

# **Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project**

*Fall 2007*

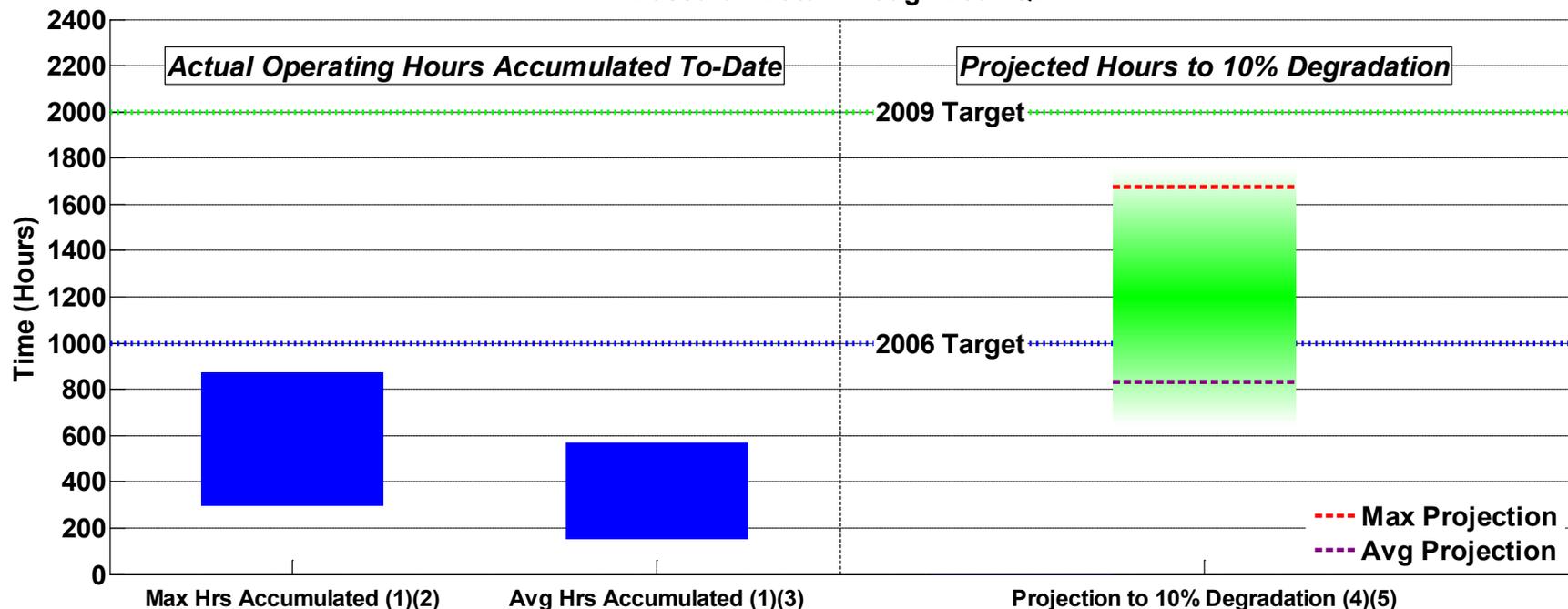
*Composite Data Products*

*September 13, 2007*

Keith Wipke, Sam Sprik, Jennifer Kurtz, Holly Thomas

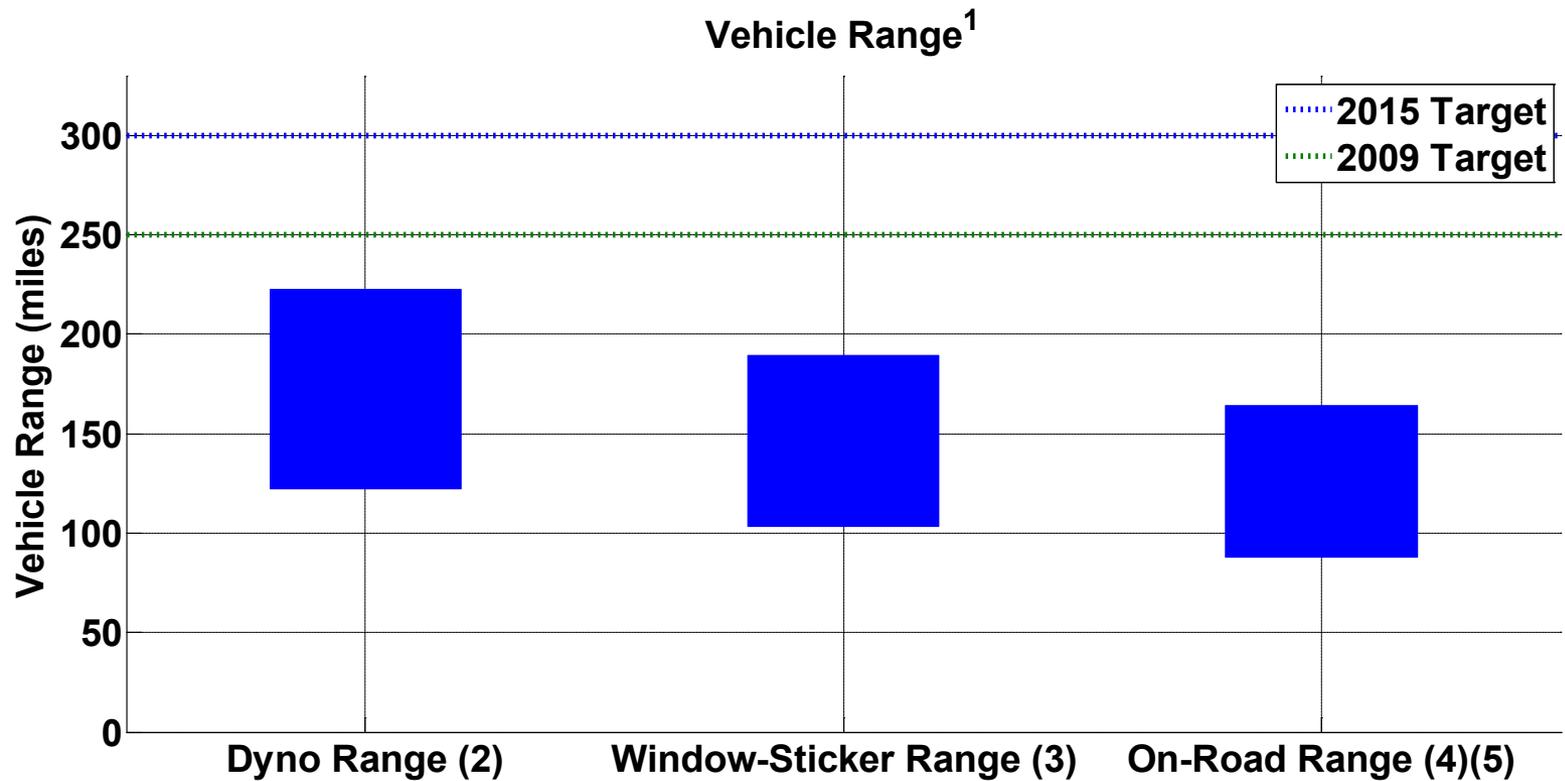
# CDP#1: Hours Accumulated and Projected Hours to 10% Stack Voltage Degradation

DOE Learning Demonstration Fuel Cell Stack Durability:  
Based on Data Through 2007 Q2



- (1) Range bars created using one data point for each OEM.
- (2) Range (highest and lowest) of the maximum operating hours accumulated to-date of any OEM's individual stack in "real-world" operation.
- (3) Range (highest and lowest) of the average operating hours accumulated to-date of all stacks in each OEM's fleet.
- (4) Projection using on-road data -- degradation calculated at high stack current. This criterion is used for assessing progress against DOE targets, may differ from OEM's end-of-life criterion, and does not address "catastrophic" failure modes, such as membrane failure.
- (5) Using one nominal projection per OEM: "Max Projection" = highest nominal projection, "Avg Projection" = average nominal projection.  
The shaded green bar represents an engineering judgment of the uncertainty due to data and methodology limitations. Projections will change as additional data are accumulated.

# CDP#2: Vehicle Range



(1) Range is based on fuel economy and usable hydrogen on-board the vehicle. One data point for each make/model.

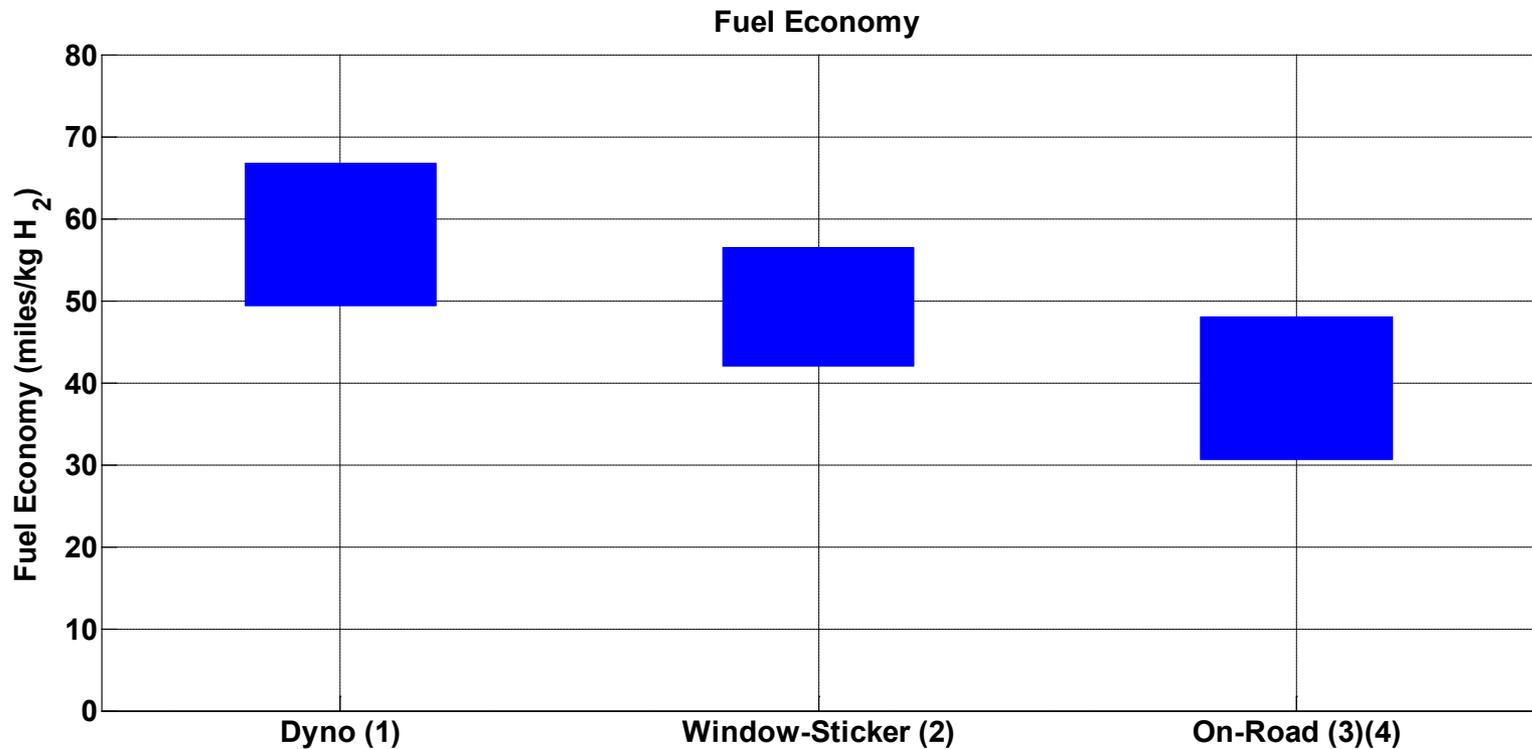
(2) Fuel economy from unadjusted combined City/Hwy per DRAFT SAE J2572.

(3) Fuel economy from EPA Adjusted combined City/Hwy (0.78 x Hwy, 0.9 x City).

(4) Excludes trips < 1 mile. One data point for on-road fleet average of each make/model.

(5) Fuel economy calculated from on-road fuel cell stack current or mass flow readings.

# CDP#6: Fuel Economy



(1) One data point for each make/model. Combined City/Hwy fuel economy per DRAFT SAE J2572.

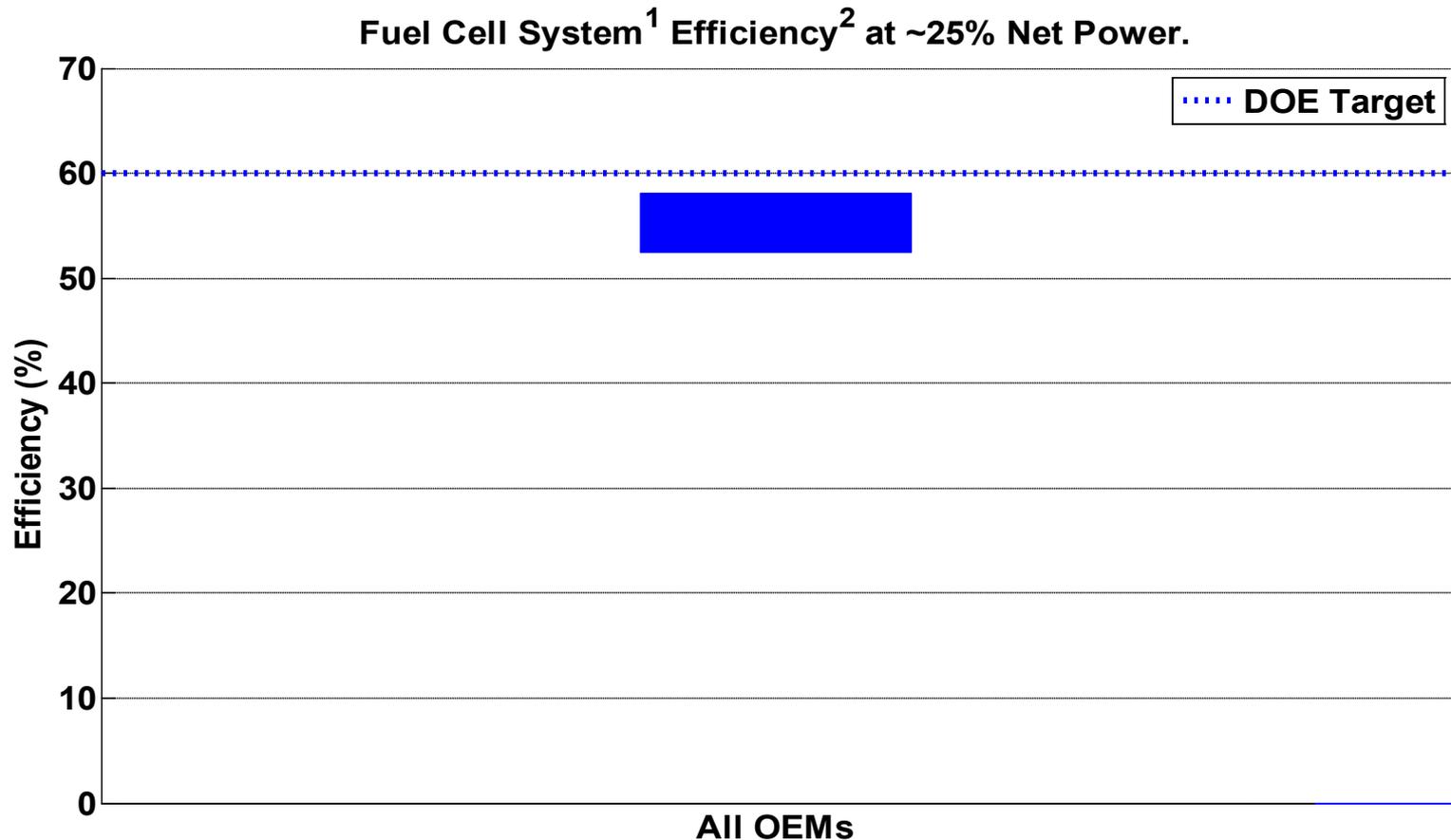
(2) Adjusted combined City/Hwy fuel economy (0.78 x Hwy, 0.9 x City).

(3) Excludes trips < 1 mile. One data point for on-road fleet average of each make/model.

(4) Calculated from on-road fuel cell stack current or mass flow readings.

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# CDP#8: FC System Efficiency

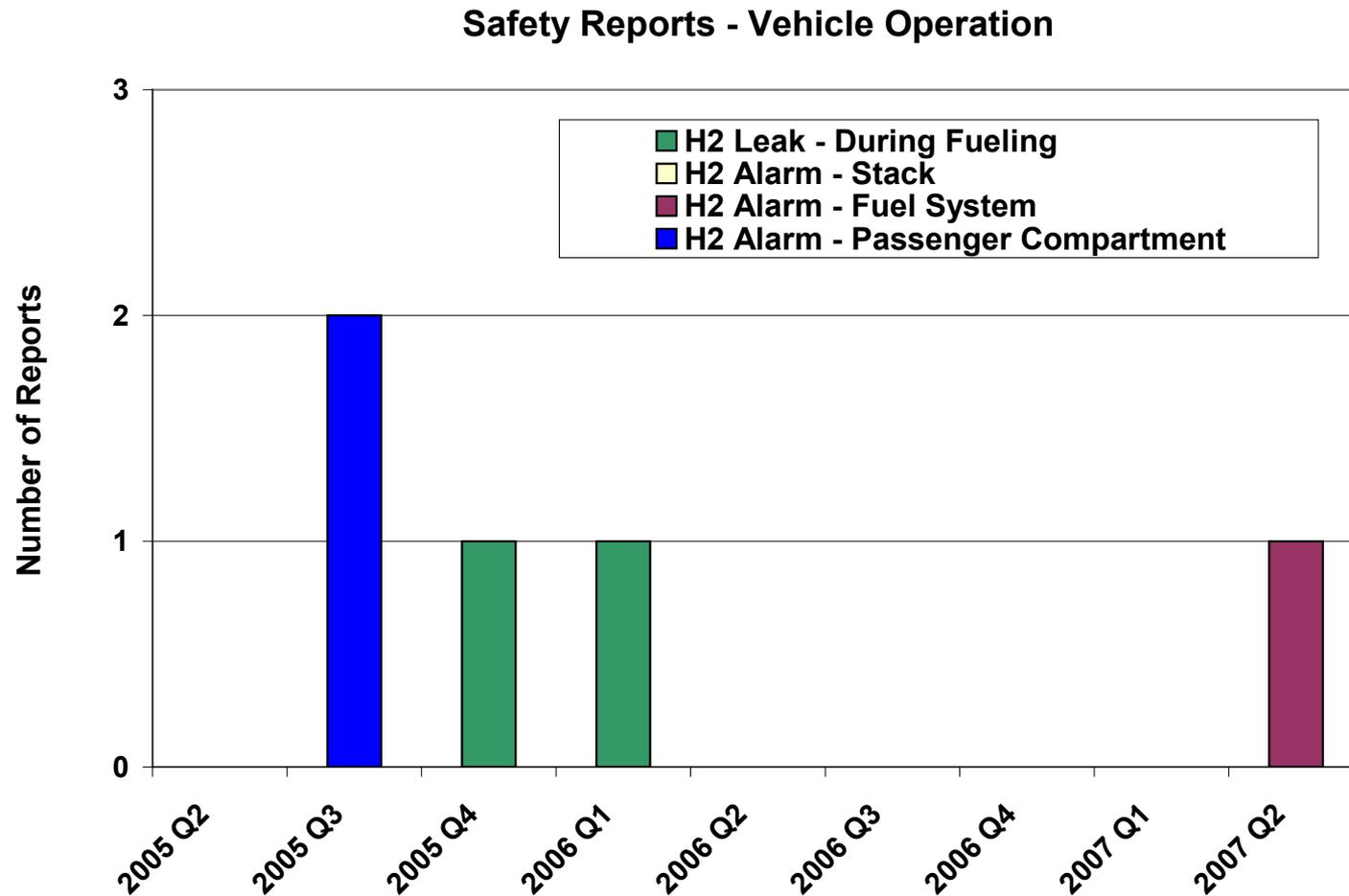


<sup>1</sup> Gross stack power minus fuel cell system auxiliaries, per DRAFT SAEJ2615.

<sup>2</sup> Ratio of DC output energy to the lower heating value of the input fuel (hydrogen). Excludes power electronics and electric drive.

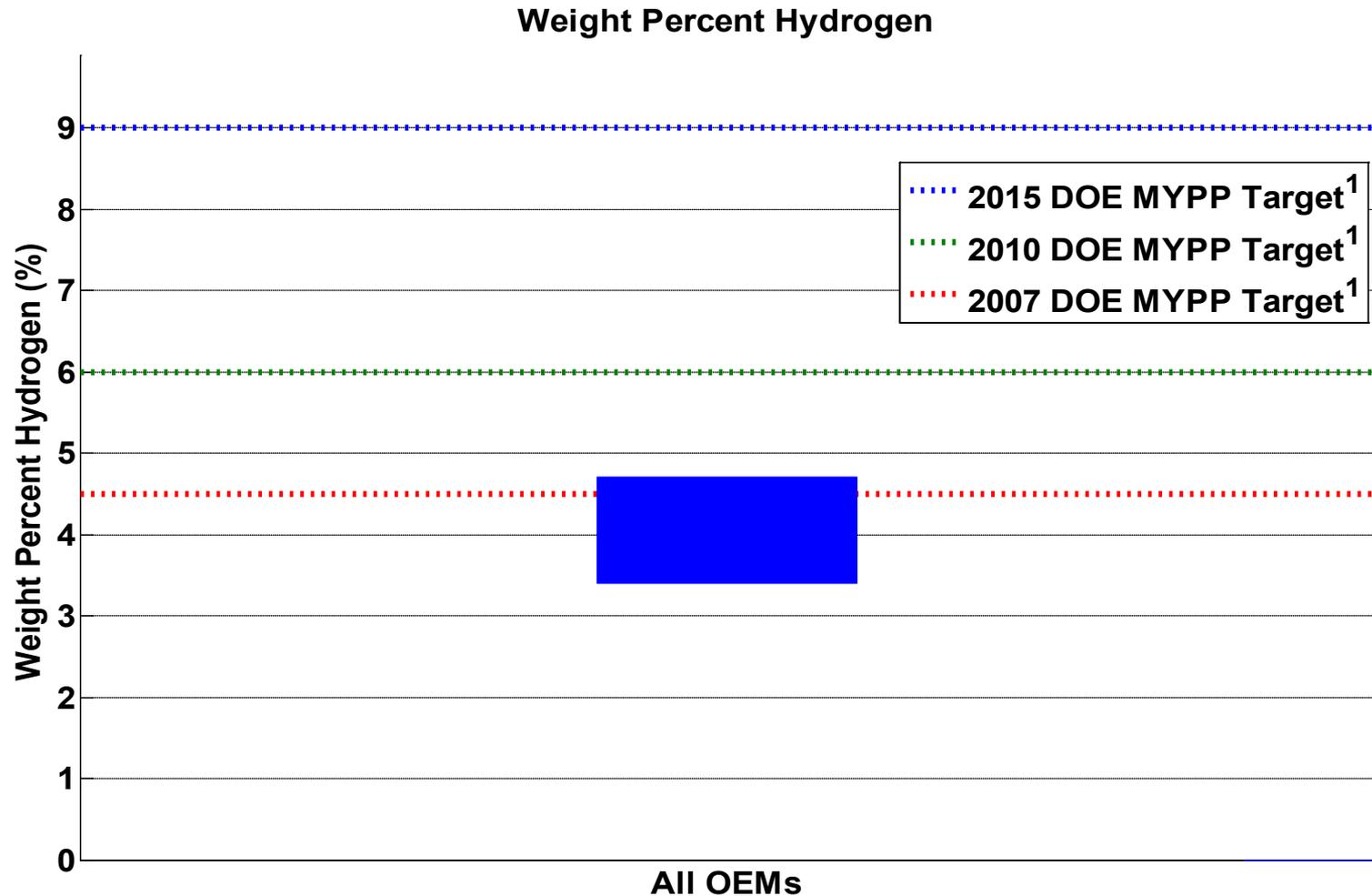
Created: Aug-29-06 4:09 PM

# CDP#9: Safety Reports – Vehicles



Created: 8/23/07 7:51PM

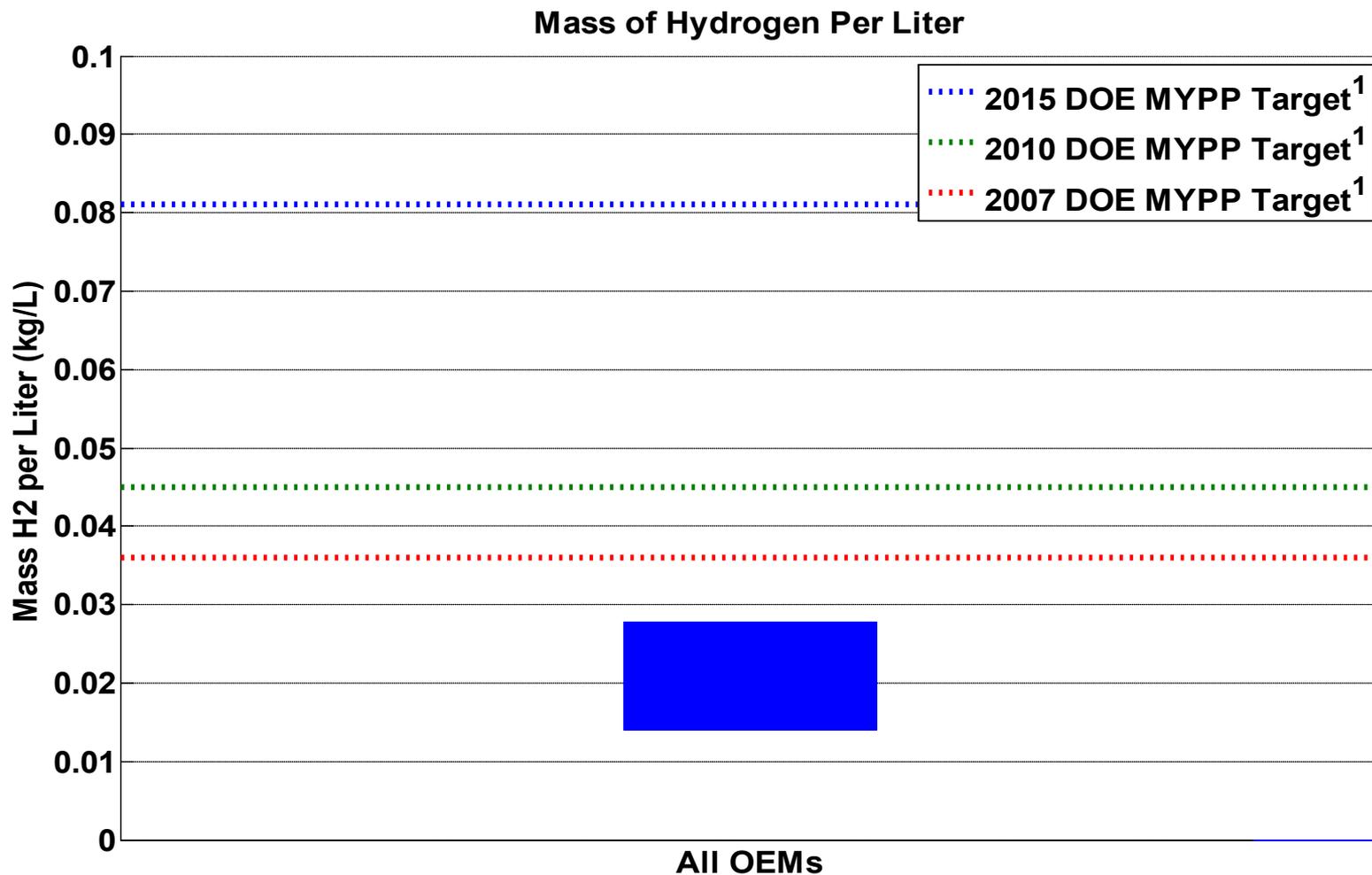
# CDP#10: Storage Weight % Hydrogen



Created: 23-Feb-2006

<sup>1</sup>Some near-term targets have been achieved with compressed and liquid tanks. Emphasis is on advanced materials-based technologies.

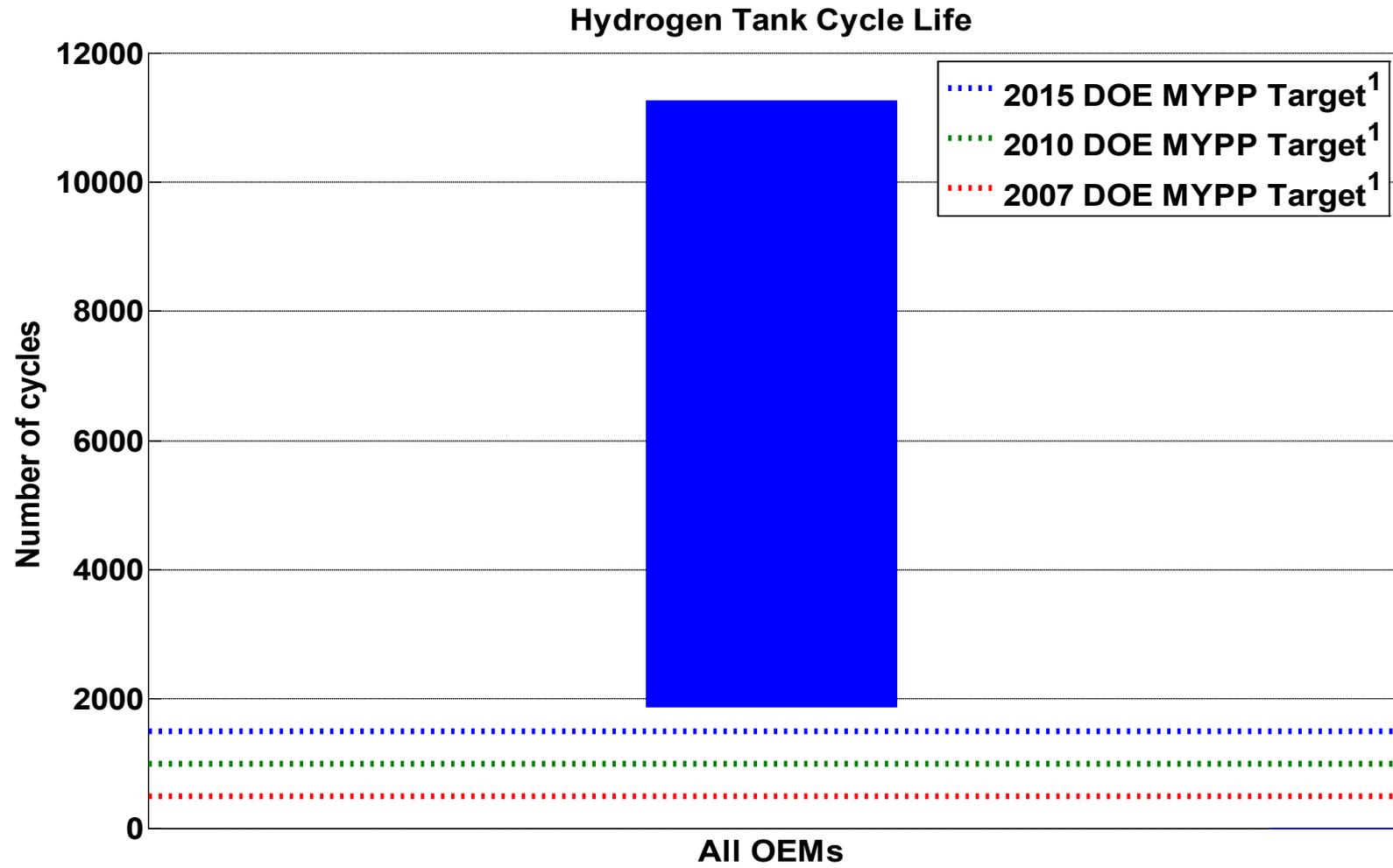
# CDP#11: Volumetric Capacity of H2 Storage



Created: 23-Feb-2006

<sup>1</sup>Emphasis is on advanced materials-based technologies.

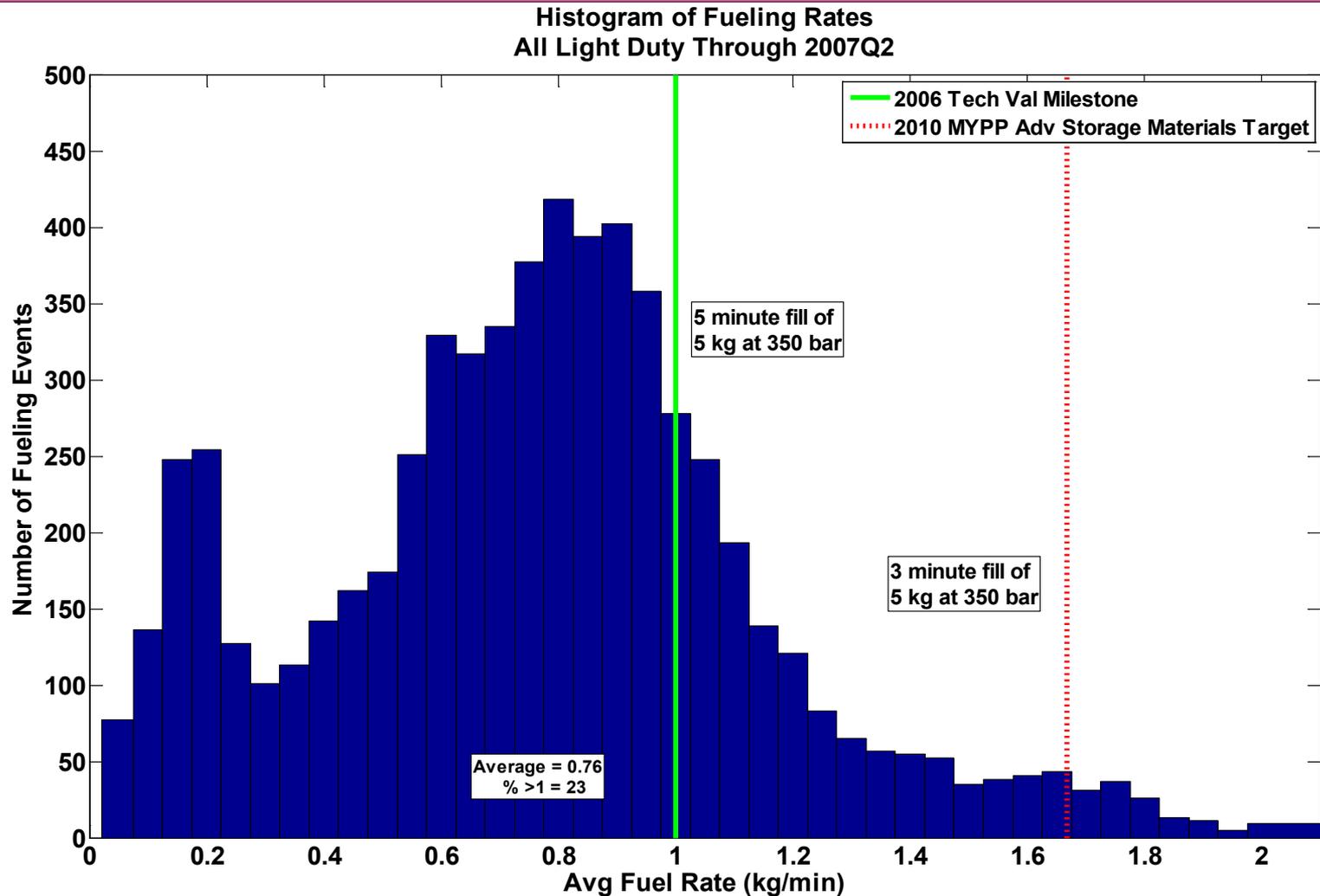
# CDP#12: Vehicle Hydrogen Tank Cycle Life



Created: 23-Feb-2006

<sup>1</sup>Some near-term targets have been achieved with compressed and liquid tanks. Emphasis is on advanced materials-based technologies.

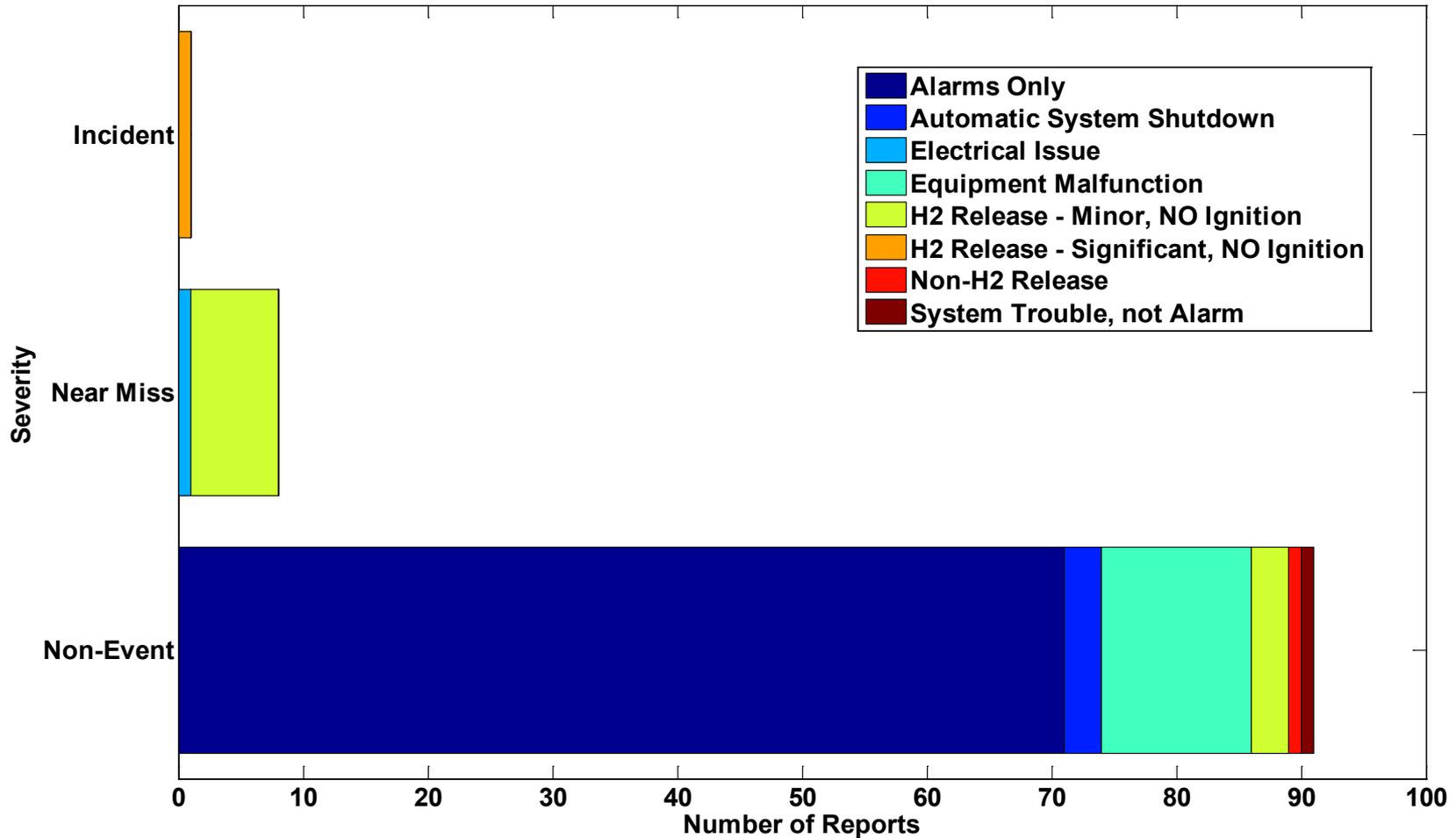
# CDP#18: Refueling Rates



Created: Aug-23-07 1:29 PM

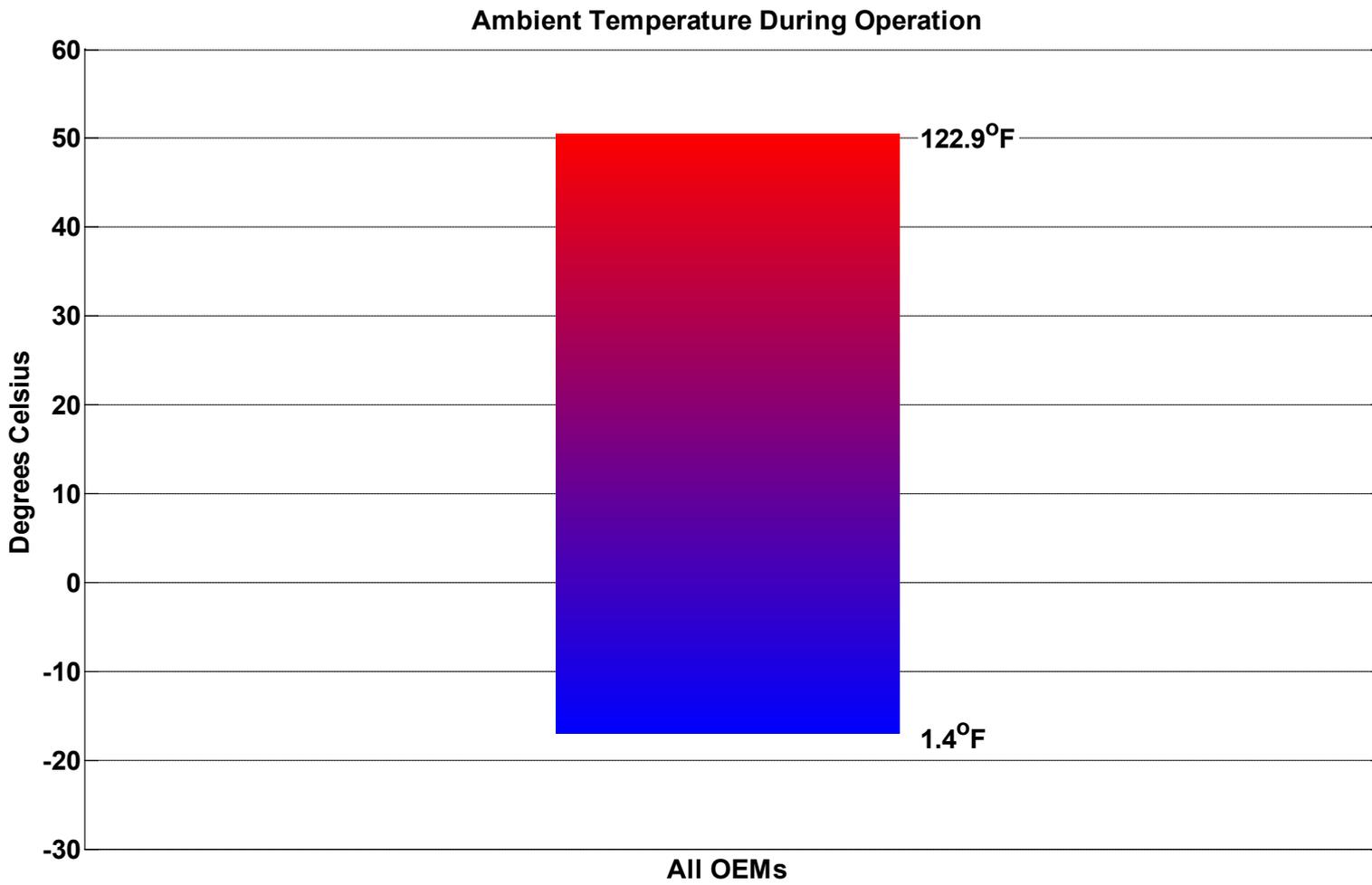
# CDP#20: Safety Reports – Infrastructure

Total Infrastructure Safety Reports by Severity and Report Type through 2007 Q2



Created: Sep-06-07 7:36 AM

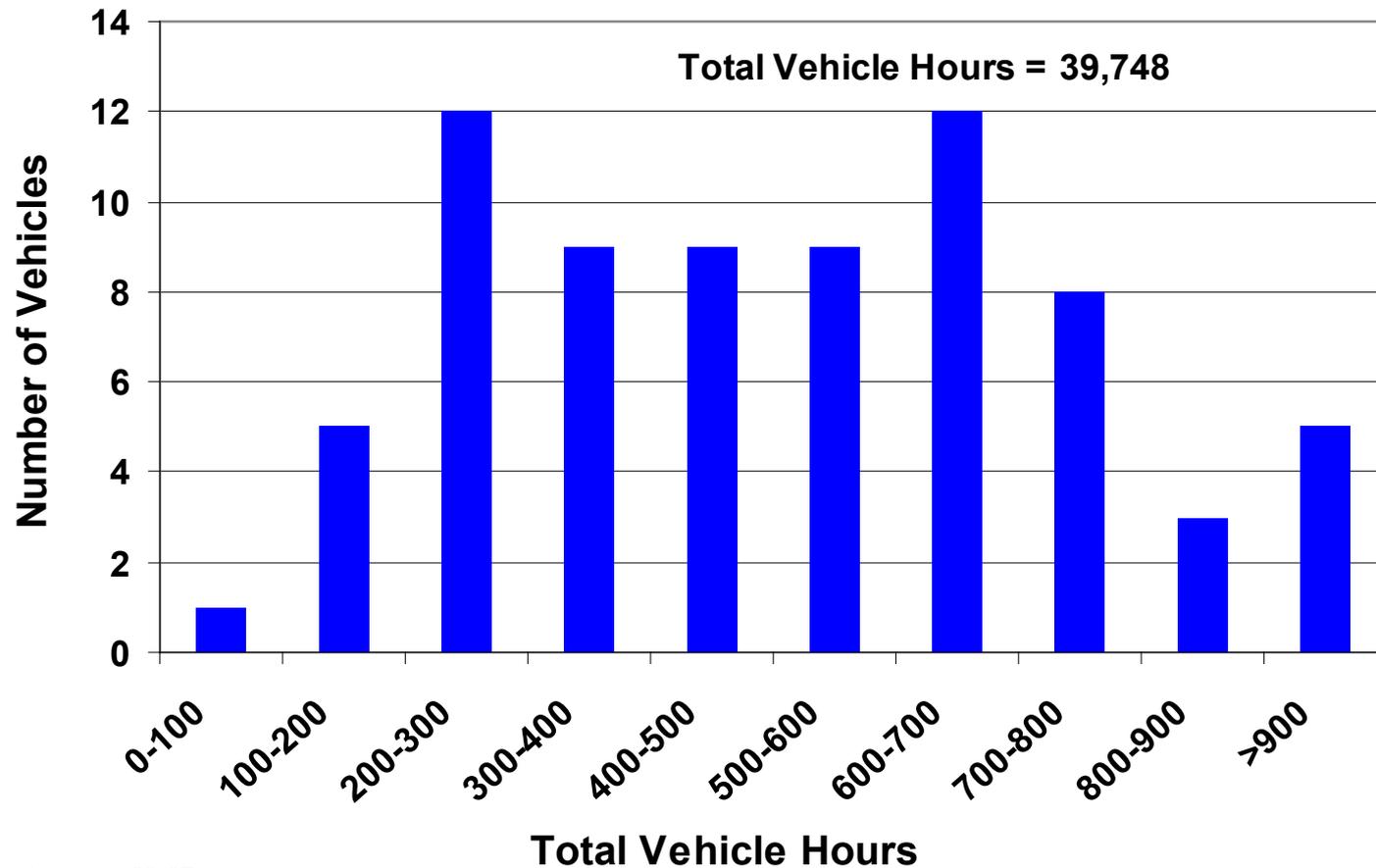
# CDP#21: Range of Ambient Temperature During Vehicle Operation



Created: Aug-23-07 9:33 AM

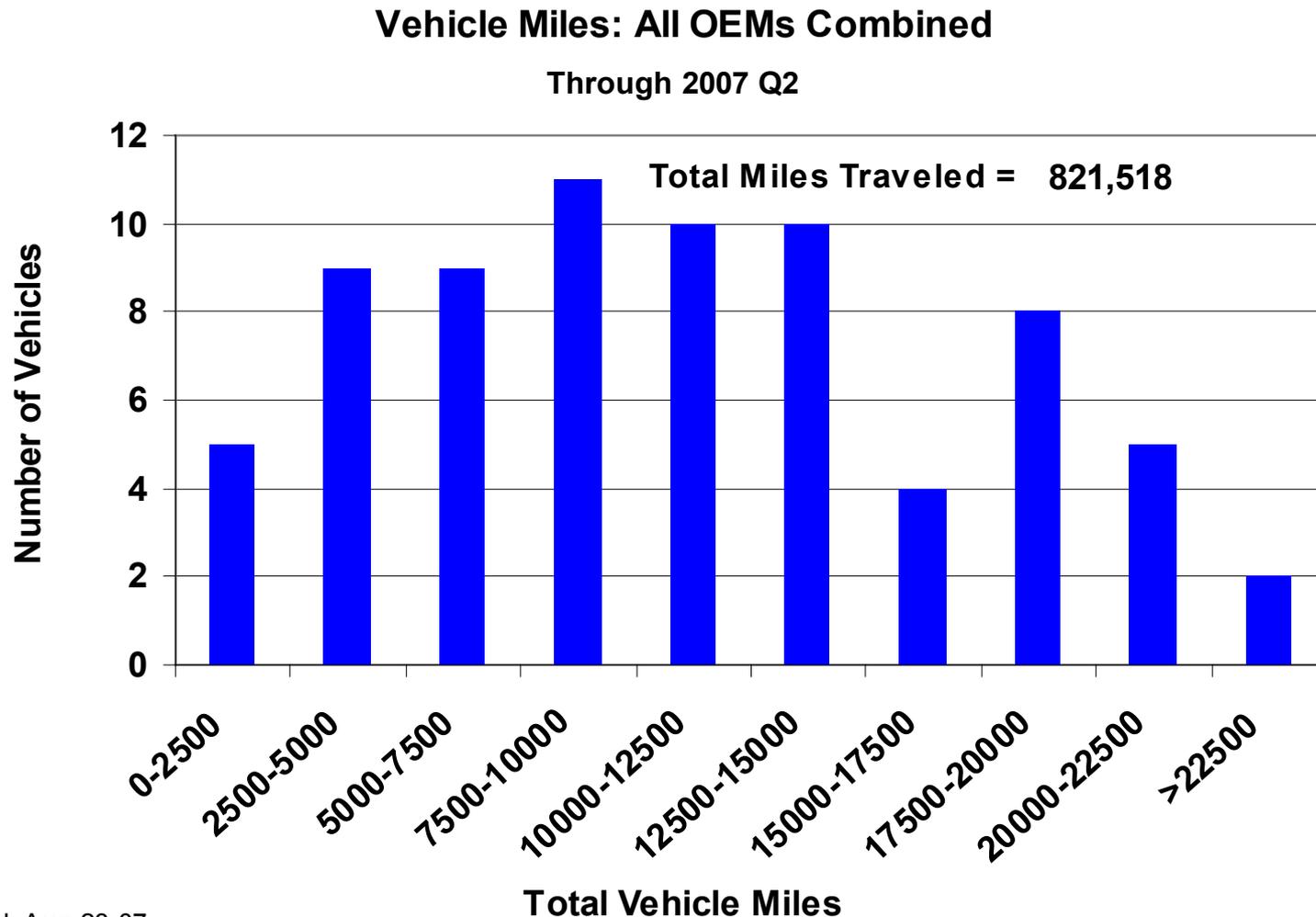
# CDP#22: Vehicle Operating Hours

Vehicle Hours: All OEMs Combined  
Through 2007 Q2



Created: Aug-23-07

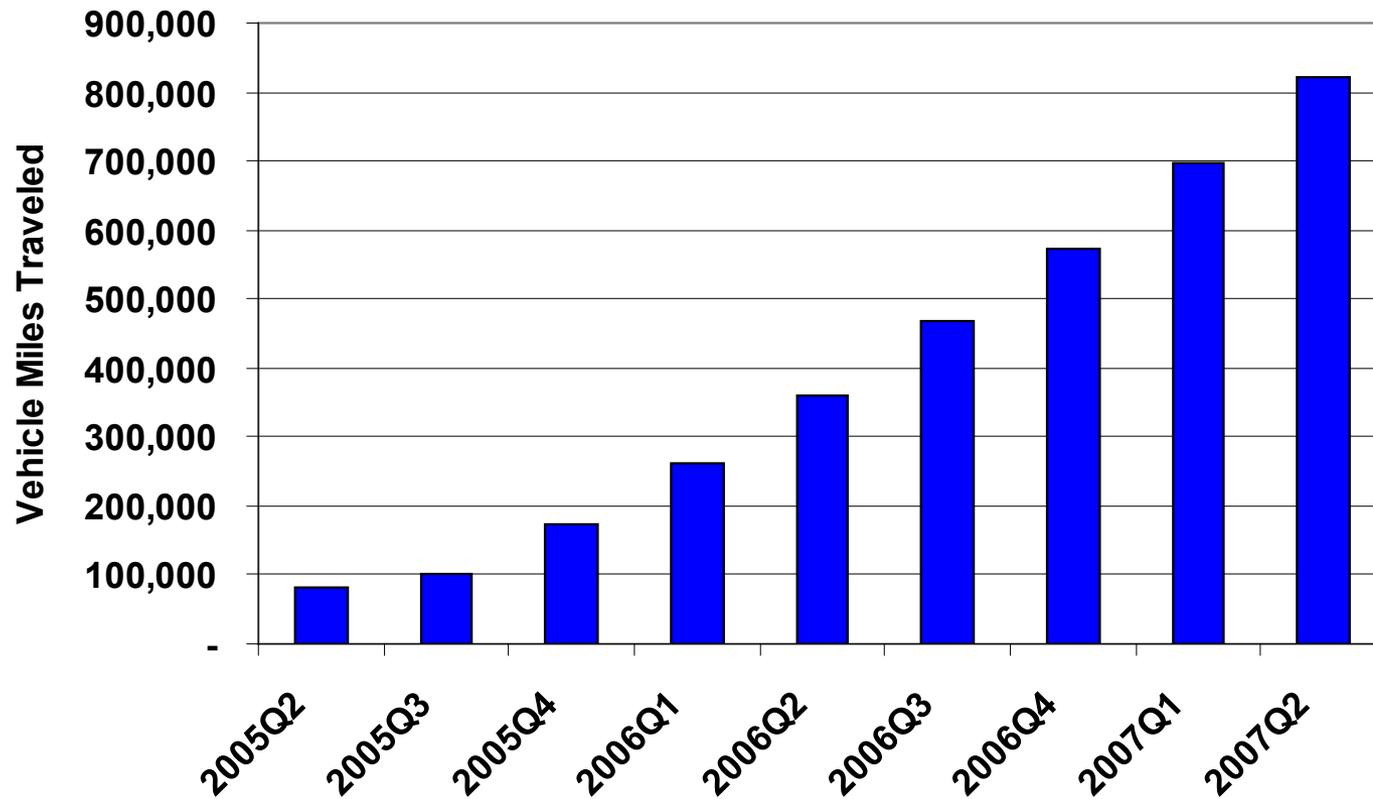
# CDP#23: Vehicles vs. Miles Traveled



Created: Aug-23-07

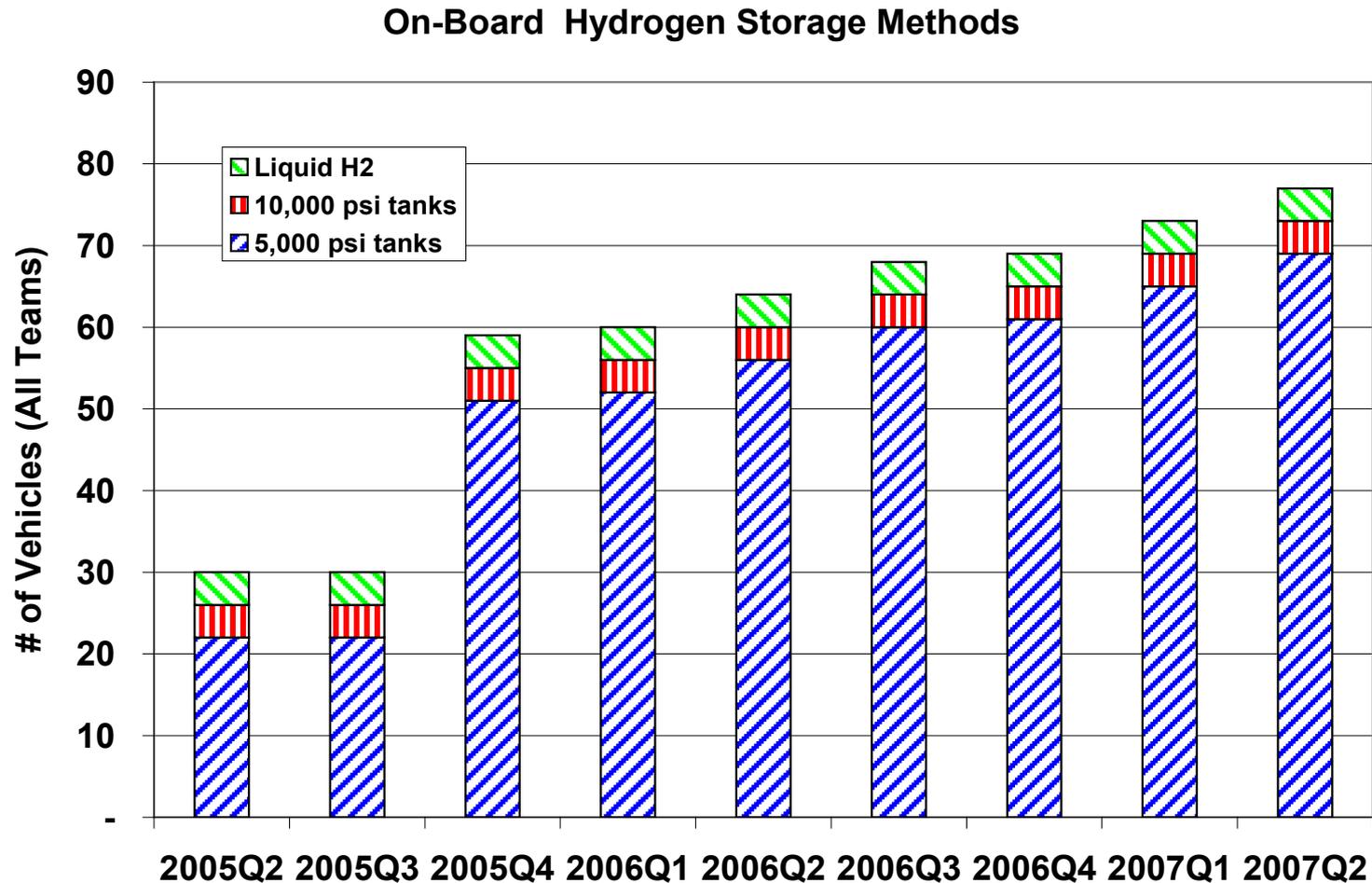
# CDP#24: Cumulative Vehicle Miles Traveled

Cumulative Vehicle Miles Traveled: All OEMs



Created: Aug-23-07

# CDP#25: Vehicle H2 Storage Technologies

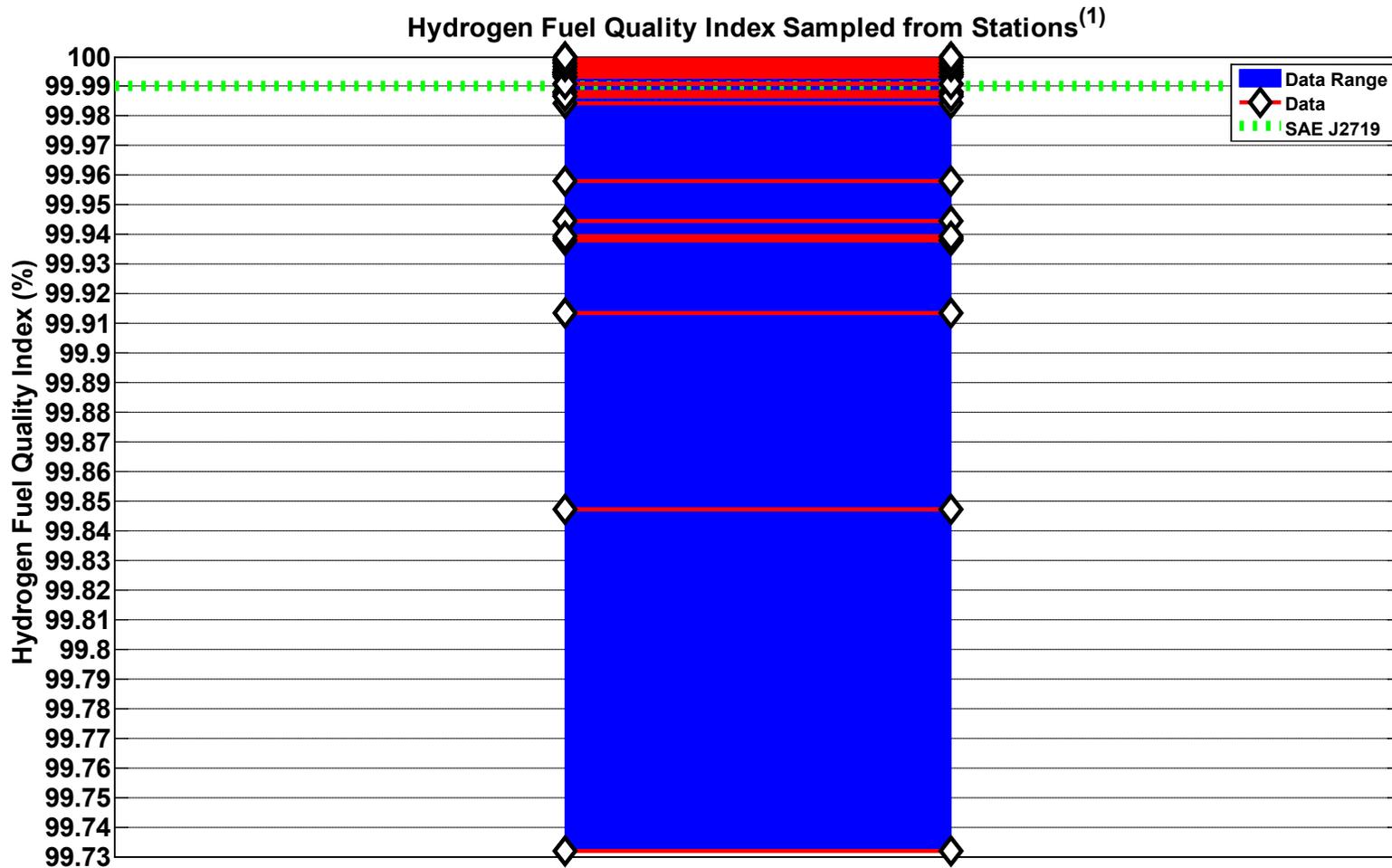


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# CDP#26: Cumulative H2 Produced or Dispensed



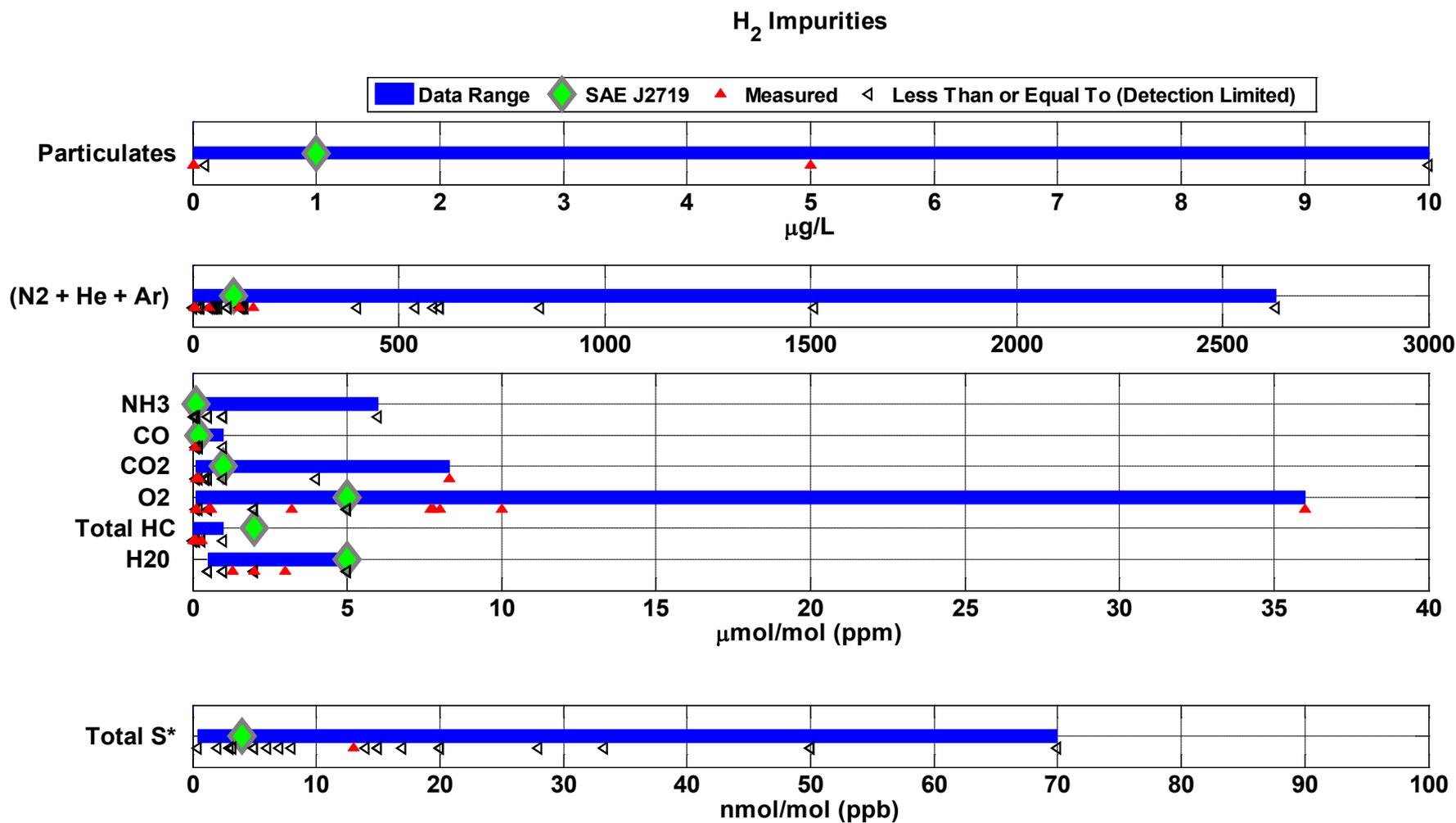
# CDP#27: Hydrogen Purity Scatter Plot



(1) Includes sampling from both electrolysis and reforming

Created: Aug-23-07 11:03 AM

# CDP #28: Hydrogen Impurities Scatter Plot

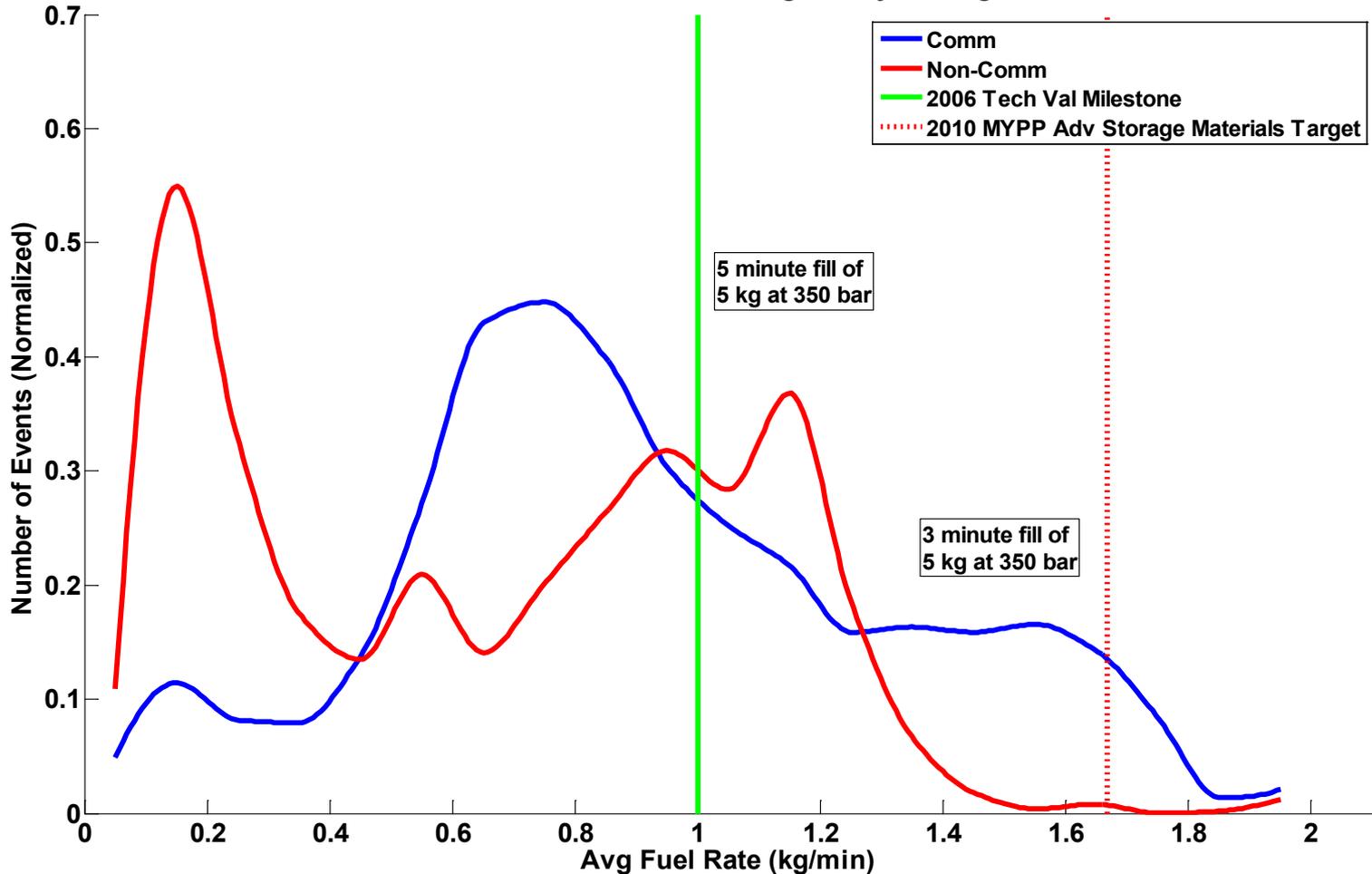


Created: Aug-23-07 11:03 AM

\*Calculated from SO<sub>2</sub>, COS, H<sub>2</sub>S, CS<sub>2</sub>, and Methyl Mercaptan (CH<sub>3</sub>SH).

# CDP#29: Fueling Rates – Communication and Non-Communication Fills

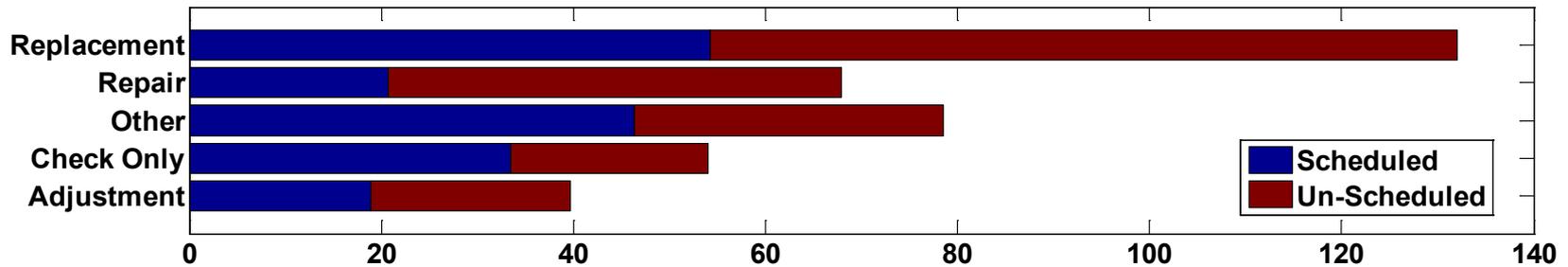
Histogram of Fueling Rates  
Comm vs Non-Comm Fills - All Light Duty Through 2007Q2



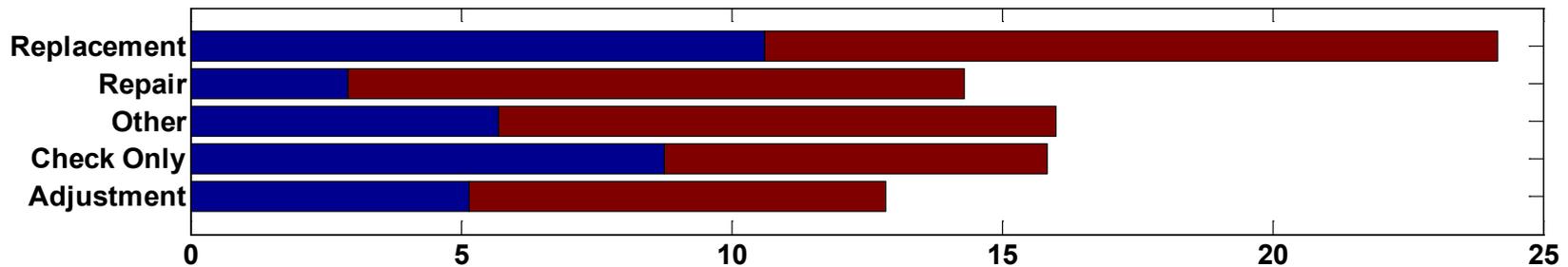
Created: Aug-22-07 5:46 PM

# CDP#30: Infrastructure Maintenance

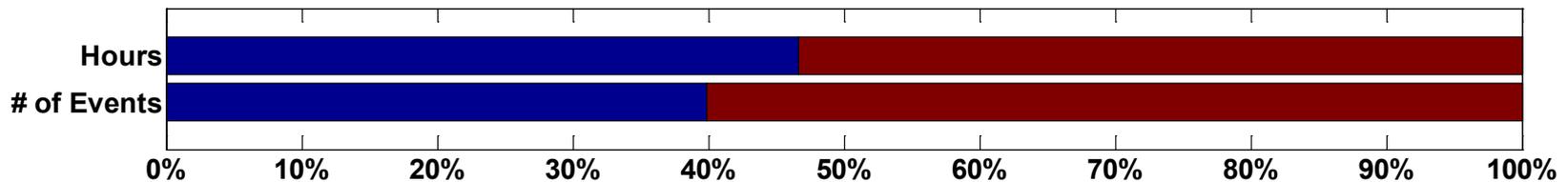
Maintenance: Average Labor Hours Per Station Since Inception



Maintenance: Average Number of Events Per Station Since Inception

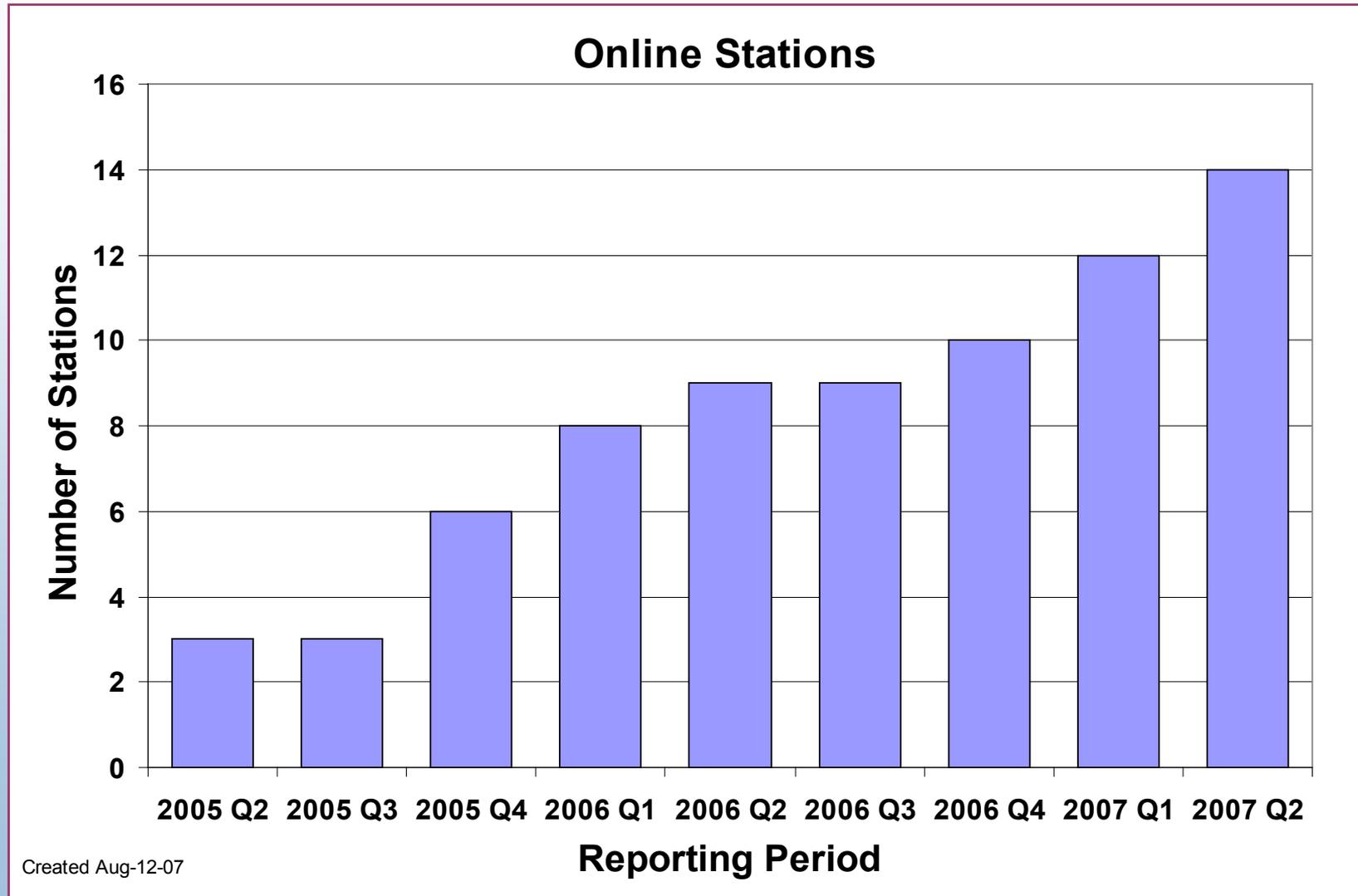


Comparison of Scheduled/Un-Scheduled Maintenance



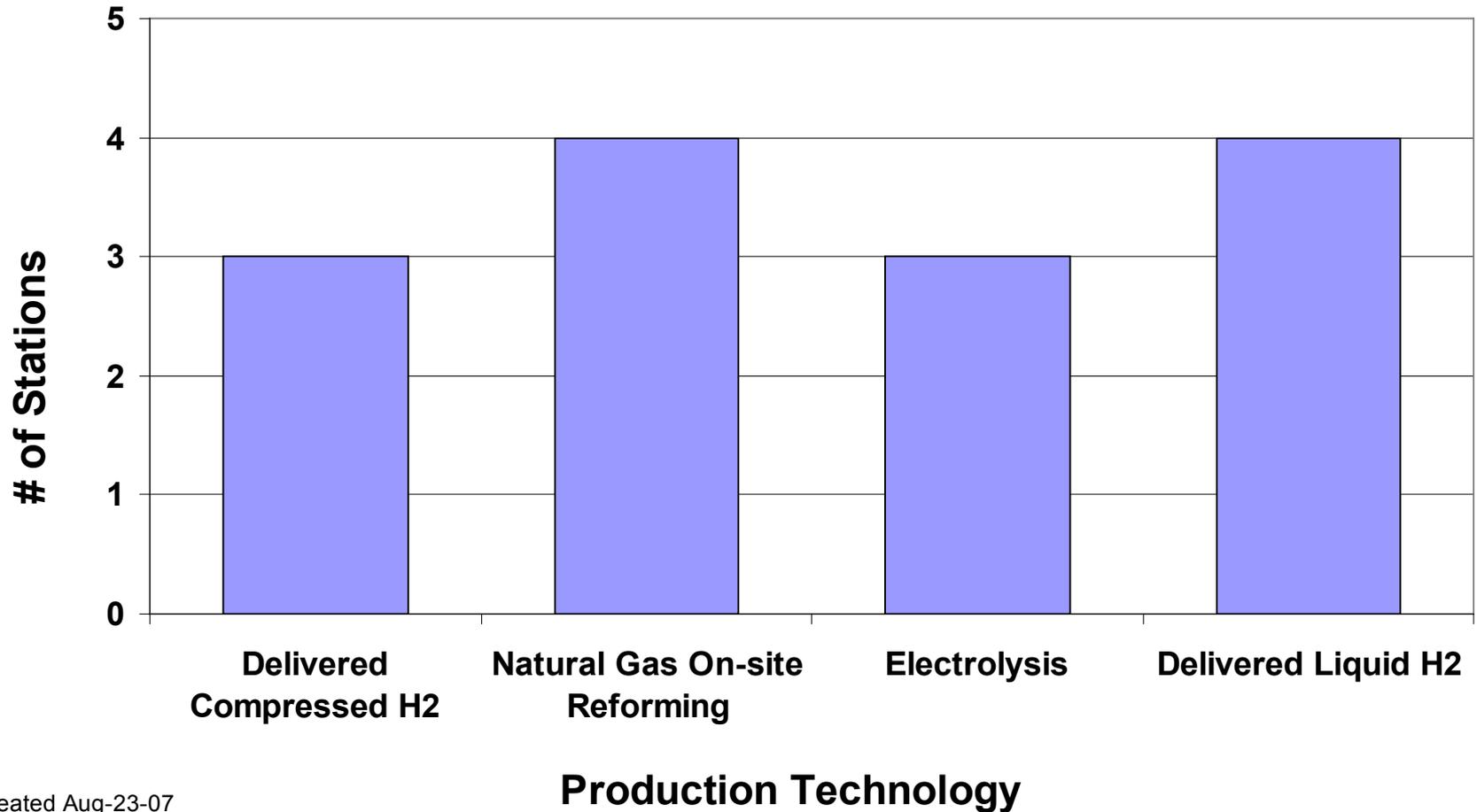
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# CDP#31: Number of Reporting Stations



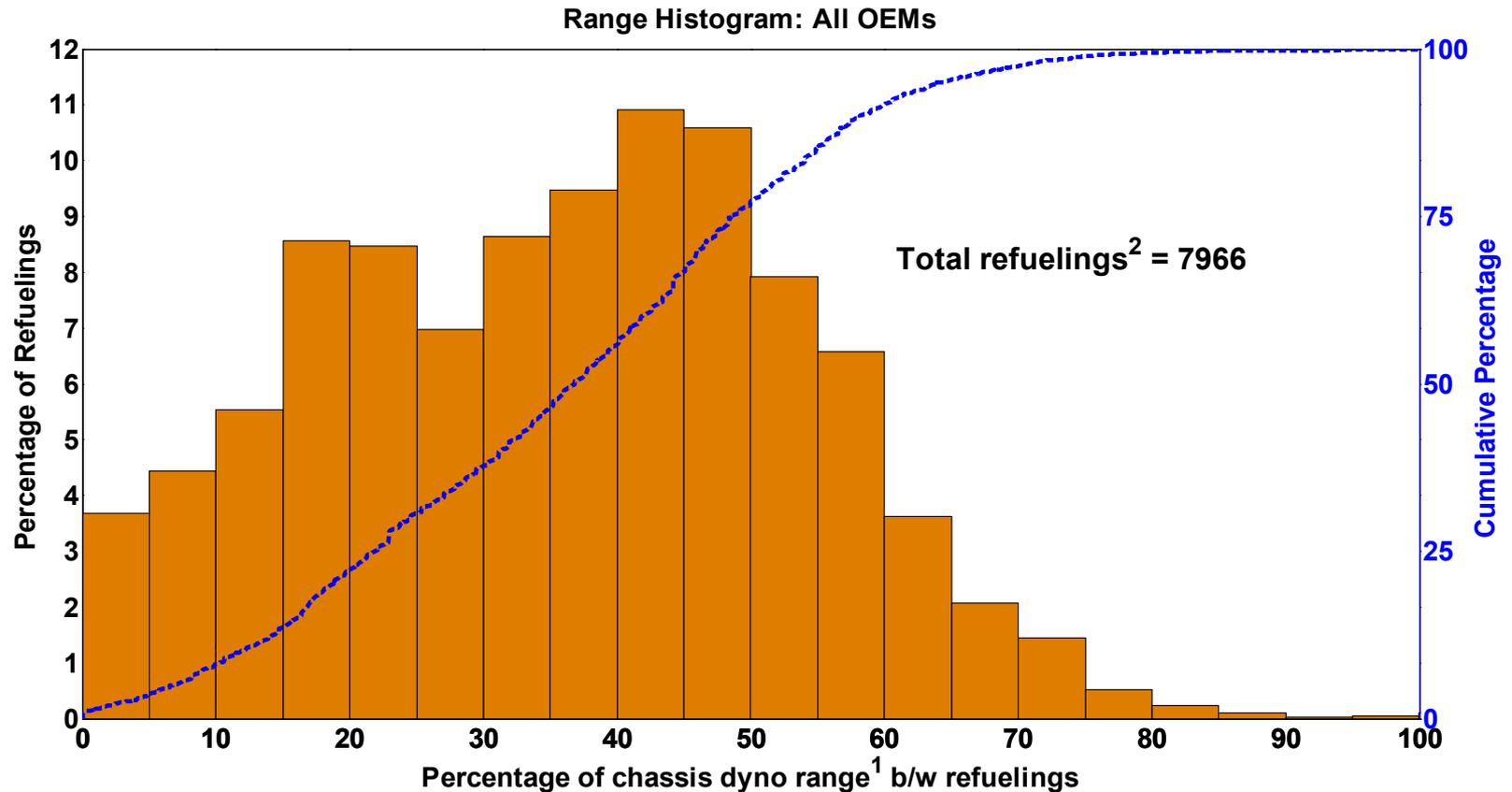
# CDP#32: Infrastructure Hydrogen Production Methods

## Infrastructure Hydrogen Production Methods



Created Aug-23-07

# CDP#33: Percentage of Theoretical Range Traveled Between Refuelings

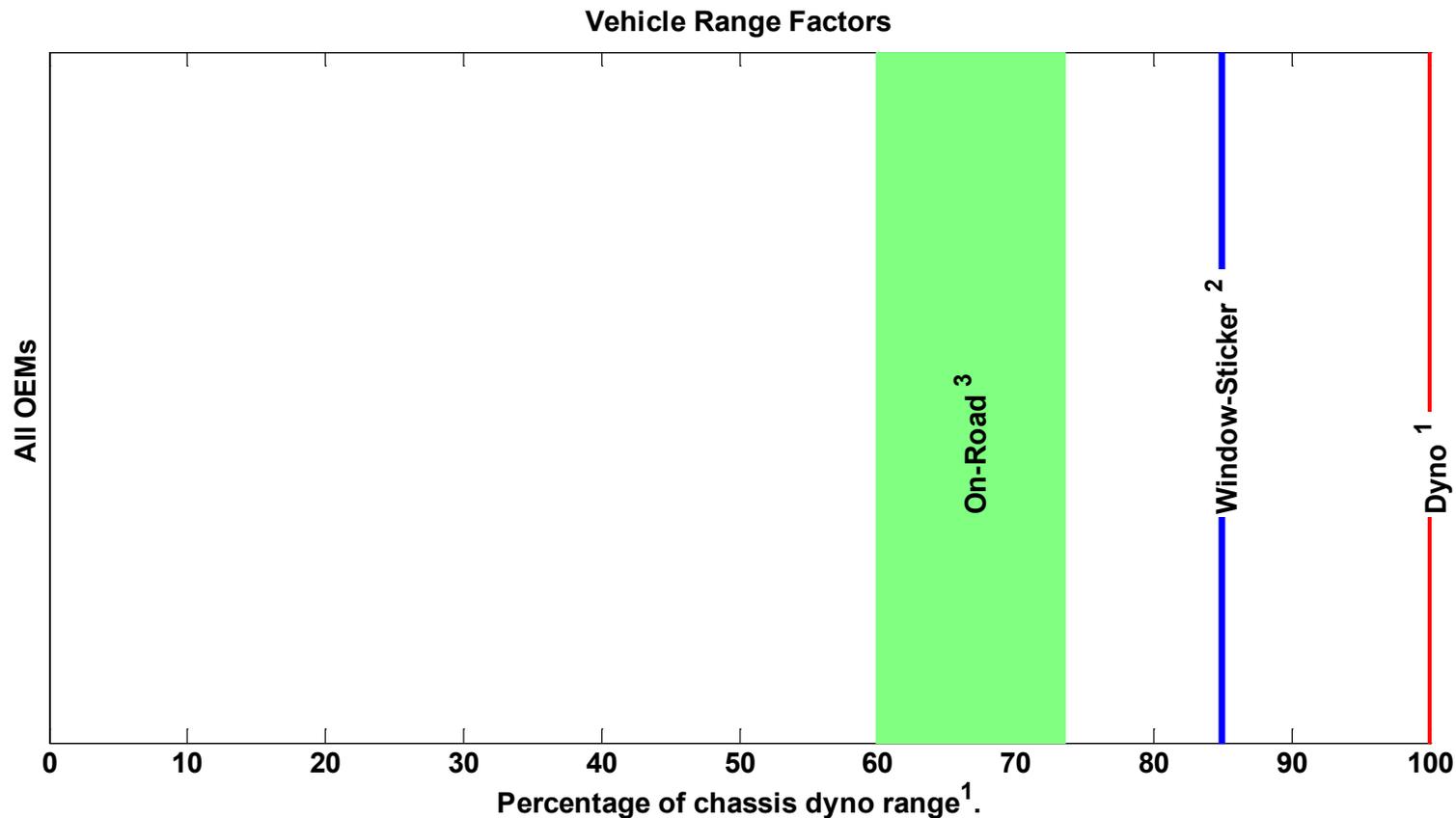


1. Range calculated using the combined City/Hwy fuel economy from dyno testing (not EPA adjusted) and usable fuel on board.

2. Some refueling events are not detected/reported due to data noise or incompleteness.

Created: Aug-23-07 3:24 PM

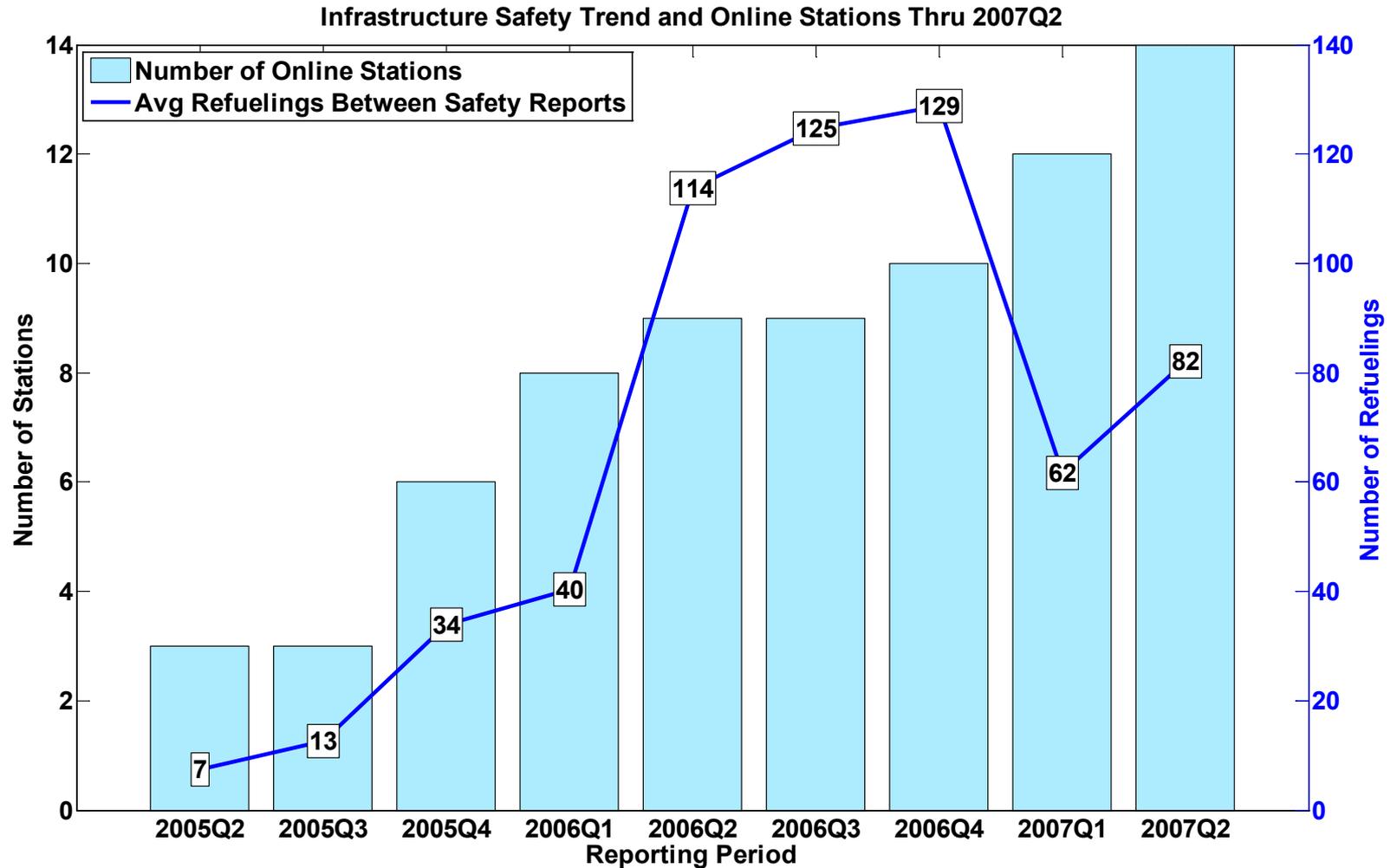
# CDP#34: Effective Vehicle Range



1. Calculated using the combined City/Hwy fuel economy from dyno testing (non-adjusted) and usable fuel on board.
2. Applying window-sticker correction factors for fuel economy:  $0.78 \times \text{Hwy}$  and  $0.9 \times \text{City}$ .
3. Using fuel economy from on-road data (excluding trips > 1 mile, consistent with other data products).

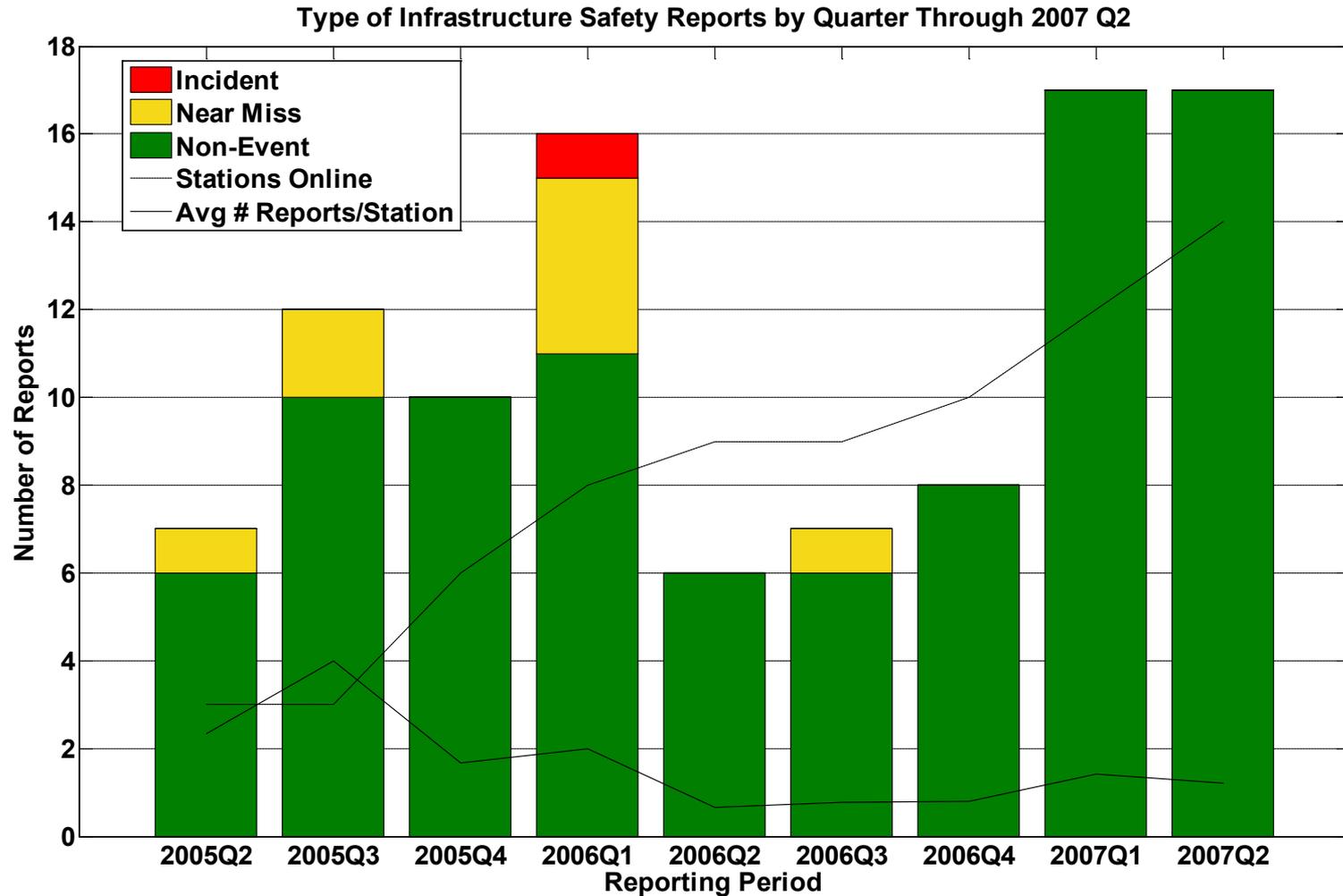
Created: Aug-23-07 12:39 PM

# CDP#35: Average Refuelings Between Infrastructure Safety Reports



Created: Sep-06-07 7:36 AM

# CDP#36: Type of Infrastructure Safety Report By Quarter

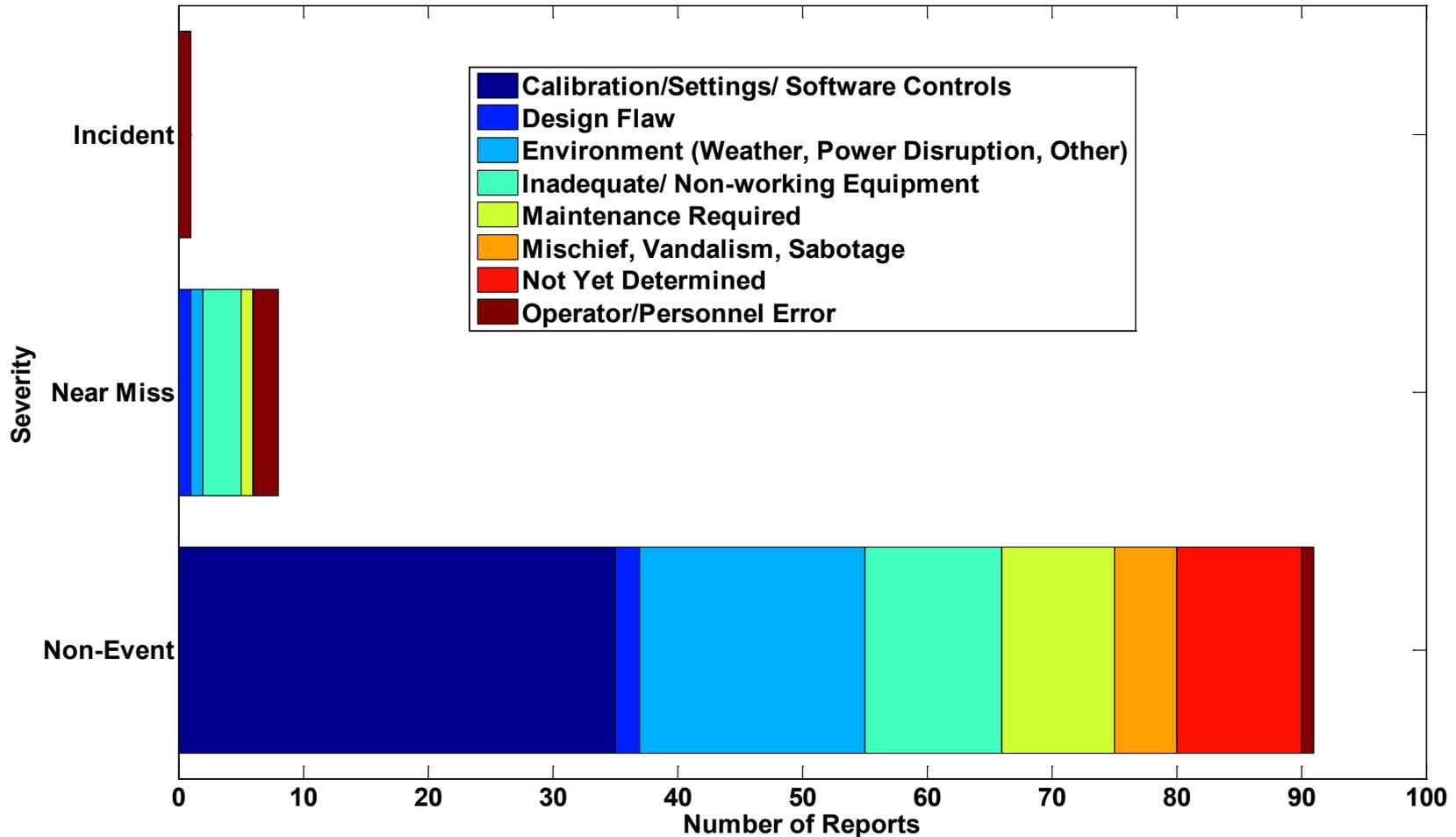


Created: Sep-06-07 7:36 AM

# CDP#37: Primary Factors of Infrastructure Safety Reports

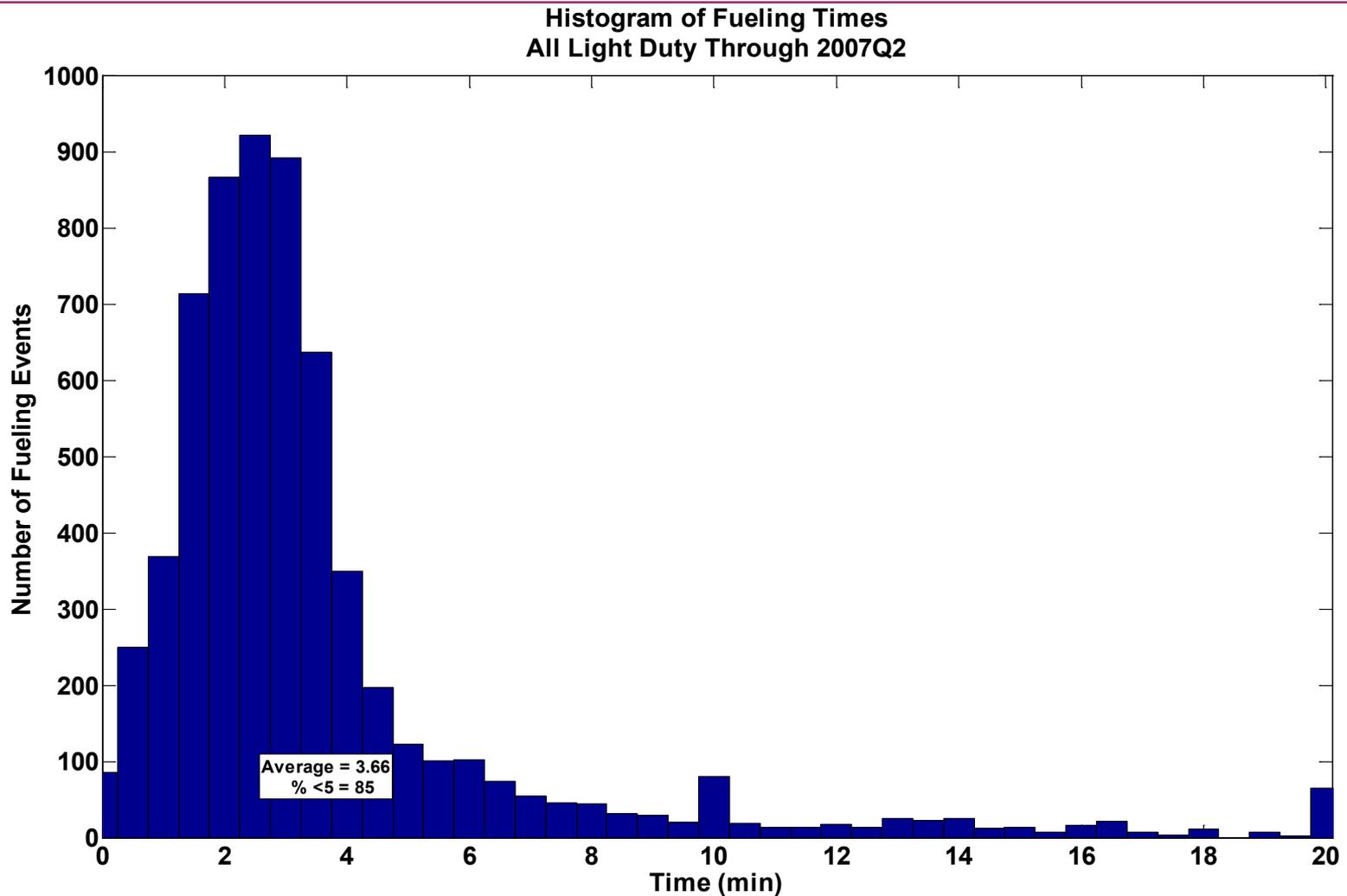
## Safety Reports

Primary Factors of Infrastructure Safety Reports  
Through 2007 Q2



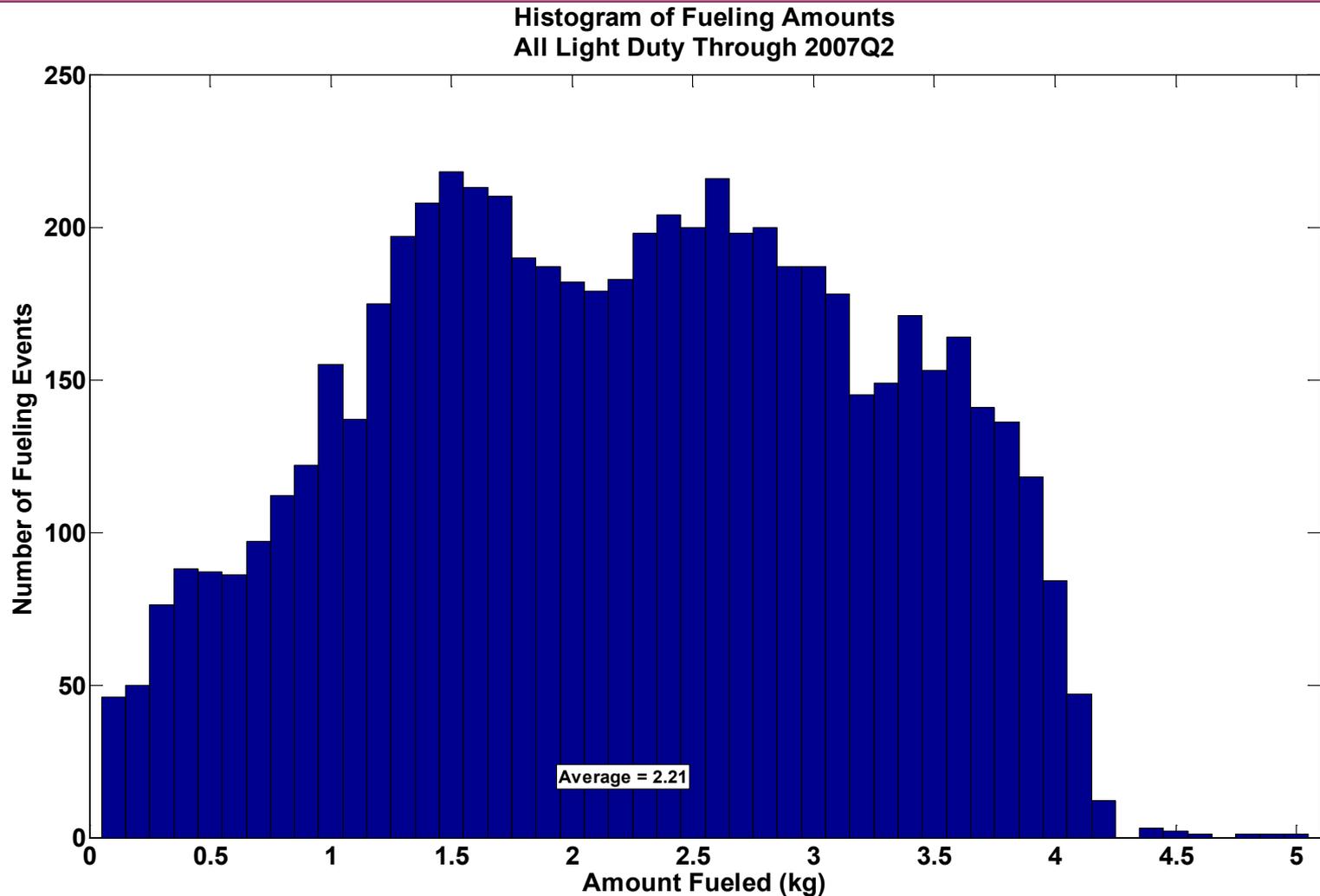
Created: Sep-06-07 7:36 AM

# CDP#38: Refueling Times



Created: Aug-23-07 1:29 PM

# CDP#39: Refueling Amounts



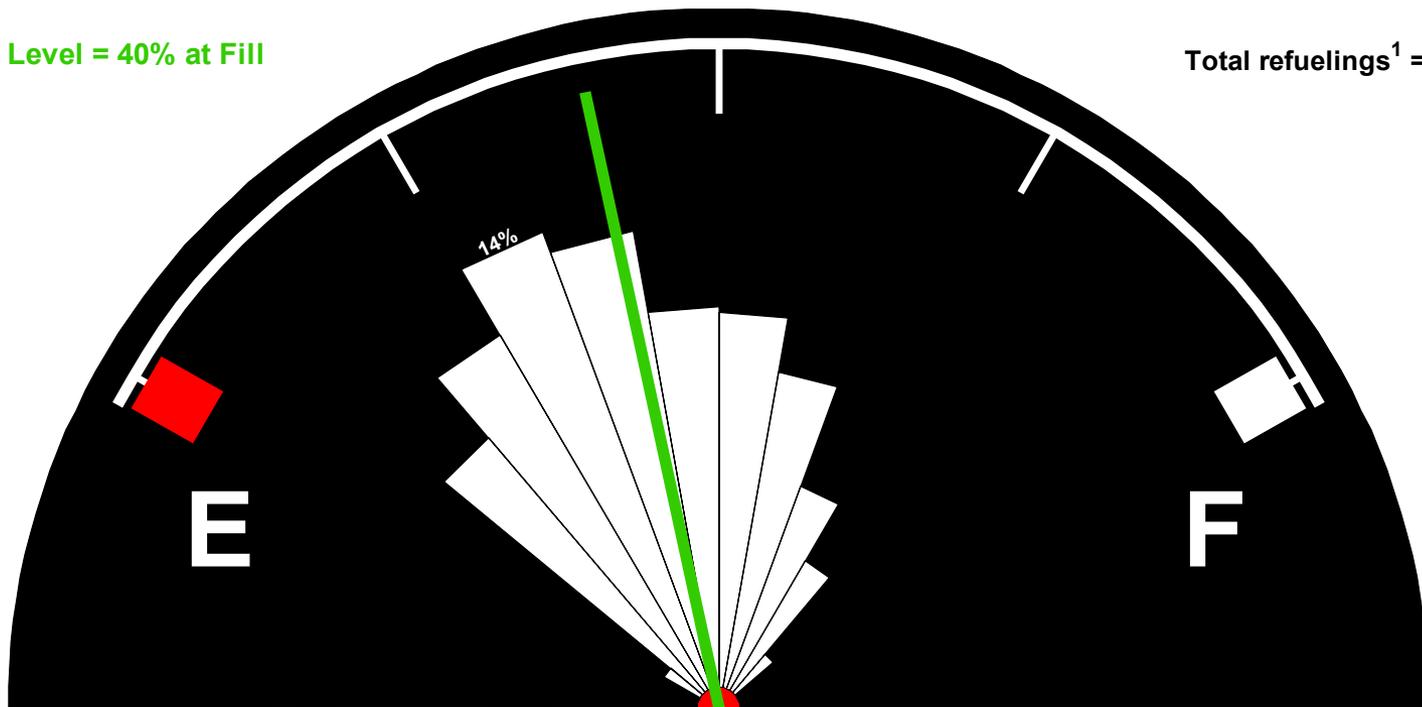
Created: Aug-23-07 1:29 PM

# CDP#40: H2 Tank Level at Refueling

Tank Levels: DOE Fleet

Median Tank Level = 40% at Fill

Total refuelings<sup>1</sup> = 10303



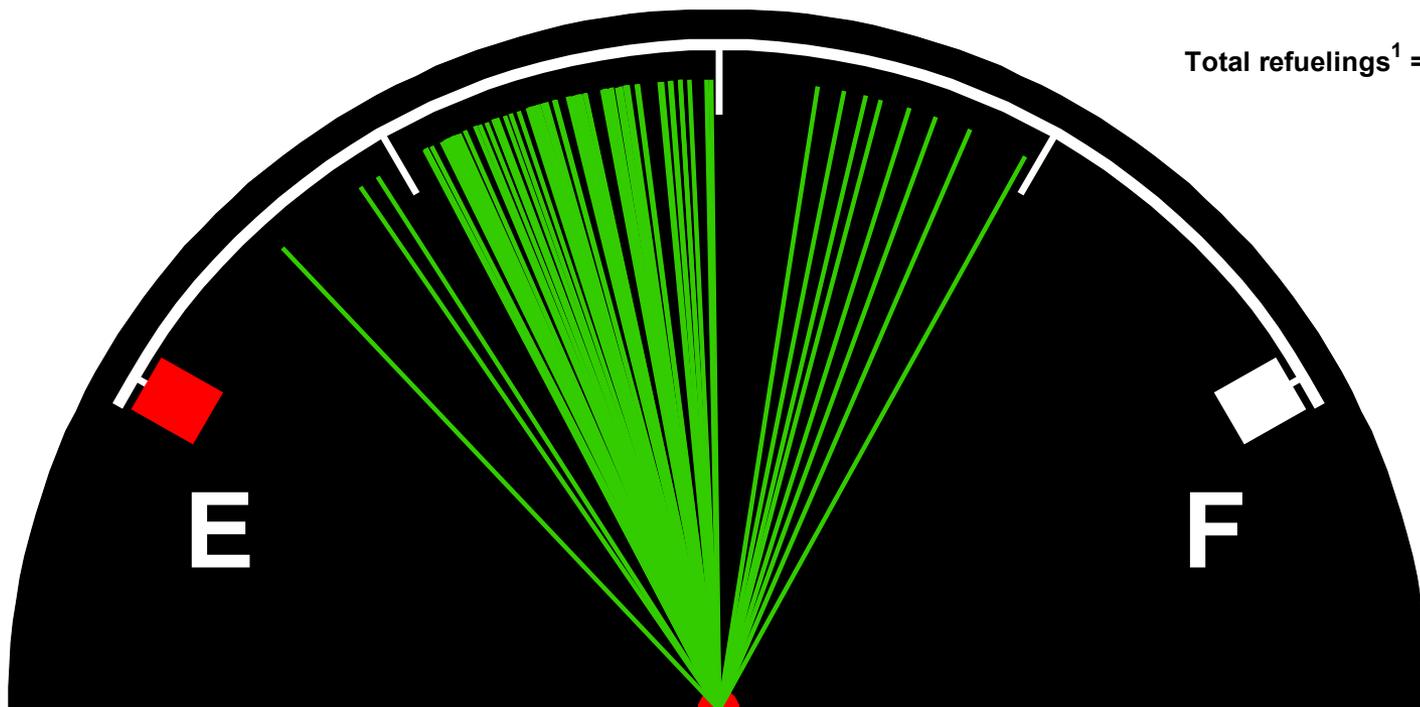
1. Some refueling events not recorded/detected due to data noise or incompleteness.
2. The outer arc is set at 20% total refuelings.
3. If tank level at fill was not available, a complete fill up was assumed.

Created: Sep-10-07 3:14 PM

# CDP#41: Refueling Tank Levels - Medians

Tank Level Medians: DOE Fleet, All Vehicles

Total refuelings<sup>1</sup> = 10303



1. Some refueling events not recorded/detected due to data noise or incompleteness.
2. If tank level at fill was not available, a complete fill up was assumed.

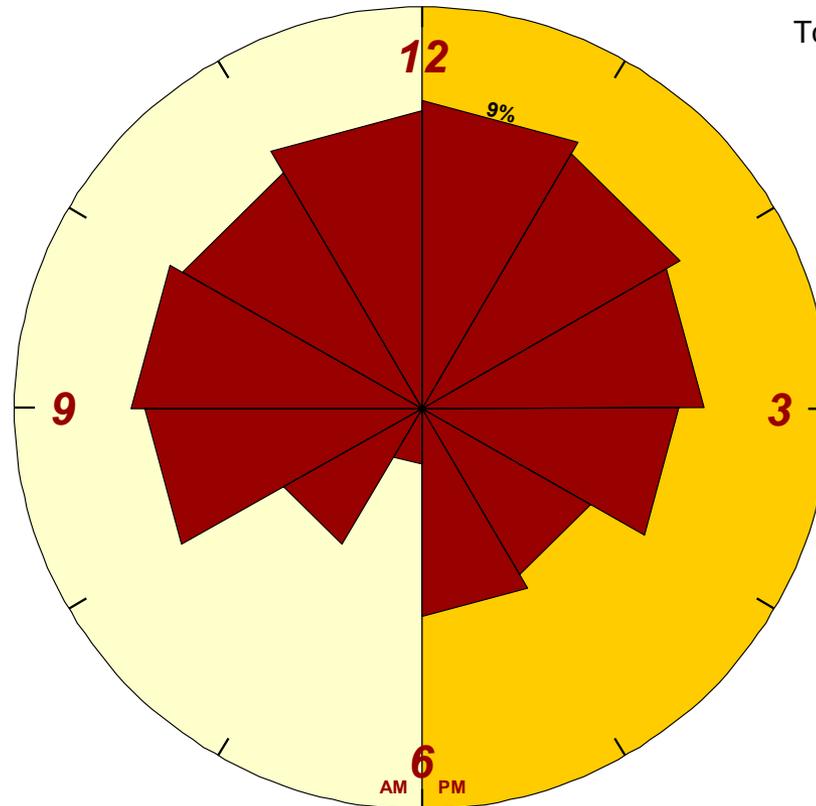
Created: Sep-10-07 3:14 PM

# CDP#42: Refueling by Time of Day

Refueling by Time of Day: DOE Fleet

% of fills b/t 6 AM & 6 PM: 86.0%

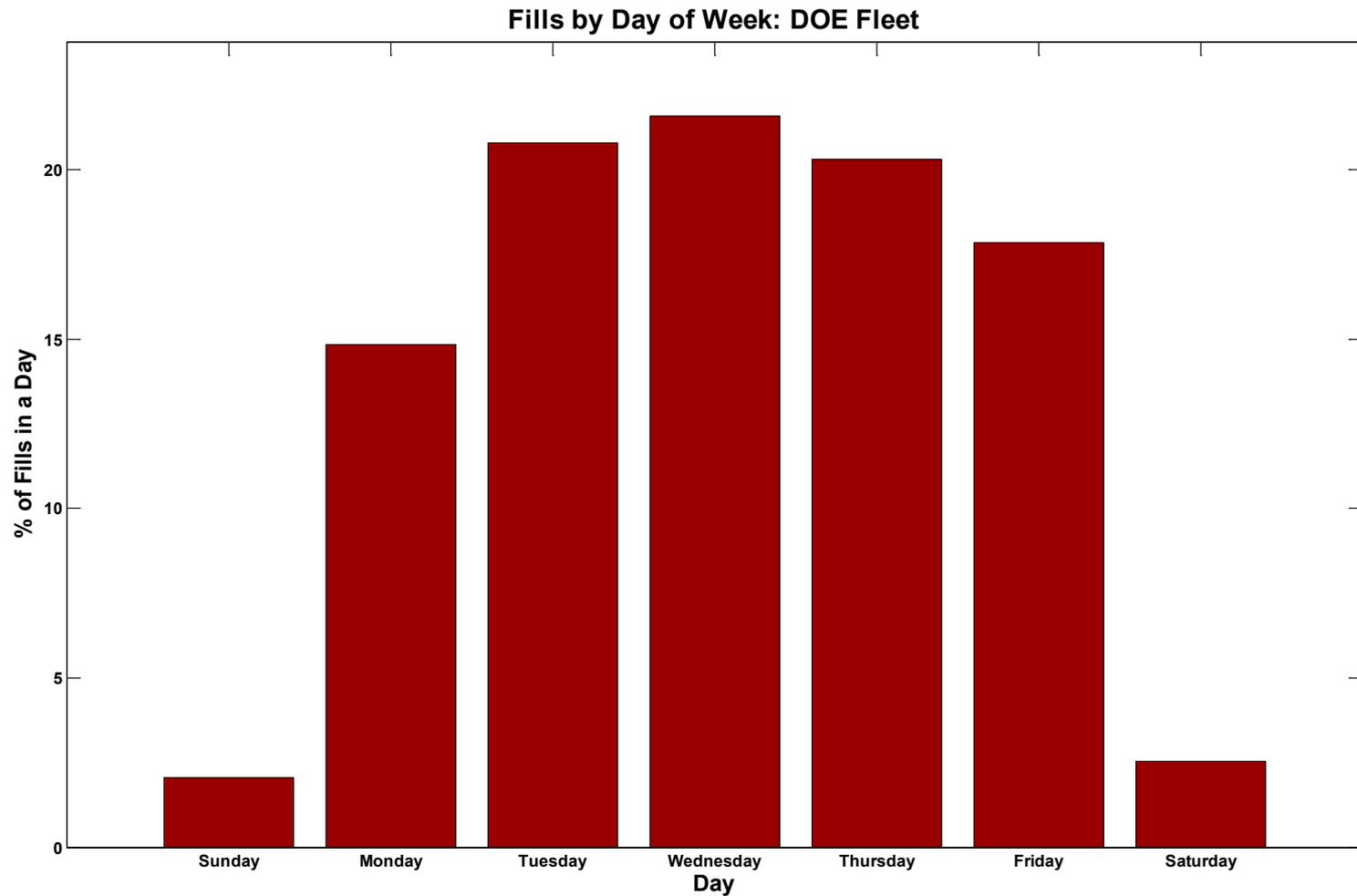
Total Fill<sup>3</sup> Events = 9070



1. Fills between 6 AM & 6 PM
2. The outer arc is set at 12 % total Fill.
3. Some events not recorded/detected due to data noise or incompleteness.

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# CDP#43: Refueling by Day of Week



Created: Sep-10-07 3:14 PM

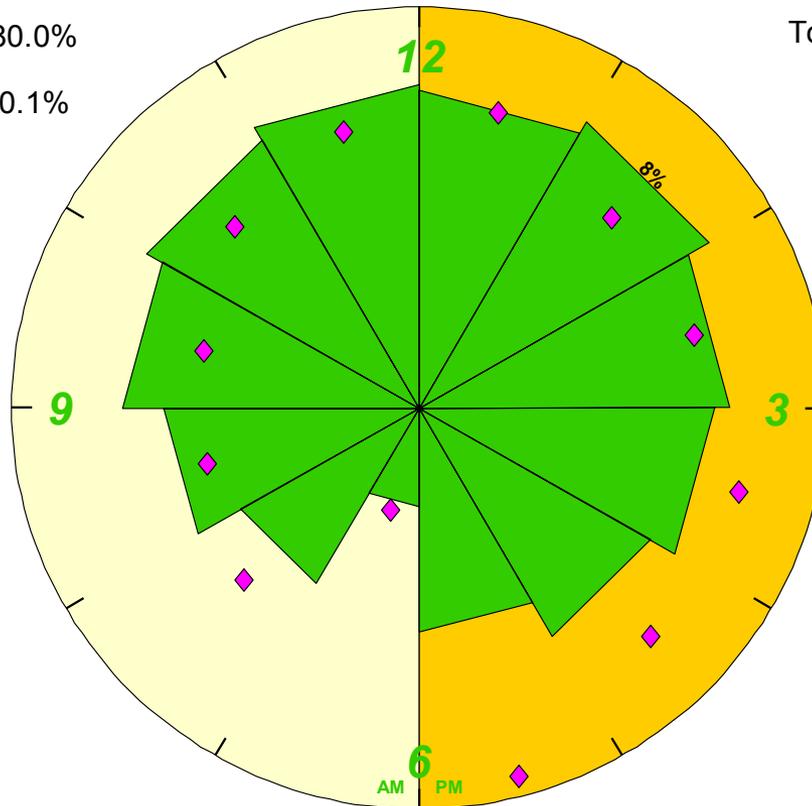
# CDP#44: Driving Start Time – Day

Driving Start Time - Day: DOE Fleet

% of driving trips b/t 6 AM & 6 PM: 80.0%

% of NHTS trips b/t 6 AM & 6 PM: 80.1%

Total Driving<sup>3</sup> Events = 103009



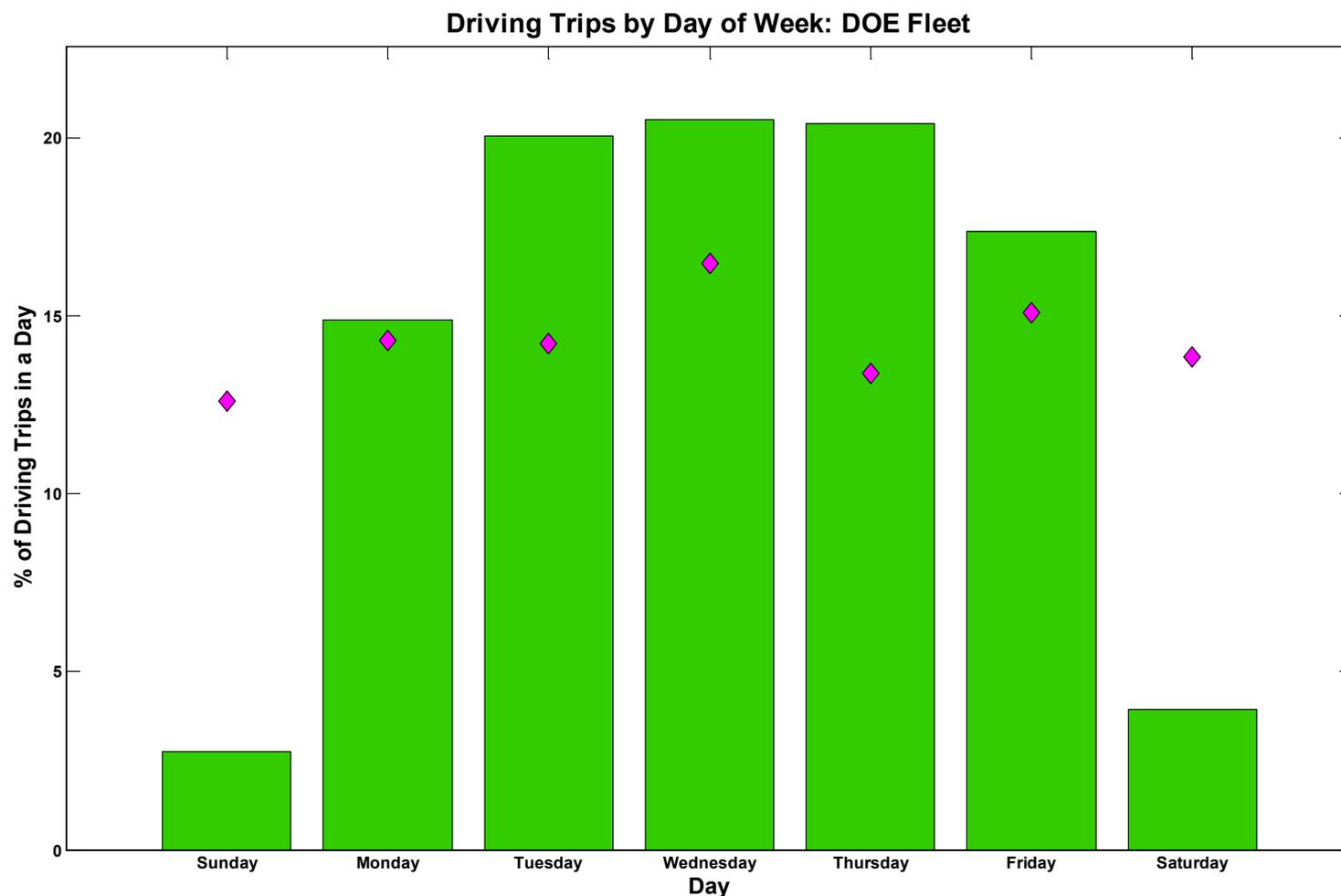
1. Driving trips between 6 AM & 6 PM
2. The outer arc is set at 10 % total Driving.
3. Some events not recorded/detected due to data noise or incompleteness.

◆ 2001 NHTS Data: Only Car, Truck, Van, & SUV trips included in data set shown here

Created: Sep-10-07 3:11 PM

Source: <http://nhts.ornl.gov/download.shtml#2001>, ASCII.csv

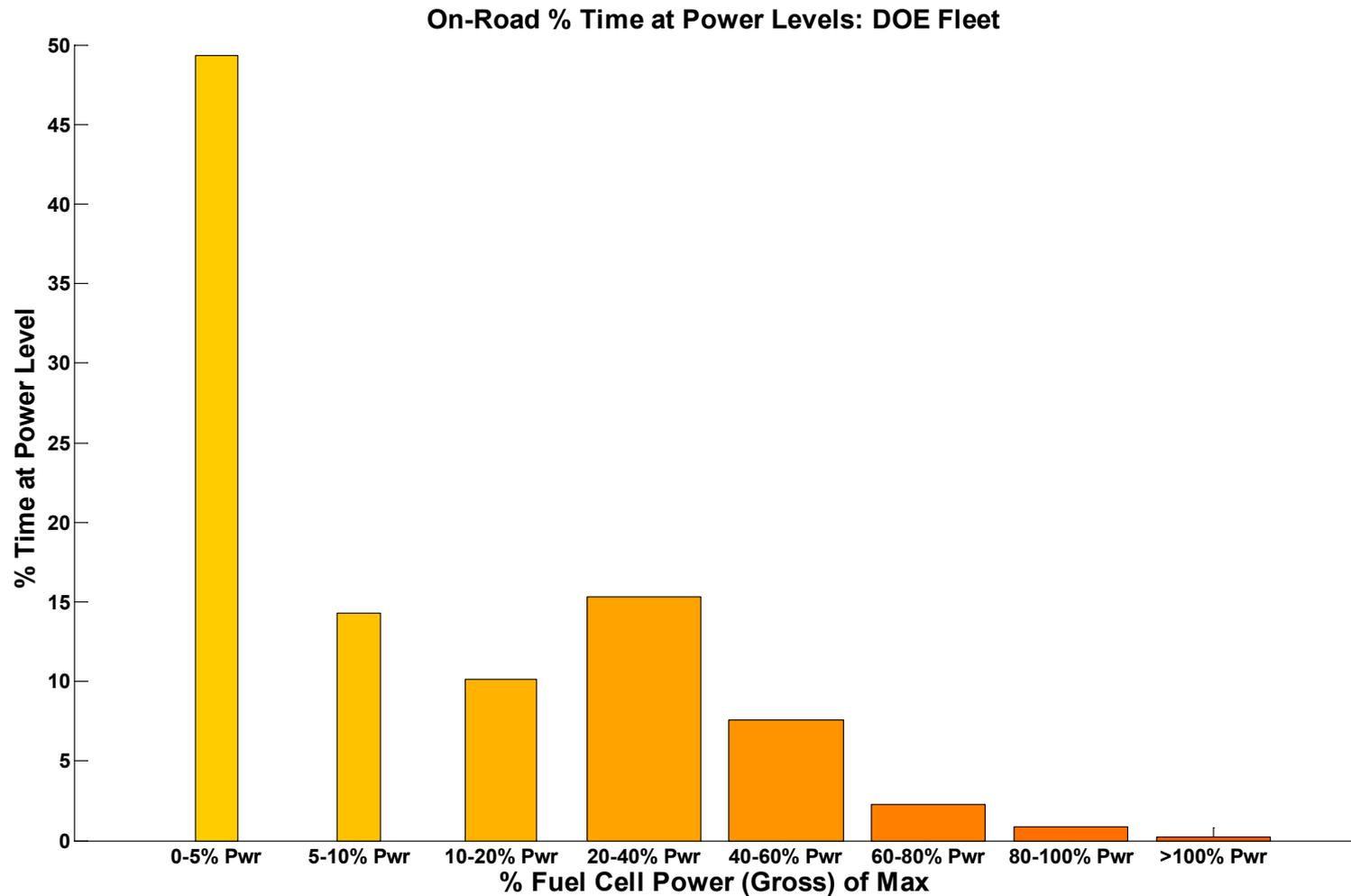
# CDP#45: Driving by Day of Week



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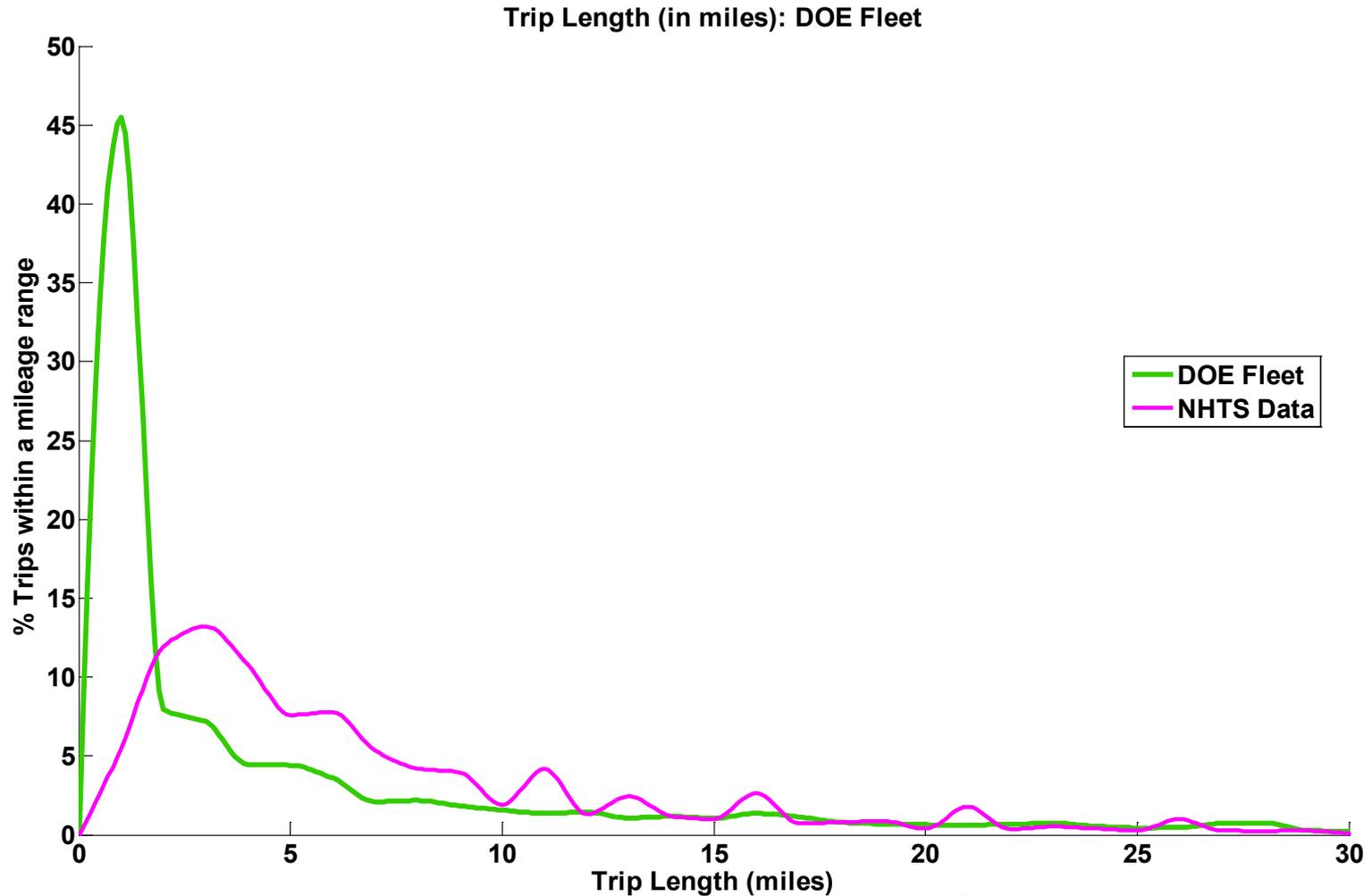
◆ 2001 NHTS Data: Only Car, Truck, Van, & SUV trips included in data set shown here  
Source: <http://nhts.ohl.gov/download.shtml#2001>, ASCII.csv

# CDP#46: Fuel Cell System Operating Powers



Created: Sep-10-07 4:31 PM

# CDP#47: Trip Length



Created: Sep-10-07 4:31 PM

2001 NHTS Data; Only Car, Truck, Van, & SUV day trips included in data set shown here  
Source: <http://nhts.ornl.gov/download.shtml#2001>, ASCII.csv

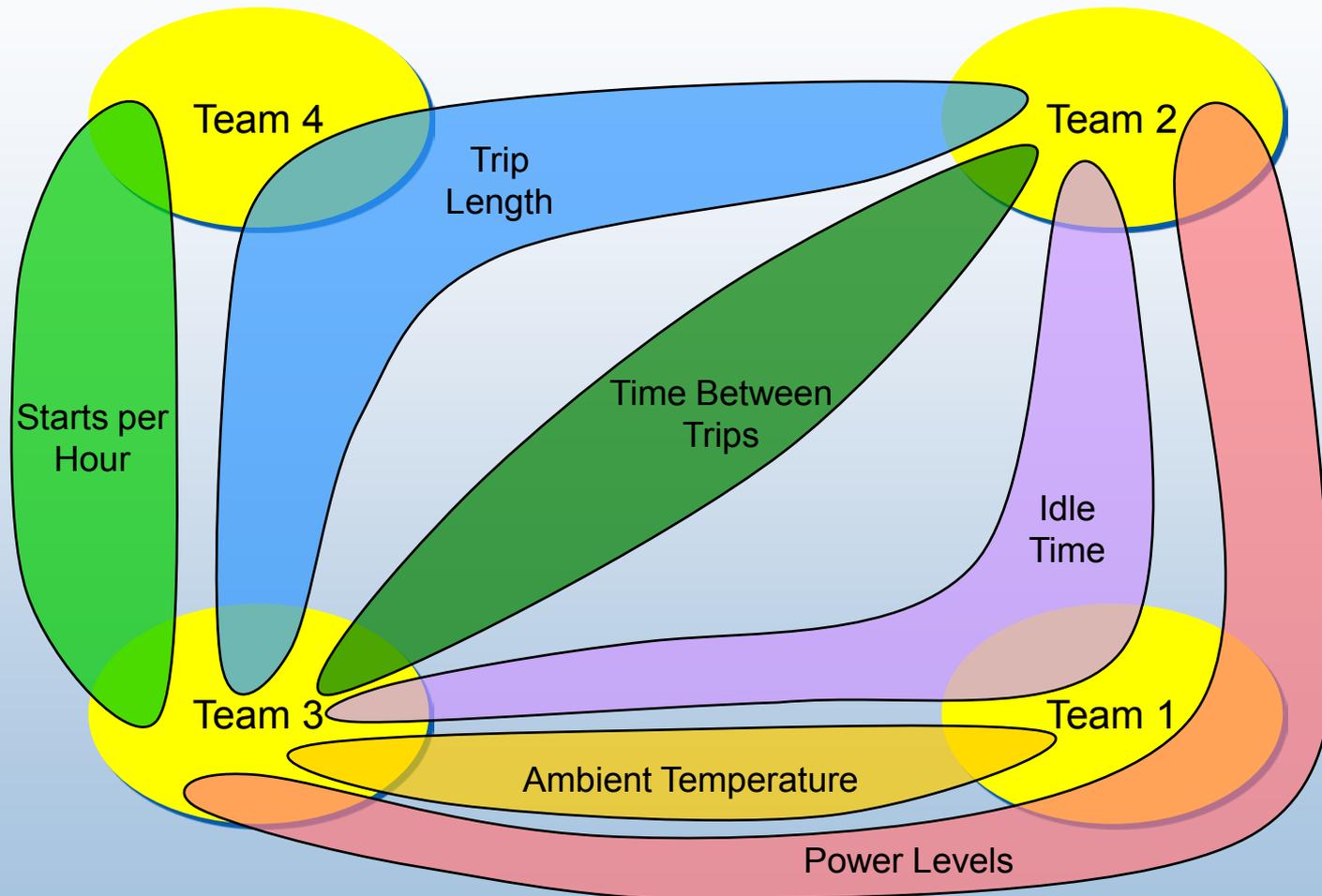
# CDP#48: Primary Factors Affecting Learning Demo Fleet Fuel Cell Degradation

<b>~29% Decay rate variance explained by a combination of the data variables below<sup>1</sup></b>	<b>Correlation to Decay Rate Data</b>
Starts per hour (+)	High decay rate <sup>2</sup>
Power levels (high & average) (+)	
Trip length (-)	
Time between trips (+)	
<b>~10% Decay rate variance explained by a combination of the data variables below<sup>1</sup></b>	<b>Correlation to Decay Rate Data</b>
Idle time (+)	High decay rate <sup>2</sup>
Power levels (low) (+)	

1. Findings based on a Learning Demonstration Fleet, Partial Least Squares (PLS) regression model. Approximately 39% decay rate variance explained by the model.

2. As part of the variable combination, a (+) indicates a directional relation to high decay rate and a (-) indicates an inverse relation.

# CDP#49: Primary Factors Affecting Learning Demo Team Fuel Cell Degradation



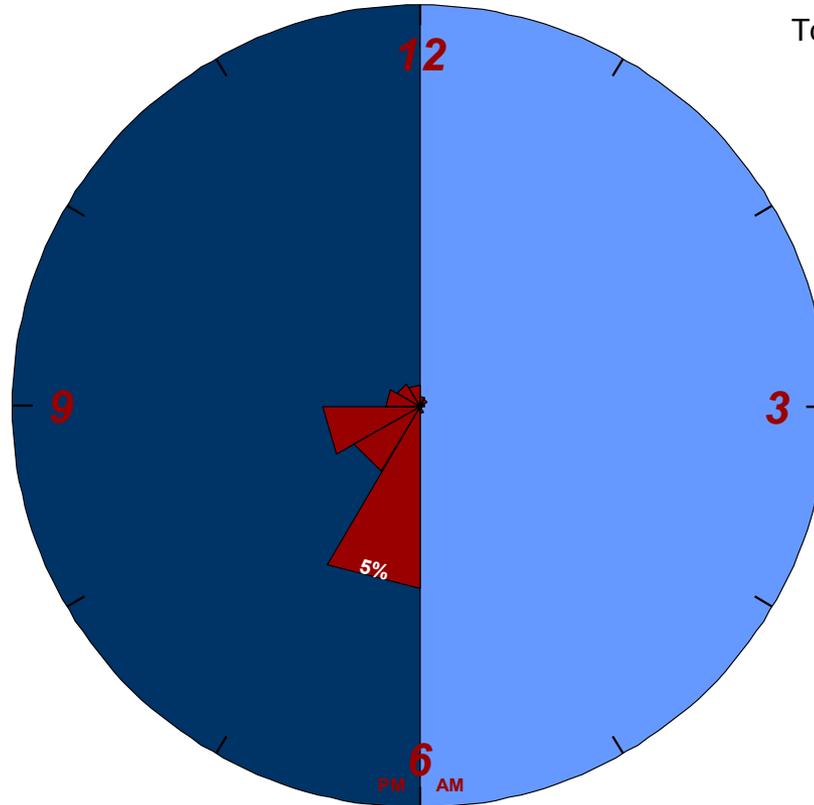
1. Results are from partial least squares (PLS) regression analysis of each team's fleet of vehicles individually
2. First two collections of factors cover ~61%-76% of decay rate variance

# CDP#50: Refueling by Time of Night

Refueling by Time of Night: DOE Fleet

% of fills b/t 6 PM & 6 AM: 14.0%

Total Fill<sup>3</sup> Events = 9070



1. Fills between 6 PM & 6 AM
2. The outer arc is set at 12 % total Fill.
3. Some events not recorded/detected due to data noise or incompleteness.

Created: Sep-10-07 2:33 PM

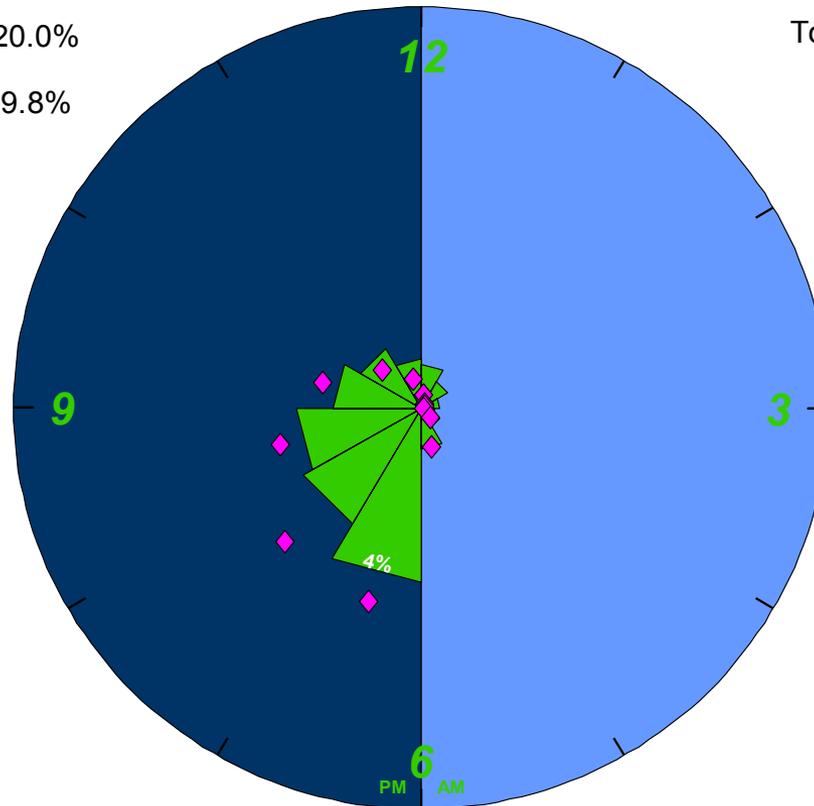
# CDP#51: Driving Start Time – Night

Driving Start Time - Night: DOE Fleet

% of driving trips b/t 6 PM & 6 AM: 20.0%

% of NHTS trips b/t 6 PM & 6 AM: 19.8%

Total Driving<sup>3</sup> Events = 103009



1. Driving trips between 6 PM & 6 AM
2. The outer arc is set at 10 % total Driving.
3. Some events not recorded/detected due to data noise or incompleteness.

◆ 2001 NHTS Data: Only Car, Truck, Van, & SUV trips included in data set shown here

Created: Sep-10-07 3:11 PM

Source: <http://nhts.orl.gov/download.shtml#2001>, ASCII.csv