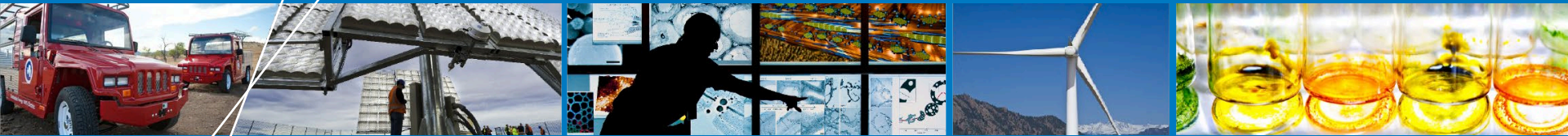# State-of-the-art Fuel Cell Voltage Durability Status
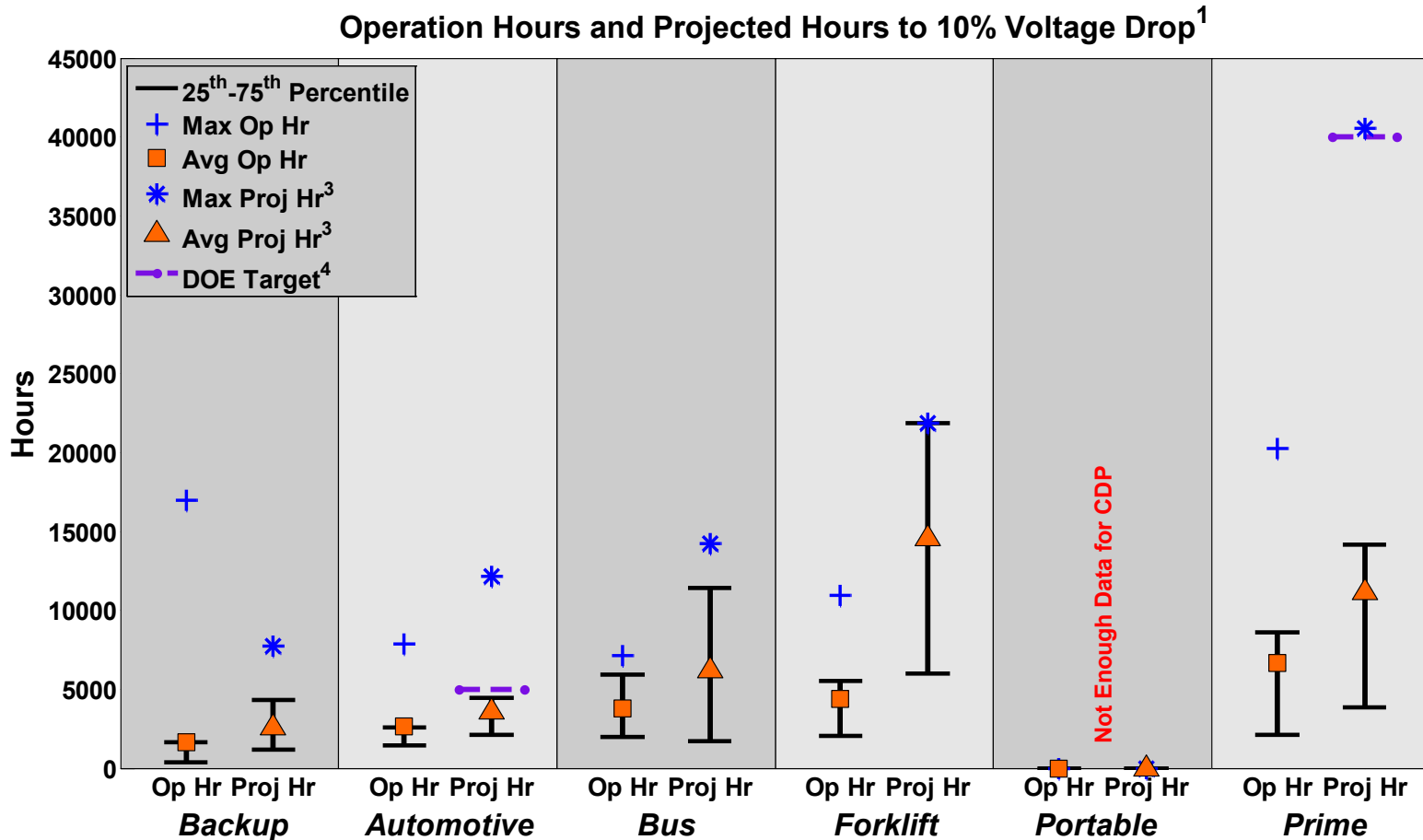
2015 Composite Data Products

Jennifer Kurtz, Huyen Dinh, Chris Ainscough, Genevieve Saur

May 2015

Operation Hours and Projected Hours to 10% Voltage Drop[1]

Legend:
- 25th-75th Percentile
- Max Op Hr
- Avg Op Hr
- Max Proj Hr[3]
- Avg Proj Hr[3]
- DOE Target[4]

Categories (Op Hr / Proj Hr): Backup, Automotive, Bus, Forklift, Portable (Not Enough Data for CDP), Prime

(1) At least 15 U.S. and international fuel cell developers supplied data. Analysis is updated periodically.
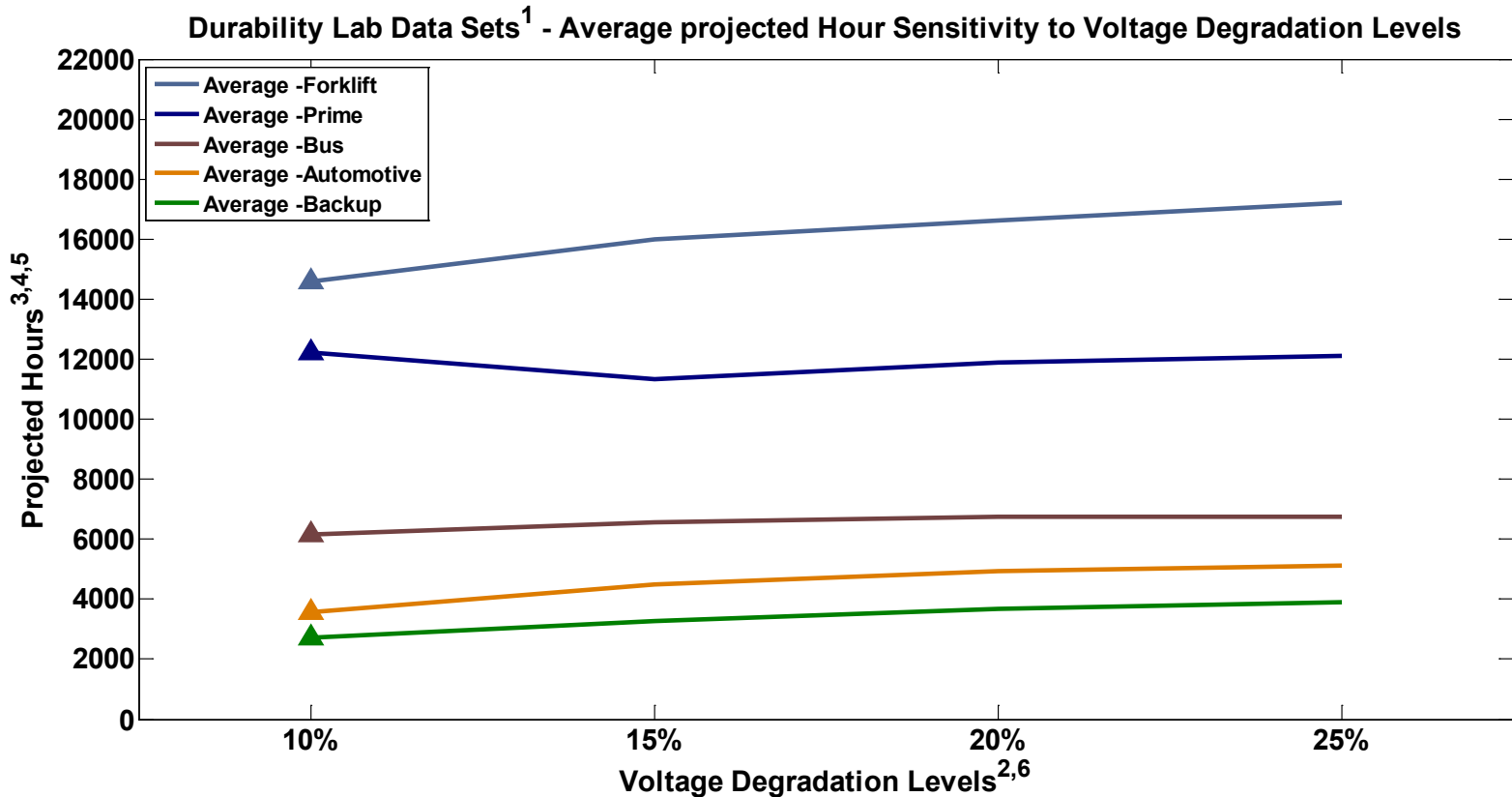(2) PEMFC, DMFC & SOFC data from lab tested, full active area short stacks and systems with full stacks. Data generated from constant load, transient load, and accelerated testing between 2004 and early 2012.
(3) The DOE 10% voltage degradation metric is used for assessing voltage degradation; it may 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.

NREL cdp_lab_01
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CDP-LAB-02: Durability Lab Data Projection Sensitivity to Voltage Degradation Levels

Durability Lab Data Sets[1] - Average projected Hour Sensitivity to Voltage Degradation Levels

Legend:
- Average -Forklift
- Average -Prime
- Average -Bus
- Average -Automotive
- Average -Backup

Y-axis: Projected Hours[3,4,5] (0 to 22000)
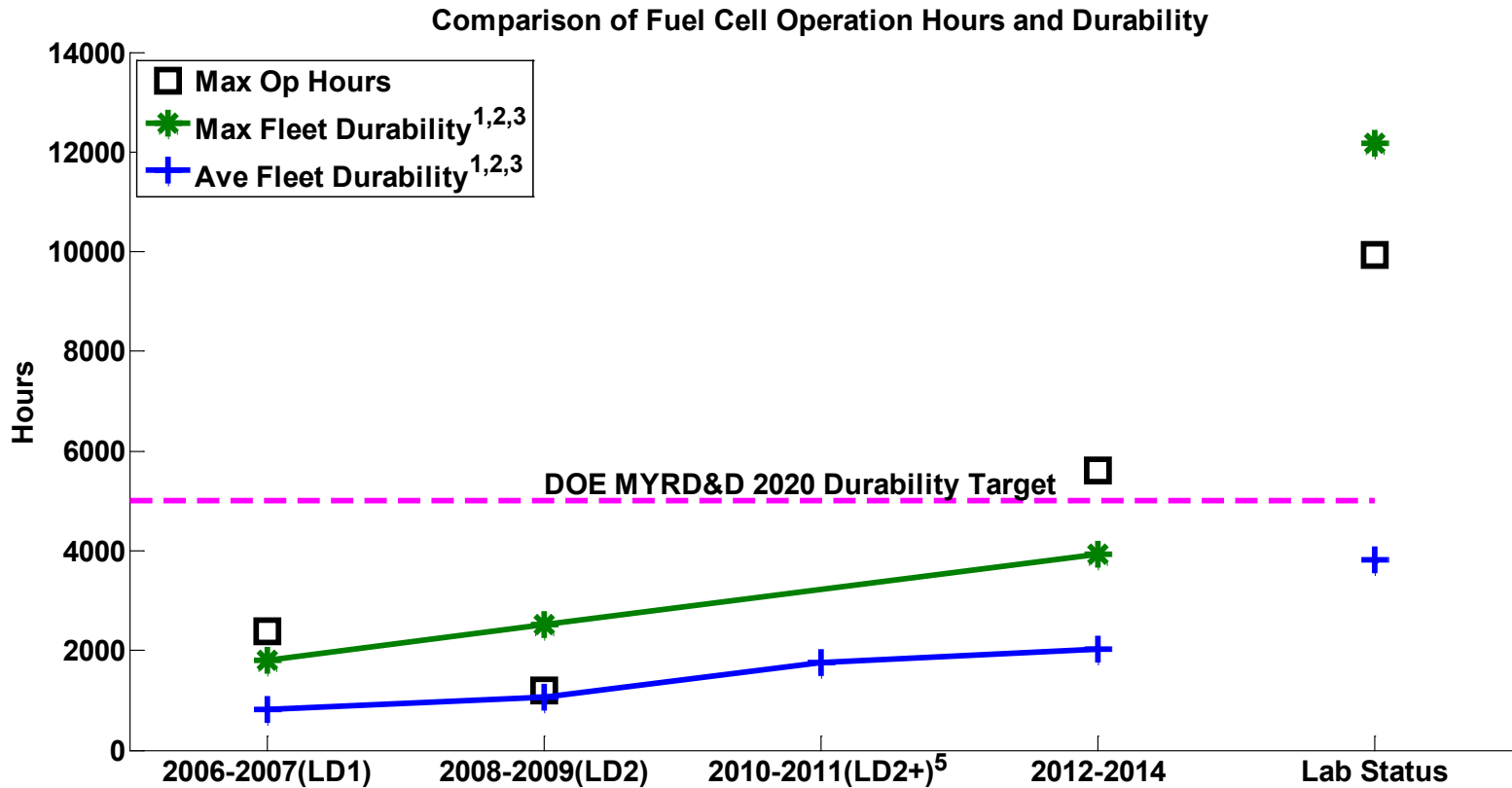X-axis: Voltage Degradation Levels[2,6] (10%, 15%, 20%, 25%)

(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 2012.
(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.

NREL cdp_lab_02
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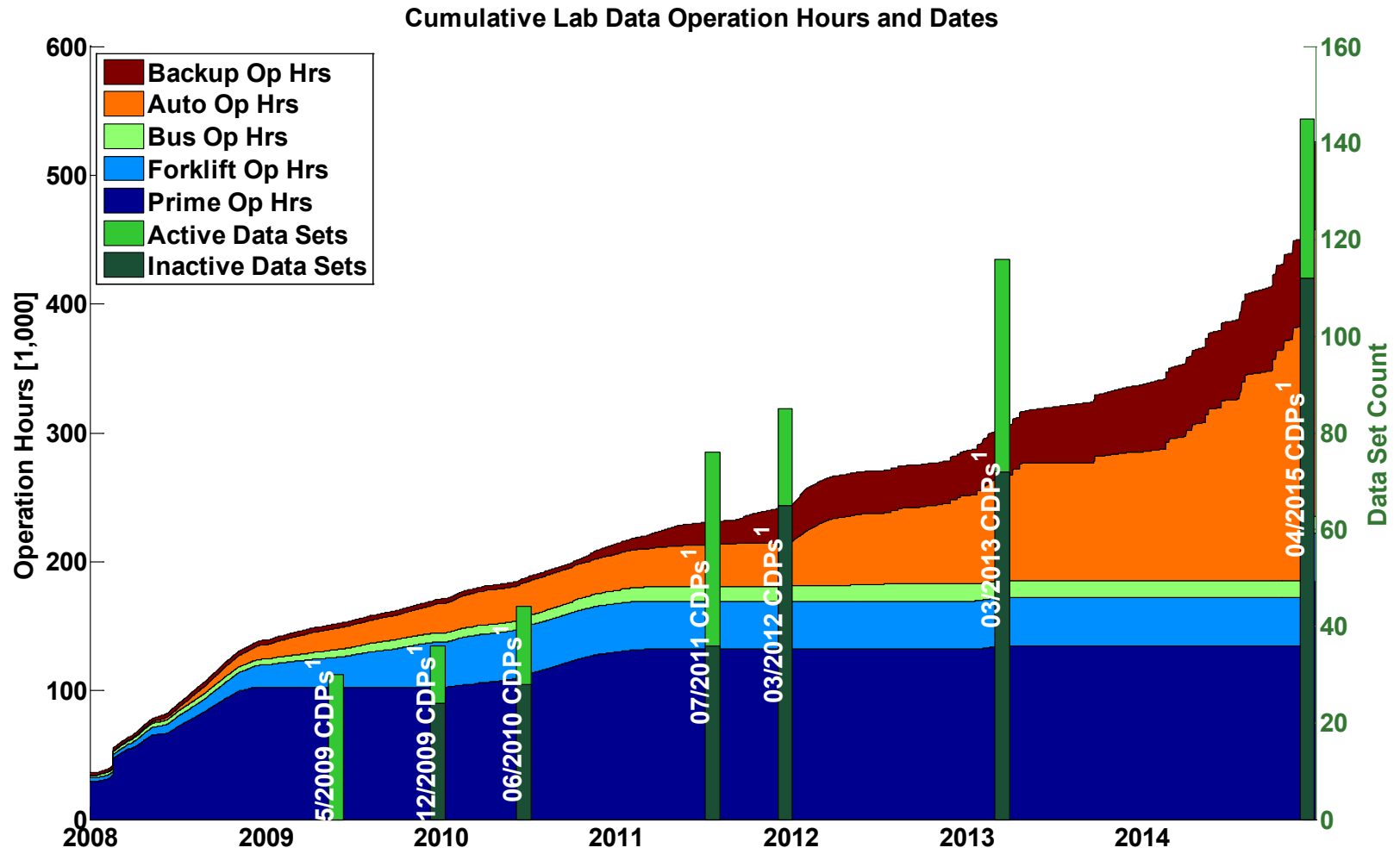# CDP-LAB-03: Field and Lab Durability Projection Comparison for Automotive Category

Comparison of Fuel Cell Operation Hours and Durability

Legend:
- □ Max Op Hours
- ✳ Max Fleet Durability[1,2,3]
- ✛ Ave Fleet Durability[1,2,3]

Y-axis: Hours (0 to 14000)

X-axis categories: 2006-2007(LD1), 2008-2009(LD2), 2010-2011(LD2+)[5], 2012-2014, Lab Status

DOE MYRD&D 2020 Durability Target

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) Percent increases are calculated relative to LD1 (2006-2007).
5) Maximum operational hours not reported in LD2+ (2010-2011).

NREL cdp_lab_03
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Cumulative Lab Data Operation Hours and Dates
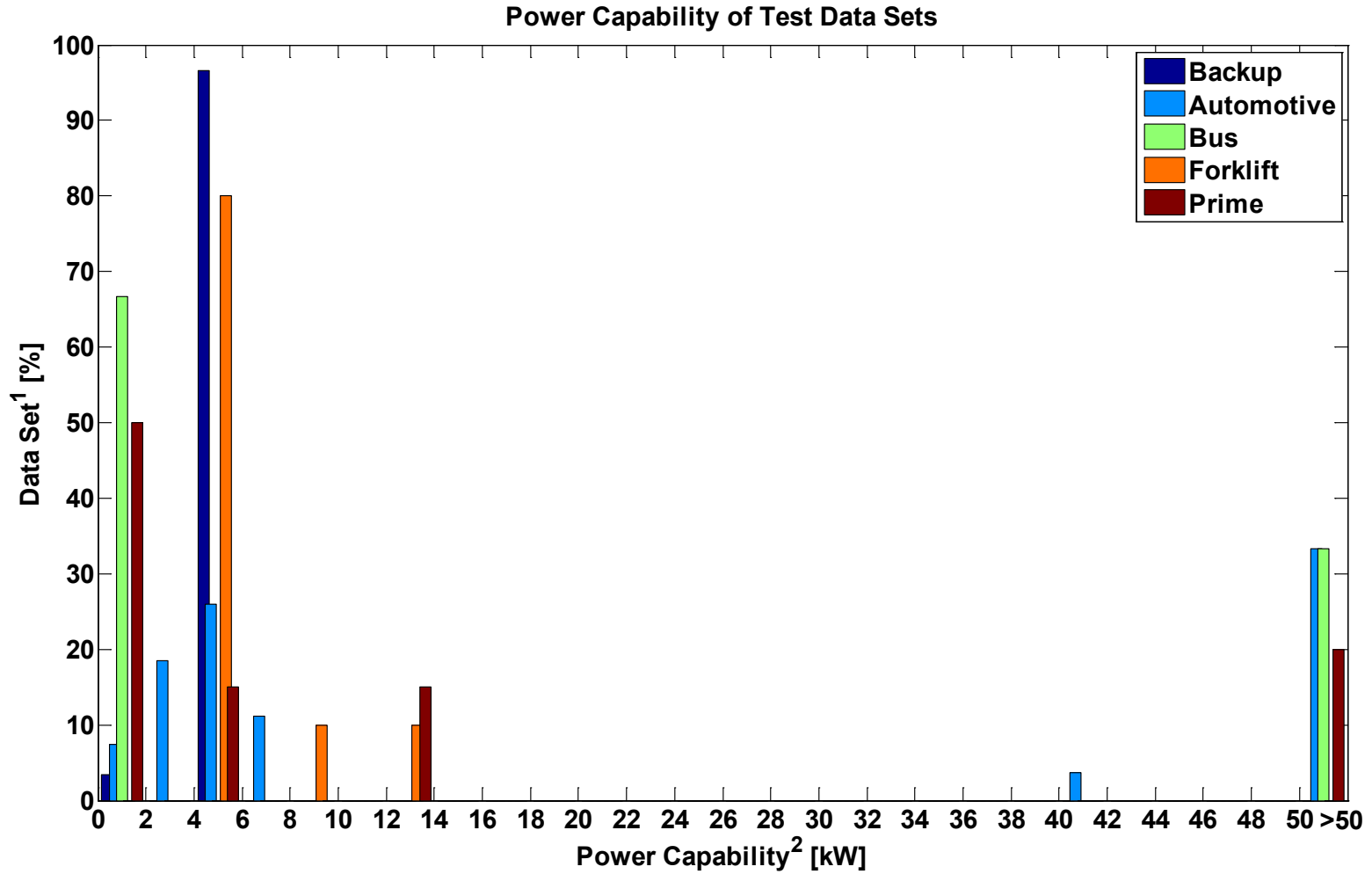
1) Data set count at publication of a CDP set - where a data set represents a short stack, full stack, or system test data.
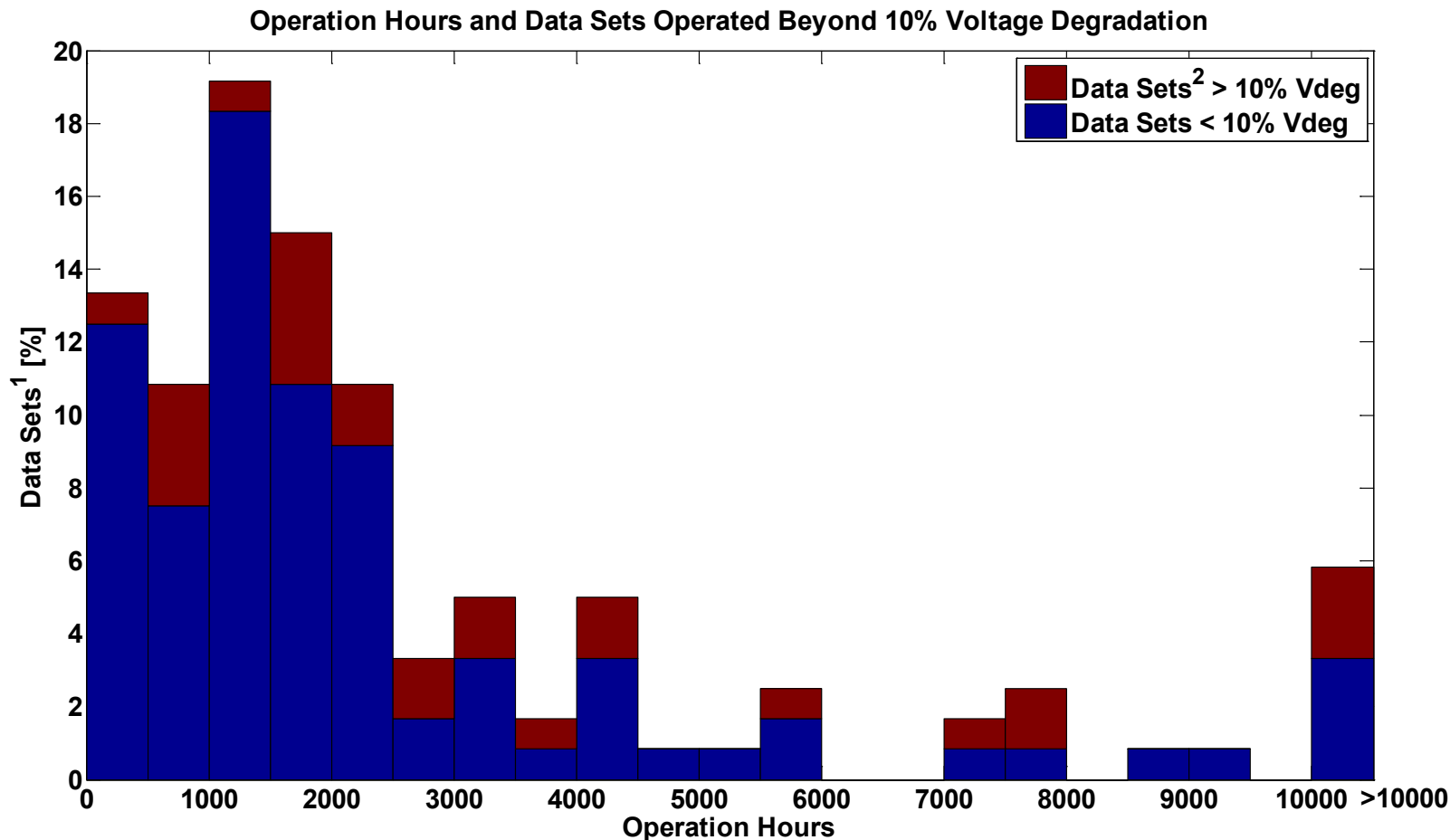
Power Capability of Test Data Sets

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.

NREL cdp_lab_06
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CDP-LAB-07: Data Set Operation Hours and Percentage of Data Sets That Have Passed 10% Voltage Degradation

Operation Hours and Data Sets Operated Beyond 10% Voltage Degradation

Legend:
- Data Sets[2] > 10% Vdeg
- Data Sets < 10% Vdeg

Y-axis: Data Sets[1] [%]
X-axis: Operation Hours

NREL cdp_lab_07
Created: May-11-15 12:17 PM

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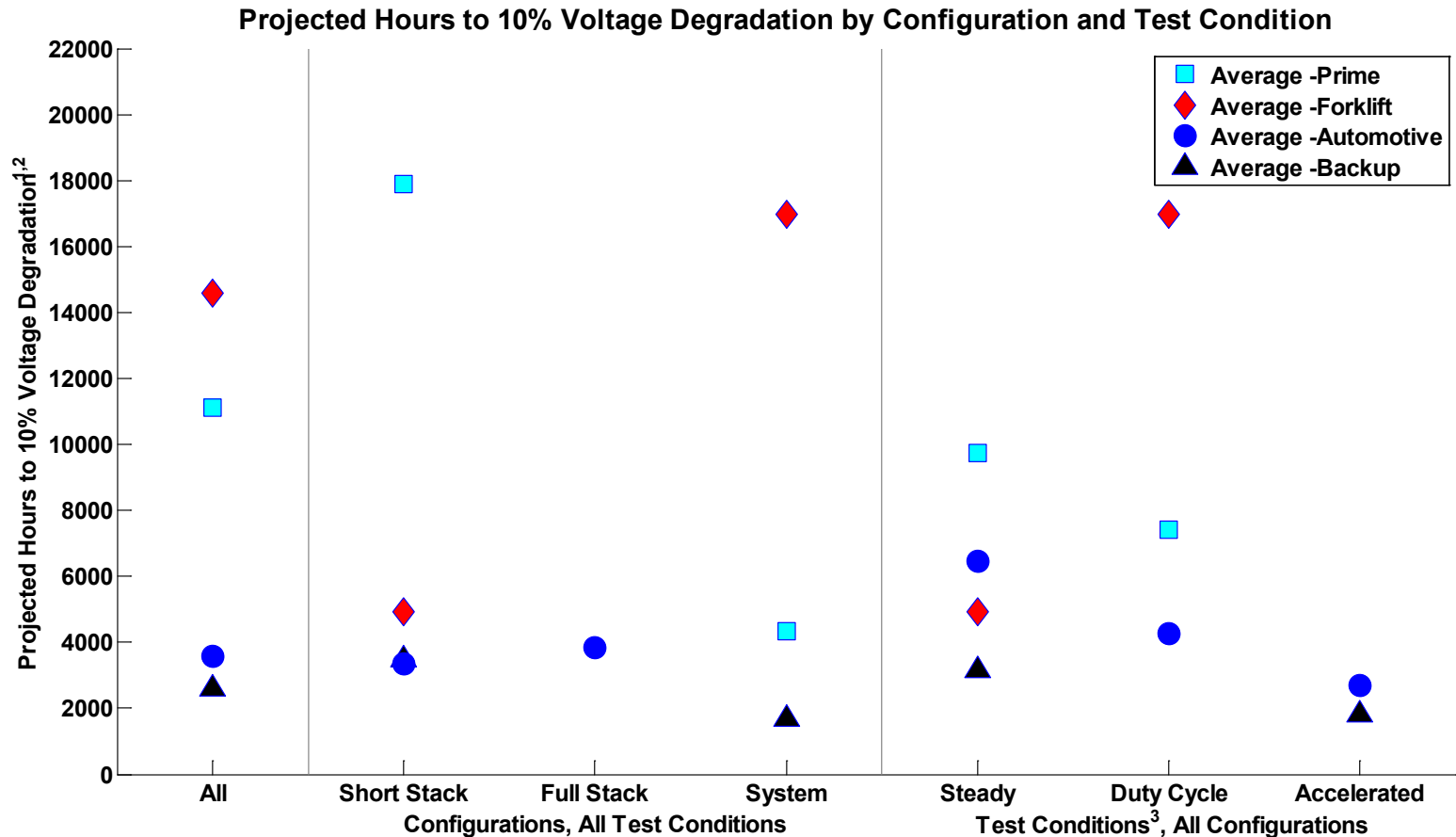   Some data sets have operated beyond 10% voltage degradation because they are able to satisfy the operating requirements
   at a higher percentage of voltage degradation or the test is designed to operate until a failure.

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

Projected Hours to 10% 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
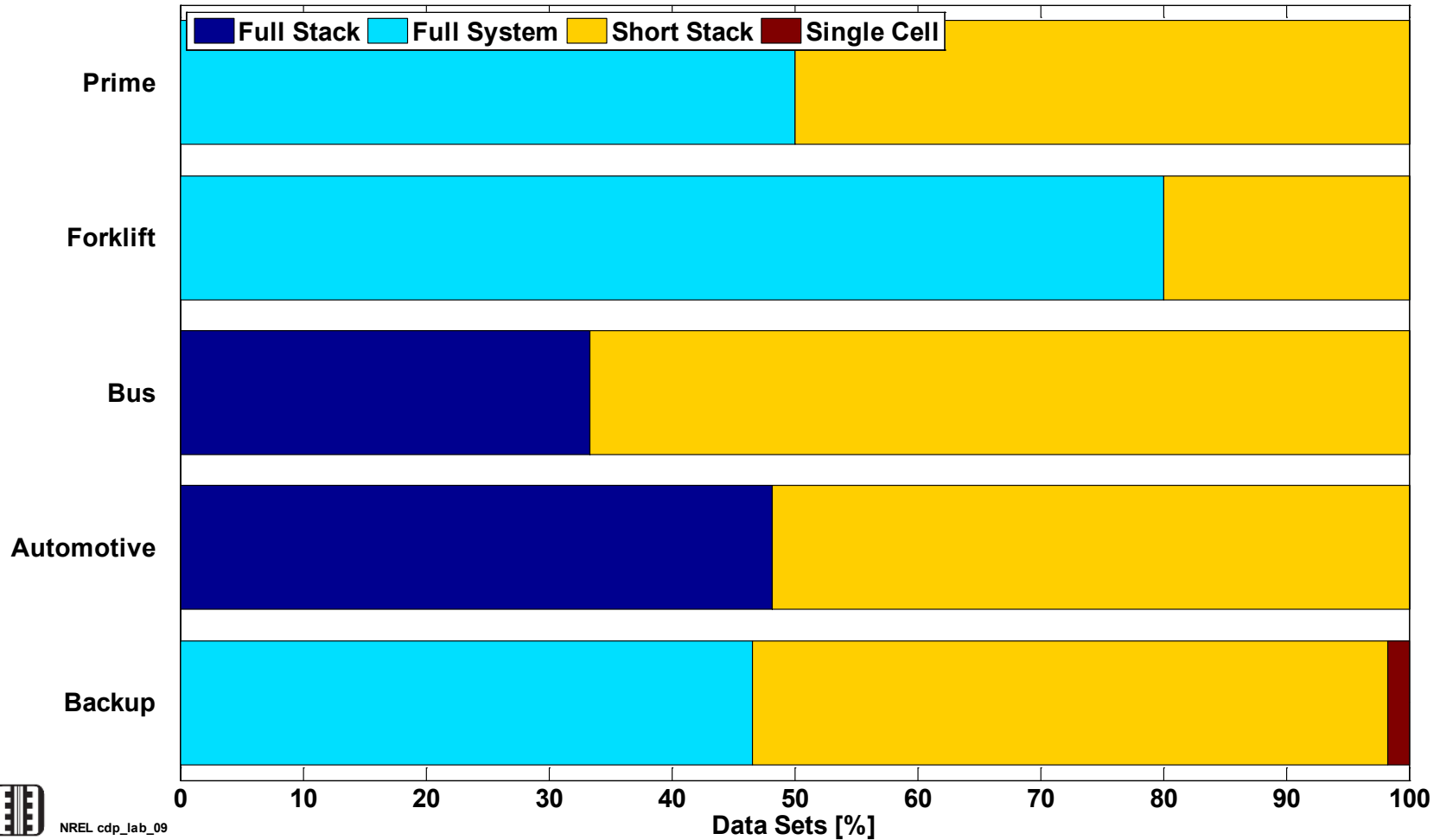
NREL cdp_lab_08
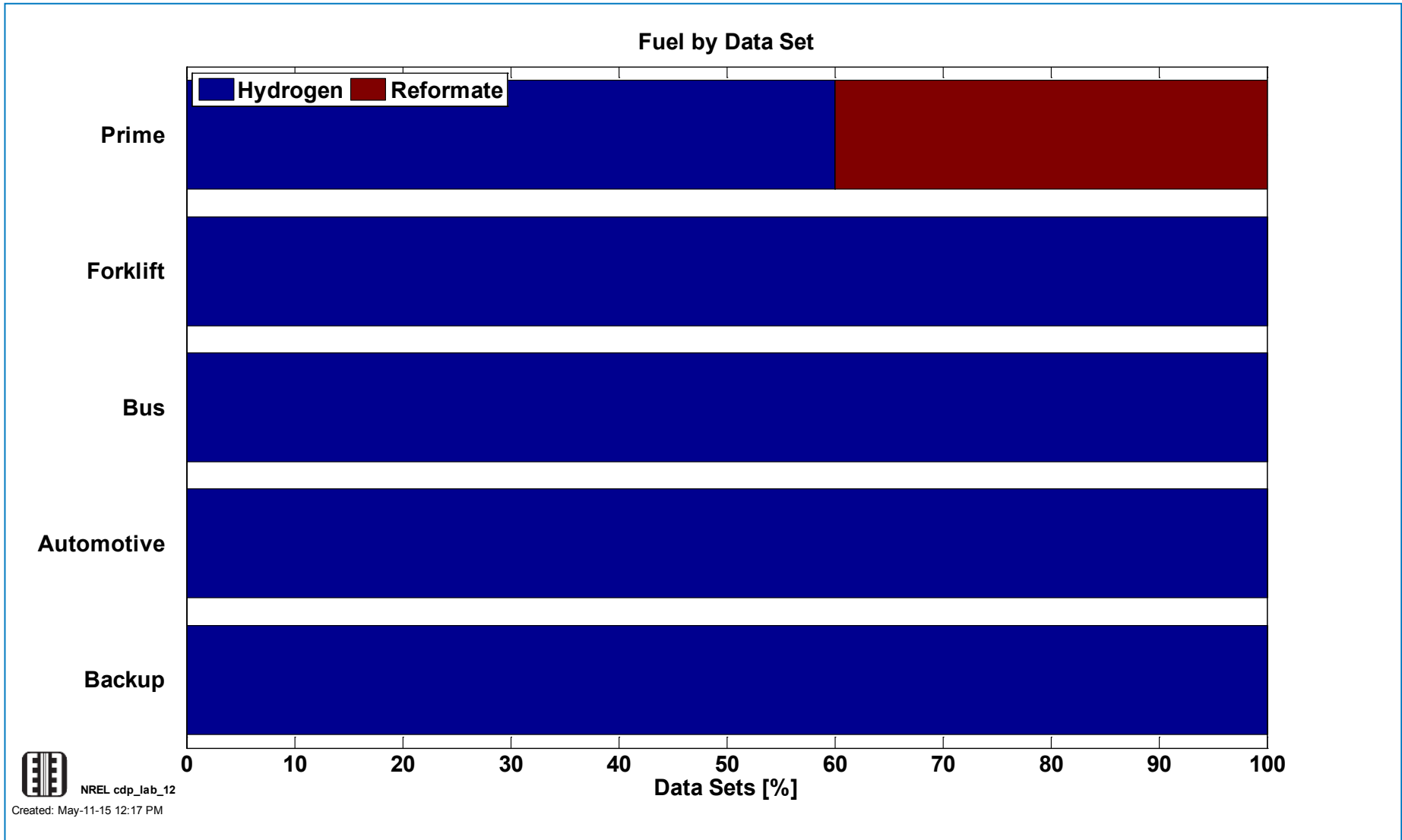Created: May-11-15 12:17 PM

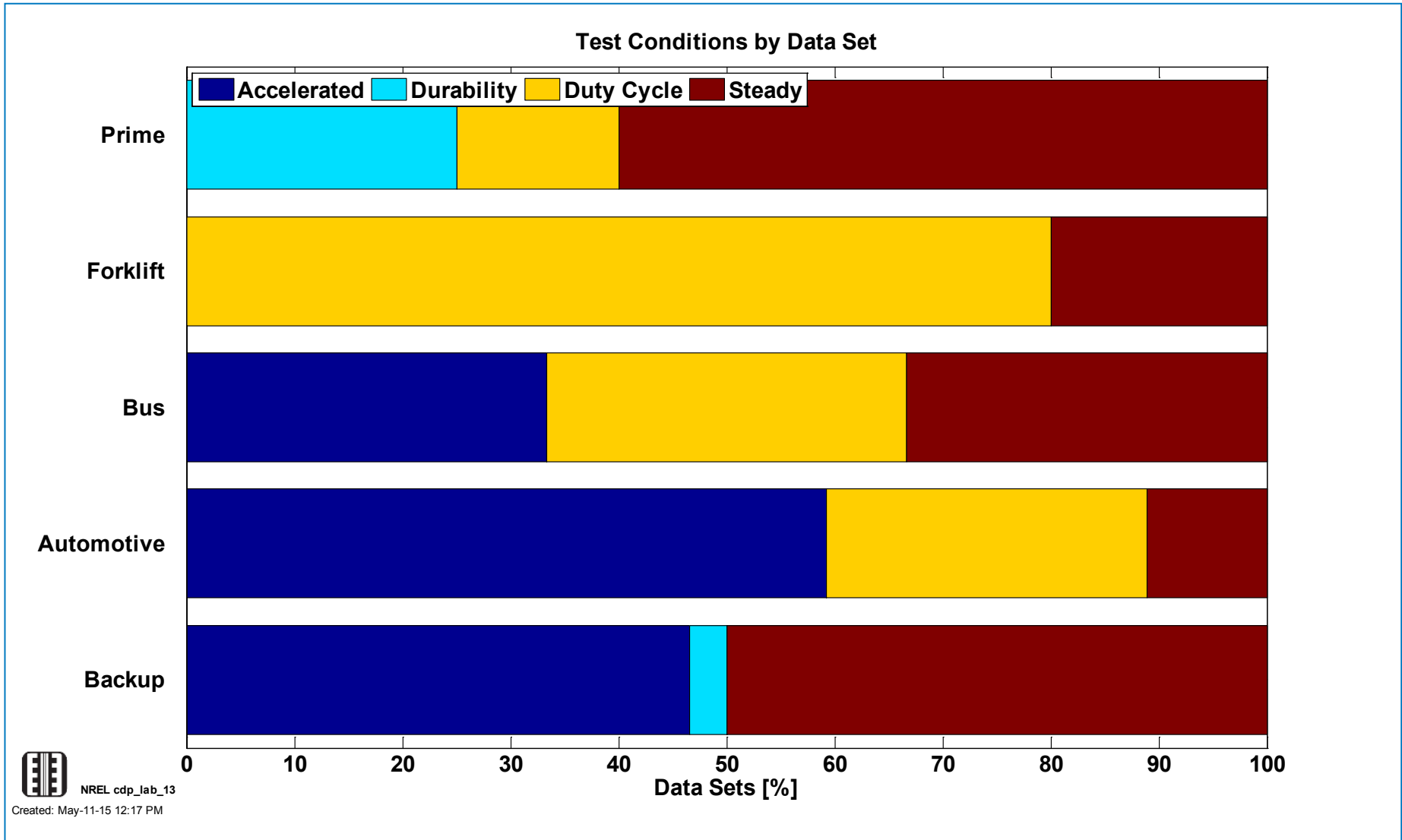# CDP-LAB-09: Data Set Configuration

Configurations by Data Set

Fuel by Data Set

CDP-LAB-13: Data Set Test Conditions

Test Conditions by Data Set

NREL cdp_lab_13
Created: May-11-15 12:17 PM

CDP-LAB-14: Current Density Points

Current Density Point by Data Set[1]

Legend: <=0.2 [A/cm^2], <=0.4 [A/cm^2], <=0.6 [A/cm^2], <=0.8 [A/cm^2], <=1.0 [A/cm^2], <=1.2 [A/cm^2]

Categories: Prime, Forklift, Automotive, Backup
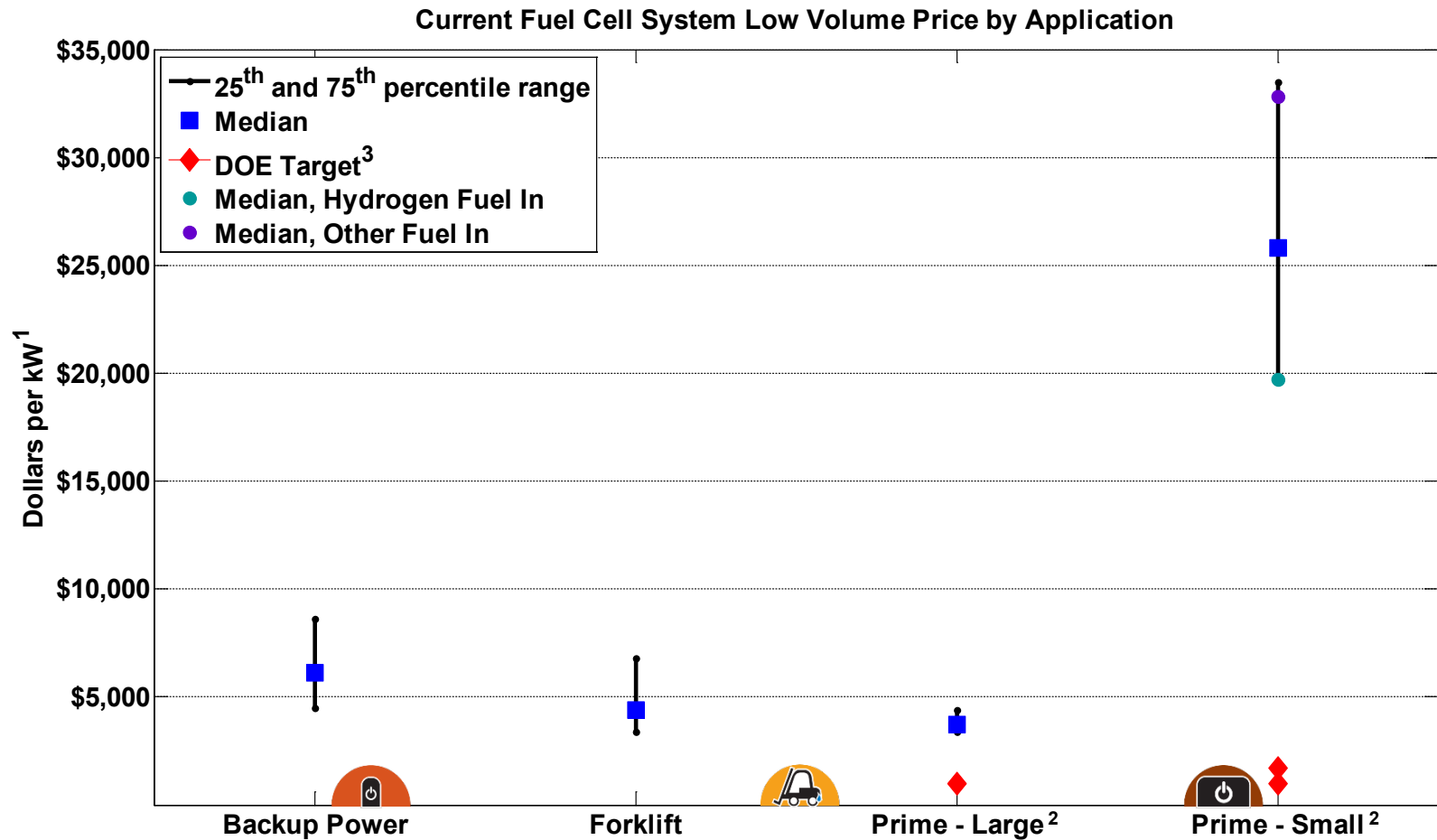
X-axis: Data Sets [%] (0 to 100)

NREL cdp_lab_14
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1) Current density referenced are the points at which the voltage degradation is analyzed in CDP Lab 01

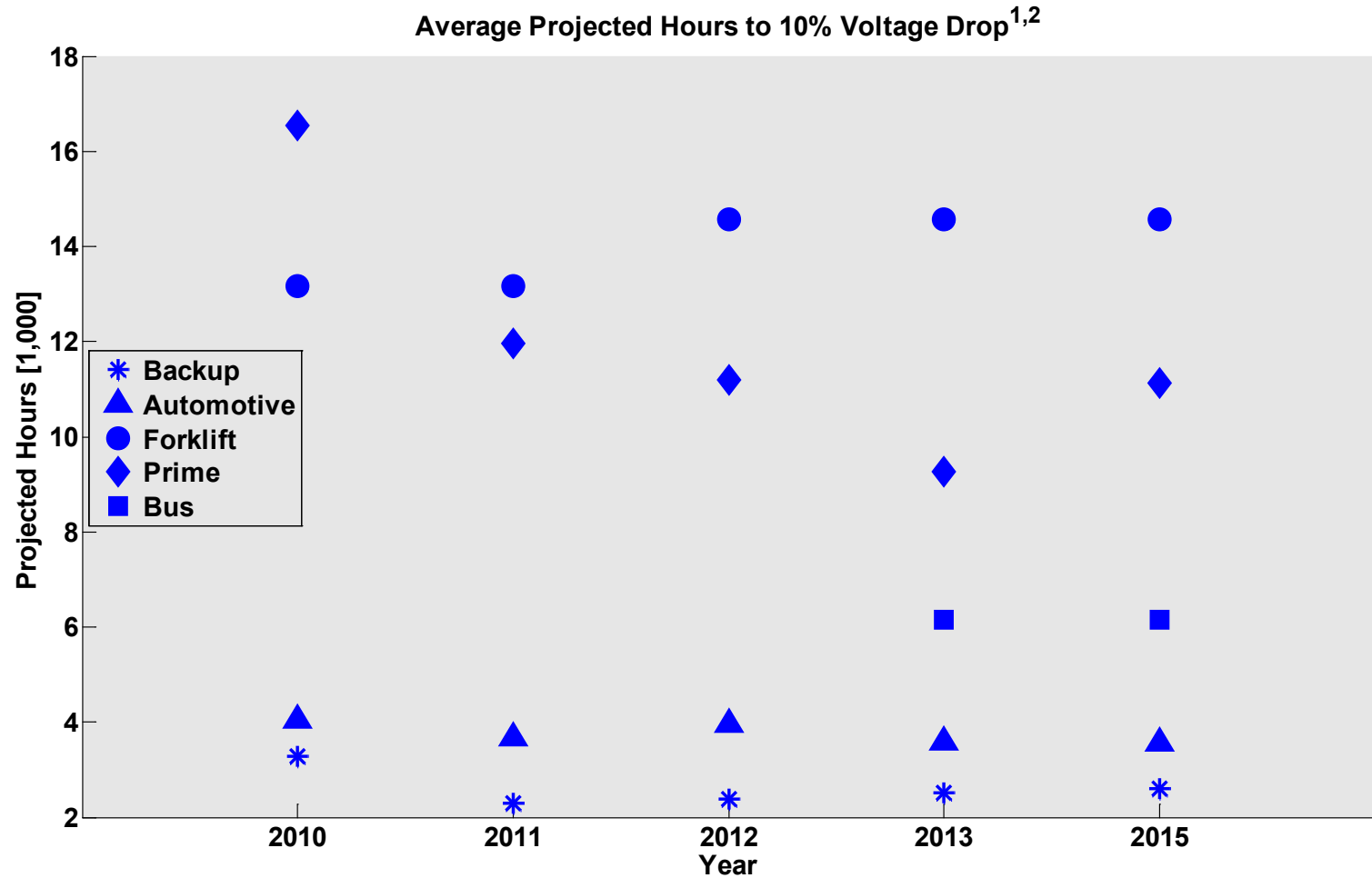# CDP-LAB-15: Low Volume Cost of Current Fuel Cell Systems

Current Fuel Cell System Low Volume Price by Application

Legend:
- 25th and 75th percentile range
- Median
- DOE Target[3]
- Median, Hydrogen Fuel In
- Median, Other Fuel In

Y-axis: Dollars per kW[1] ($35,000 to $0)

X-axis categories: Backup Power, Forklift, Prime - Large[2], Prime - Small[2]

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

Average Projected Hours to 10% Voltage Drop[1,2]

Legend:
- ✳ Backup
- ▲ Automotive
- ● Forklift
- ◆ Prime
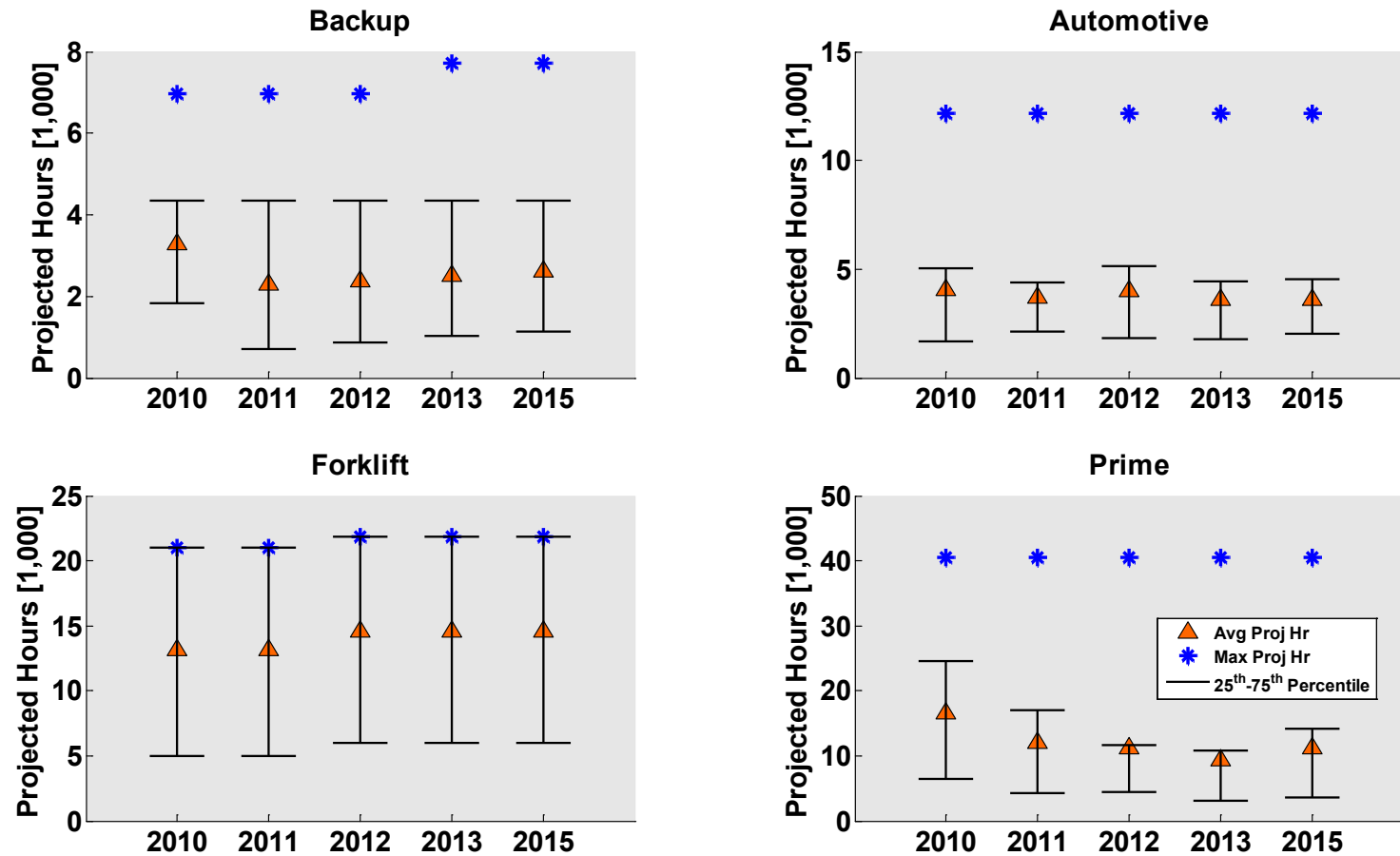- ■ Bus

Y-axis: Projected Hours [1,000]
X-axis: Year (2010, 2011, 2012, 2013, 2015)

(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.

NREL cdp_lab_16
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Projected Hours to 10% Voltage Drop[1,2]