



Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project

Spring 2009

Composite Data Products
Final Version March 13, 2009

Keith Wipke, Sam Sprik, Jennifer Kurtz, and Todd Ramsden

Technical Report
NREL/TP-560-45451
March 2009

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Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project



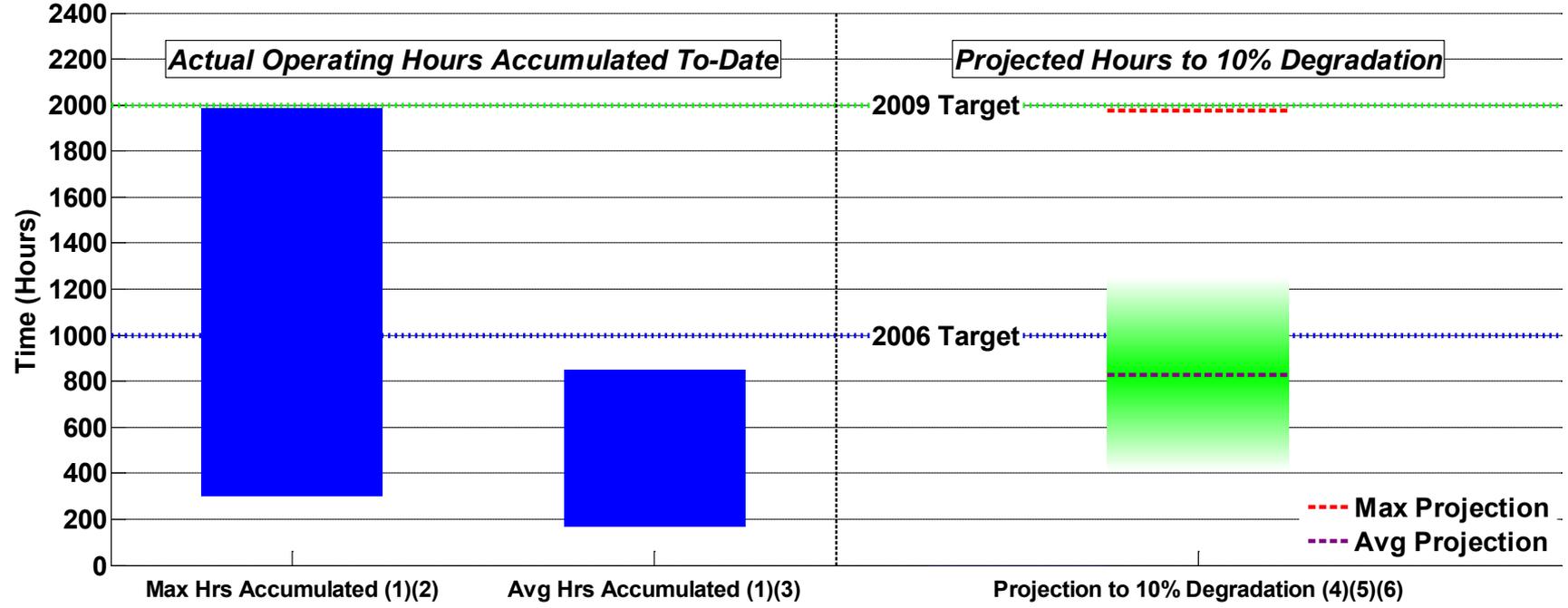
**Spring 2009
Composite Data
Products**

March 13, 2009

**Keith Wipke, Sam Sprik,
Jennifer Kurtz, Todd
Ramsden**

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

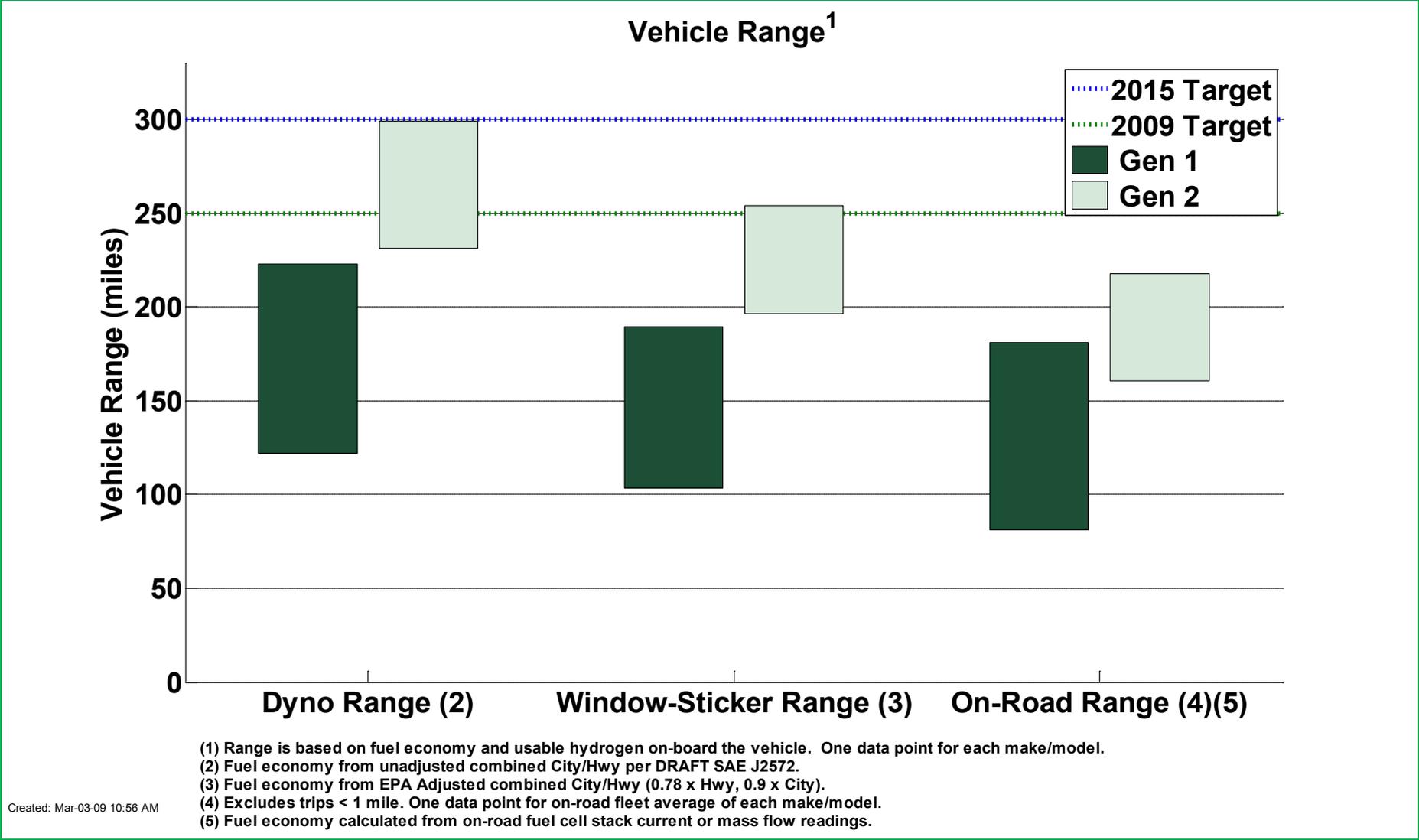
DOE Learning Demonstration Fuel Cell Stack Durability:
Based on Data Through 2008 Q4



- (1) Range bars created using one data point for each OEM. Some stacks have accumulated hours beyond 10% voltage degradation.
- (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 on the "Avg Projection" due to data and methodology limitations. Projections will change as additional data are accumulated.
- (6) Projection method was modified beginning with 2008 Q2 data.

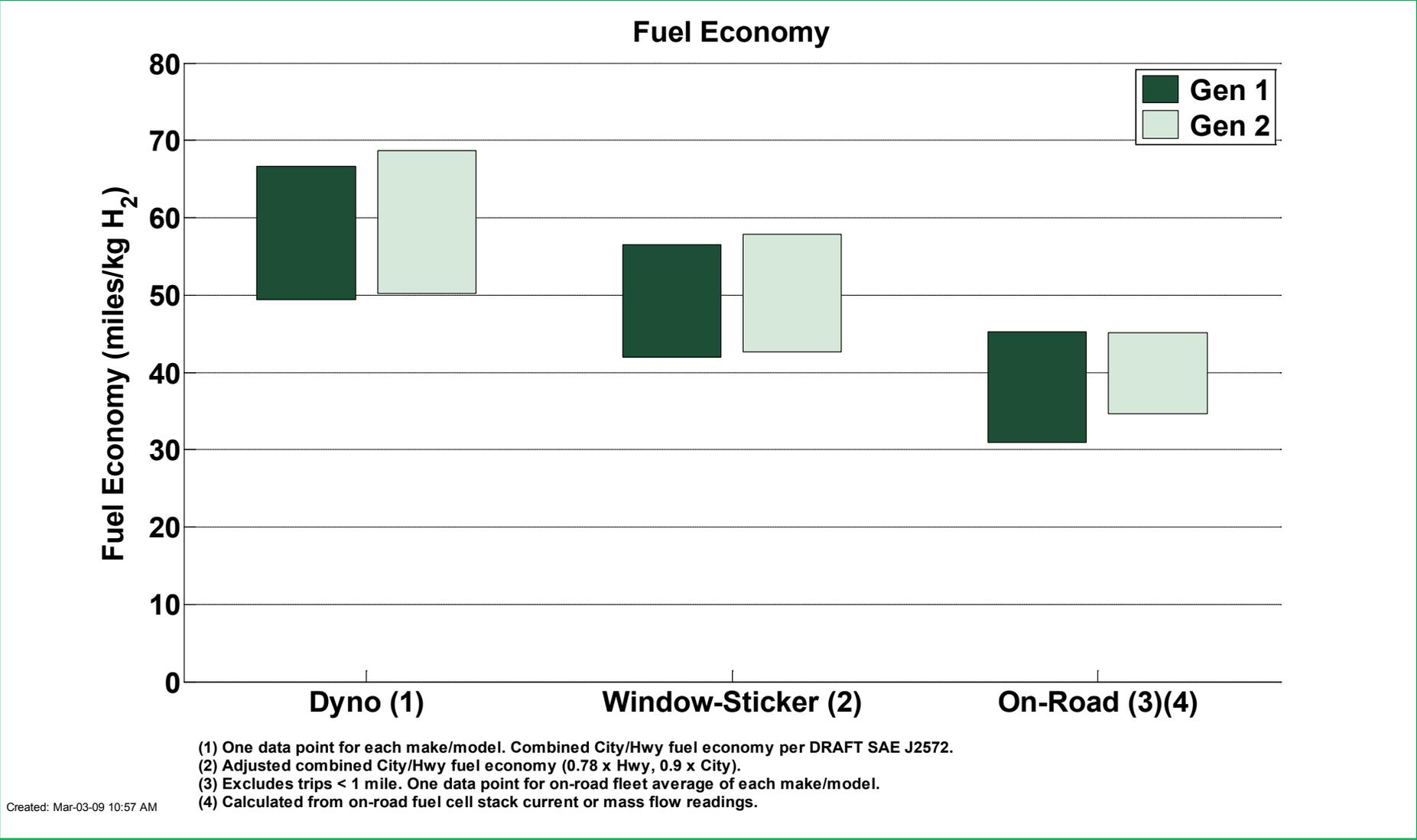
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CDP#2: Vehicle Range

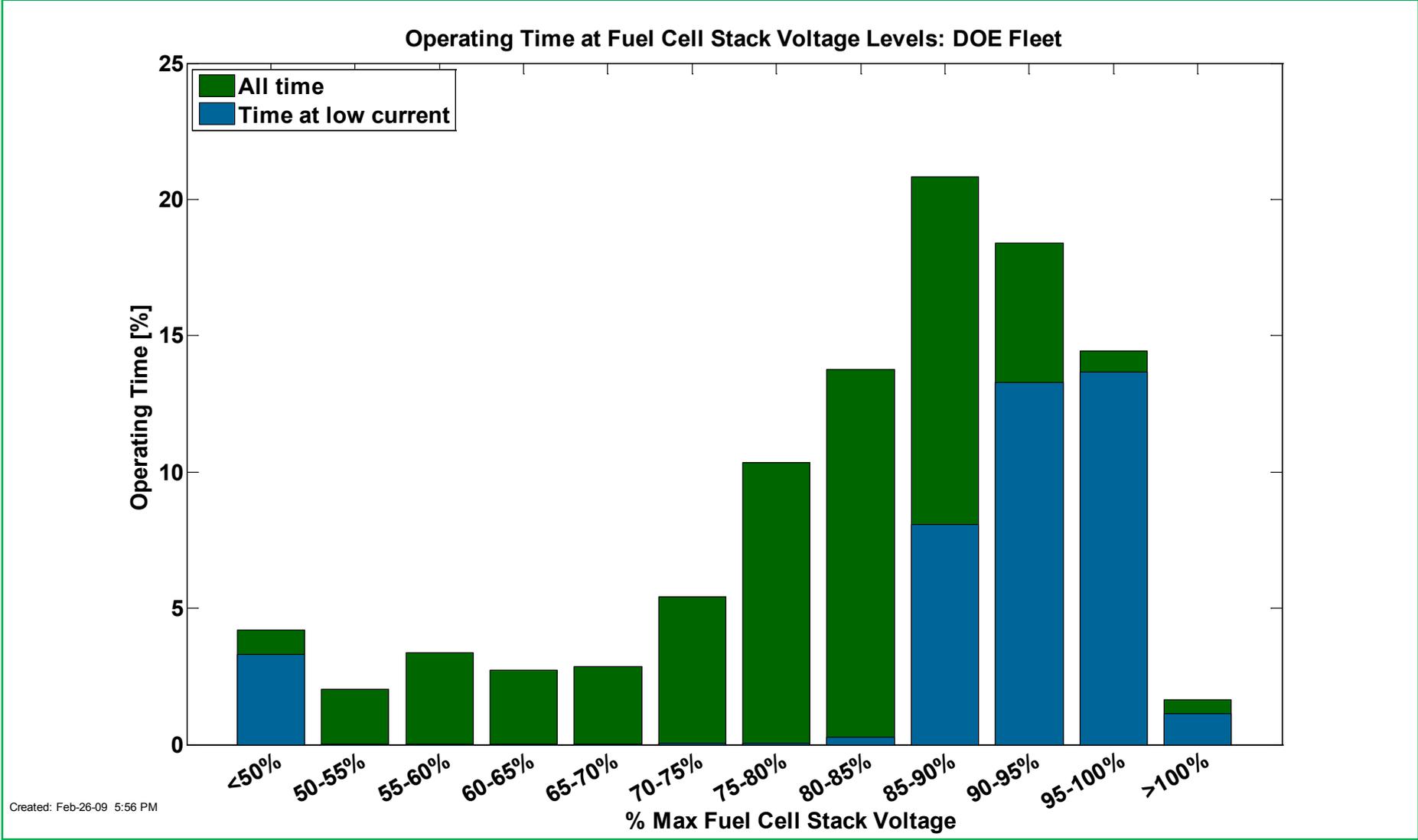


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CDP#6: Fuel Economy

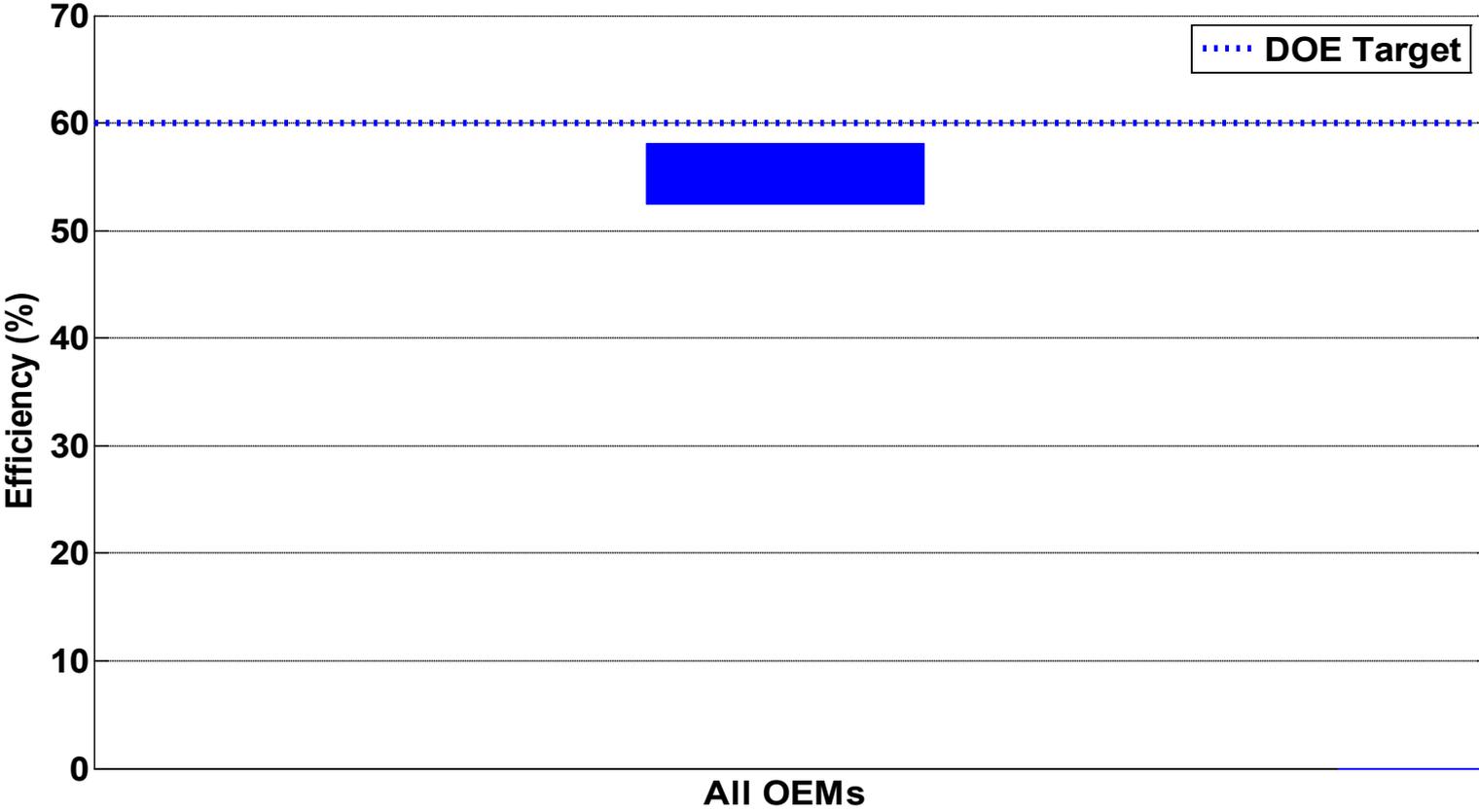


CDP#7: Fuel Cell Voltage



CDP#8: FC System Efficiency

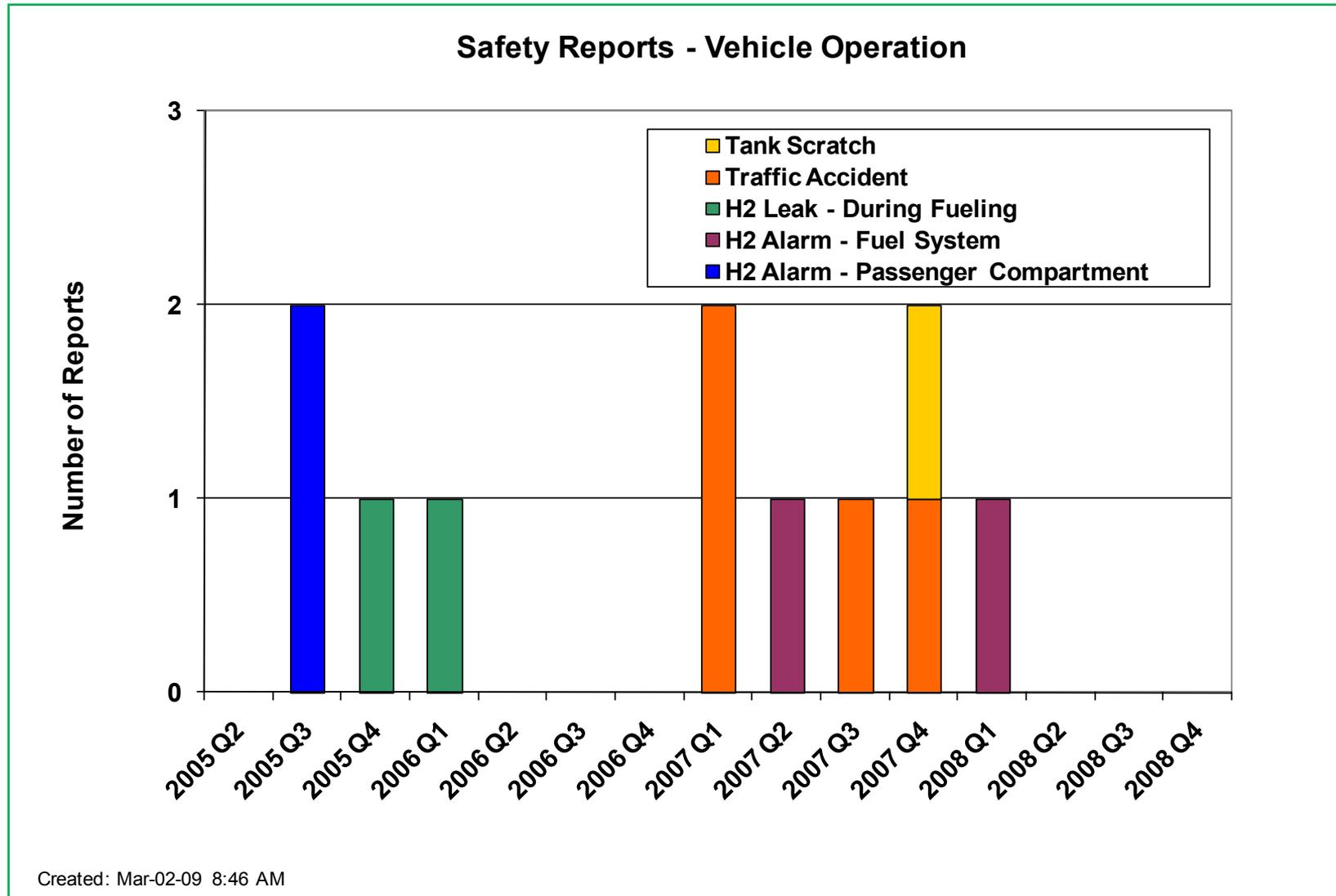
Fuel Cell System¹ Efficiency² at ~25% Net Power.



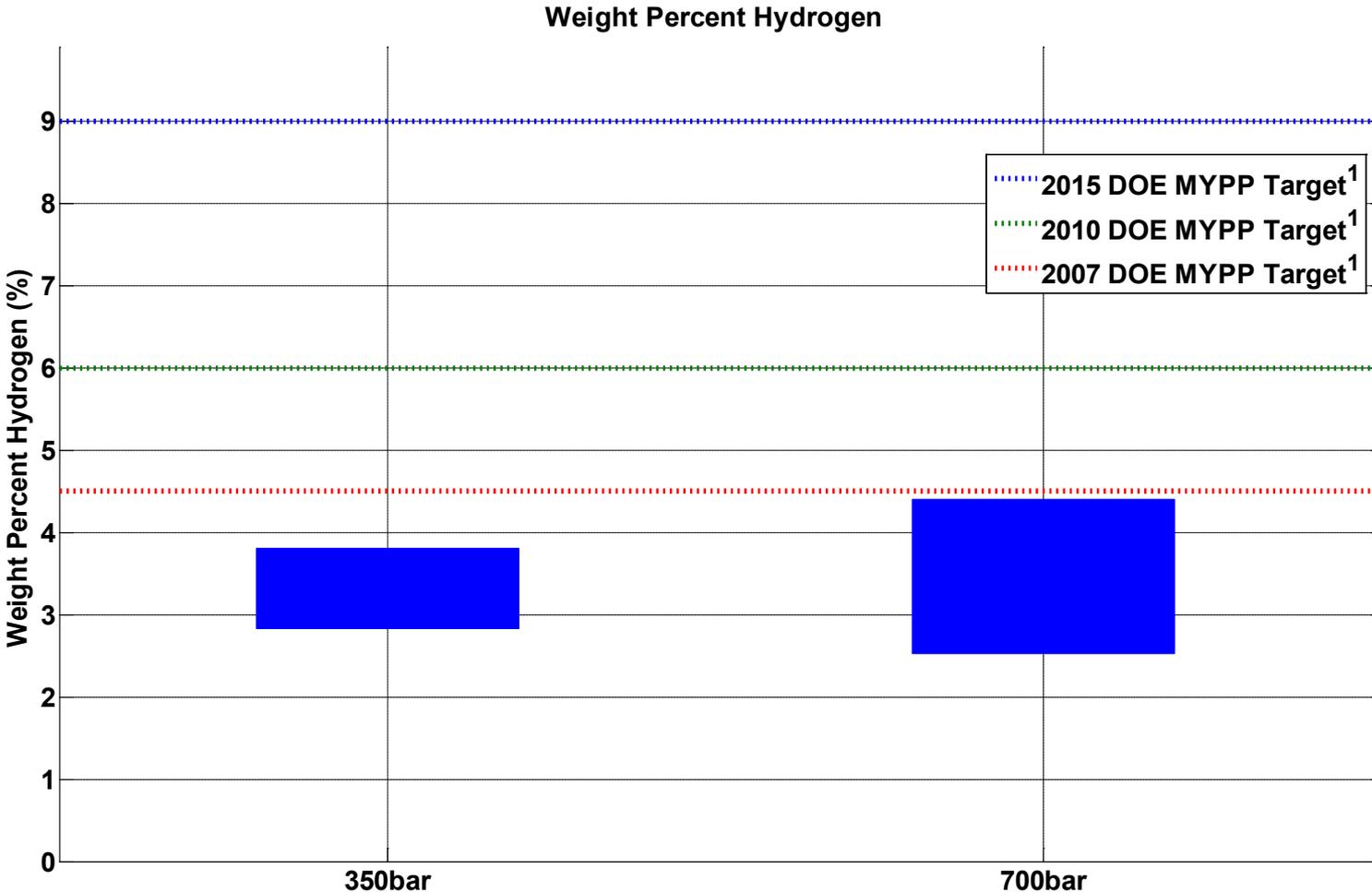
¹ Gross stack power minus fuel cell system auxiliaries, per DRAFT SAEJ2615.

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

CDP#9: Safety Reports – Vehicles



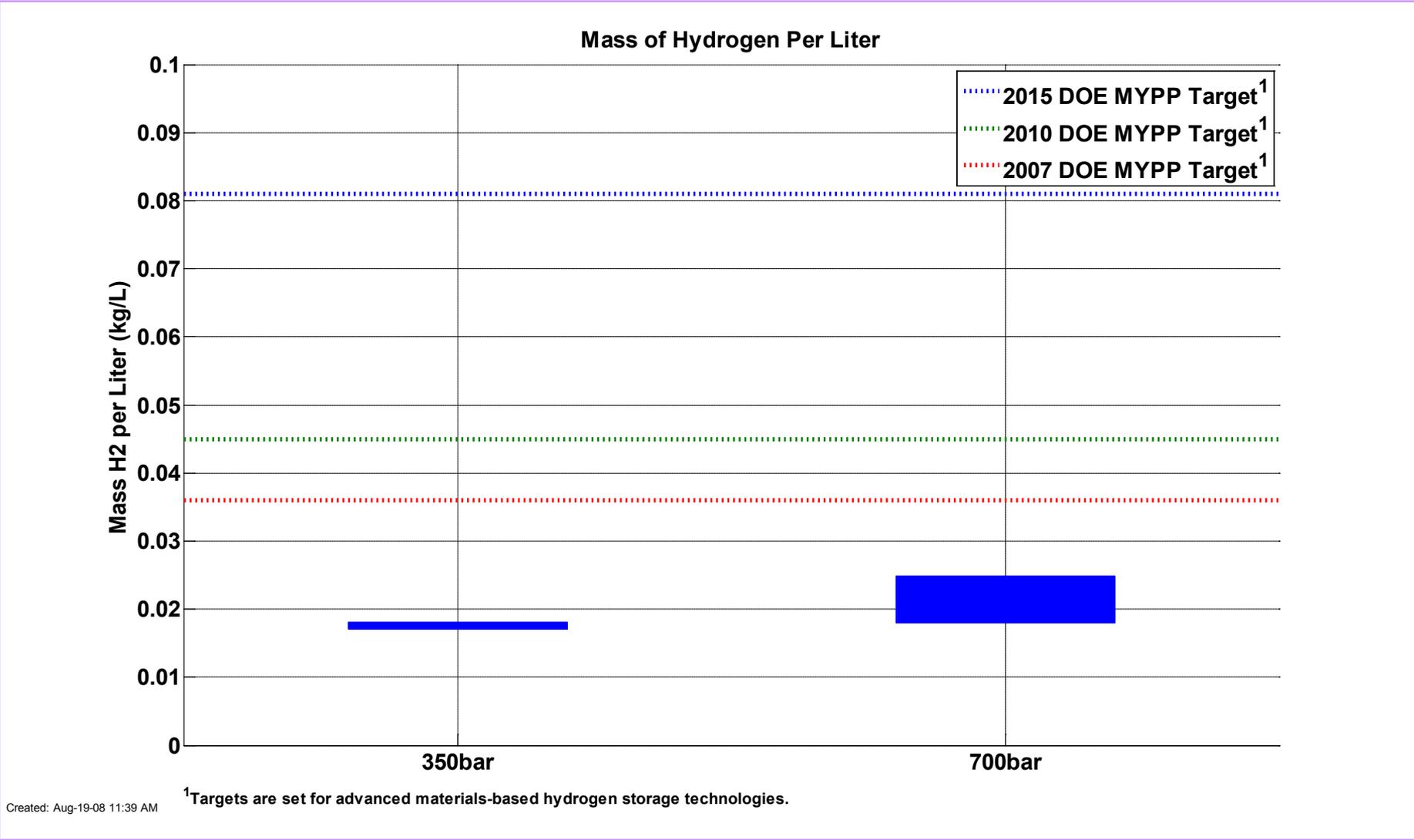
CDP#10: Storage Weight % Hydrogen



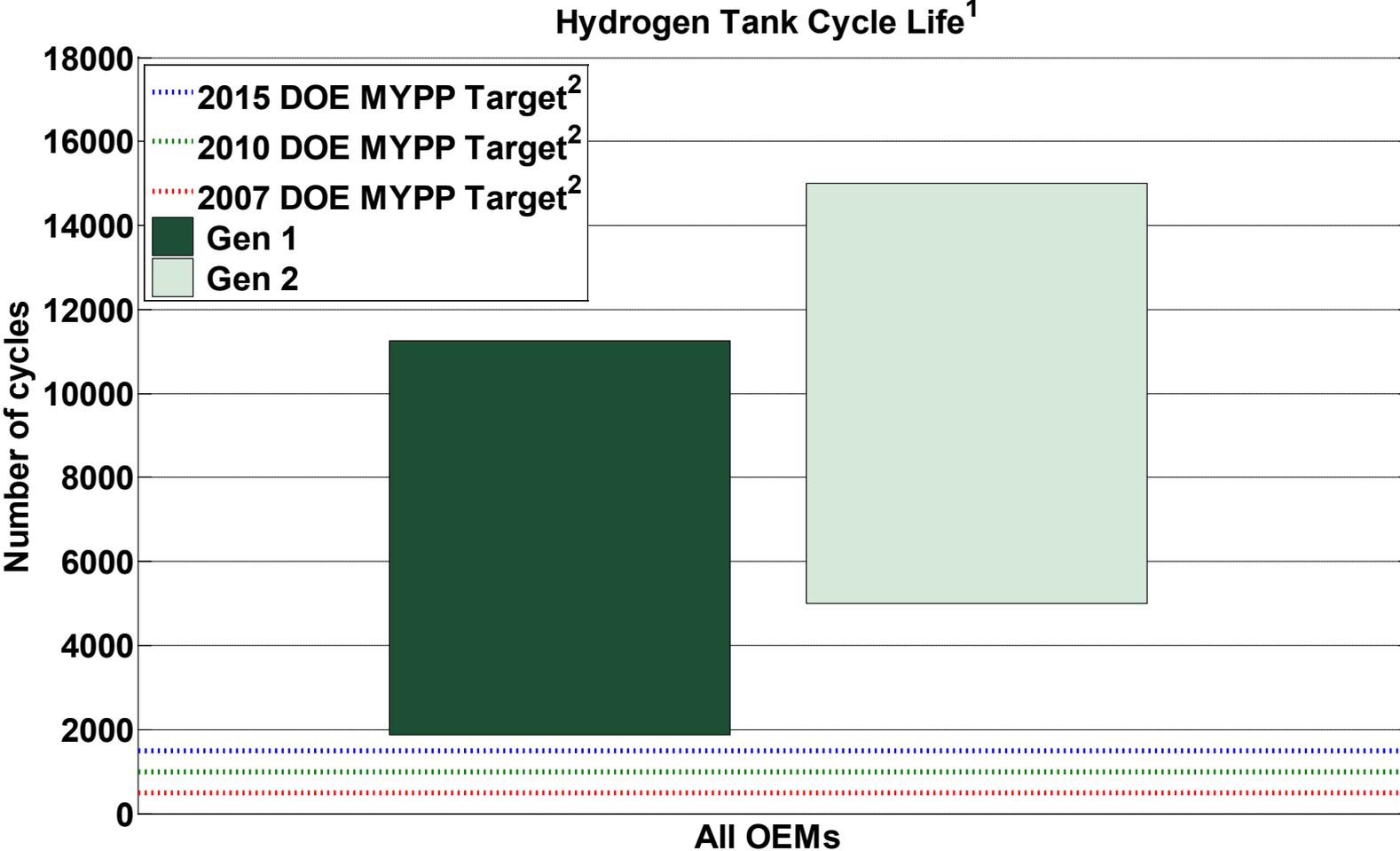
¹Targets are set for advanced materials-based hydrogen storage technologies.

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CDP#11: Volumetric Capacity of H2 Storage



CDP#12: Vehicle Hydrogen Tank Cycle Life

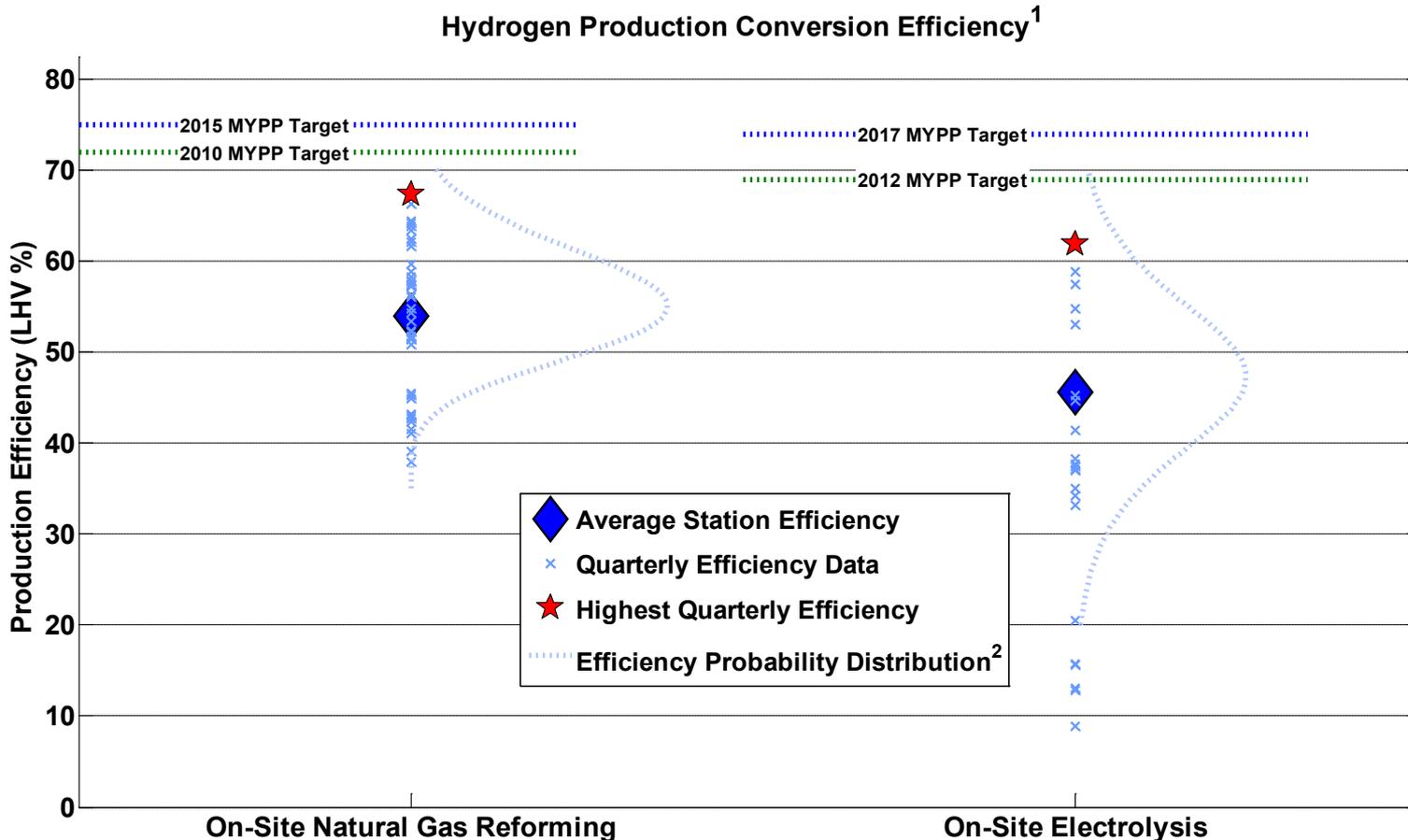


¹Data reported reference NGV2, HGV2, or EIHP standards.

²Some near-term targets have been achieved with compressed and liquid tanks. Emphasis is on advanced materials-based technologies.

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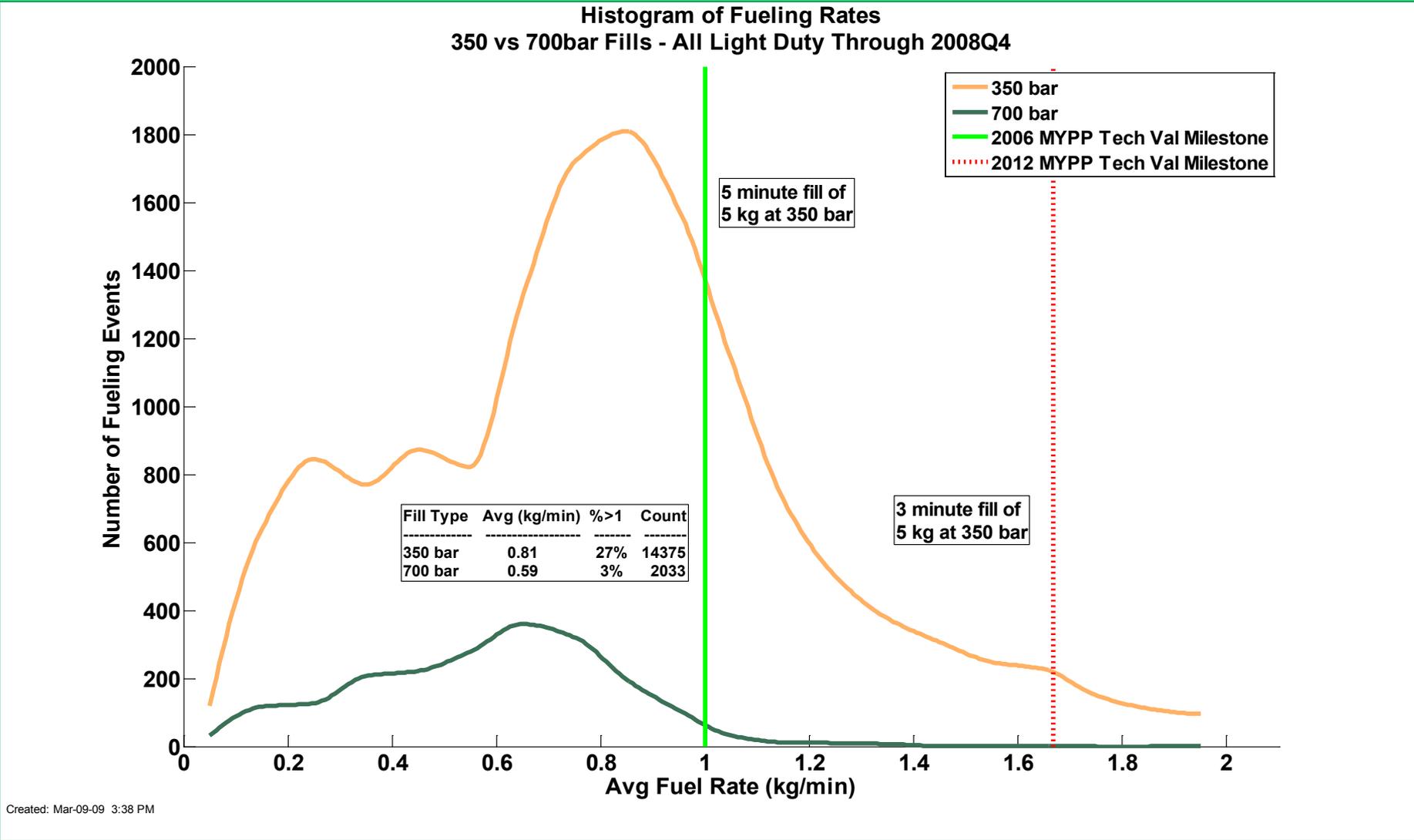
CDP#13: On-Site Hydrogen Production Efficiency



¹Production conversion efficiency is defined as the energy of the hydrogen out of the process (on an LHV basis) divided by the sum of the energy into the production process from the feedstock and all other energy as needed. Conversion efficiency does not include energy used for compression, storage, and dispensing.
²The efficiency probability distribution represents the range and likelihood of hydrogen production conversion efficiency based on monthly conversion efficiency data from the Learning Demonstration.

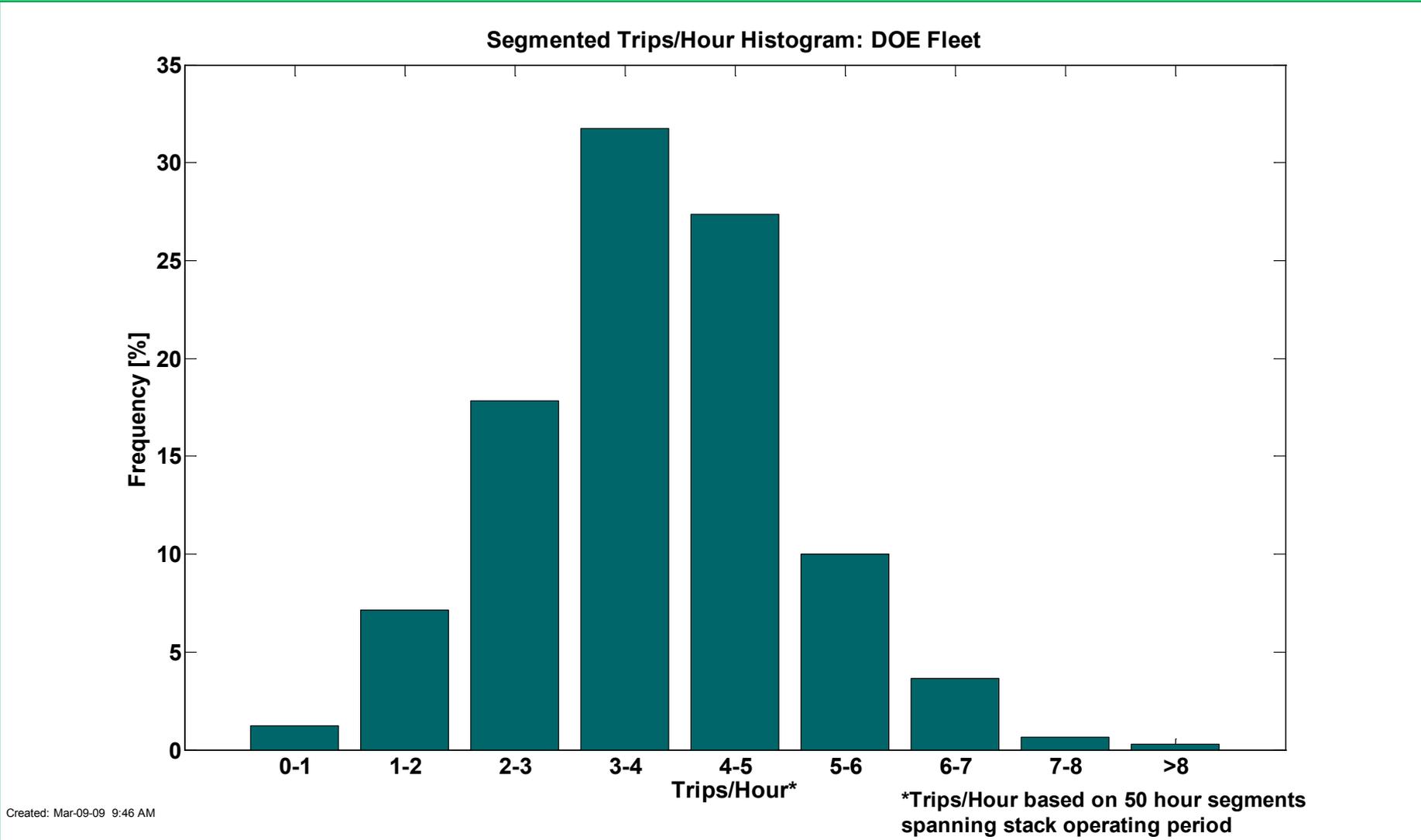
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CDP#14: Fueling Rates – 350 and 700 bar

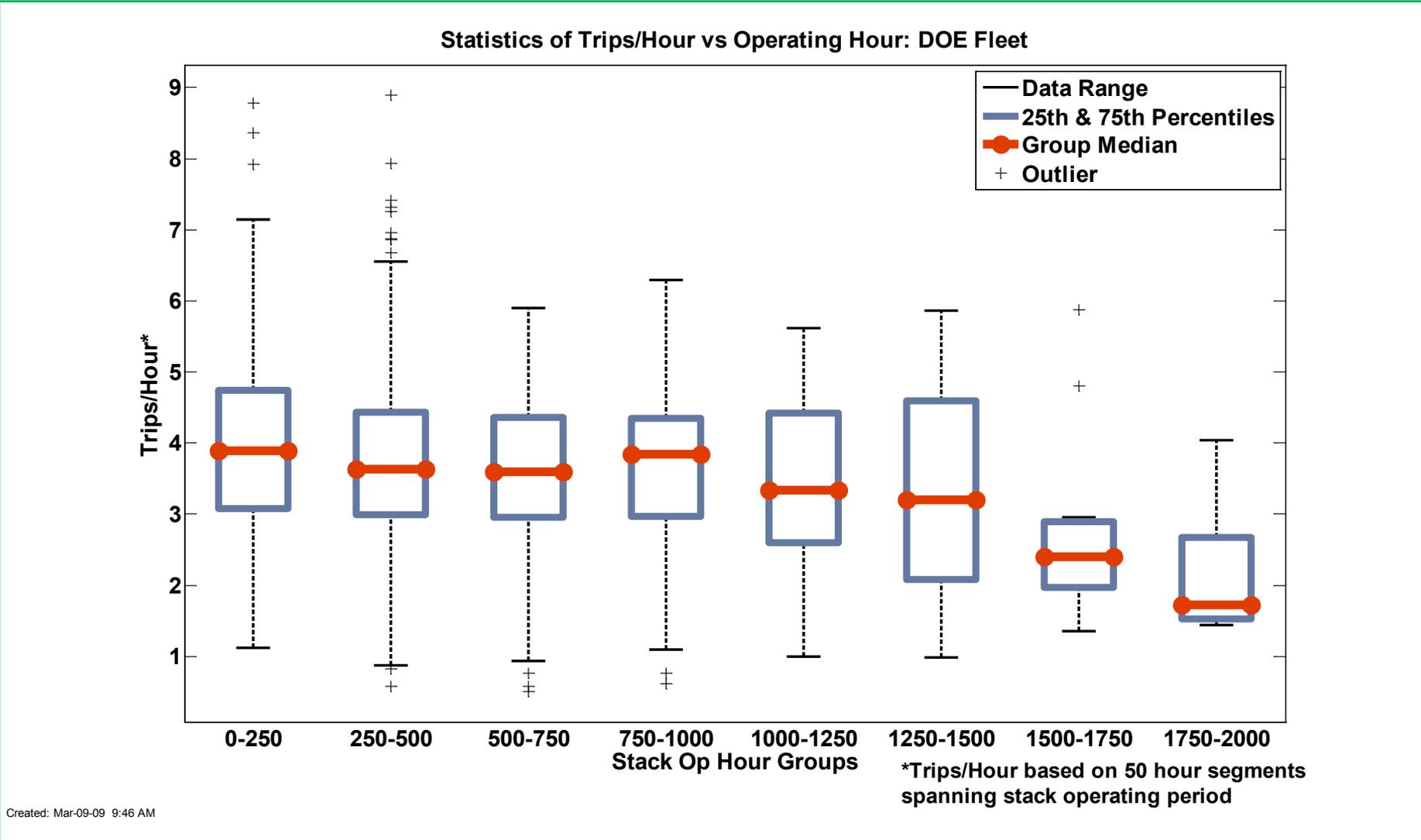


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CDP#16: Fuel Cell Stack Trips Per Hour Histogram

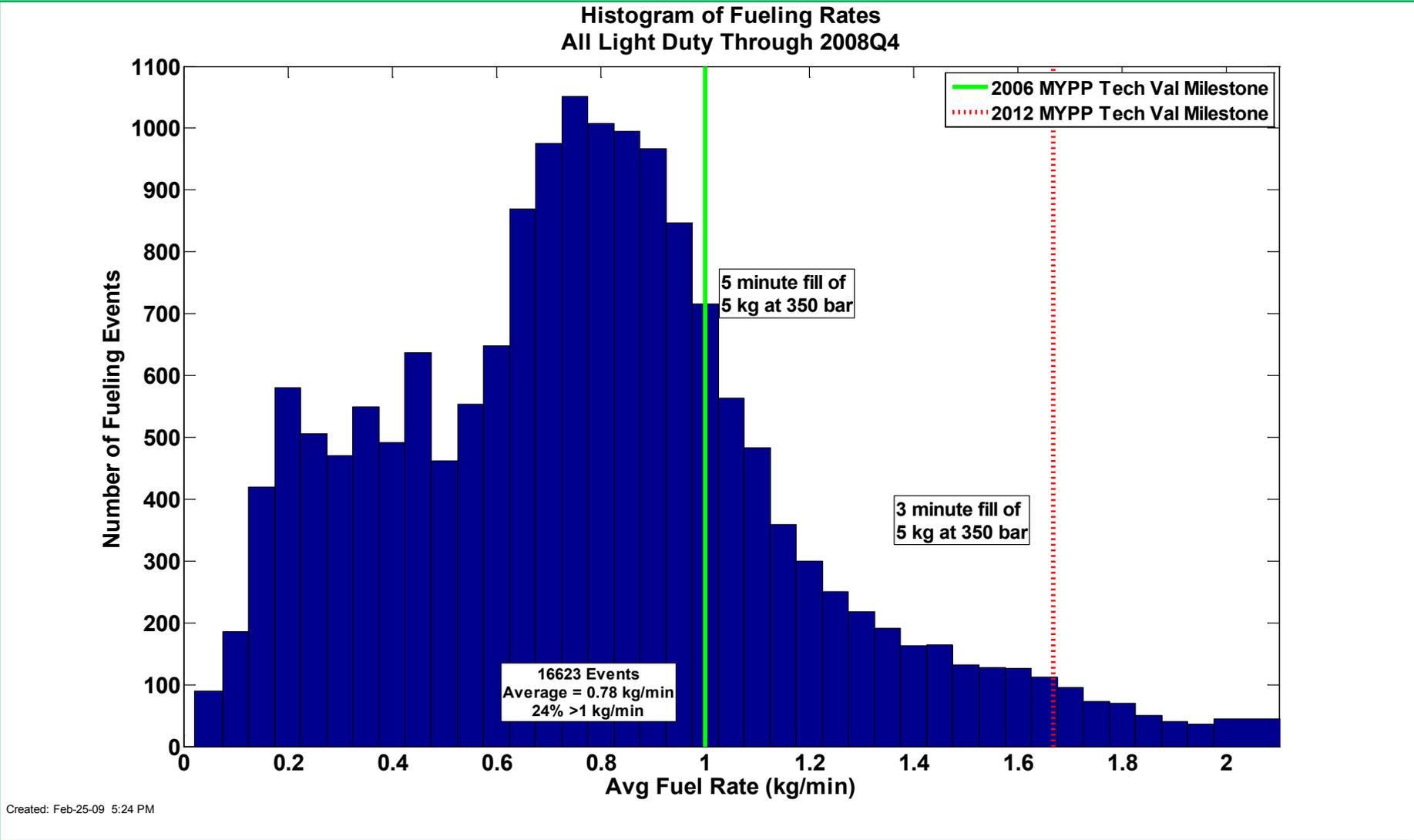


CDP#17: Statistics of Trips/Hour vs. Operating Hour



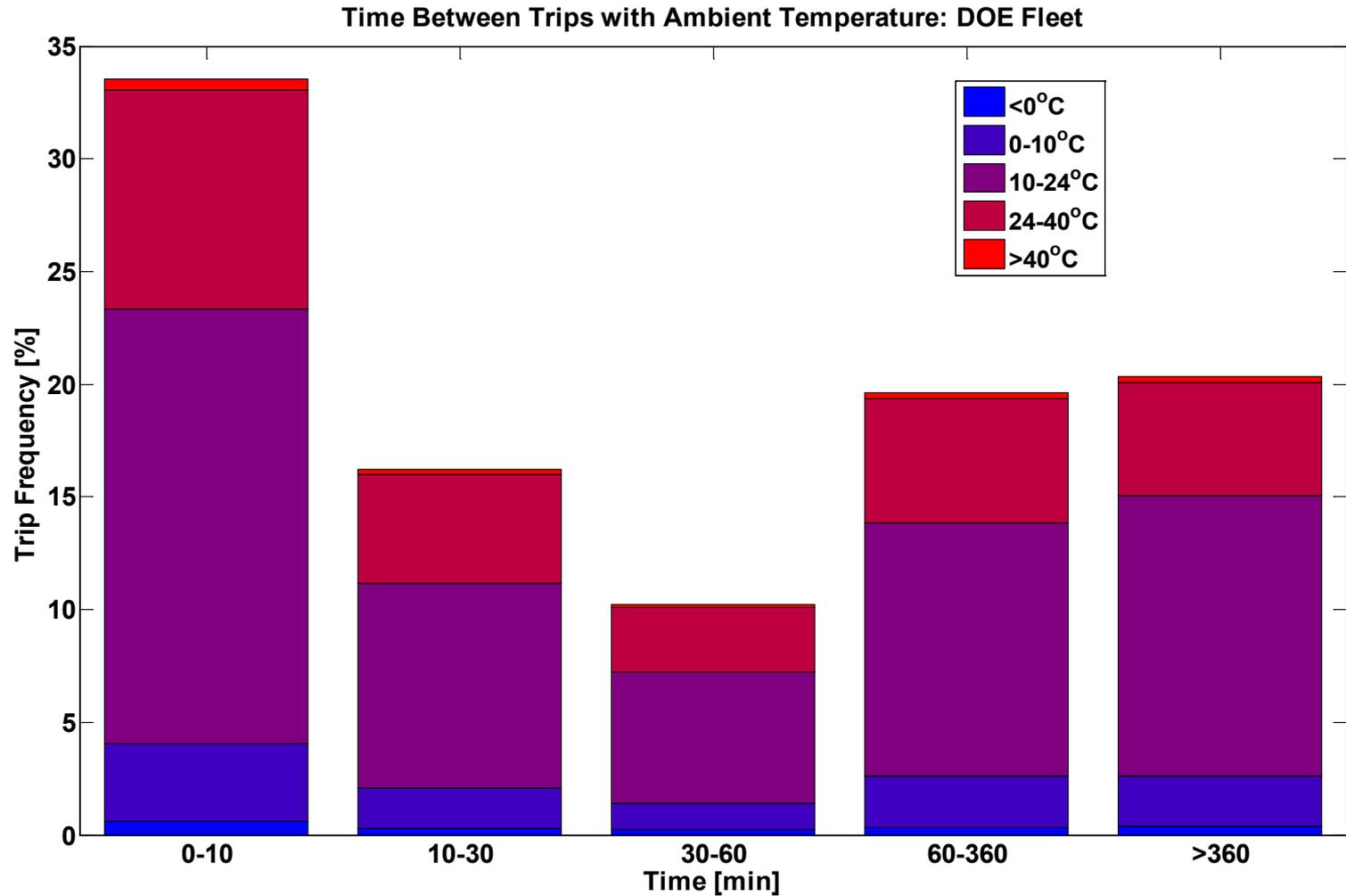
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CDP#18: Refueling Rates



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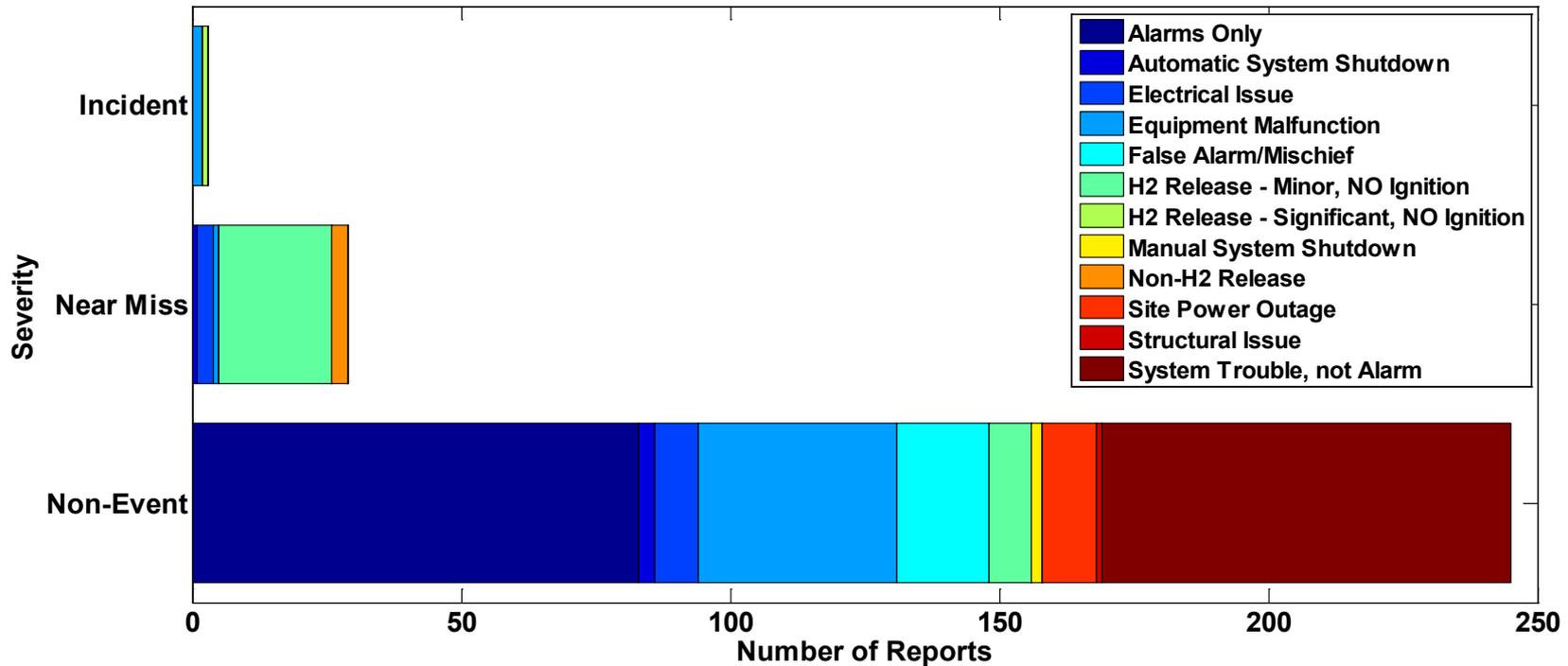
CDP#19: Time Between Trips & Ambient Temperature



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CDP#20: Safety Reports – Infrastructure

Total Infrastructure Safety Reports by Severity and Report Type Through 2008 Q4



An INCIDENT is an event that results in:

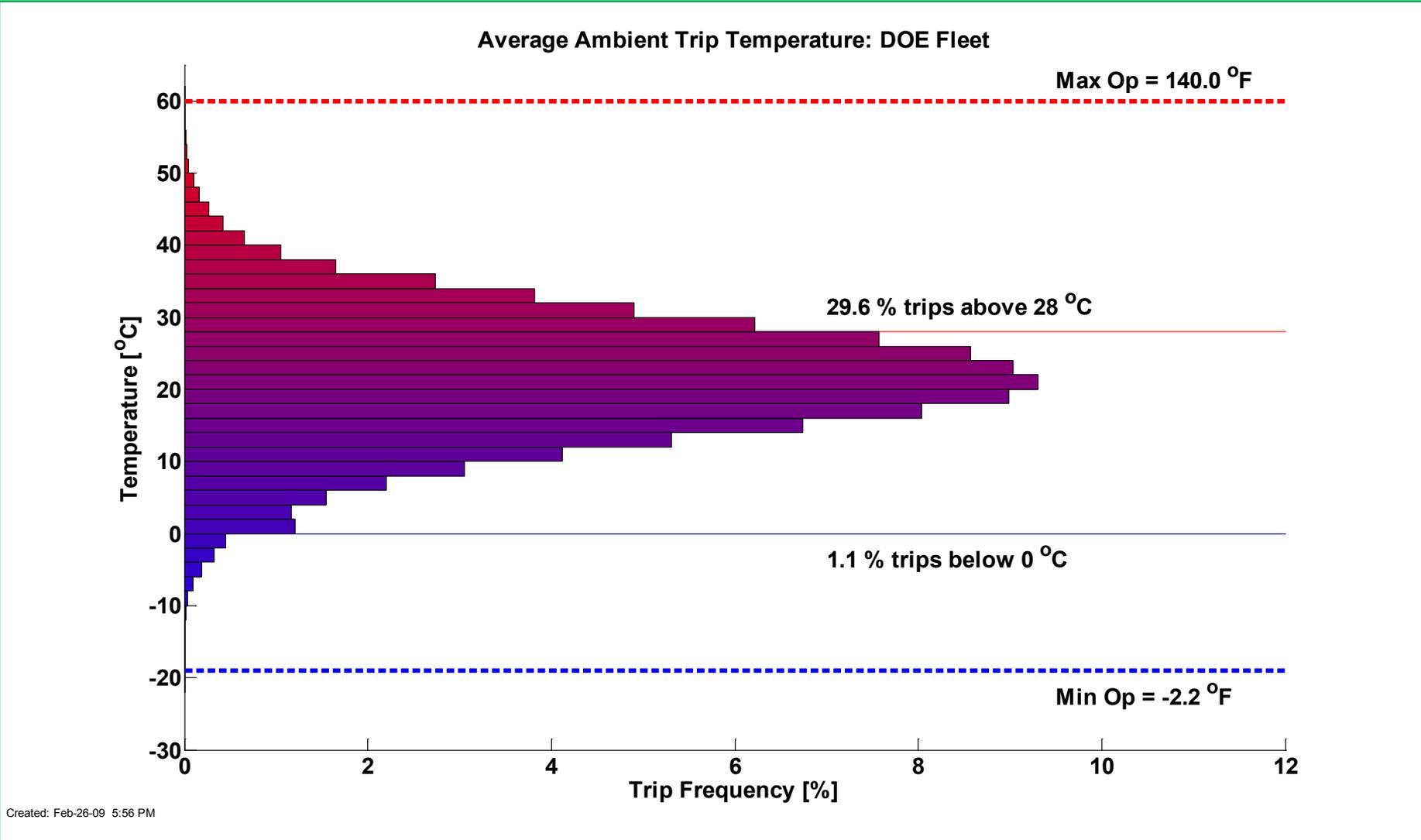
- a lost time accident and/or injury to personnel
- damage/unplanned downtime for project equipment, facilities or property
- impact to the public or environment
- any hydrogen release that unintentionally ignites or is sufficient to sustain a flame if ignited
- release of any volatile, hydrogen containing 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

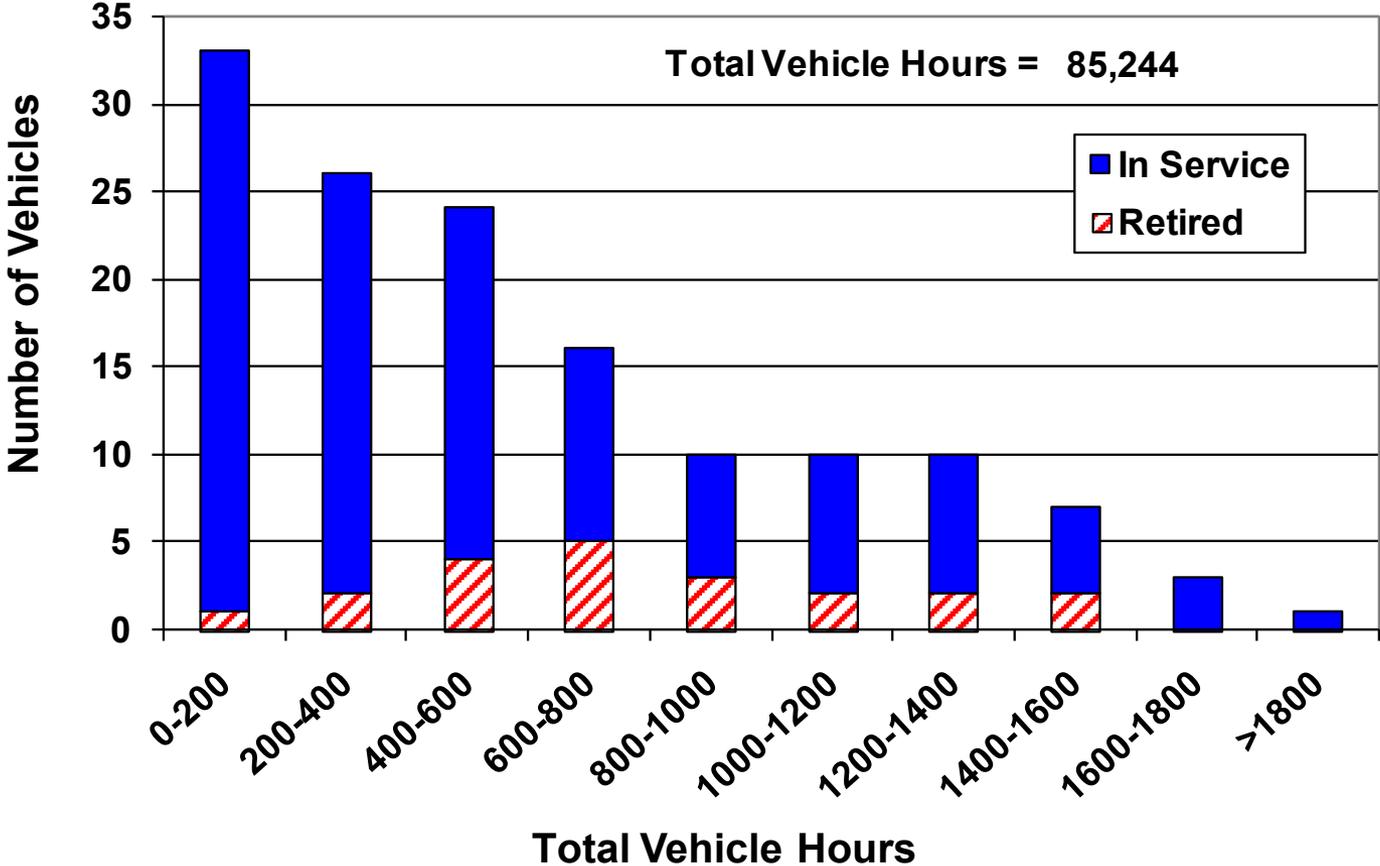
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CDP#21: Range of Ambient Temperature During Vehicle Operation



CDP#22: Vehicle Operating Hours

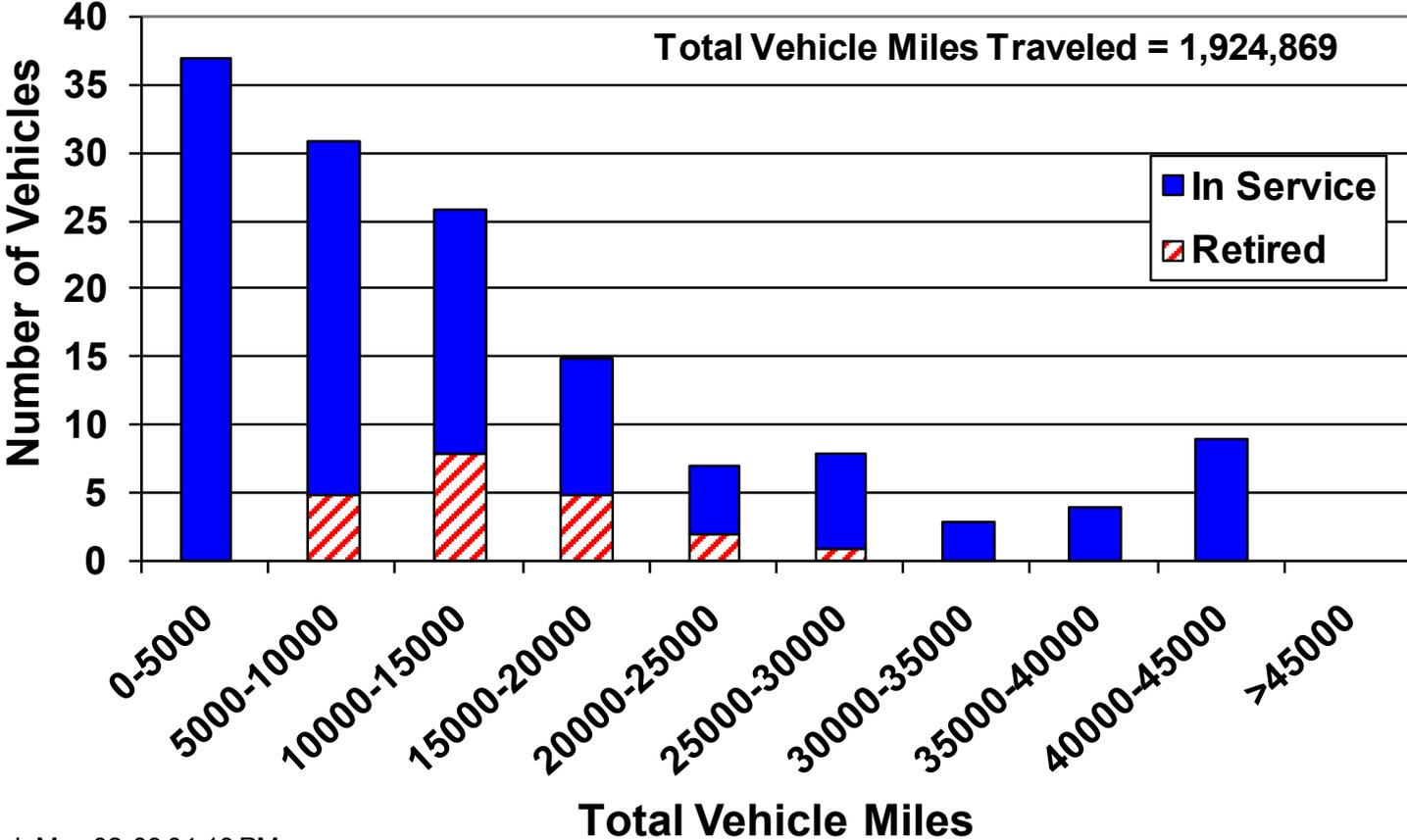
Vehicle Hours: All OEMs, Gen 1 and Gen 2
Through 2008 Q4



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CDP#23: Vehicles vs. Miles Traveled

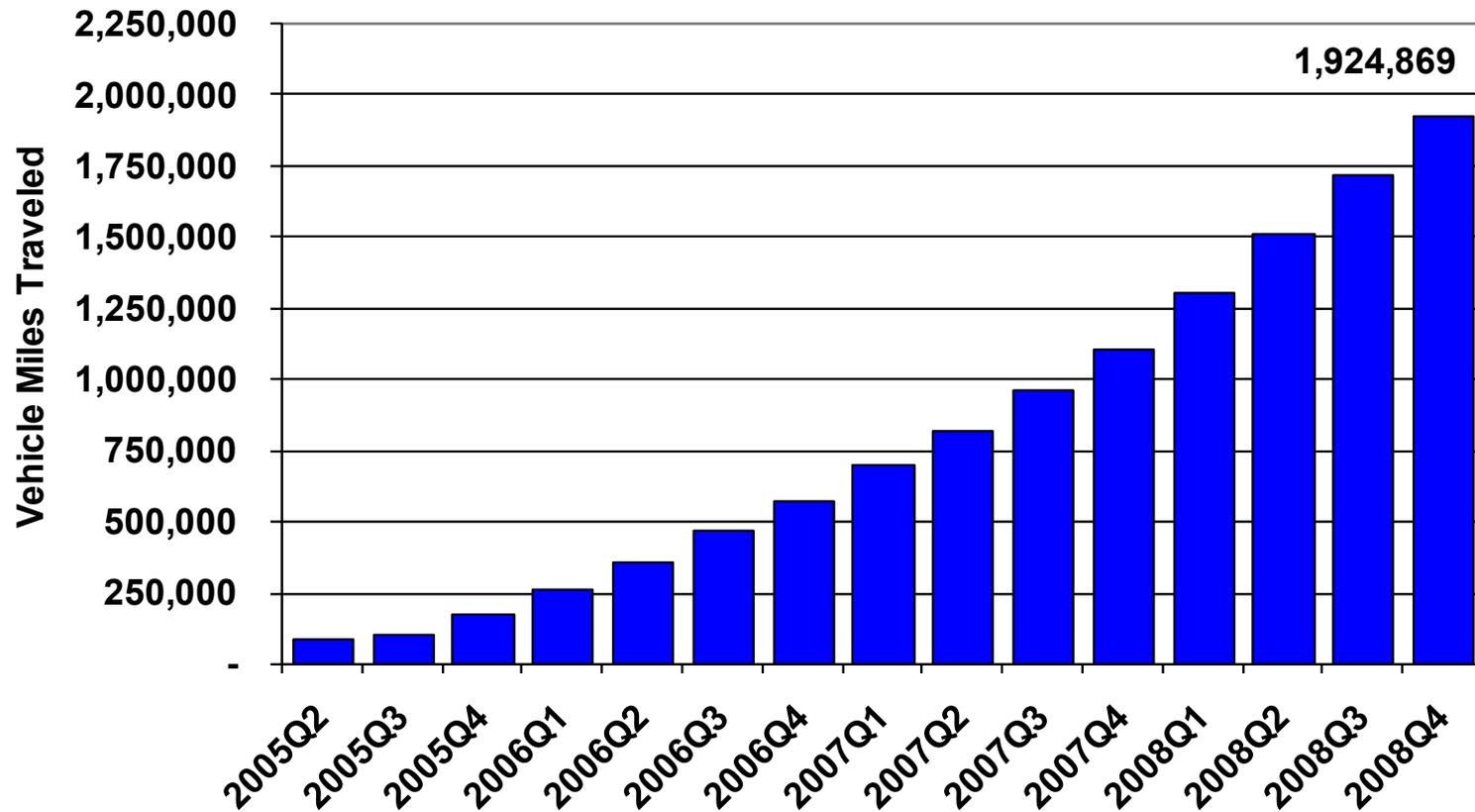
Vehicle Miles: All OEMs Combined, Gen 1 and 2
Through 2008 Q4



Created: Mar-02-09 04:13 PM

CDP#24: Cumulative Vehicle Miles Traveled

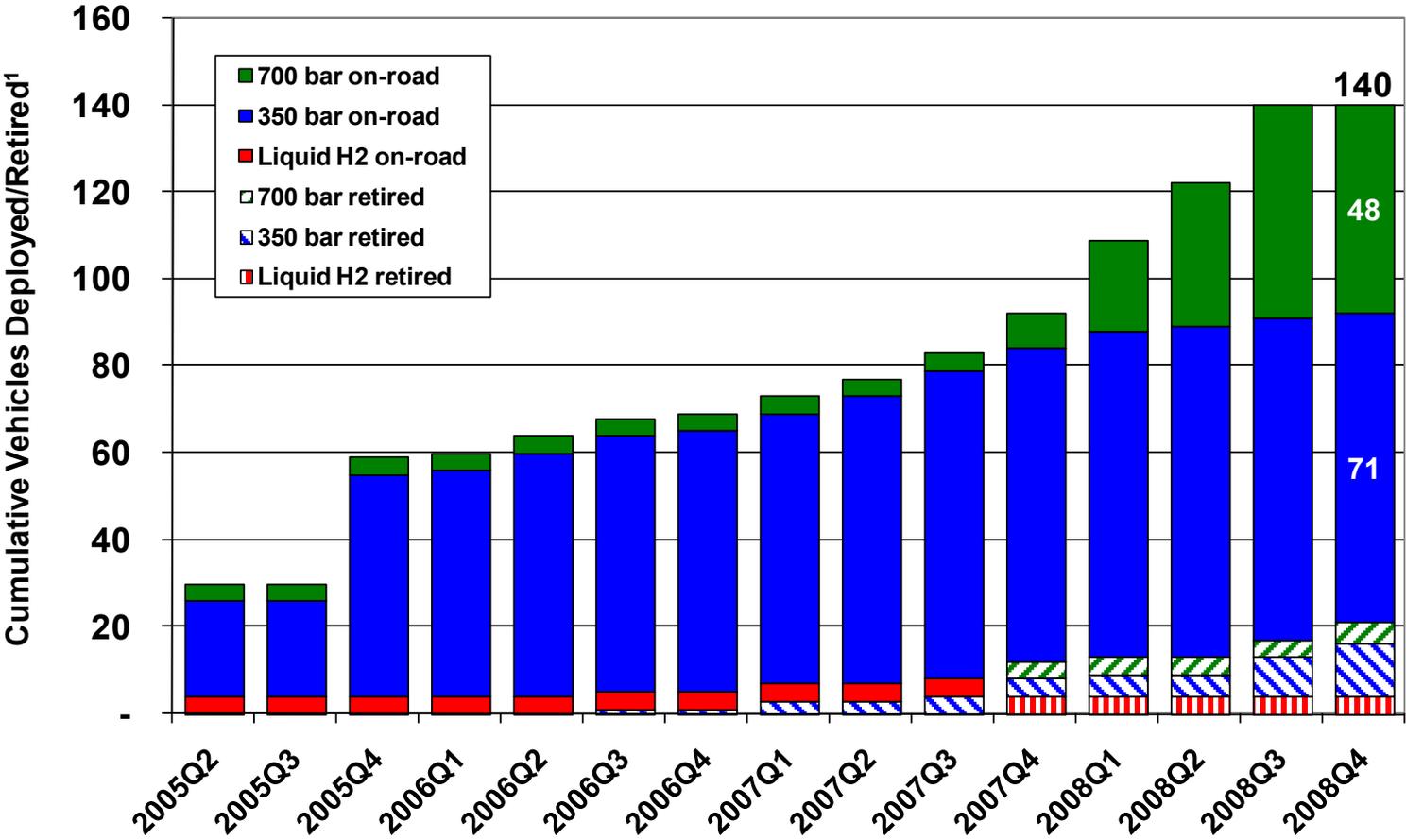
Cumulative Vehicle Miles: All OEMs, Gen 1 and Gen 2
Through 2008 Q4



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CDP#25: Vehicle H2 Storage Technologies

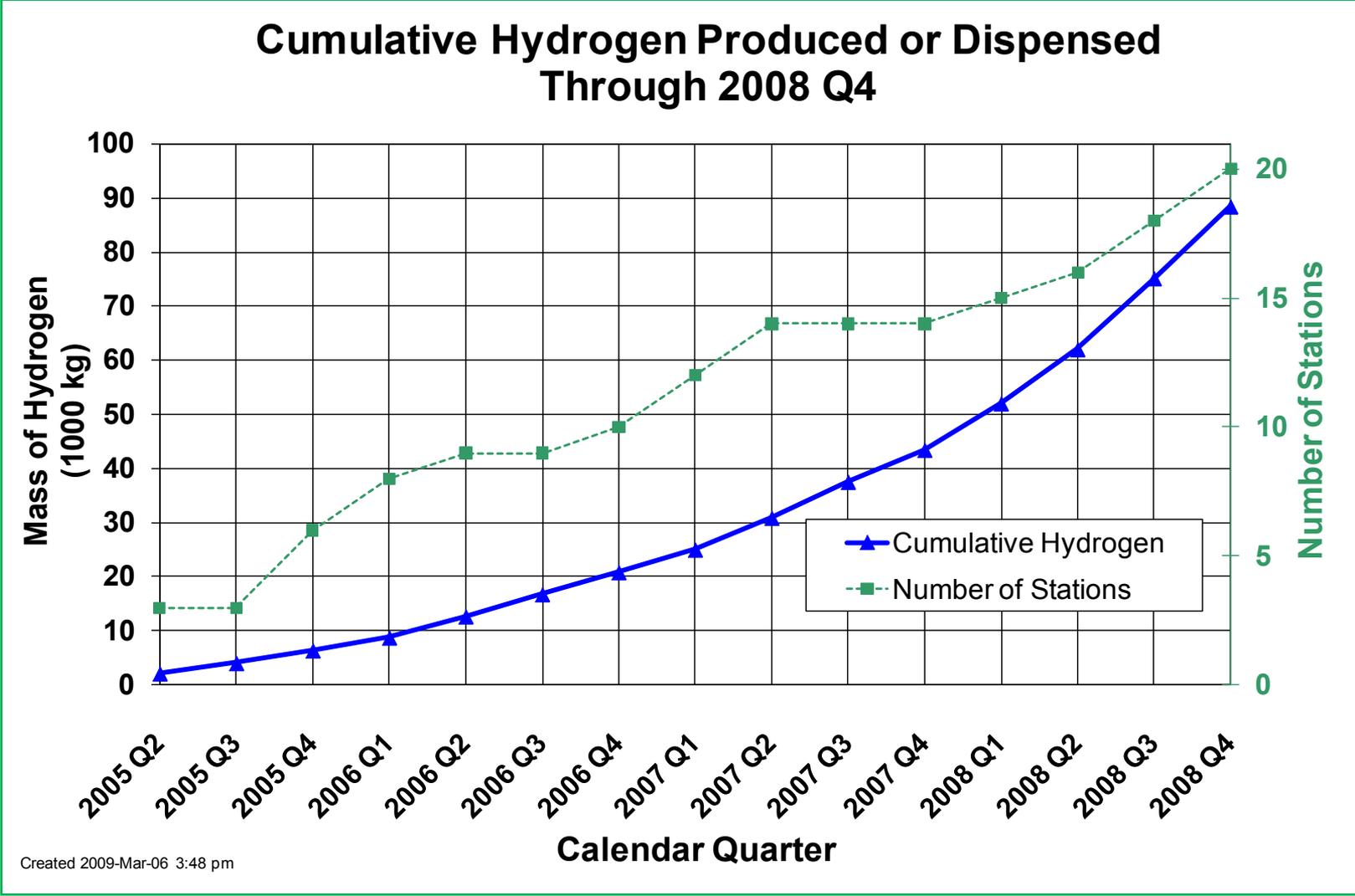
Vehicle Deployment by On-Board Hydrogen Storage Type



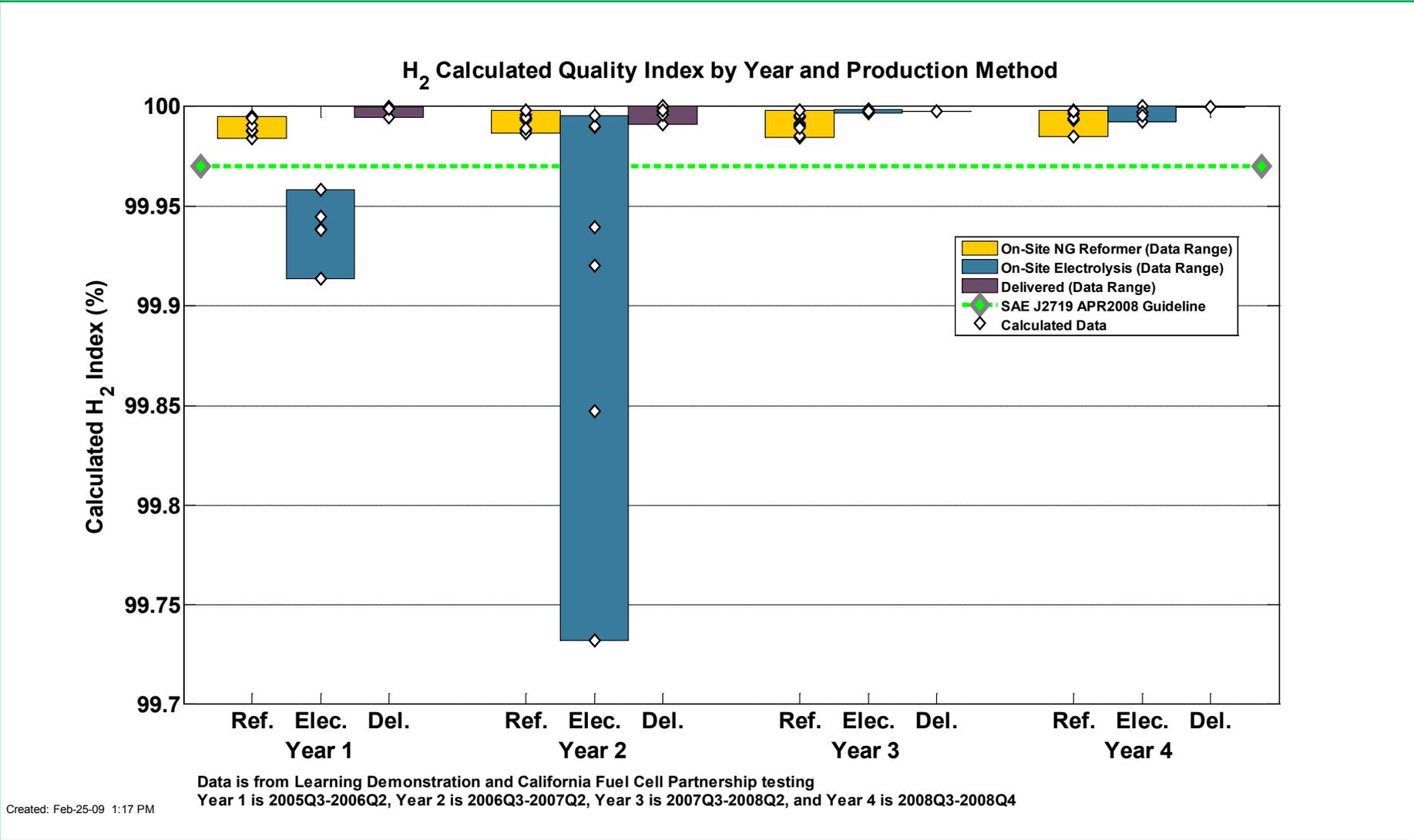
Created Feb-27-2009 9:10 AM

(1) Retired vehicles have left DOE fleet and are no longer providing data to NREL

CDP#26: Cumulative H2 Produced or Dispensed

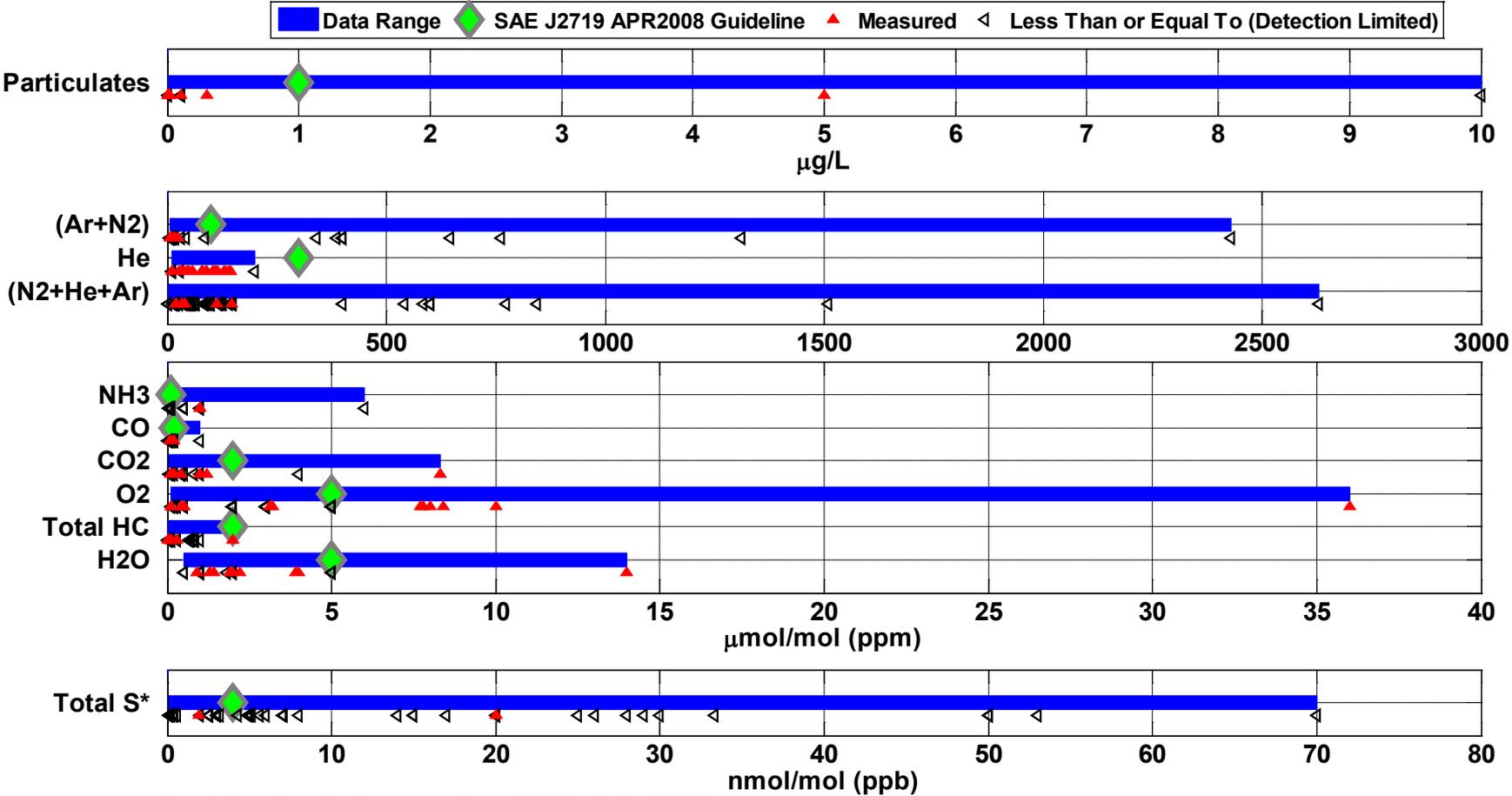


CDP#27: Hydrogen Quality Index



CDP#28: Hydrogen Fuel Constituents

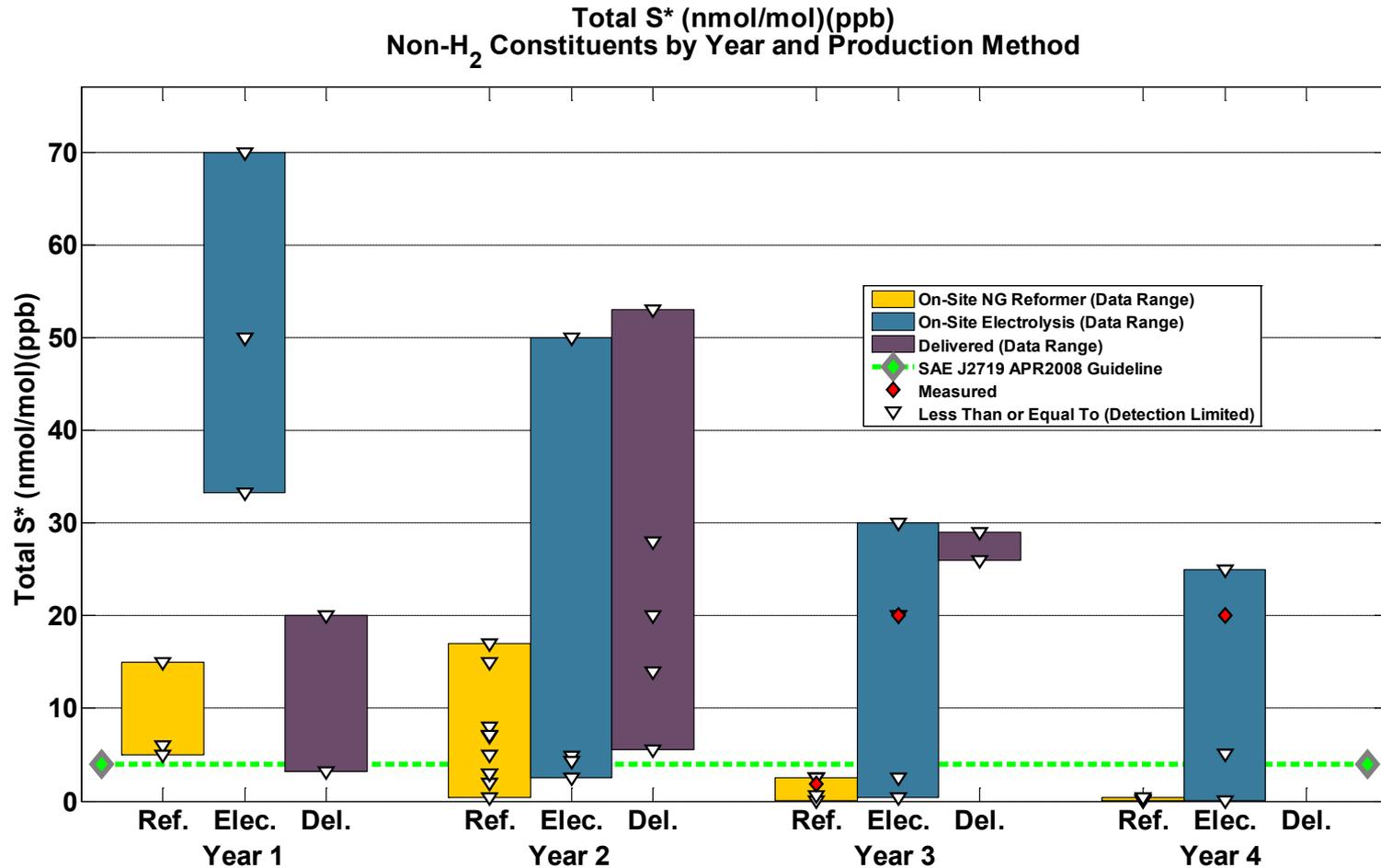
H₂ Fuel Constituents



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Data is from Learning Demonstration and California Fuel Cell Partnership testing
 *Total S calculated from SO₂, COS, H₂S, CS₂, and Methyl Mercaptan (CH₃SH).

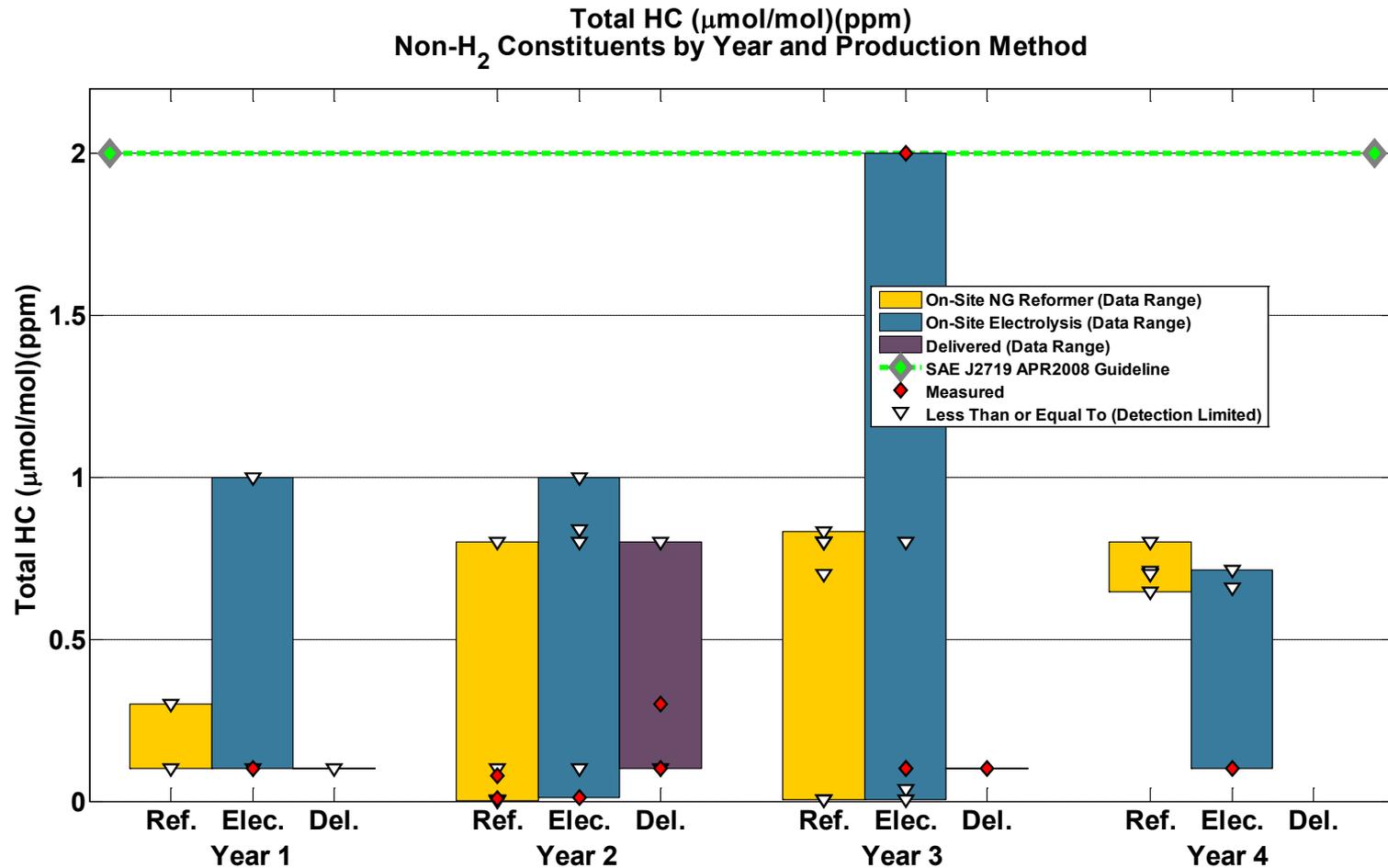
CDP#28 Supplemental: Hydrogen Constituents by Year and Production Method



Data is from Learning Demonstration and California Fuel Cell Partnership testing
 Year 1 is 2005Q3-2006Q2, Year 2 is 2006Q3-2007Q2, Year 3 is 2007Q3-2008Q2, and Year 4 is 2008Q3-2008Q4
 *Total S calculated from SO₂, COS, H₂S, CS₂, and Methyl Mercaptan (CH₃SH).

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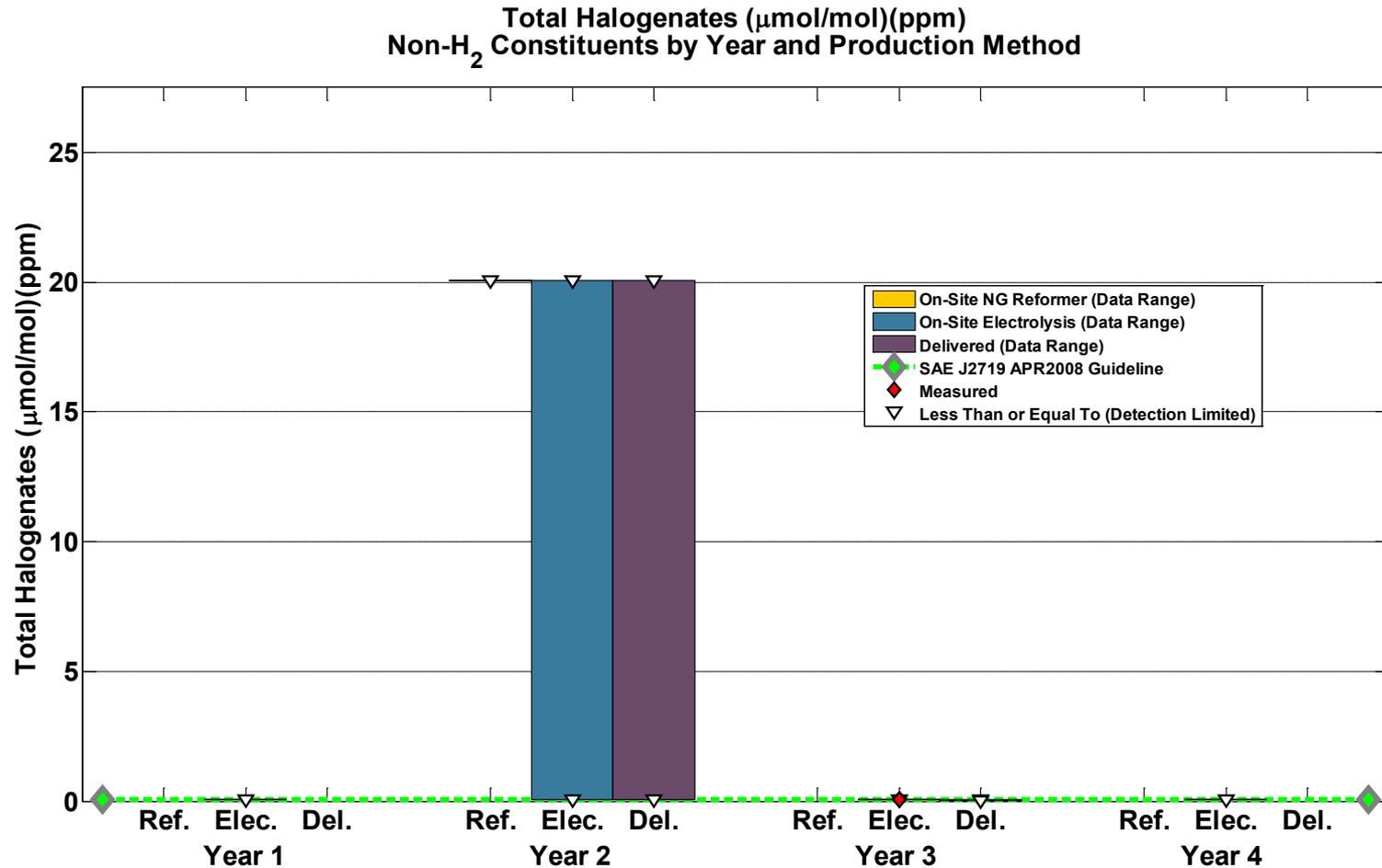
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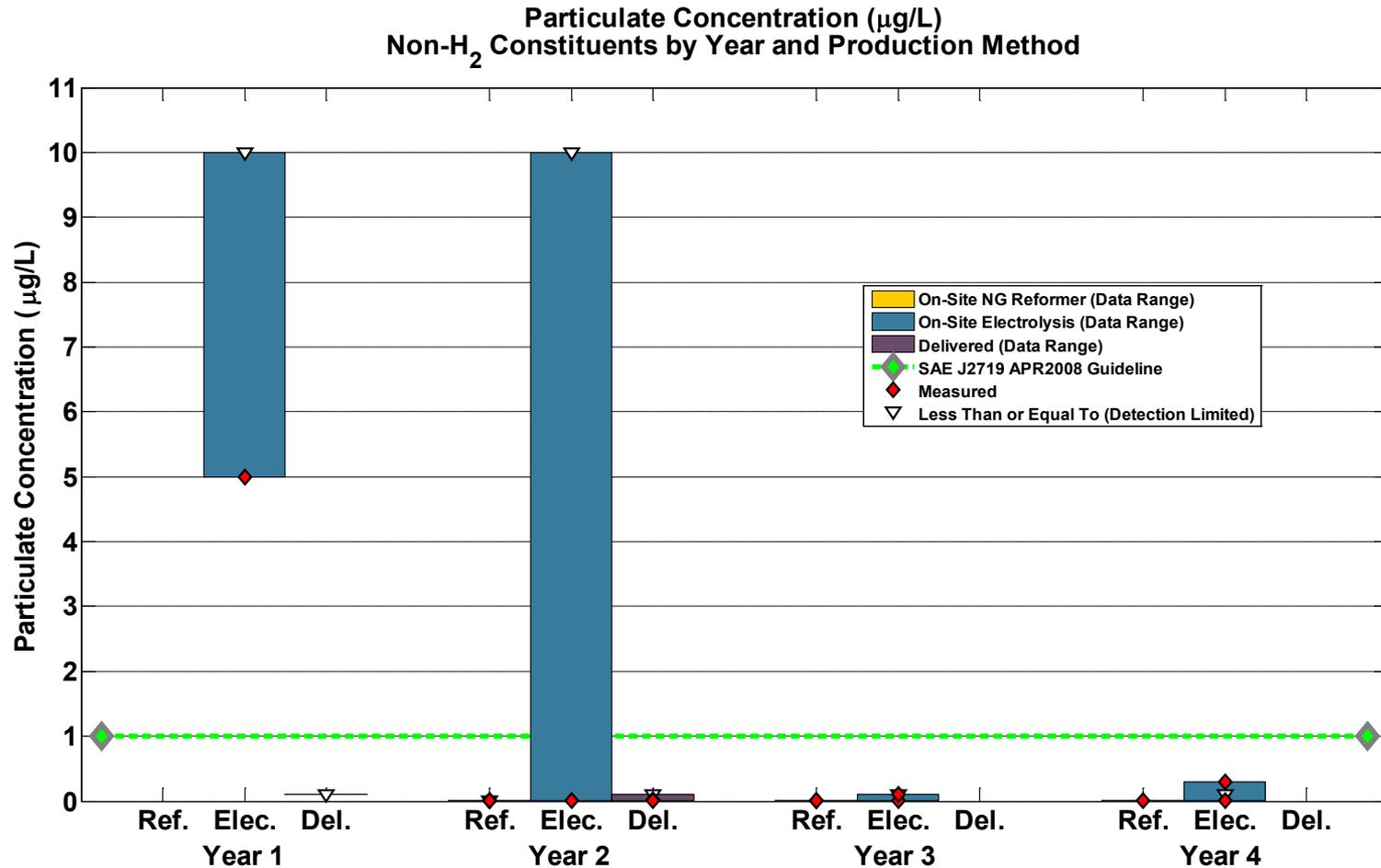
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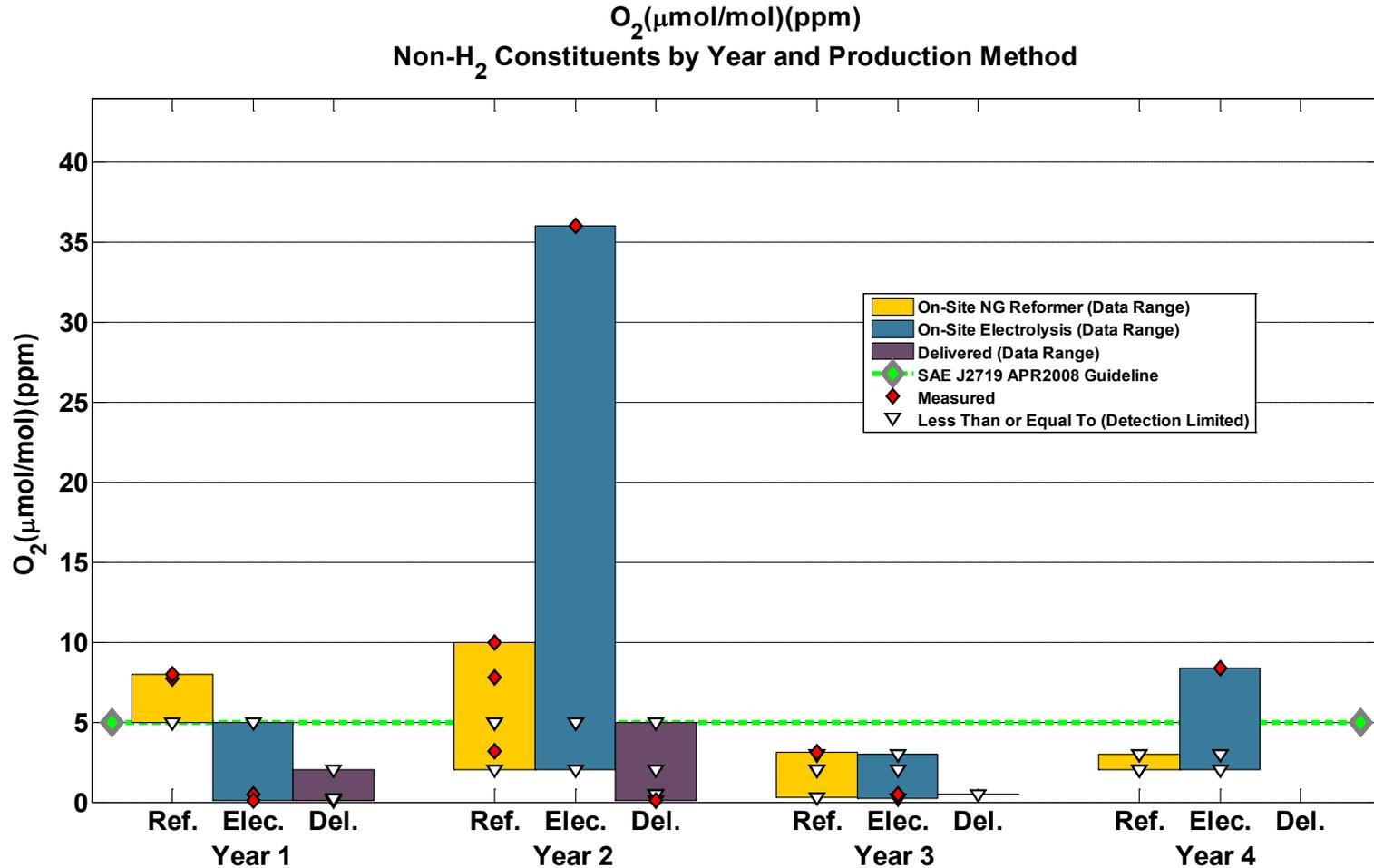
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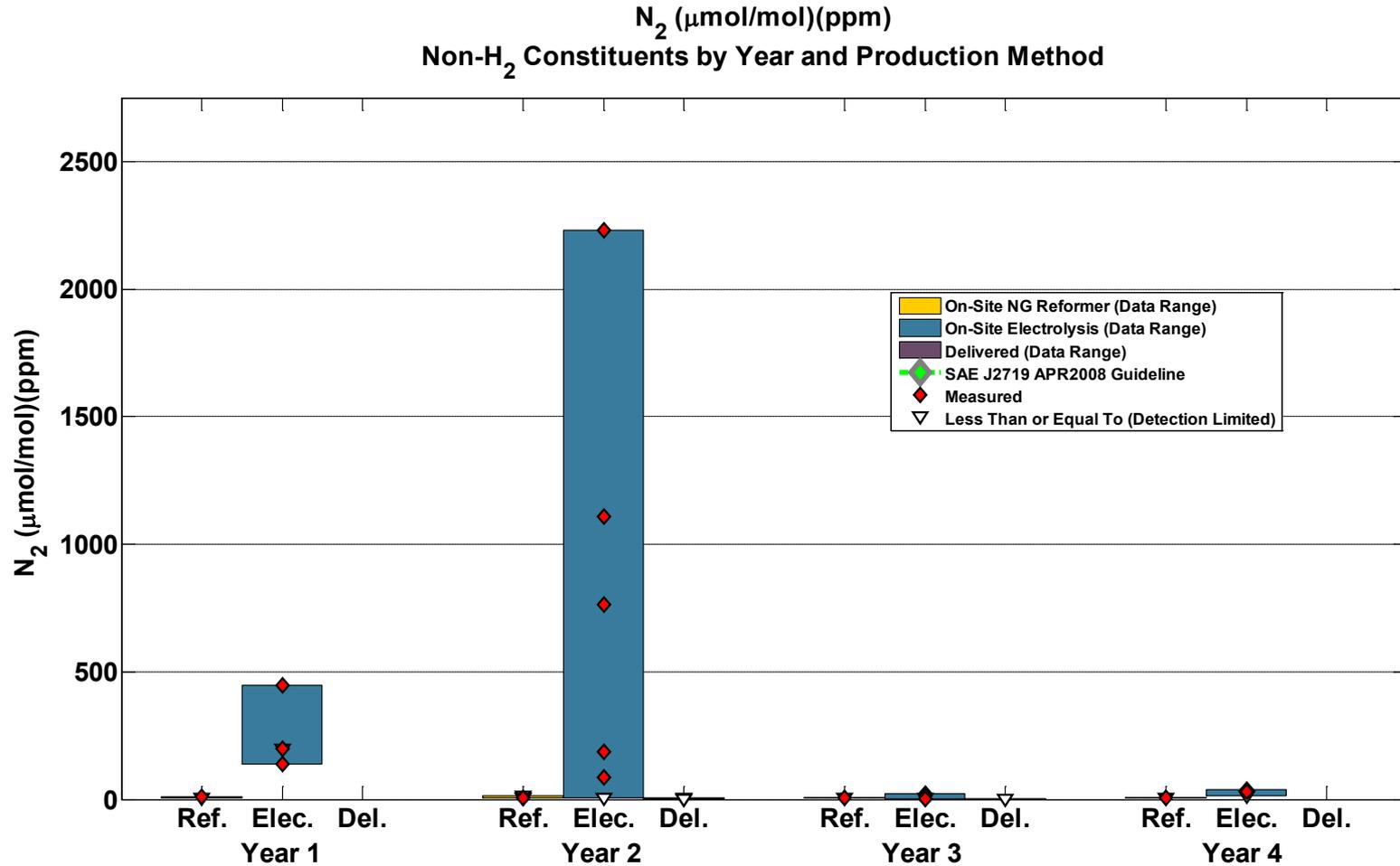
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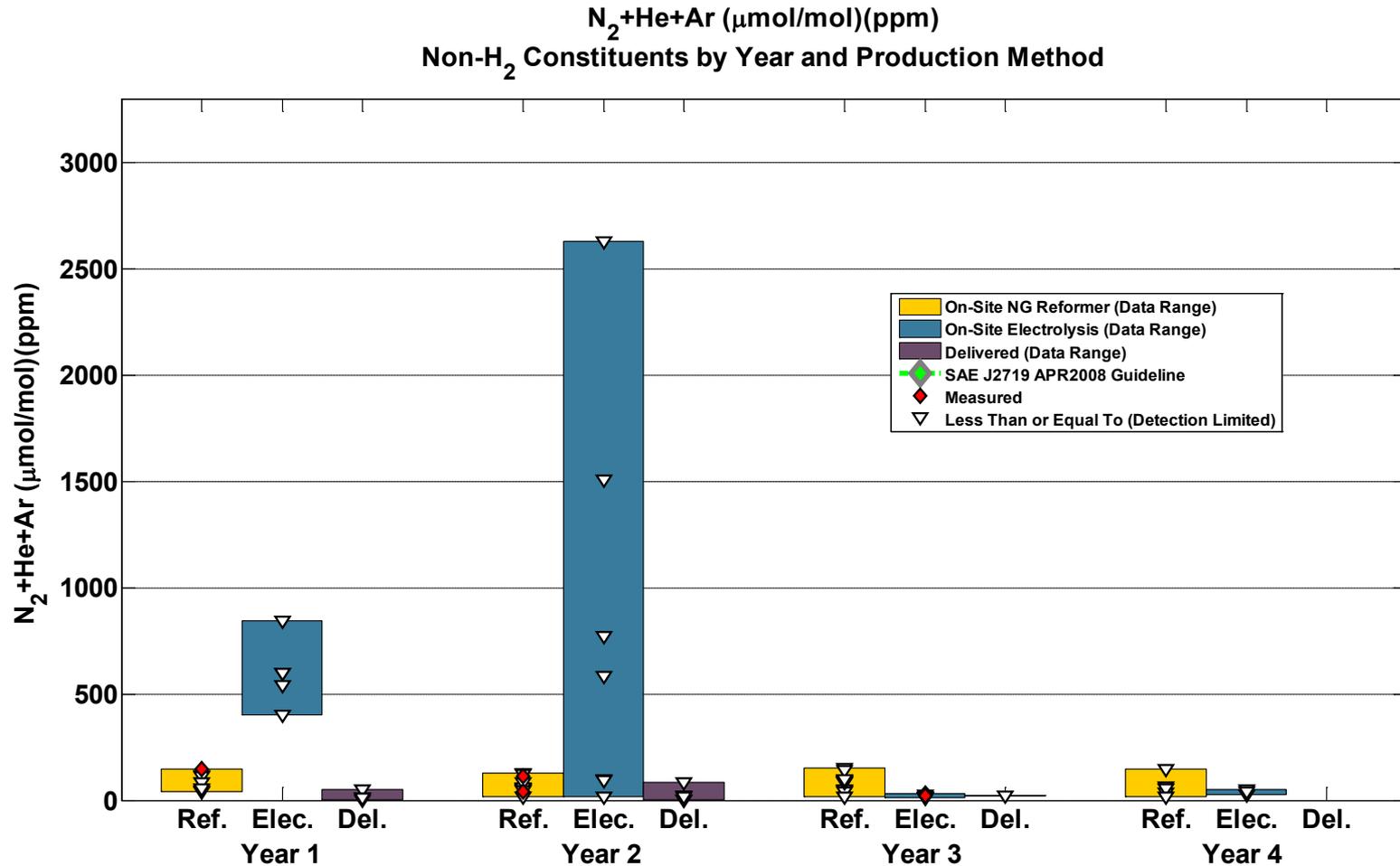
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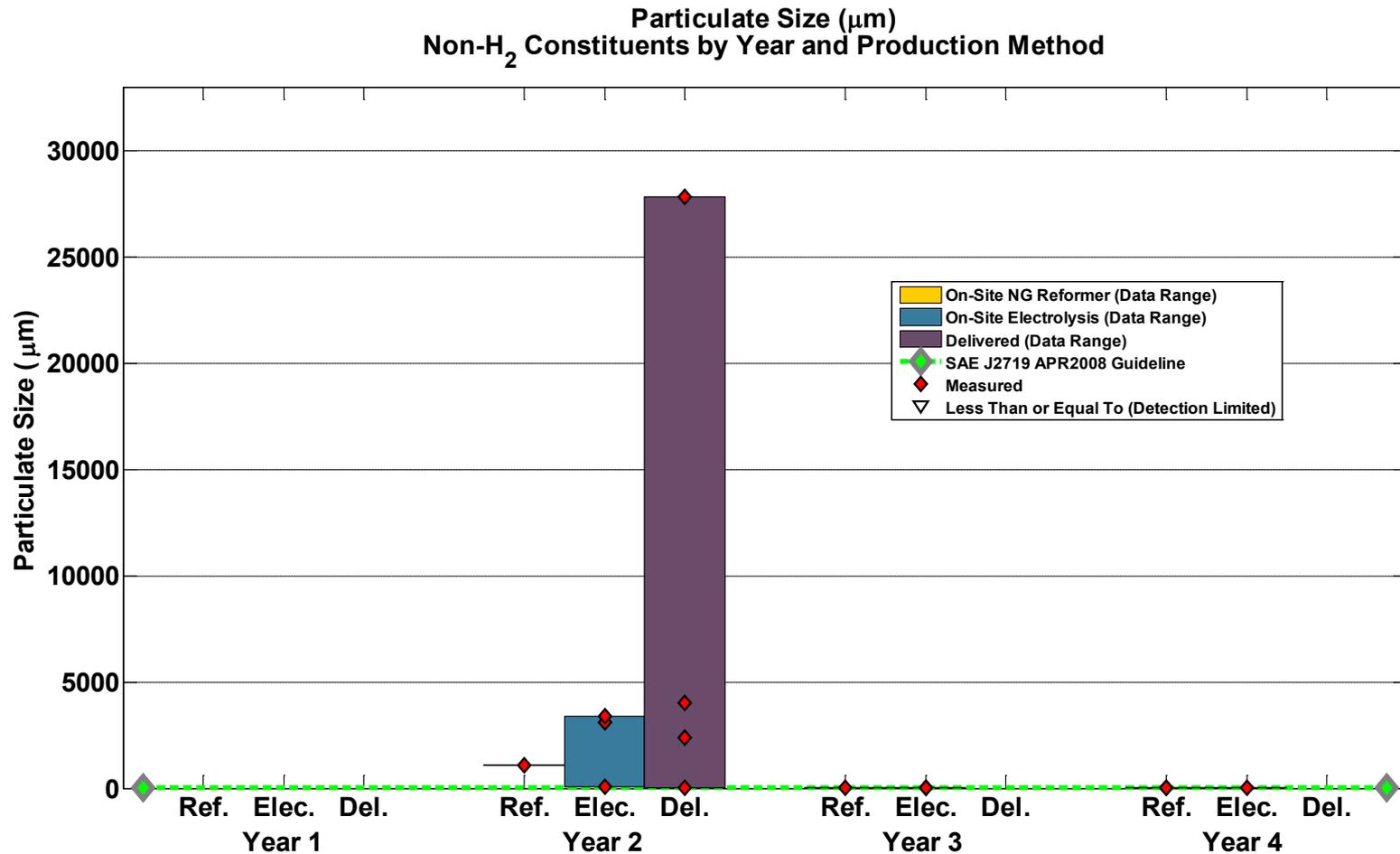
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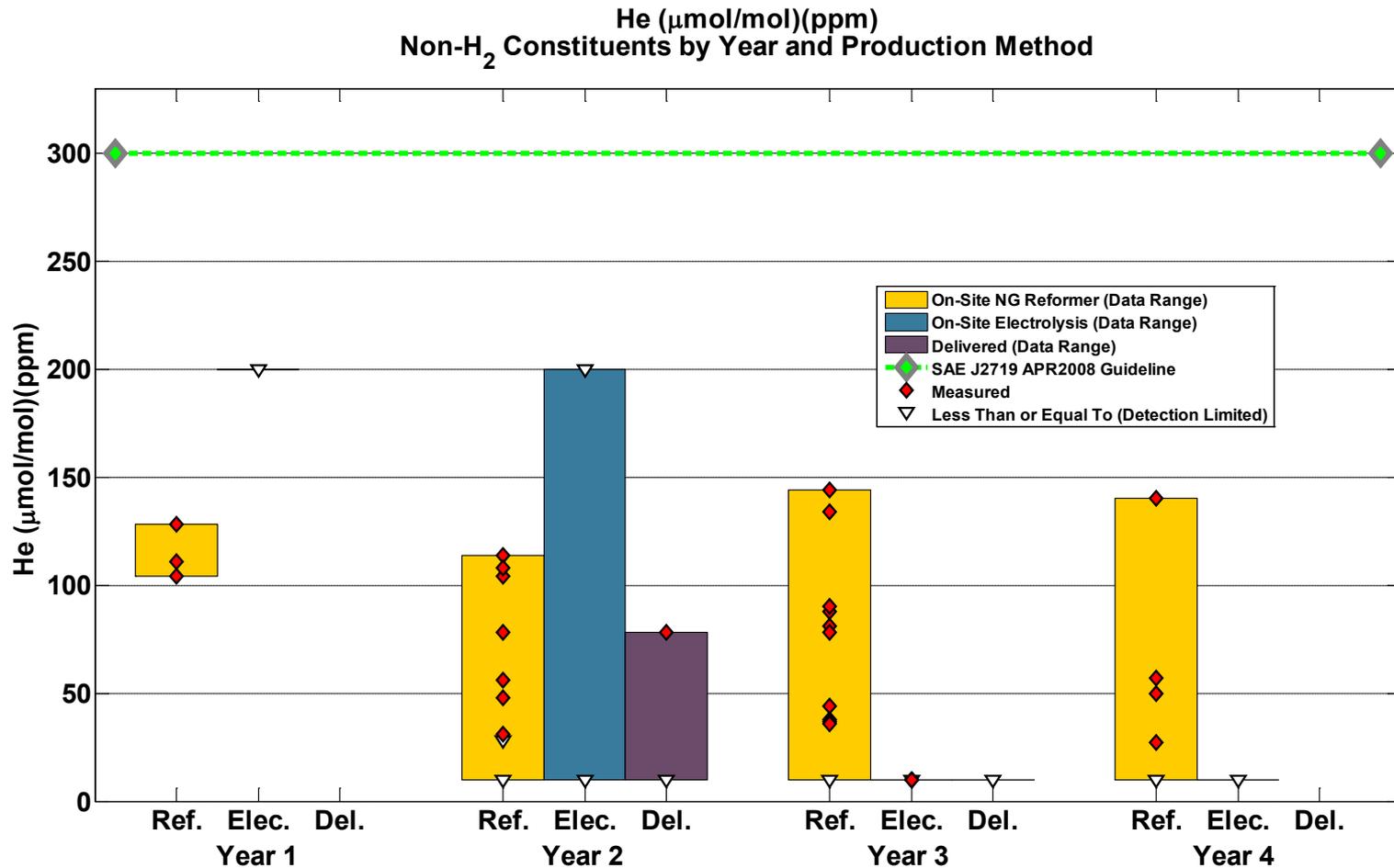
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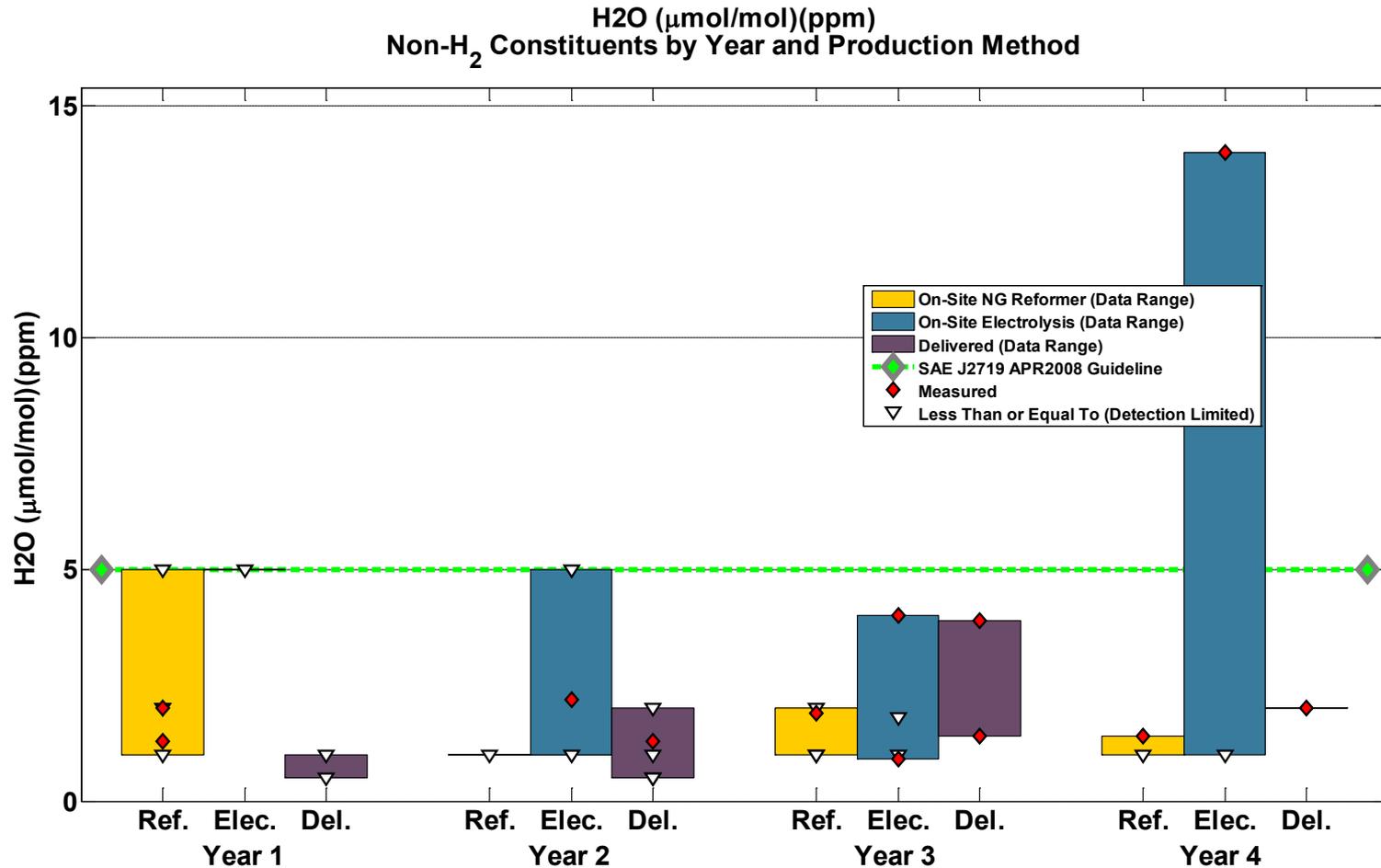
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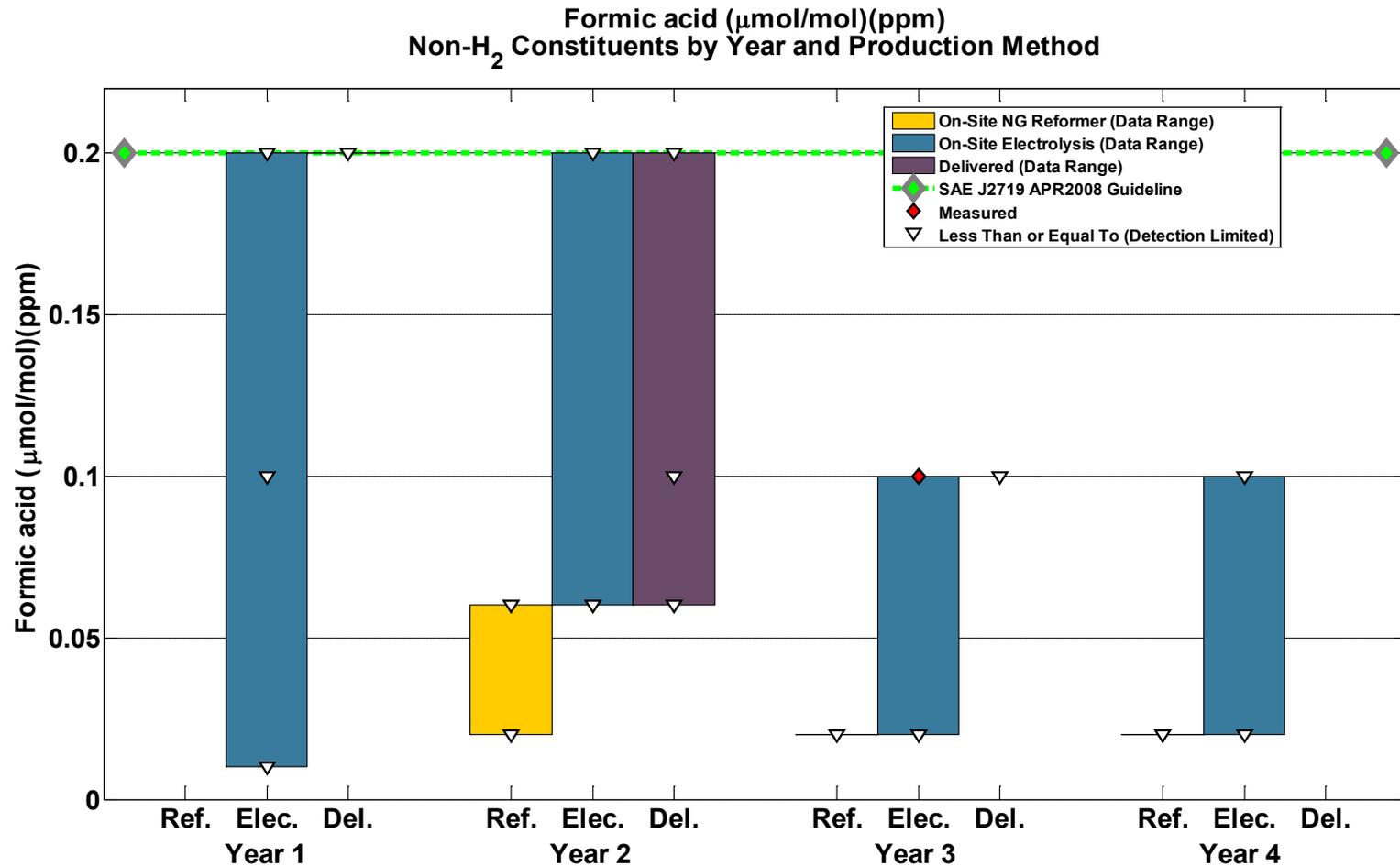
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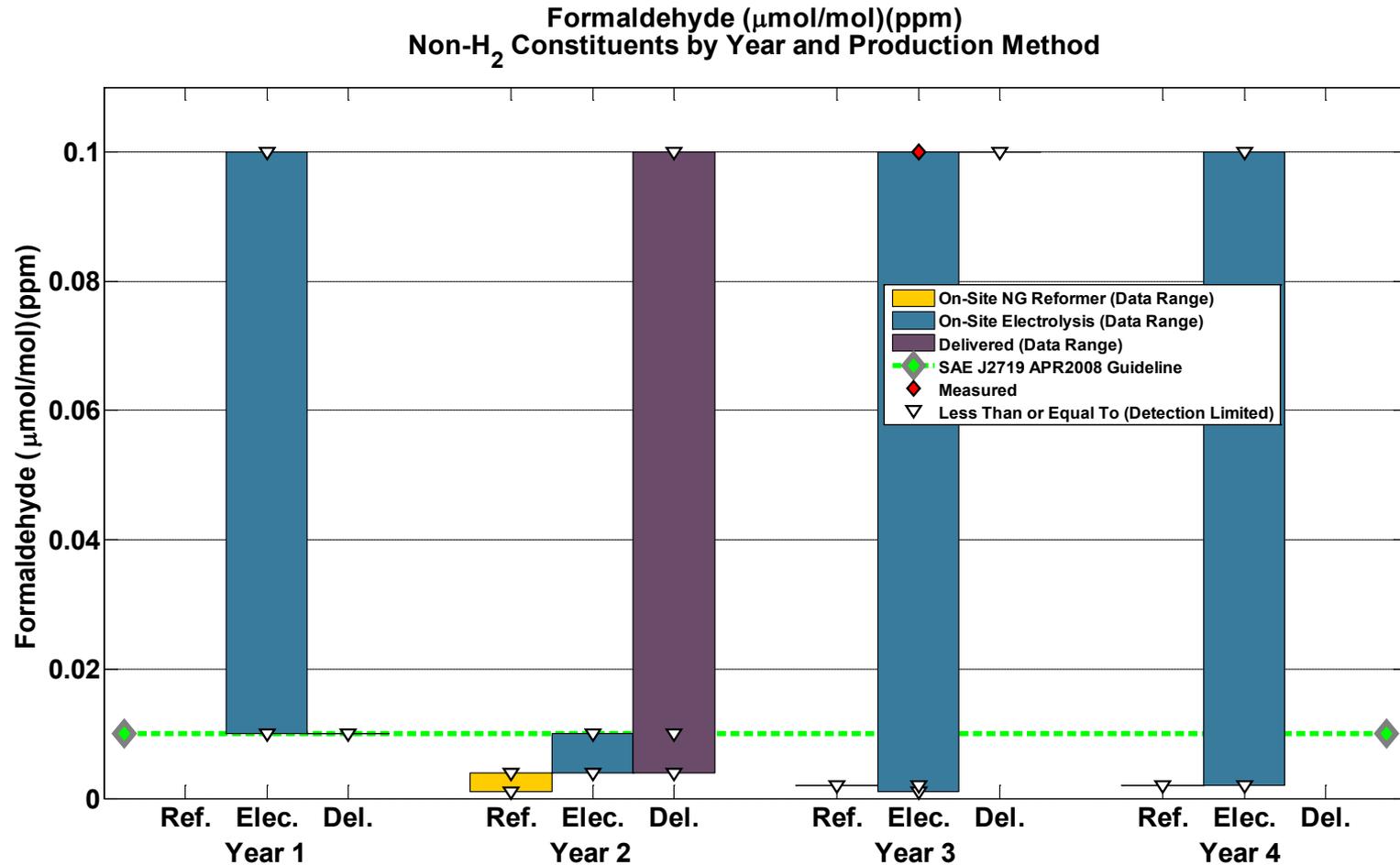
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 Year 1 is 2005Q3-2006Q2, Year 2 is 2006Q3-2007Q2, Year 3 is 2007Q3-2008Q2, and Year 4 is 2008Q3-2008Q4

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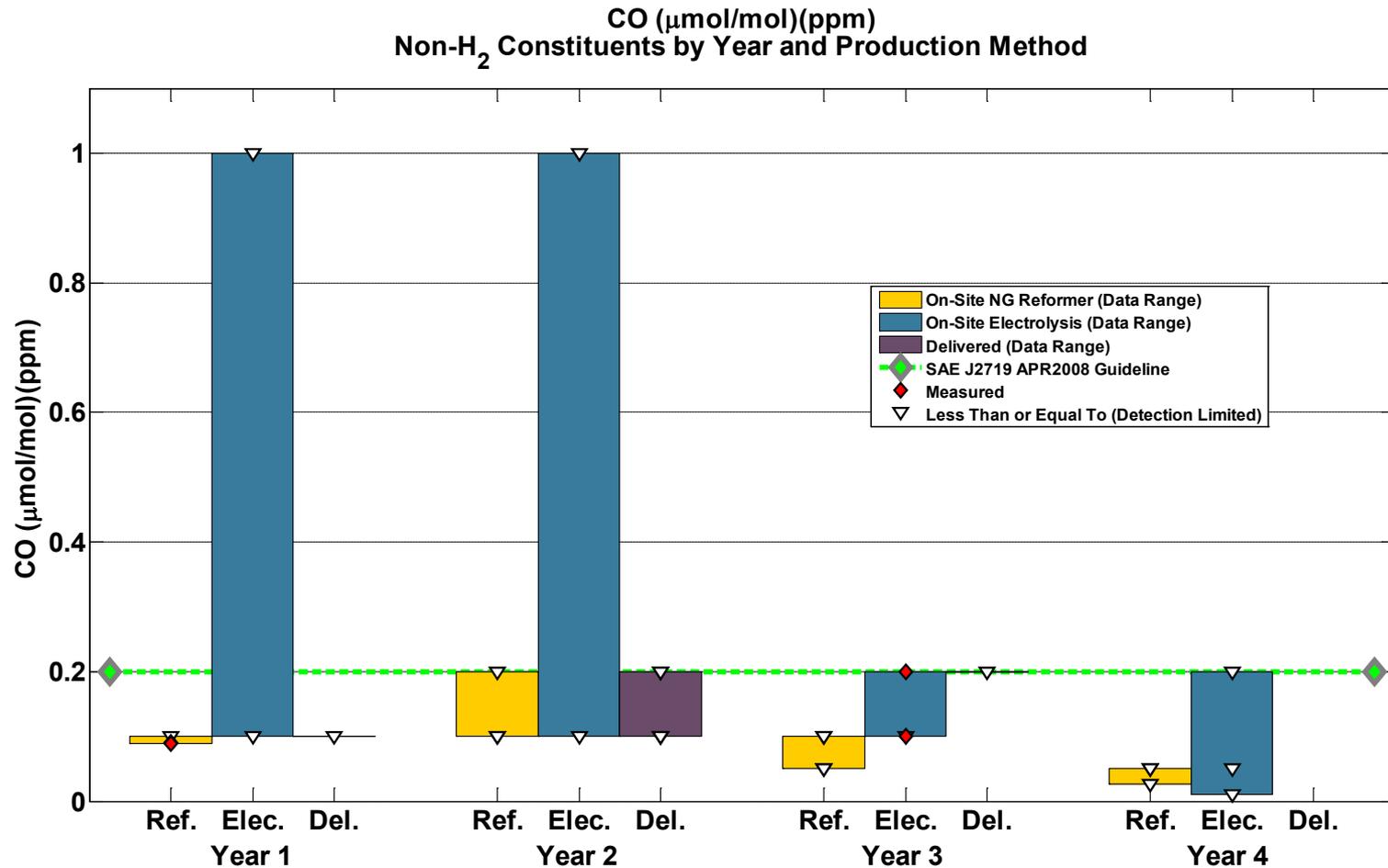
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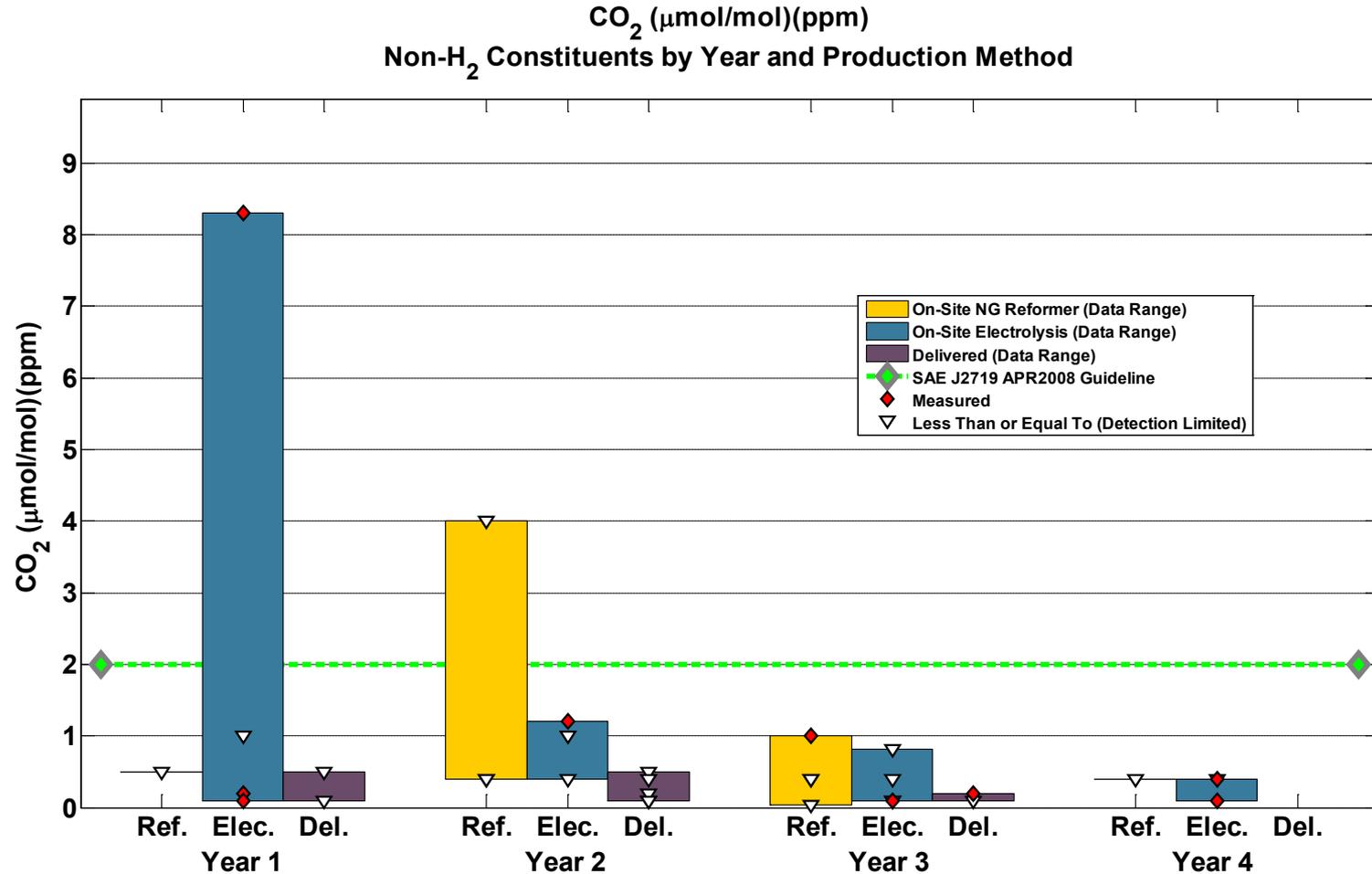
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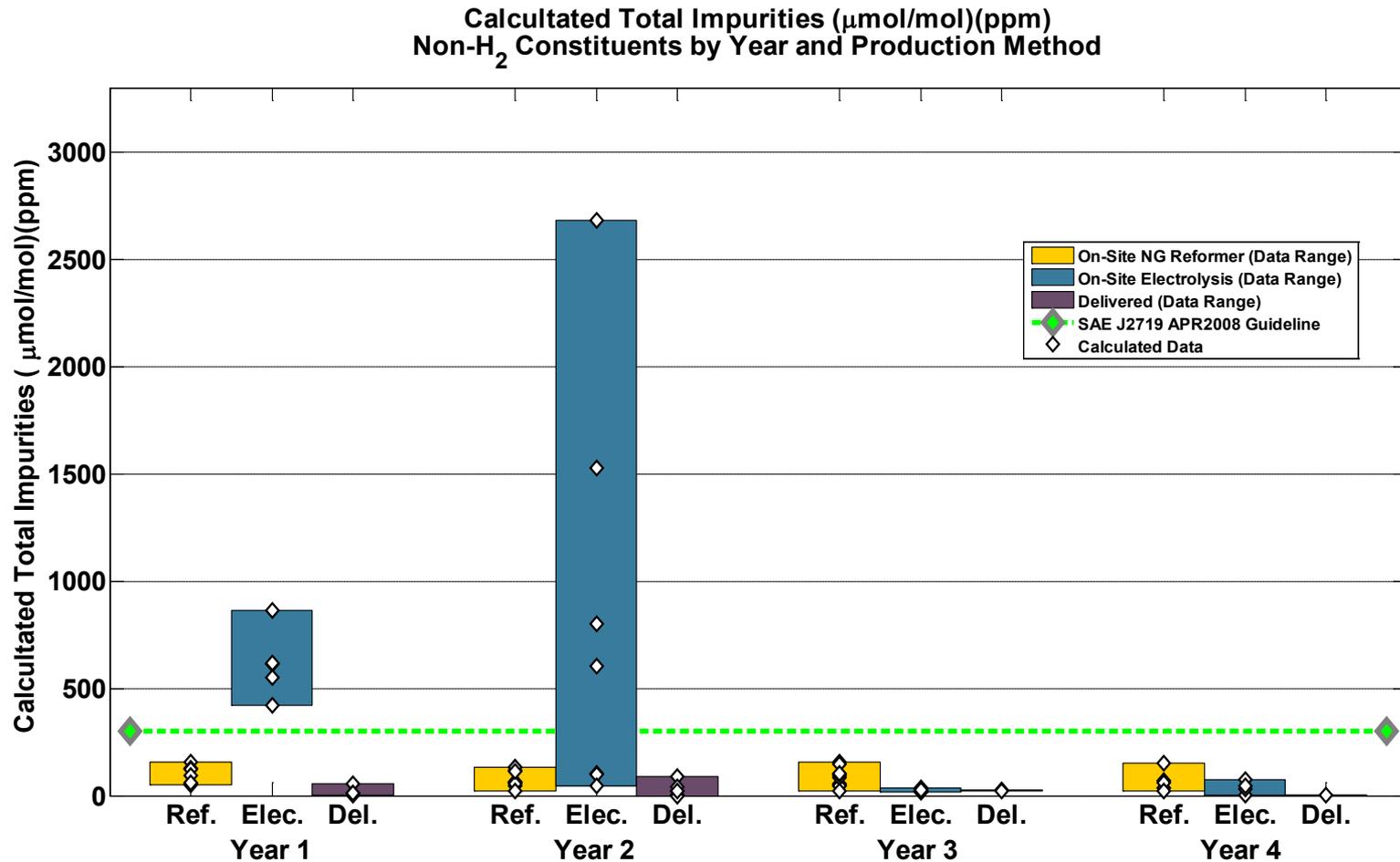
CDP#28 Supplemental: Hydrogen Constituents by Year and Production Method



Data is from Learning Demonstration and California Fuel Cell Partnership testing
Year 1 is 2005Q3-2006Q2, Year 2 is 2006Q3-2007Q2, Year 3 is 2007Q3-2008Q2, and Year 4 is 2008Q3-2008Q4

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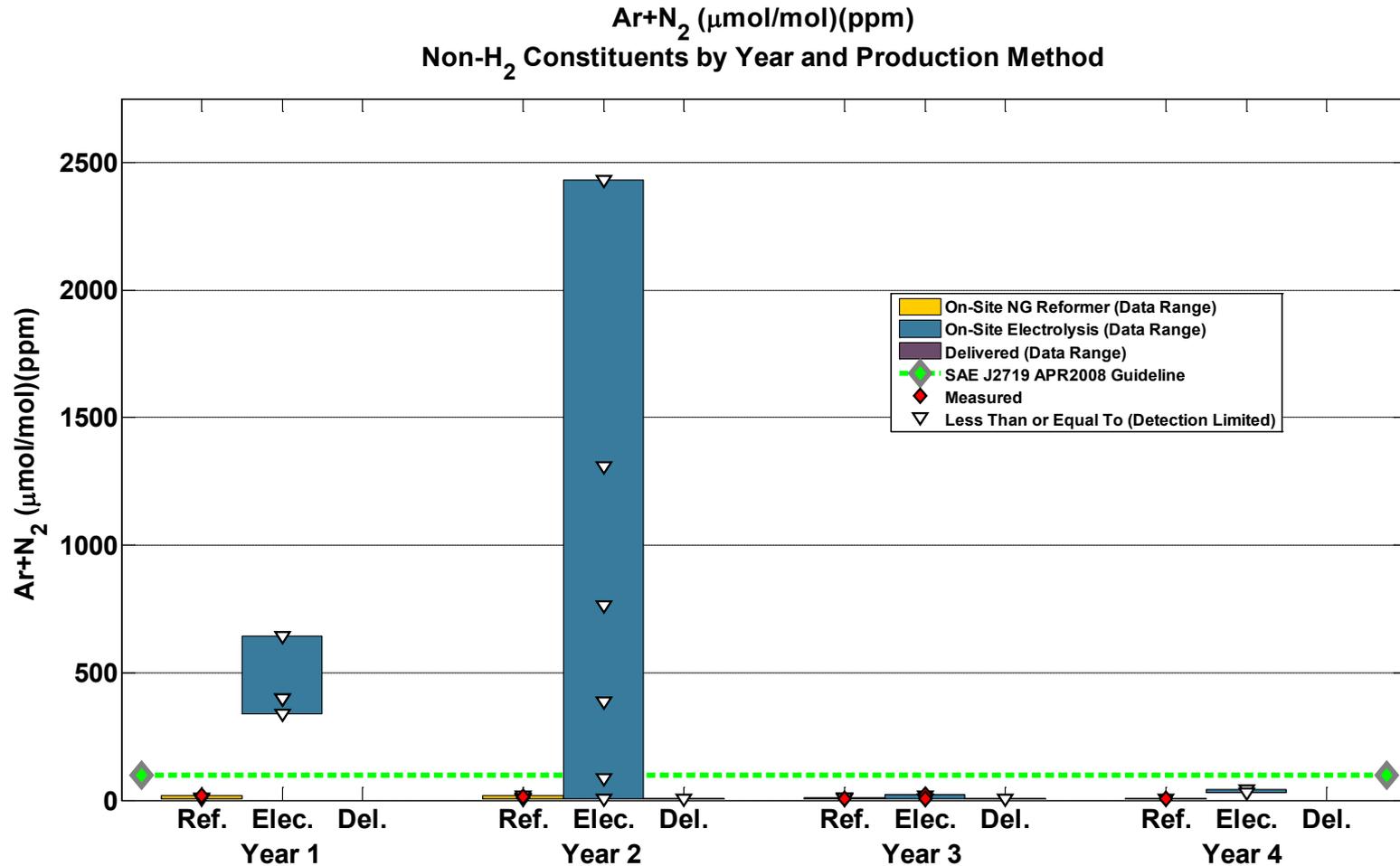
CDP#28 Supplemental: Hydrogen Constituents by Year and Production Method



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Year 1 is 2005Q3-2006Q2, Year 2 is 2006Q3-2007Q2, Year 3 is 2007Q3-2008Q2, and Year 4 is 2008Q3-2008Q4

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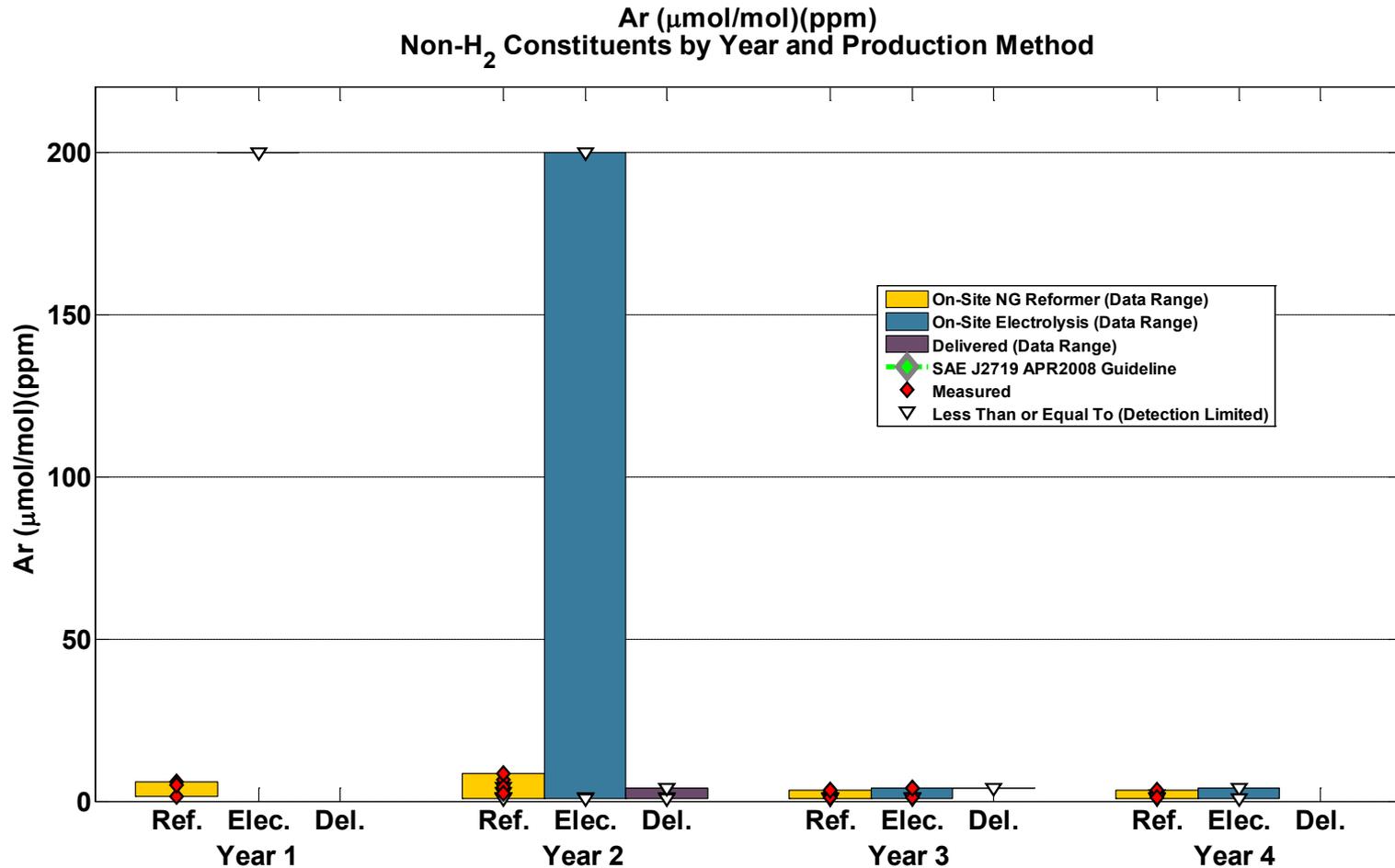
CDP#28 Supplemental: Hydrogen Constituents by Year and Production Method



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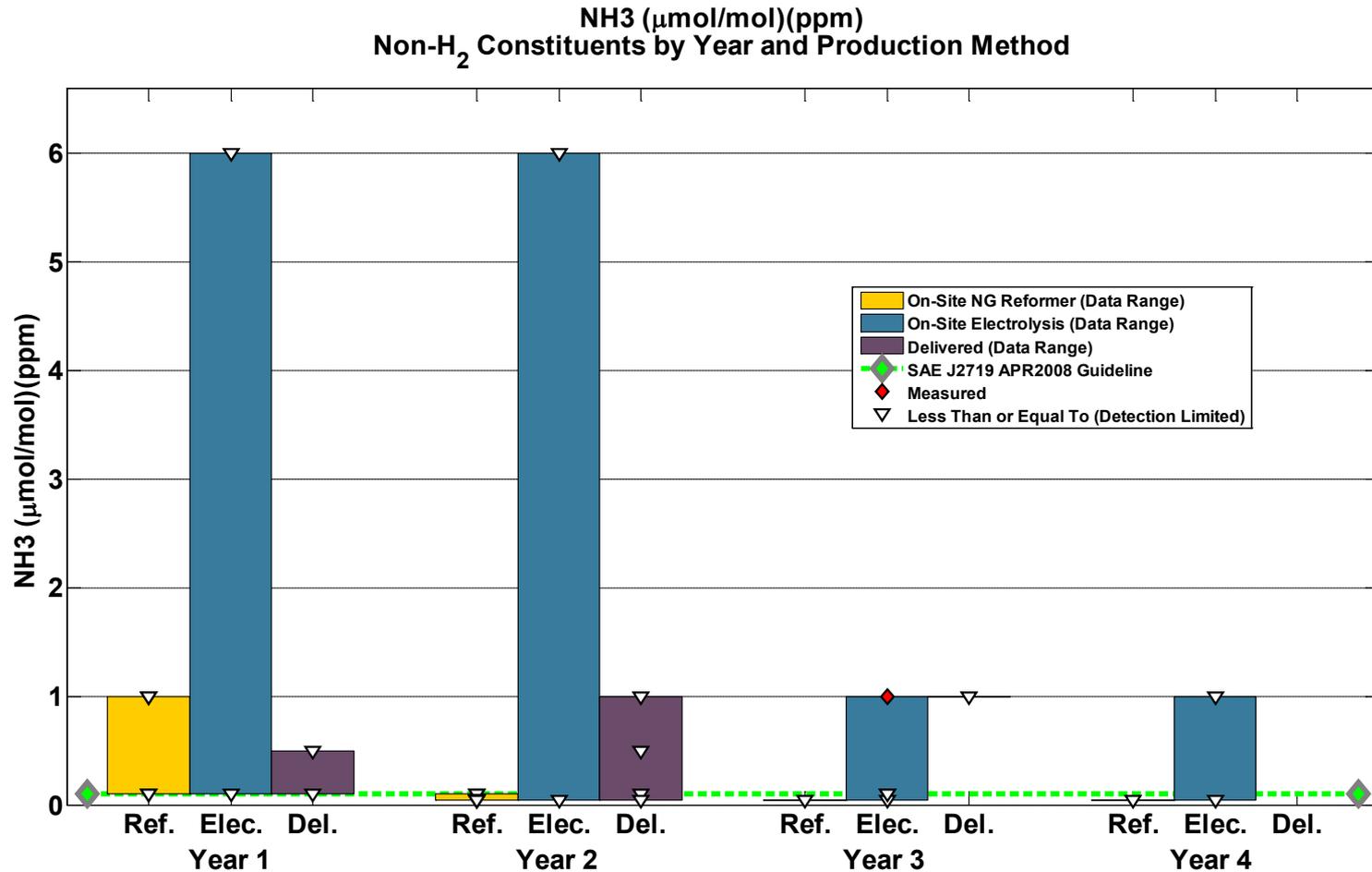
CDP#28 Supplemental: Hydrogen Constituents by Year and Production Method



Data is from Learning Demonstration and California Fuel Cell Partnership testing
 Year 1 is 2005Q3-2006Q2, Year 2 is 2006Q3-2007Q2, Year 3 is 2007Q3-2008Q2, and Year 4 is 2008Q3-2008Q4

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CDP#28 Supplemental: Hydrogen Constituents by Year and Production Method

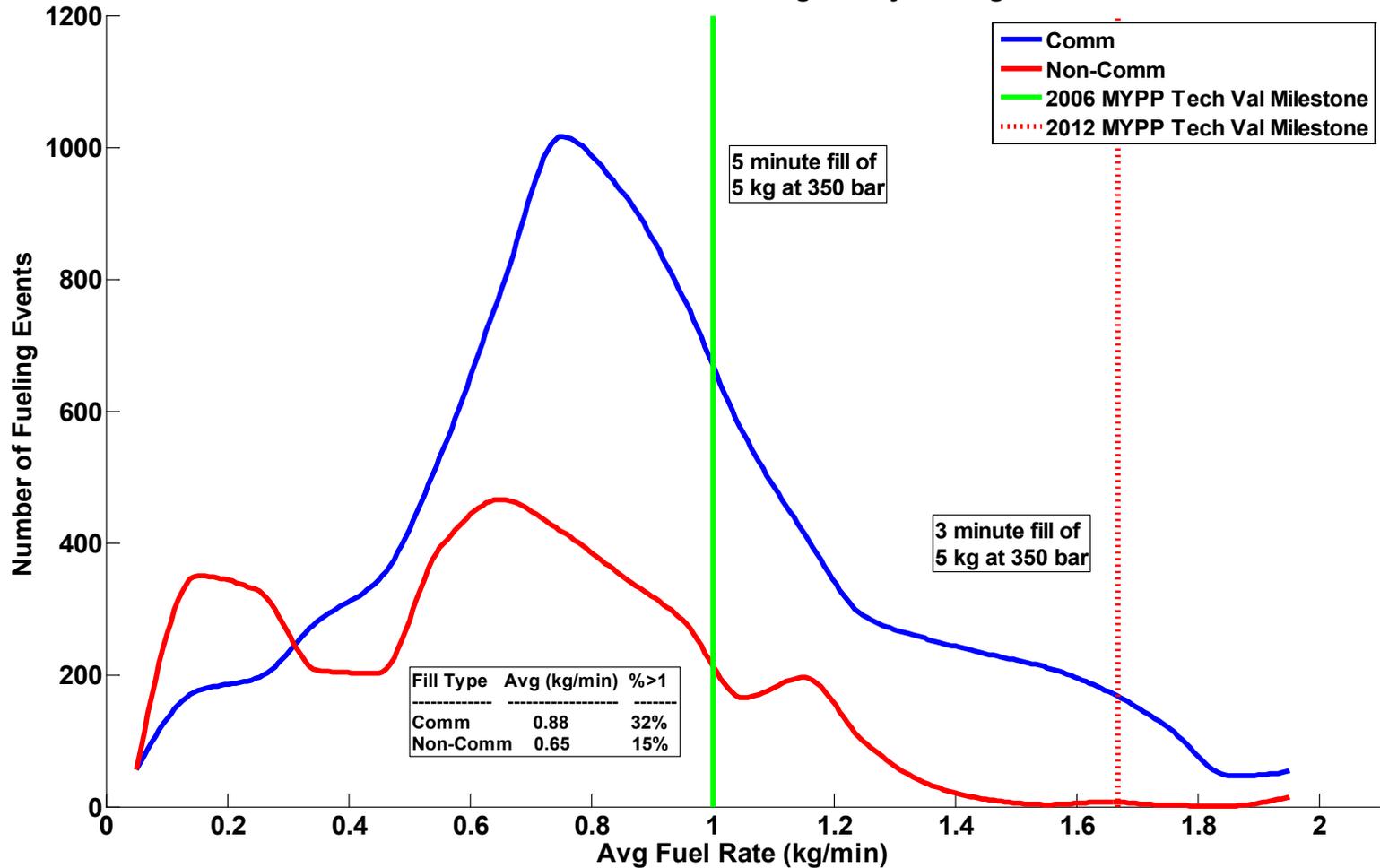


Data is from Learning Demonstration and California Fuel Cell Partnership testing
 Year 1 is 2005Q3-2006Q2, Year 2 is 2006Q3-2007Q2, Year 3 is 2007Q3-2008Q2, and Year 4 is 2008Q3-2008Q4

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

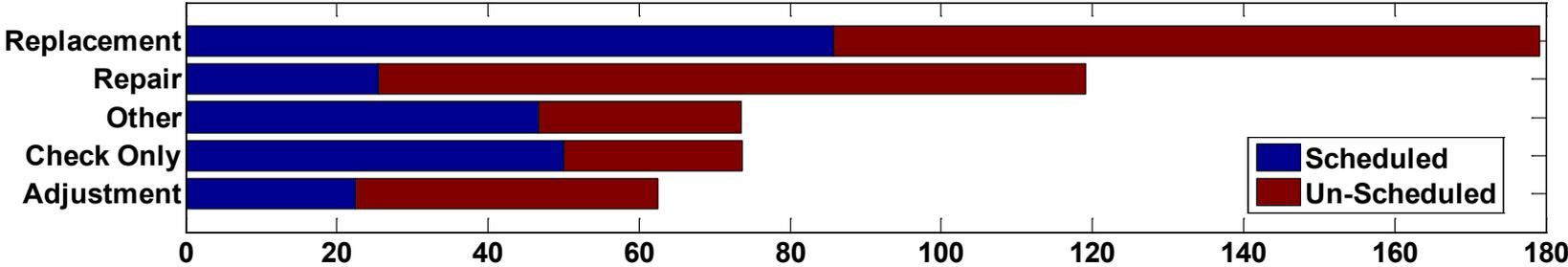
Histogram of Fueling Rates
Comm vs Non-Comm Fills - All Light Duty Through 2008Q4



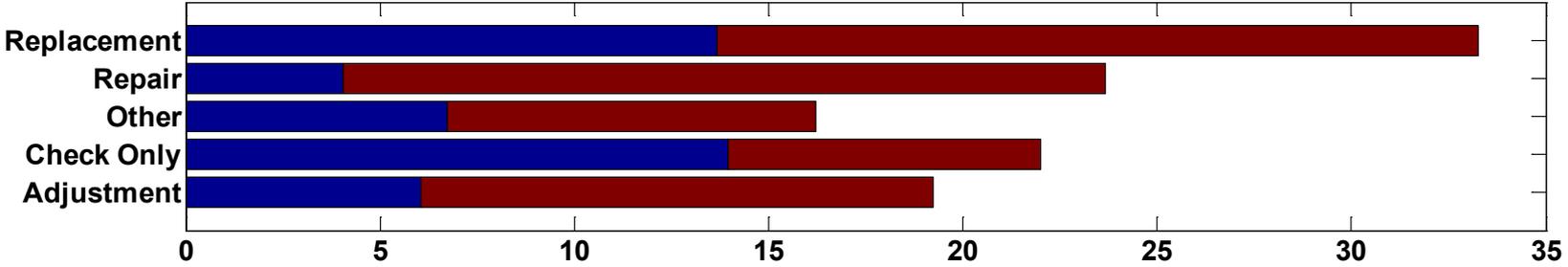
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CDP#30: Infrastructure Maintenance

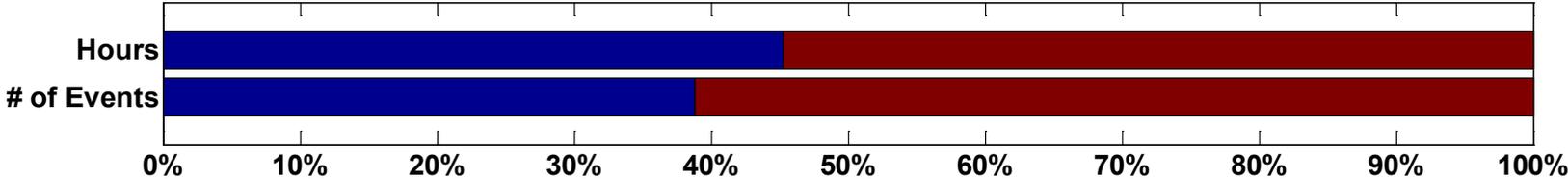
Maintenance: Average Labor Hours Per Station Since Inception Through 2008 Q4



Maintenance: Average Number of Events Per Station Since Inception

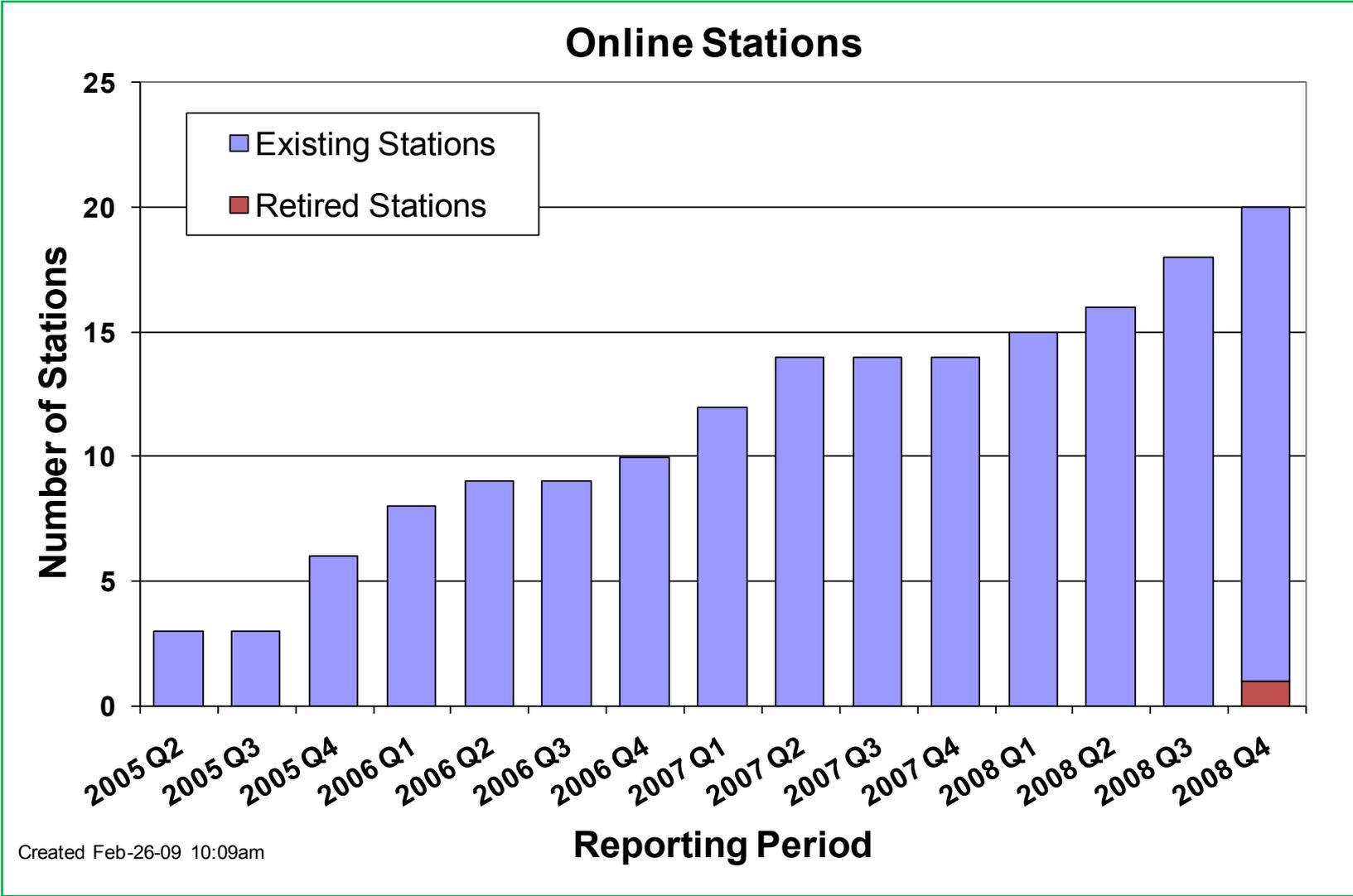


Comparison of Scheduled/Un-Scheduled Maintenance

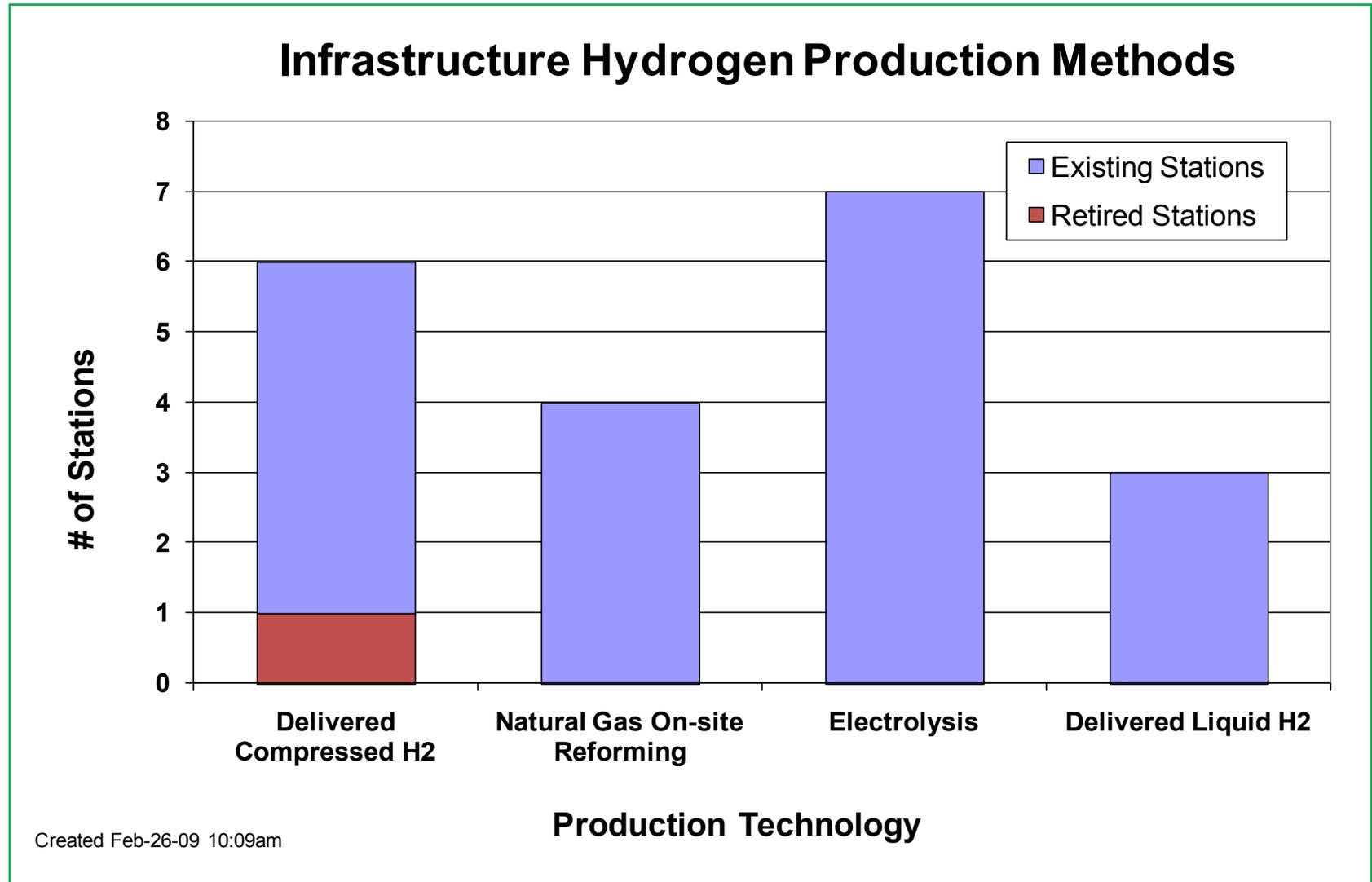


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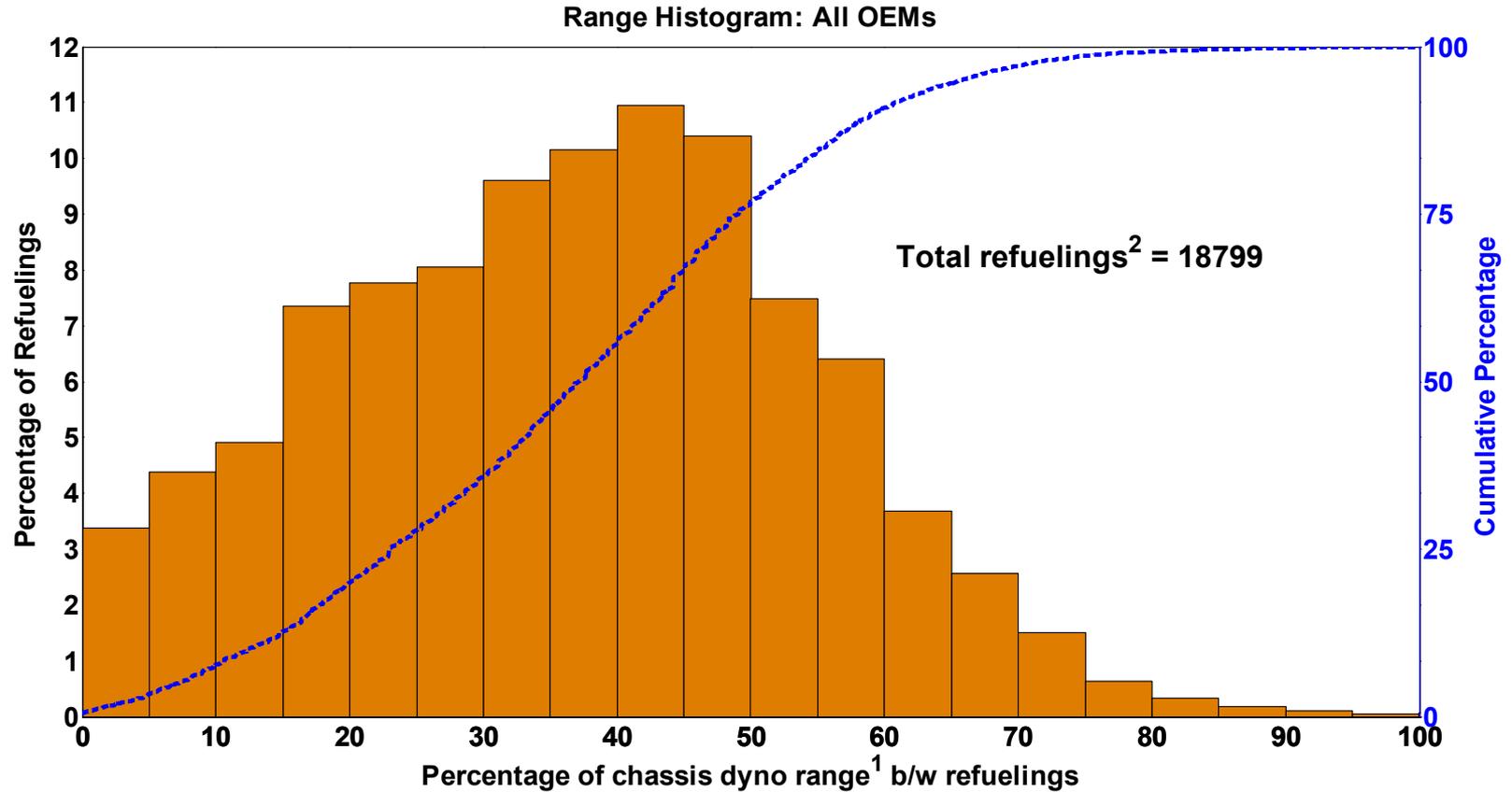
CDP#31: Number of Online Stations



CDP#32: Infrastructure Hydrogen Production Methods



CDP#33: Percentage of Theoretical Range Traveled Between Refuelings

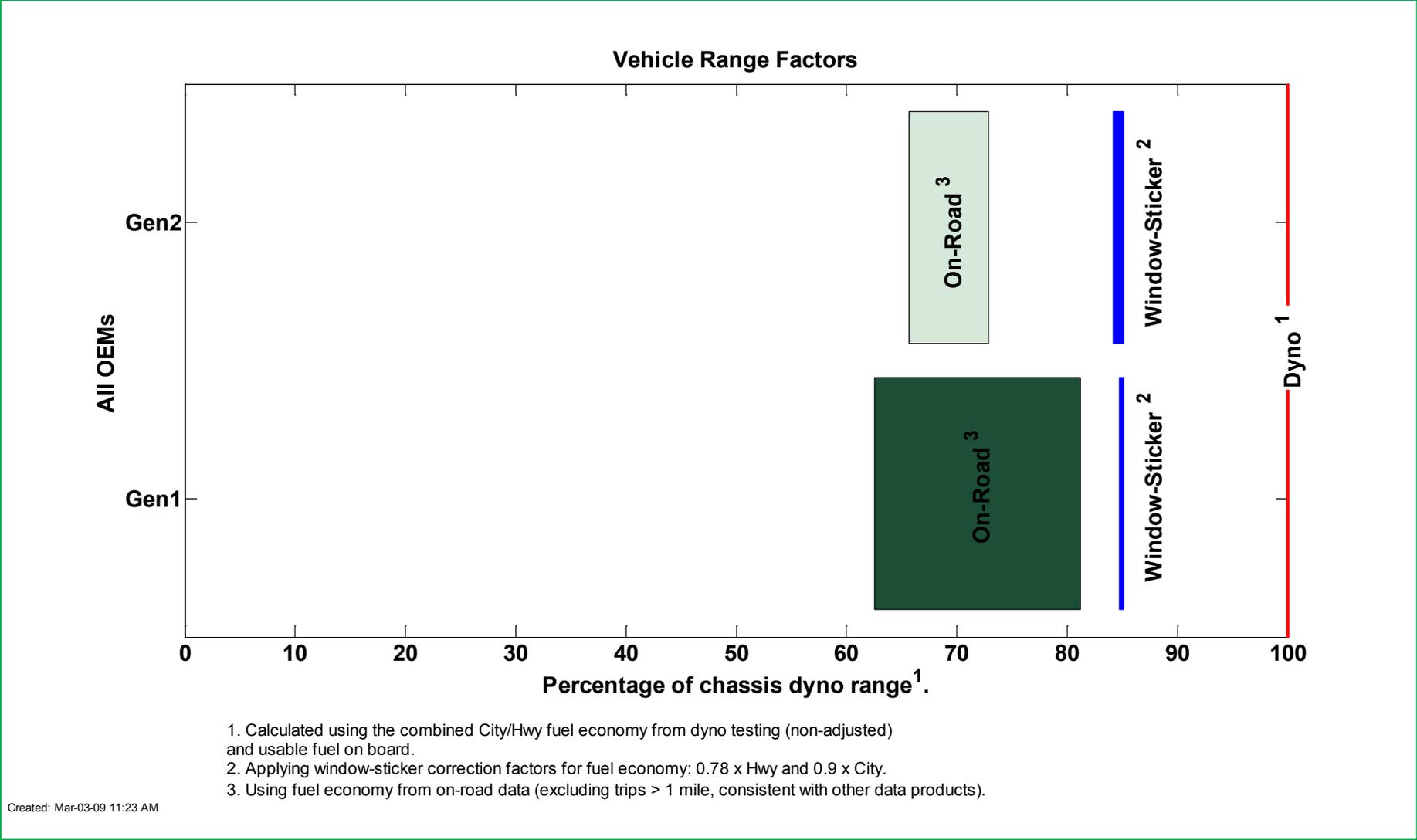


1. Range calculated using the combined City/Hwy fuel economy from dyno testing (not EPA adjusted) and usable fuel on board.

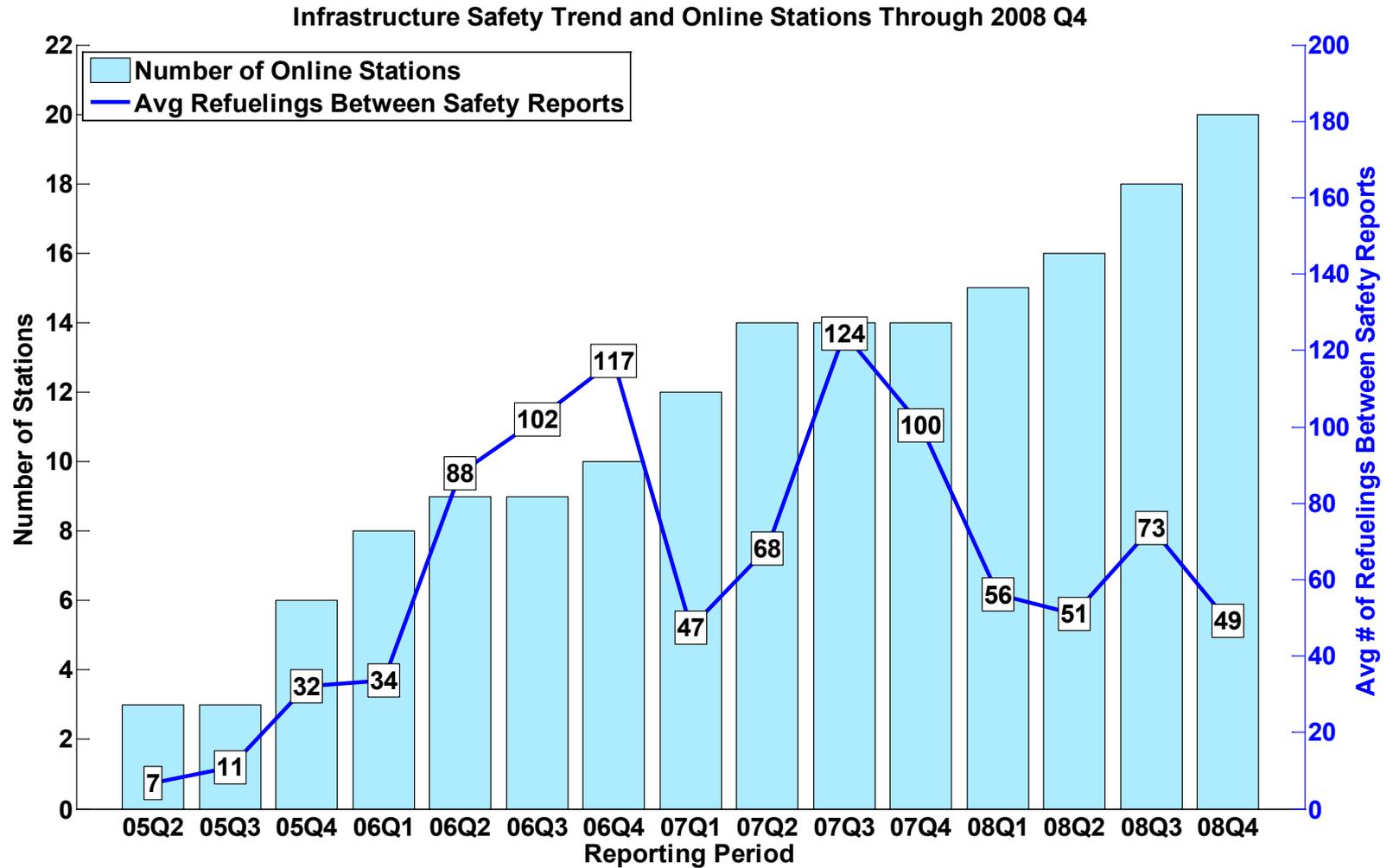
2. Some refueling events are not detected/reported due to data noise or incompleteness.

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CDP#34: Effective Vehicle Range

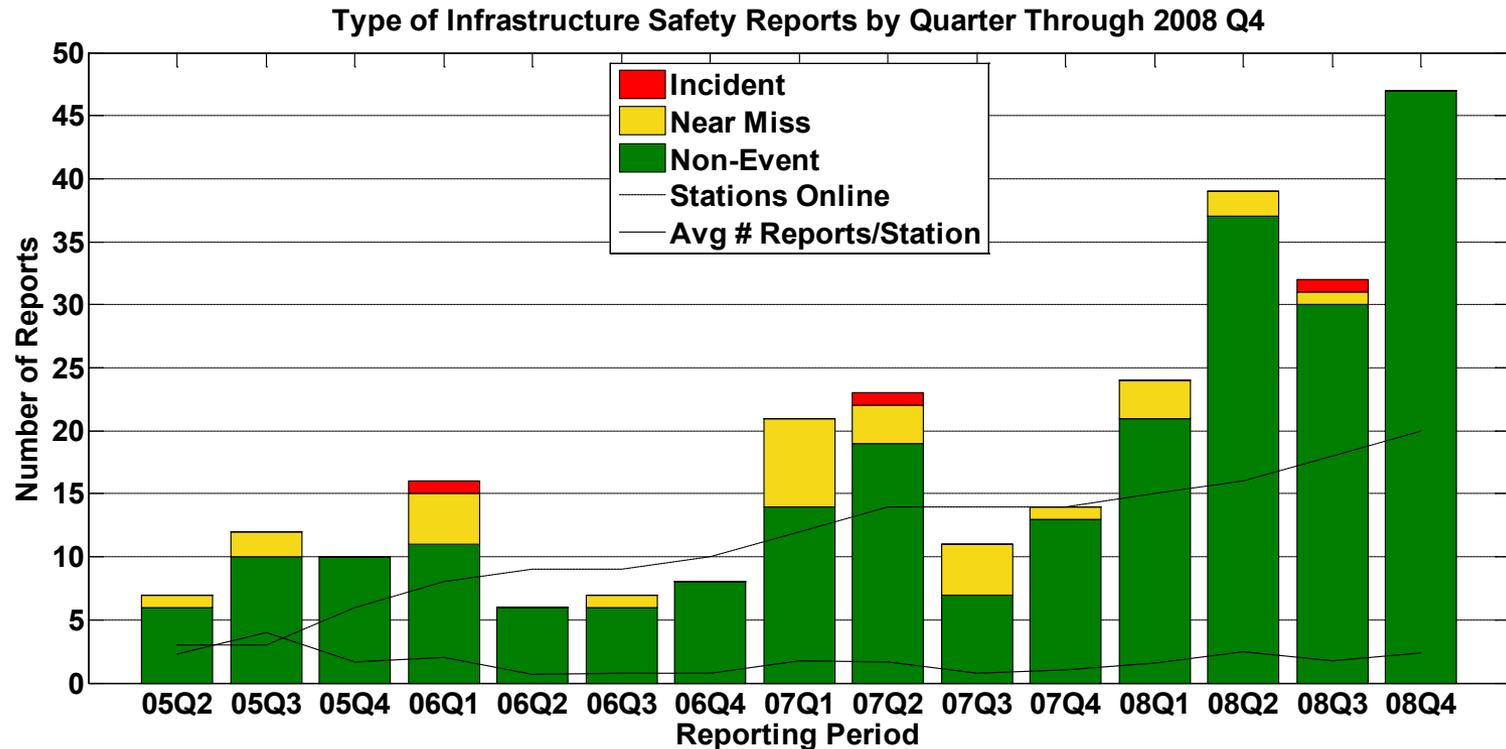


CDP#35: Average Refuelings Between Infrastructure Safety Reports



Created: Feb-27-09 8:18 AM

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)

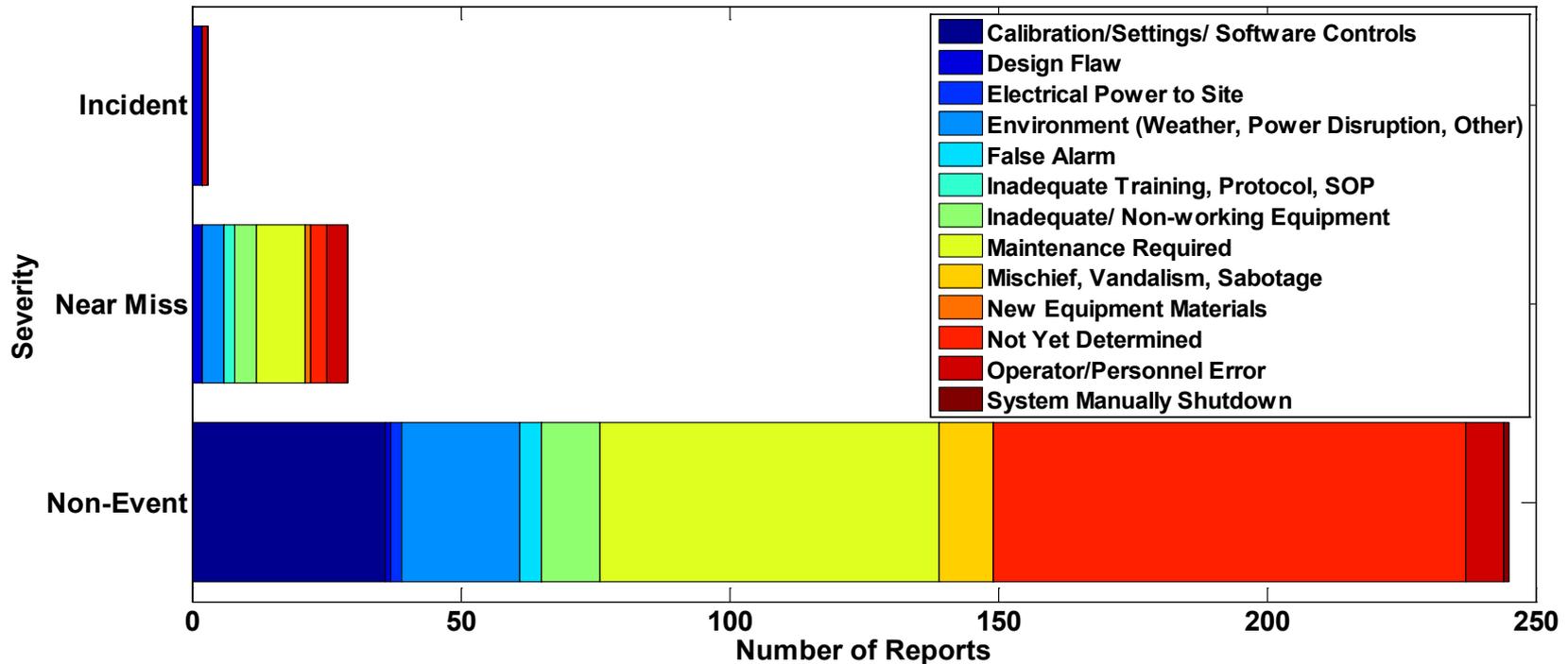
A NEAR-MISS is:

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

Created: Feb-27-09 8:18 AM

CDP#37: Primary Factors of Infrastructure Safety Reports

Primary Factors of Infrastructure Safety Reports
Through 2008 Q4



An INCIDENT is an event that results in:

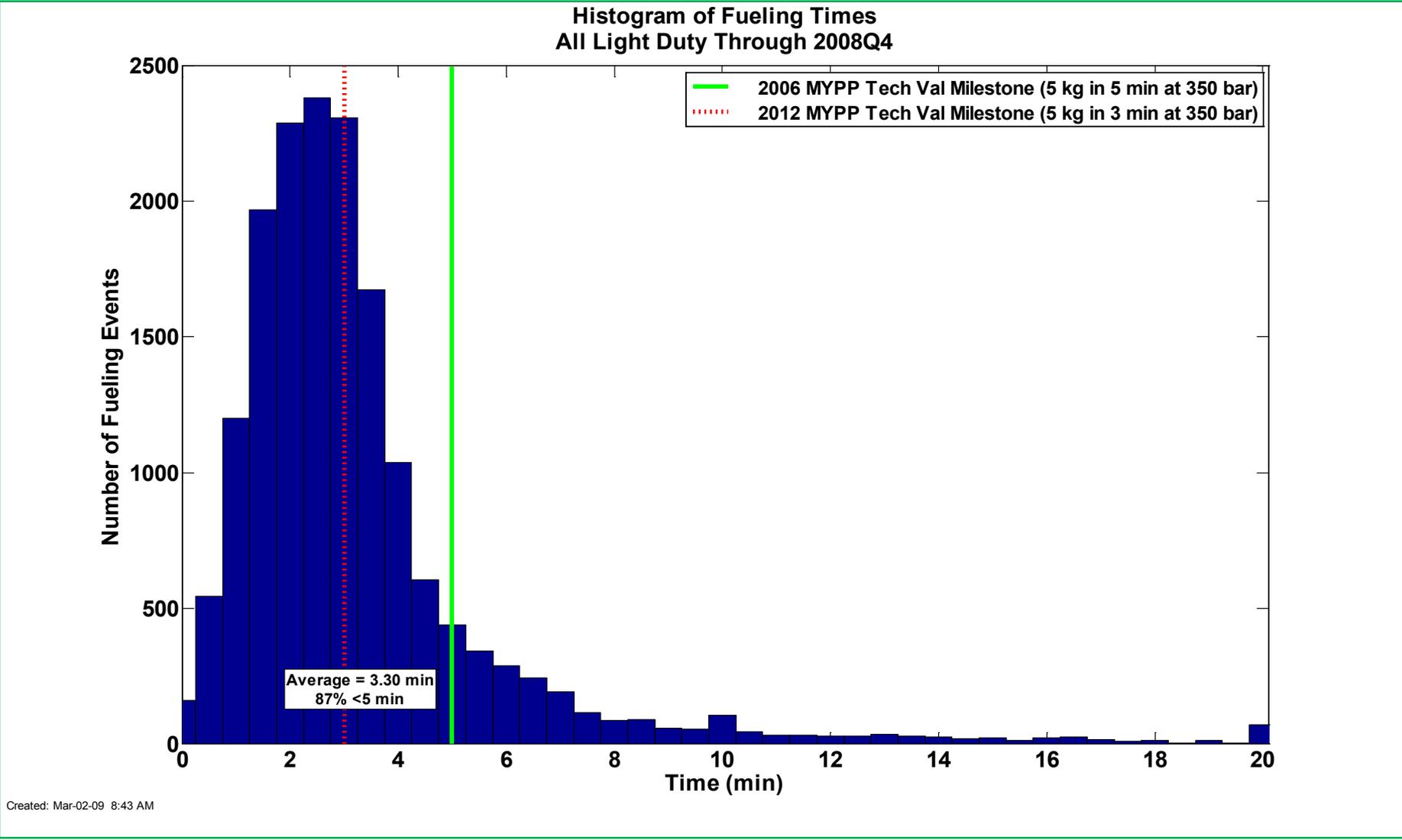
- a lost time accident and/or injury to personnel
- damage/unplanned downtime for project equipment, facilities or property
- impact to the public or environment
- any hydrogen release that unintentionally ignites or is sufficient to sustain a flame if ignited
- release of any volatile, hydrogen containing 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

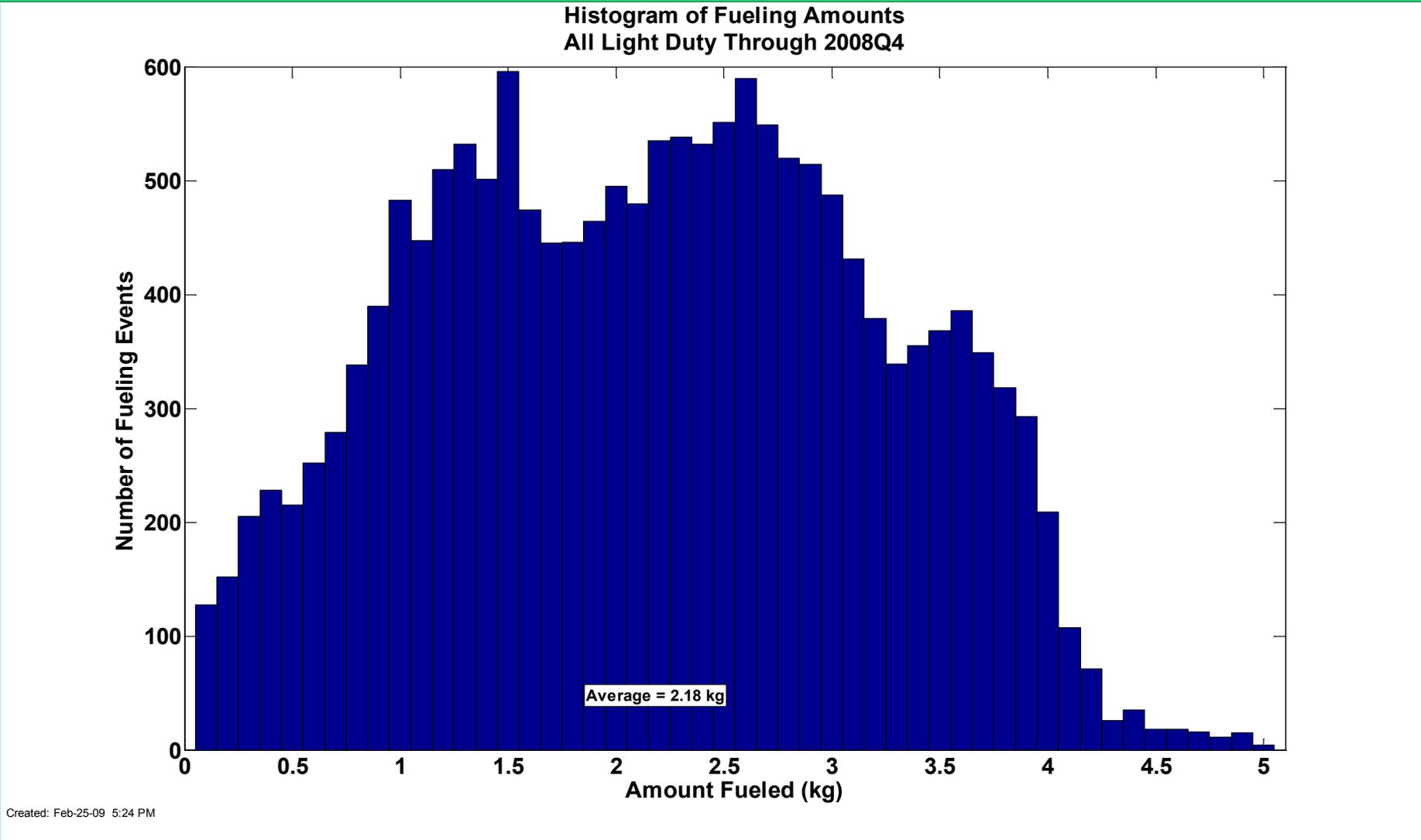
Created: Feb-27-09 8:16 AM

CDP#38: Refueling Times



Created: Mar-02-09 8:43 AM

CDP#39: Refueling Amounts



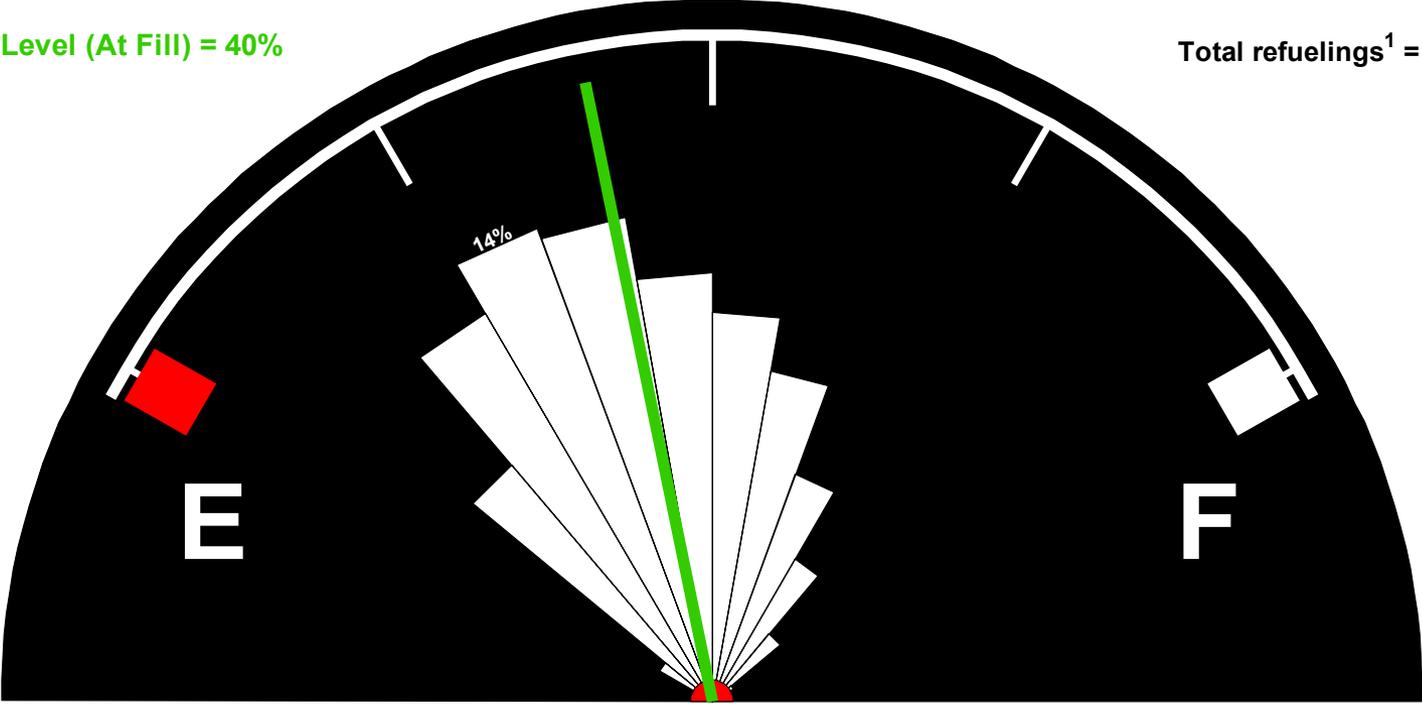
Created: Feb-25-09 5:24 PM

CDP#40: H2 Tank Level at Refueling

Tank Levels: DOE Fleet

Median Tank Level (At Fill) = 40%

Total refuelings¹ = 20639



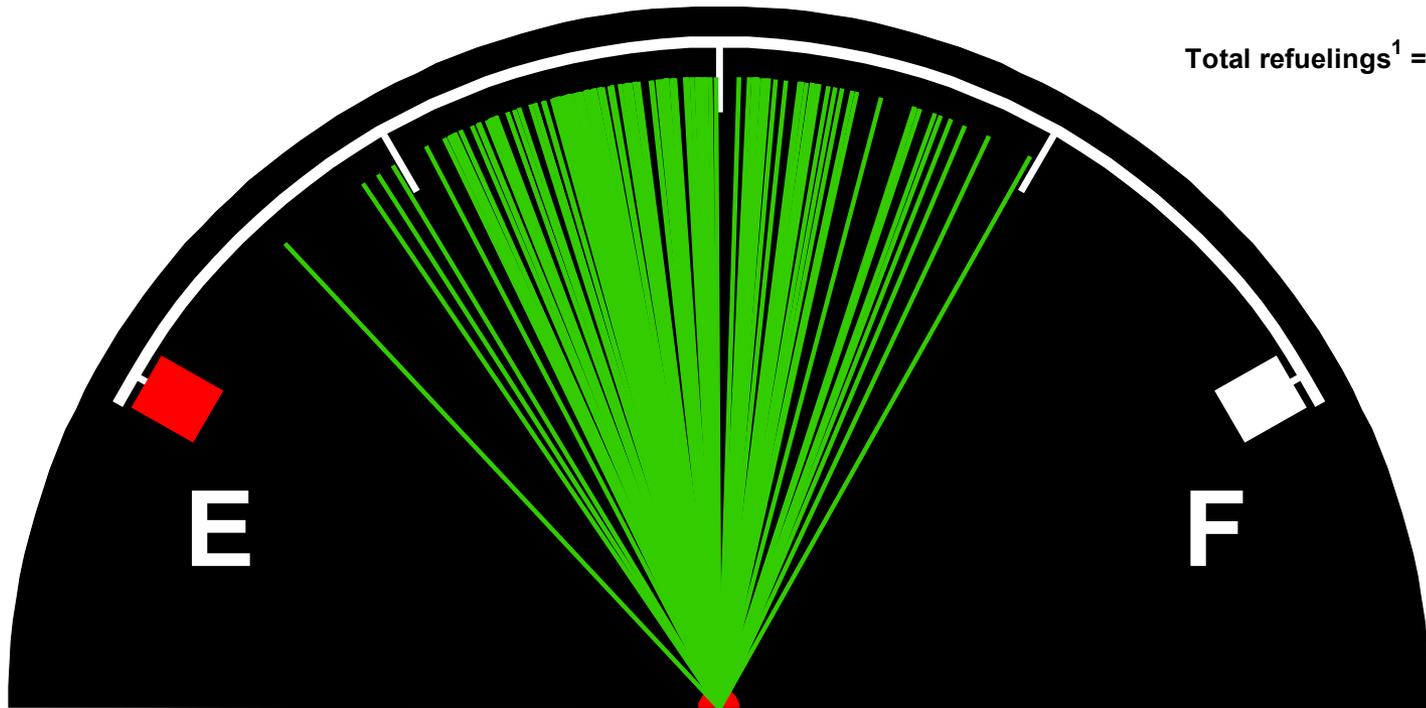
1. Some refueling events not recorded/detected due to data noise or incompleteness.
2. The outer arc is set at 20% total refuelings.
3. If tank level at fill was not available, a complete fill up was assumed.

Created: Feb-20-09 12:37 PM

CDP#41: Refueling Tank Levels - Medians

Tank Level Medians (At Fill): DOE Fleet, All Vehicles

Total refuelings¹ = 20639



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.

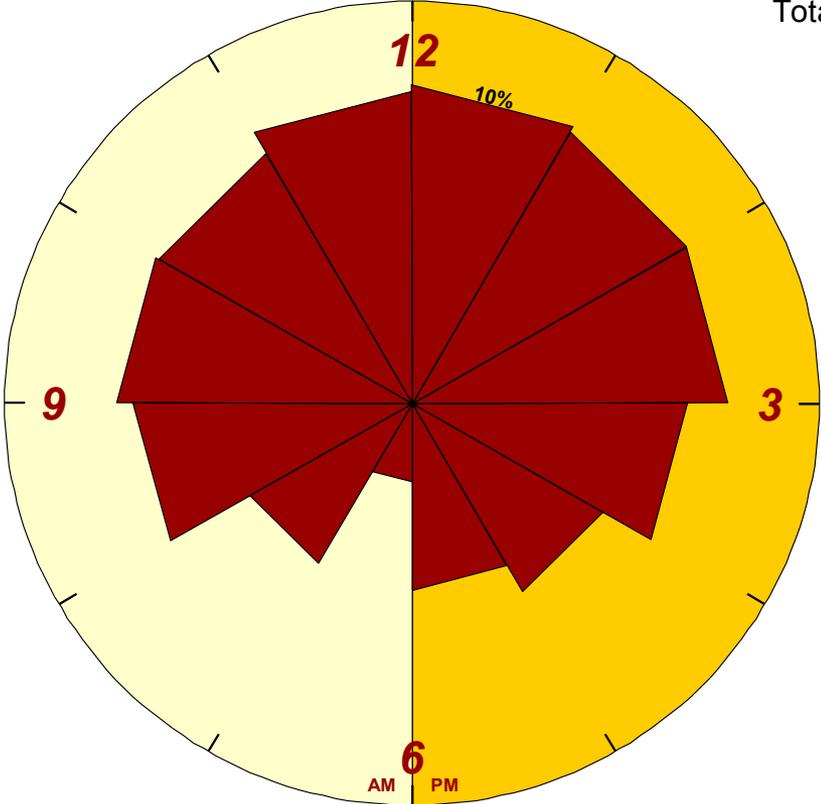
Created: Feb-20-09 12:37 PM

CDP#42: Refueling by Time of Day

Refueling by Time of Day: DOE Fleet

% of fills b/t 6 AM & 6 PM: 91.1%

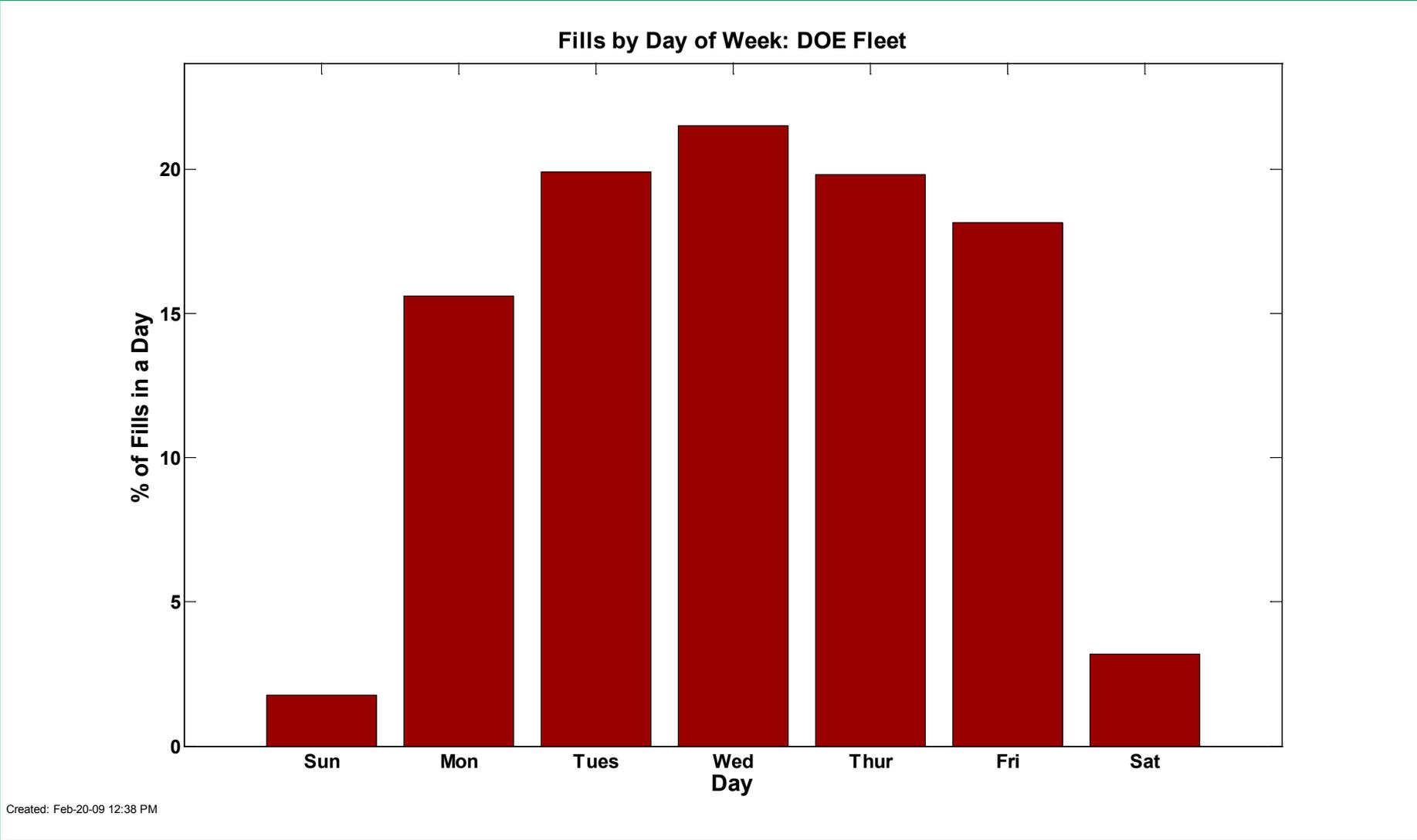
Total Fill³ Events = 17237



- 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-20-09 12:37 PM

CDP#43: Refueling by Day of Week

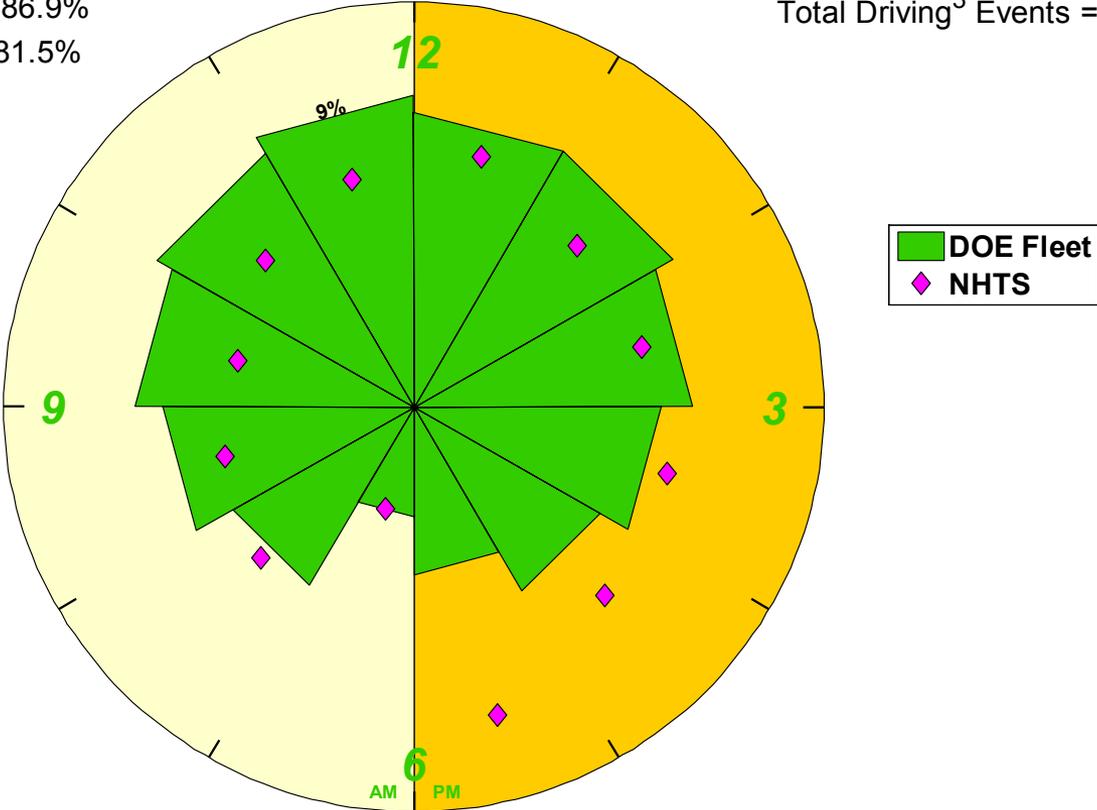


CDP#44: Driving Start Time – Day

Driving Start Time - Day: DOE Fleet

% of driving trips b/t 6 AM & 6 PM: 86.9%
 % of NHTS trips b/t 6 AM & 6 PM: 81.5%

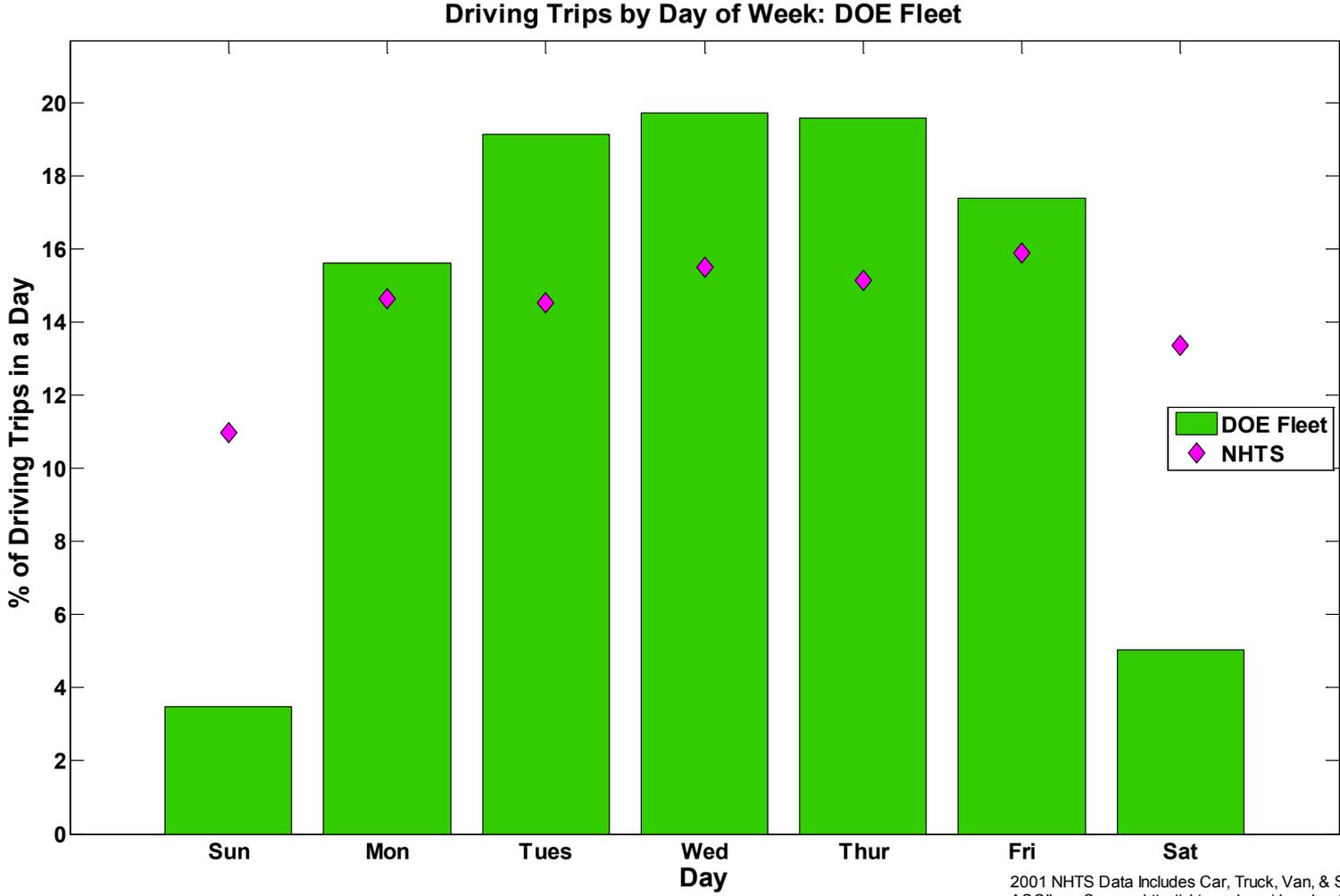
Total Driving³ Events = 224309



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>

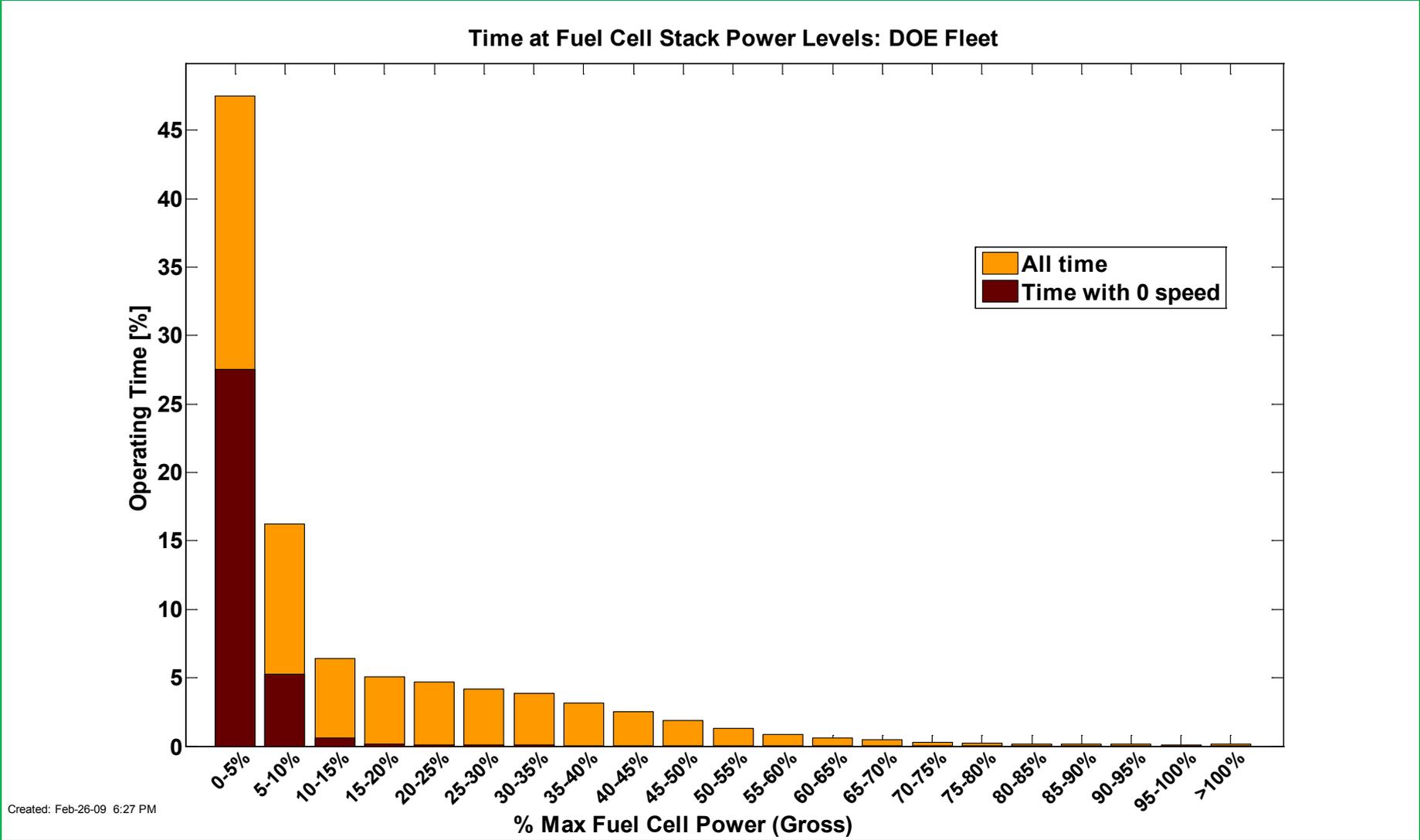
CDP#45: Driving by Day of Week



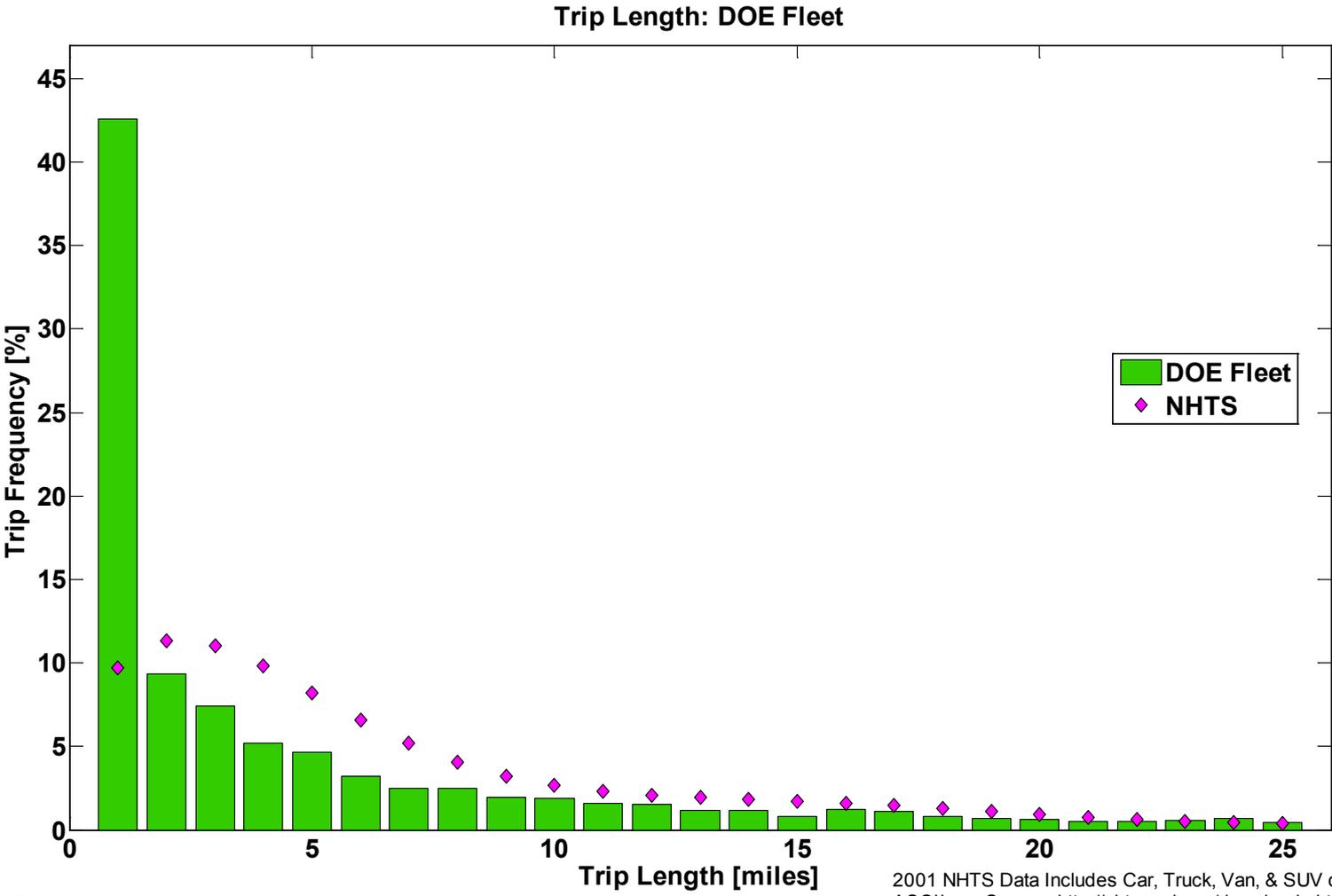
Created: Feb-26-09 6:21 PM

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



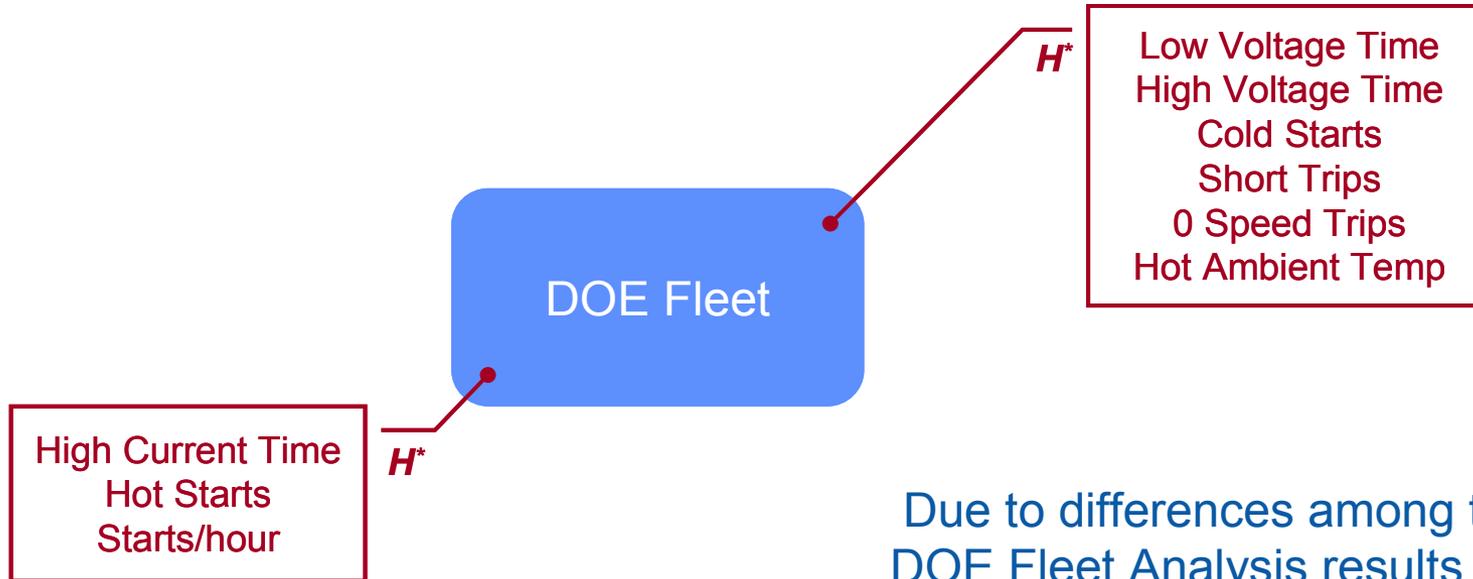
CDP#47: Trip Length



Created: Feb-26-09 6:11 PM

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

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



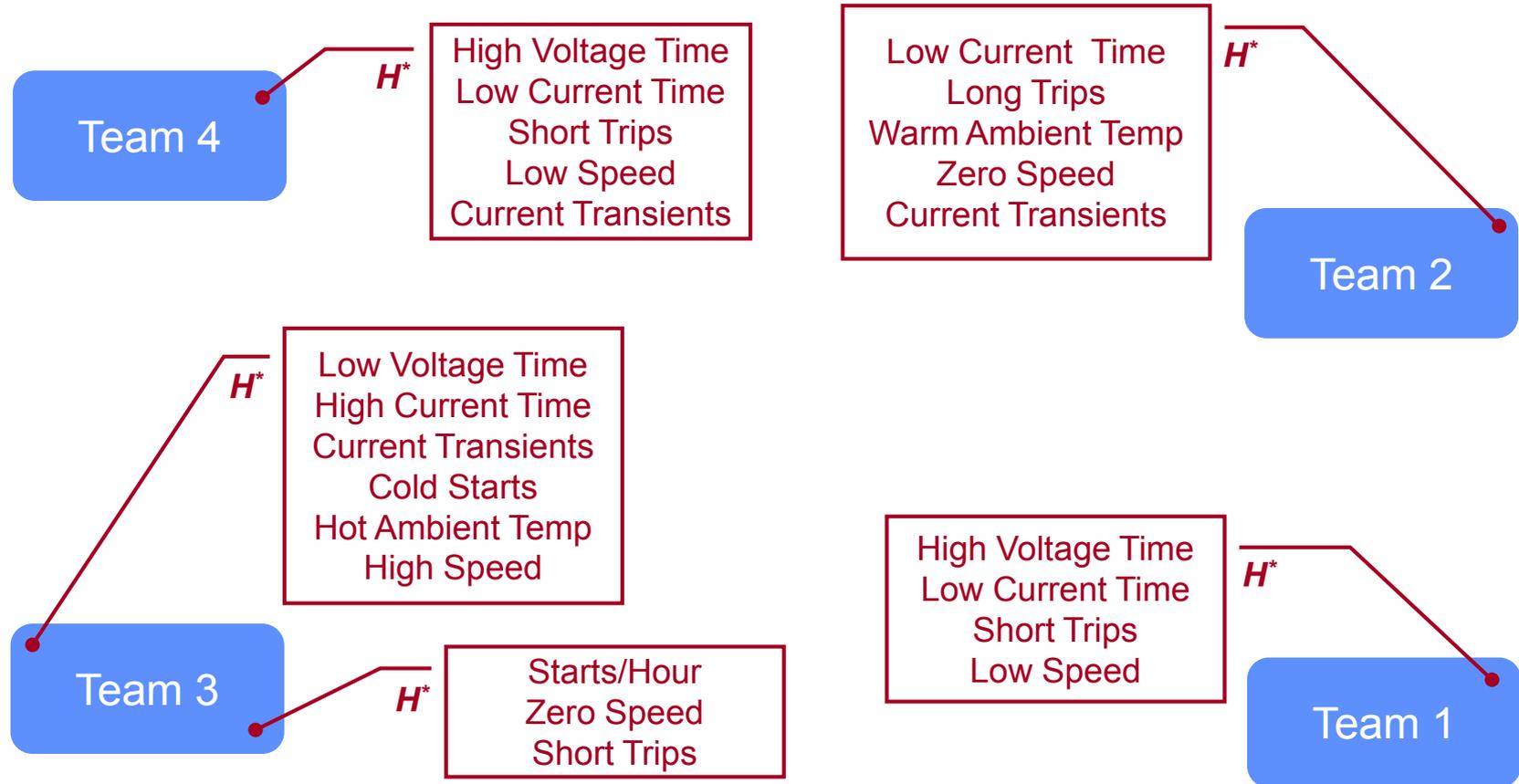
Due to differences among teams, the DOE Fleet Analysis results are spread out and concrete conclusions are difficult to draw.

Individual team analyses (CDP#49) focused on patterns within a fleet.

- 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's Gen 1 fleet.
- 2) Teams' PLS models have a high percentage of explained decay rate variance, but the models are not robust and results are scattered.
- 3) Factor groups associated with stacks that are opposite to the identified groups here are not specified.

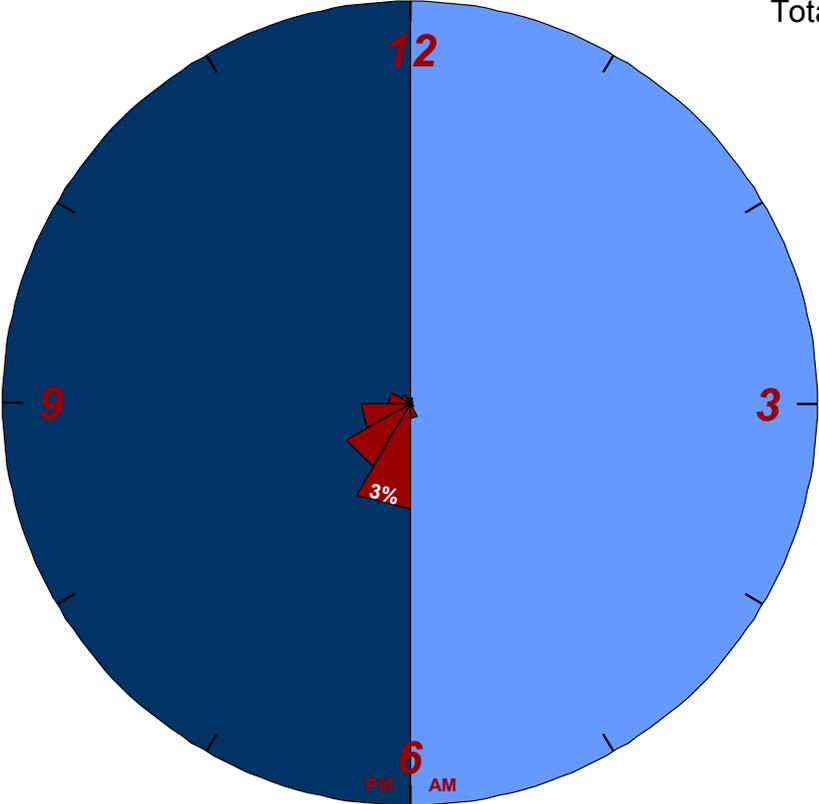
H^* : Factor group associated with high decay rate fuel cell stacks

CDP#50: Refueling by Time of Night

Refueling by Time of Night: DOE Fleet

% of fills b/t 6 PM & 6 AM: 8.9%

Total Fill³ Events = 17237



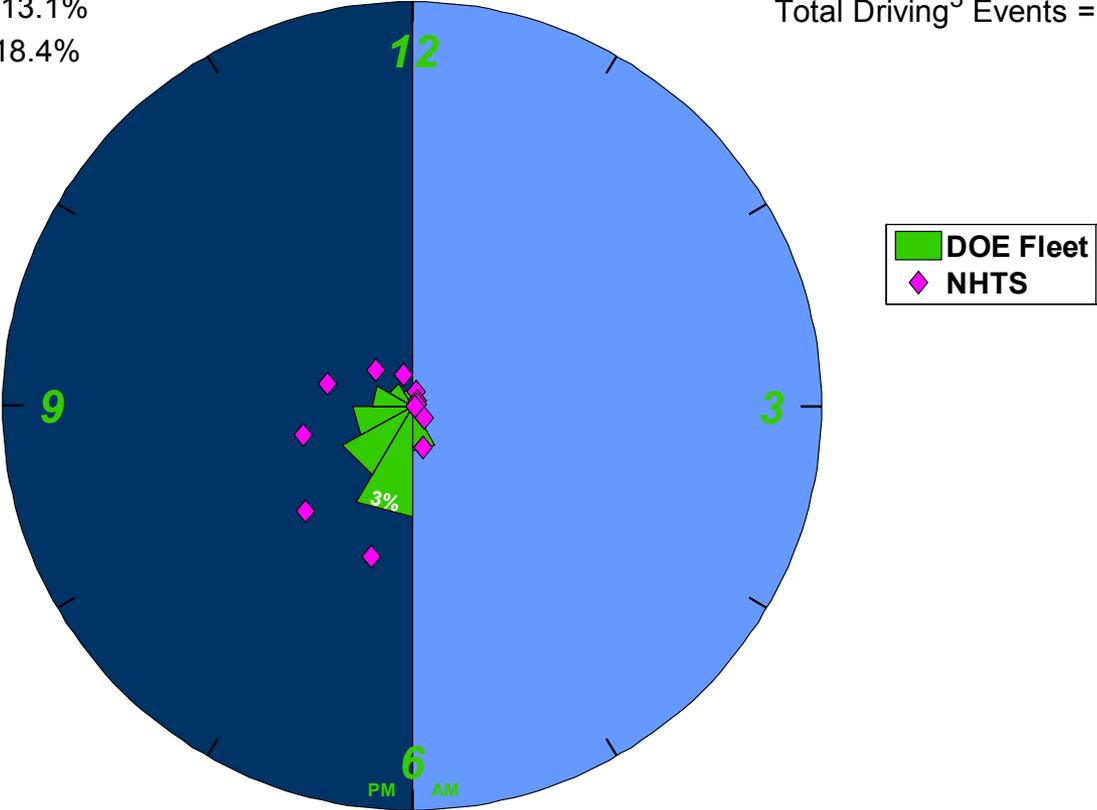
- 1. Fills between 6 PM & 6 AM
- 2. The outer arc is set at 12 % total Fill.
- 3. Some events not recorded/detected due to data noise or incompleteness.

CDP#51: Driving Start Time – Night

Driving Start Time - Night: DOE Fleet

% of driving trips b/t 6 PM & 6 AM: 13.1%
 % of NHTS trips b/t 6 PM & 6 AM: 18.4%

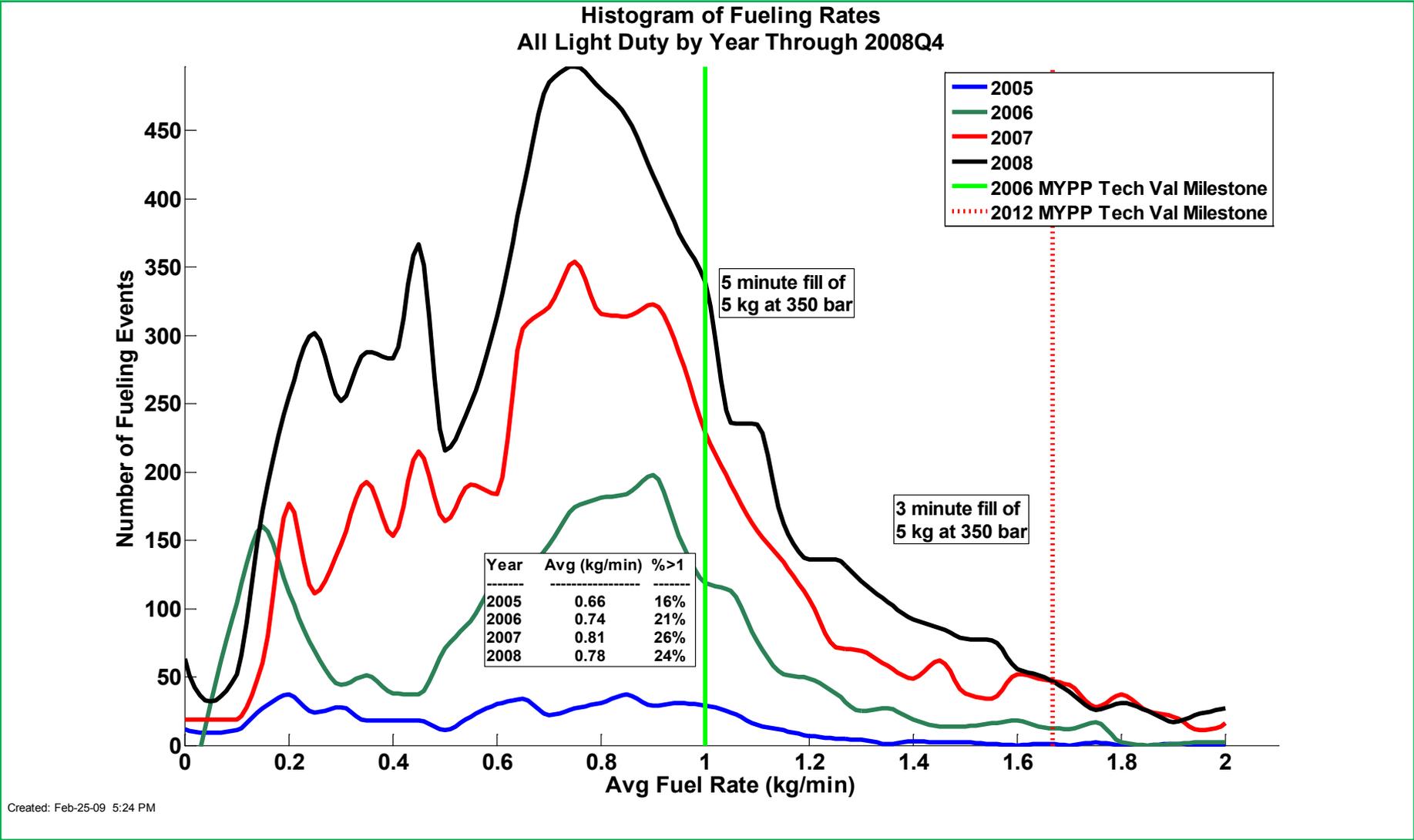
Total Driving³ Events = 224309



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.

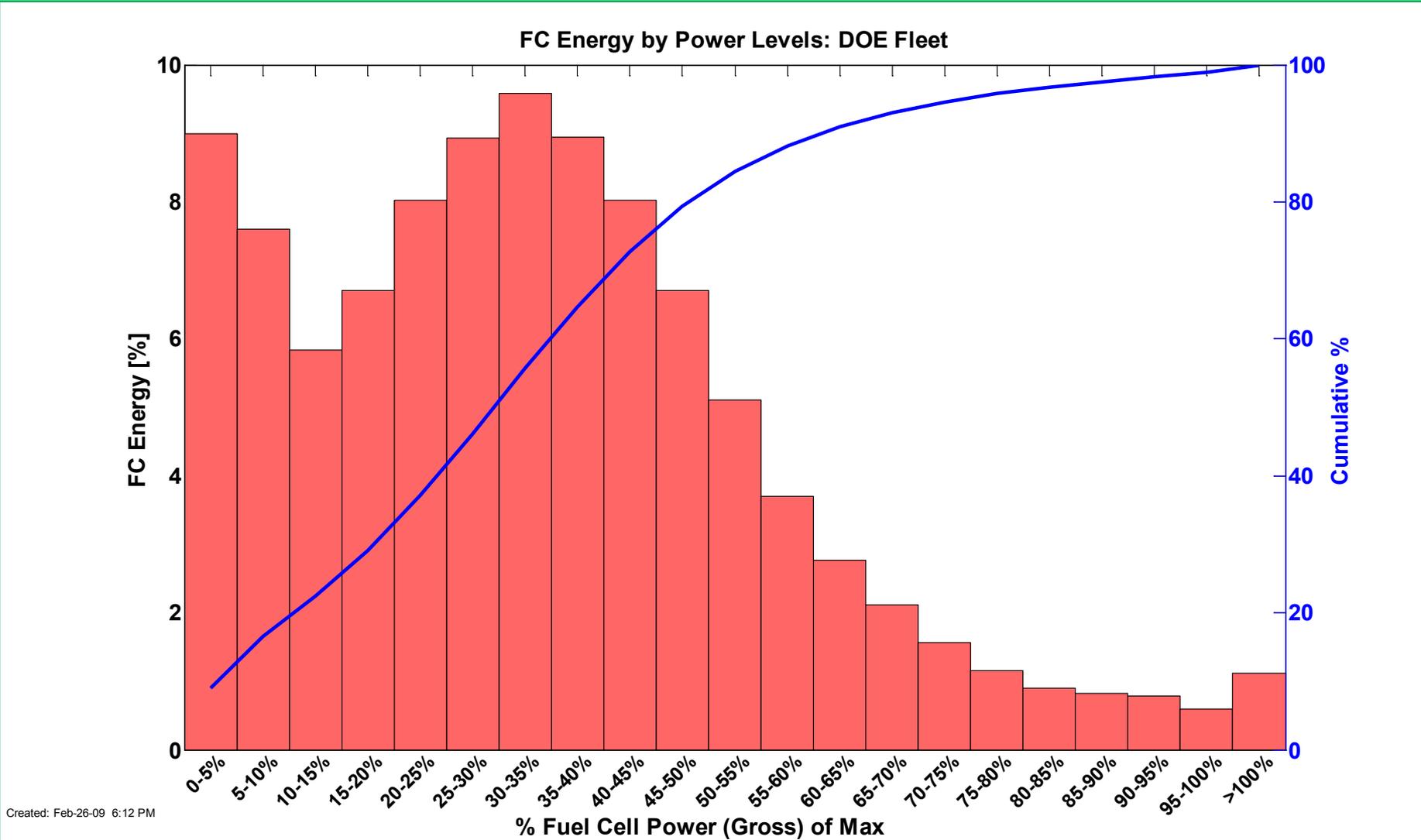
2001 NHTS Data Includes Car, Truck, Van, & SUV day trips
 ASCII.csv Source: <http://nhts.ornl.gov/download.shtml#2001>

CDP#52: Refueling Data by Year



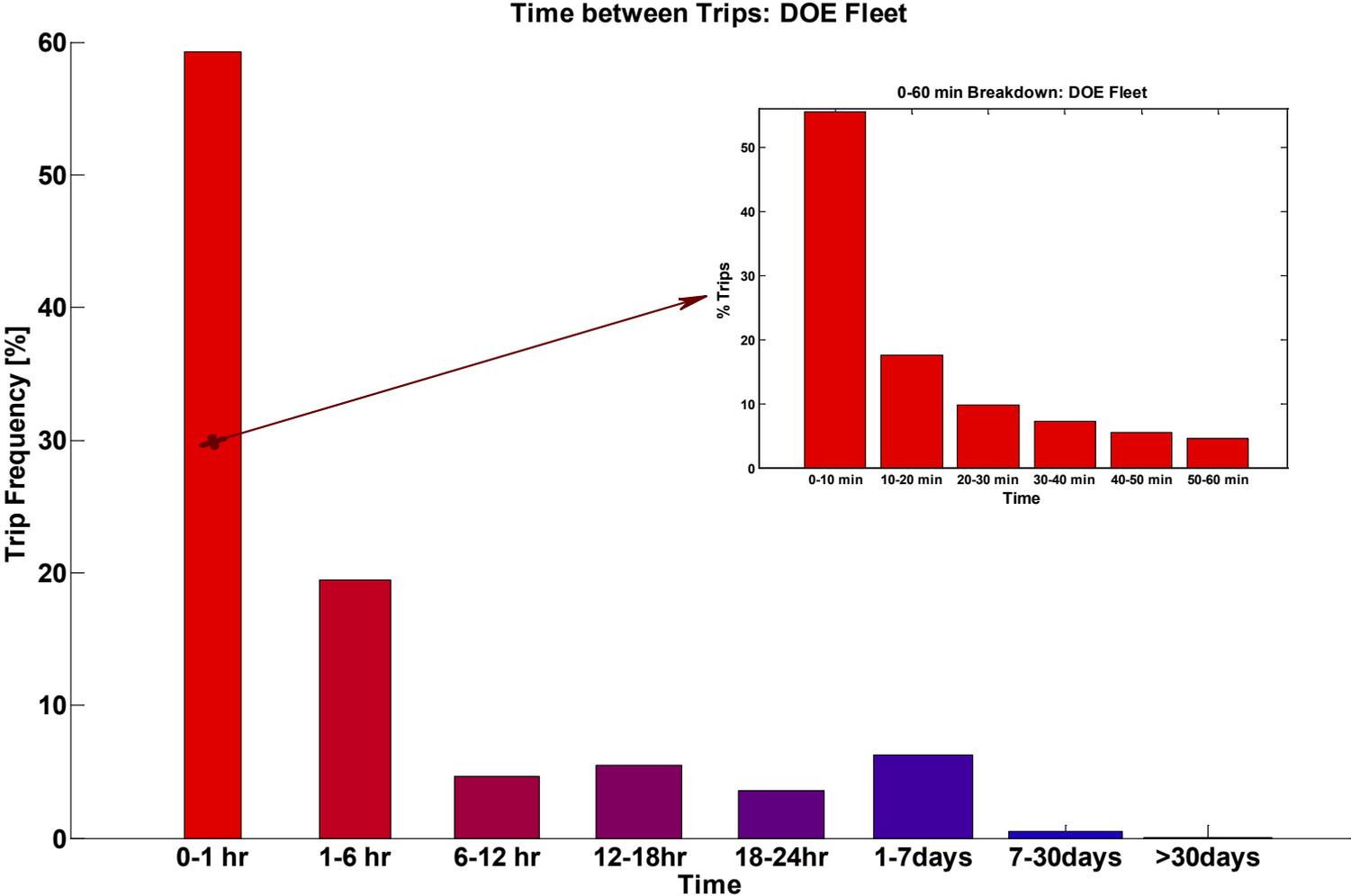
Created: Feb-25-09 5:24 PM

CDP#53: Fuel Cell System Energy within Power Levels



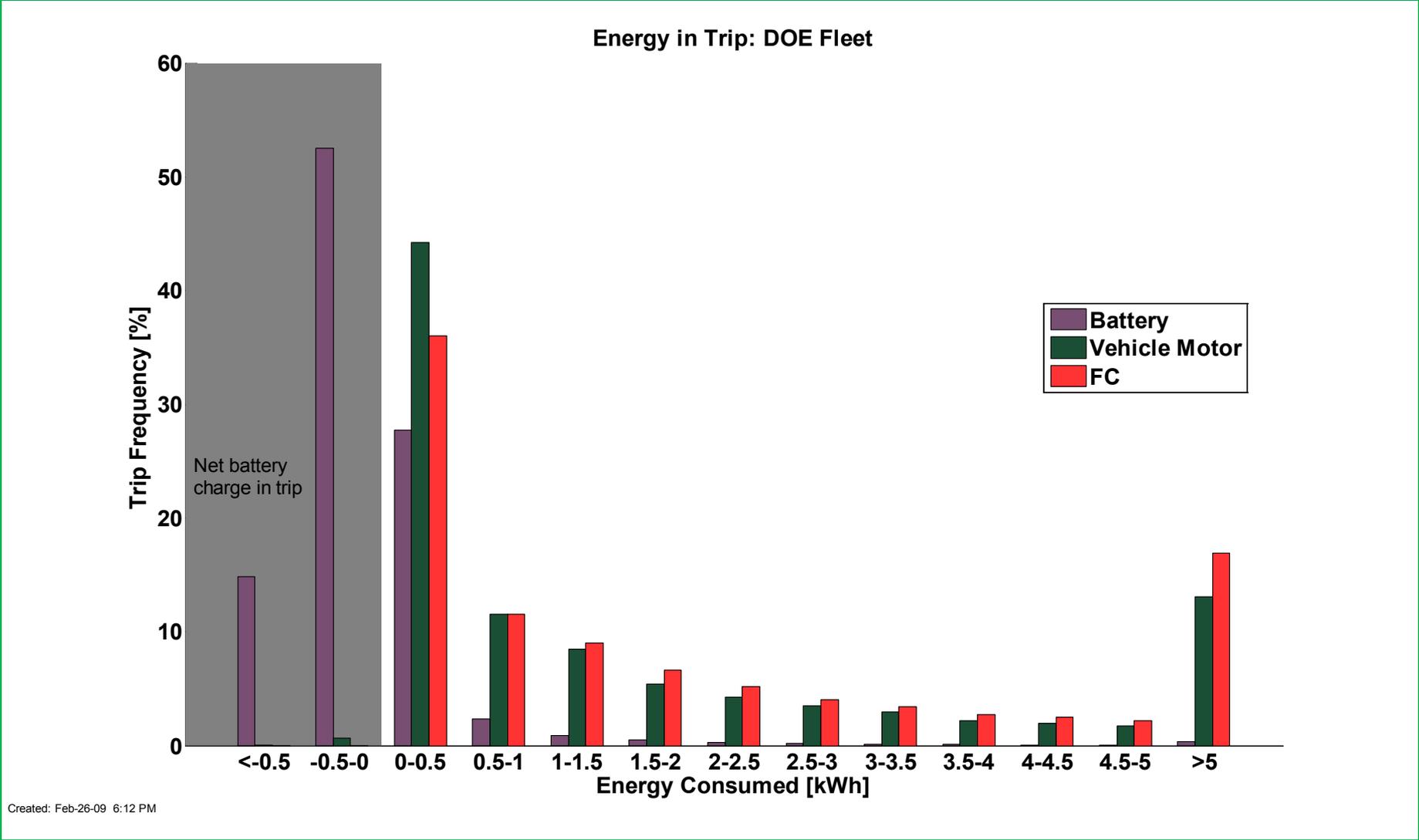
Created: Feb-26-09 6:12 PM

CDP#54: Time Between Trips

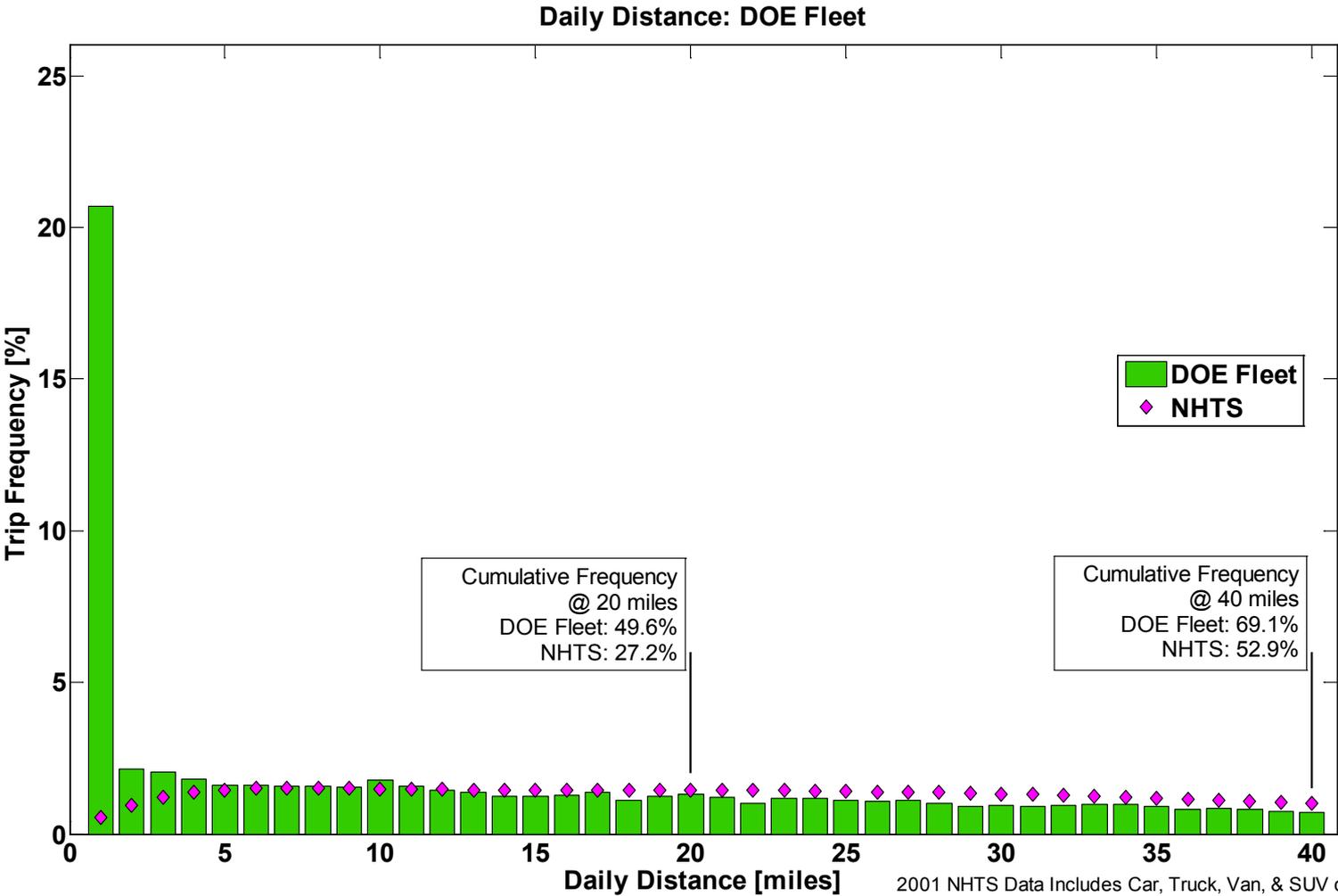


Created: Feb-26-09 5:56 PM

CDP#55: Fuel Cell System Energy



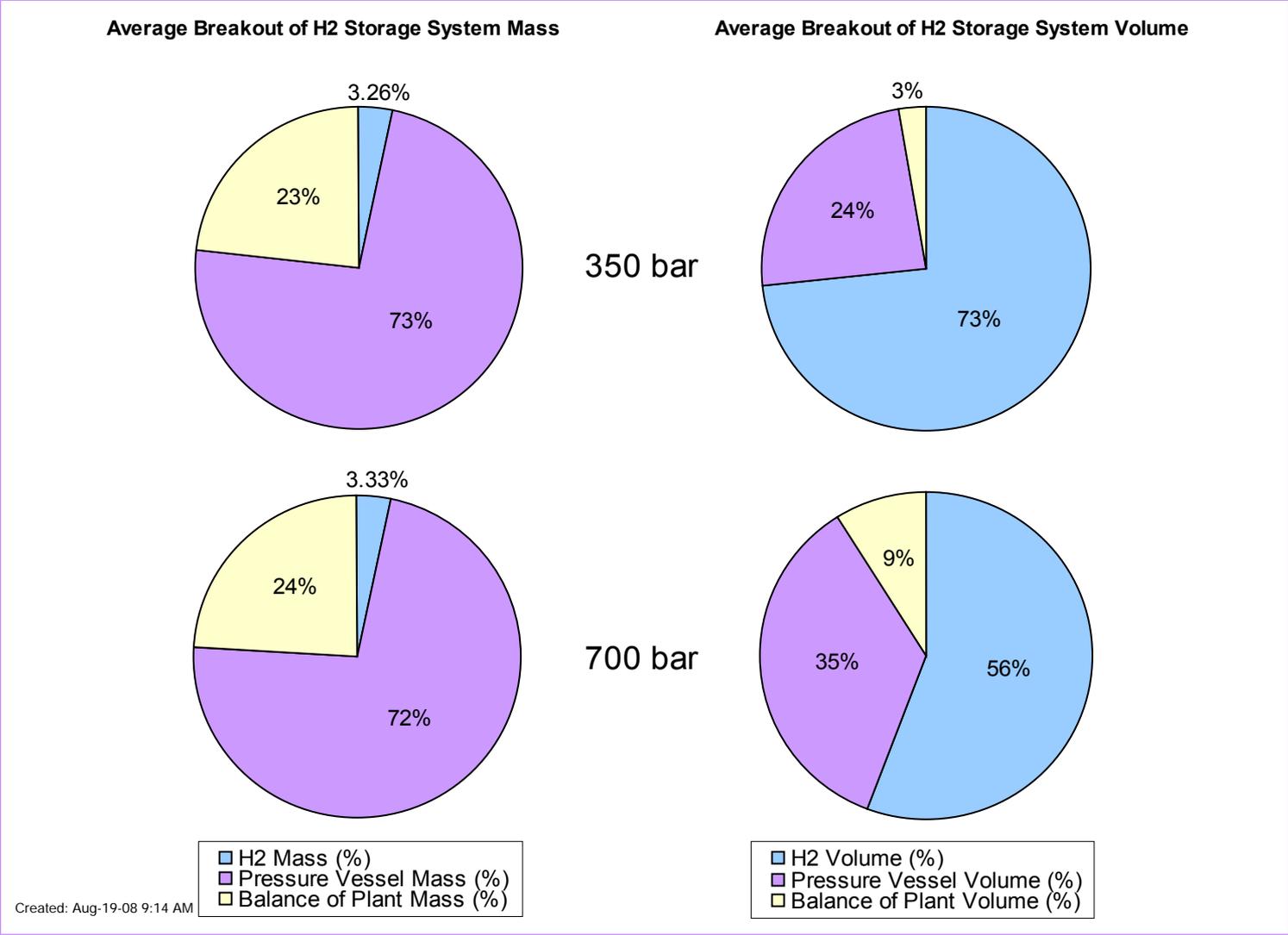
CDP#56: Daily Driving Distance



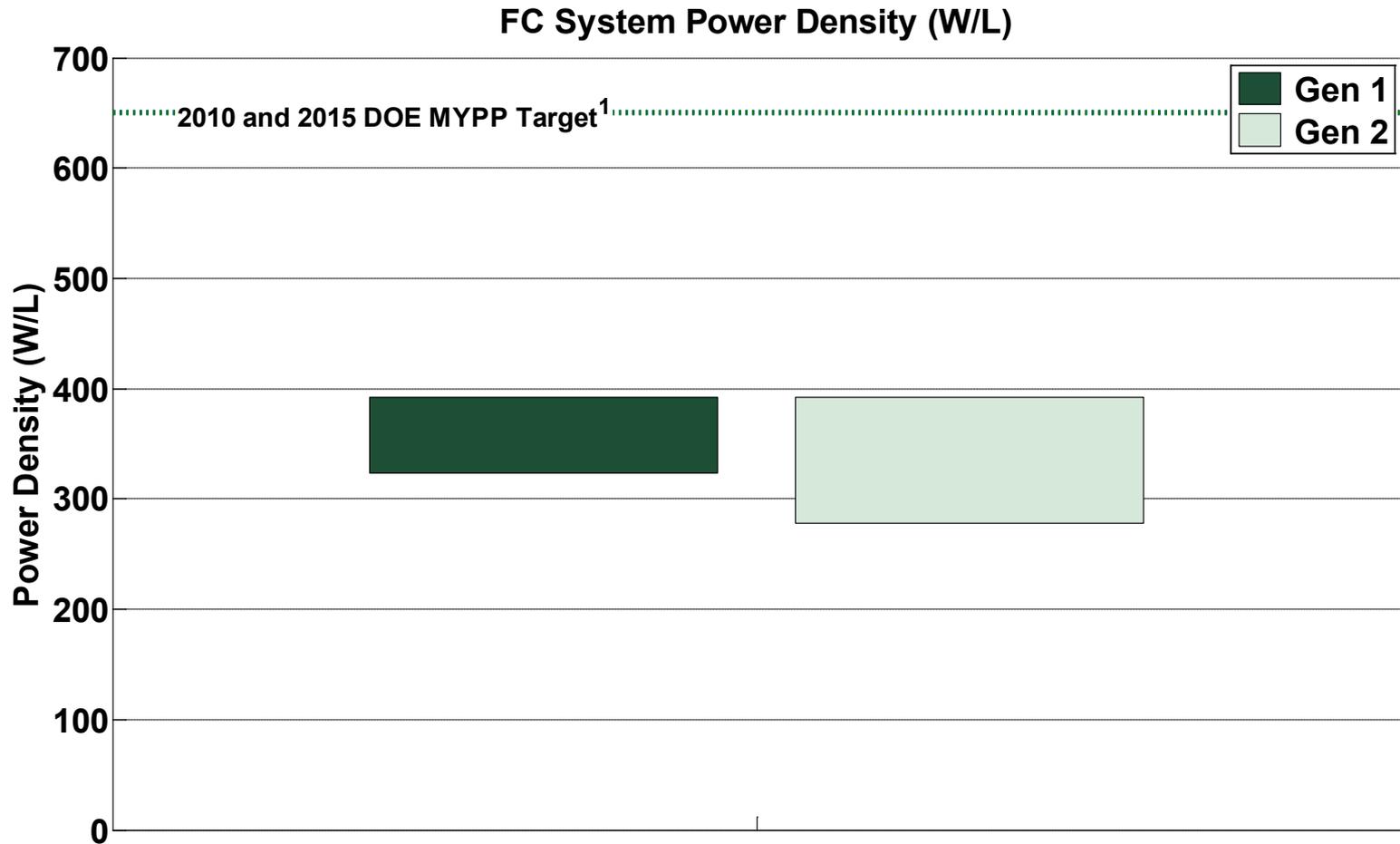
Created: Feb-26-09 6:12 PM

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



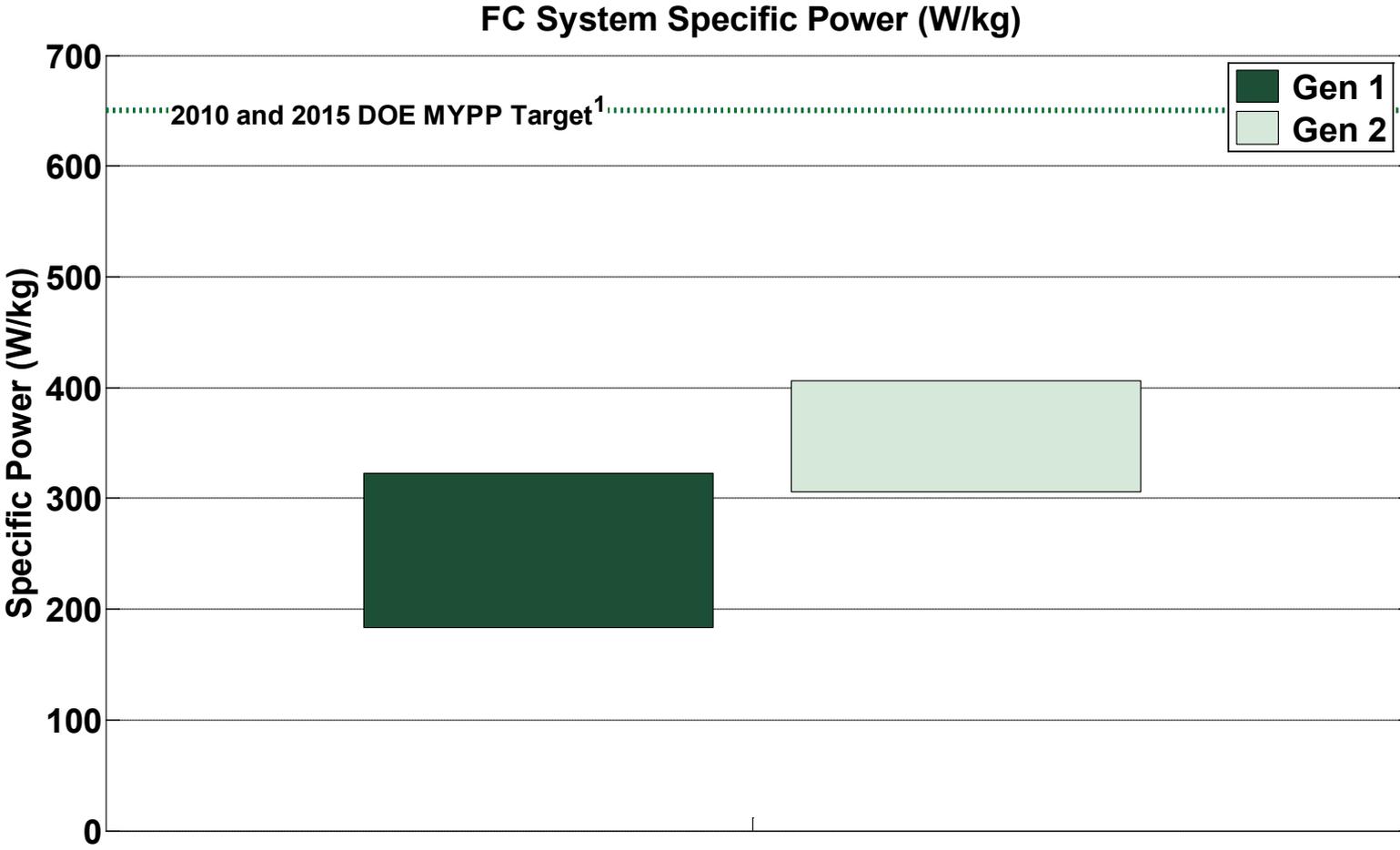
CDP#58: Fuel Cell System Power Density



Created: Sep-17-08 10:29 AM

(1) Fuel cell system includes fuel cell stack and BOP but excludes H2 storage, power electronics, and electric drive.

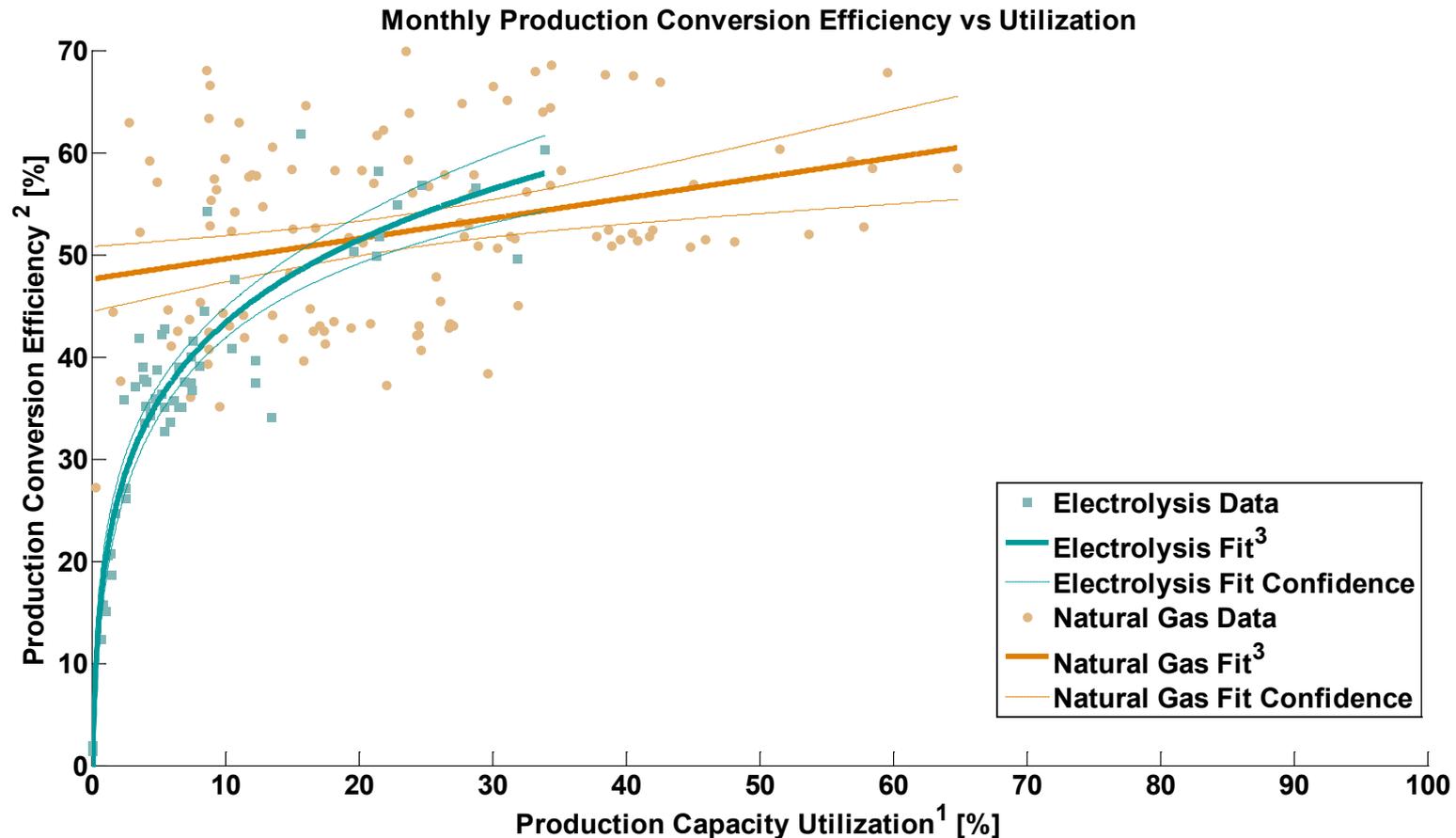
CDP#59: Fuel Cell System Specific Power



Created: Sep-17-08 10:30 AM

(1) Fuel cell system includes fuel cell stack and BOP but excludes H2 storage, power electronics, and electric drive.

CDP#60: On-Site Hydrogen Production Efficiency vs. Capacity Utilization



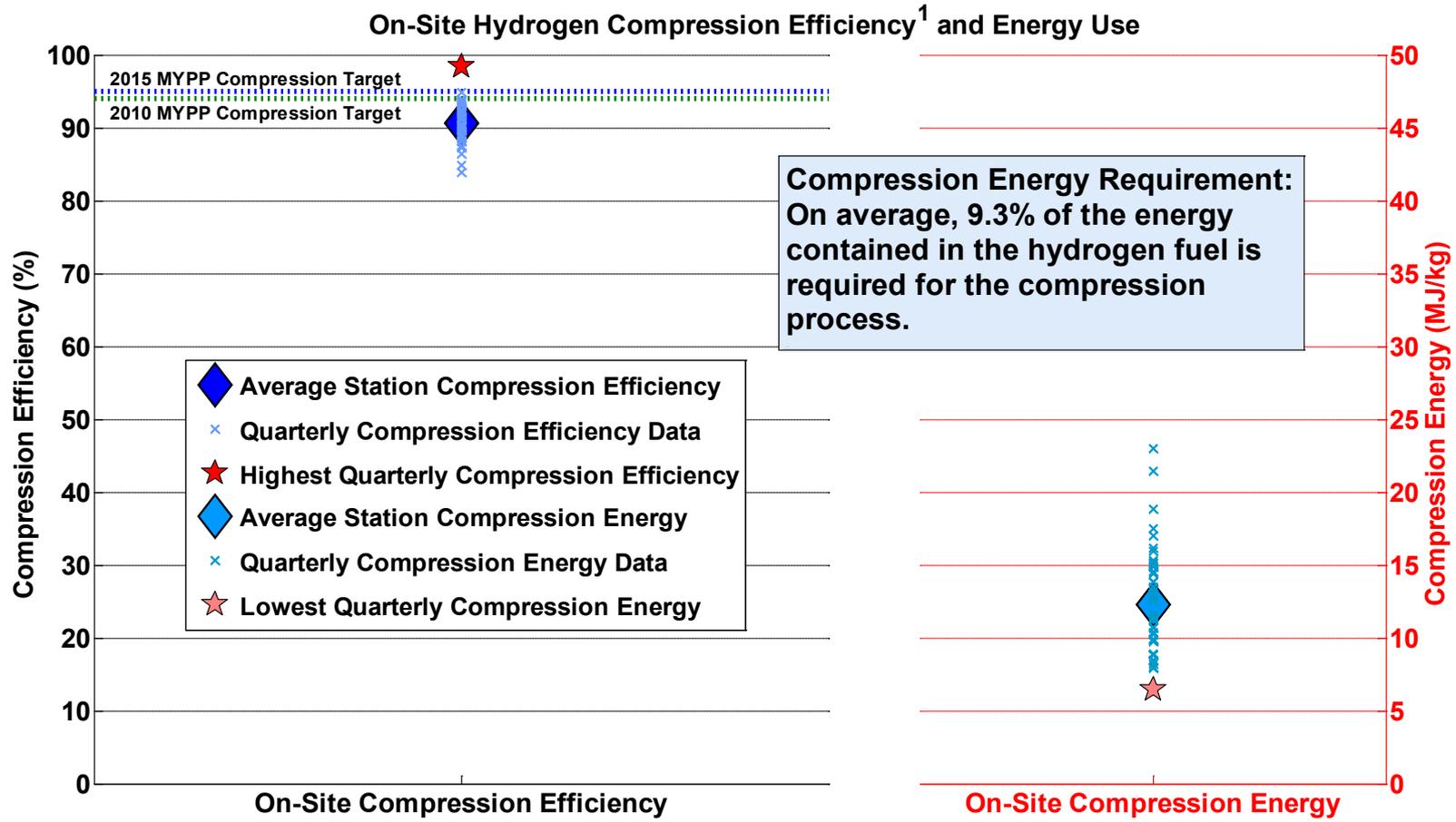
1) 100% production utilization assumes operation 24 hrs a day, 7 days a week

2) Production conversion efficiency is defined as the energy of the hydrogen out of the process (on a LHV basis) divided by the sum of the energy into the production process from the feedstock and all other energy as needed. Conversion efficiency does not include energy used for compression, storage, and dispensing.

3) High correlation with electrolysis data ($R^2 = 0.87$) & low correlation with natural gas data ($R^2 = 0.018$)

Created: Mar-02-09 9:09 AM

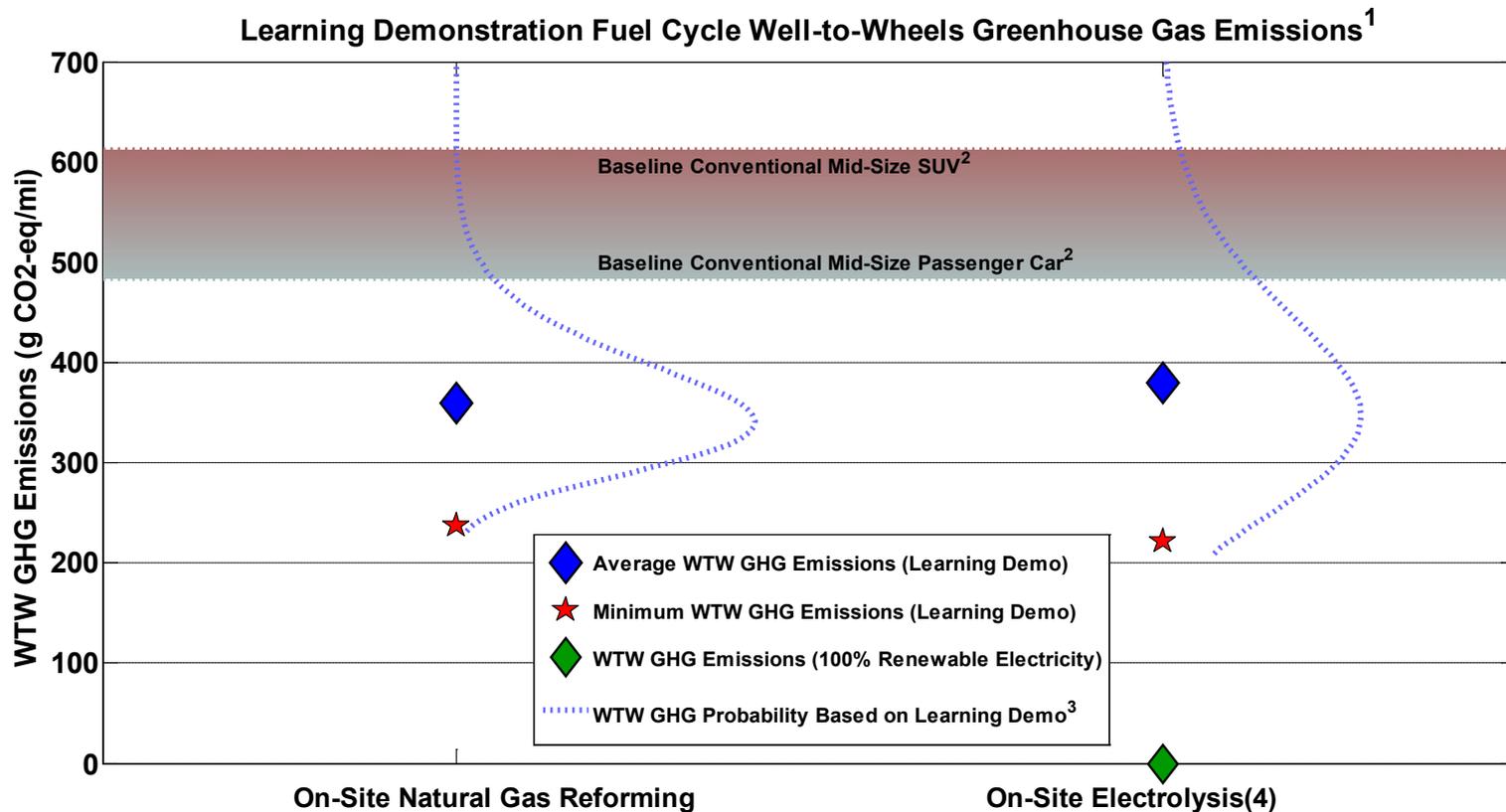
CDP#61: Refueling Station Compressor Efficiency



¹Consistent with the MYPP, compression efficiency is defined as the energy of the hydrogen out of the process (on an LHV basis) divided by the sum of the energy of the hydrogen output plus all other energy needed for the compression process. Data shown for on-site hydrogen production and storage facilities only, not delivered hydrogen sites.

Created: Mar-02-09 8:35 AM

CDP#62: Learning Demonstration Vehicle Greenhouse Gas Emissions



1. Well-to-Wheels greenhouse gas emissions based on DOE's GREET model, version 1.8b. Analysis uses default GREET values except for FCV fuel economy, hydrogen production conversion efficiency, and electricity grid mix. Fuel economy values are the Gen 1 and Gen 2 window-sticker fuel economy data for all teams (as used in CDP #6); conversion efficiency values are the production efficiency data used in CDP #13.

2. Baseline conventional passenger car and light duty truck GHG emissions are determined by GREET 1.8b, based on the EPA window-sticker fuel economy of a conventional gasoline mid-size passenger car and mid-size SUV, respectively. The Learning Demonstration fleet includes both passenger cars and SUVs.

3. The Well-to-Wheels GHG probability distribution represents the range and likelihood of GHG emissions resulting from the hydrogen FCV fleet based on window-sticker fuel economy data and monthly conversion efficiency data from the Learning Demonstration.

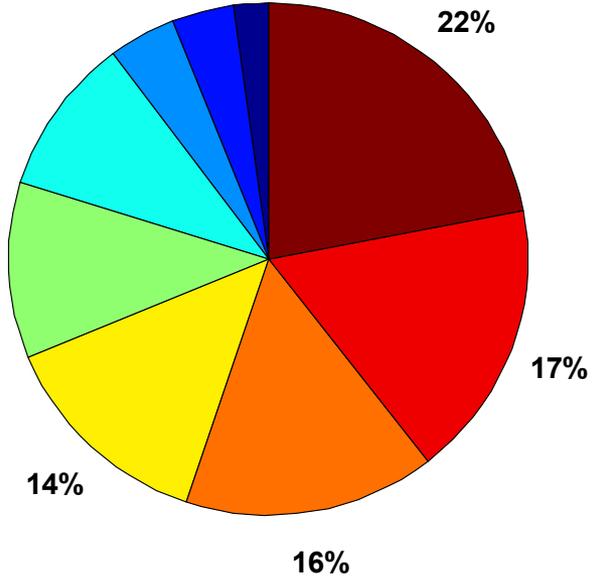
4. On-site electrolysis GHG emissions are based on the average mix of electricity production used by the Learning Demonstration production sites, which includes both grid-based electricity and renewable on-site solar electricity. GHG emissions associated with on-site production of hydrogen from electrolysis are highly dependent on electricity source. GHG emissions from a 100% renewable electricity mix would be zero, as shown. If electricity were supplied from the U.S. average grid mix, average GHG emissions would be 1241 g/mile.

Created: Feb-26-09 11:32 AM

CDP#63: Hydrogen Fueling Station Maintenance by System

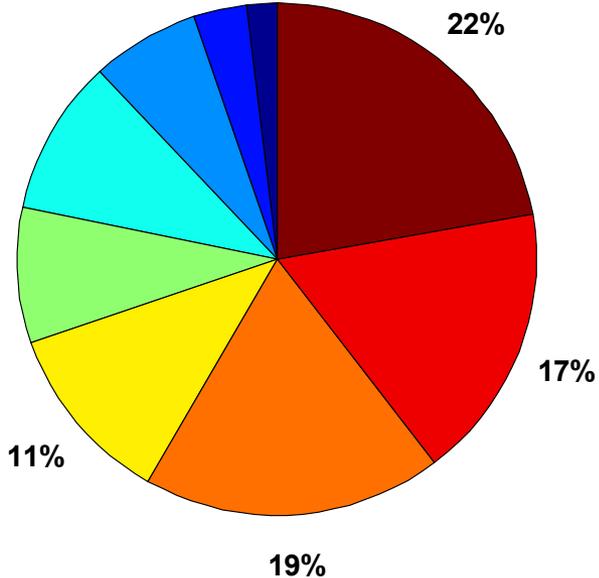
Hydrogen Fueling Station Maintenance

By Number of Events
Total Number of Events = 1860



- system control & safety
- compressor
- electrolyzer
- reformer
- dispenser
- other
- electrical
- valves & piping
- storage

By Labor Hours
Total Hours = 9093

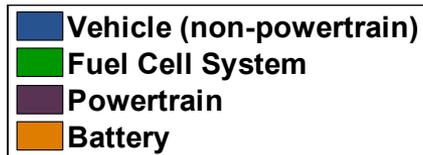
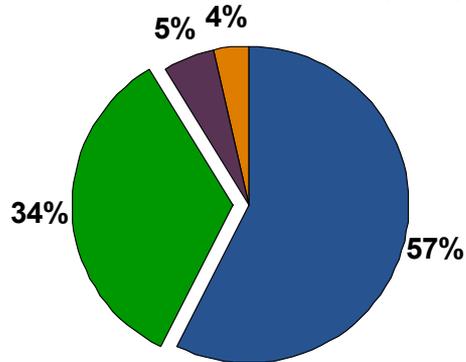


Created: Mar-03-09 3:50 PM

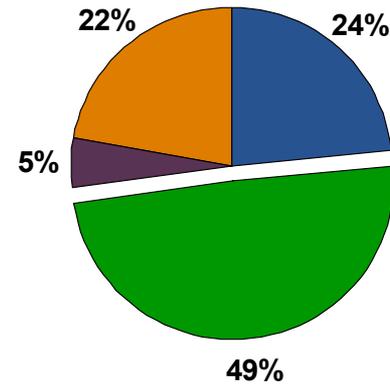
CDP#64: Fuel Cell Vehicle Maintenance by System

Fuel Cell Vehicle Maintenance Events and Labor Hours

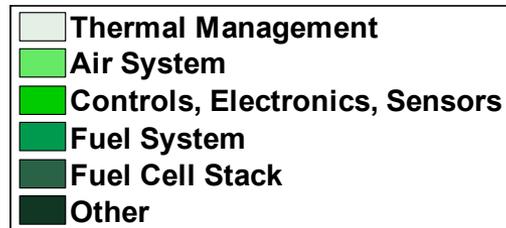
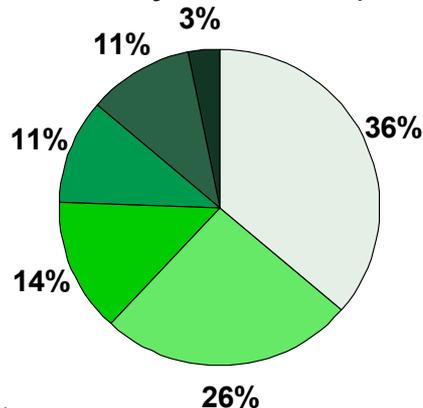
Fuel Cell Vehicle Events (9357)



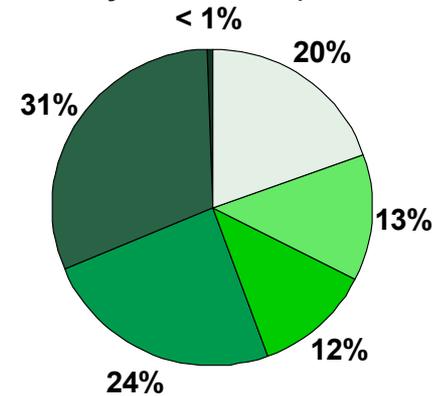
Fuel Cell Vehicle Labor (10216 hours)



Fuel Cell System Events (3175)



Fuel Cell System Labor (5035 hours)



Created: Mar-09-09 3:16 PM

REPORT DOCUMENTATION PAGE

Form Approved
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				5c. PROGRAM ELEMENT NUMBER		
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				5e. TASK NUMBER FC087810		
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