

Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project

Spring 2008

Composite Data Products

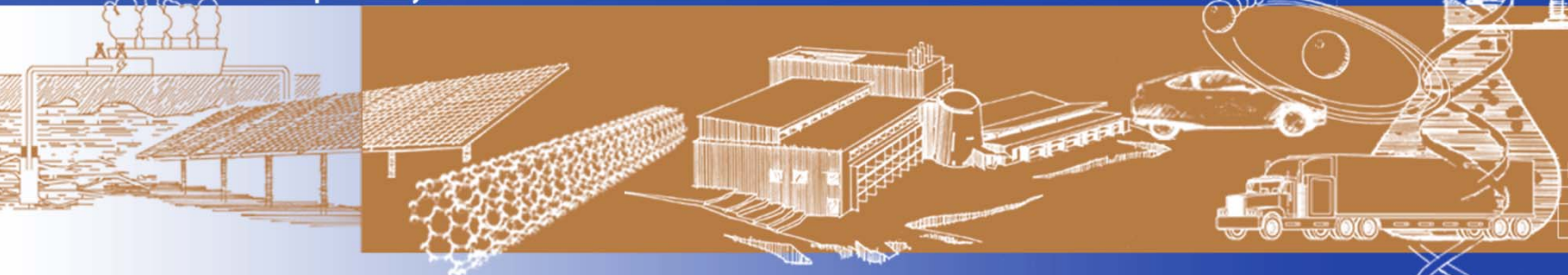
Final Version: February 29, 2008

Keith Wipke, Sam Sprik, Jennifer Kurtz

Technical Report
NREL/TP-560-
April 2008

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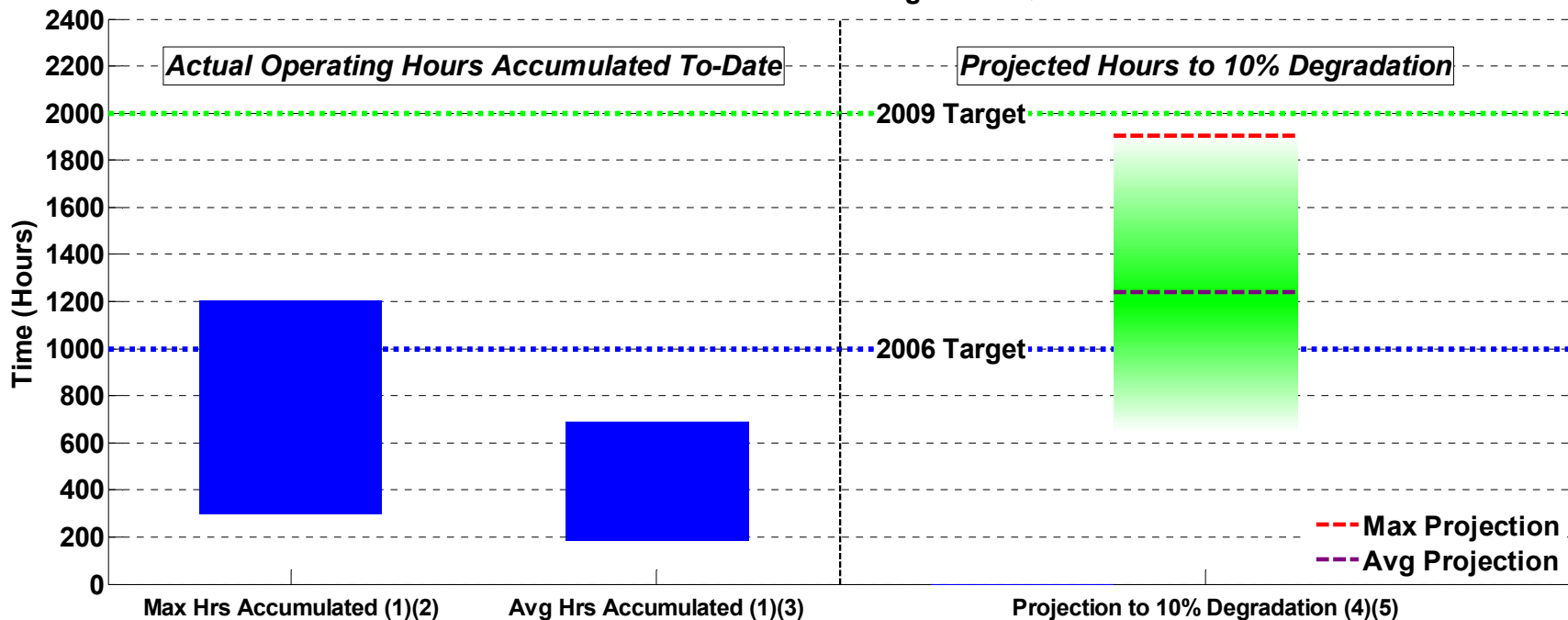
Composite Data Products

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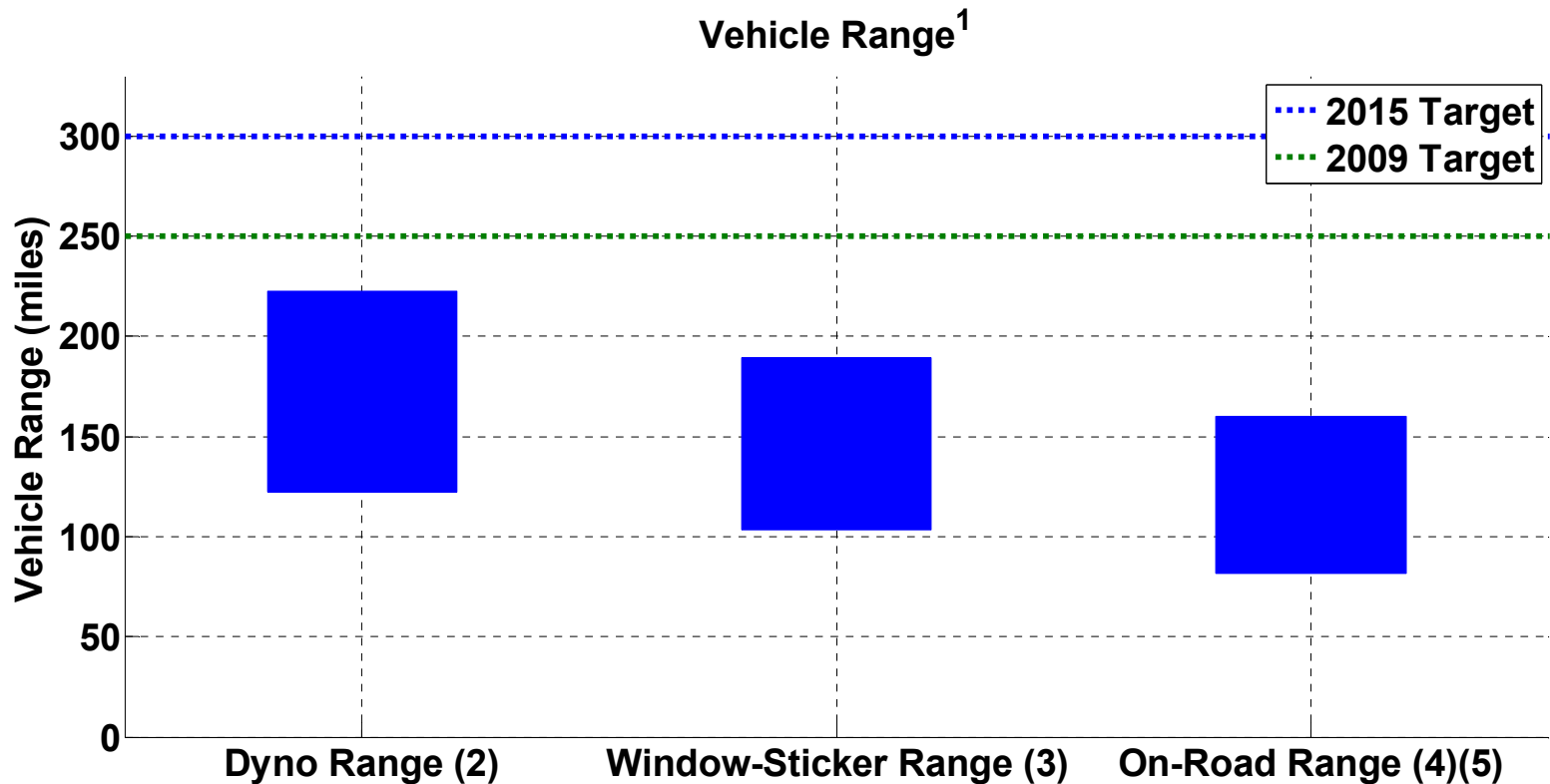
CDP#1: Hours Accumulated and Projected Hours to 10% Stack Voltage Degradation

DOE Learning Demonstration Fuel Cell Stack Durability:
Based on Data Through 2007 Q4



- (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.

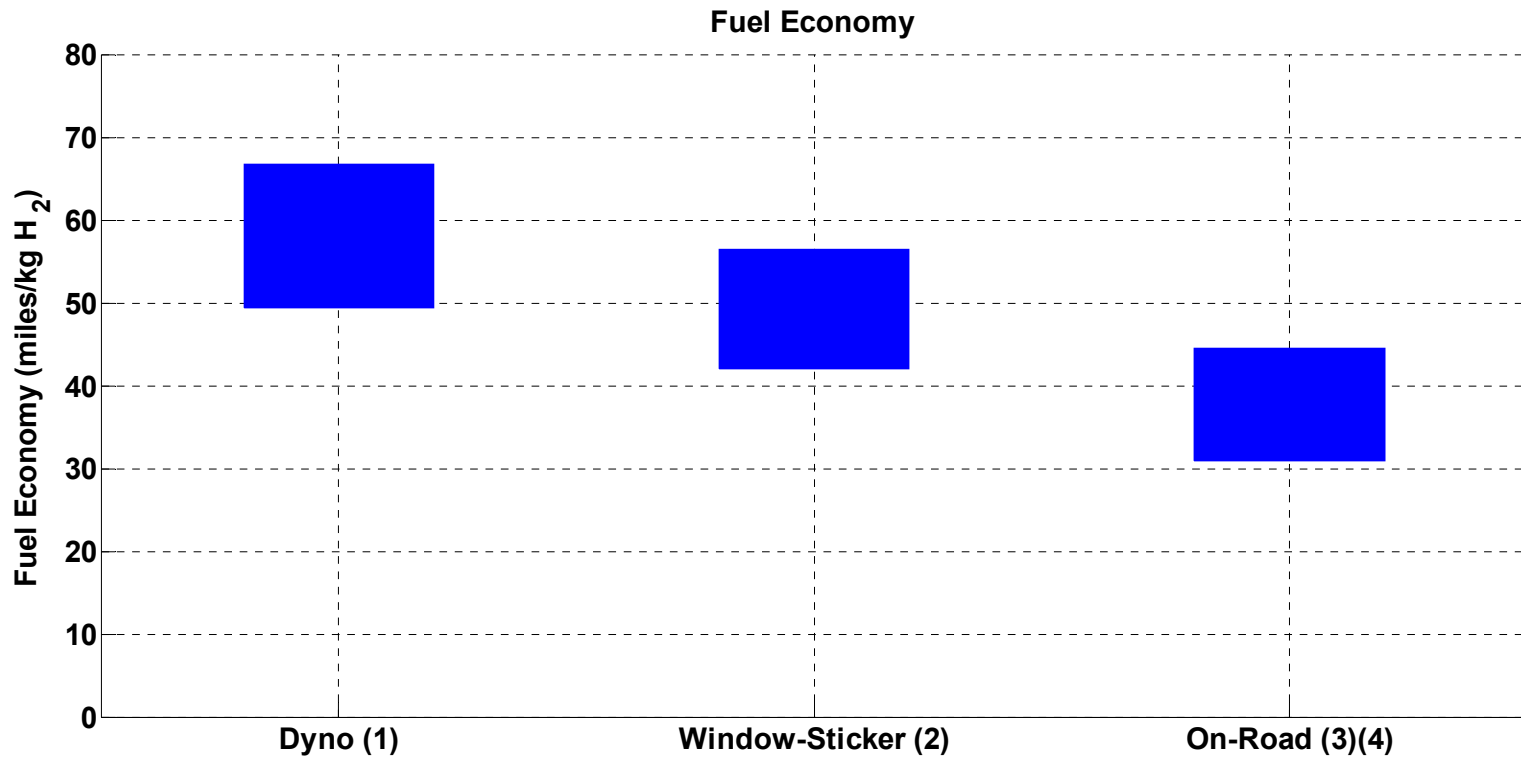
(2) Fuel economy from unadjusted combined City/Hwy per DRAFT SAE J2572.

(3) Fuel economy from EPA Adjusted combined City/Hwy ($0.78 \times \text{Hwy}$, $0.9 \times \text{City}$).

(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.

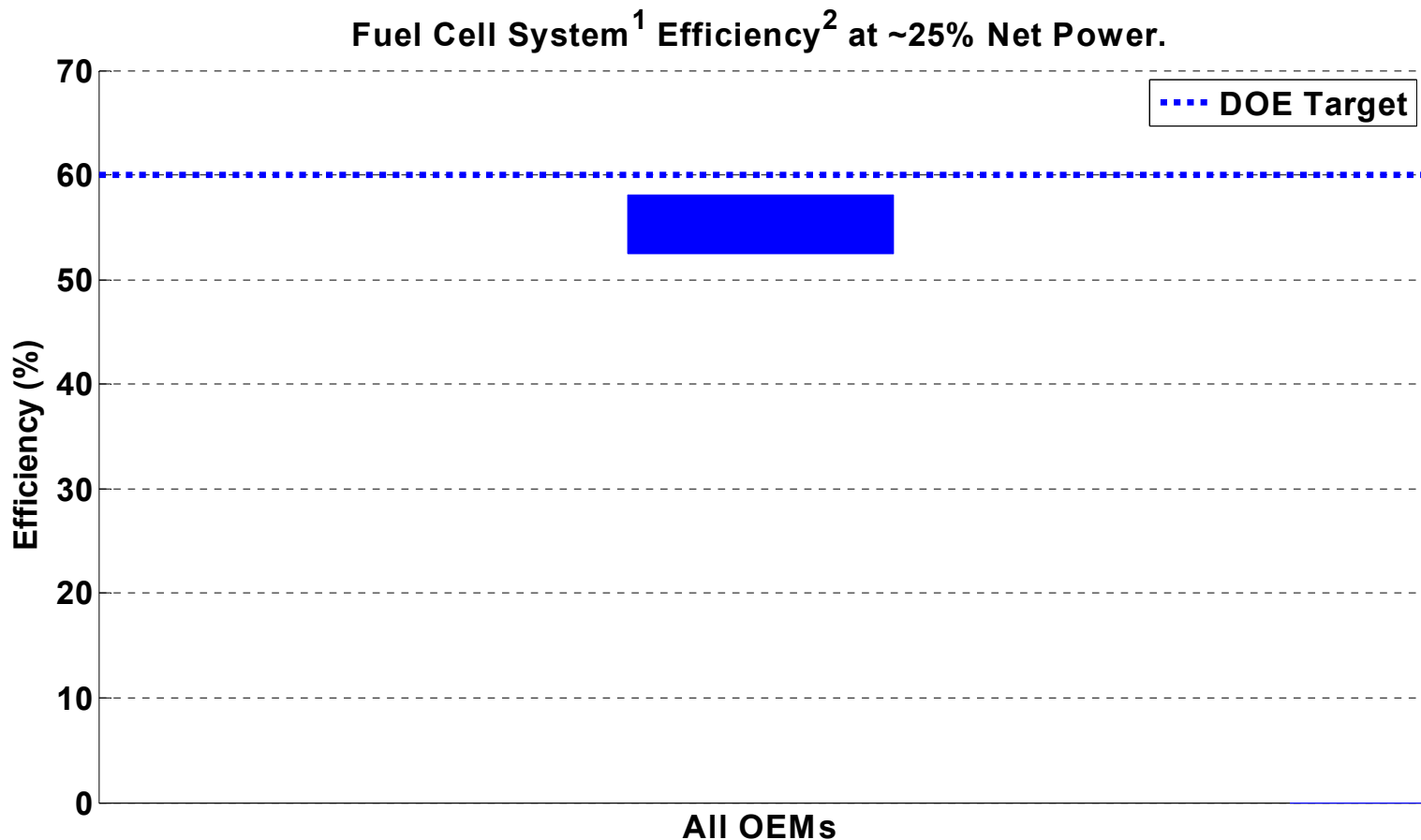
(2) Adjusted combined City/Hwy fuel economy ($0.78 \times \text{Hwy}$, $0.9 \times \text{City}$).

(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



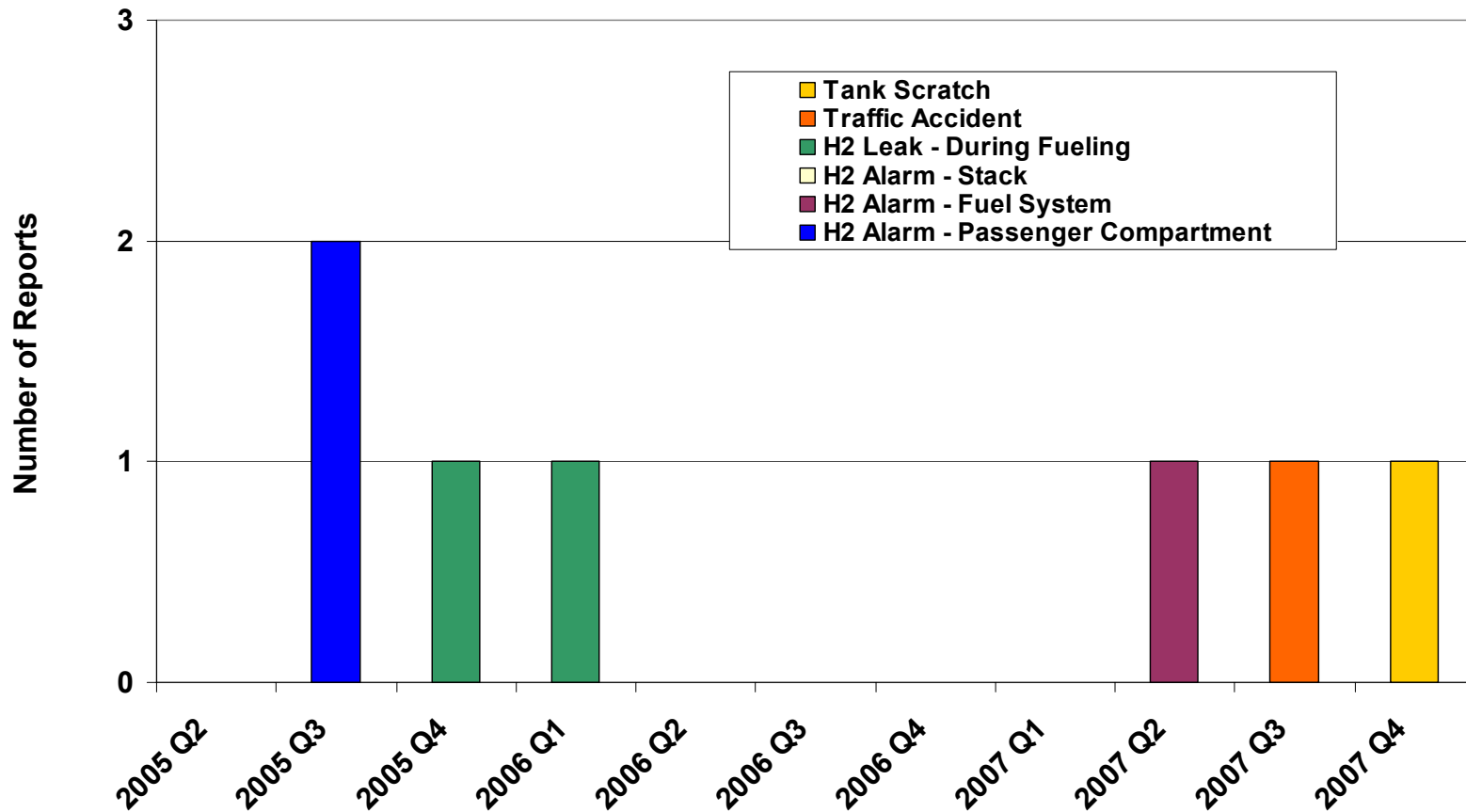
¹ Gross stack power minus fuel cell system auxiliaries, per DRAFT SAEJ2615.

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

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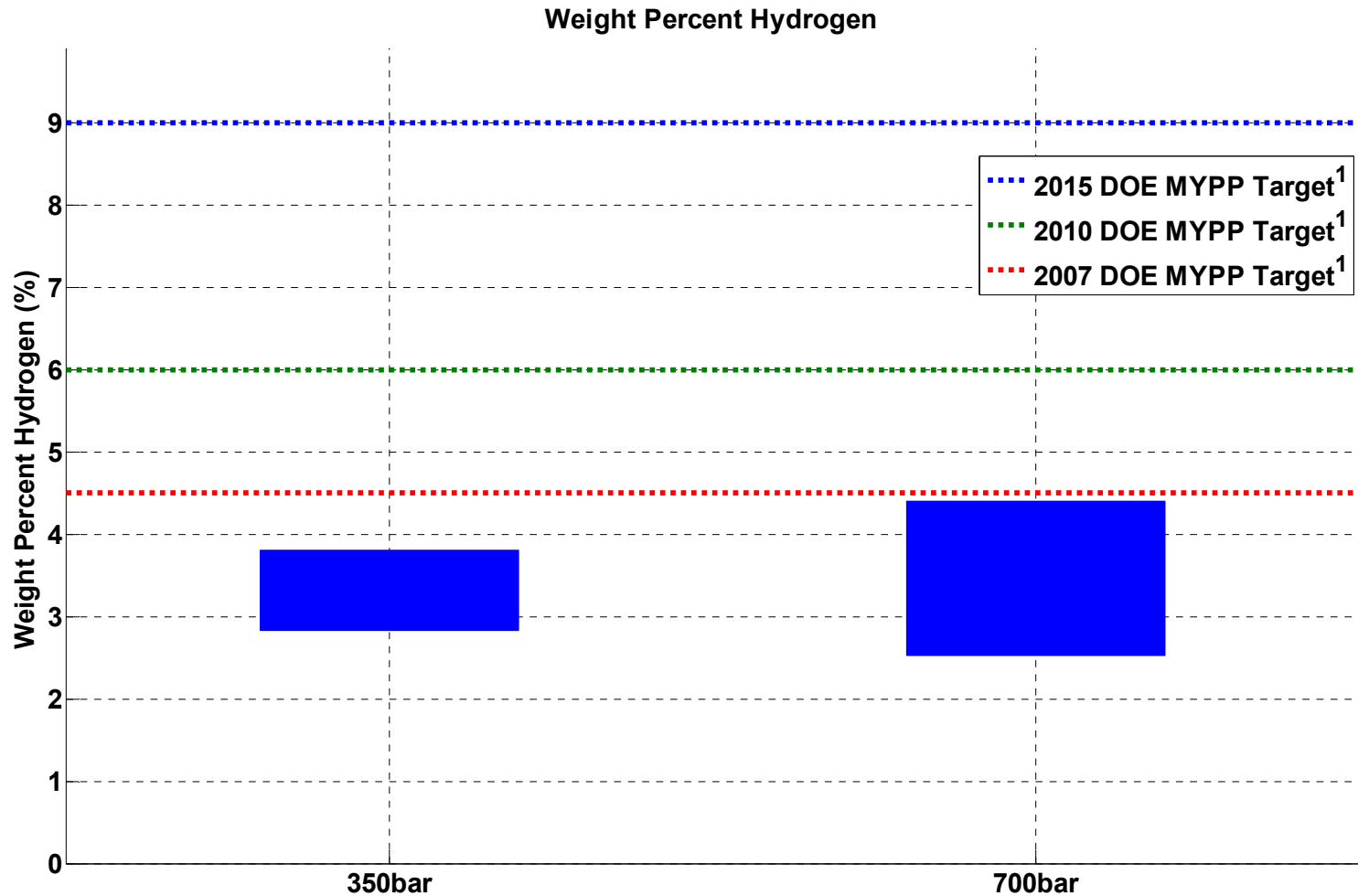
CDP#9: Safety Reports – Vehicles

Safety Reports - Vehicle Operation



Created: 2/15/07 9AM

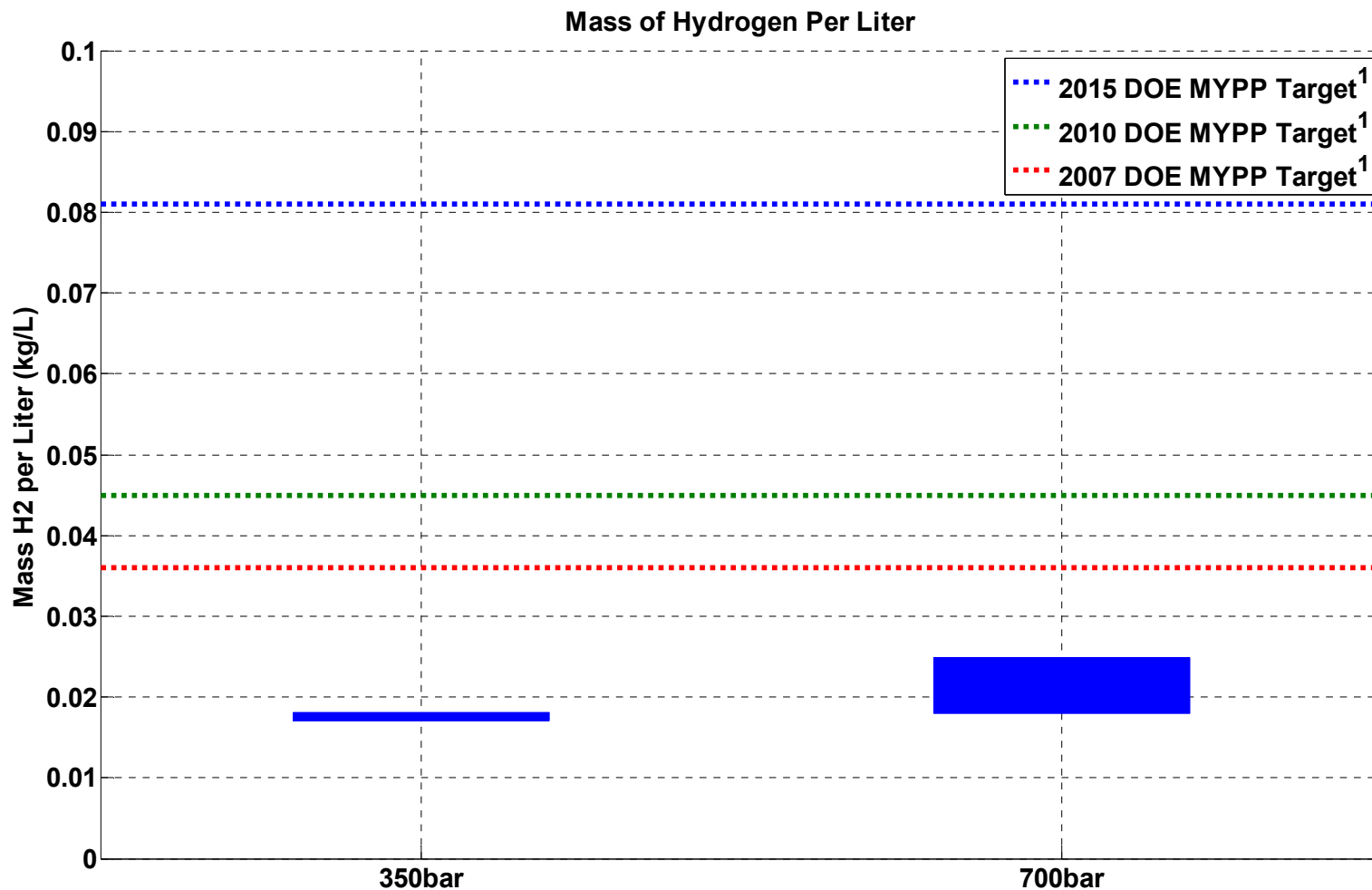
CDP#10: Storage Weight % Hydrogen



¹Targets are set for advanced materials-based hydrogen storage technologies.

Created: Feb-15-08 7:32 AM

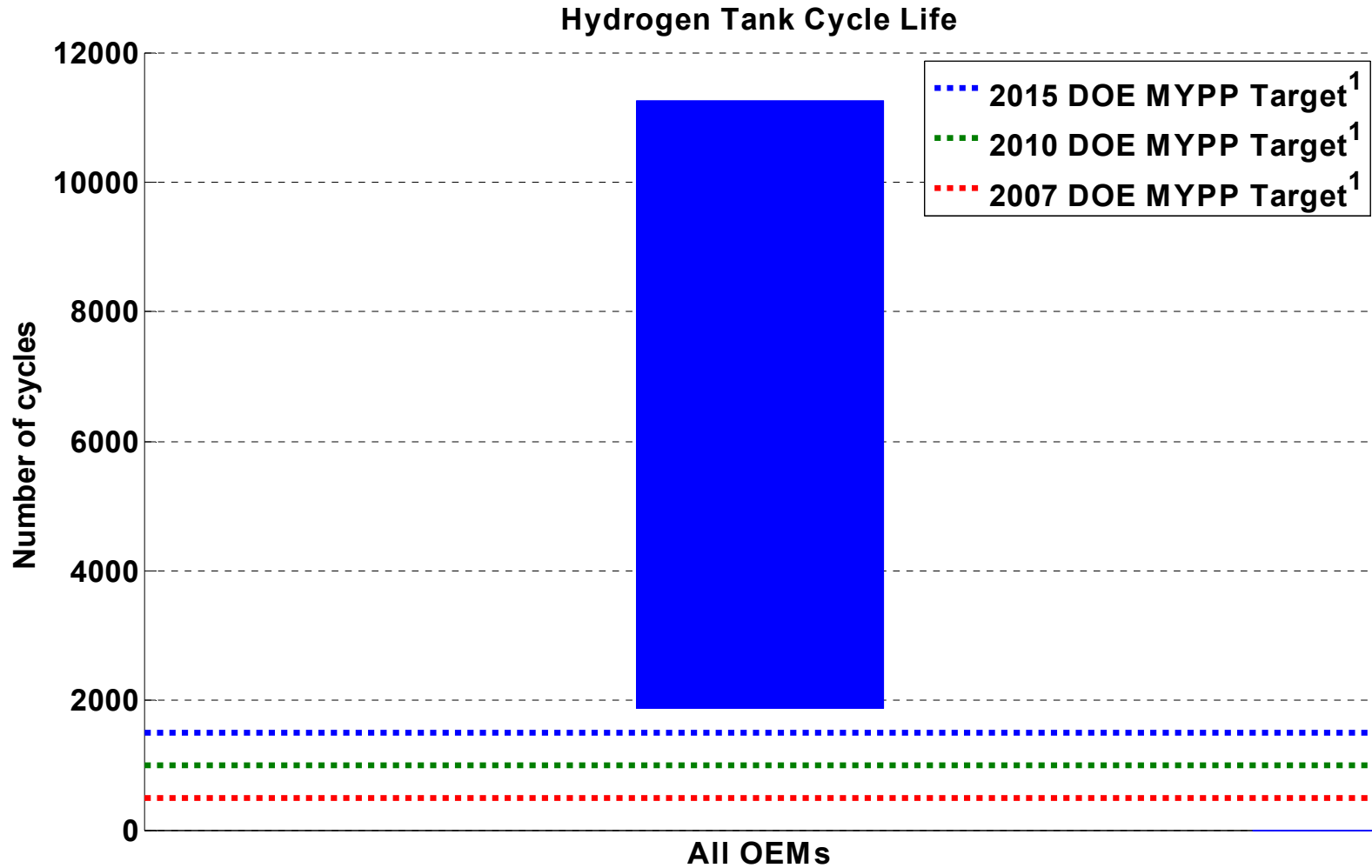
CDP#11: Volumetric Capacity of H2 Storage



¹Targets are set for advanced materials-based hydrogen storage technologies.

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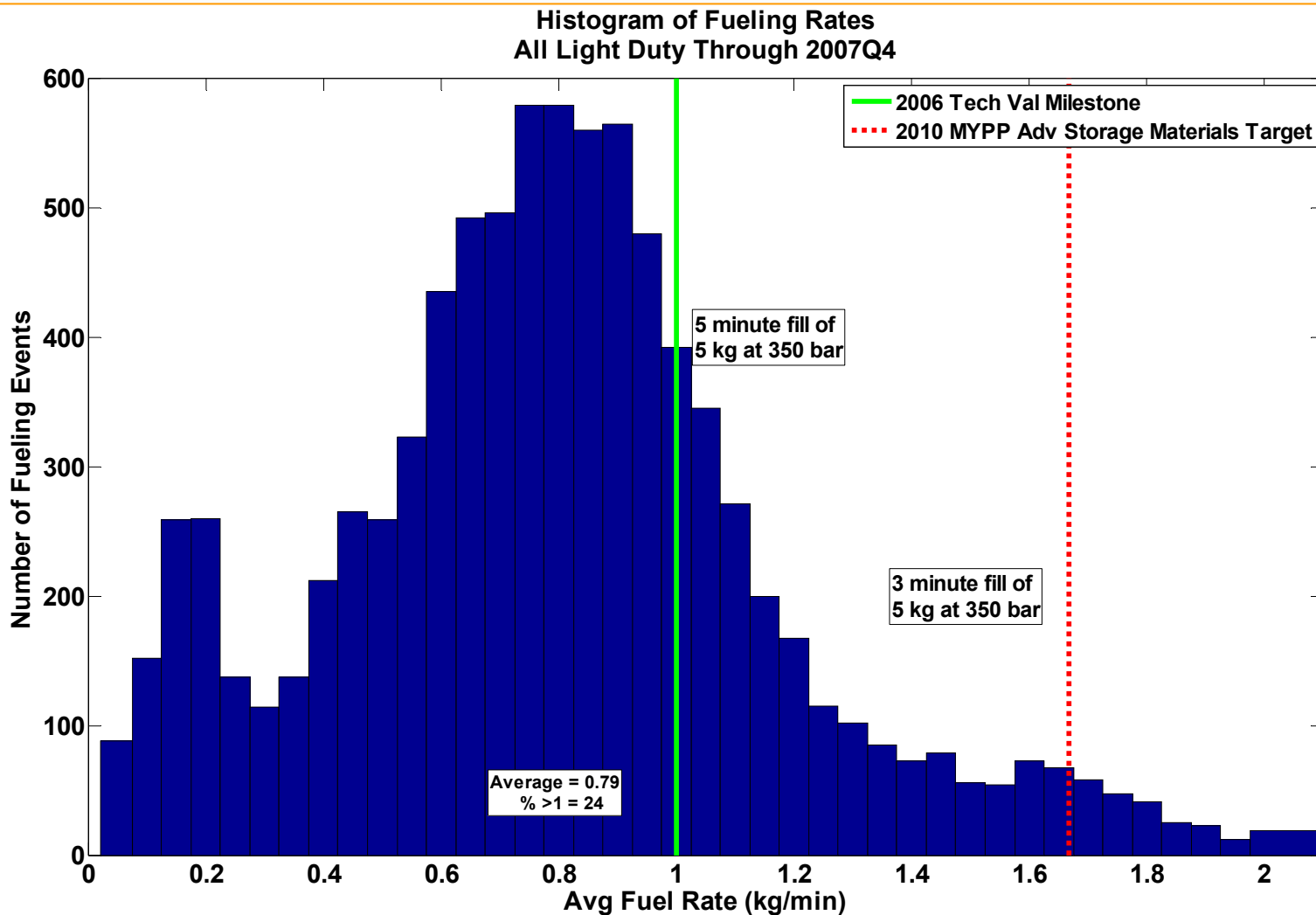
CDP#12: Vehicle Hydrogen Tank Cycle Life



Created: 23-Feb-2006

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

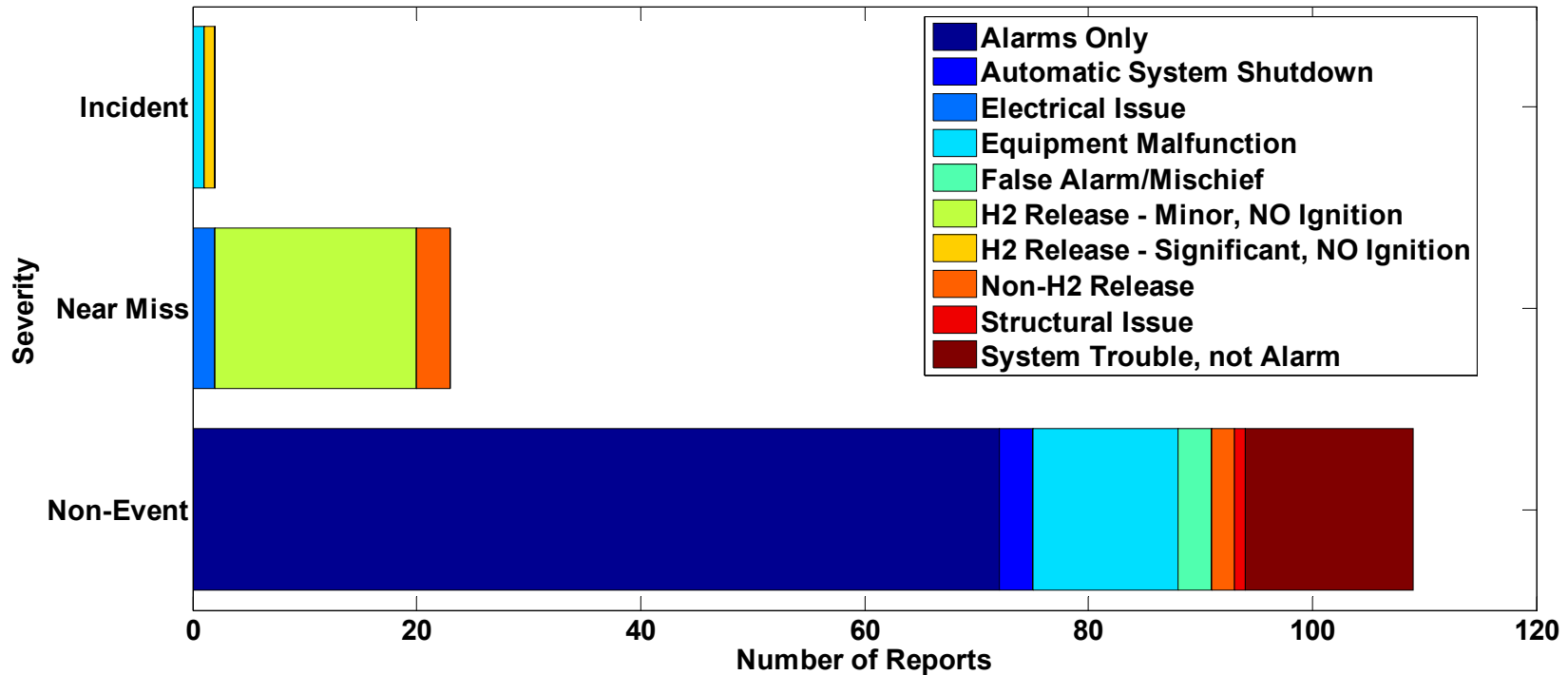
CDP#18: Refueling Rates



Created: Feb-15-08 1:44 PM

CDP#20: Safety Reports – Infrastructure

Total Infrastructure Safety Reports by Severity and Report Type Through 2007 Q4



An INCIDENT is an event that results in:

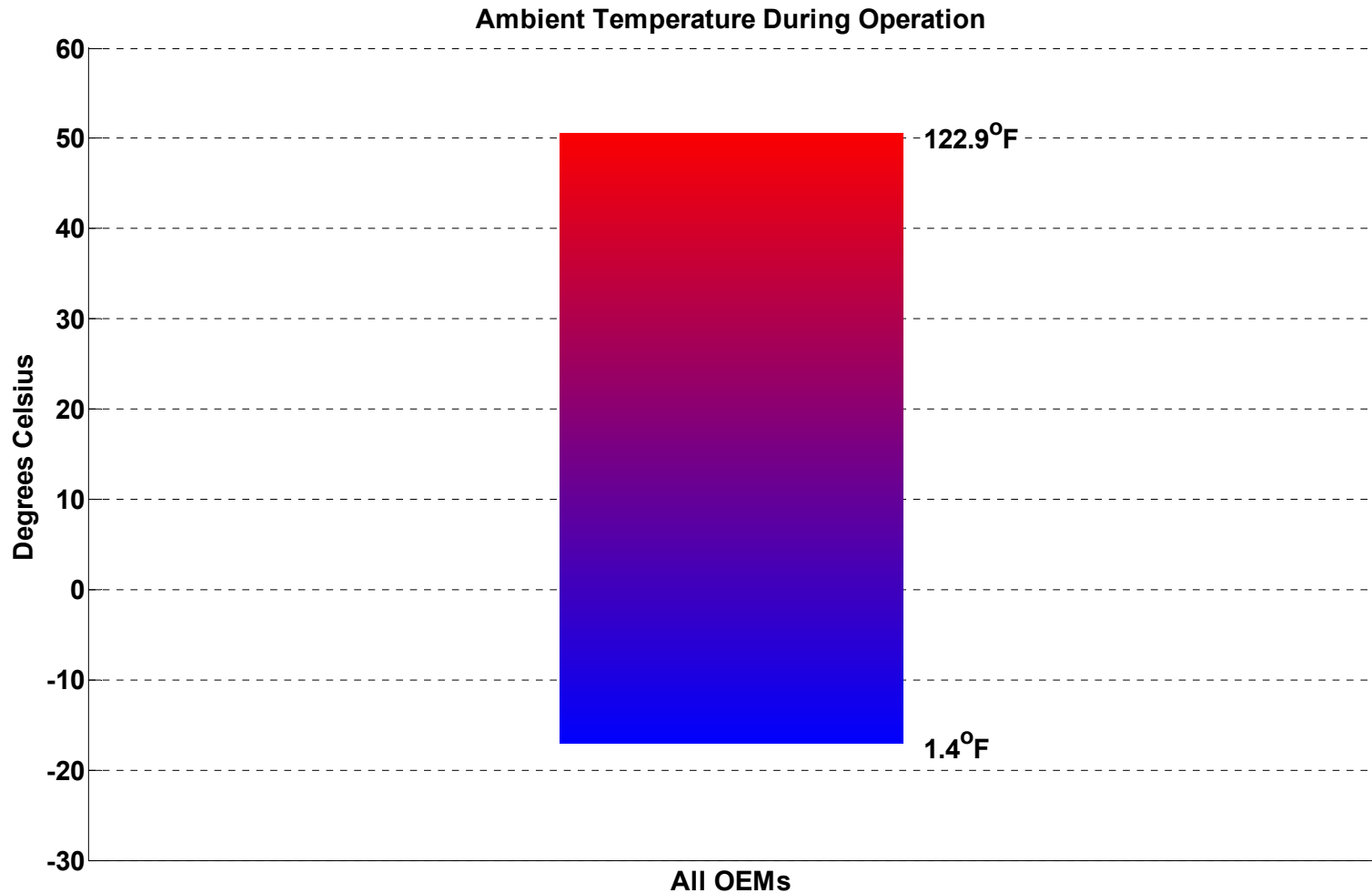
- a lost time accident and/or injury to personnel
- damage/unplanned downtime for project equipment, facilities or property
- impact to the public or environment
- any hydrogen release that unintentionally ignites or is sufficient to sustain a flame if ignited
- release of any volatile, hydrogen containing compound (other than the hydrocarbons used as common fuels)

A NEAR-MISS is:

- an event that under slightly different circumstances could have become an incident
- unplanned H2 release insufficient to sustain a flame

Created: Feb-15-08 1:24 PM

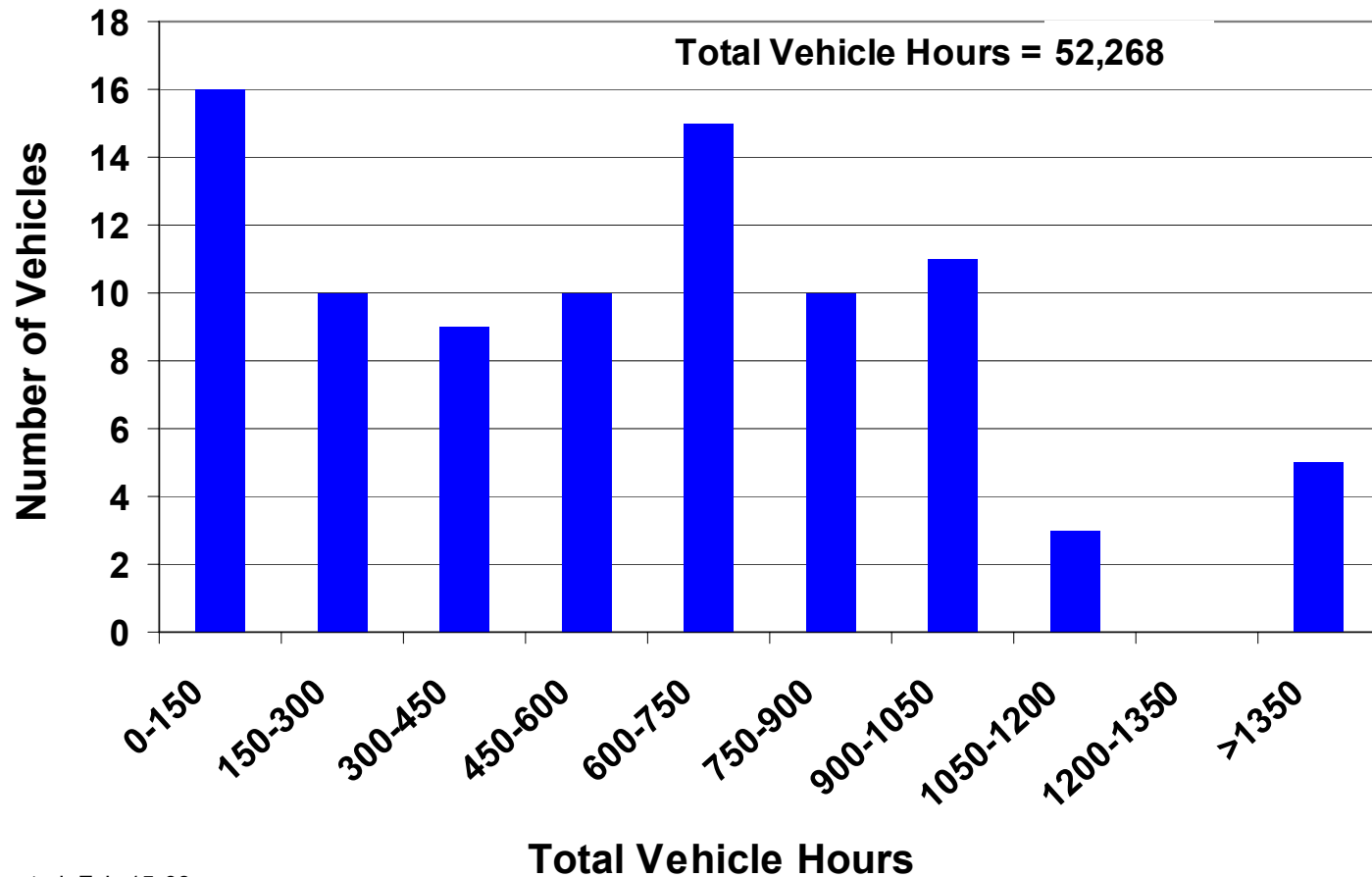
CDP#21: Range of Ambient Temperature During Vehicle Operation



Created: Feb-14-08 5:40 PM

CDP#22: Vehicle Operating Hours

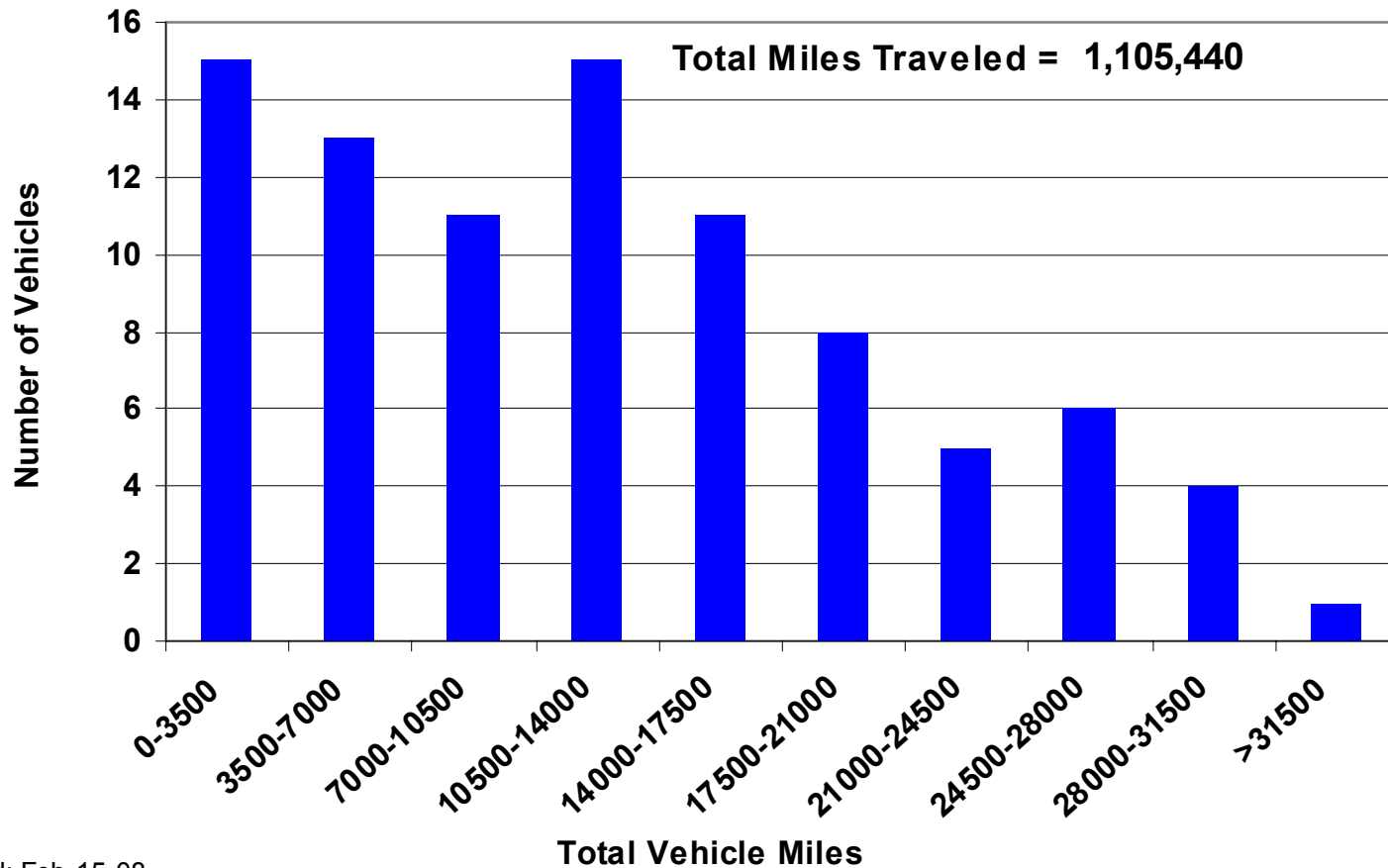
Vehicle Hours: All OEMs Combined
Through 2007 Q4



Created: Feb-15-08

CDP#23: Vehicles vs. Miles Traveled

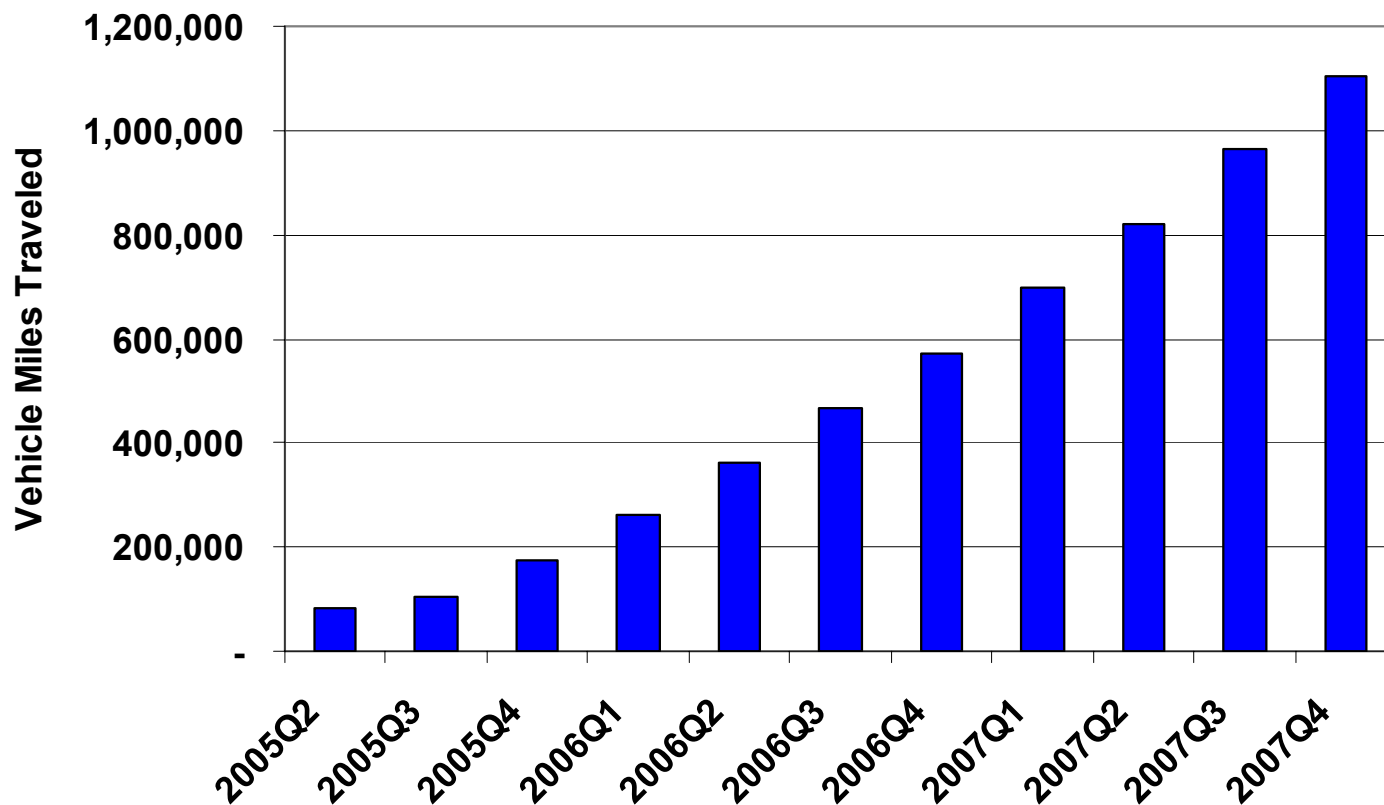
Vehicle Miles: All OEMs Combined
Through 2007 Q4



Created: Feb-15-08

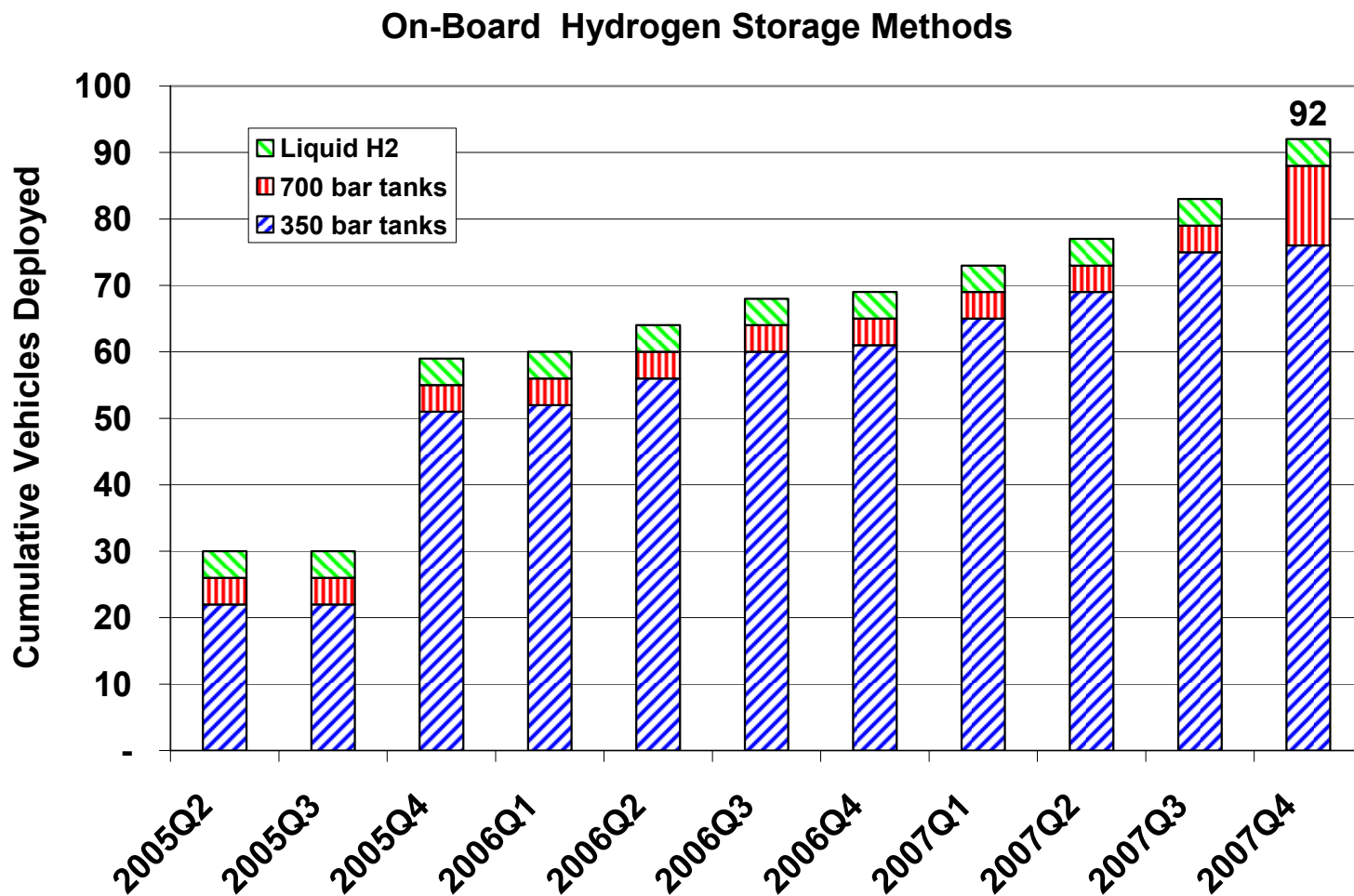
CDP#24: Cumulative Vehicle Miles Traveled

Cumulative Vehicle Miles Traveled: All OEMs



Created: Feb-15-08

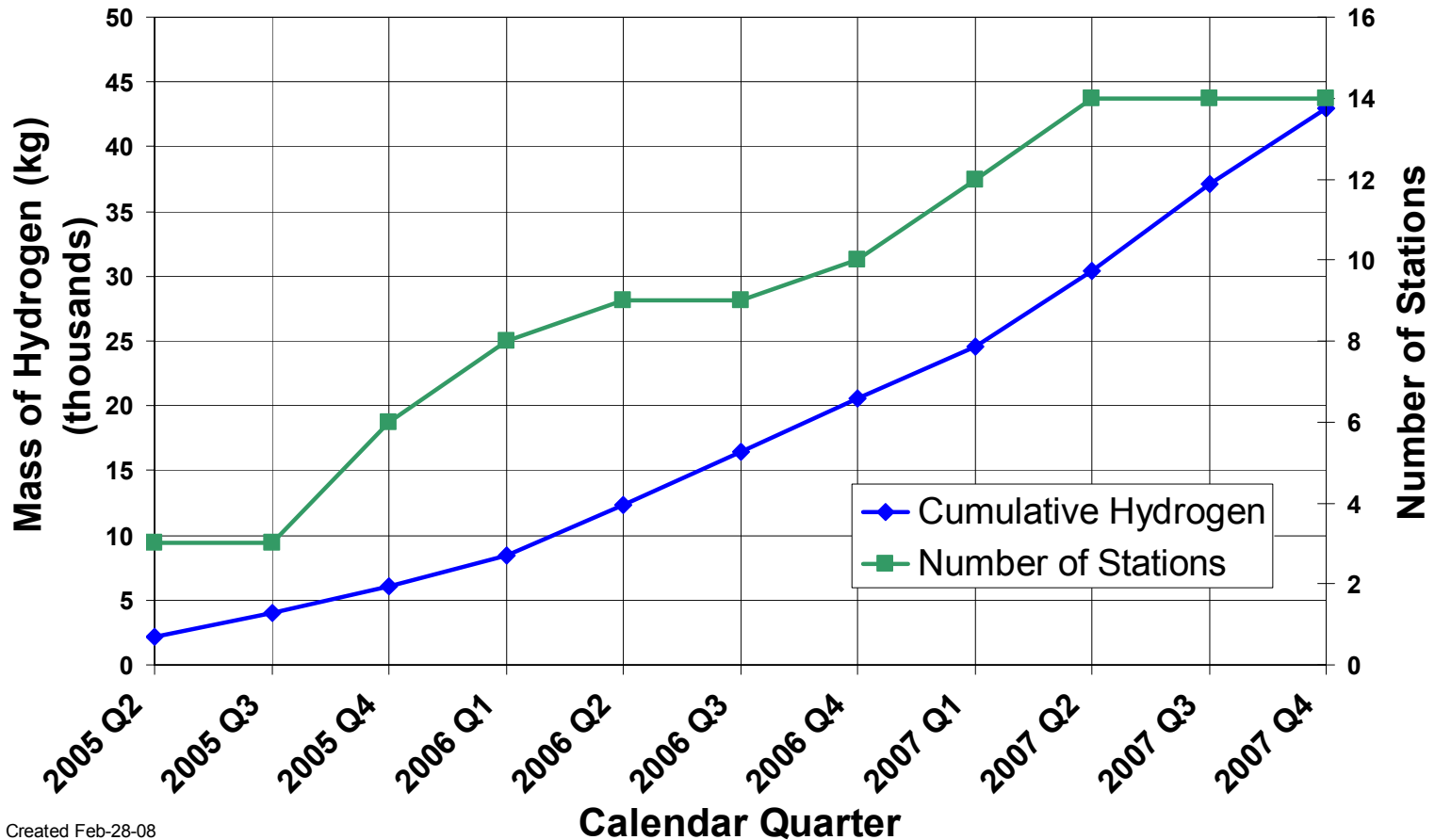
CDP#25: Vehicle H2 Storage Technologies



Created Feb-08-2008 8:57AM

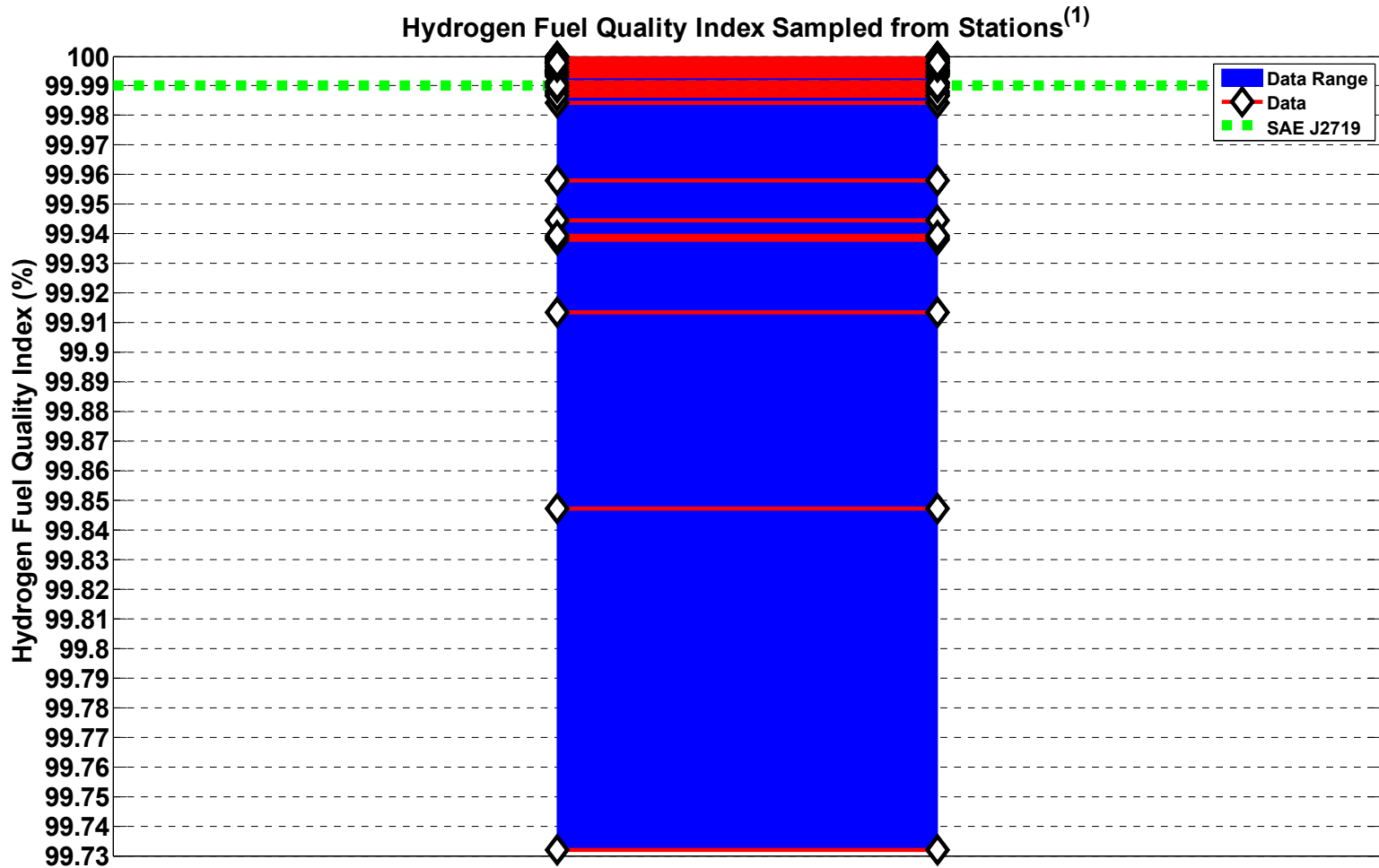
CDP#26: Cumulative H2 Produced or Dispensed

Cumulative Hydrogen Produced or Dispensed Through 2007 Q4



Created Feb-28-08

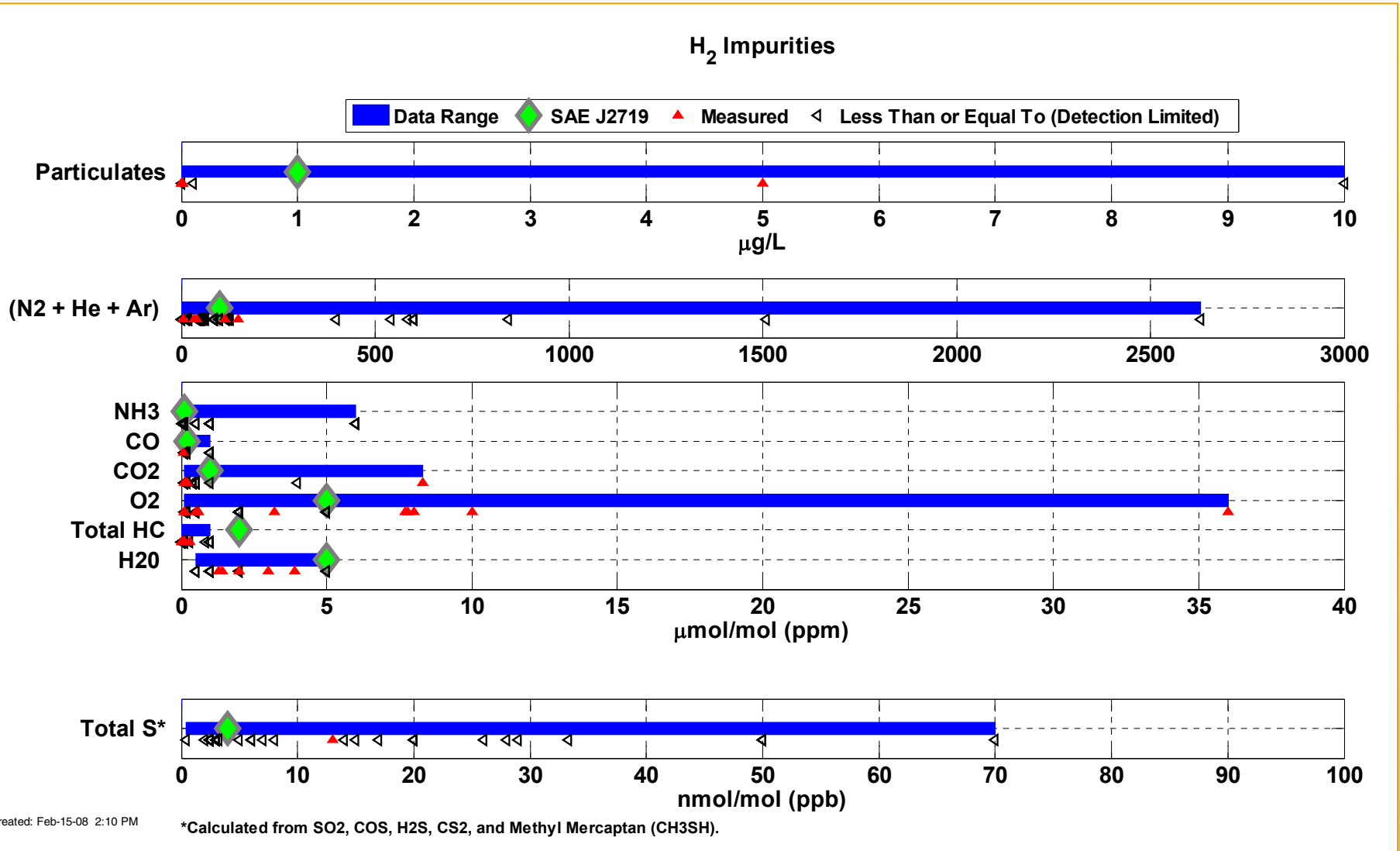
CDP#27: Hydrogen Purity Scatter Plot



(1) Includes sampling from both electrolysis and reforming

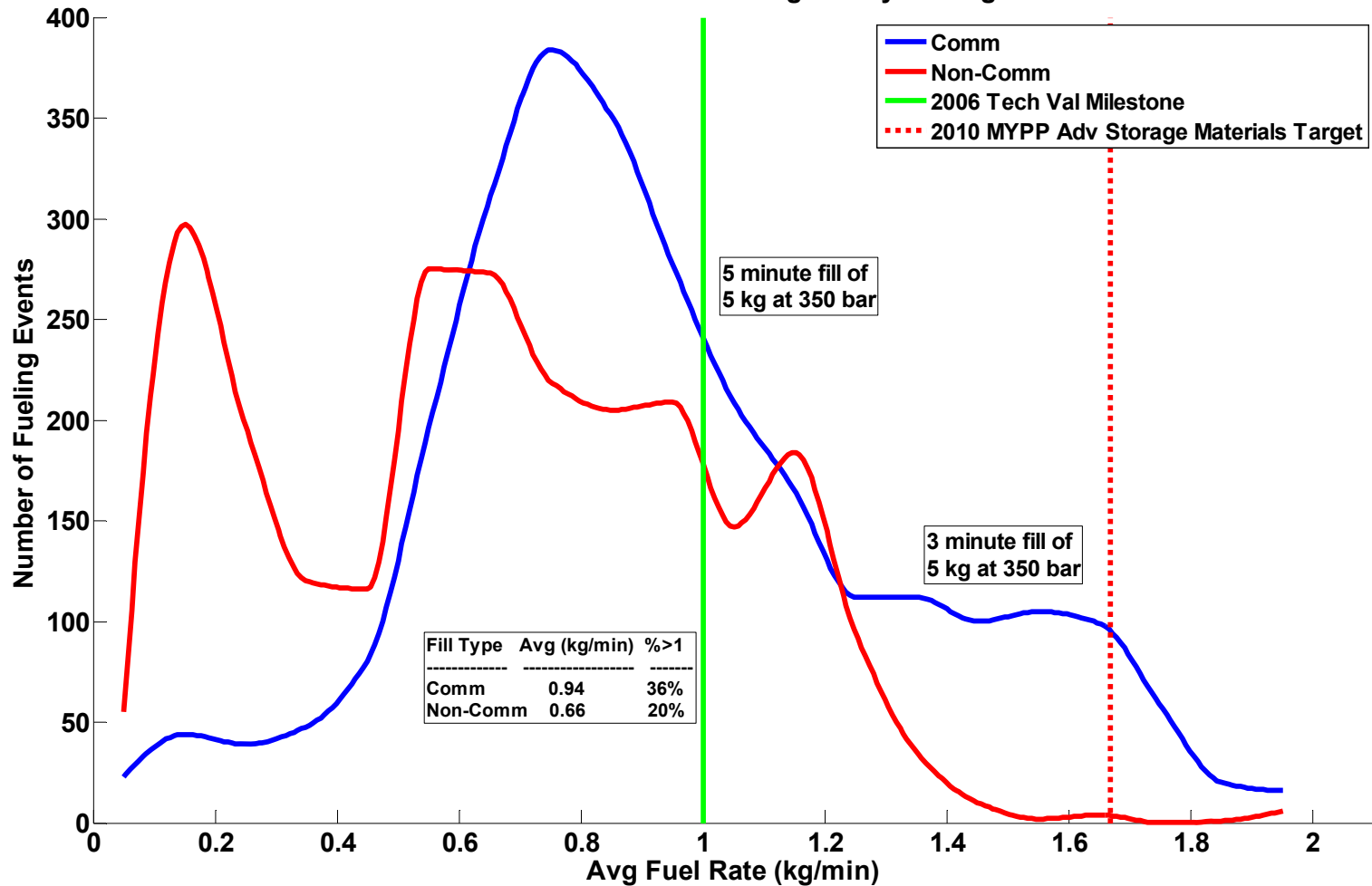
Created: Feb-15-08 2:10 PM

CDP #28: Hydrogen Impurities Scatter Plot



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

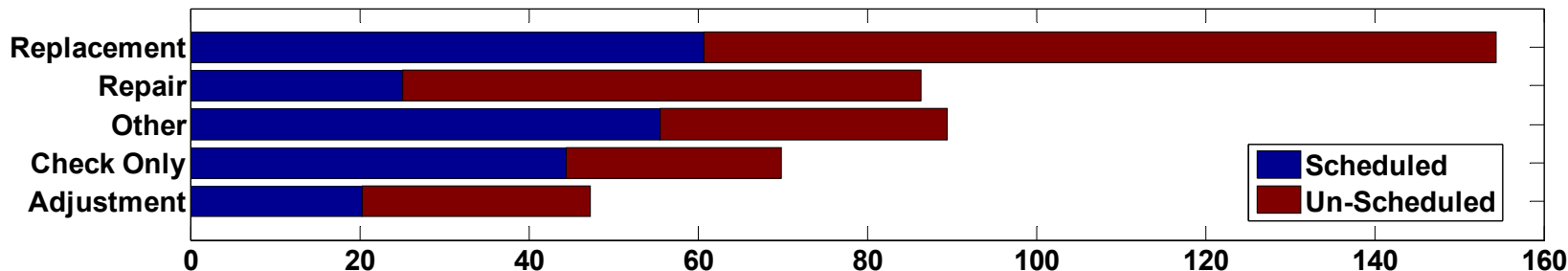
Histogram of Fueling Rates
Comm vs Non-Comm Fills - All Light Duty Through 2007Q4



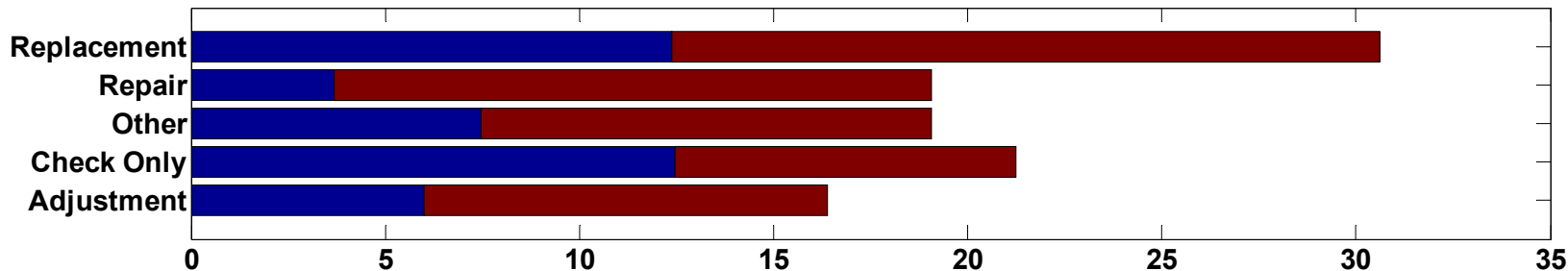
Created: Feb-27-08 11:26 AM

CDP#30: Infrastructure Maintenance

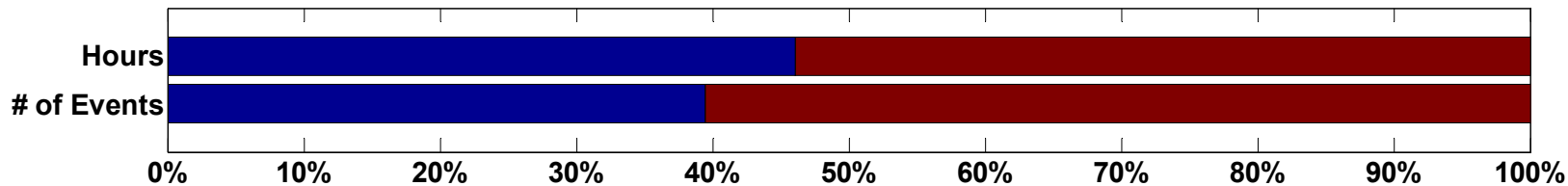
Maintenance: Average Labor Hours Per Station Since Inception Through 2007 Q4



Maintenance: Average Number of Events Per Station Since Inception

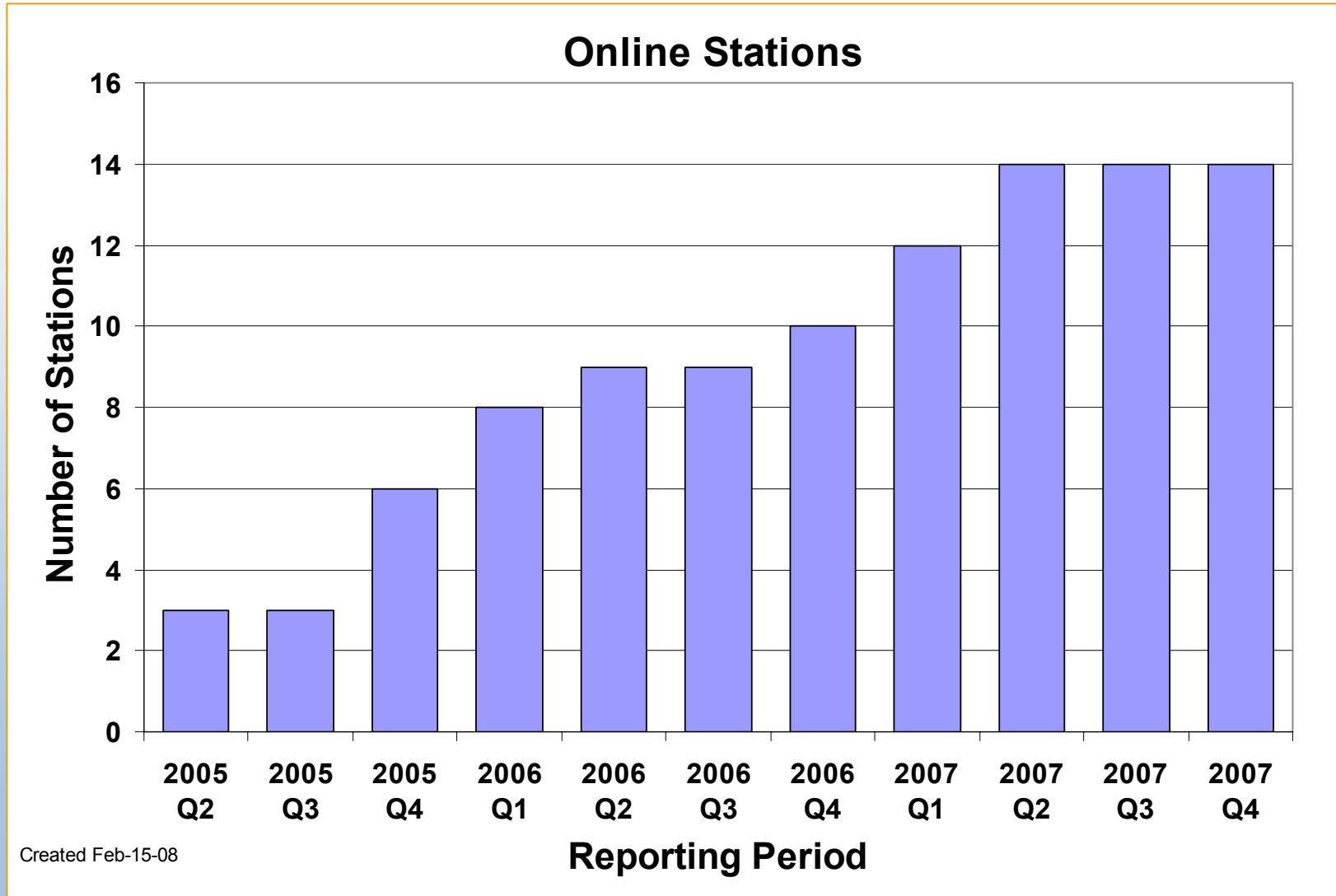


Comparison of Scheduled/Un-Scheduled Maintenance



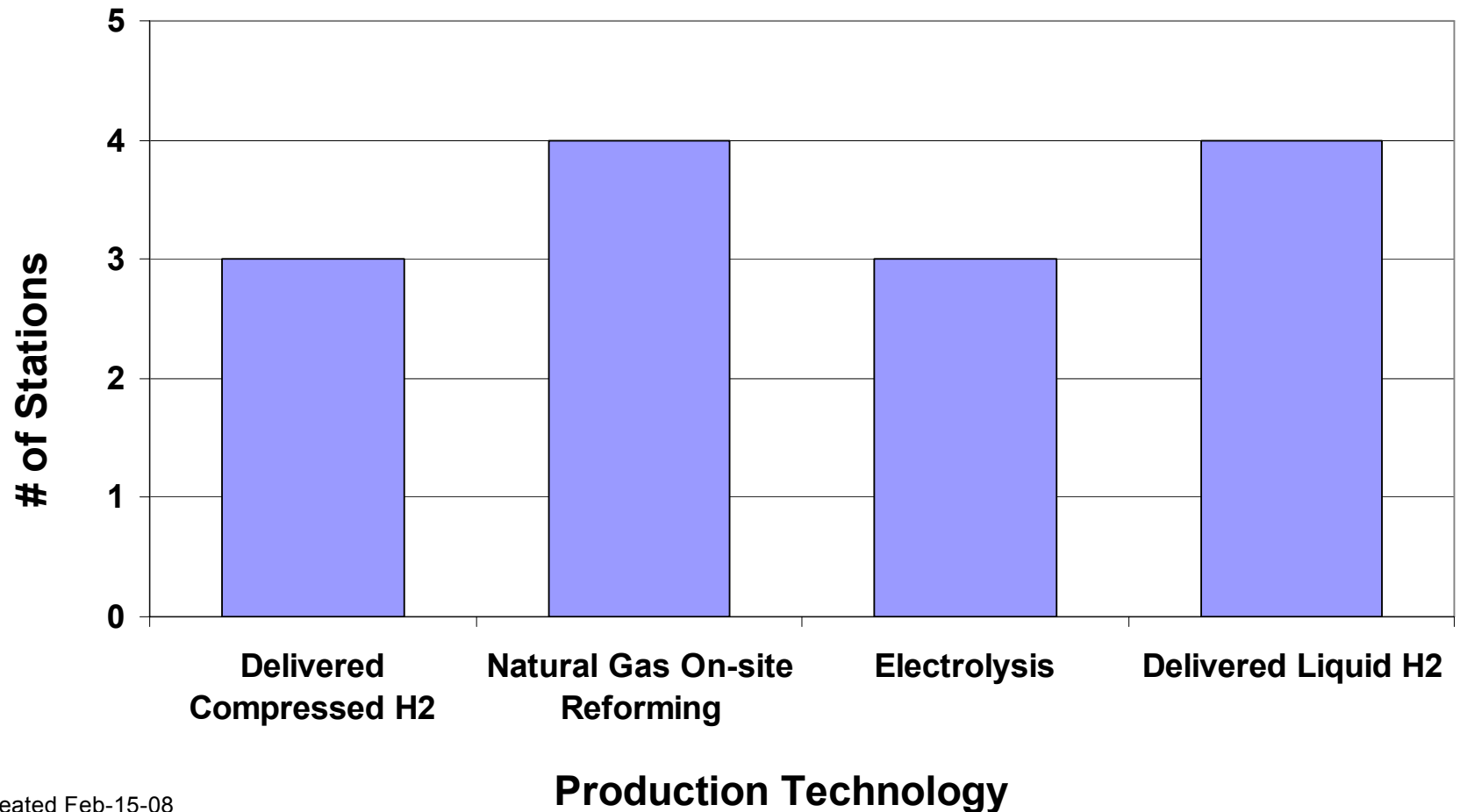
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CDP#31: Number of Reporting Stations



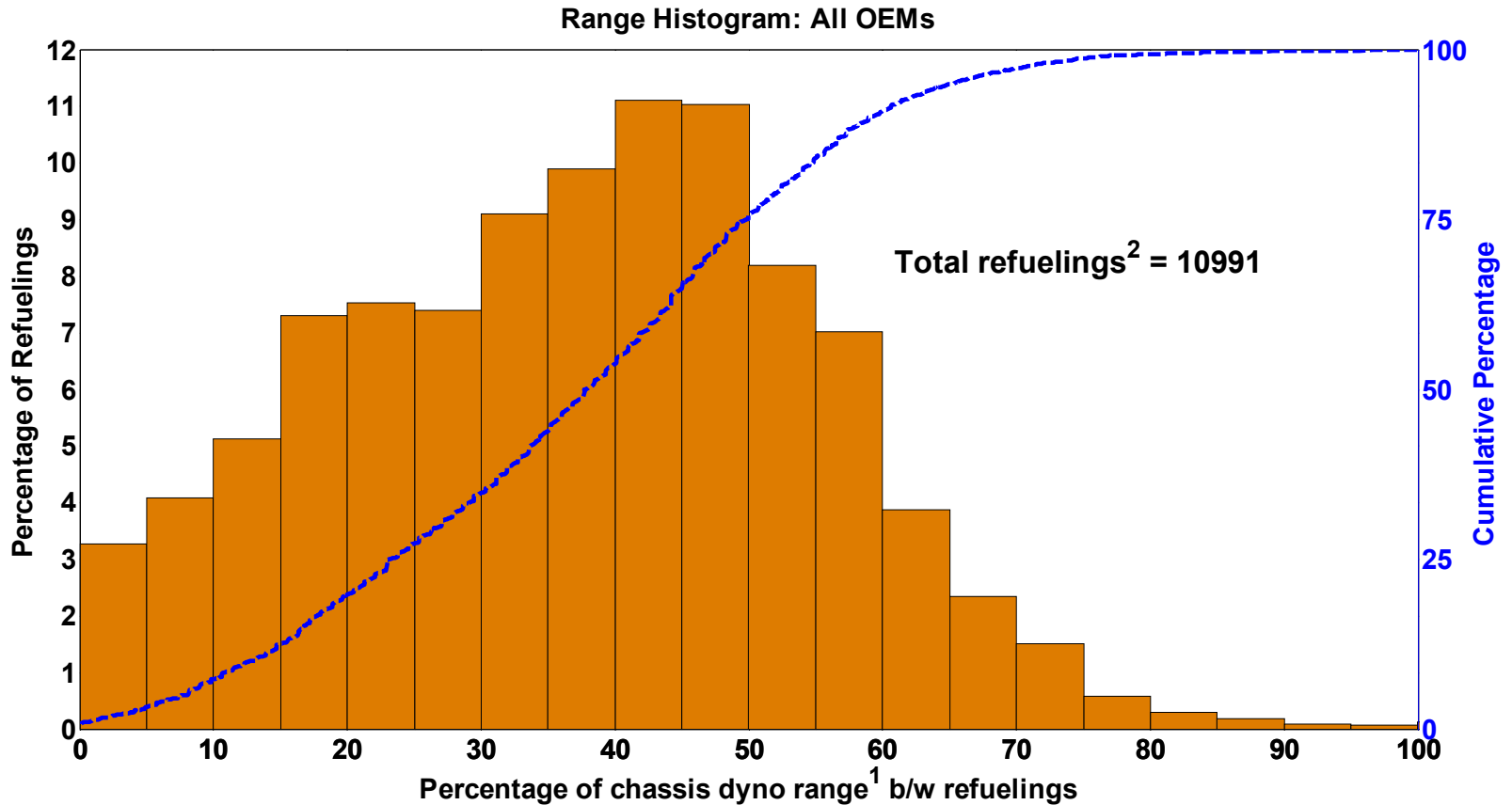
CDP#32: Infrastructure Hydrogen Production Methods

Infrastructure Hydrogen Production Methods



Created Feb-15-08

CDP#33: Percentage of Theoretical Range Traveled Between Refuelings

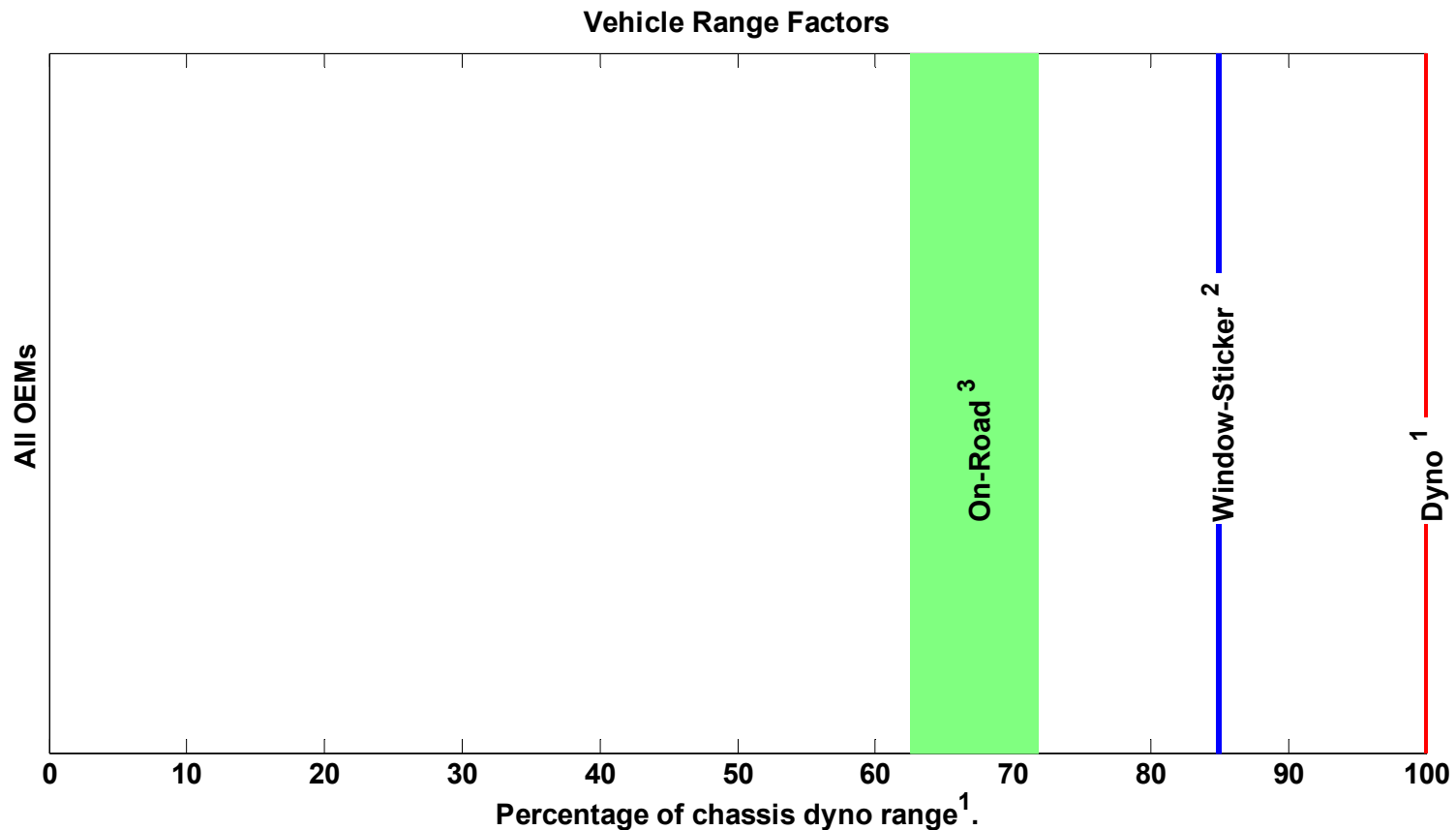


1. Range calculated using the combined City/Hwy fuel economy from dyno testing (not EPA adjusted) and usable fuel on board.

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

Created: Feb-15-08 9:20 AM

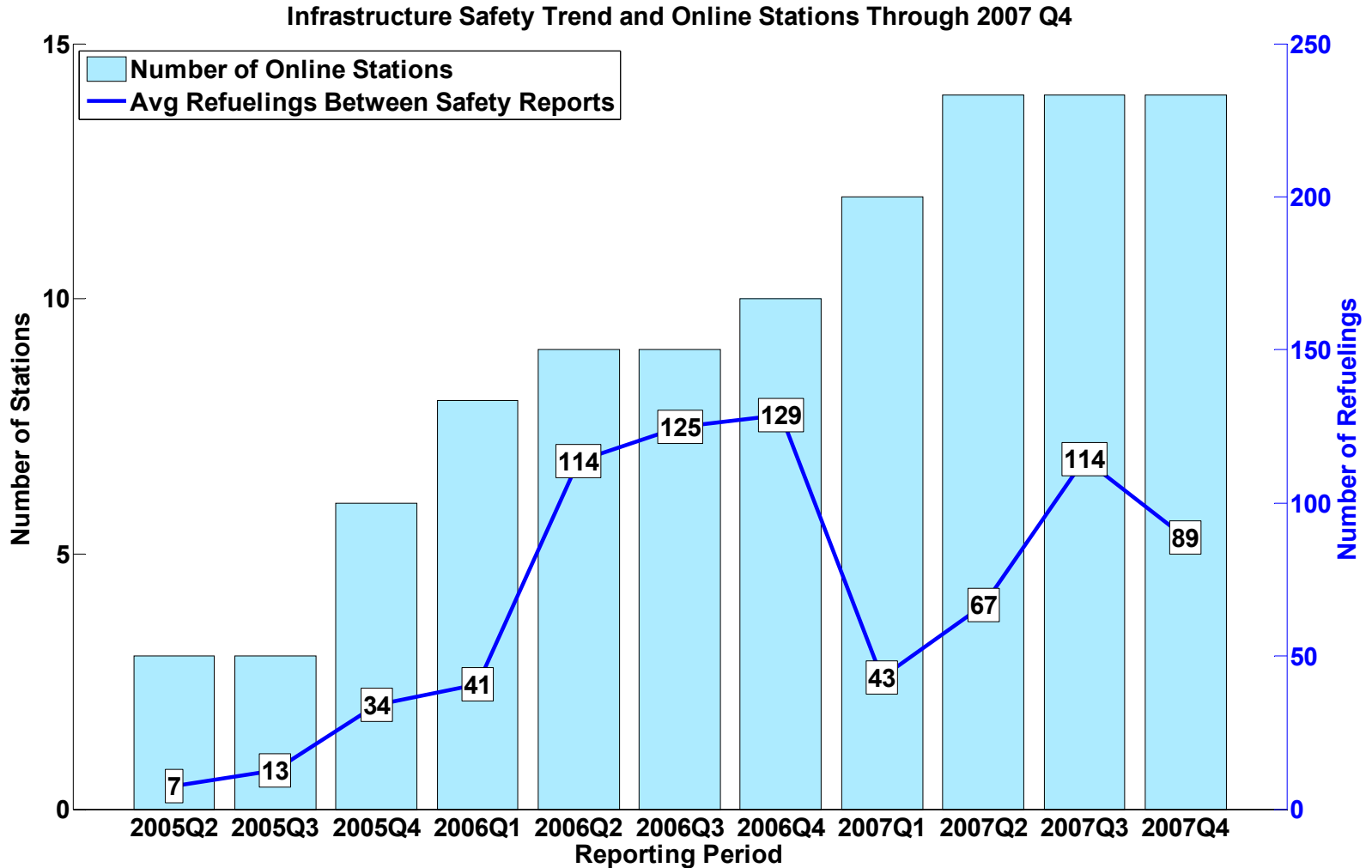
CDP#34: Effective Vehicle Range



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).

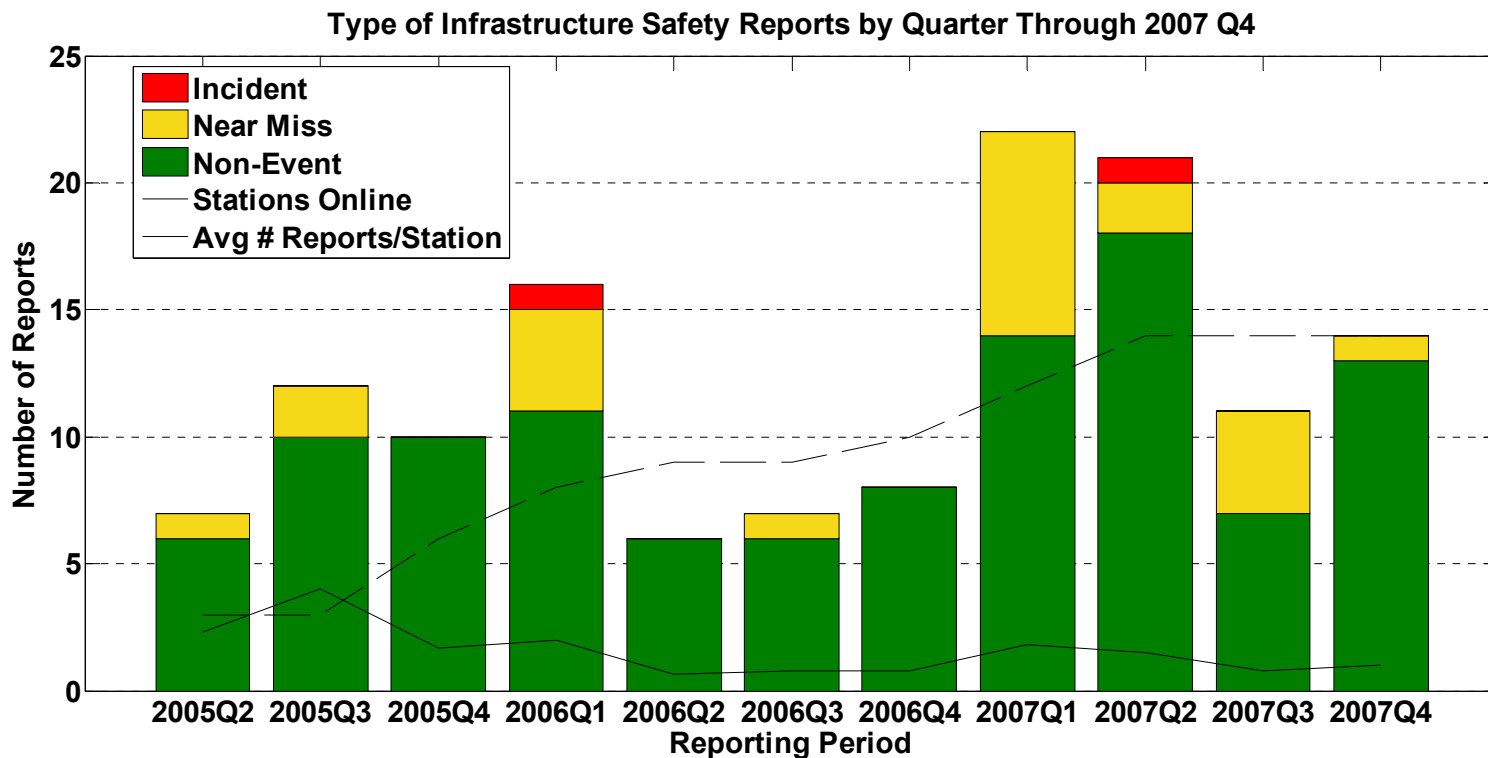
Created: Feb-15-08 9:20 AM

CDP#35: Average Refuelings Between Infrastructure Safety Reports



Created: Feb-15-08 1:24 PM

CDP#36: Type of Infrastructure Safety Report By Quarter



An INCIDENT is an event that results in:

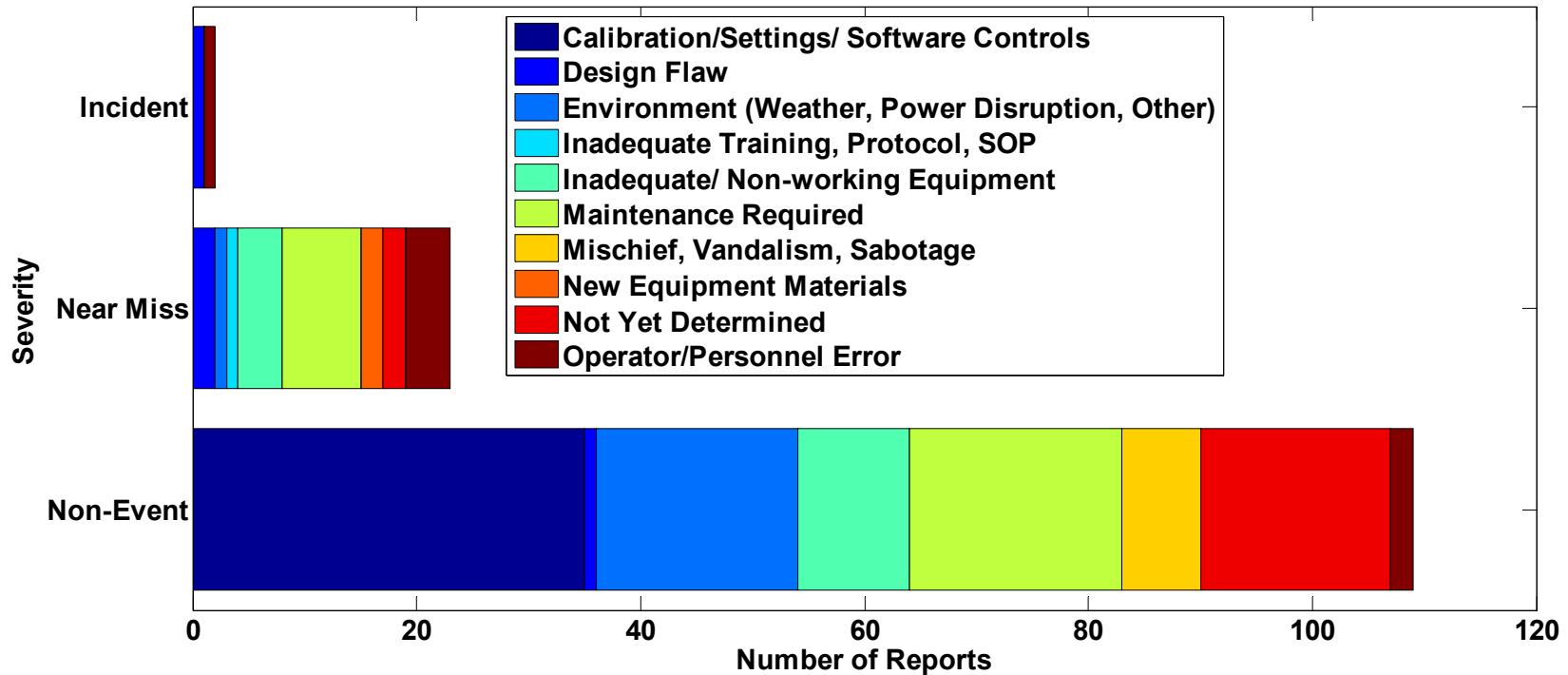
- a lost time accident and/or injury to personnel
- damage/unplanned downtime for project equipment, facilities or property
- impact to the public or environment
- any hydrogen release that unintentionally ignites or is sufficient to sustain a flame if ignited
- release of any volatile, hydrogen containing compound (other than the hydrocarbons used as common fuels)

A NEAR-MISS is:

- an event that under slightly different circumstances could have become an incident
- unplanned H2 release insufficient to sustain a flame

CDP#37: Primary Factors of Infrastructure Safety Reports

Primary Factors of Infrastructure Safety Reports Through 2007 Q4



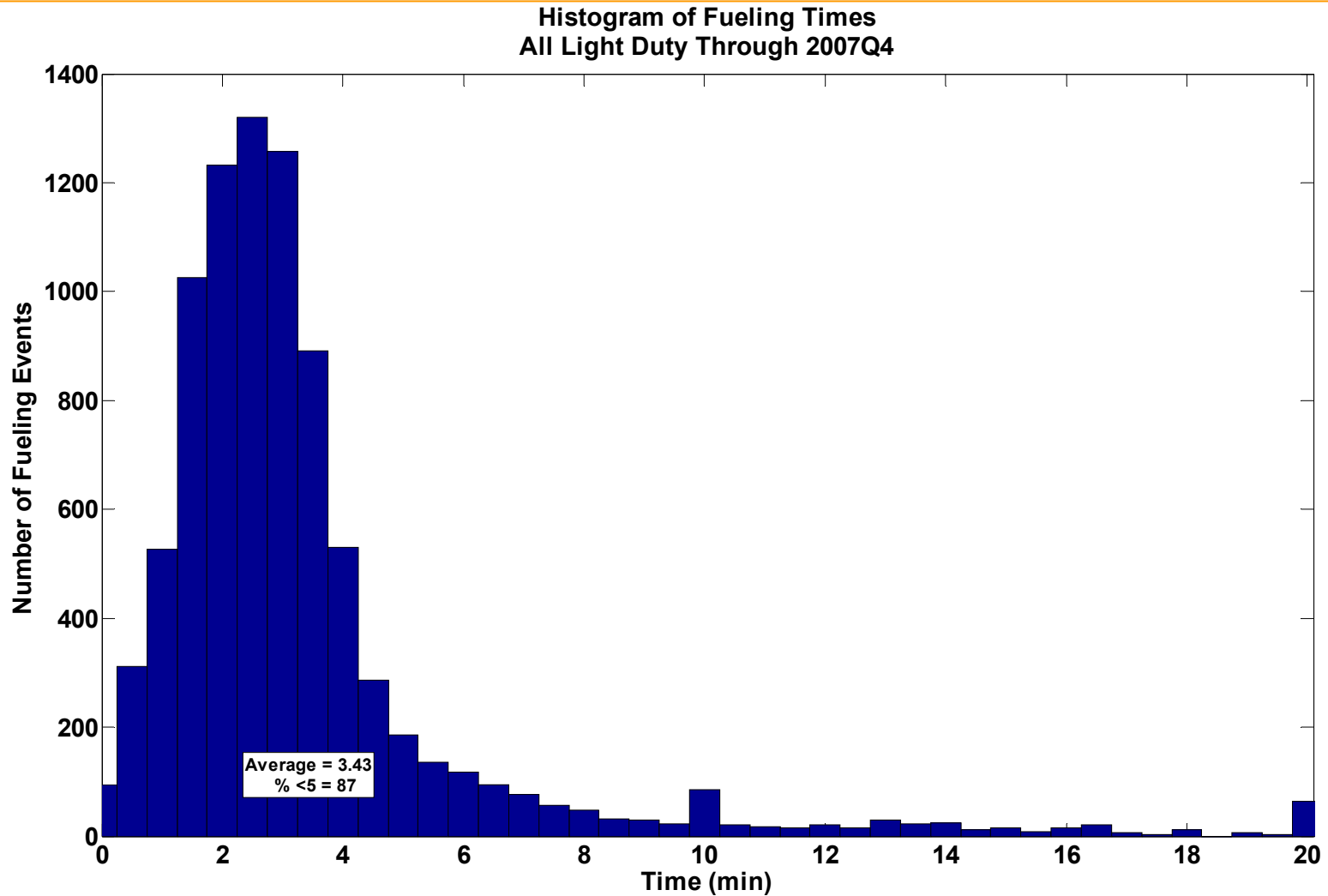
An INCIDENT is an event that results in:

- a lost time accident and/or injury to personnel
- damage/unplanned downtime for project equipment, facilities or property
- impact to the public or environment
- any hydrogen release that unintentionally ignites or is sufficient to sustain a flame if ignited
- release of any volatile, hydrogen containing compound (other than the hydrocarbons used as common fuels)

A NEAR-MISS is:

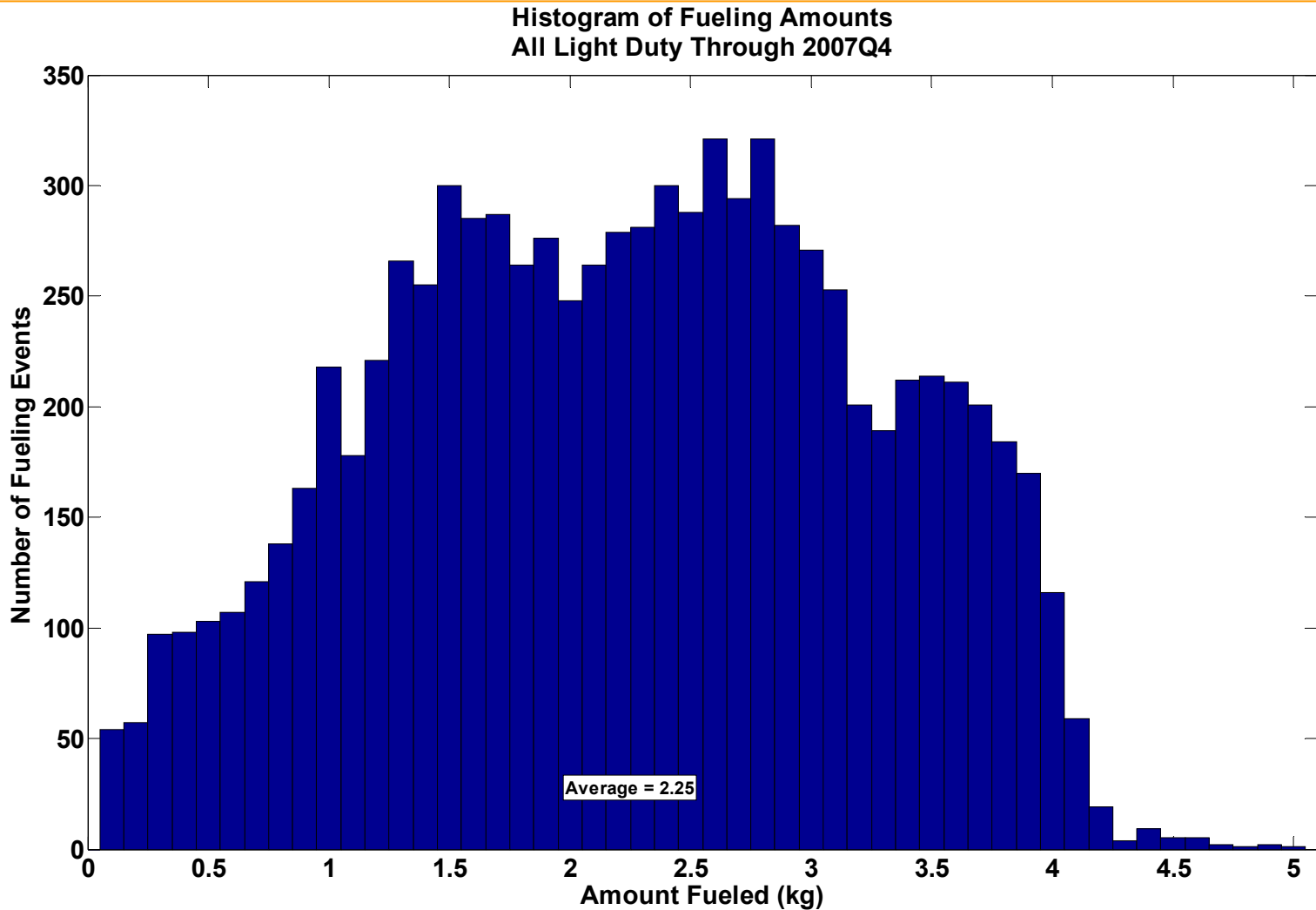
- an event that under slightly different circumstances could have become an incident
- unplanned H2 release insufficient to sustain a flame

CDP#38: Refueling Times



Created: Feb-15-08 1:44 PM

CDP#39: Refueling Amounts



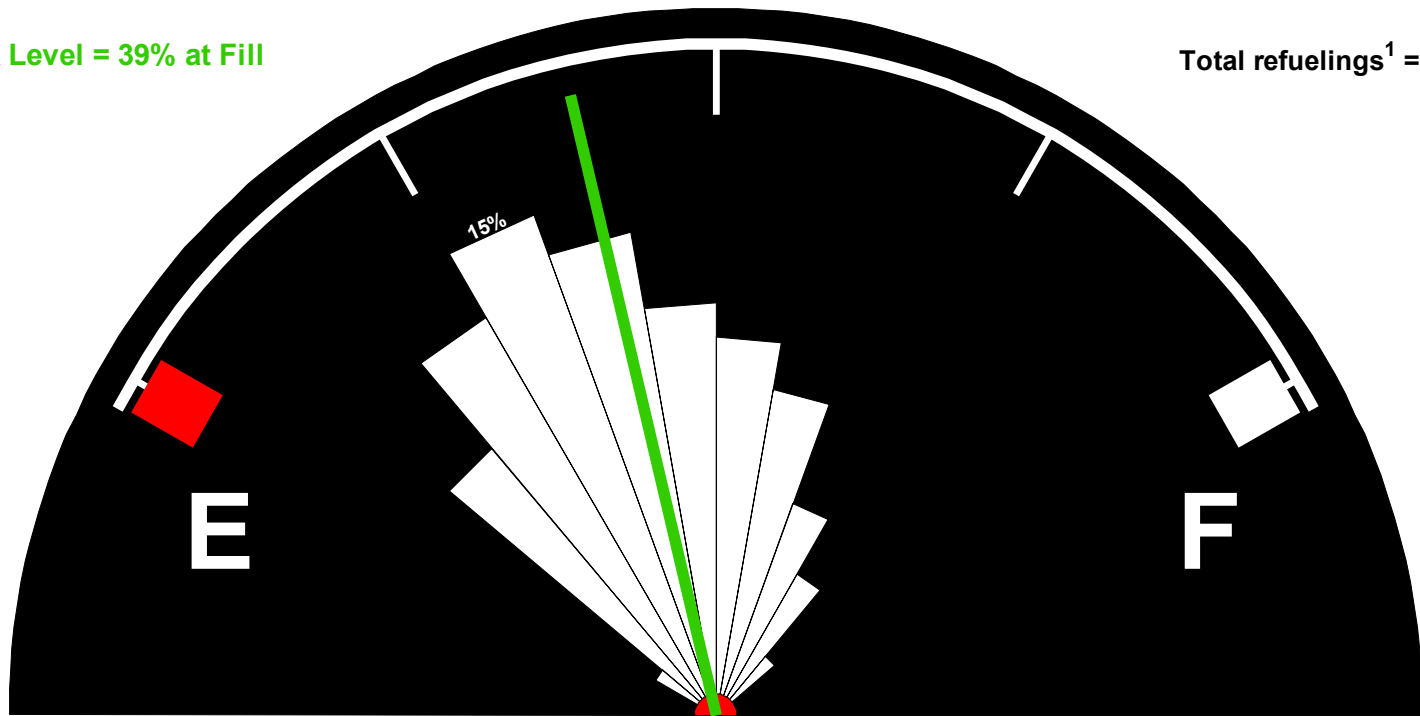
Created: Feb-15-08 1:44 PM

CDP#40: H2 Tank Level at Refueling

Tank Levels: DOE Fleet

Median Tank Level = 39% at Fill

Total refuelings¹ = 13085



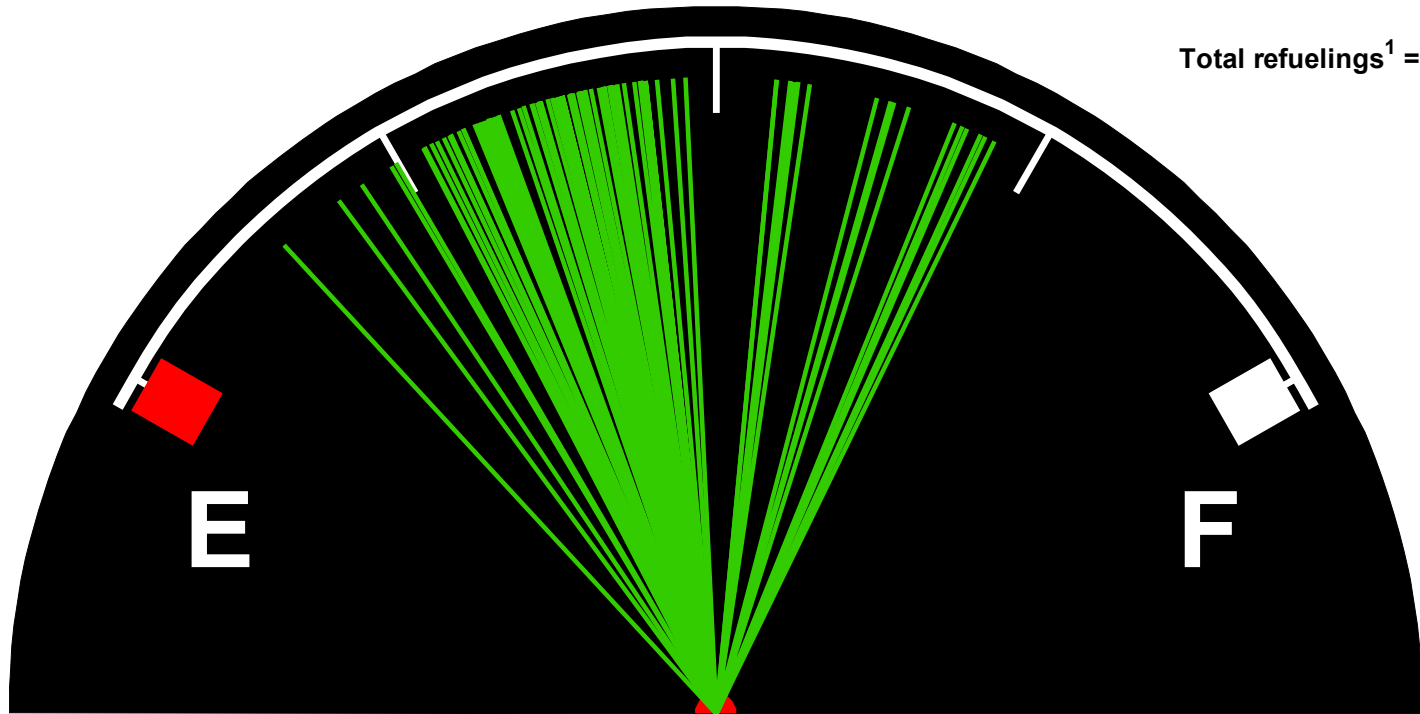
1. Some refueling events not recorded/detected due to data noise or incompleteness.
2. The outer arc is set at 20% total refuelings.
3. If tank level at fill was not available, a complete fill up was assumed.

Created: Feb-27-08 10:51 AM

CDP#41: Refueling Tank Levels - Medians

Tank Level Medians: DOE Fleet, All Vehicles

Total refuelings¹ = 13085



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.

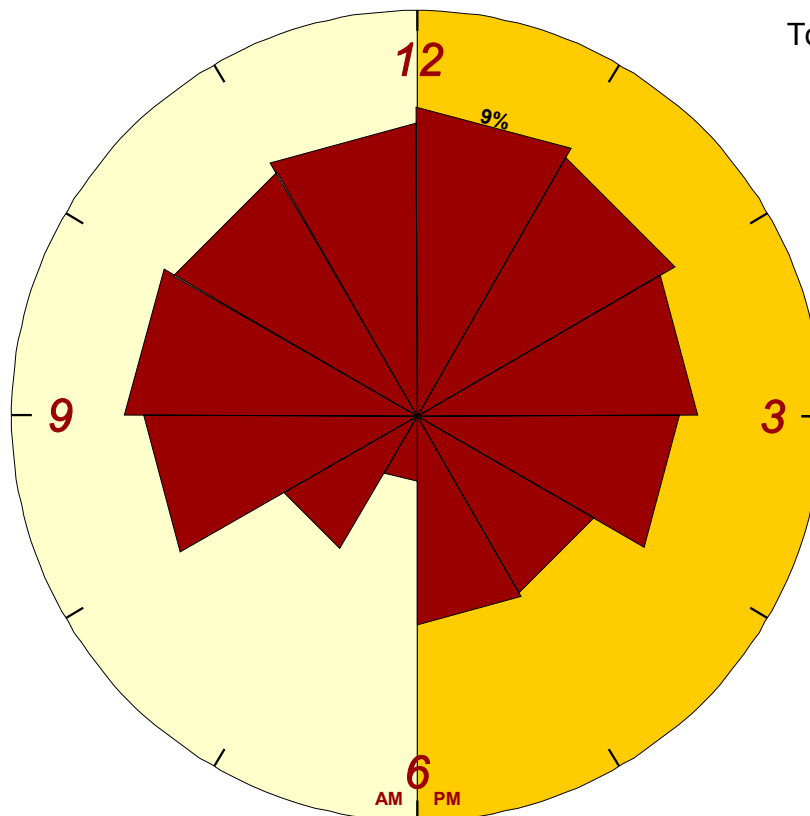
Created: Feb-27-08 10:51 AM

CDP#42: Refueling by Time of Day

Refueling by Time of Day: DOE Fleet

% of fills b/t 6 AM & 6 PM: 86.5%

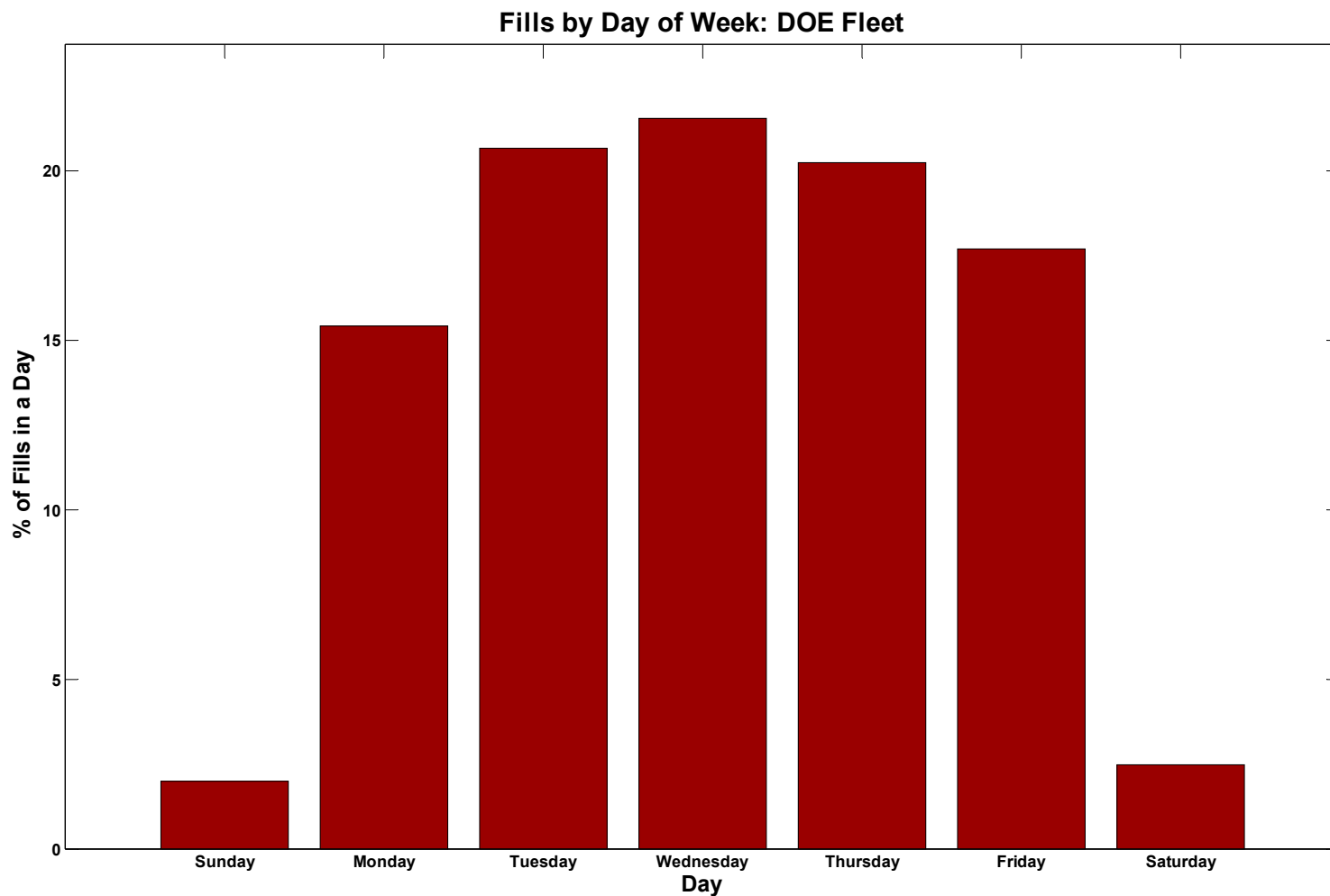
Total Fill³ Events = 11356



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.

Created: Feb-27-08 10:51 AM

CDP#43: Refueling by Day of Week



Created: Feb-27-08 10:51 AM

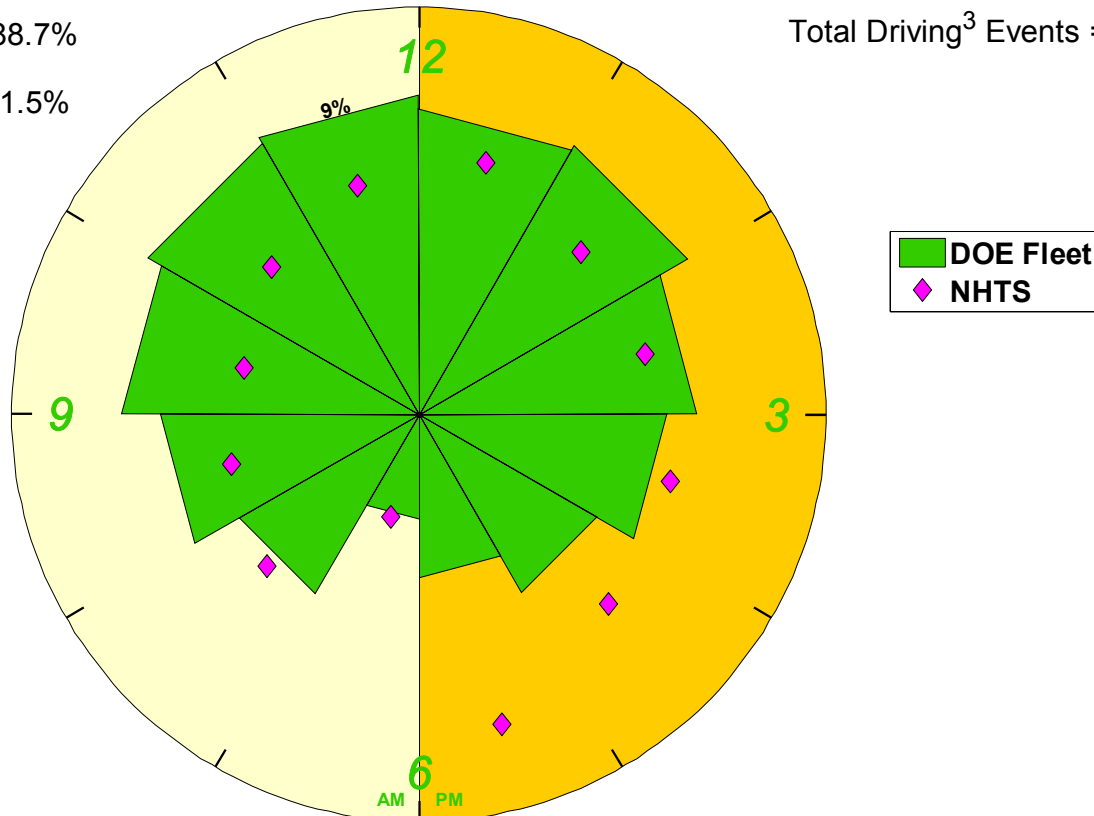
CDP#44: Driving Start Time – Day

Driving Start Time - Day: DOE Fleet

% of driving trips b/t 6 AM & 6 PM: 88.7%

% of NHTS trips b/t 6 AM & 6 PM: 81.5%

Total Driving³ Events = 139968

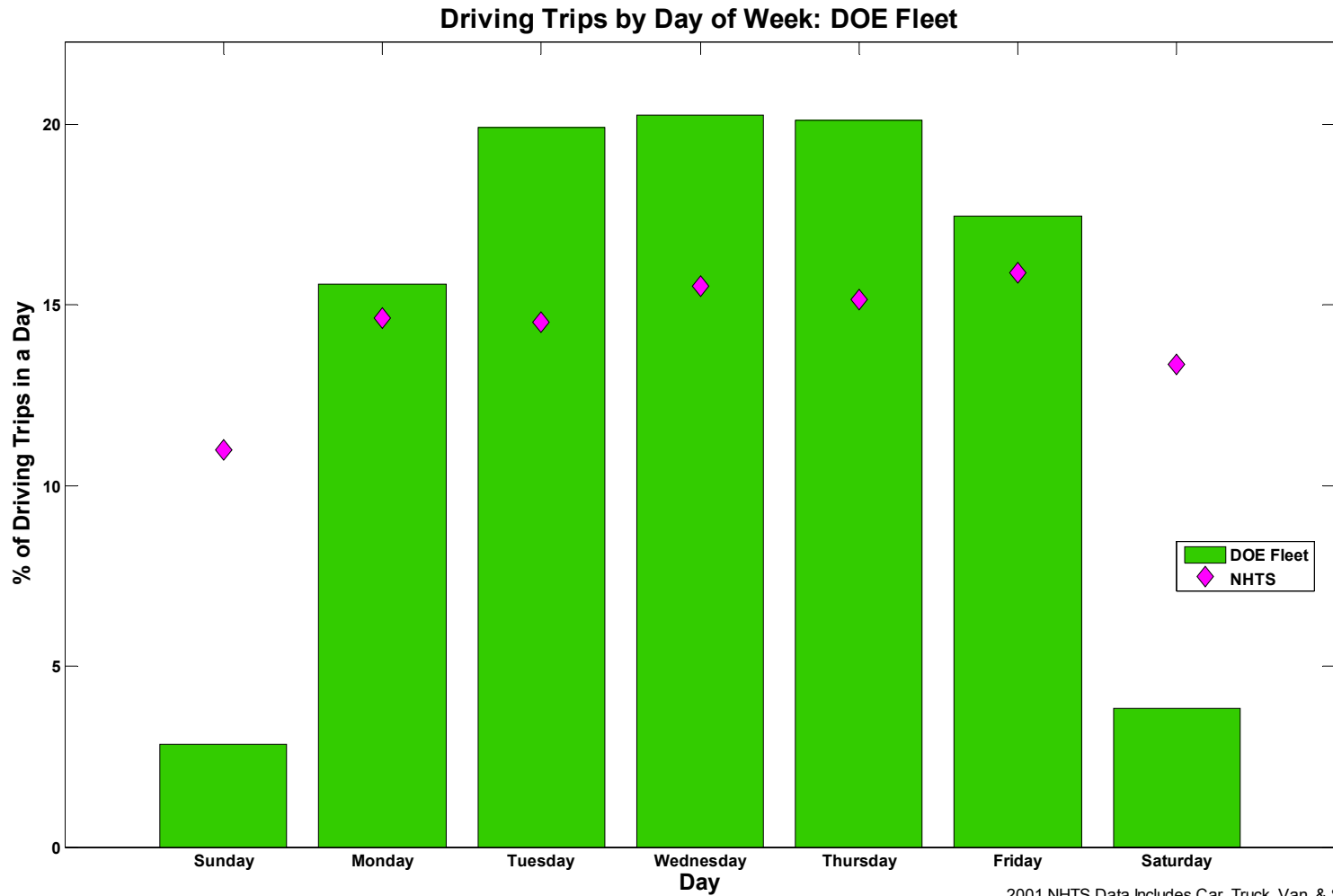


1. Driving trips between 6 AM & 6 PM
2. The outer arc is set at 12 % total Driving.
3. Some events not recorded/detected due to data noise or incompleteness.

2001 NHTS Data Includes Car, Truck, Van, & SUV day trips
 ASCII.csv Source: <http://nhts.ornl.gov/download.shtml#2001>

Created: Feb-27-08 10:51 AM

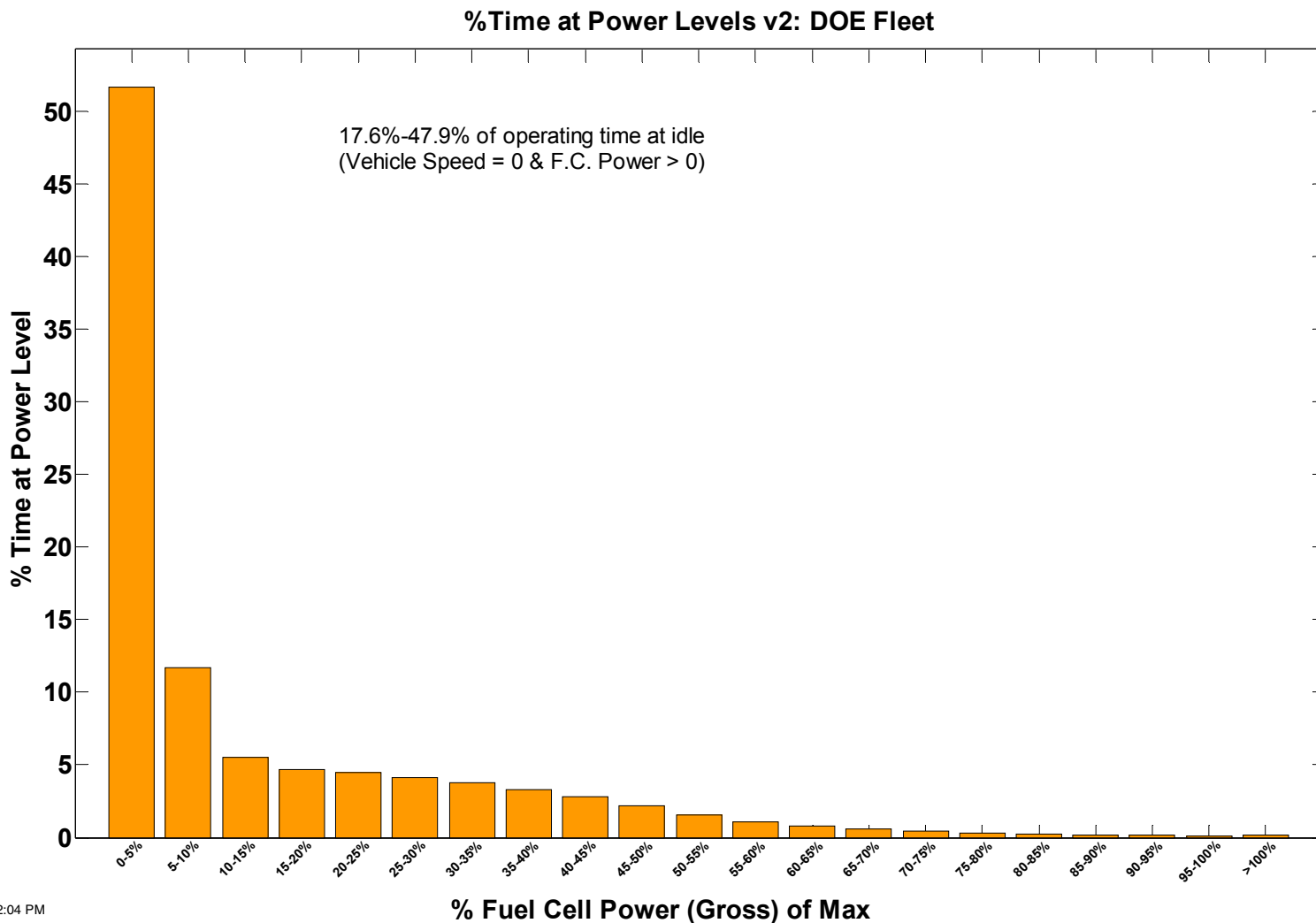
CDP#45: Driving by Day of Week



Created: Feb-27-08 10:51 AM

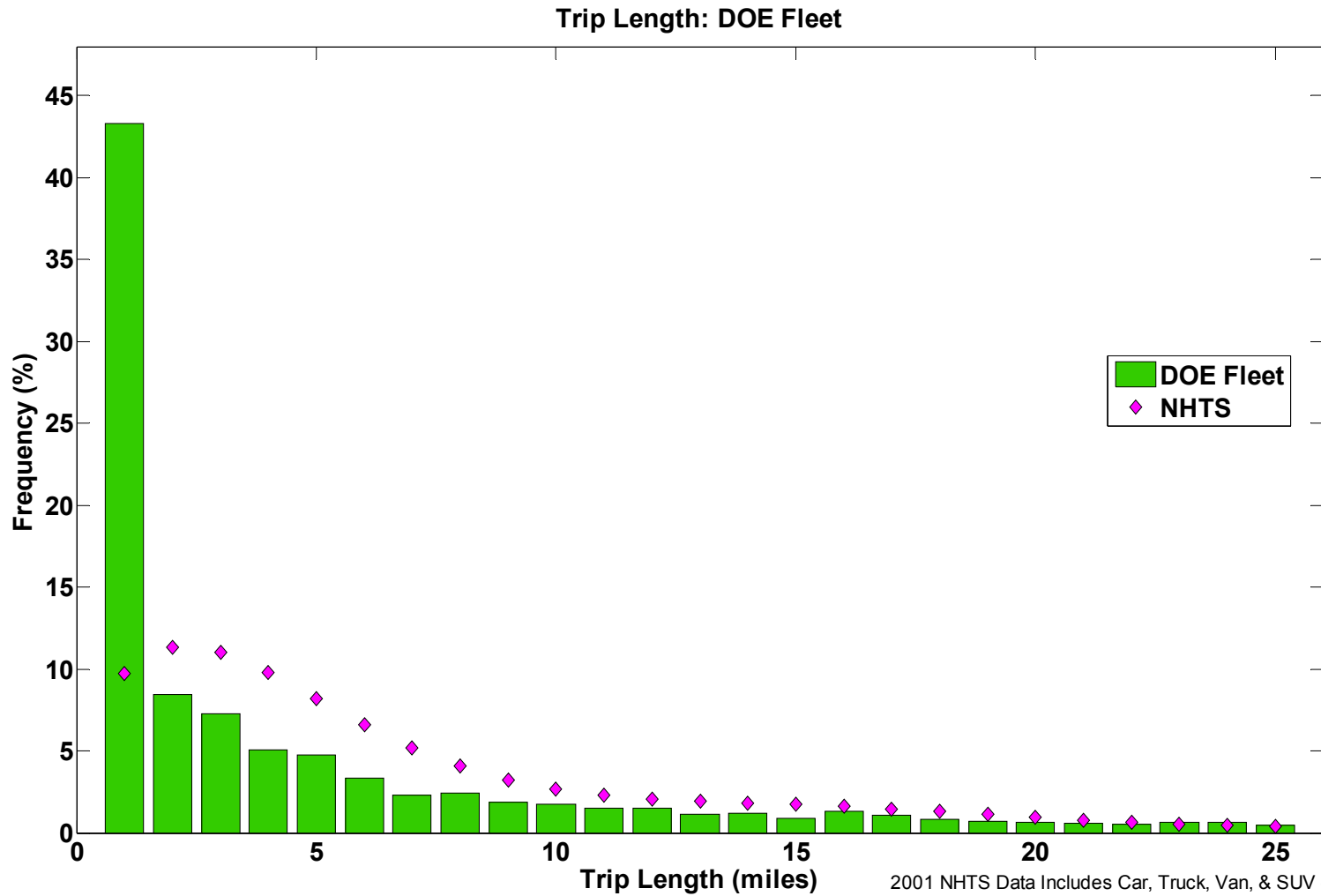
2001 NHTS Data Includes Car, Truck, Van, & SUV day trips
ASCII.csv Source: <http://nhts.ornl.gov/download.shtml#2001>

CDP#46: Fuel Cell System Operating Power



Created: Feb-27-08 12:04 PM

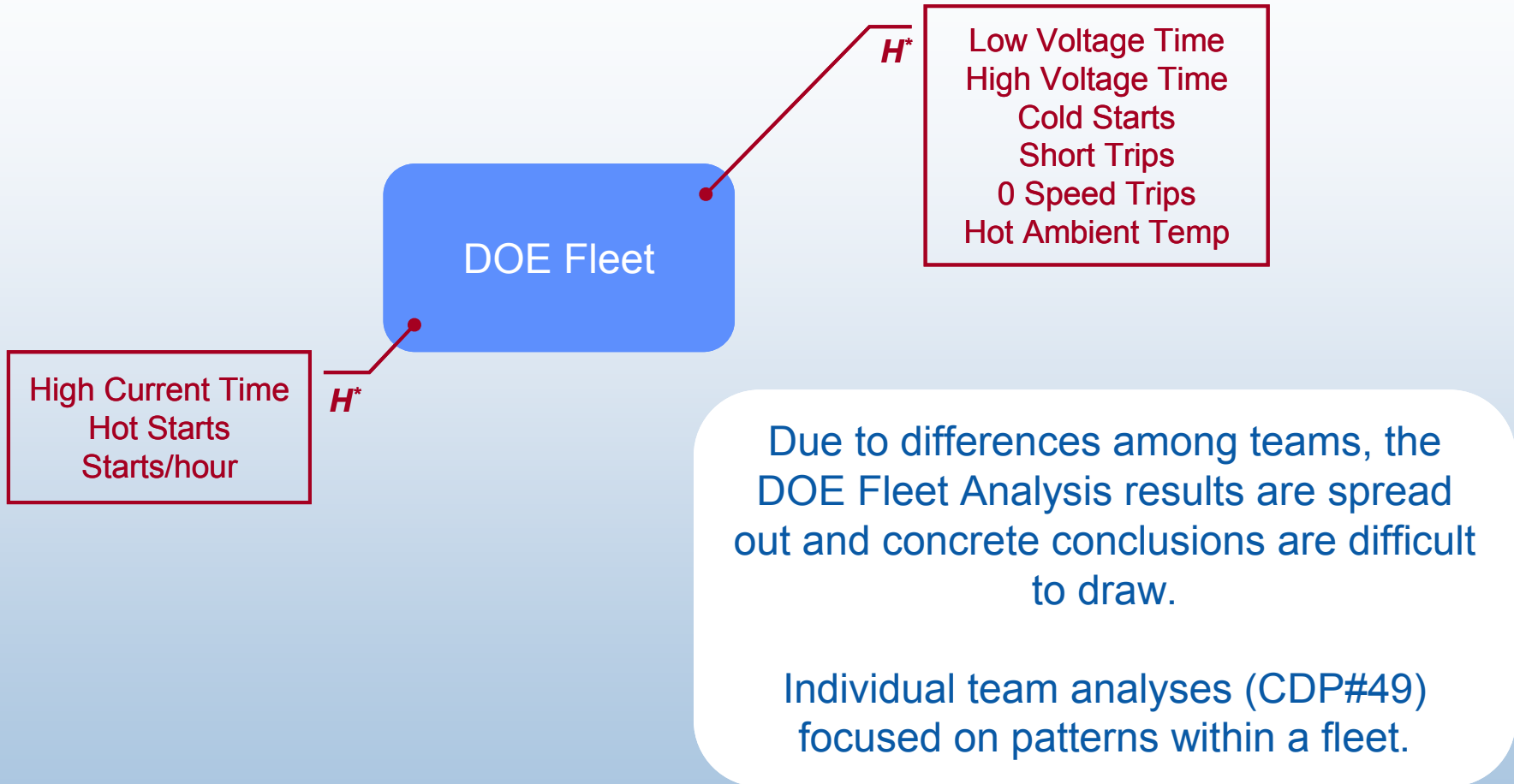
CDP#47: Trip Length



Created: Feb-27-08 11:56 AM

2001 NHTS Data Includes Car, Truck, Van, & SUV day trips
ASCII.csv Source: <http://nhts.oml.gov/download.shtml#2001>

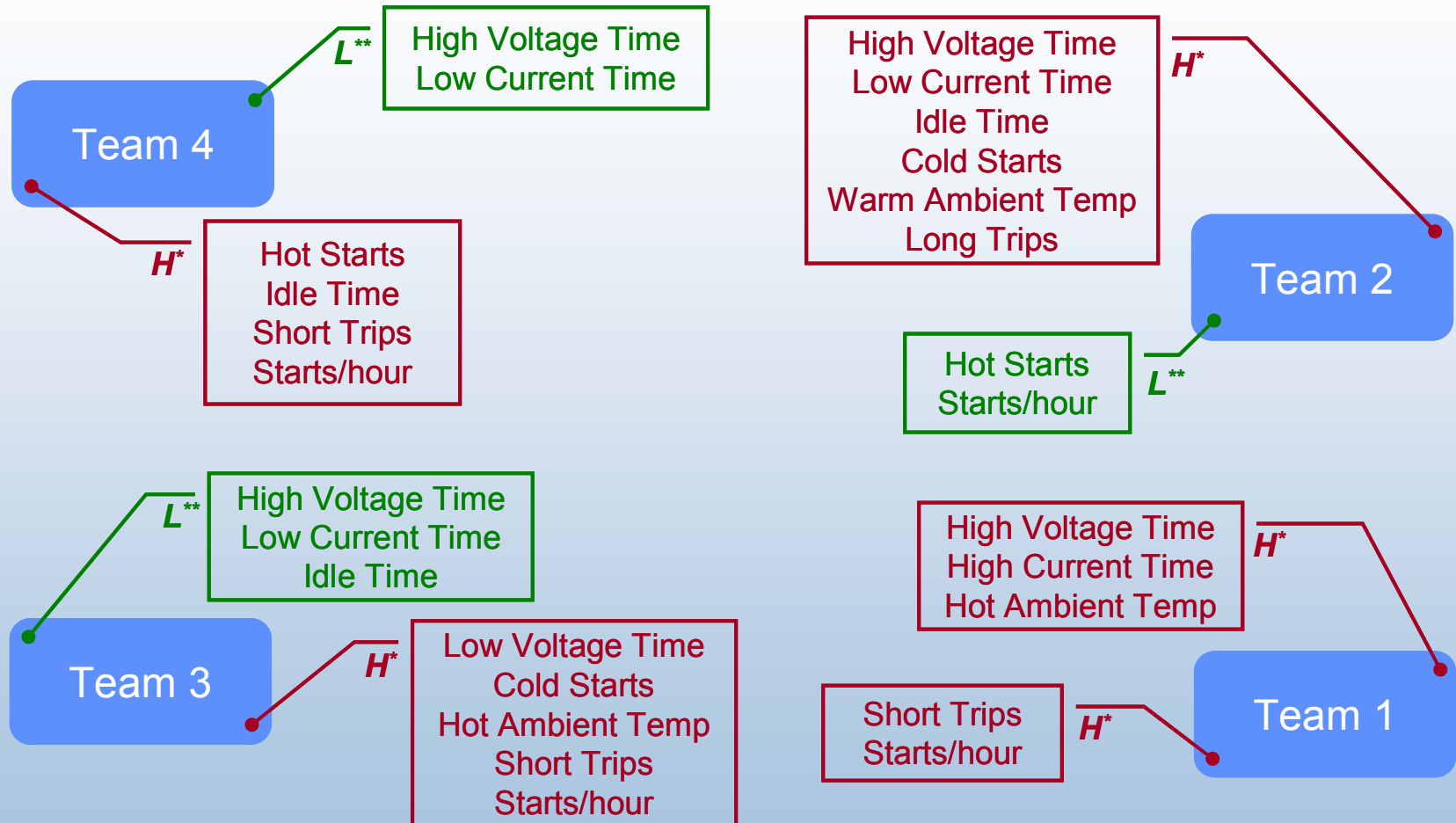
CDP#48: Primary Factors Affecting Learning Demo Fleet Fuel Cell Degradation



- 1) On-going fuel cell degradation study using Partial Least Squares (PLS) regression model for combined Learning Demonstration Fleet.
- 2) DOE Fleet model has a low percentage of explained decay rate variance.

H*: Factor group associated with high decay rate fuel cell stacks
L**: Factor group associated with low decay rate fuel cell stacks

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



- 1) On-going fuel cell degradation study using Partial Least Squares (PLS) regression model for each team.
- 2) Teams' PLS models have a high percentage of explained decay rate variance, but the models are not robust and results are scattered.

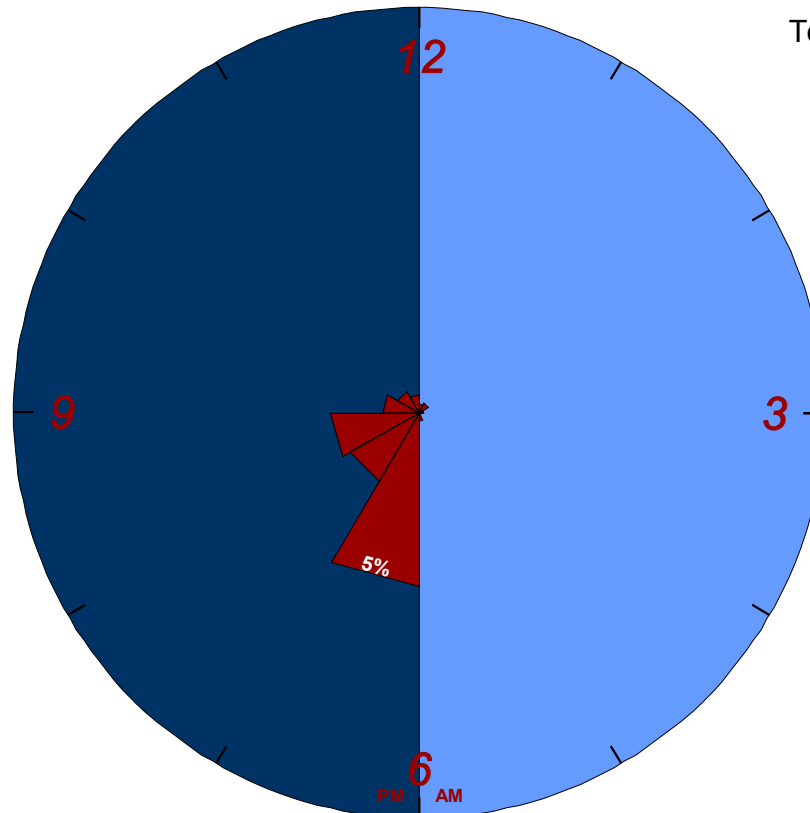
H^* : Factor group associated with high decay rate fuel cell stacks
 L^{**} : Factor group associated with low decay rate fuel cell stacks

CDP#50: Refueling by Time of Night

Refueling by Time of Night: DOE Fleet

% of fills b/t 6 PM & 6 AM: 13.5%

Total Fill³ Events = 11356



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: Feb-27-08 10:51 AM

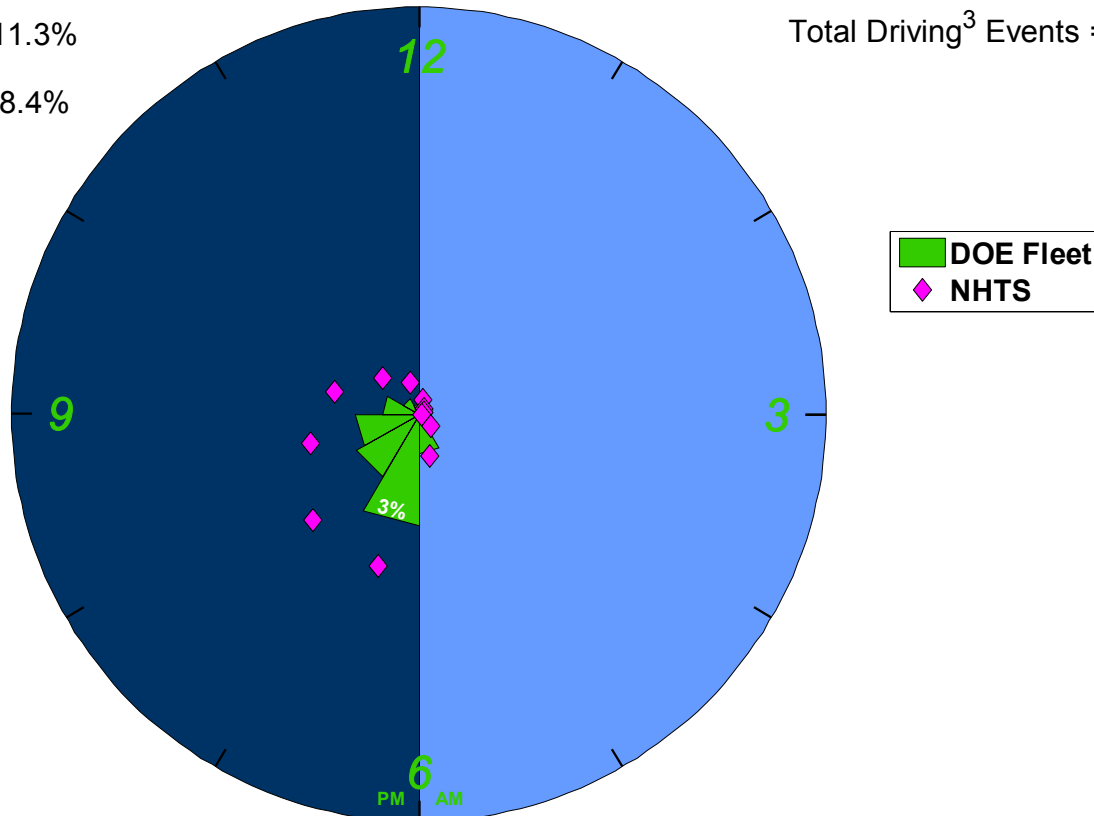
CDP#51: Driving Start Time – Night

Driving Start Time - Night: DOE Fleet

% of driving trips b/t 6 PM & 6 AM: 11.3%

% of NHTS trips b/t 6 PM & 6 AM: 18.4%

Total Driving³ Events = 139968

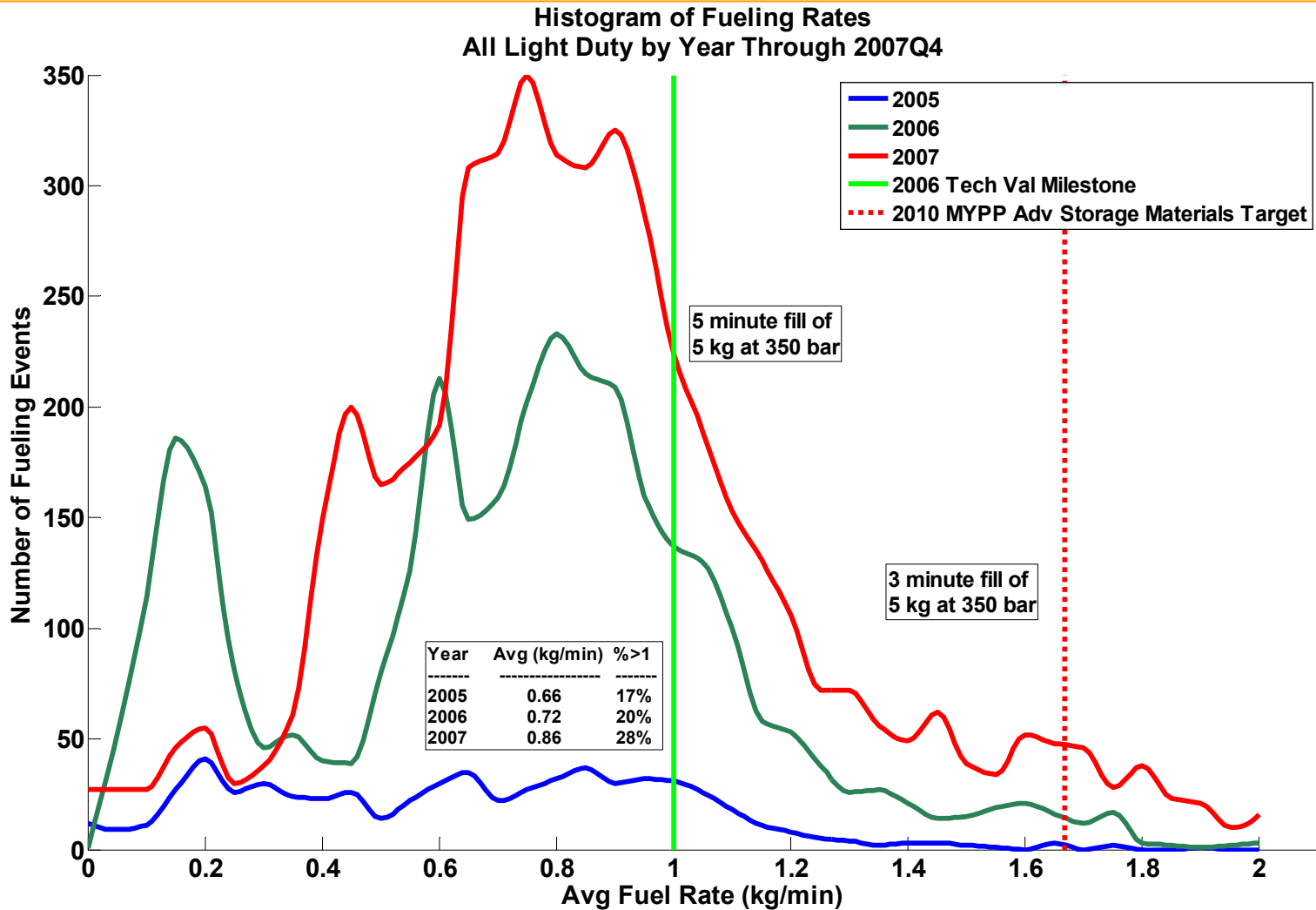


1. Driving trips between 6 PM & 6 AM
2. The outer arc is set at 12 % total Driving.
3. Some events not recorded/detected due to data noise or incompleteness.

2001 NHTS Data Includes Car, Truck, Van, & SUV day trips
ASCII.csv Source: <http://nhts.ornl.gov/download.shtml#2001>

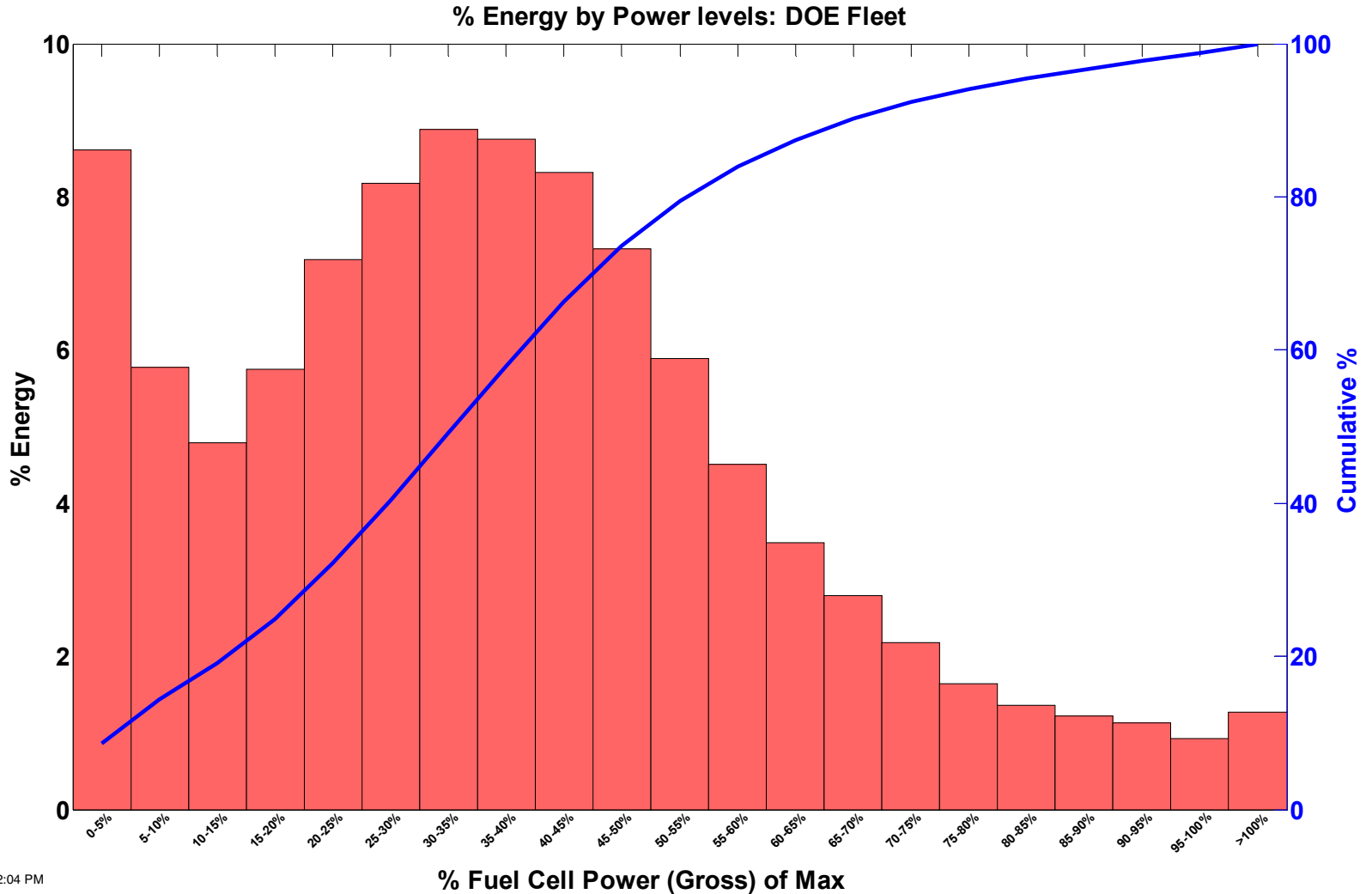
Created: Feb-27-08 10:51 AM

CDP#52: Refueling Data by Year



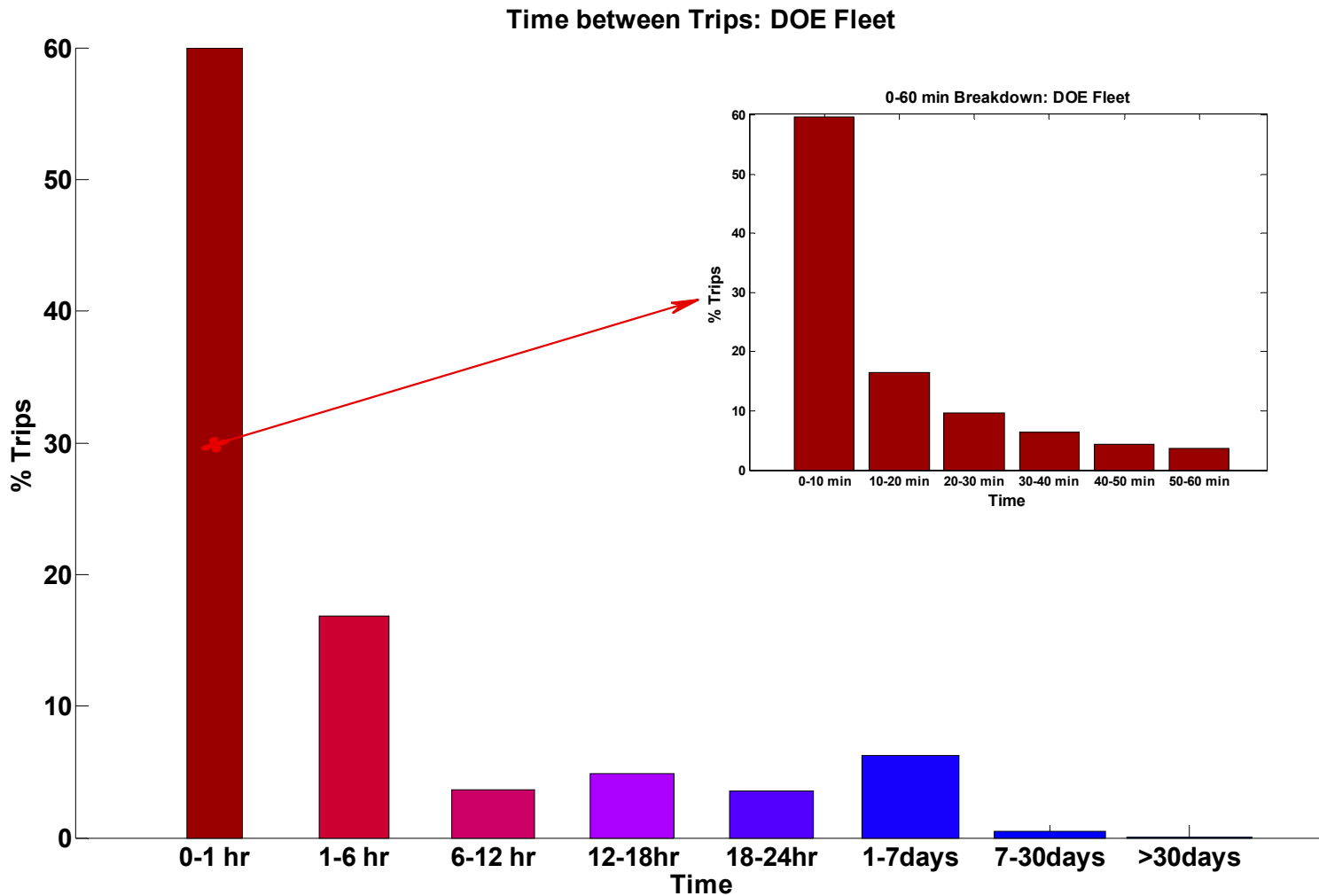
Created: Feb-27-08 11:39 AM

CDP#53: Fuel Cell System Energy within Power Levels



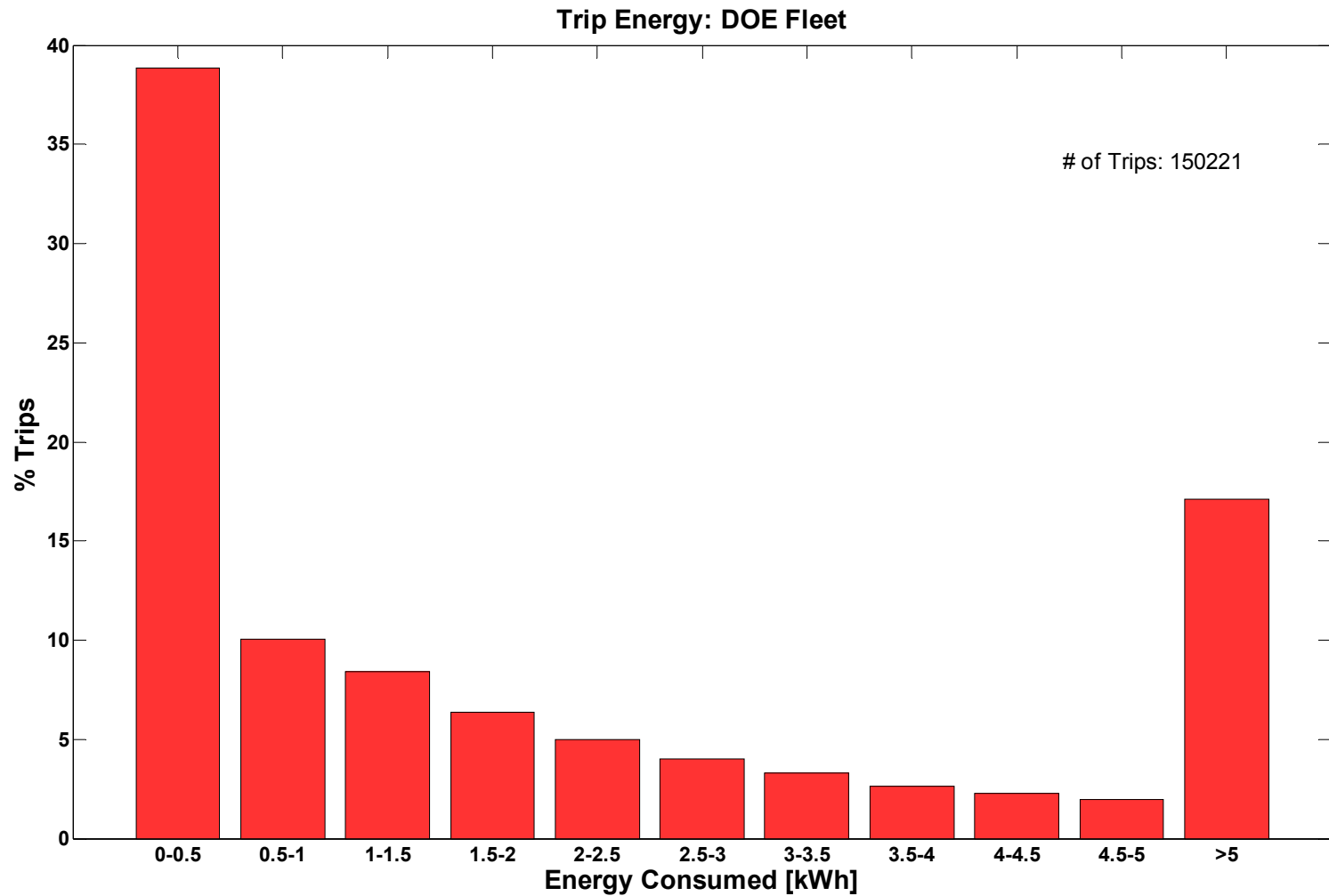
Created: Feb-27-08 12:04 PM

CDP#54: Time Between Trips



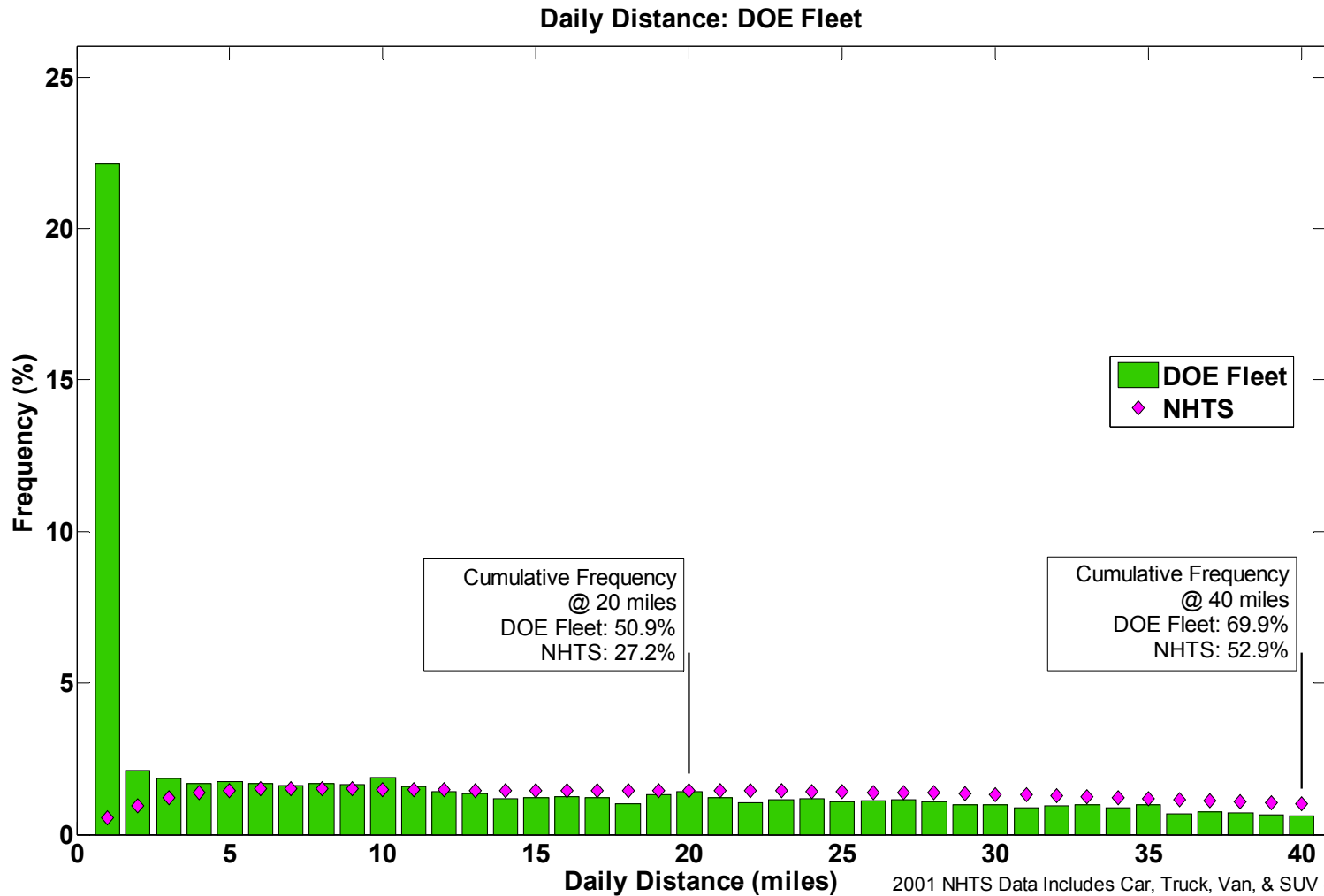
Created: Feb-27-08 11:56 AM

CDP#55: Fuel Cell System Energy



Created: Feb-27-08 12:04 PM

CDP#56: Daily Driving Distance

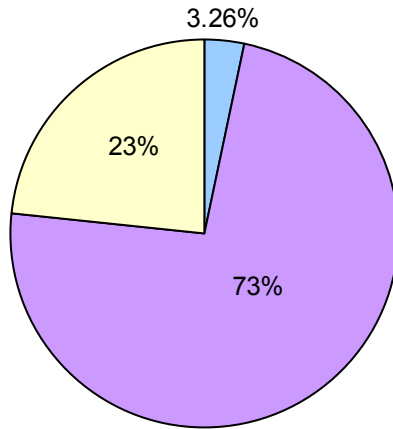


Created: Feb-27-08 11:56 AM

2001 NHTS Data Includes Car, Truck, Van, & SUV day trips
ASCII.csv Source: <http://nhts.ornl.gov/download.shtml#2001>

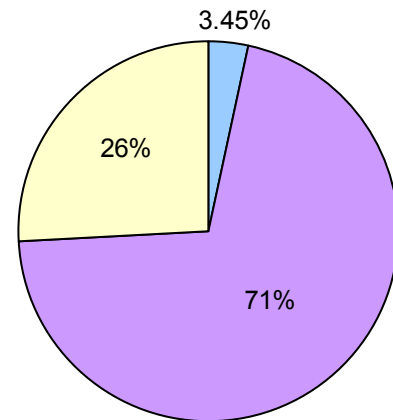
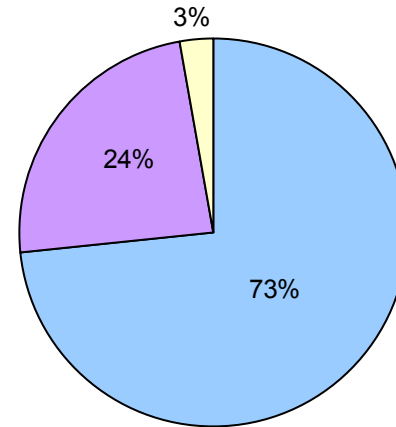
CDP#57: H2 Storage System Mass and Volume Breakdown

Average Breakout of H2 Storage System Mass

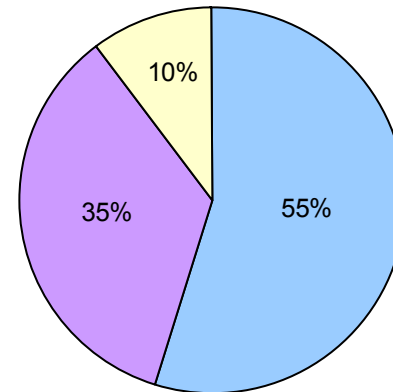


350 bar

Average Breakout of H2 Storage System Volume



700 bar



■ H2 Mass (%)
■ Pressure Vessel Mass (%)
■ Balance of Plant Mass (%)

■ H2 Volume (%)
■ Pressure Vessel Volume (%)
■ Balance of Plant Volume (%)

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