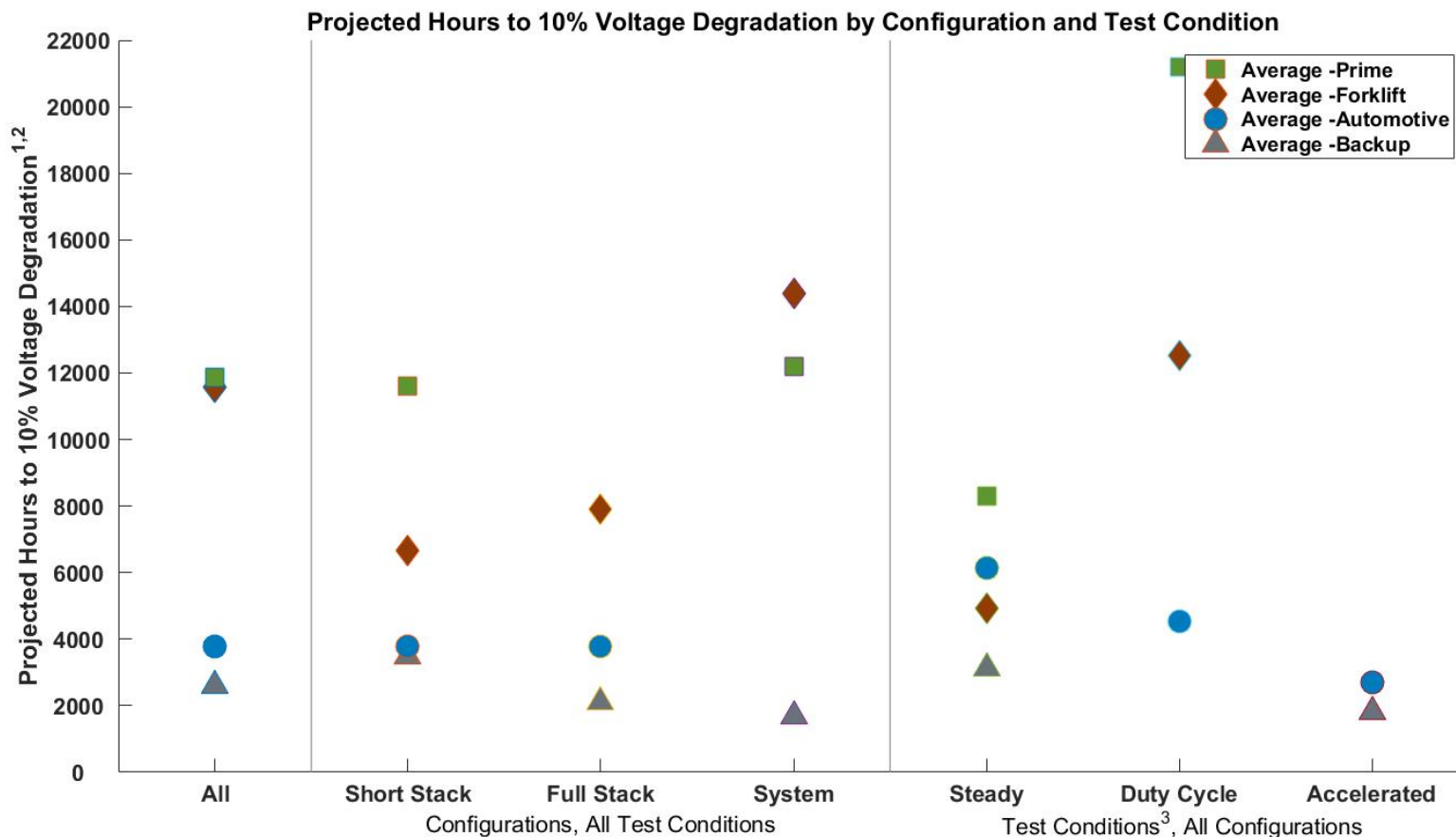
Some data sets have operated beyond 10% voltage degradation because they are able to satisfy the operating requirements at a higher percentage of voltage degradation or the test is designed to operate until a failure.



NREL cdp_lab_07

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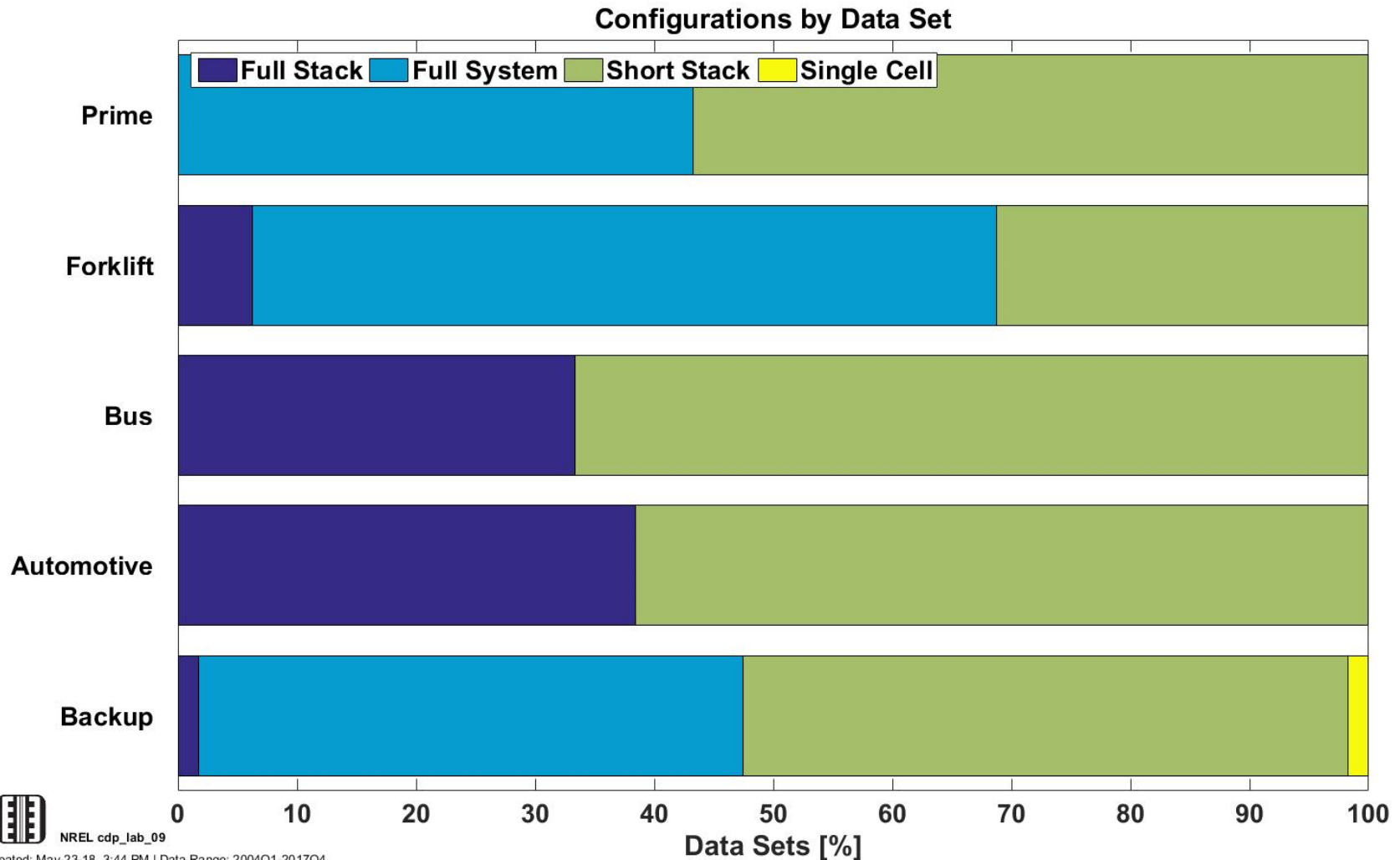
CDP-LAB-08: Voltage Degradation by Configuration and Test Condition



- 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

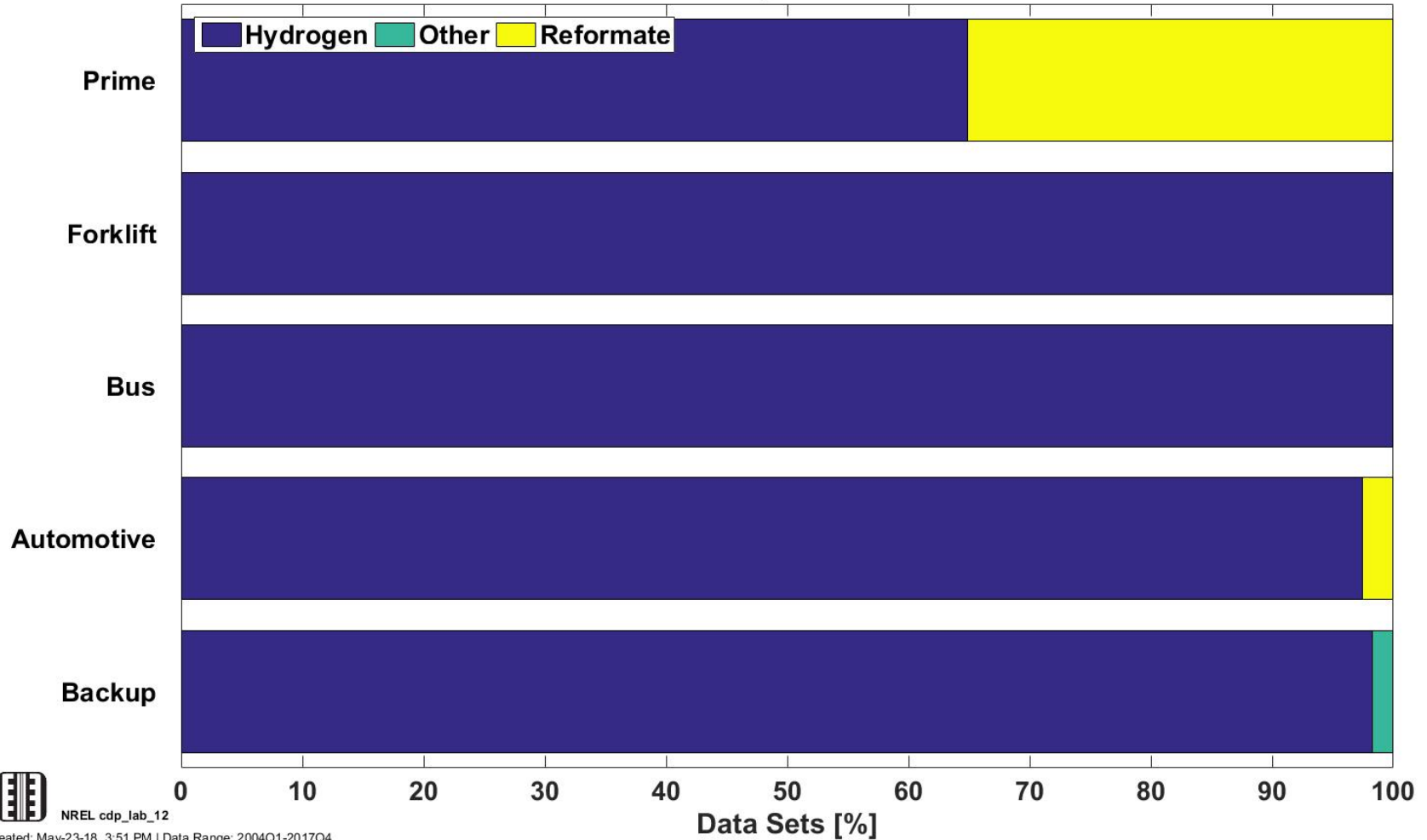


NREL cdp_lab_09

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CDP-LAB-12: Data Set Fuel

Fuel by Data Set

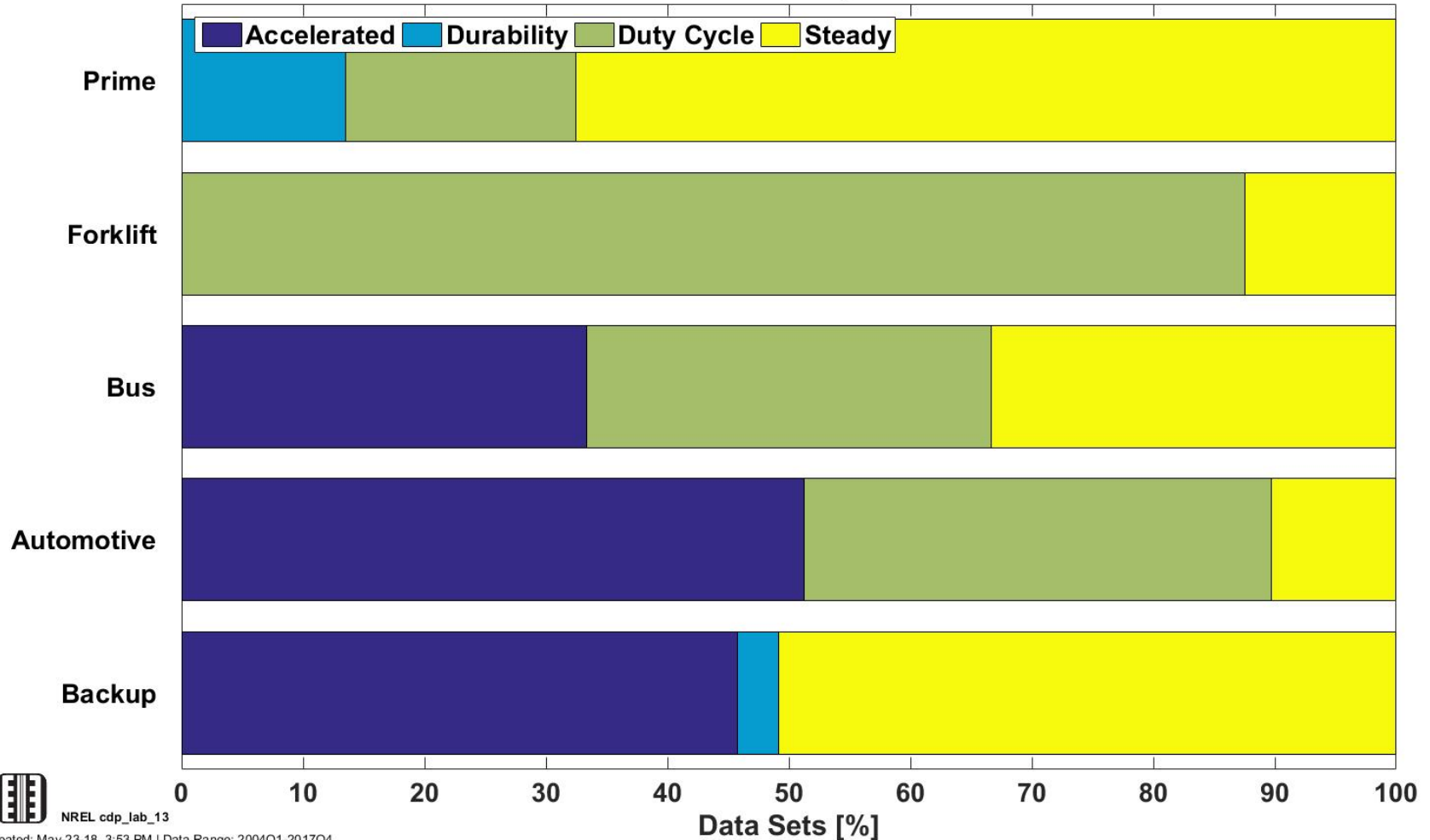


NREL cdp_lab_12

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CDP-LAB-13: Data Set Test Conditions

Test Conditions by Data Set

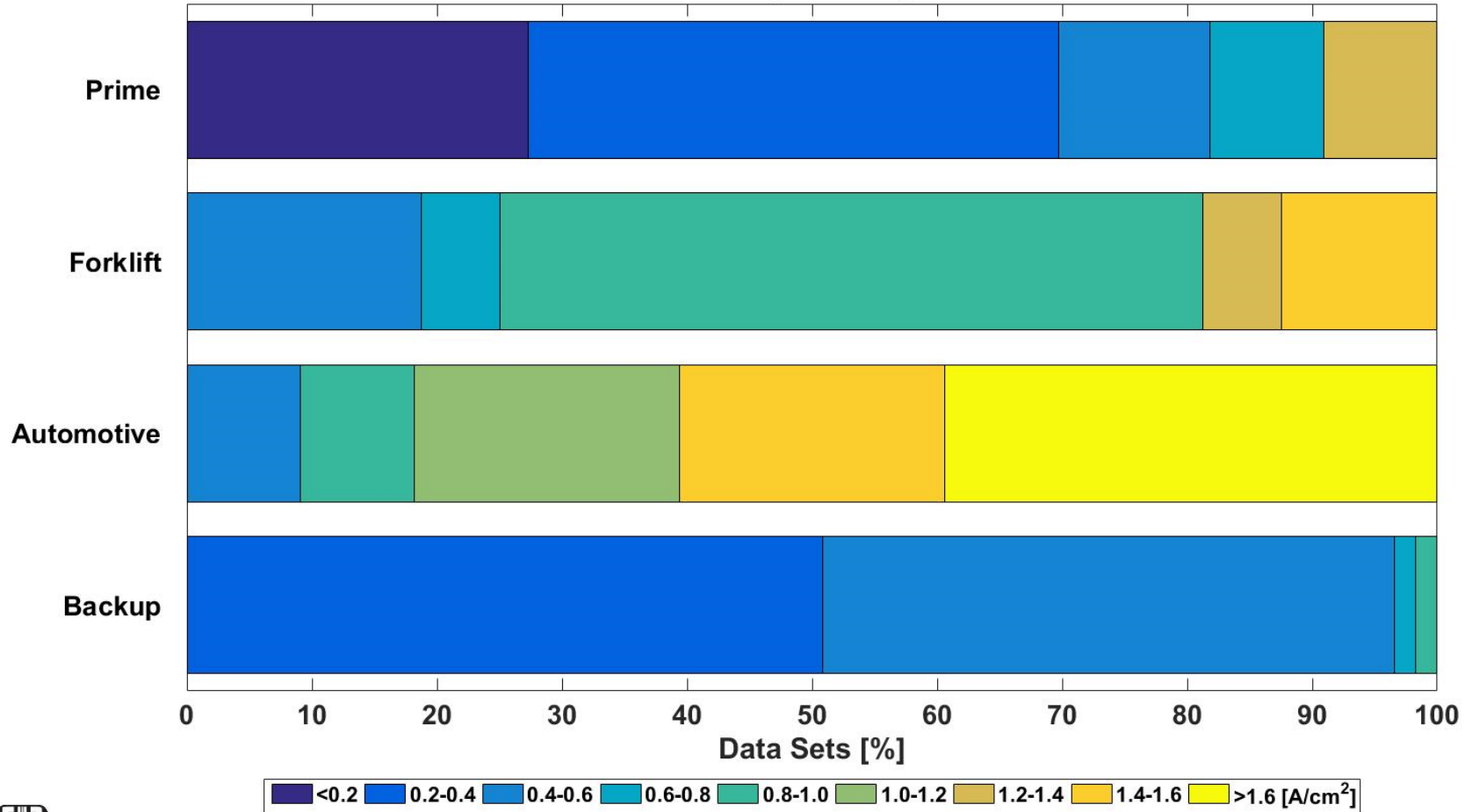


NREL cdp_lab_13

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CDP-LAB-14: Current Density Points

Current Density Point by Data Set¹

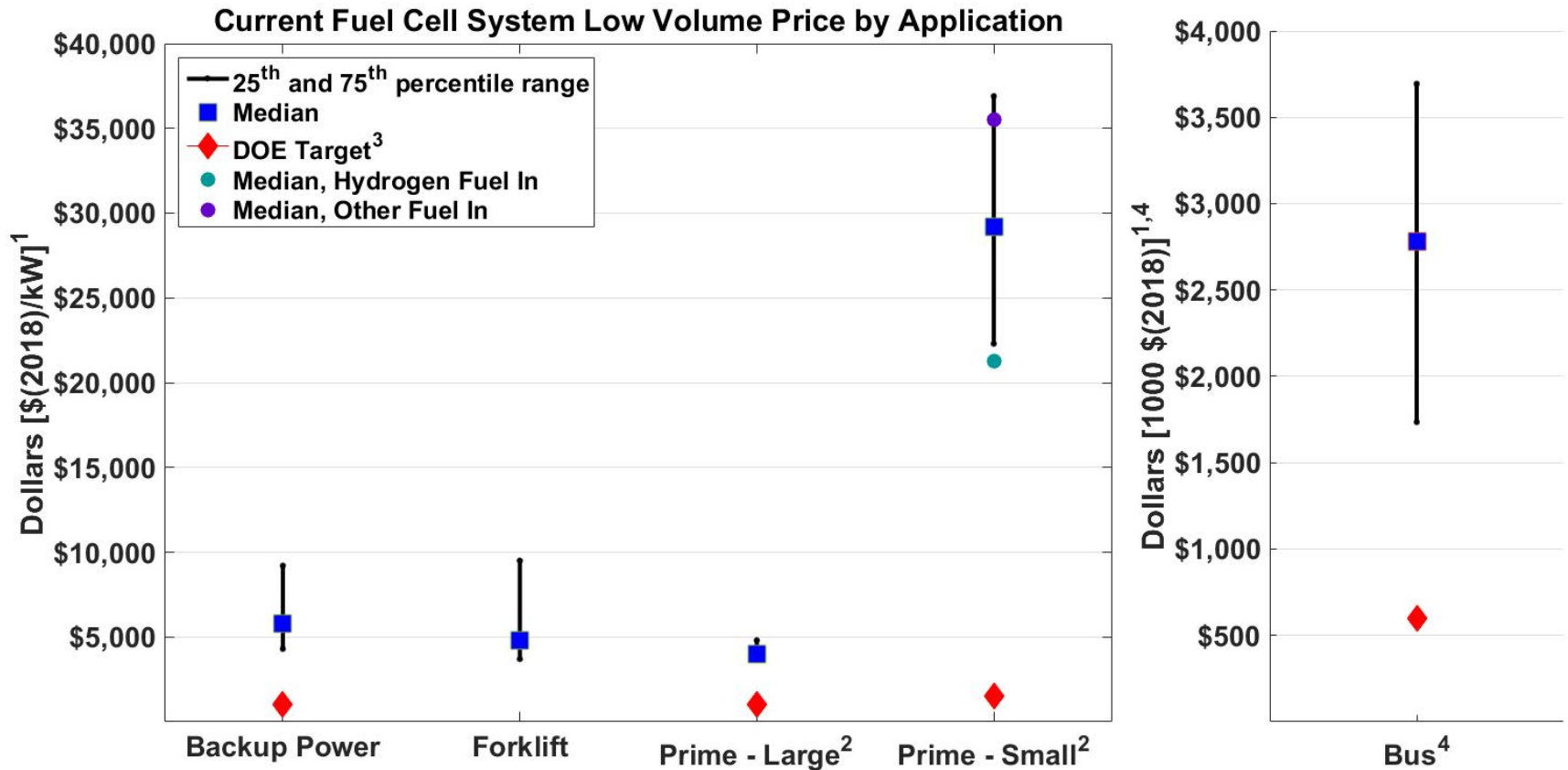


NREL cdp_lab_14

Created: May-23-18 3:55 PM | Data Range: 2004Q1-2017Q4

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



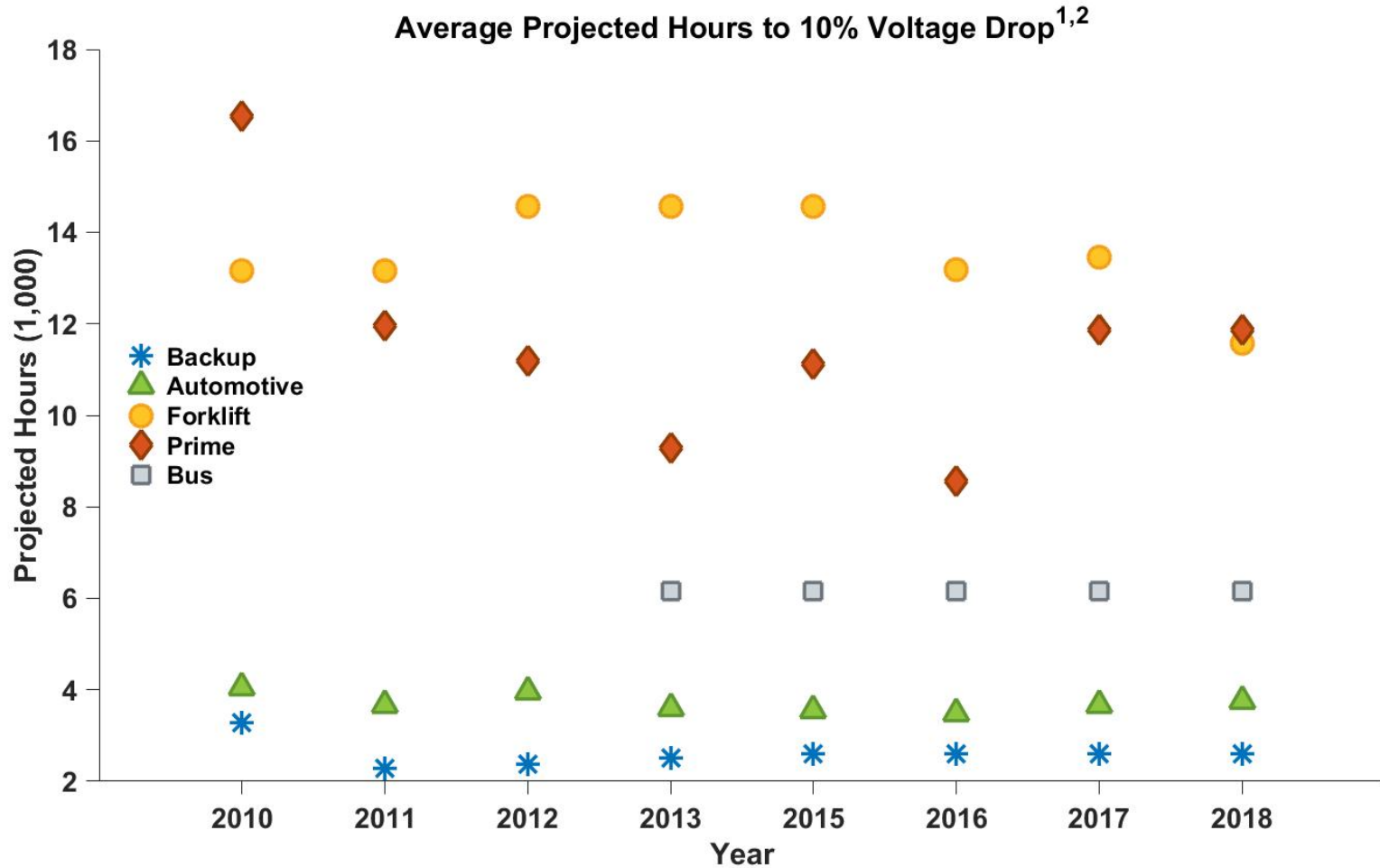
1. Data (in 2018 dollars without incentives) sources include public information, ARRA deployments, and fuel cell developers (voluntarily supplied). Includes over 35 different data points from more than 10 domestic and international fuel cell developers.
2. Prime power data includes multiple system sizes, 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.



NREL cdp_lab_15

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CDP-LAB-16: Average Projected Voltage Degradation by Year



NREL cdp_lab_16

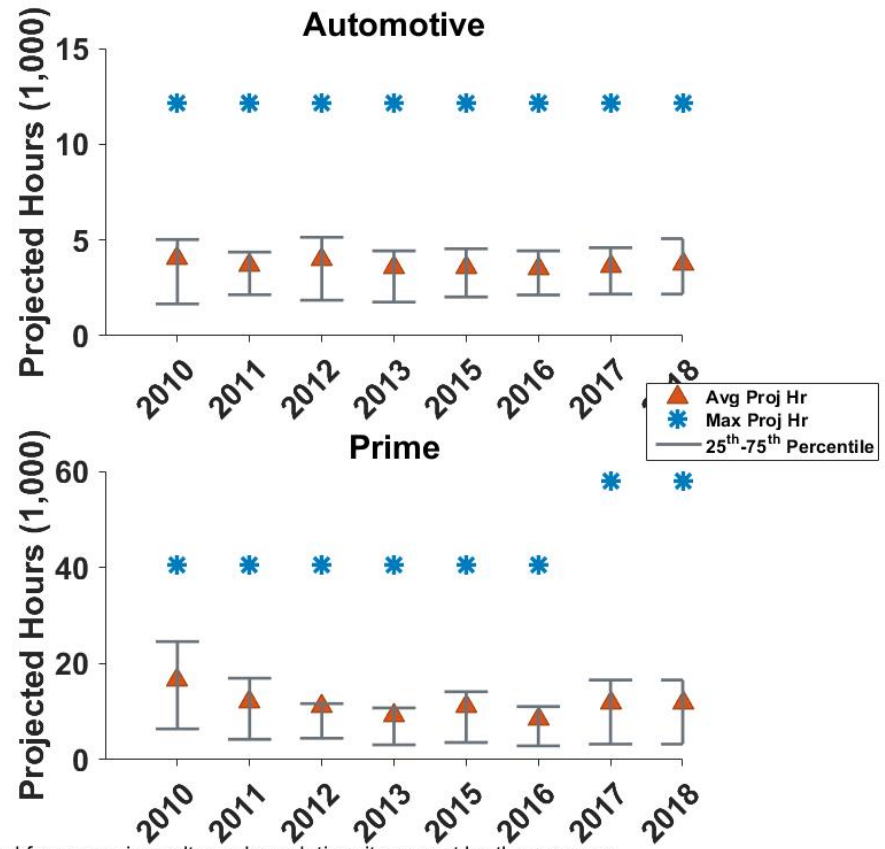
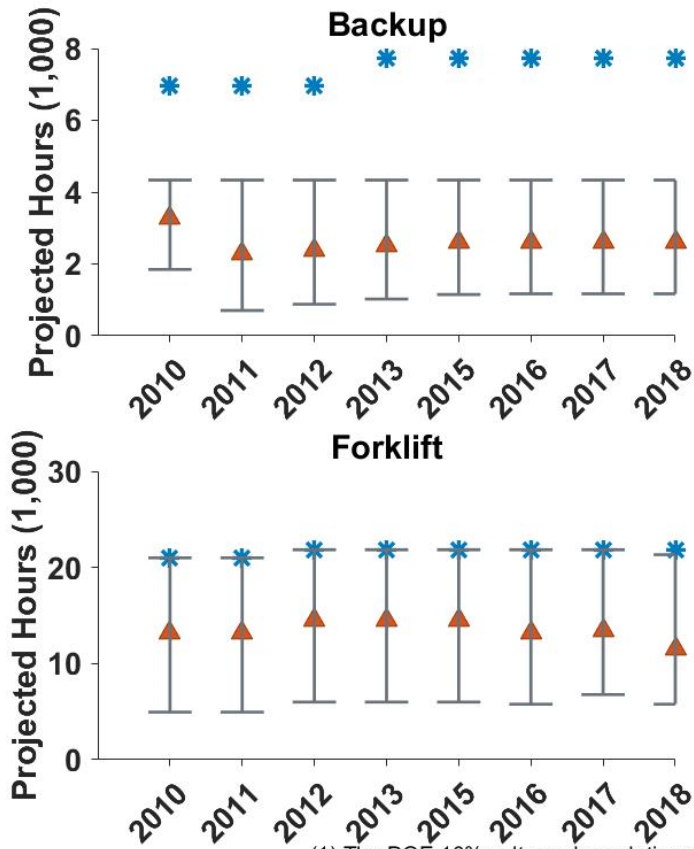
(1) The DOE 10% voltage degradation metric is used for assessing voltage degradation; it may not be the same as end-of-life criteria and does not address catastrophic failure modes.

(2) At least 23 developers supplied data, including international. Analysis is updated periodically. Durability results were not published in 2014.

Created: May-23-18 3:58 PM | Data Range: 2004Q1-2017Q4

CDP-LAB-17: Voltage Degradation by Year

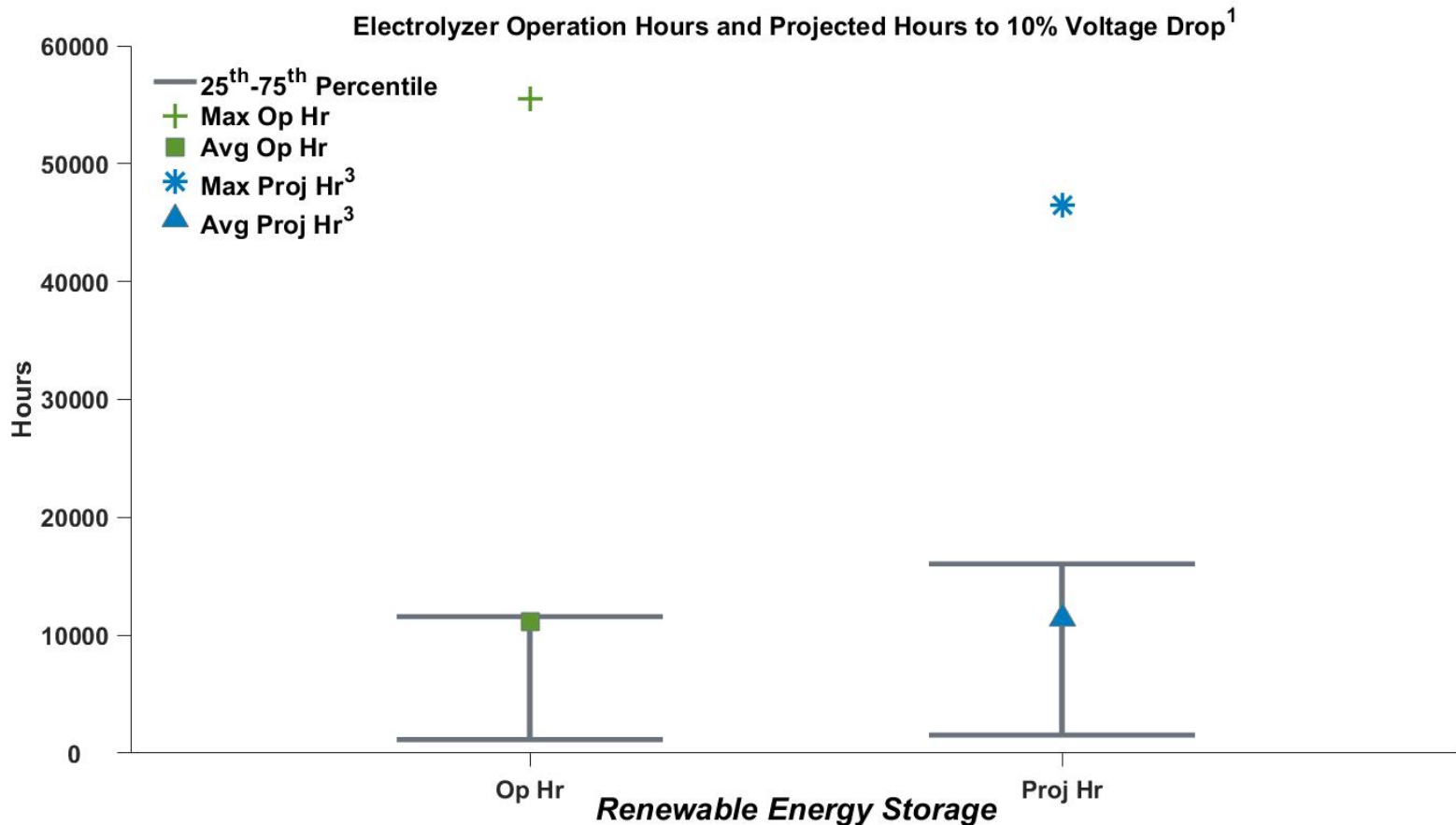
Projected Hours to 10% Voltage Drop^{1,2}



(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.



CDP-LAB-18: Electrolyzer Operation Hours and Voltage Degradation



(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.



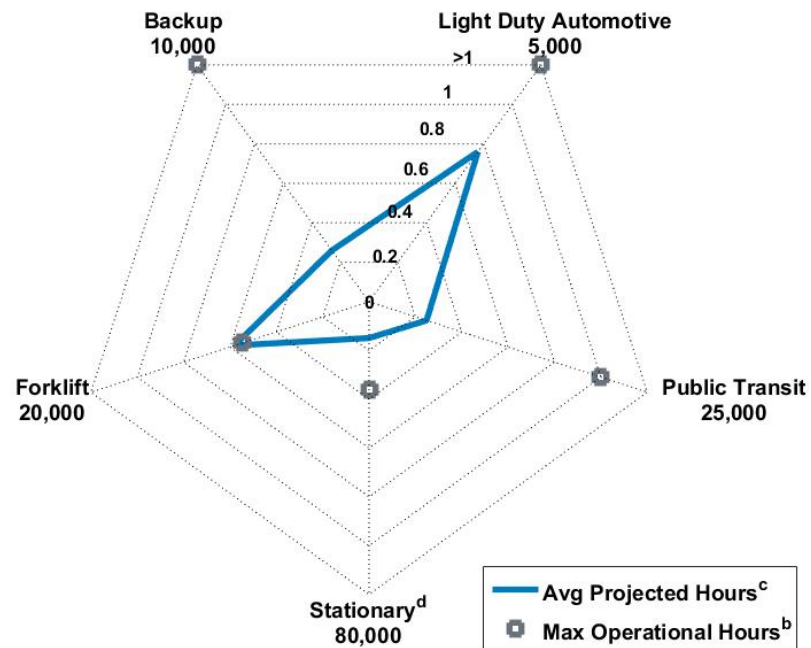
NREL cdp_lab_18

Created: May-23-18 3:59 PM | Data Range: 2004Q1-2017Q4

CDP-LAB-19: Lab Durability Summary Table

Lab Durability Summary Table

Application	2020 DOE Durability Target ^a	Lab Status - Ave Hrs to 10% Voltage Degradation ^b
Light Duty Automotive	5,000 Hours	3,800
Public Transit	25,000 Hours	6,200
Stationary	1-10 kW	0.3%/1,000 Hours
	100 kW - 3 MW	80,000 Hours
Forklift	20,000 Hours - Target Under Review	11,600
Backup	10,000 Hours	2,600



a. Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan (MYRDD)

<<https://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22>>

b. 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)

c. Results are a fraction of the 2020 targets in the MYRDD.

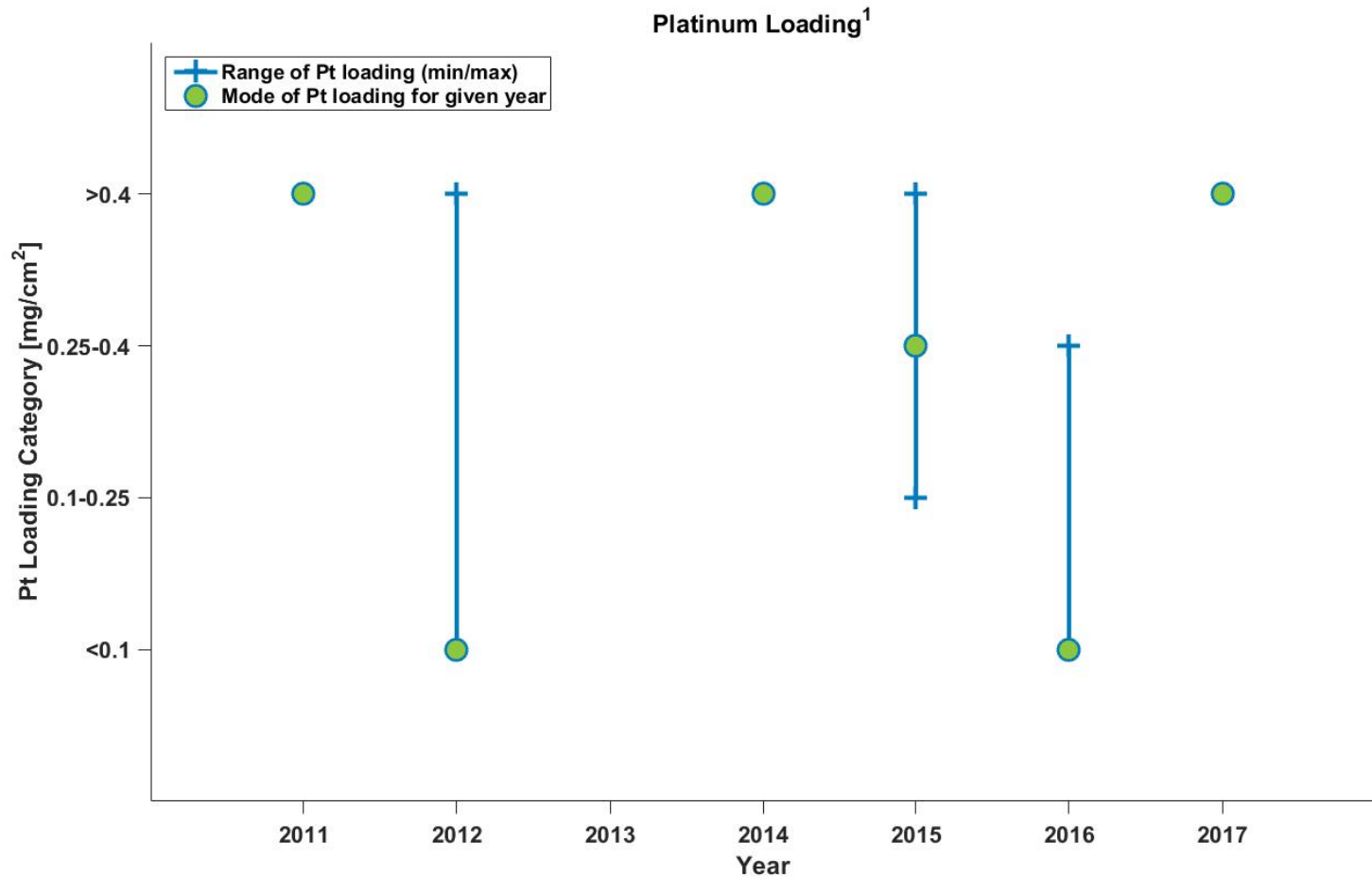
d. Stationary 100kW-3MW vs DOE target of 80,000 hrs.



NREL cdp_lab_19

Created: May-23-18 3:59 PM | Data Range: 2004Q1-2017Q4

CDP-LAB-20: Platinum Loading

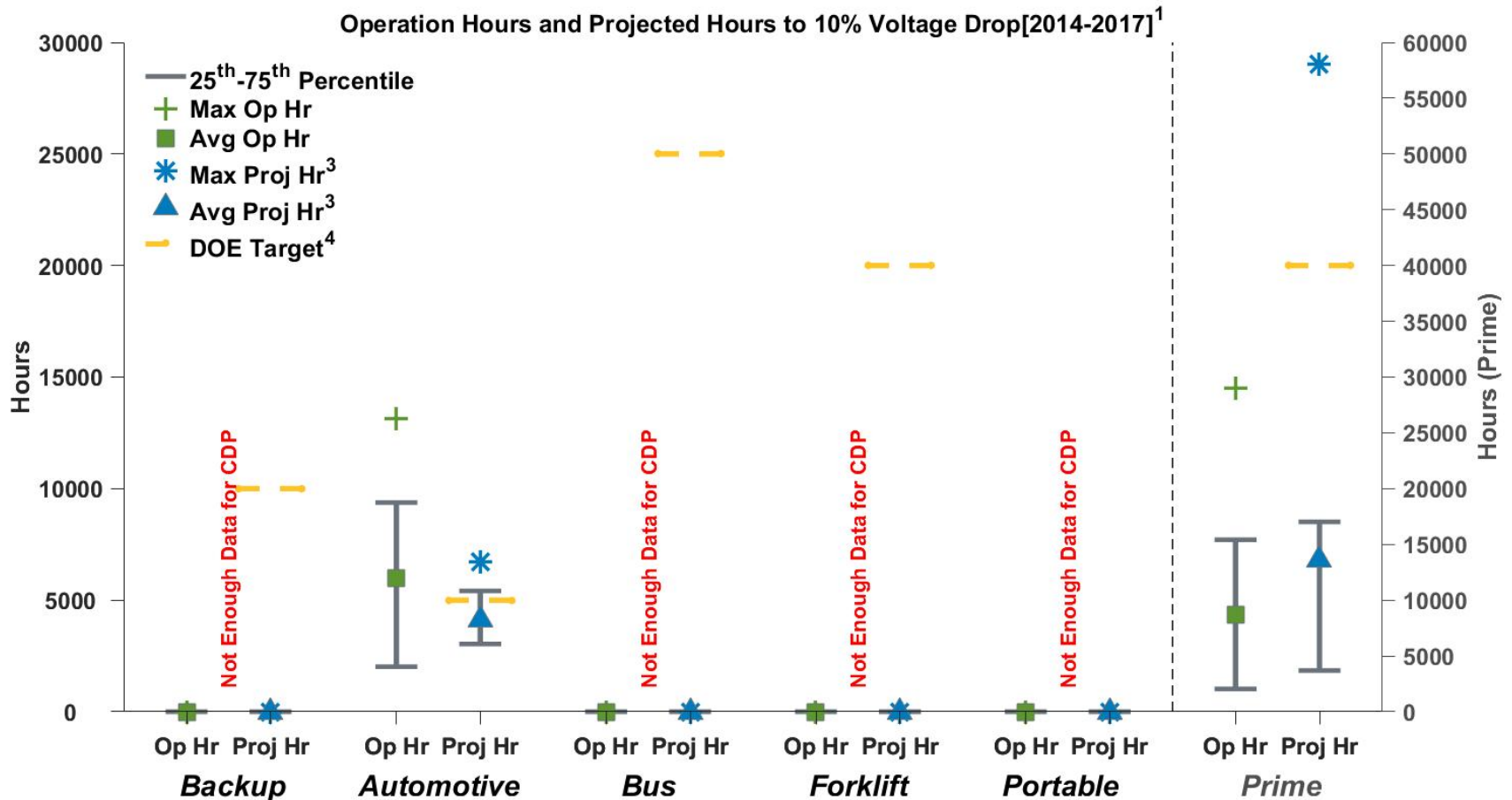


NREL cdp_lab_20

Created: May-23-18 3:59 PM | Data Range: 2004Q1-2017Q4

1. 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.



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