



**Technical Report**  
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January 2012

# All Composite Data Products: National FCEV Learning Demonstration With Updates Through January 18, 2012

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Chris Ainscough, and Genevieve Saur

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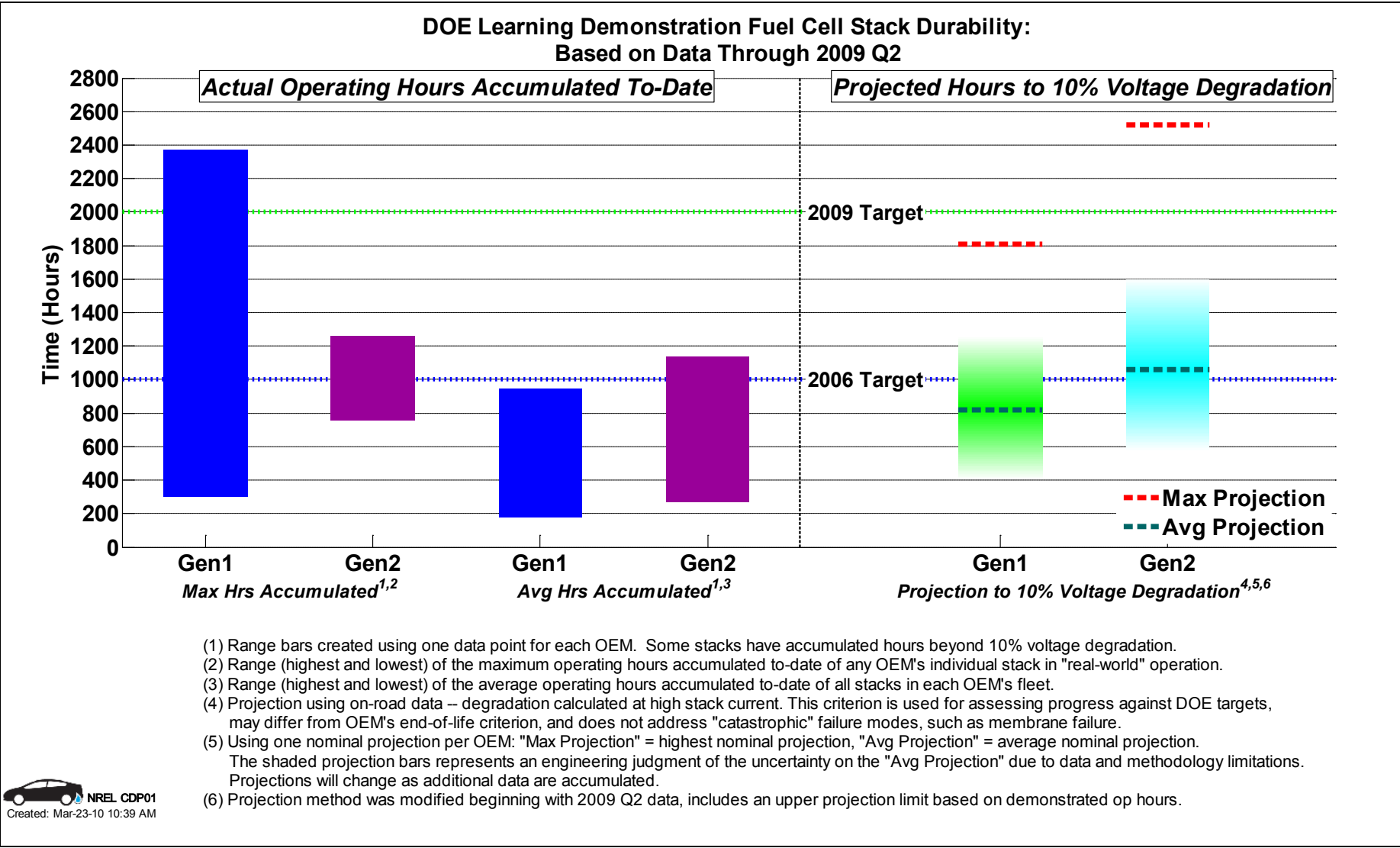
# All Composite Data Products: National FCEV Learning Demonstration



**With Updates Through  
January 18, 2012**

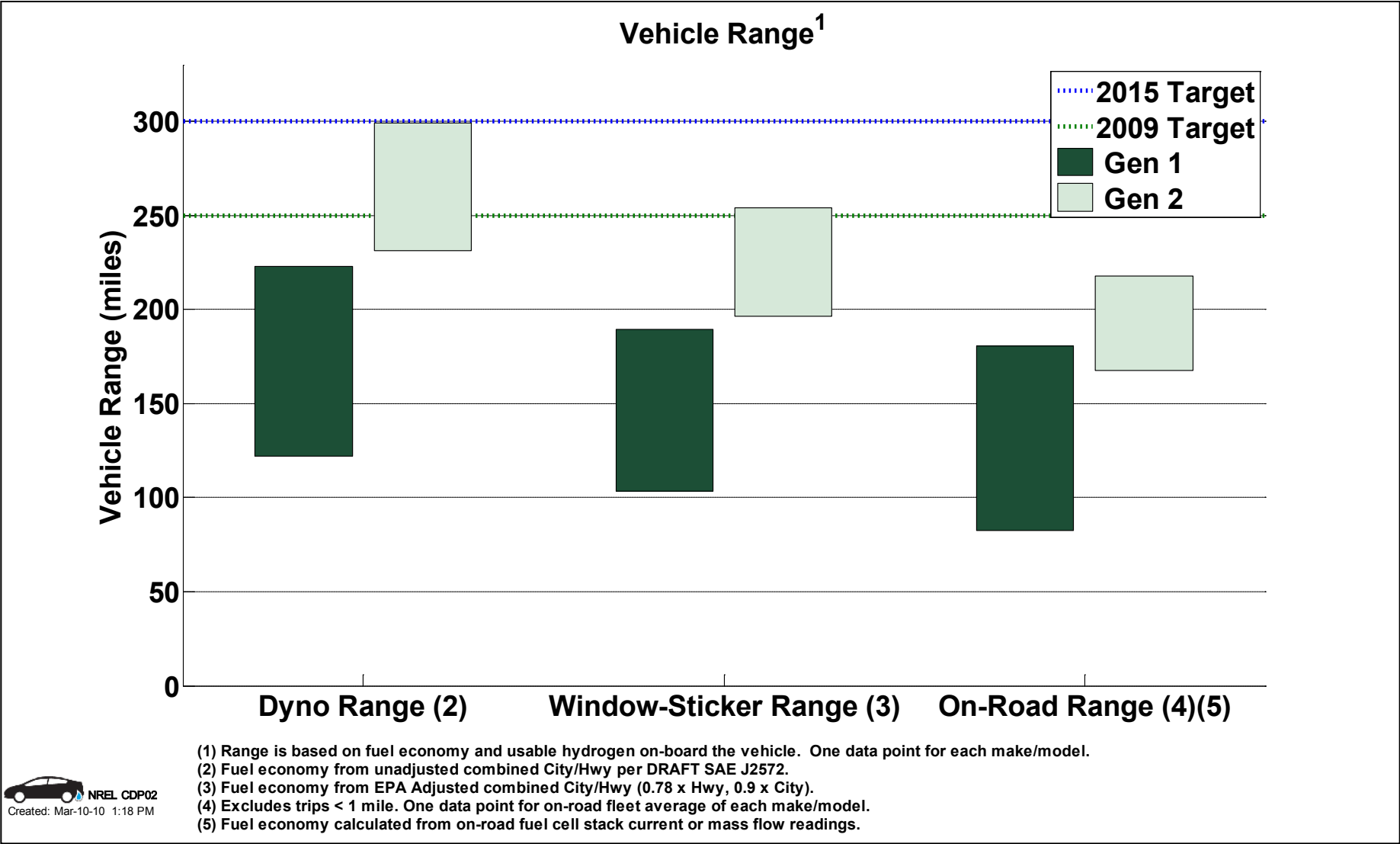
**Keith Wipke, Sam Sprik,  
Jennifer Kurtz, Todd  
Ramsden, Chris  
Ainscough, Genevieve  
Saur**

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



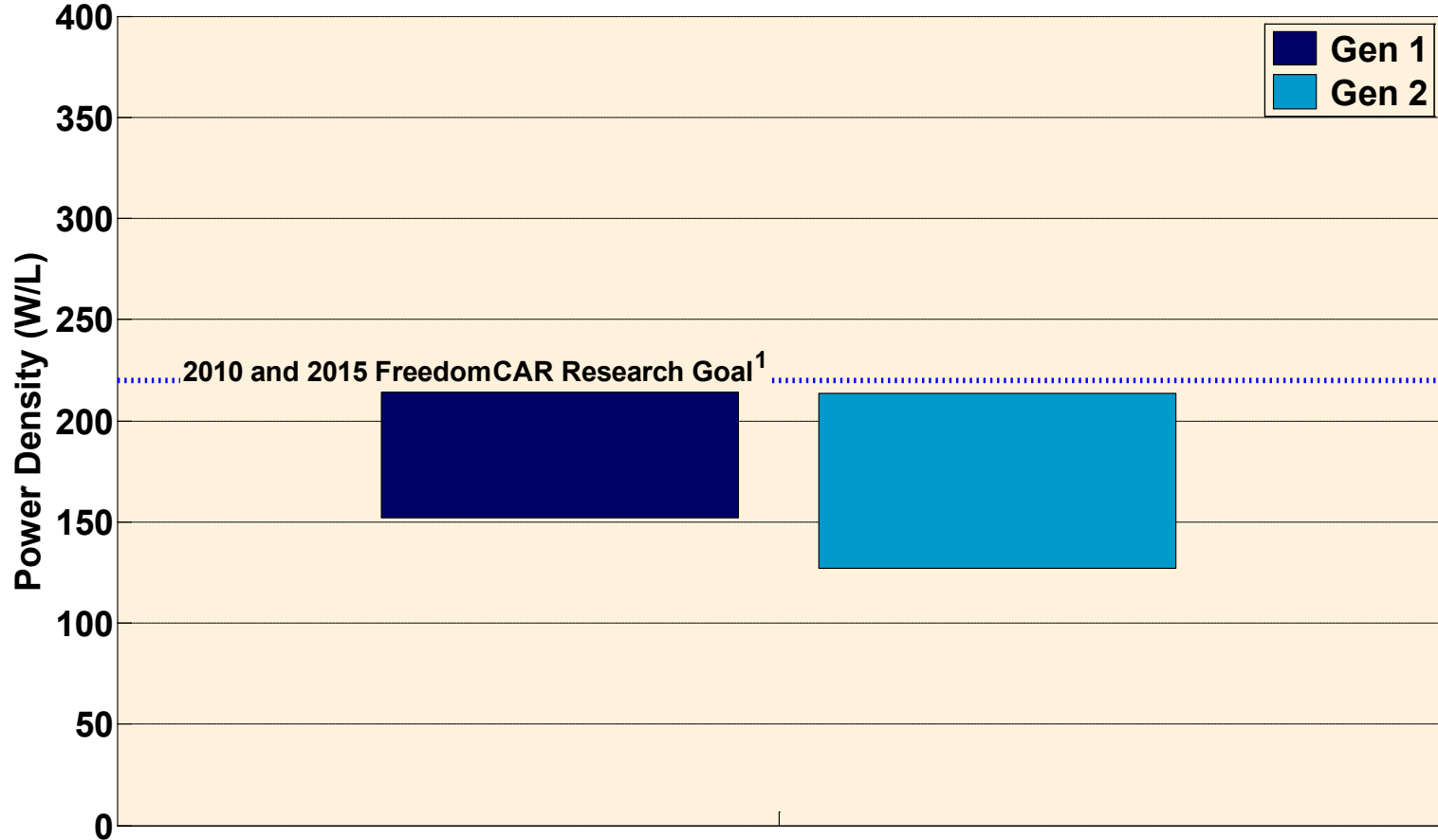
- (1) Range bars created using one data point for each OEM. Some stacks have accumulated hours beyond 10% voltage degradation.
- (2) Range (highest and lowest) of the maximum operating hours accumulated to-date of any OEM's individual stack in "real-world" operation.
- (3) Range (highest and lowest) 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 projection bars 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 2009 Q2 data, includes an upper projection limit based on demonstrated op hours.

# CDP#2: Vehicle Range



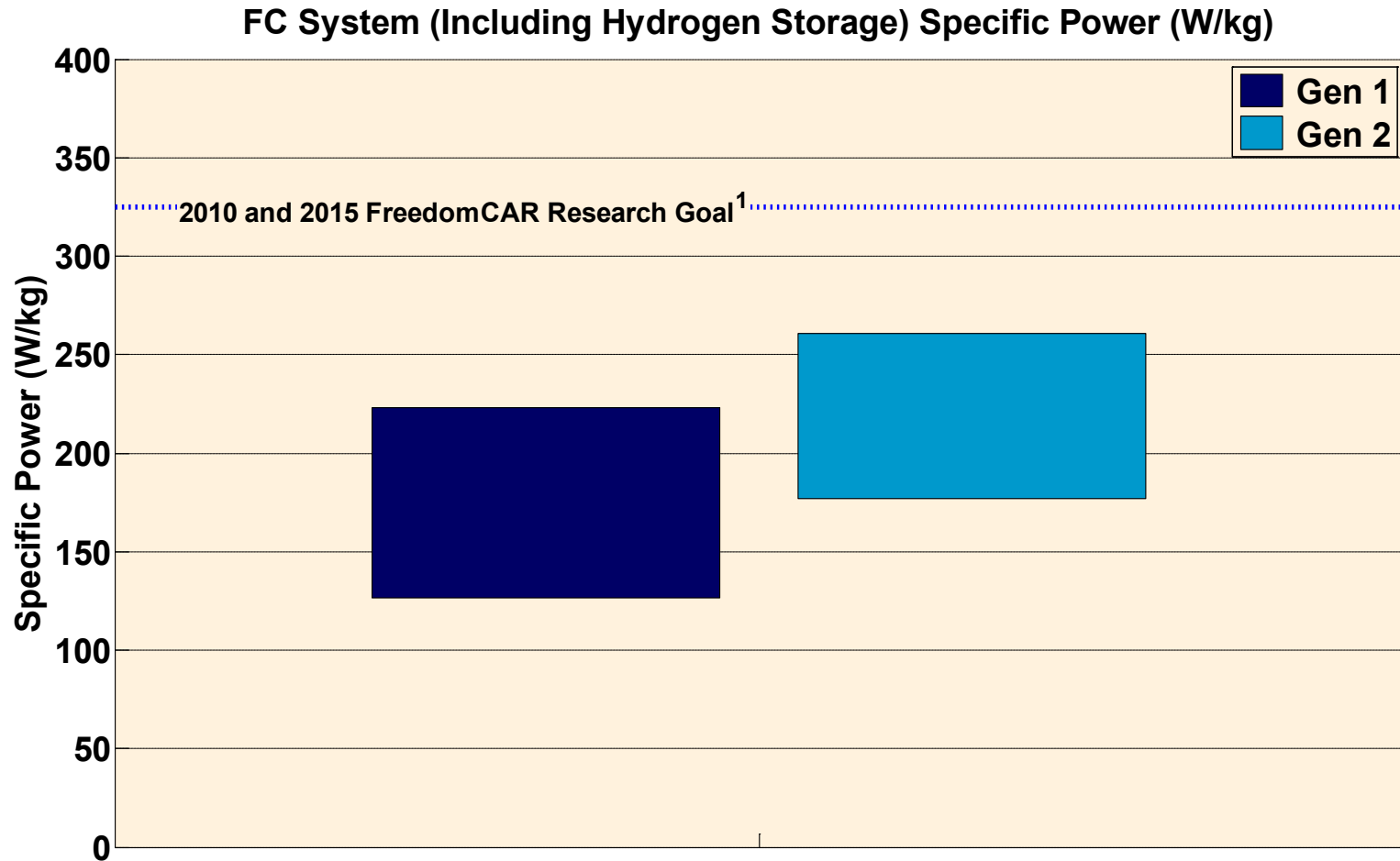
# CDP#3: Fuel Cell System Power Density, Including Hydrogen Storage

FC System (Including Hydrogen Storage) Power Density (W/L)



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

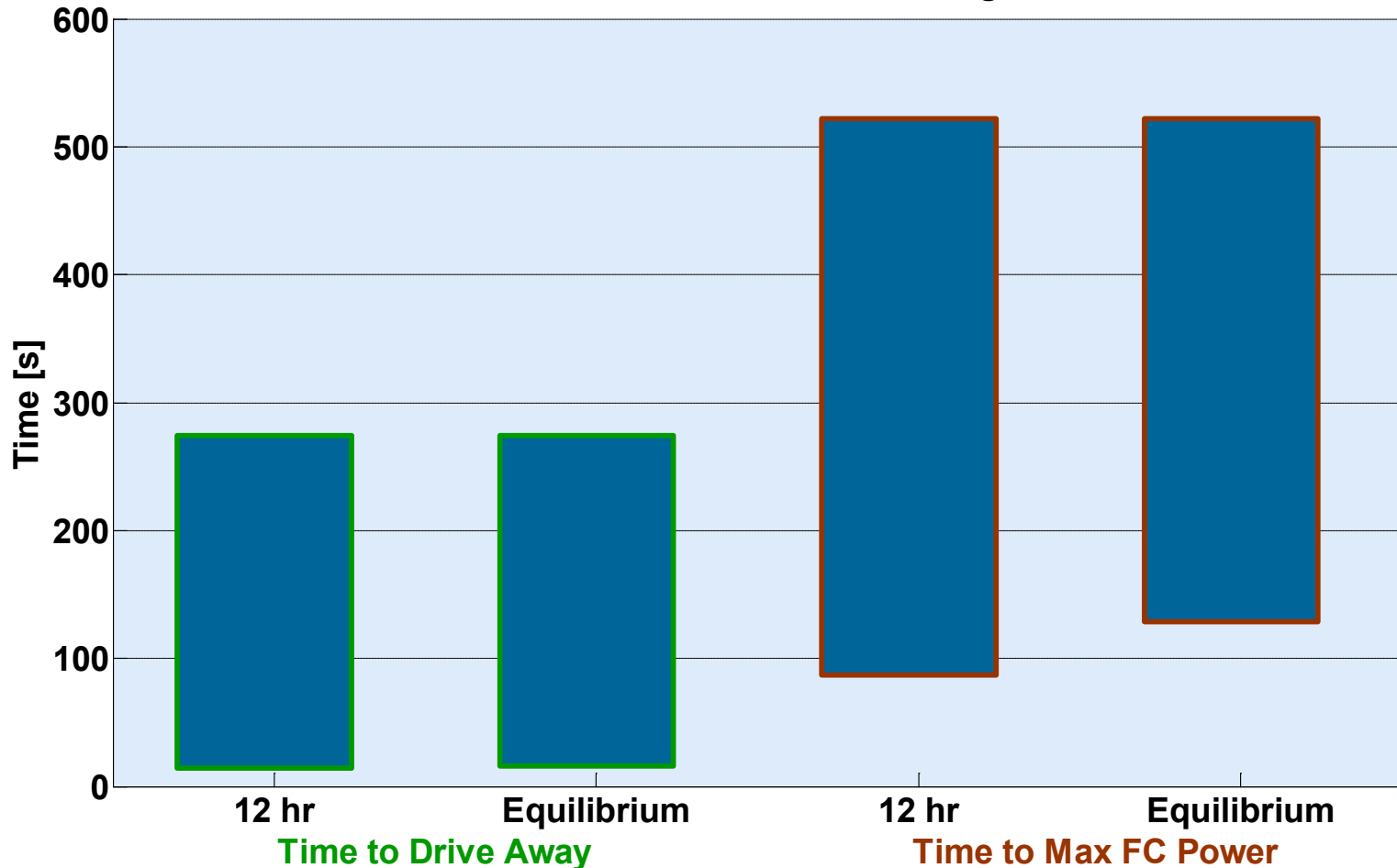
# CDP#4: Fuel Cell System Specific Power, Including Hydrogen Storage



(1) Fuel cell system includes fuel cell stack, BOP and H<sub>2</sub> storage, but excludes power electronics, battery storage, and electric drive.

# CDP#5: Fuel Cell Start Times from Sub-Freezing Soak Conditions

Fuel Cell Vehicle Start Time from Sub-Freezing Soak Condition<sup>1</sup>

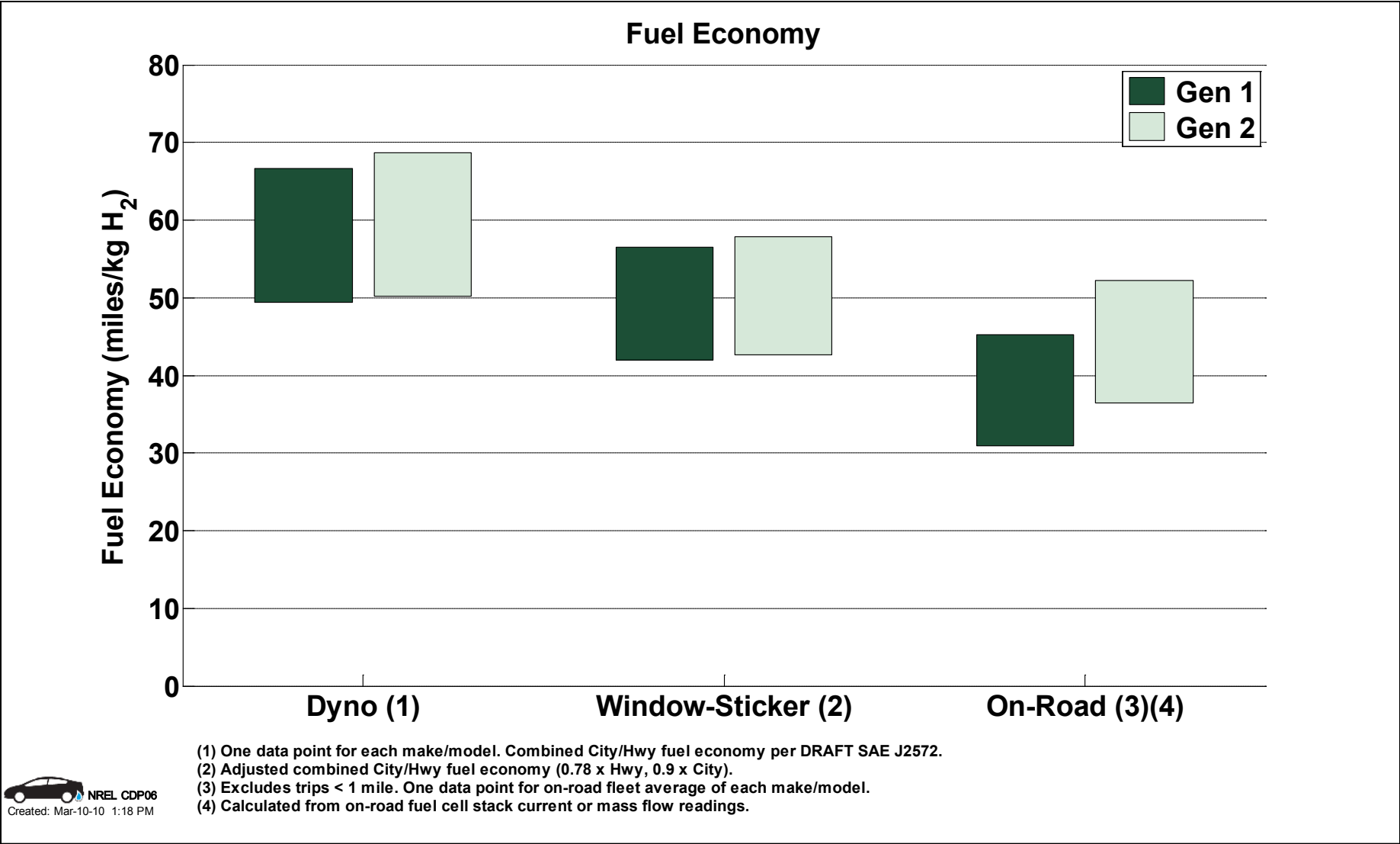


(1) Learning Demo soak temperature for freeze tests were between -9 and -20 °C

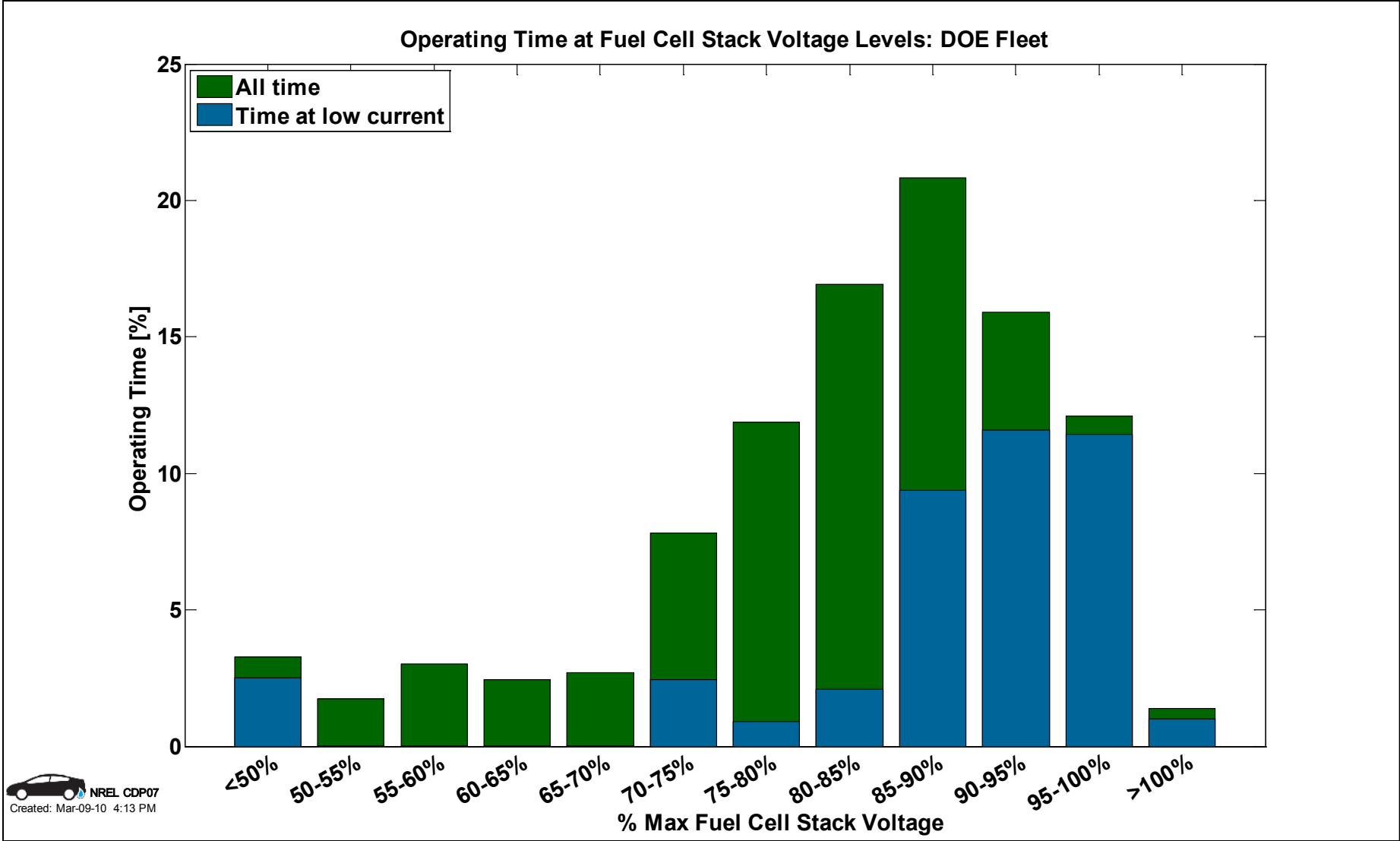
(2) 2010 & 2015 DOE MYPP Cold Start Up Time Target: 30 seconds to 50% of rated power from -20 °C (soak duration not specified).



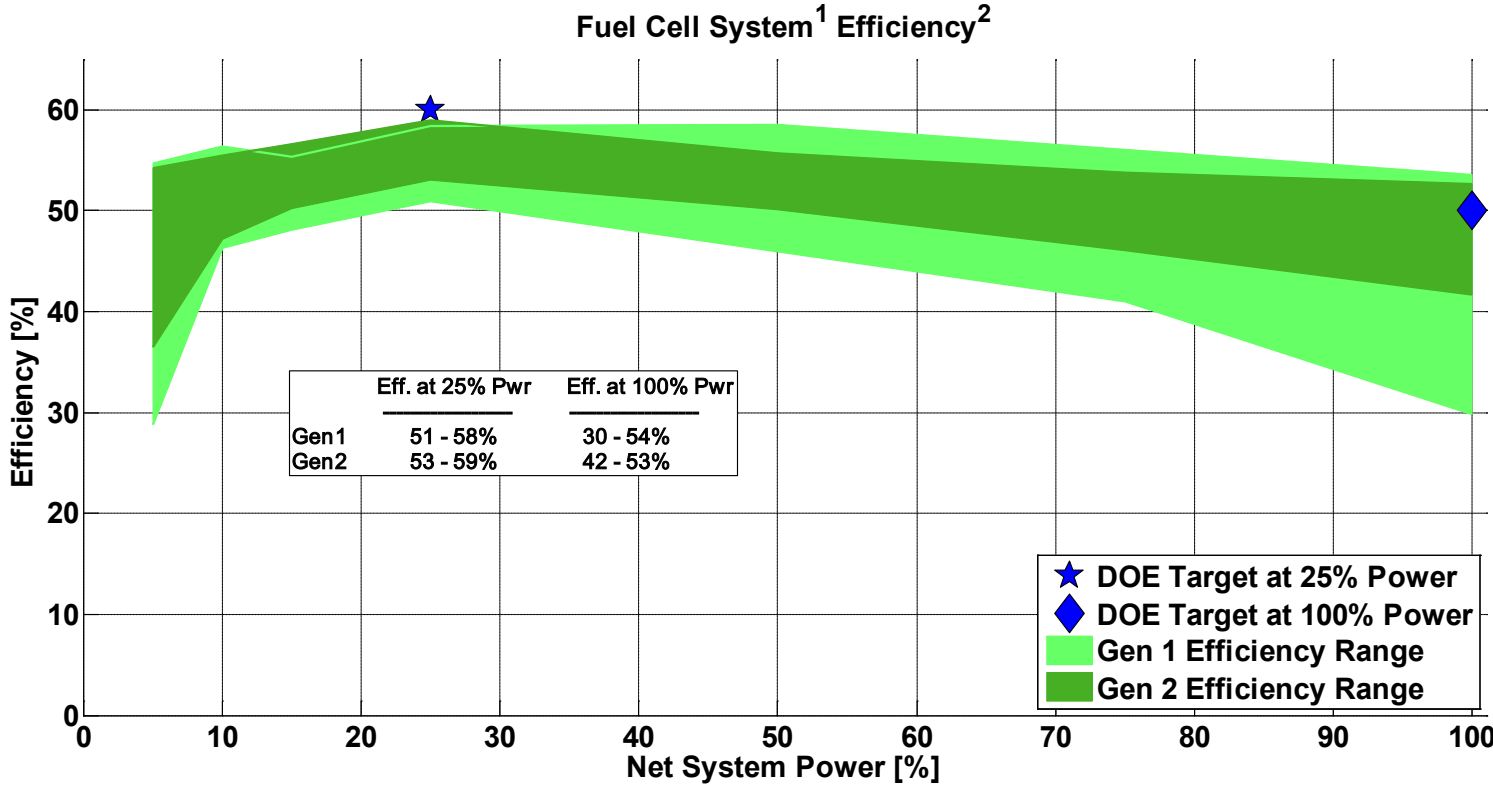
# CDP#6: Fuel Economy



# CDP#7: Fuel Cell Voltage

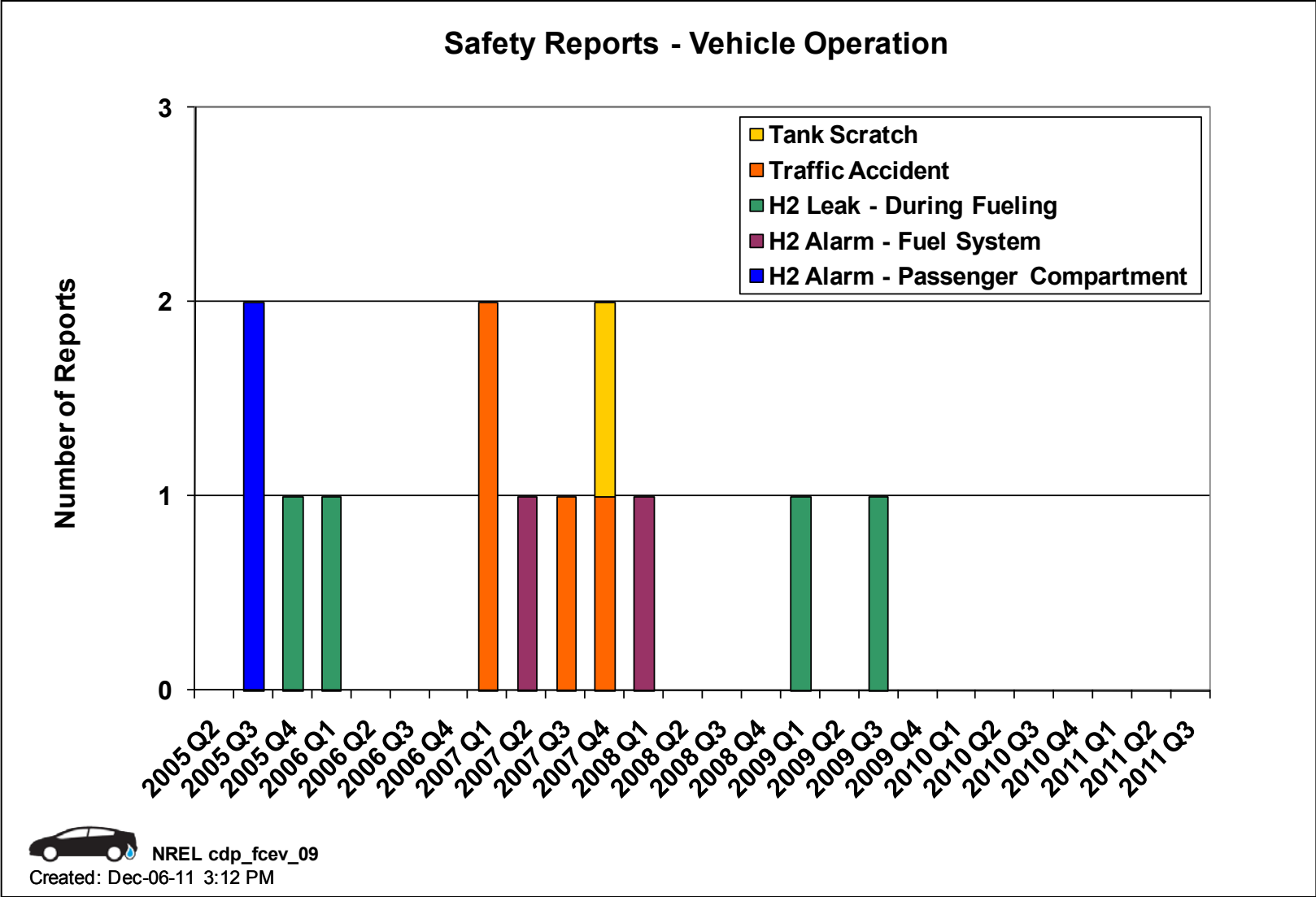


# CDP#8: FC System Efficiency

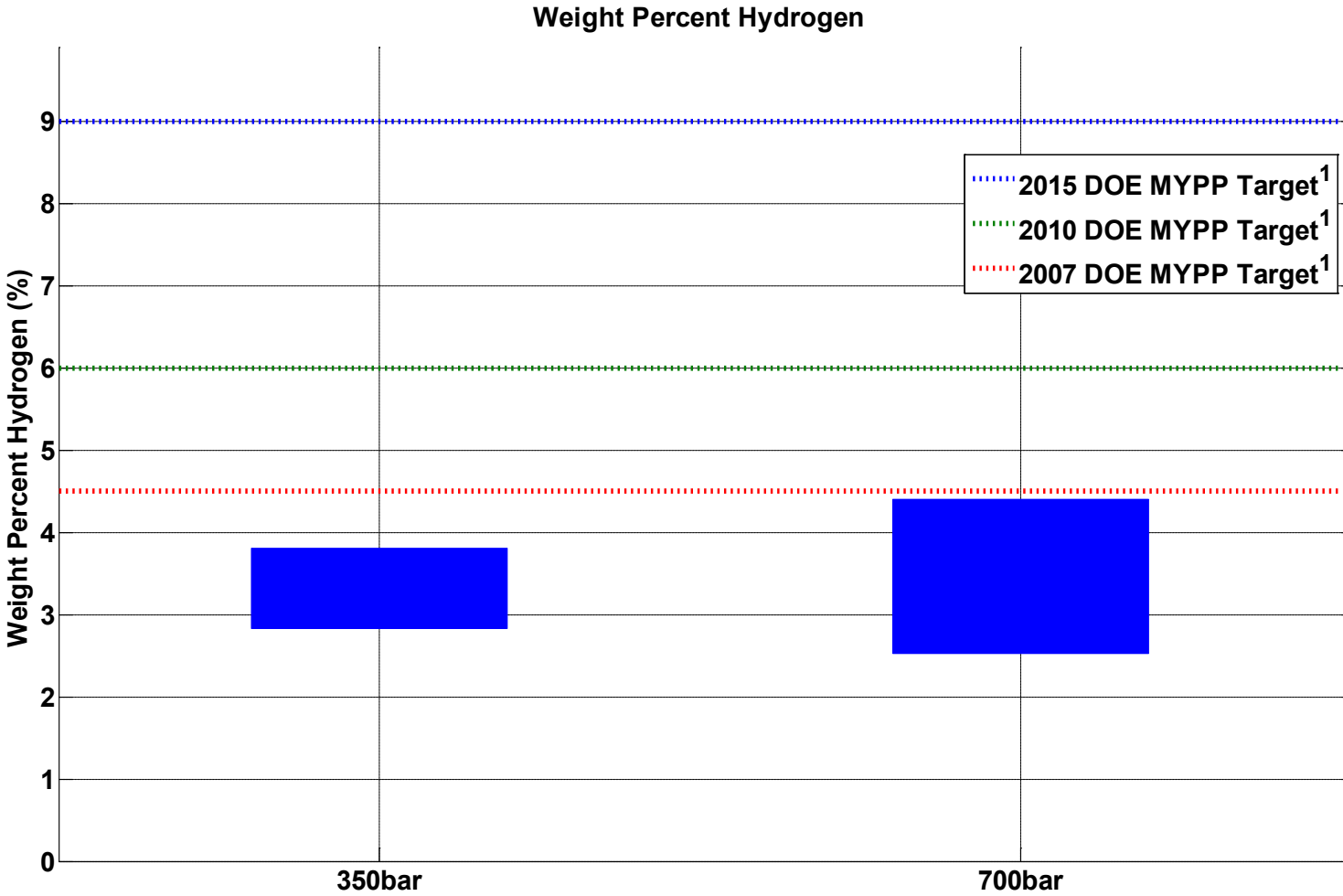


<sup>1</sup> Gross stack power minus fuel cell system auxiliaries, per DRAFT SAE J2615. Excludes power electronics and electric drive.  
<sup>2</sup> Ratio of DC output energy to the lower heating value of the input fuel (hydrogen).  
<sup>3</sup> Individual test data linearly interpolated at 5,10,15,25,50,75, and 100% of max net power. Values at high power linearly extrapolated due to steady state dynamometer cooling limitations.

# CDP#9: Safety Reports – Vehicles

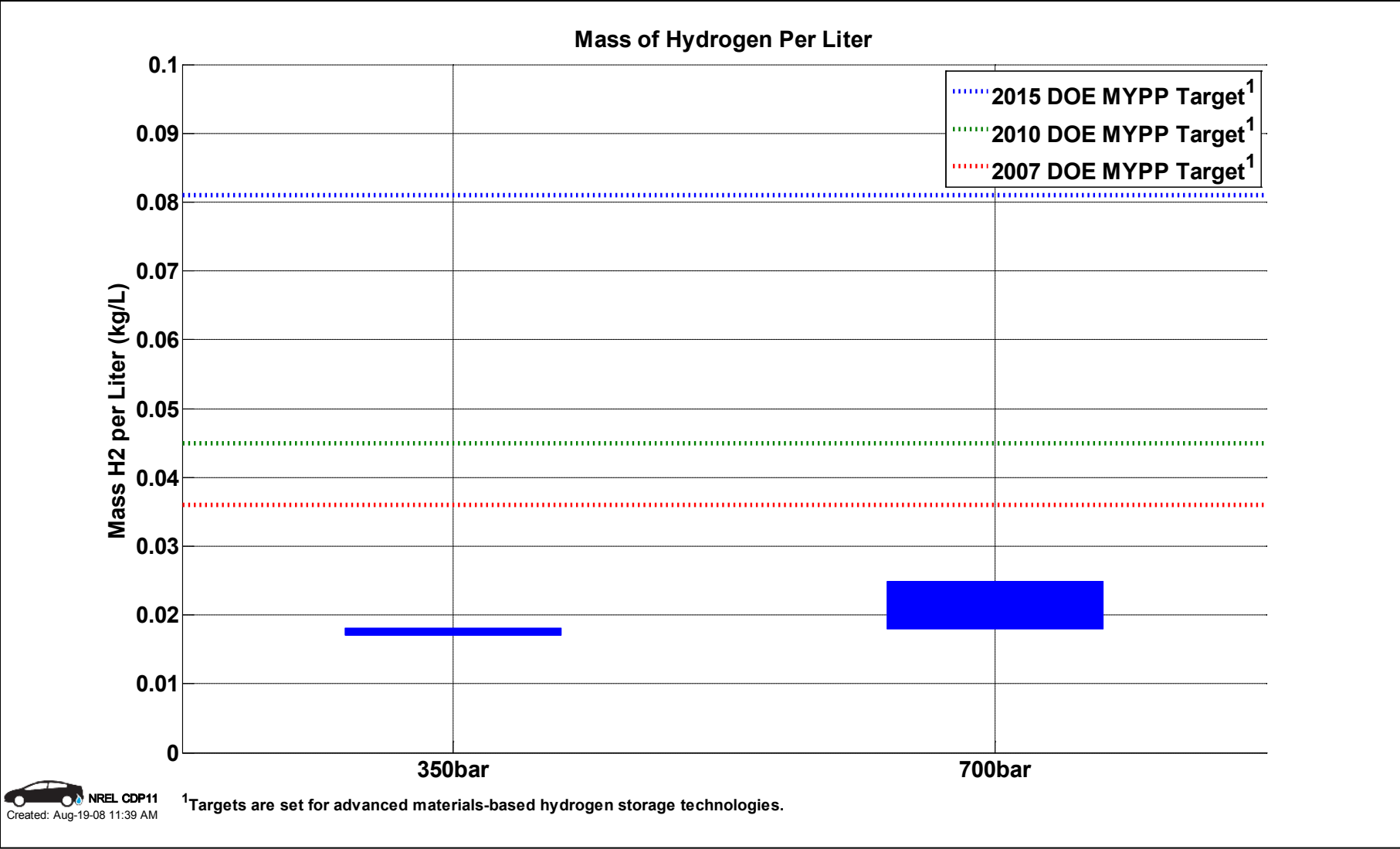


# CDP#10: Storage Weight % Hydrogen

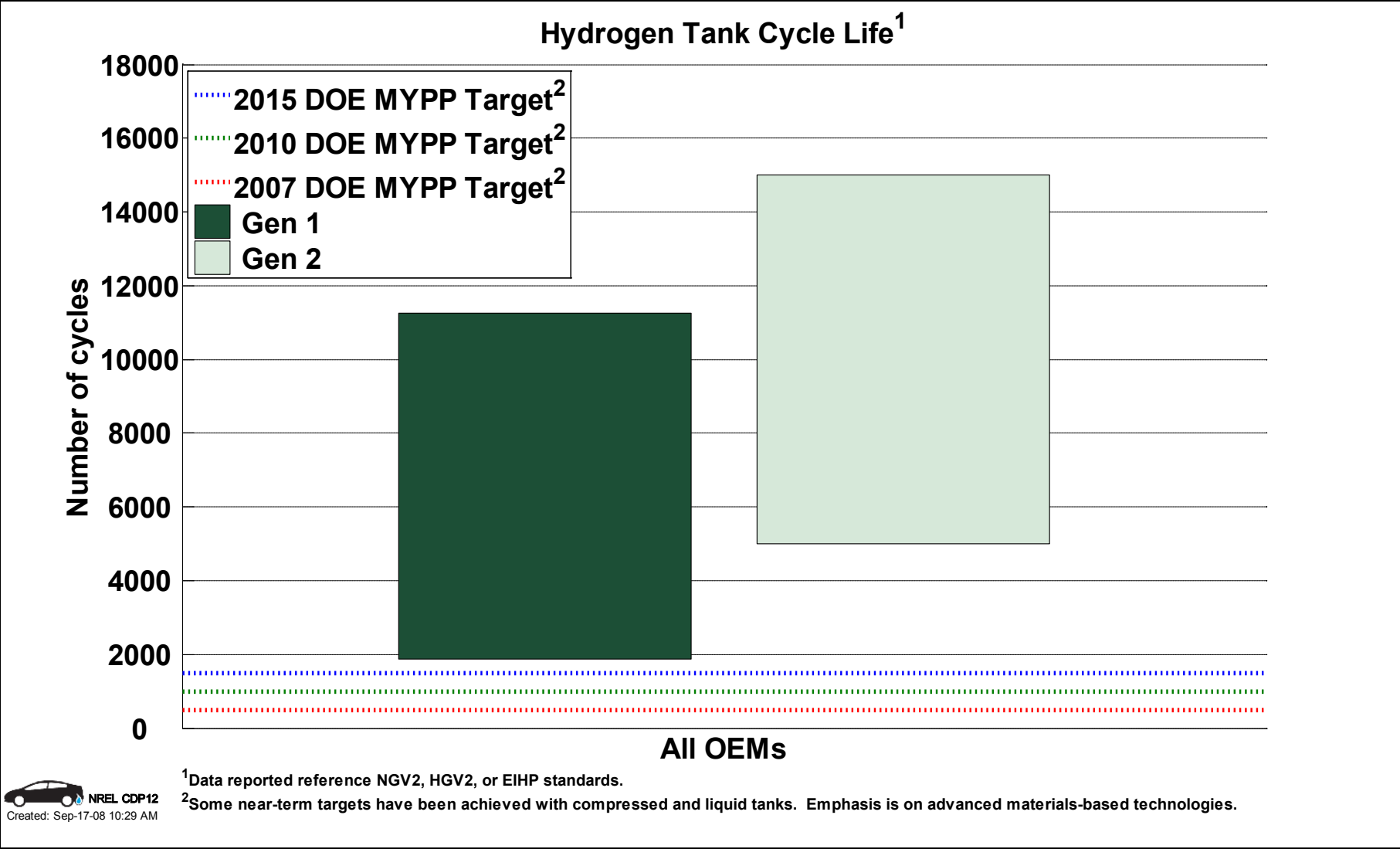


<sup>1</sup>Targets are set for advanced materials-based hydrogen storage technologies.

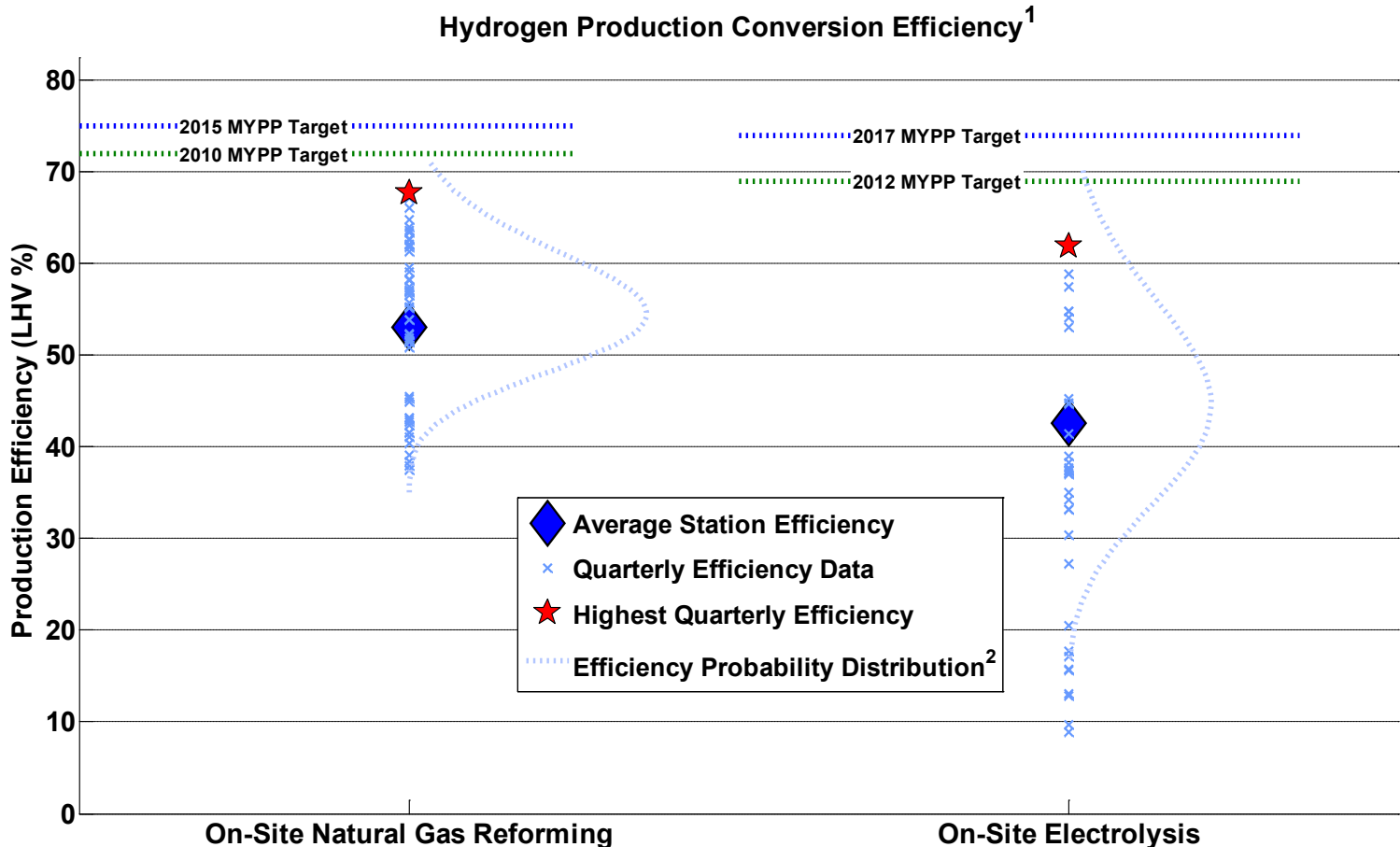
# CDP#11: Volumetric Capacity of H2 Storage



# CDP#12: Vehicle Hydrogen Tank Cycle Life



# CDP#13: On-Site Hydrogen Production Efficiency

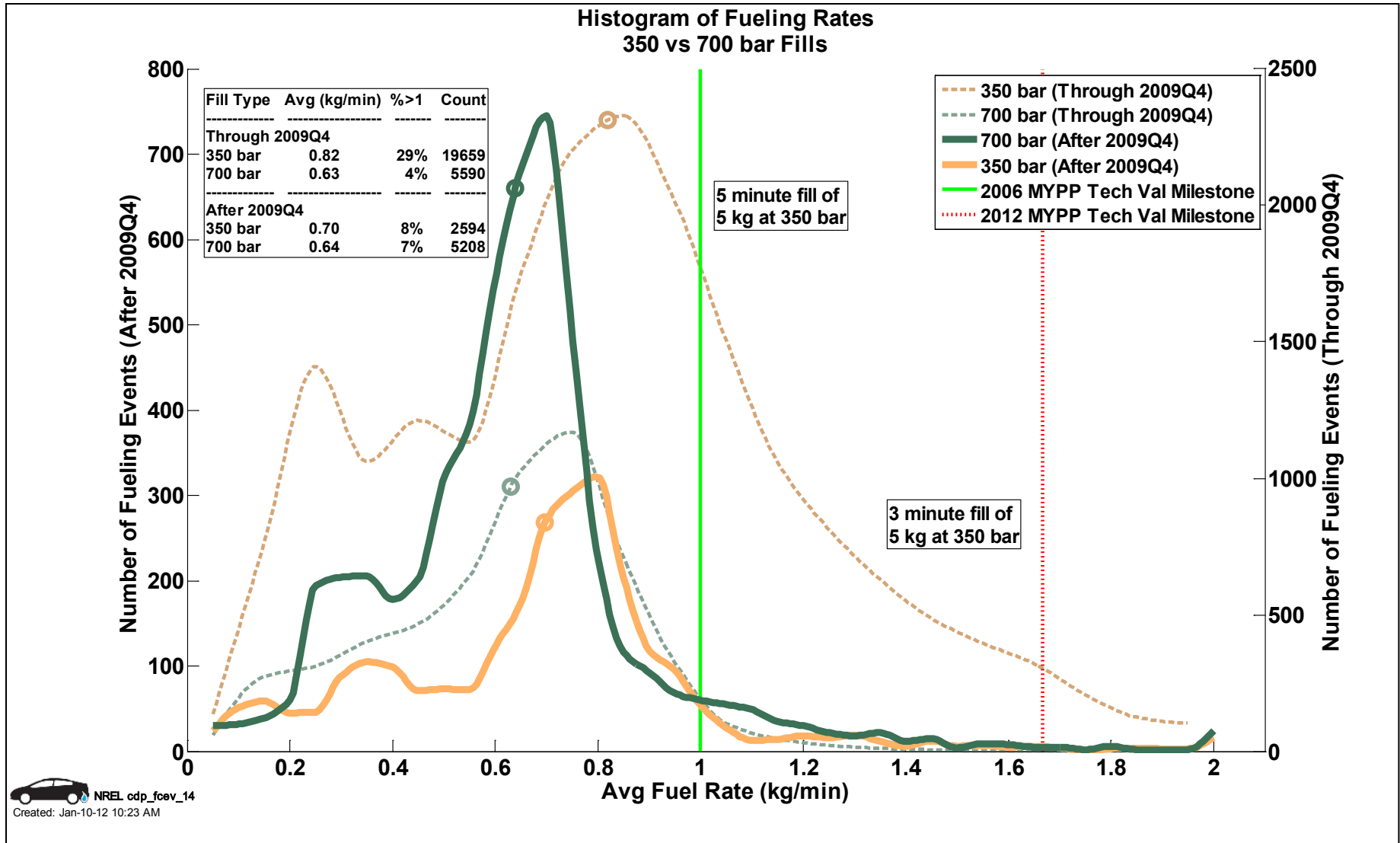


<sup>1</sup>Production conversion efficiency is defined as the energy of the hydrogen out of the process (on an LHV basis) divided by the sum of the energy into the production process from the feedstock and all other energy as needed. Conversion efficiency does not include energy used for compression, storage, and dispensing.

<sup>2</sup>The efficiency probability distribution represents the range and likelihood of hydrogen production conversion efficiency based on monthly conversion efficiency data from the Learning Demonstration.

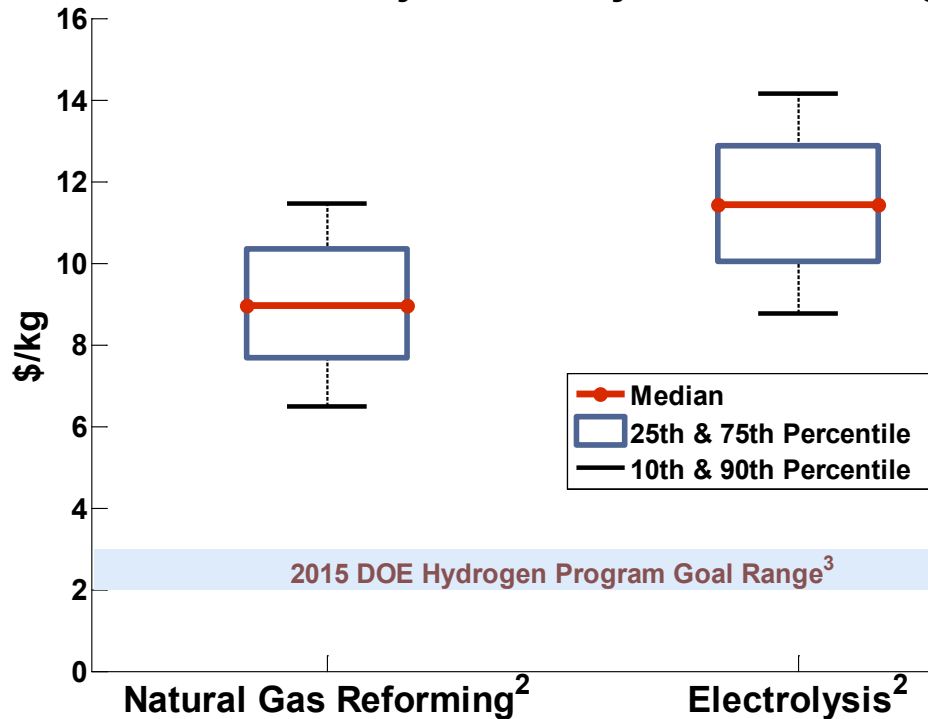


# CDP#14: Fueling Rates by Fill Pressure



# CDP#15: H2 Production Cost vs. Process

Projected Early Market 1500 kg/day Hydrogen Cost<sup>1</sup>



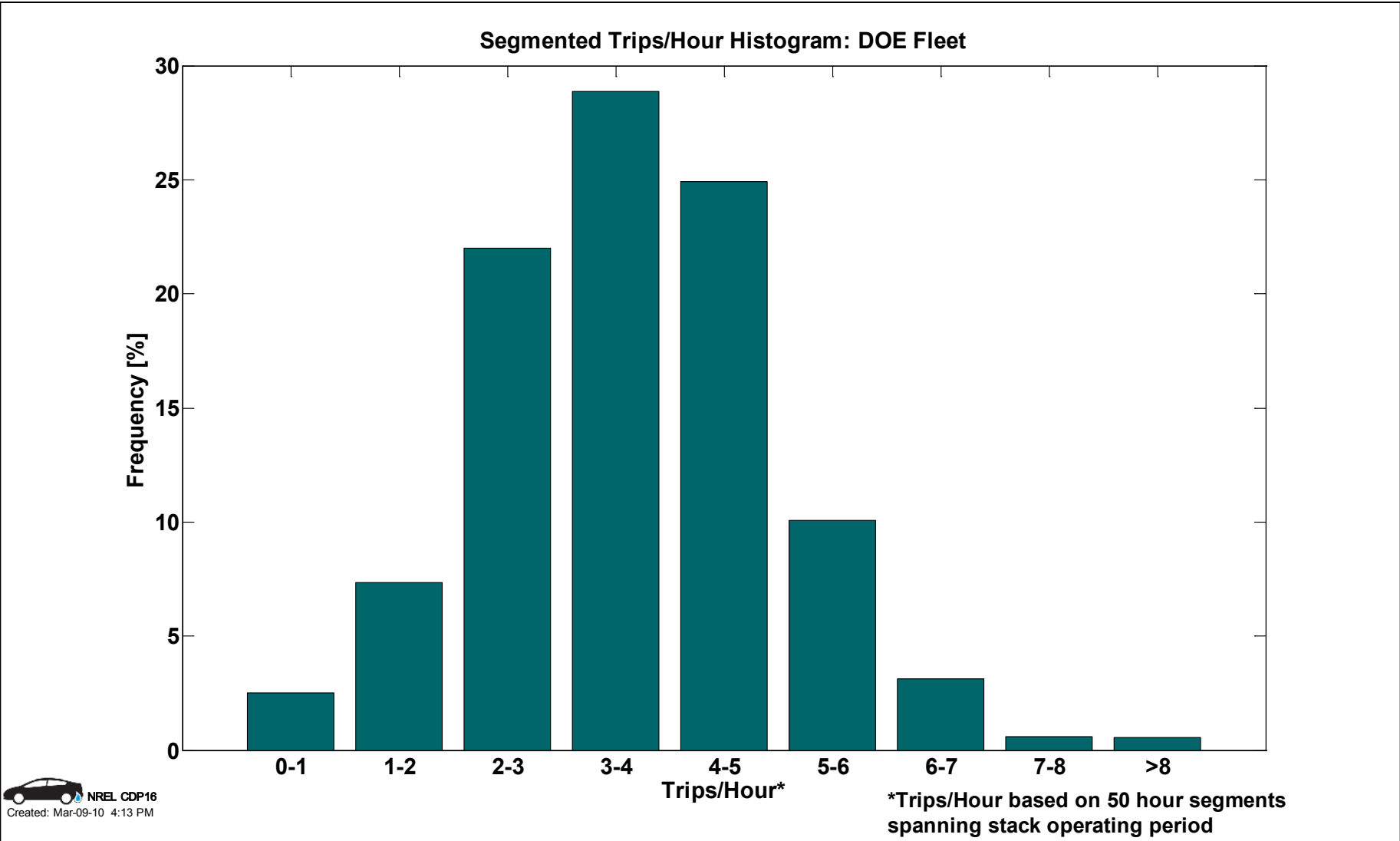
Key H2 Cost Elements and Ranges		
Input Parameter	Minimum (P10)	Maximum (P90)
Facility Direct Capital Cost	\$10M	\$25M
Facility Capacity Utilization	85%	95%
Annual Maintenance & Repairs	\$150K	\$600K
Annual Other O&M	\$100K	\$200K
Annual Facility Land Rent	\$50K	\$200K
Natural Gas Prod. Efficiency (LHV)	65%	75%
Electrolysis Prod. Efficiency (LHV)	35%	62%

(1) Reported hydrogen costs are based on estimates of key cost elements from Learning Demonstration energy company partners and represent the cost of producing hydrogen on-site at the fueling station, using either natural gas reformation or water electrolysis, dispensed to the vehicle. Costs reflect an assessment of hydrogen production technologies, not an assessment of hydrogen market demand.

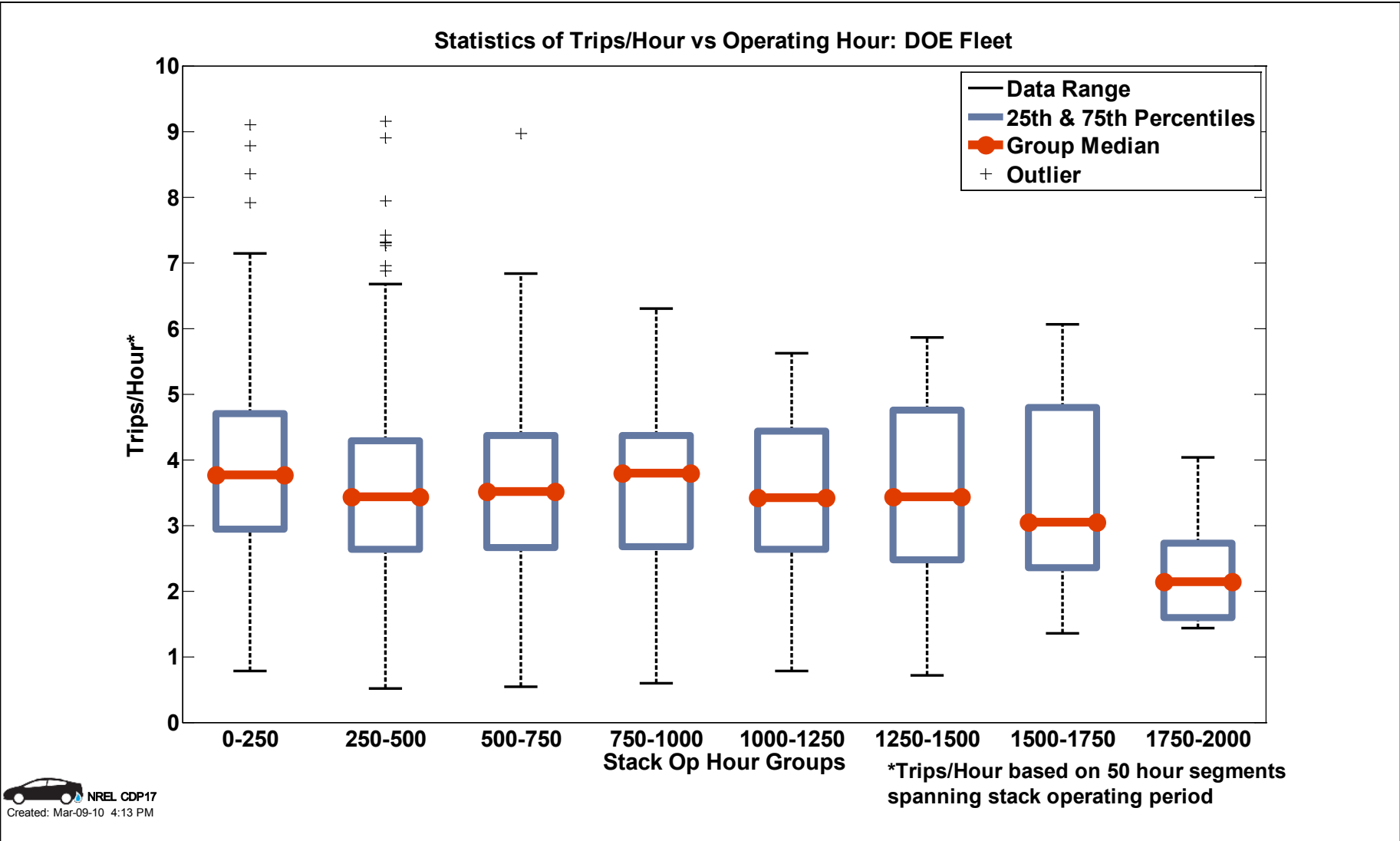
(2) Hydrogen production costs for 1500 kg/day stations developed using DOE's H2A Production model, version 2.1. Cost modeling represents the lifetime cost of producing hydrogen at fueling stations installed during an early market rollout of hydrogen infrastructure and are not reflective of the costs that might be seen in a fully mature market for hydrogen installations. Modeling uses default H2A Production model inputs supplemented with feedback from Learning Demonstration energy company partners, based on their experience operating on-site hydrogen production stations. H2A-based Monte Carlo simulations (2,000 trials) were completed for both natural gas reforming and electrolysis stations using default H2A values and 10th percentile to 90th percentile estimated ranges for key cost parameters as shown in the table. Capacity utilization range is based on the capabilities of the production technologies and could be significantly lower if there is inadequate demand for hydrogen.

(3) DOE has a hydrogen cost goal of \$2-\$3/kg for future (2015) 1500 kg/day hydrogen production stations installed at a rate of 500 stations per year.

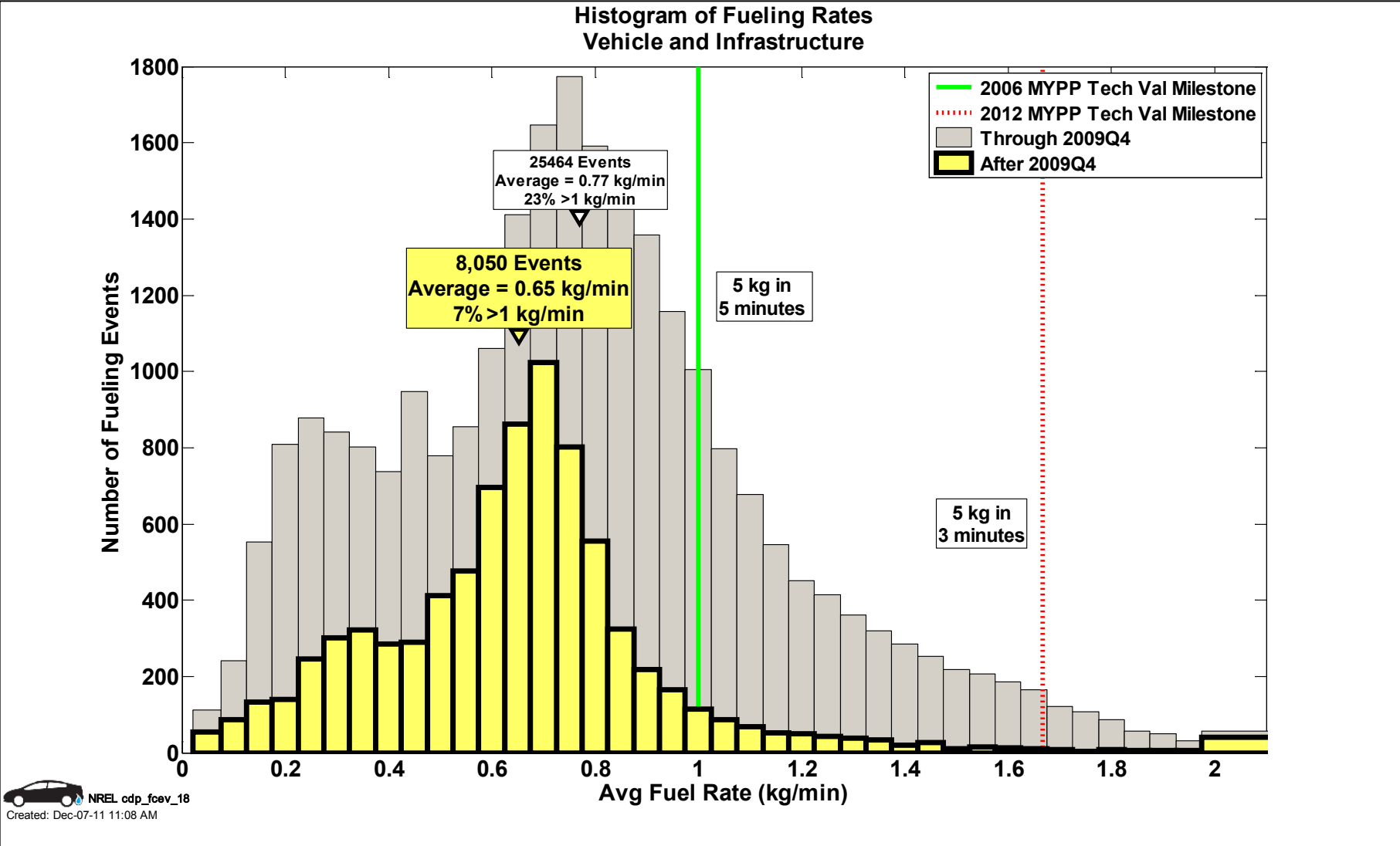
# CDP#16: Fuel Cell Stack Trips Per Hour Histogram



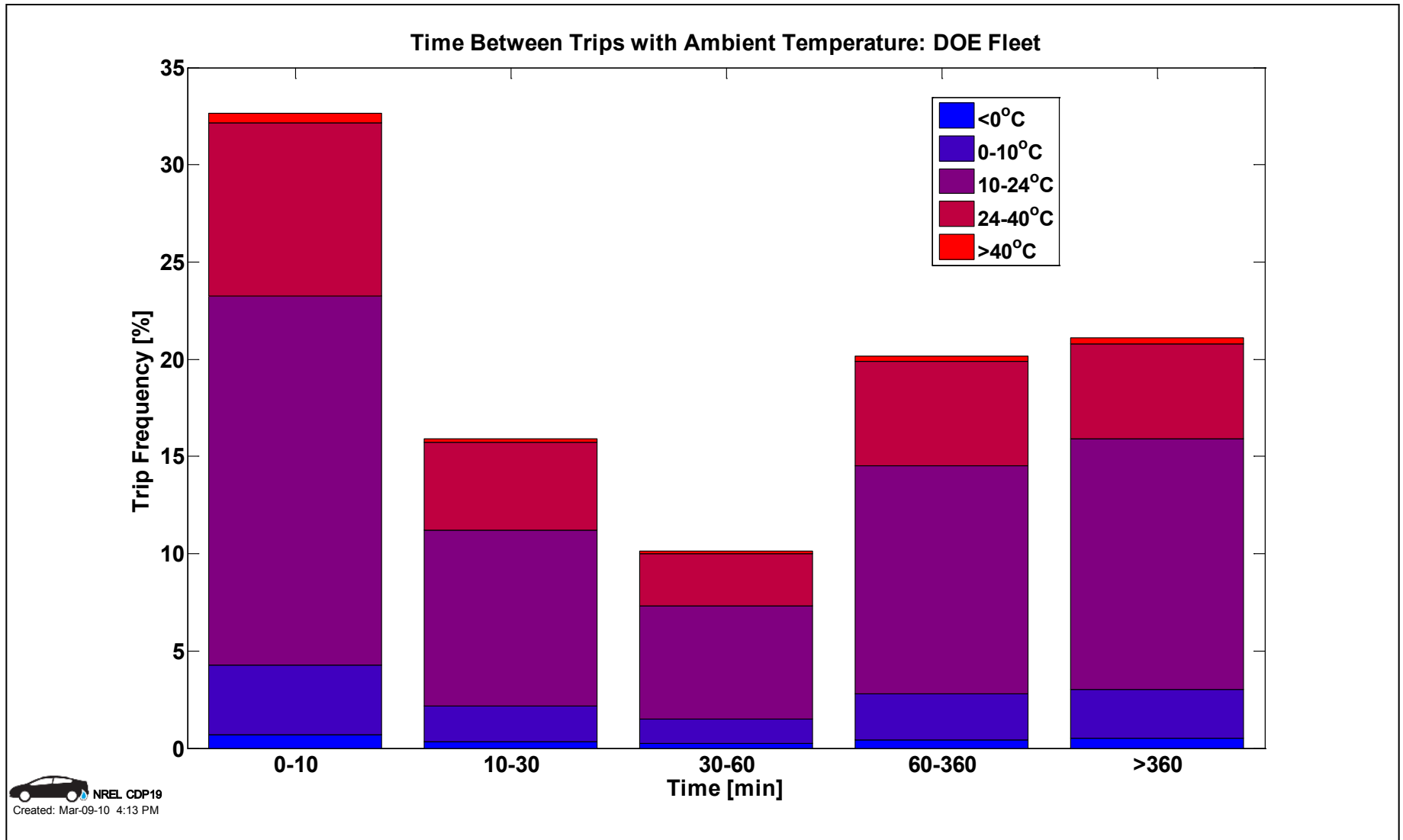
# CDP#17: Statistics of Trips/Hour vs. Operating Hour



# CDP#18: Refueling Rates

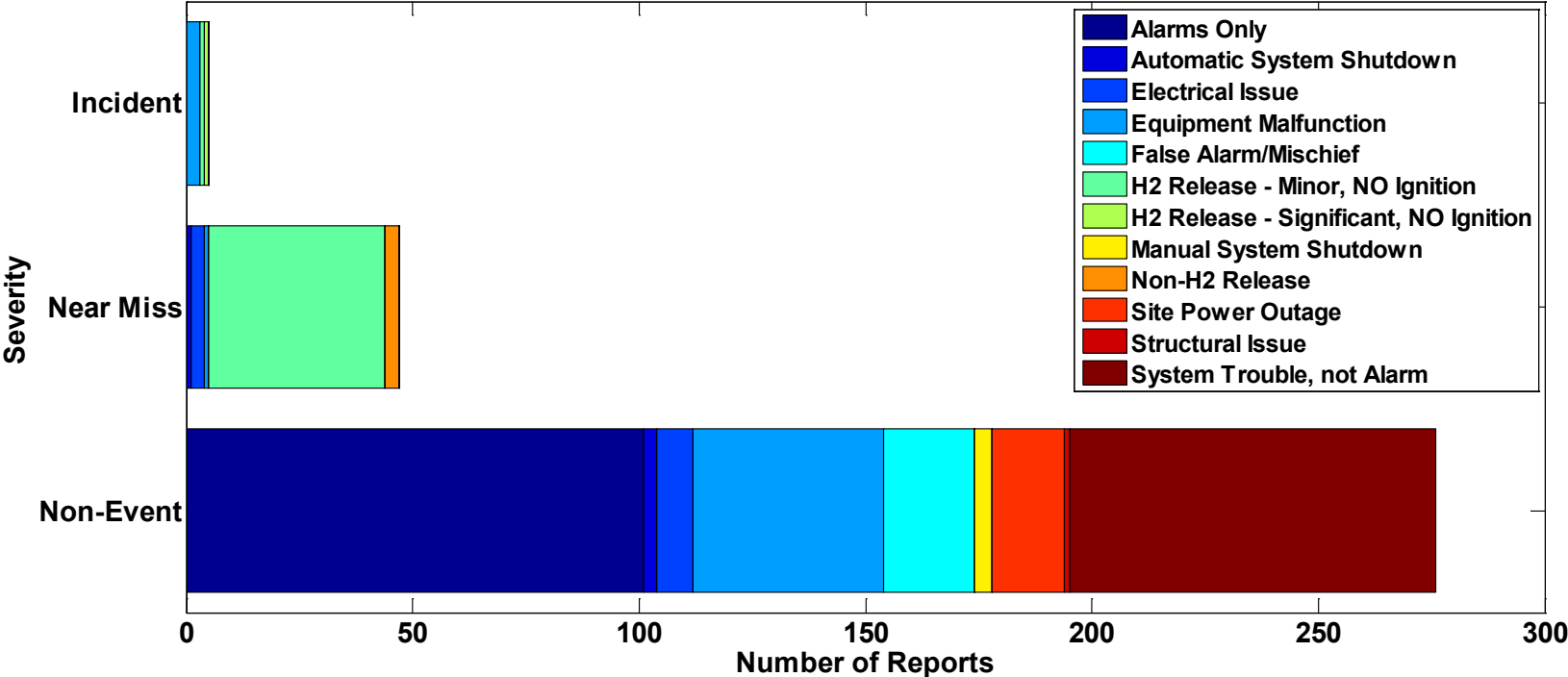


# CDP#19: Time Between Trips & Ambient Temperature



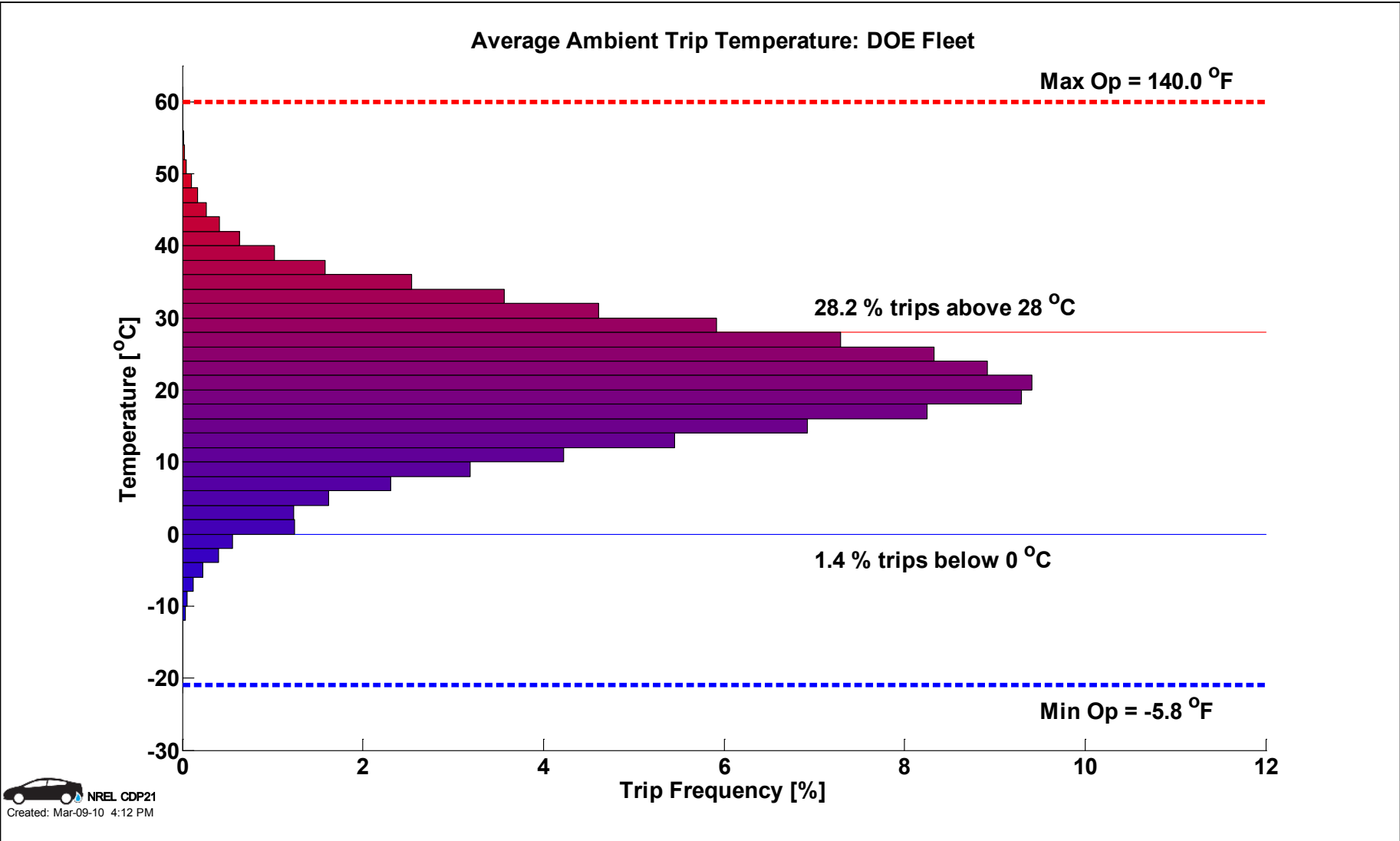
# CDP#20: Safety Reports – Infrastructure

Total Infrastructure Safety Reports by Severity and Report Type Through 2009 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

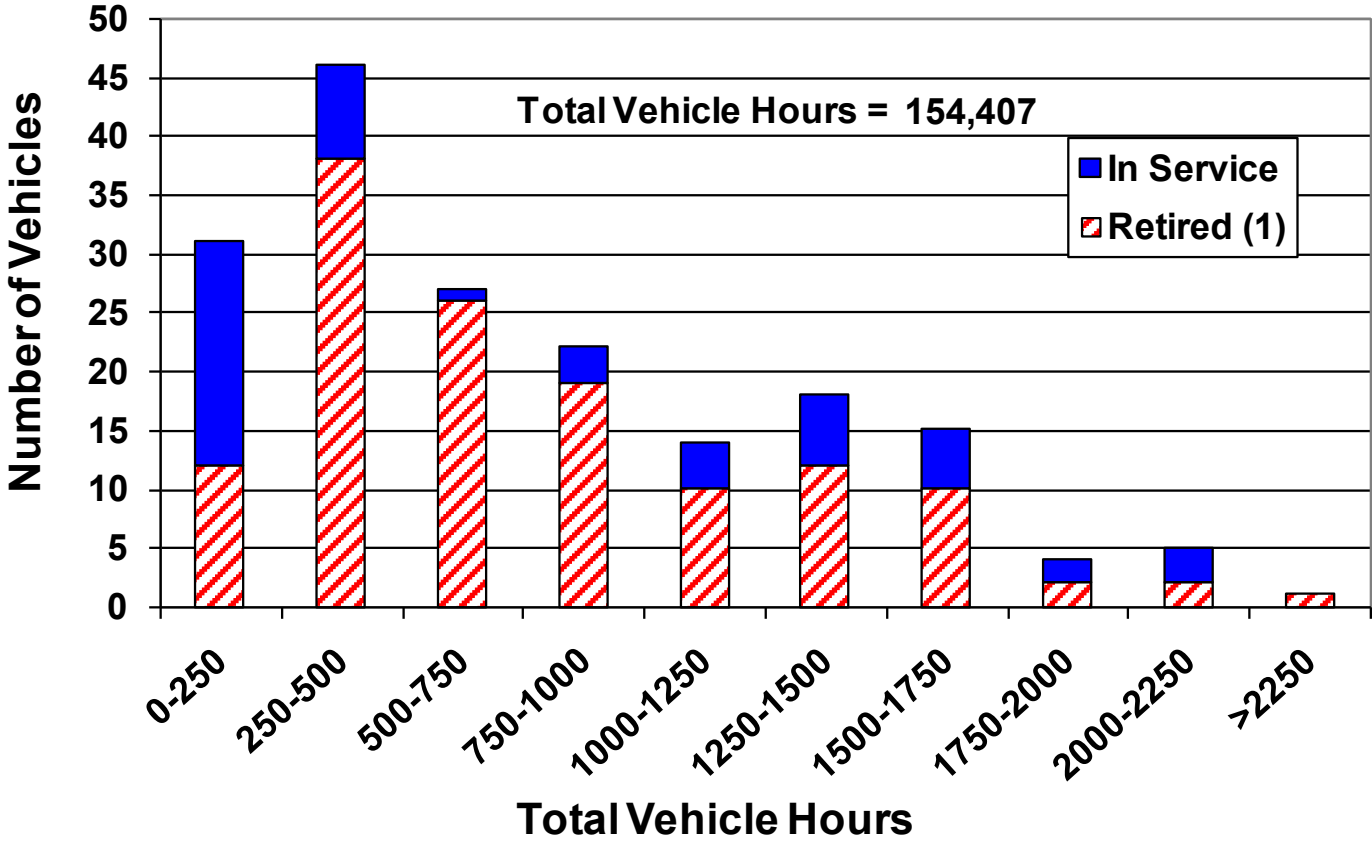
# CDP#21: Range of Ambient Temperature During Vehicle Operation





# CDP#22: Vehicle Operating Hours

Vehicle Hours: All OEMs, Gen 1 and Gen 2  
Through 2011 Q3



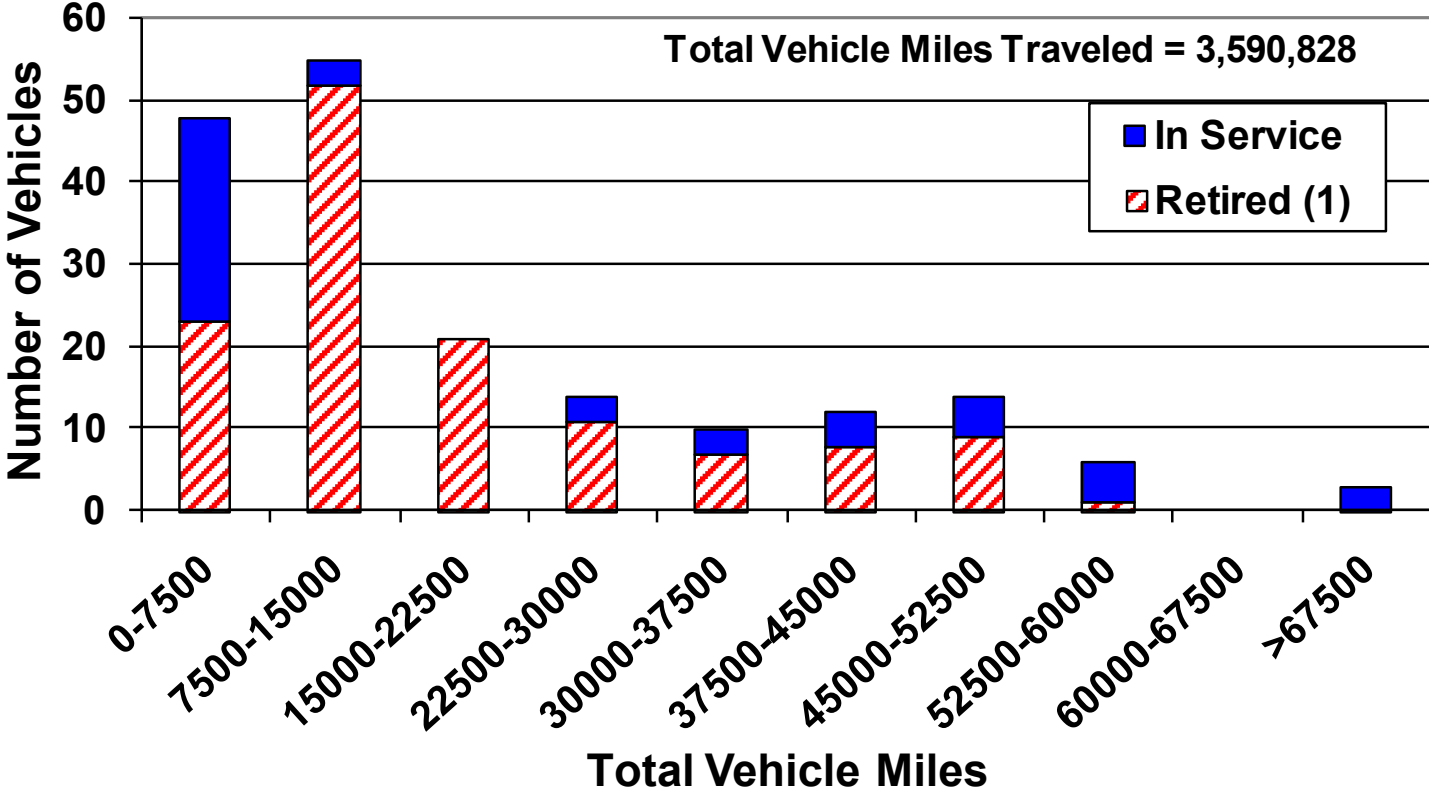
NREL cdp\_fcvev\_22

Created: Dec-13-11 04:15 PM

(1) Retired vehicles have left DOE fleet and are no longer providing data to NREL. Some project teams concluded in Fall/Winter 2009

# CDP#23: Vehicles vs. Miles Traveled

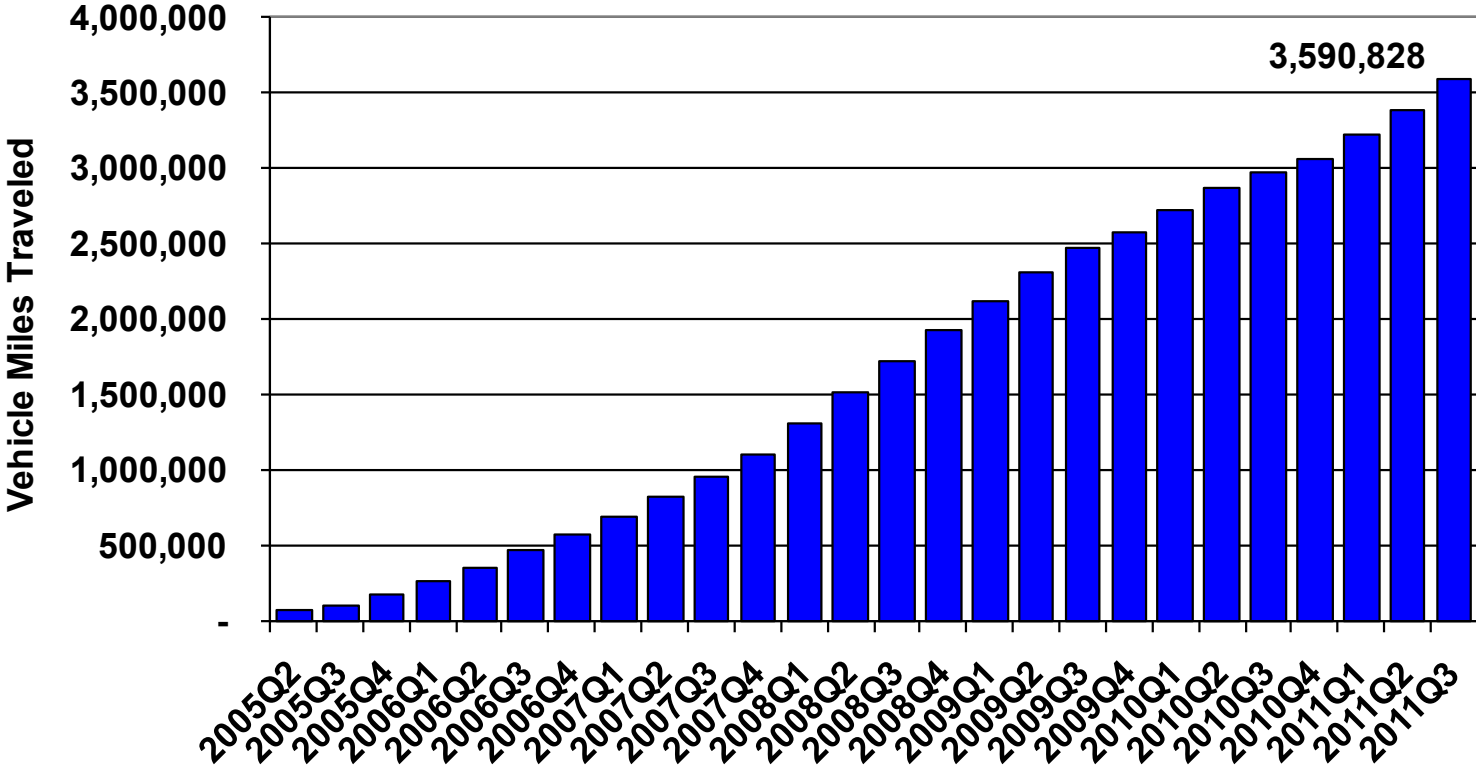
Vehicle Miles: All OEMs, Gen 1 and 2  
Through 2011 Q3



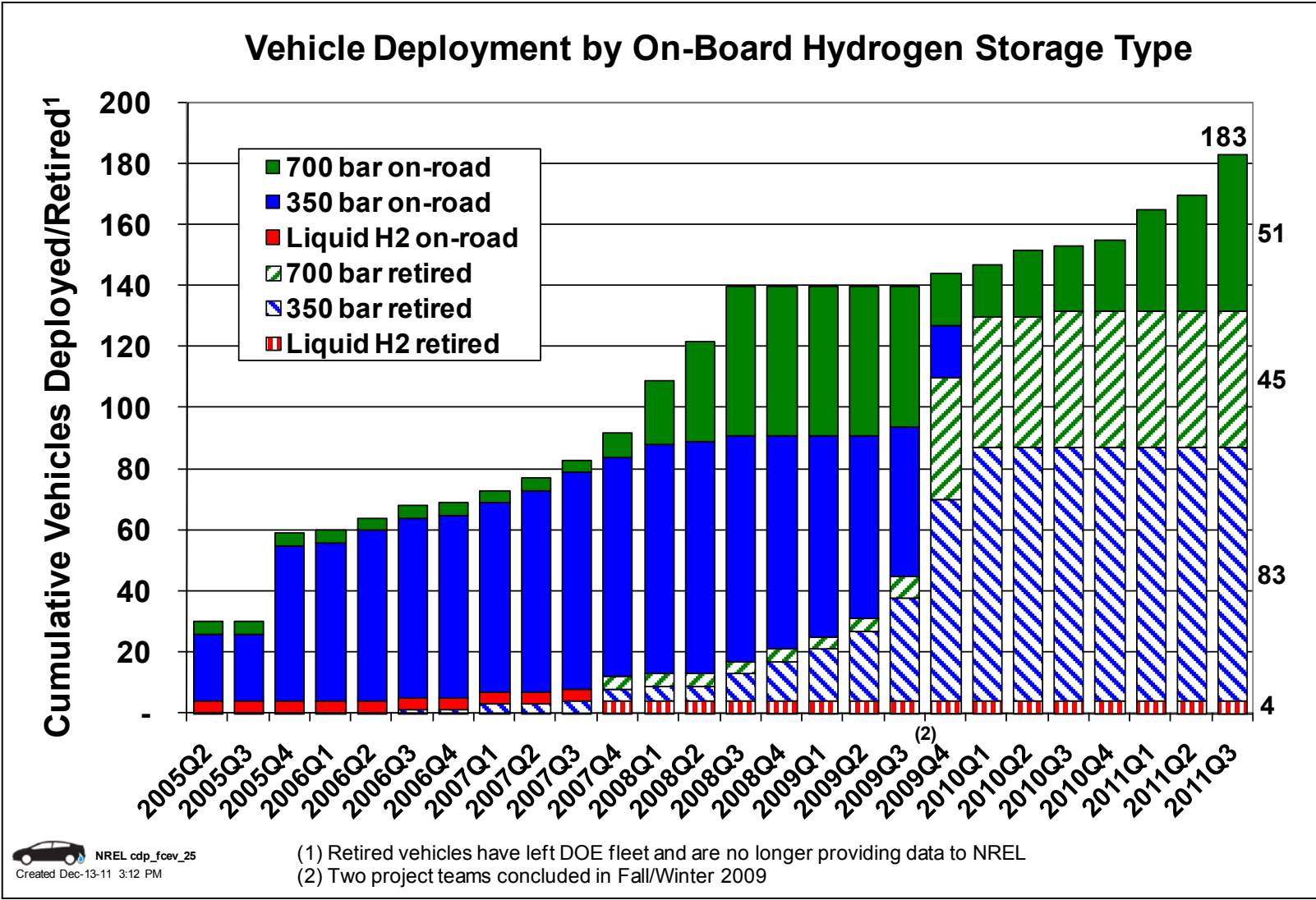
(1) Retired vehicles have left DOE fleet and are no longer providing data to NREL  
Some project teams concluded in Fall/Winter 2009

# CDP#24: Cumulative Vehicle Miles Traveled

Cumulative Vehicle Miles: All OEMs, Gen 1 and Gen 2  
Through 2011 Q3

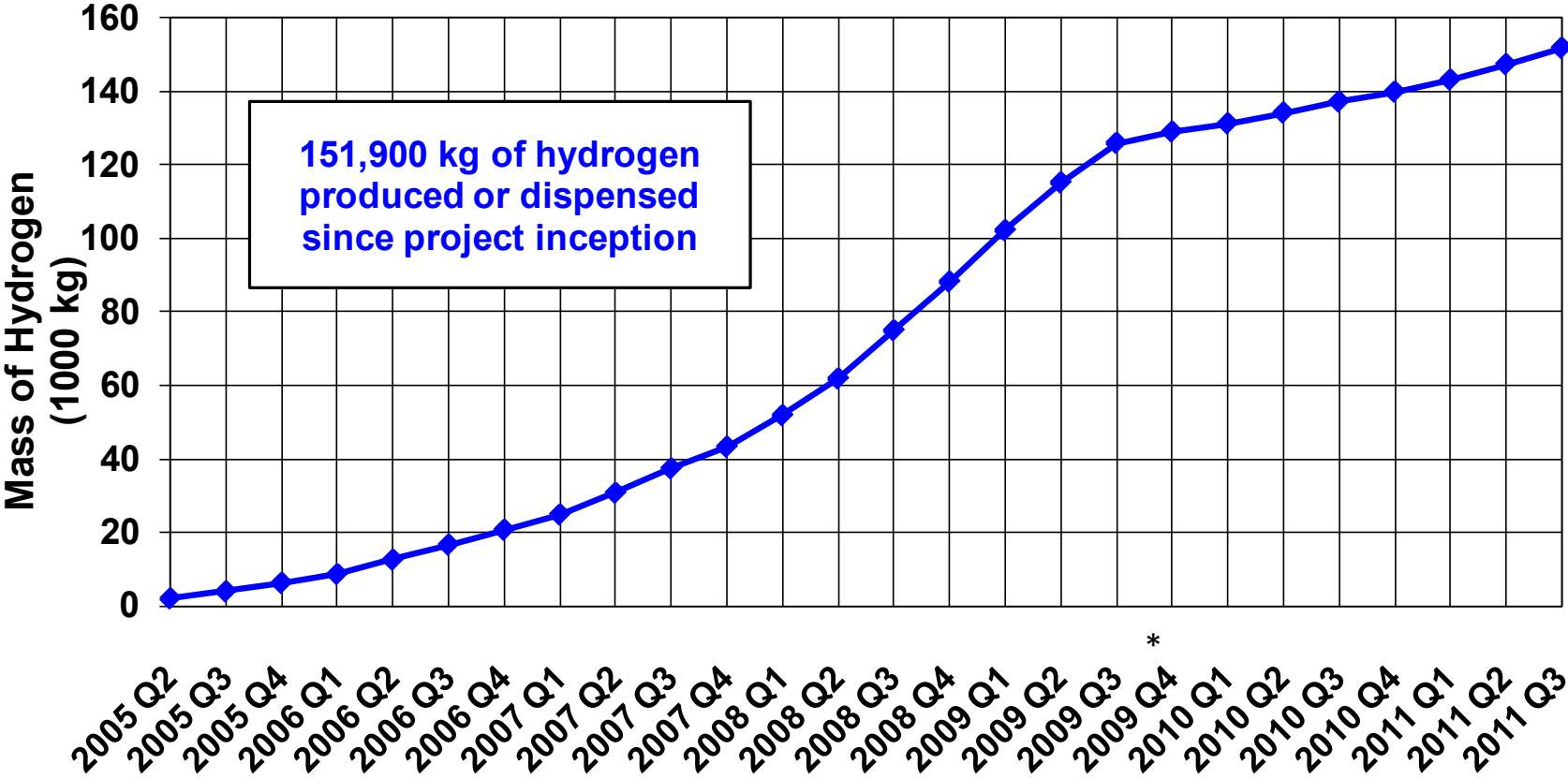


# CDP#25: Vehicle H2 Storage Technologies

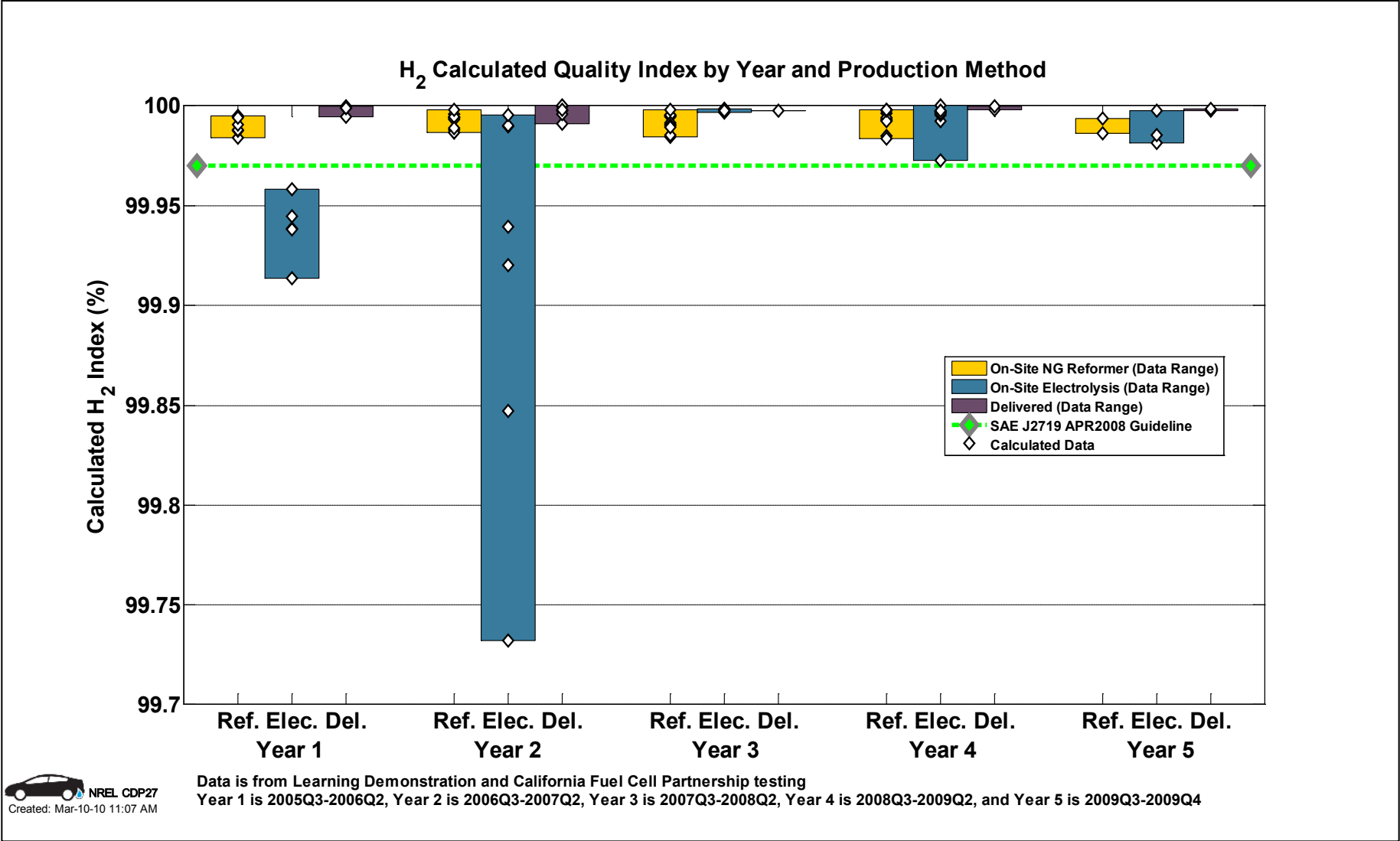


# CDP#26: Cumulative H2 Produced or Dispensed

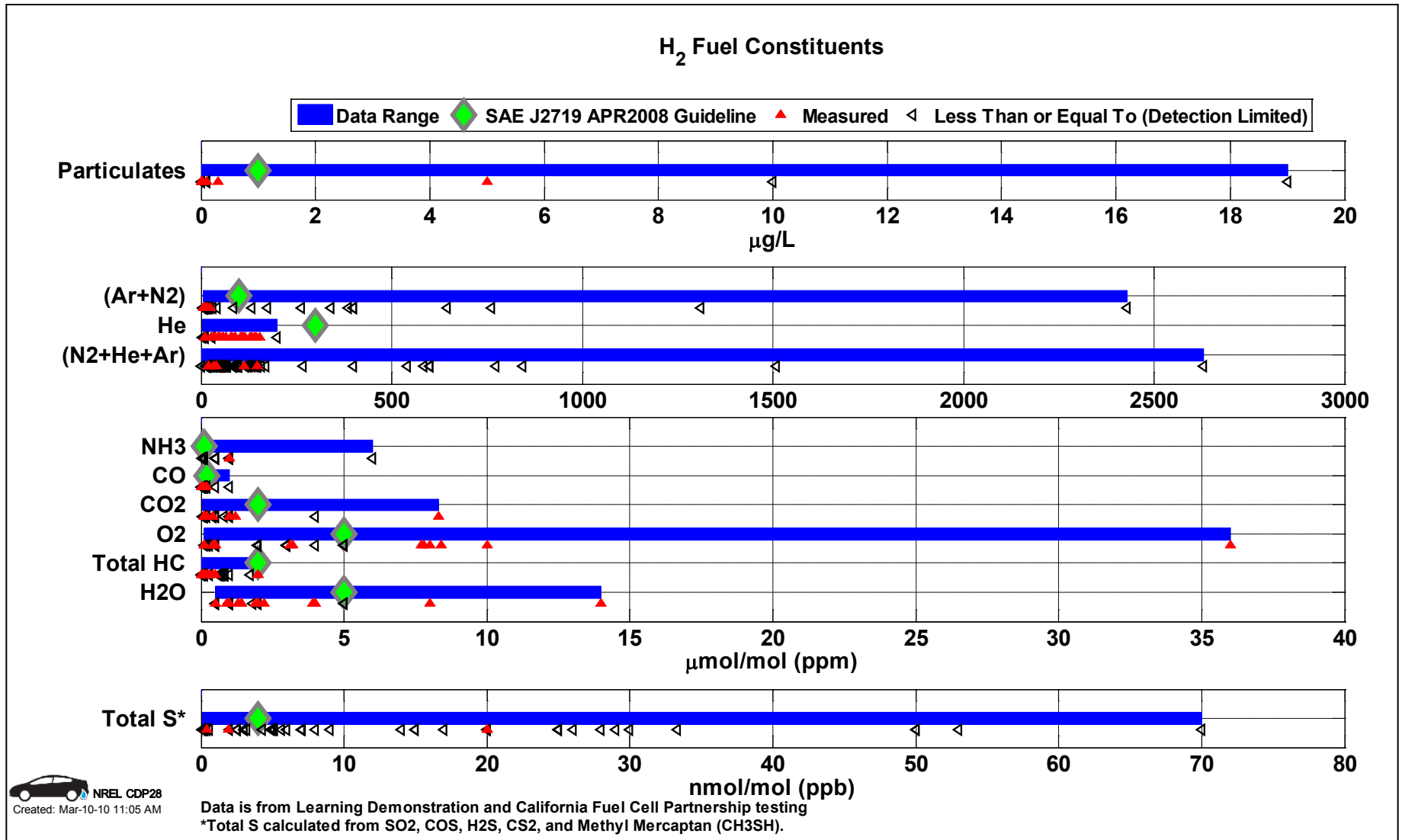
## Cumulative Hydrogen Produced or Dispensed Through 2011 Q3



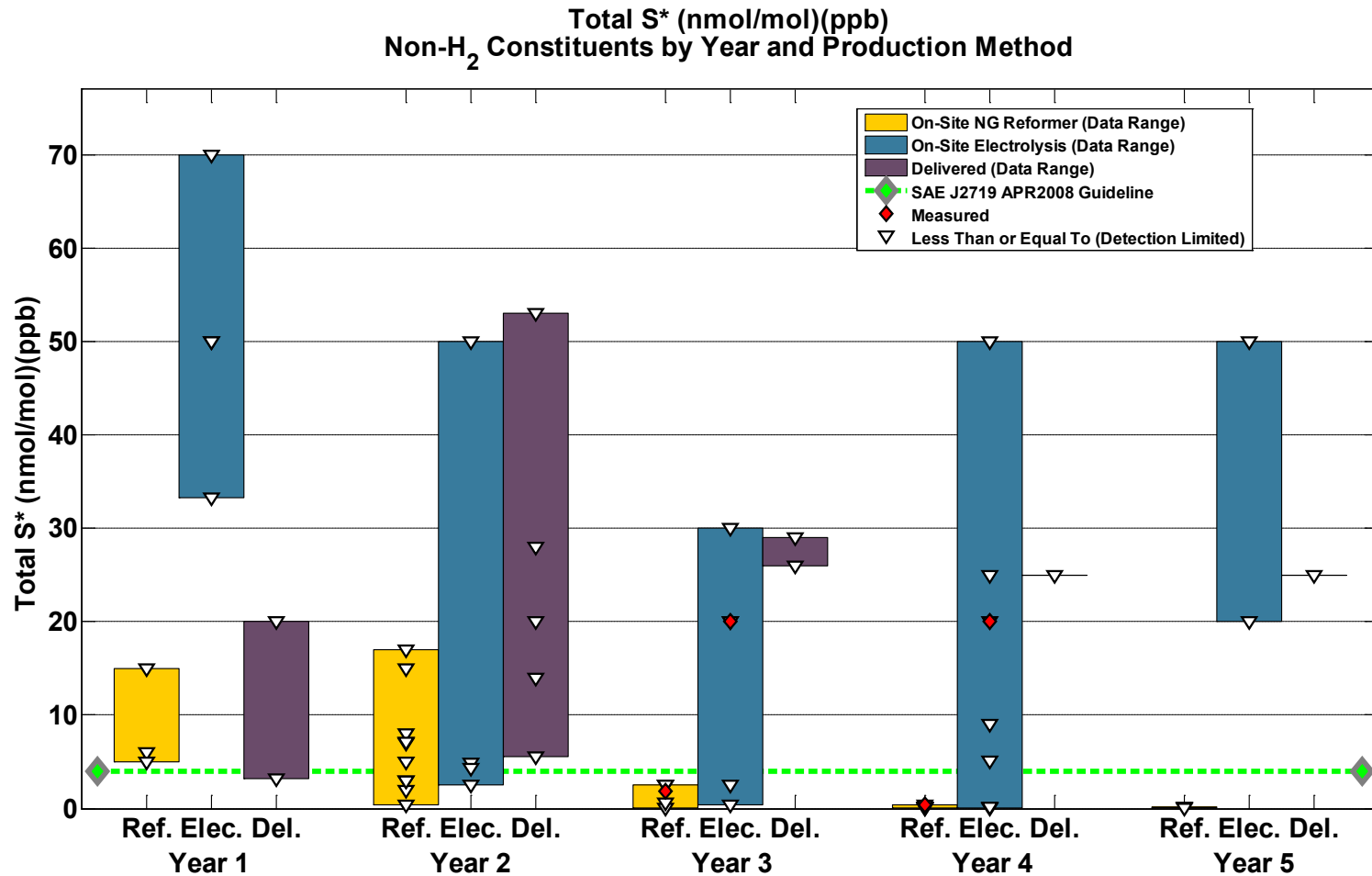
# CDP#27: Hydrogen Quality Index



# CDP#28: Hydrogen Fuel Constituents



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

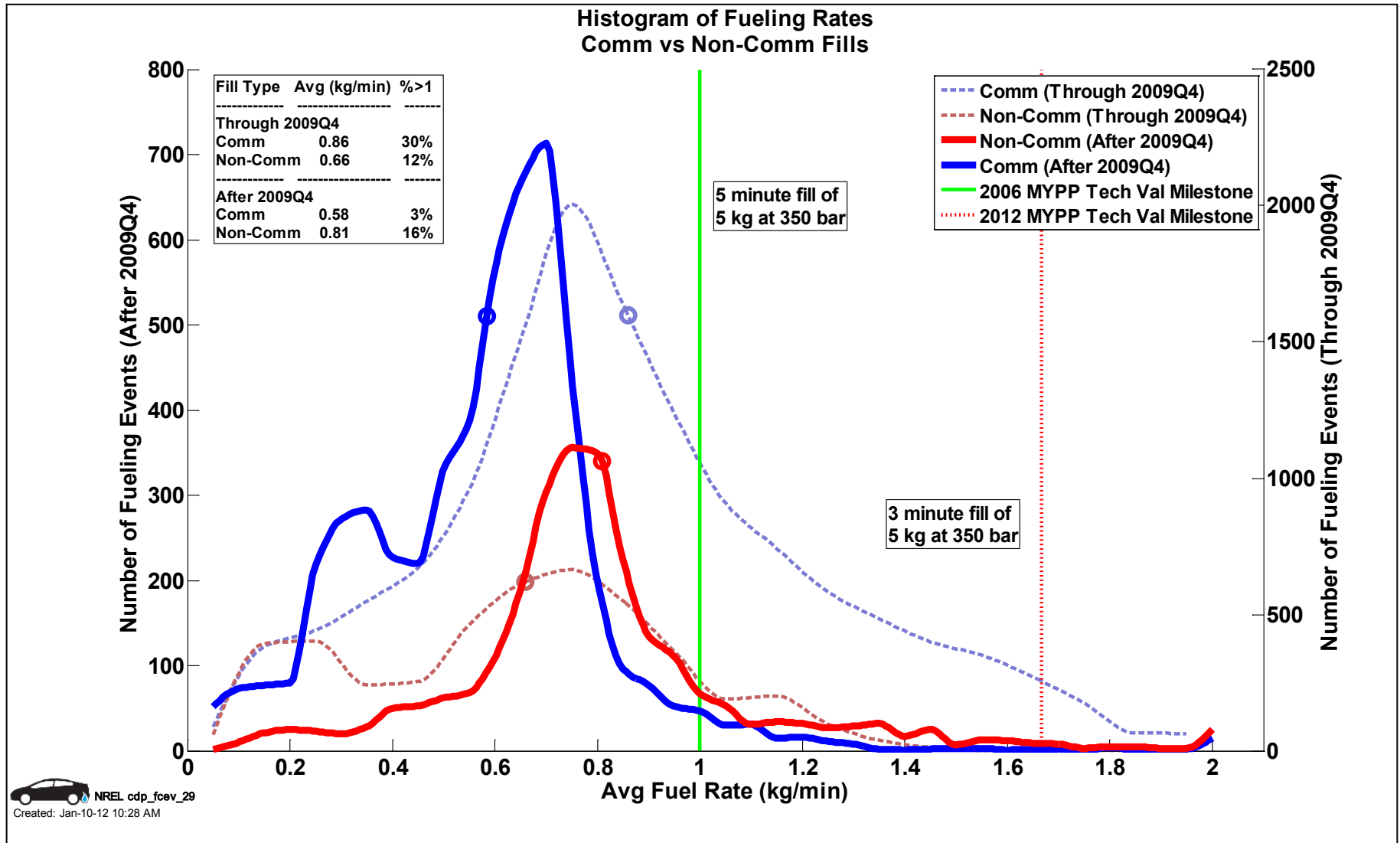


Data is from Learning Demonstration and California Fuel Cell Partnership testing  
 Year 1 is 2005Q3-2006Q2, Year 2 is 2006Q3-2007Q2, Year 3 is 2007Q3-2008Q2, Year 4 is 2008Q3-2009Q2, and Year 5 is 2009Q3-2009Q4  
 \*Total S calculated from SO<sub>2</sub>, COS, H<sub>2</sub>S, CS<sub>2</sub>, and Methyl Mercaptan (CH<sub>3</sub>SH).

(This slide contains 18 graphs (1 for each constituent): view in slide-show mode)

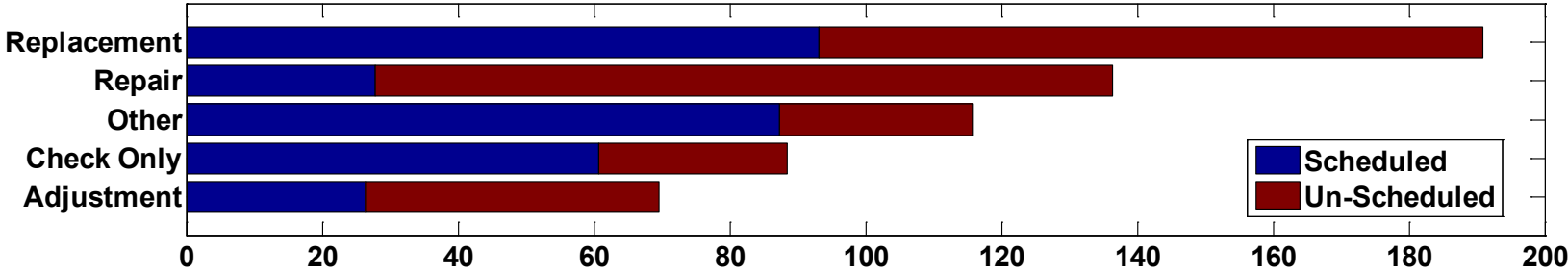


# CDP#29: Fueling Rates by Communication Type

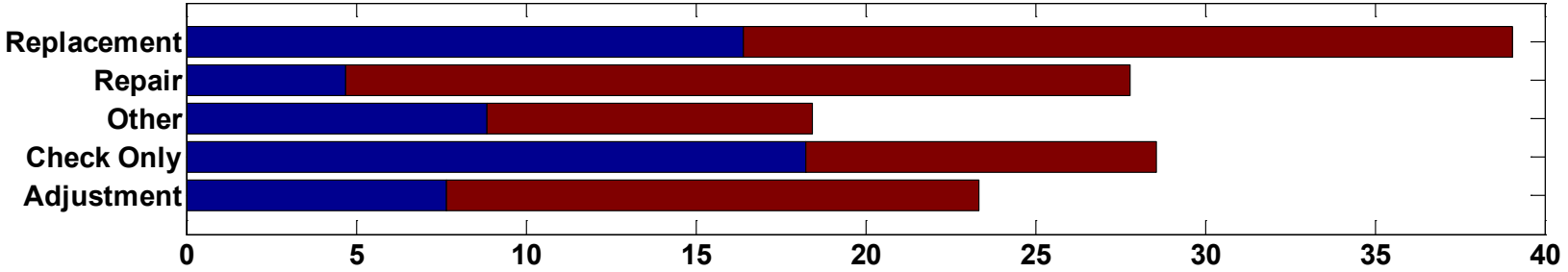


# CDP#30: Infrastructure Maintenance

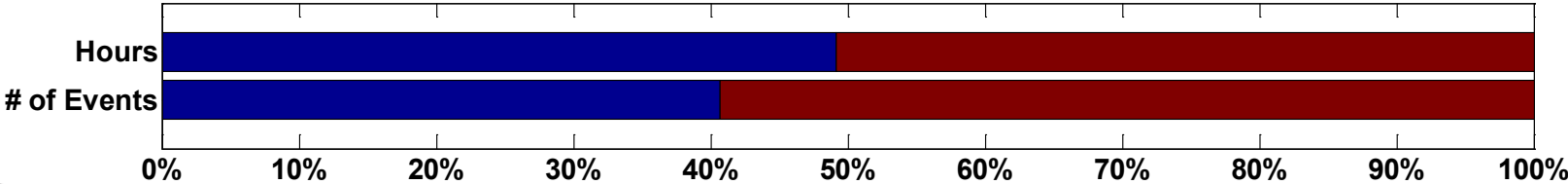
Maintenance: Average Labor Hours Per Station Since Inception Through 2009 Q4



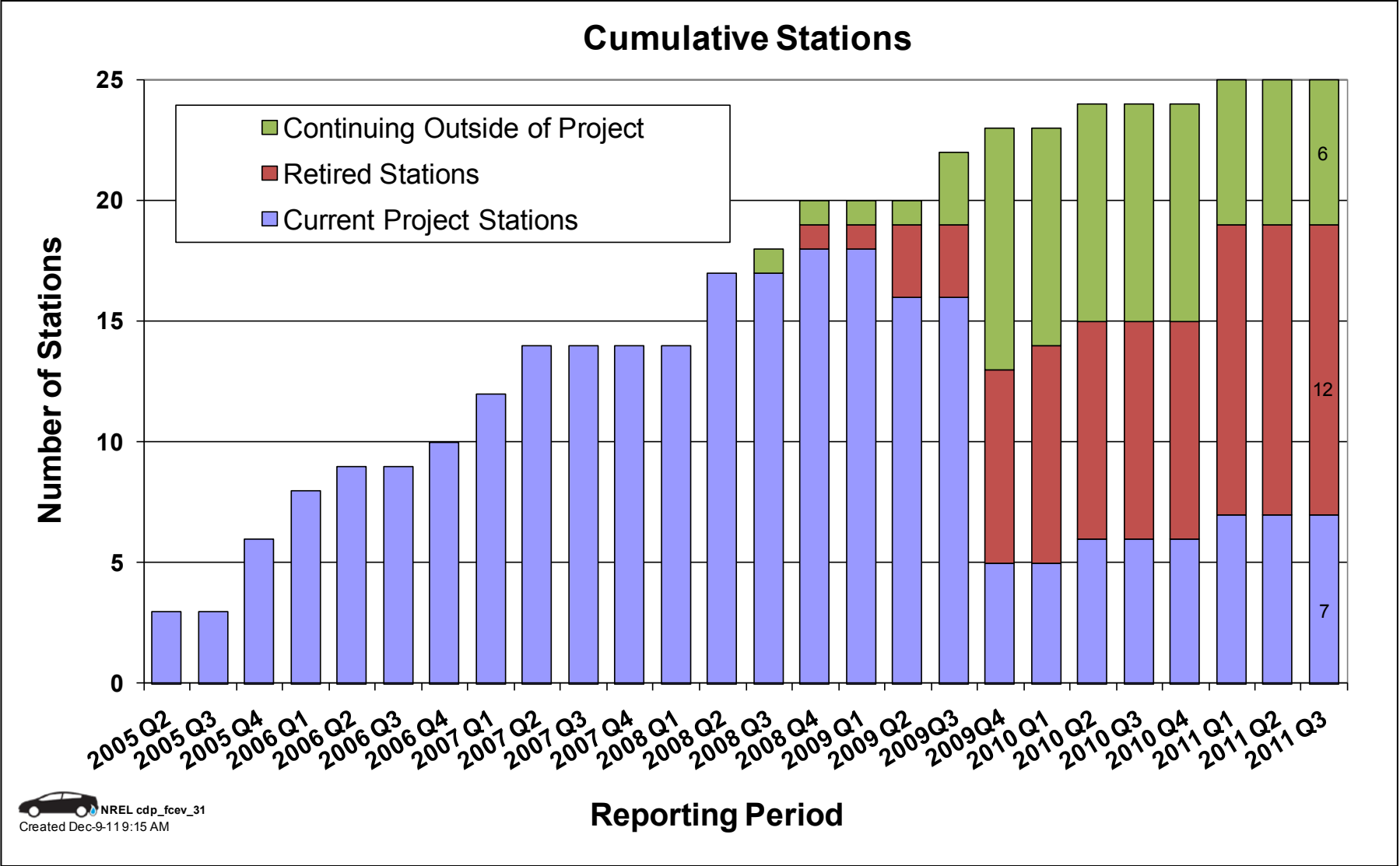
Maintenance: Average Number of Events Per Station Since Inception



Comparison of Scheduled/Un-Scheduled Maintenance

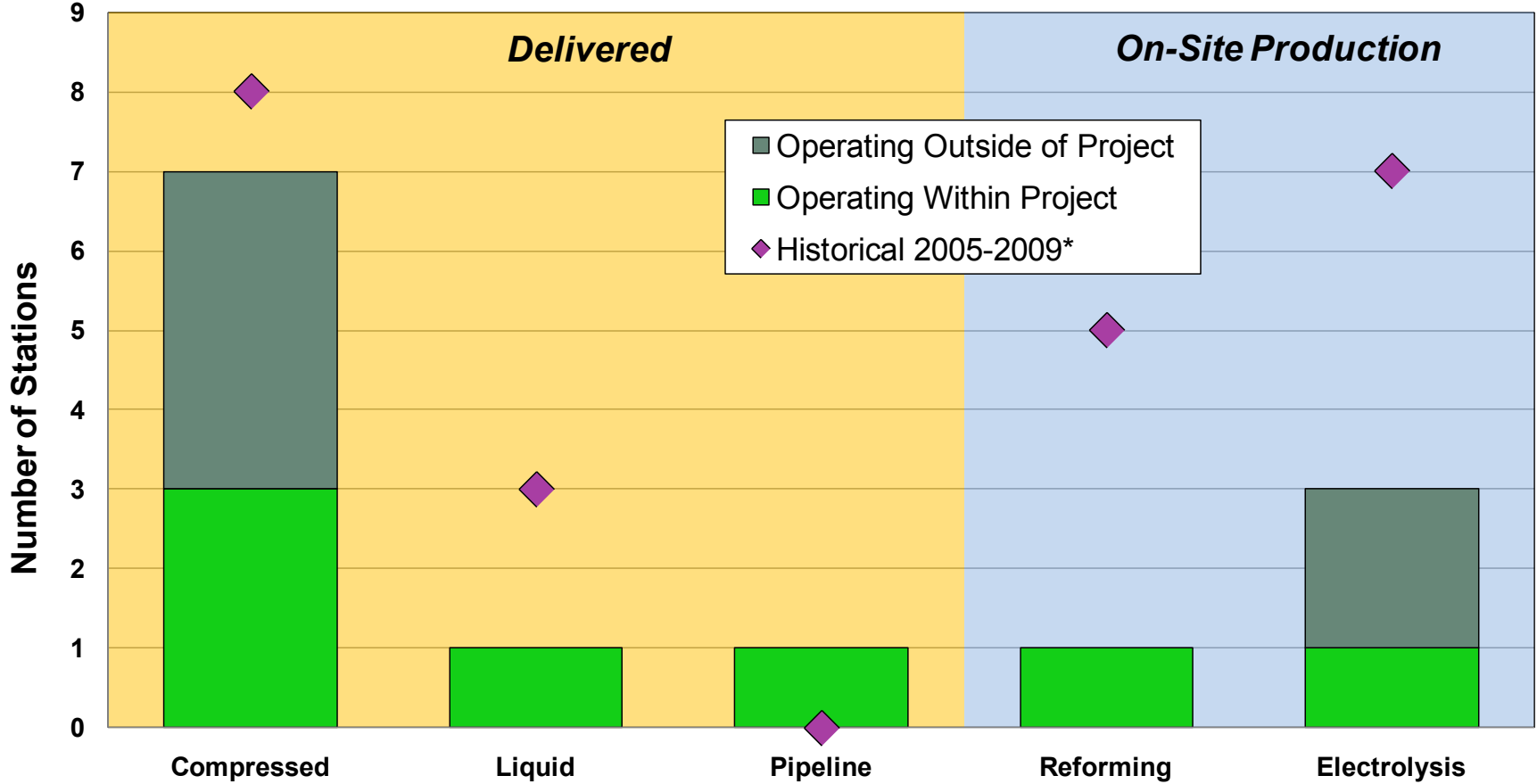


# CDP#31: Number of Online Stations



# CDP#32: Infrastructure Hydrogen Production Methods

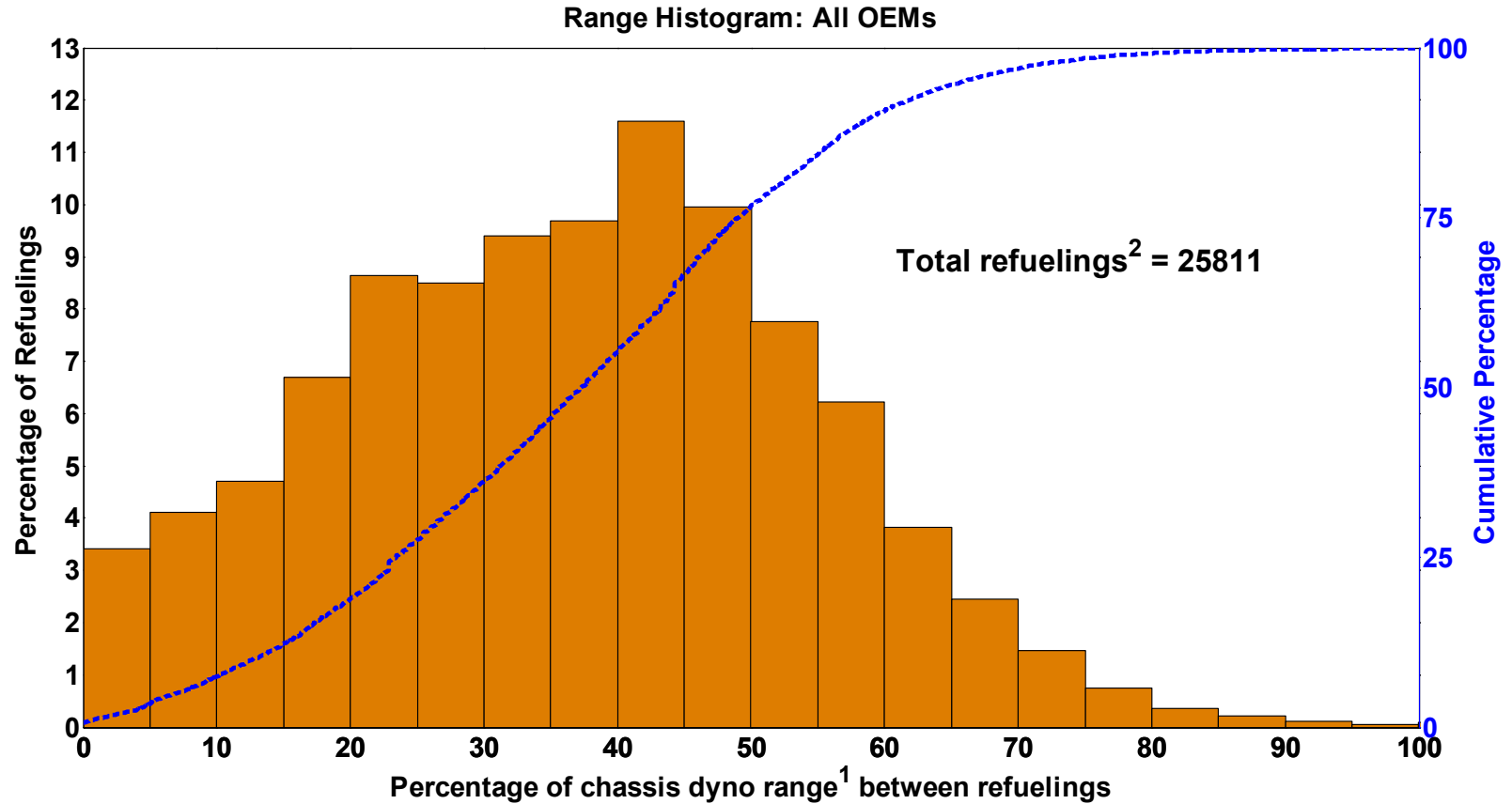
Learning Demonstration Hydrogen Stations by Type



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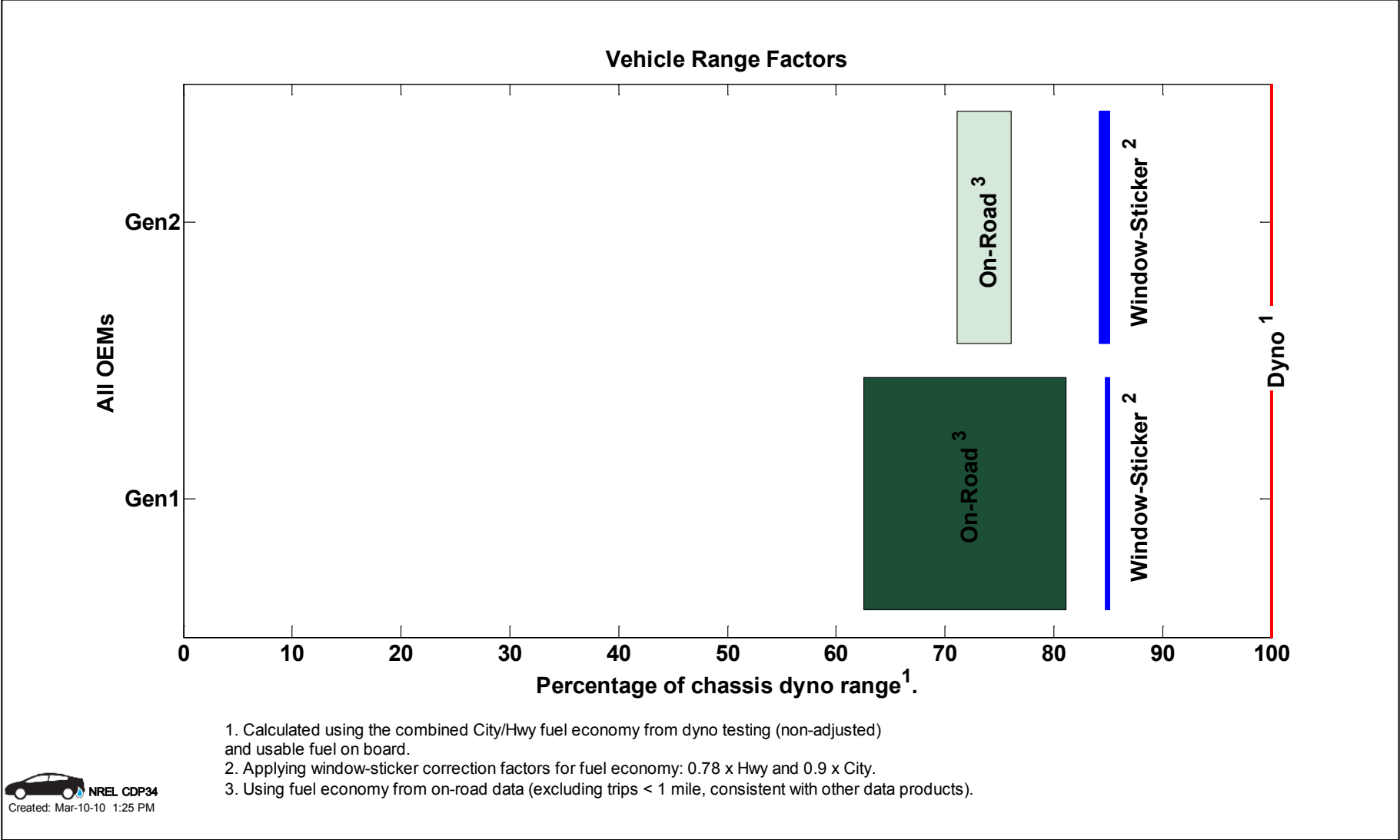
\*Some project teams concluded Fall/Winter 2009. Markers show the cumulative stations operated during the 2005-2009 period

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



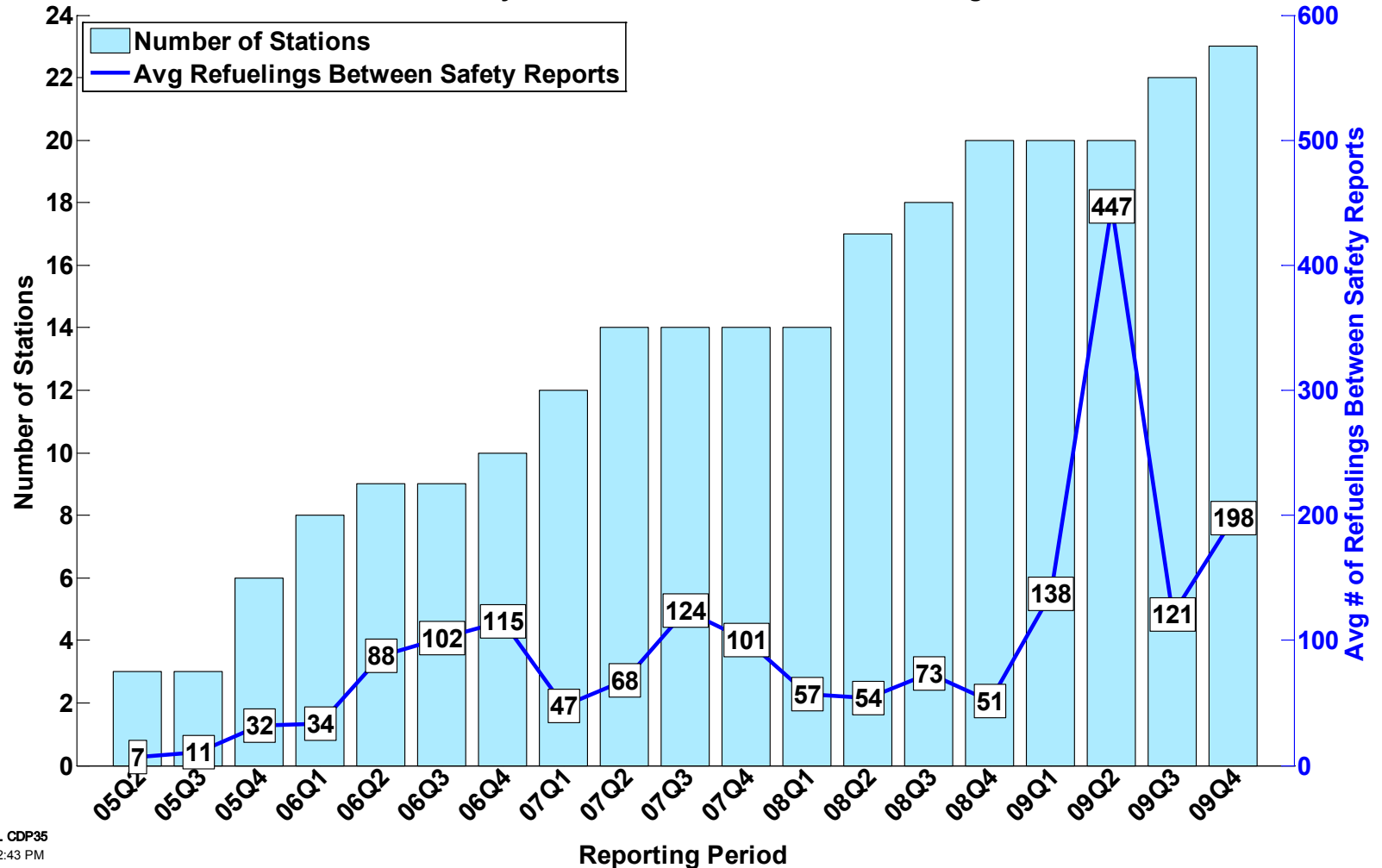
1. Range calculated using the combined City/Hwy fuel economy from dyno testing (not EPA adjusted) and usable fuel on board.
2. Some refueling events are not detected/reported due to data noise or incompleteness.

# CDP#34: Effective Vehicle Range

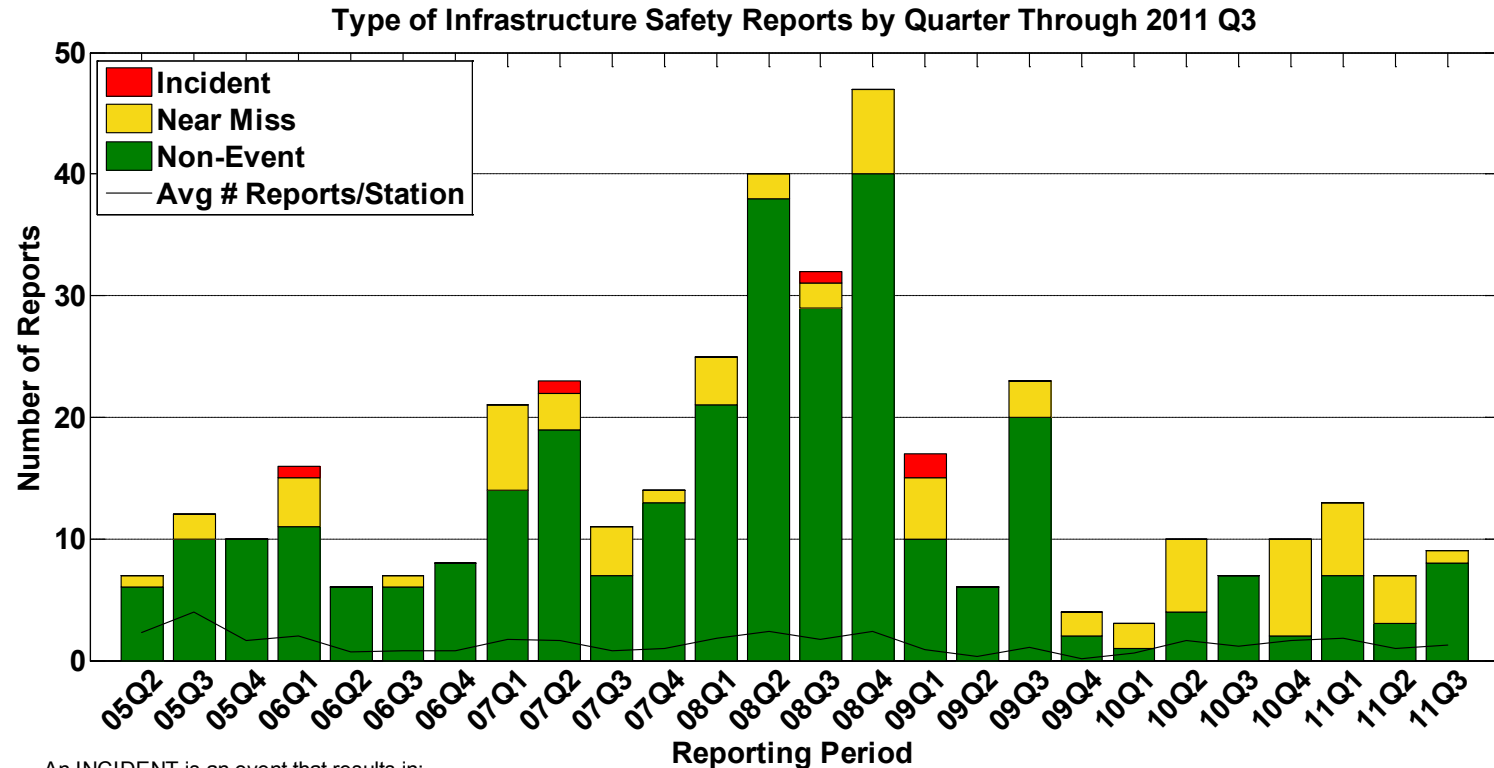


# CDP#35: Average Refuelings Between Infrastructure Safety Reports

Infrastructure Safety Trend and Number of Stations Through 2009 Q4



# 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:

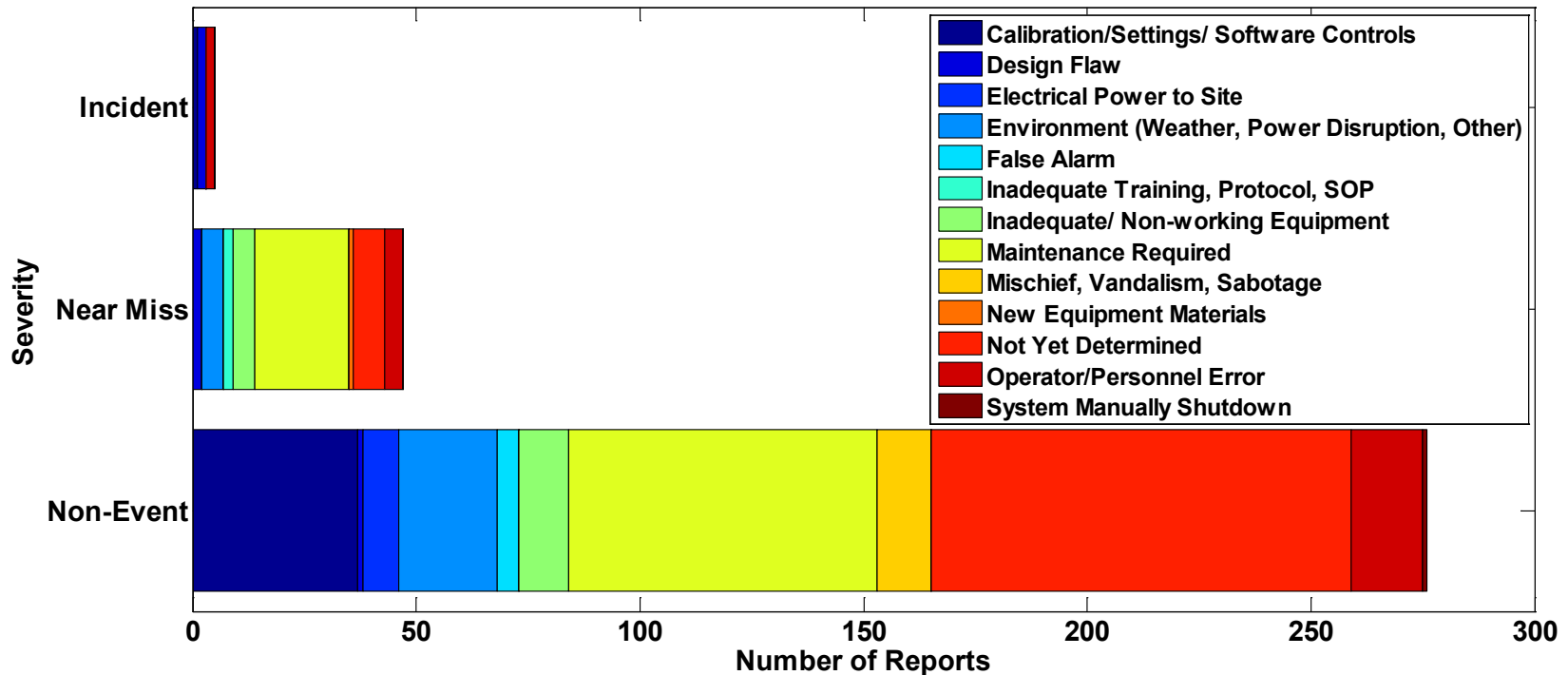
- an event that under slightly different circumstances could have become an incident
- unplanned H2 release insufficient to sustain a flame



# CDP#37: Primary Factors of Infrastructure Safety Reports

## Safety Reports

Primary Factors of Infrastructure Safety Reports  
Through 2009 Q4



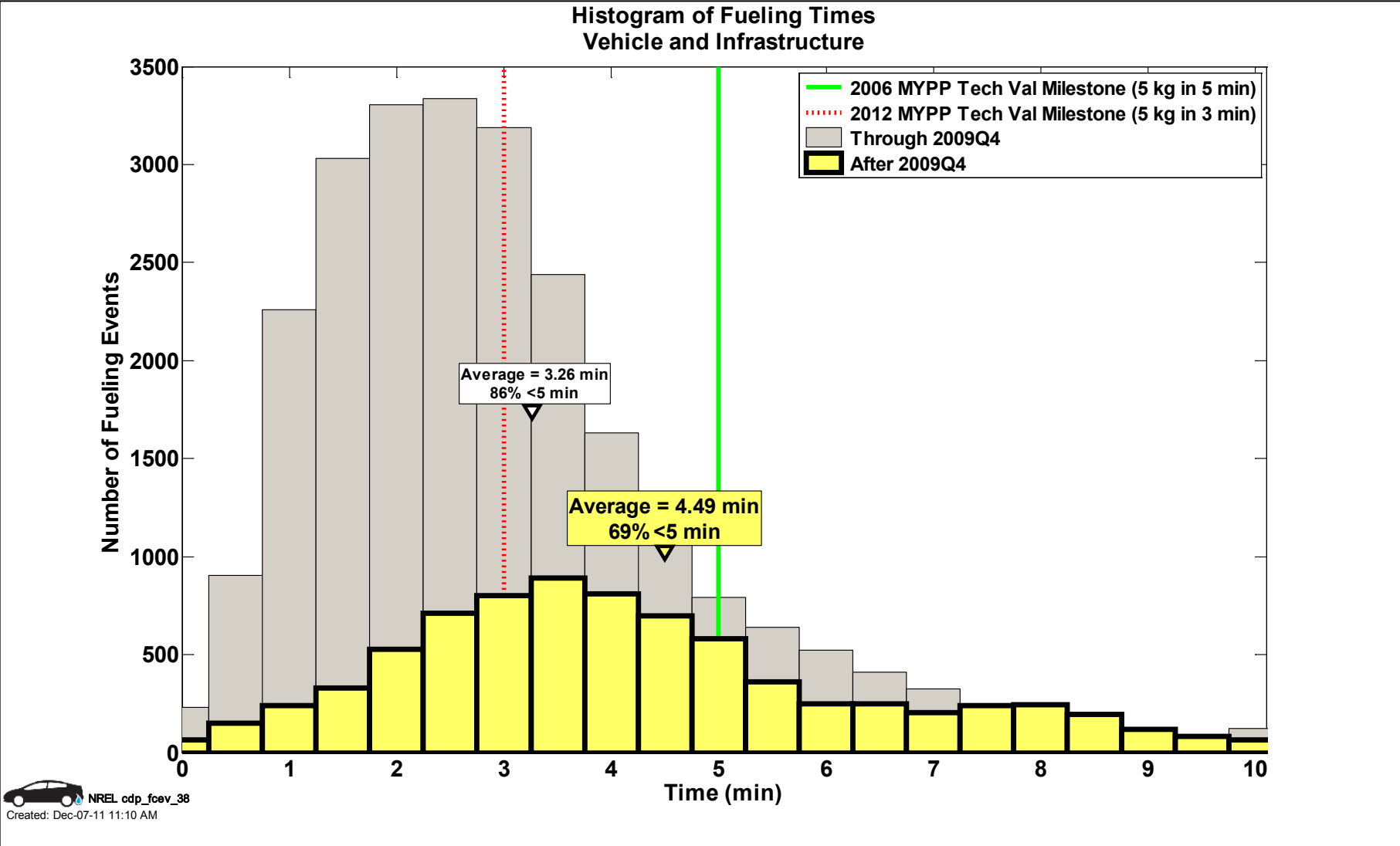
An INCIDENT is an event that results in:

- 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)

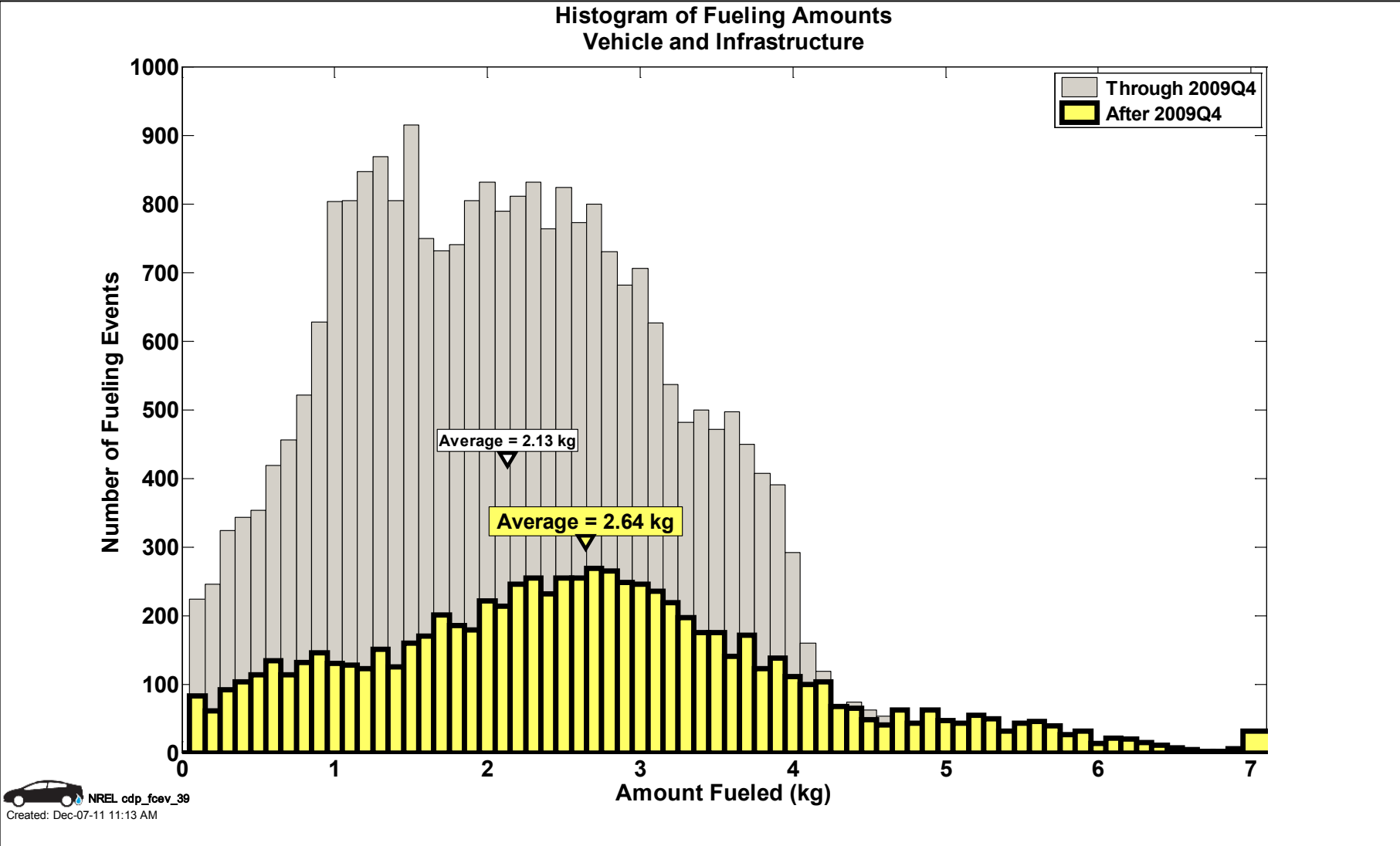
A NEAR-MISS is:

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

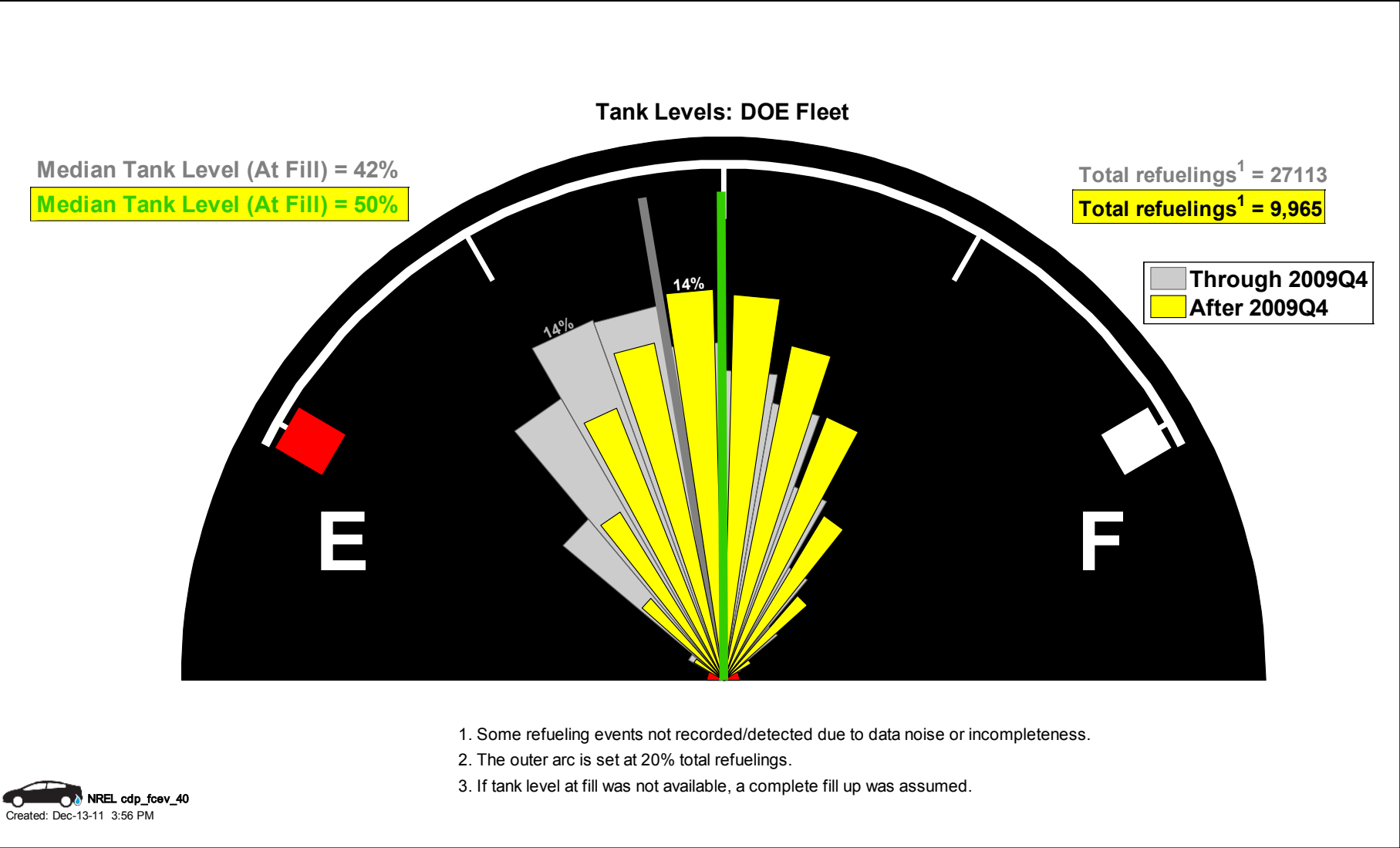
# CDP#38: Refueling Times



# CDP#39: Refueling Amounts



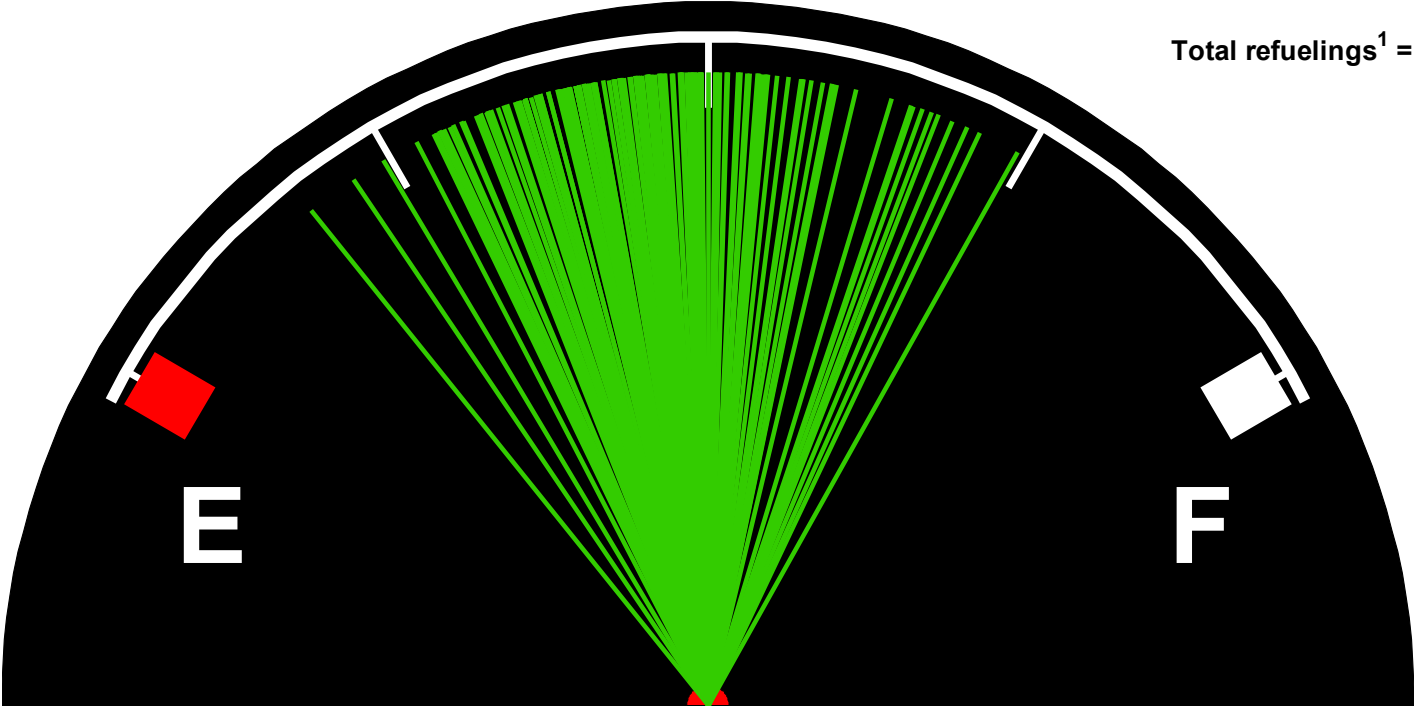
# CDP#40: H2 Tank Level at Refueling



# CDP#41: Refueling Tank Levels - Medians

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

Total refuelings<sup>1</sup> = 27113



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.

# CDP#42: Refueling by Time of Day

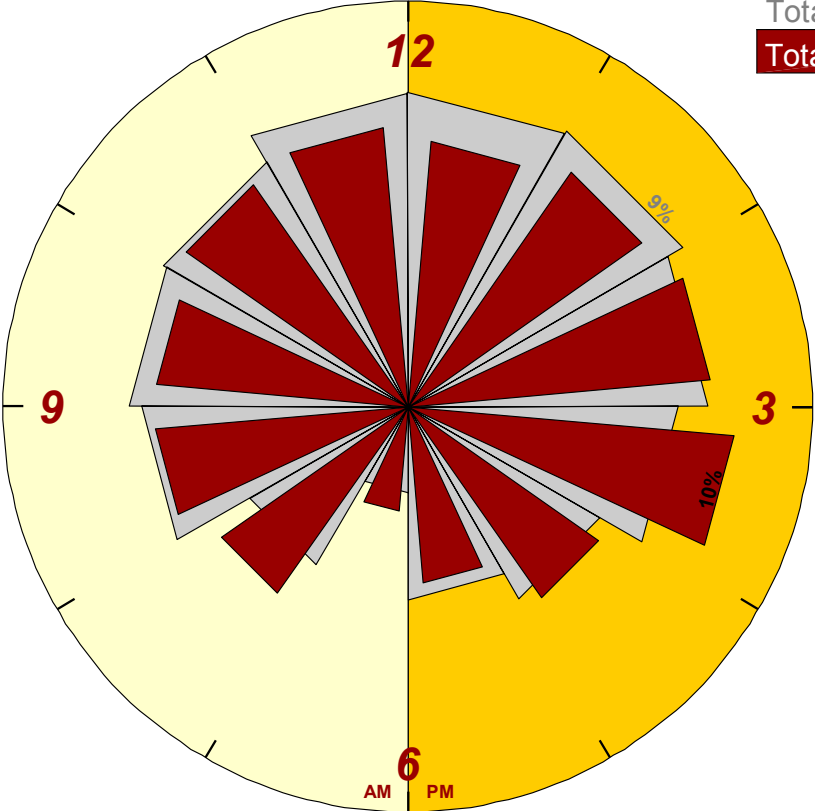
Refueling by Time of Day

% of fills b/t 6 AM & 6 PM: 89.7%

**% of fills b/t 6 AM & 6 PM: 88.3%**

Total Fill<sup>3</sup> Events = 22657

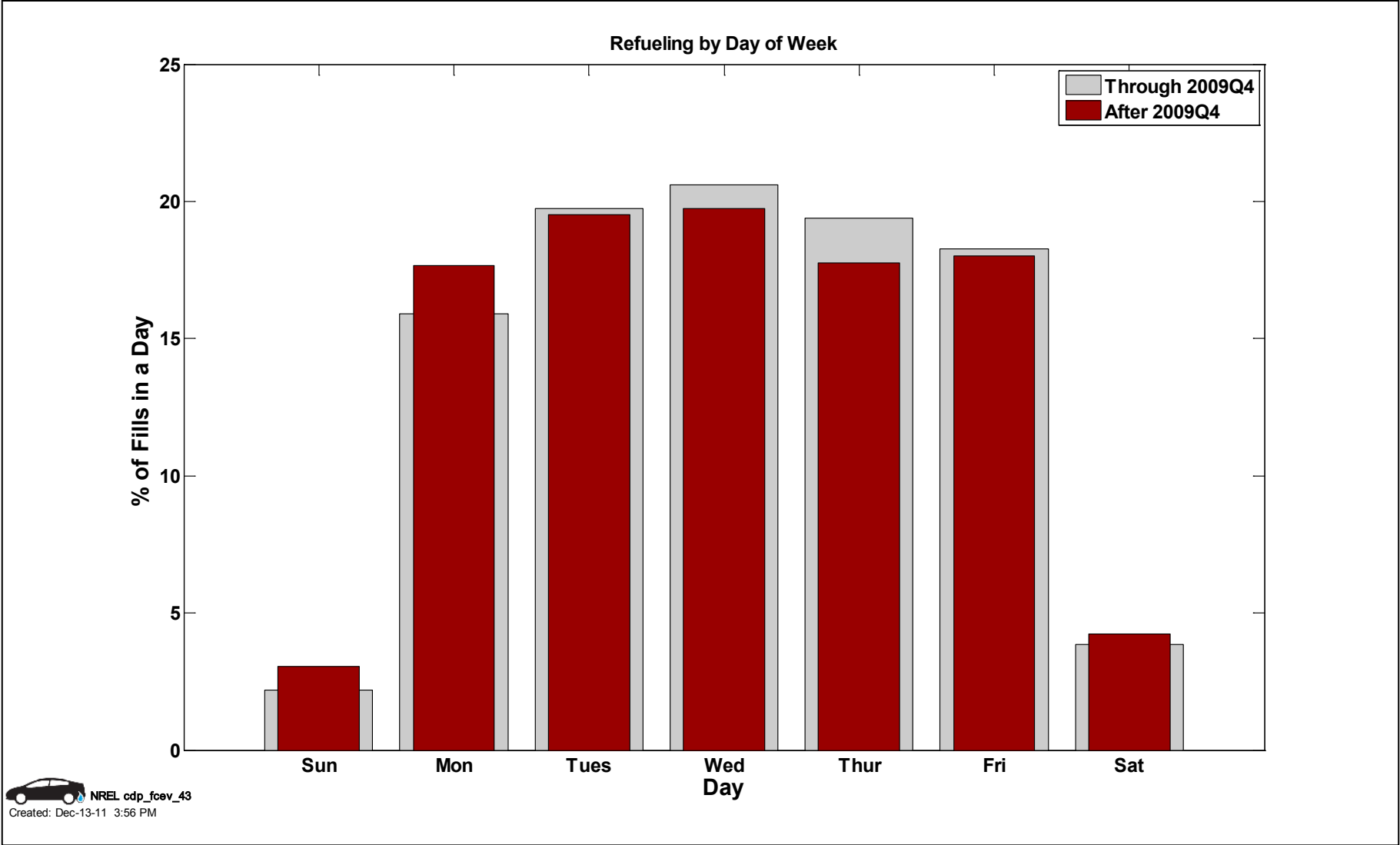
**Total Fill<sup>3</sup> Events = 9983**



Through 2009Q4  
After 2009Q4

- 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.

# CDP#43: Refueling by Day of Week



# CDP#44: Driving Start Time – Day

Driving by Time of Day

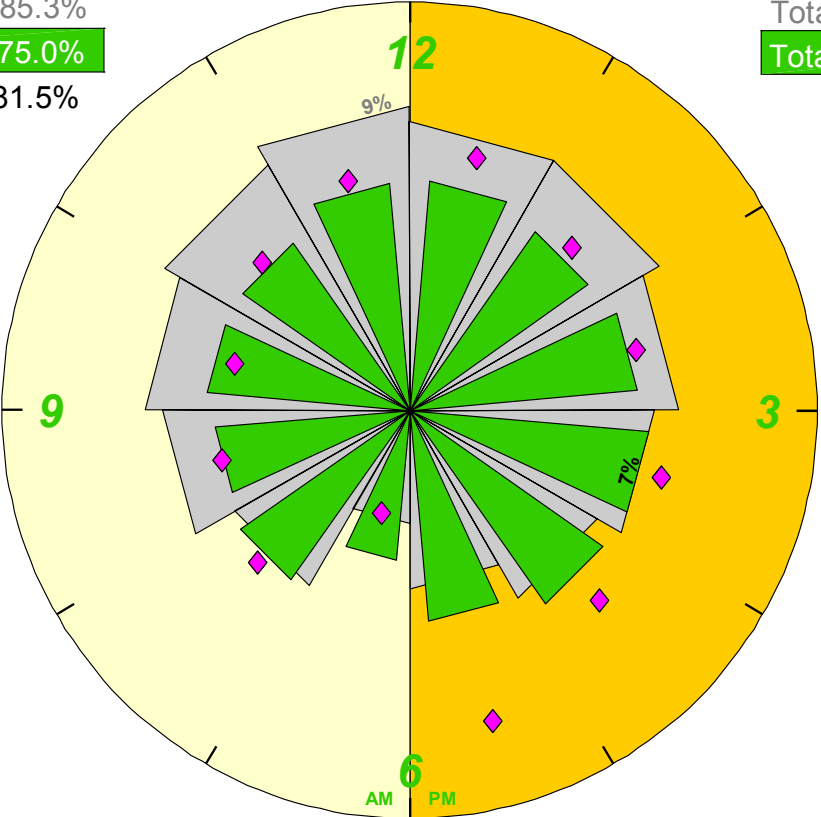
% of driving trips b/t 6 AM & 6 PM: 85.3%

**% of driving trips b/t 6 AM & 6 PM: 75.0%**

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

Total Driving<sup>3</sup> Events = 295222

**Total Drive<sup>3</sup> Events = 60623**



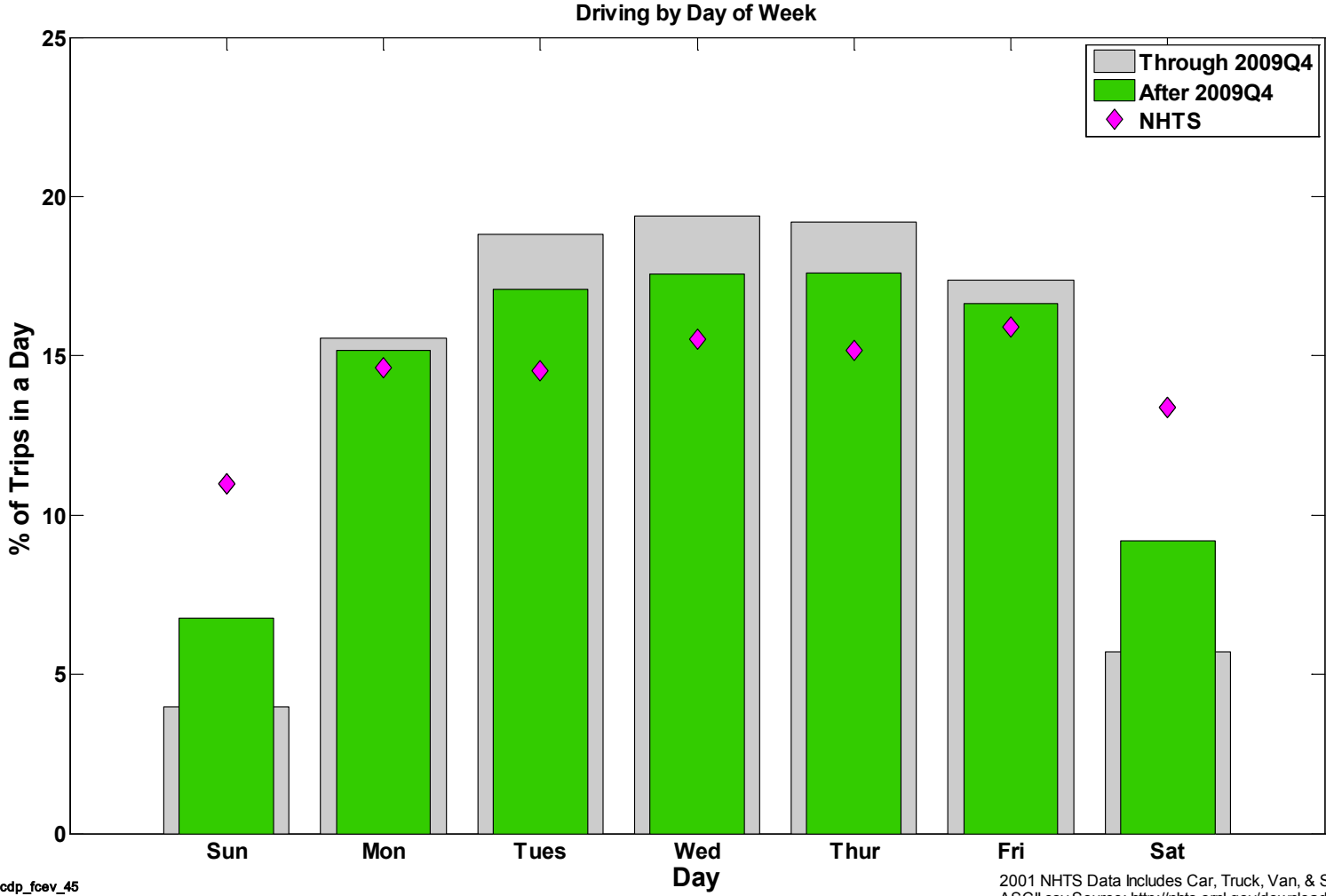
Through 2009Q4  
 After 2009Q4  
 NHTS

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.

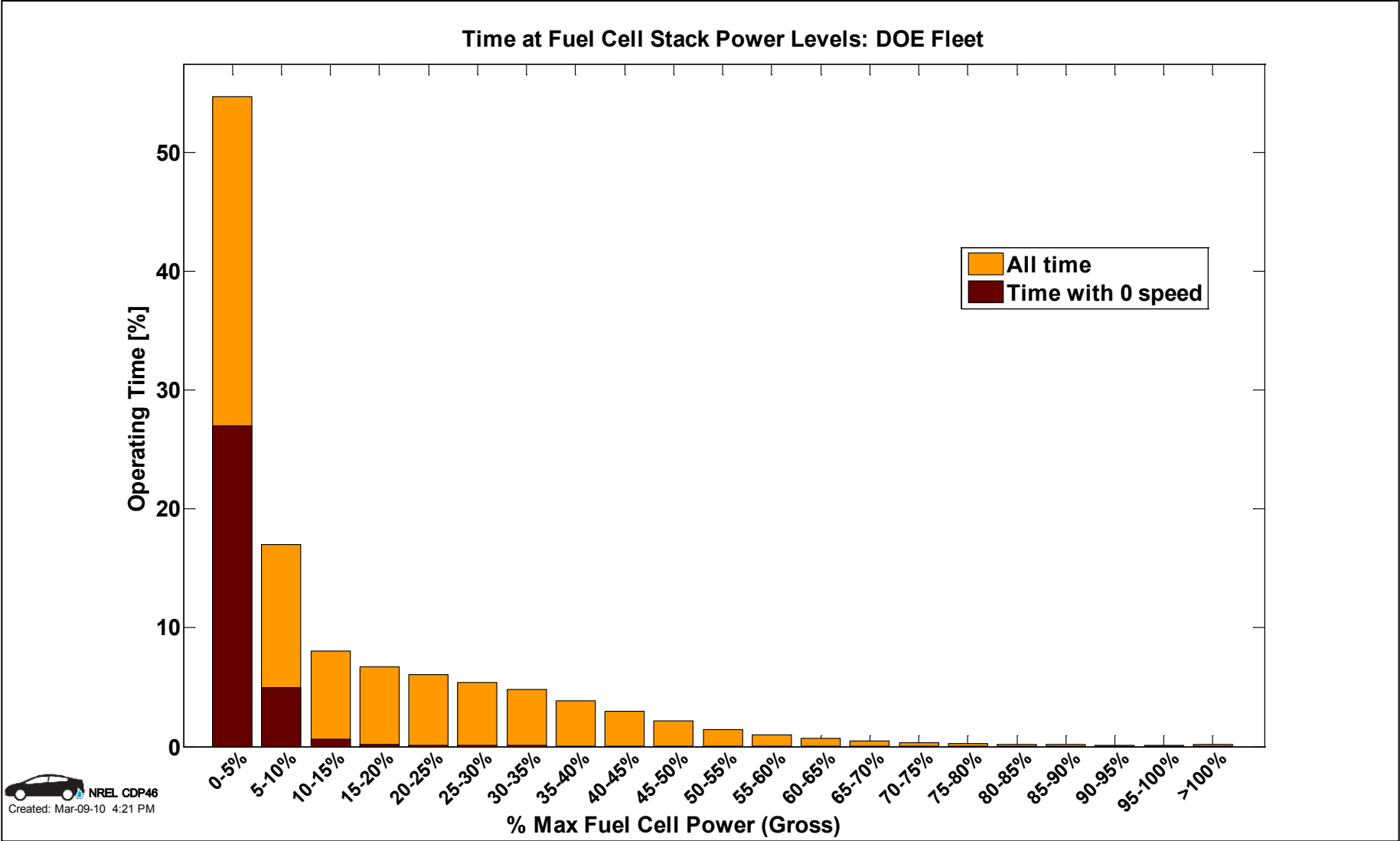
2001 NHTS Data Includes Car, Truck, Van, & SUV day trips  
 ASCII.csv Source: <http://nhts.ornl.gov/download.shtml#2001>



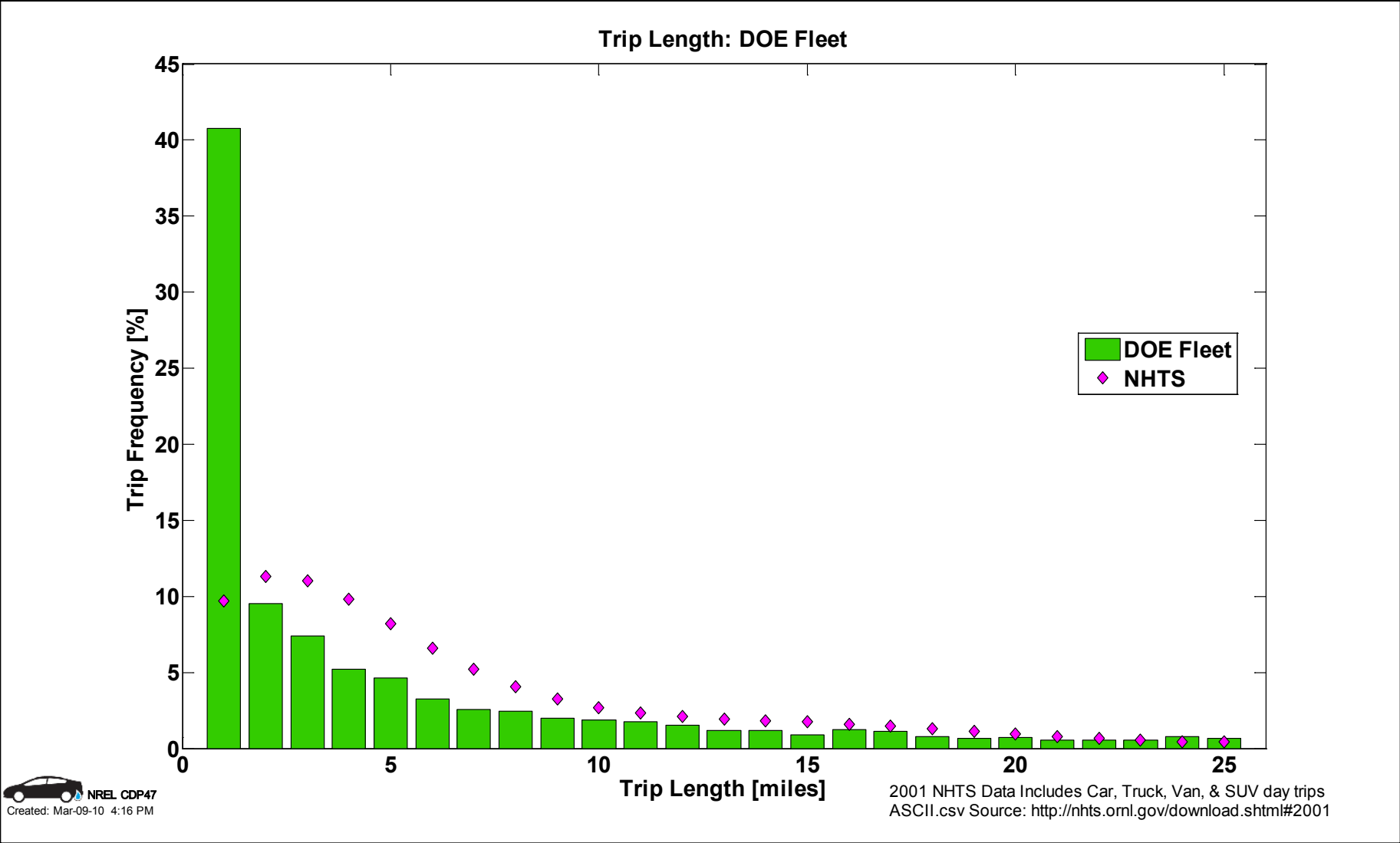
# CDP#45: Driving by Day of Week



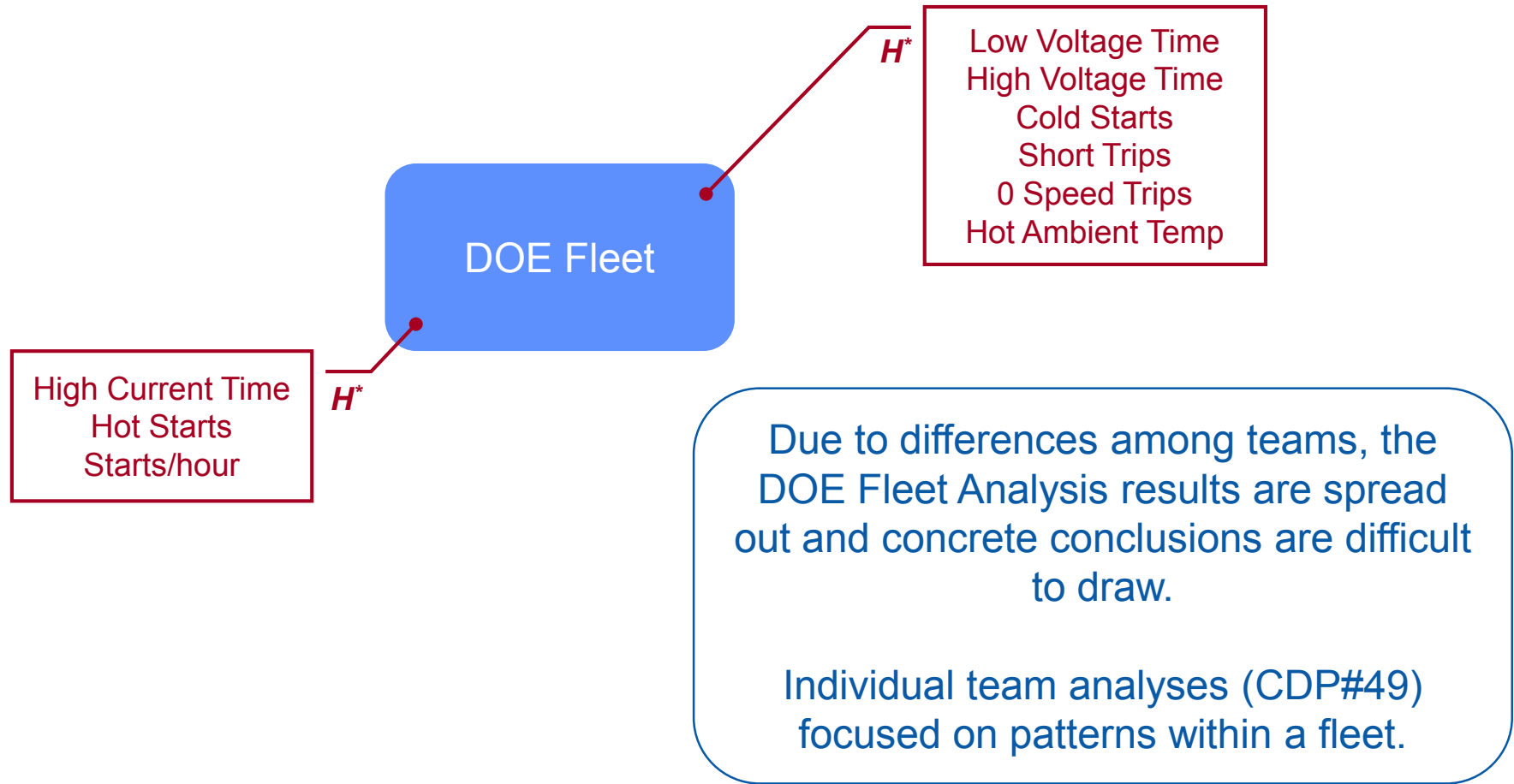
# CDP#46: Fuel Cell System Operating Power



# CDP#47: Trip Length



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

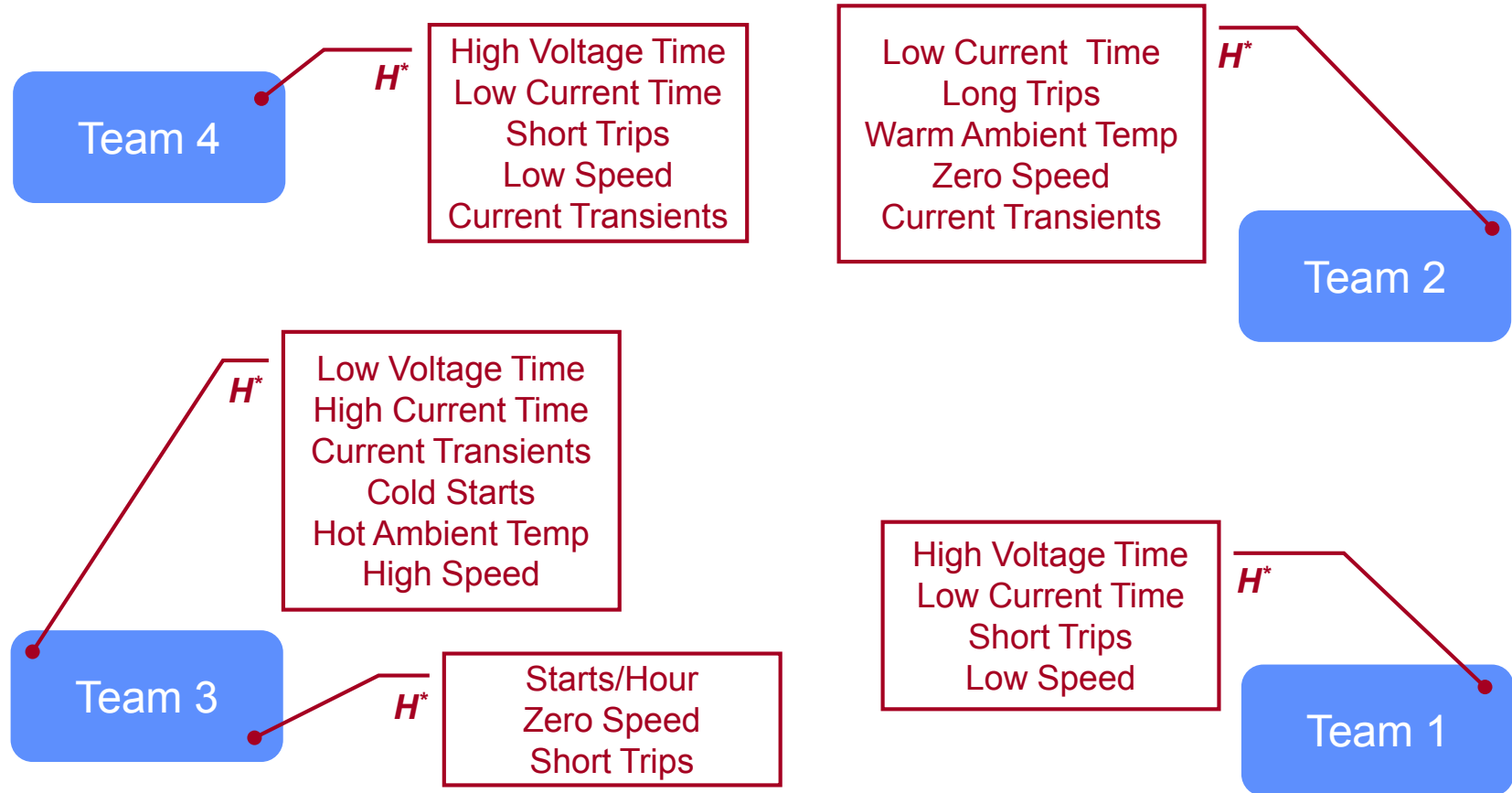


- 1) On-going fuel cell degradation study using Partial Least Squares (PLS) regression model for combined Learning Demonstration Fleet.
- 2) DOE Fleet model has a low percentage of explained decay rate variance.

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'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.

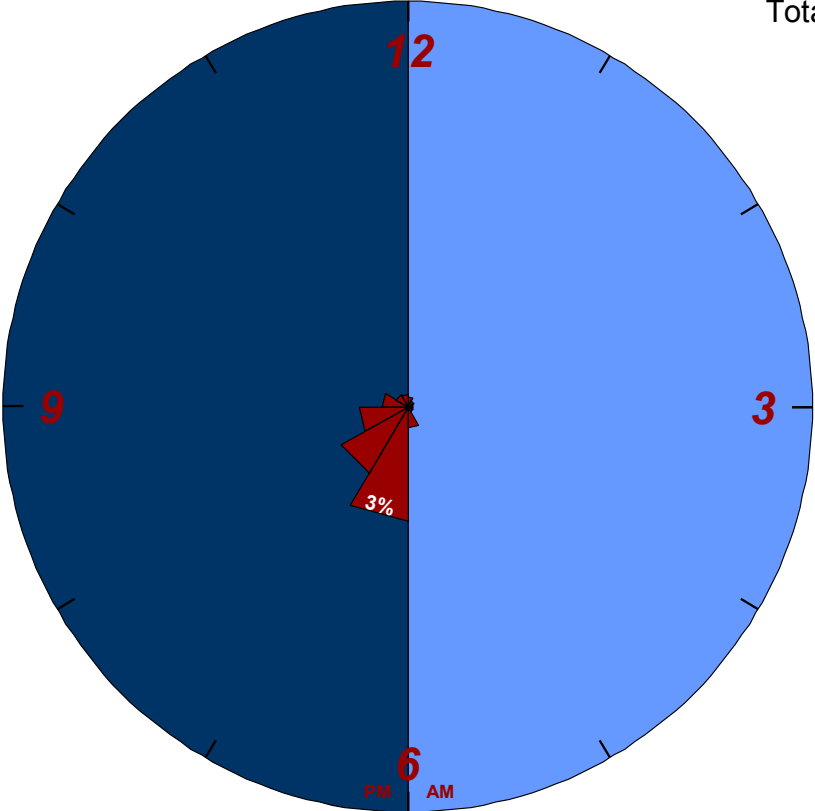
$H^*$ : Factor group associated with high decay rate fuel cell stacks

# CDP#50: Refueling by Time of Night

Refueling by Time of Night: DOE Fleet

% of fills b/t 6 PM & 6 AM: 10.3%

Total Fill<sup>3</sup> Events = 22657



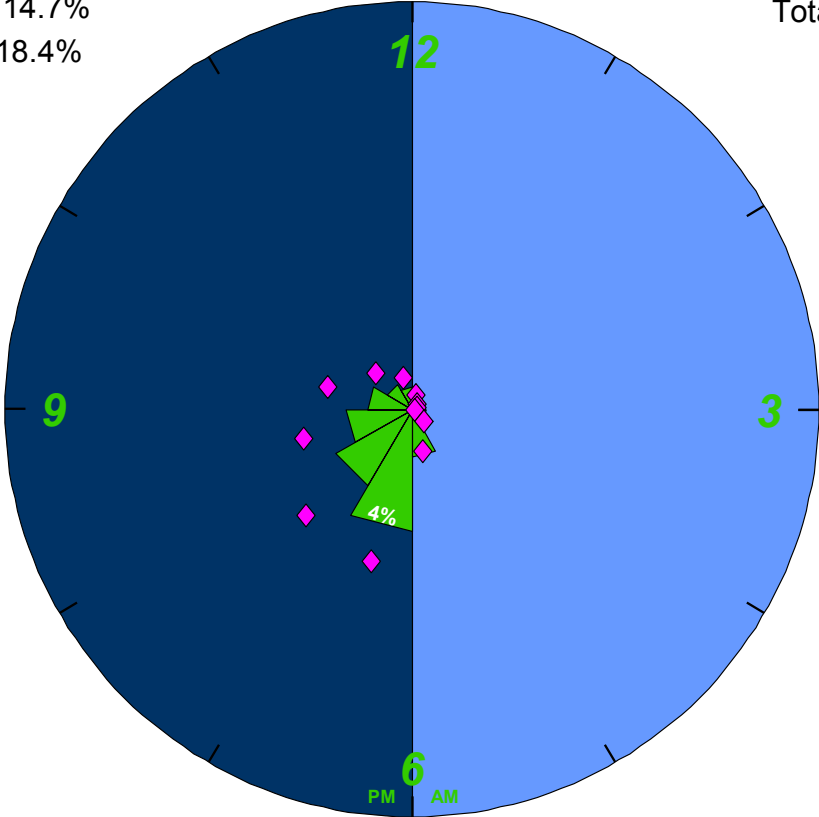
- 1. Fills between 6 PM & 6 AM
- 2. The outer arc is set at 12 % total Fill.
- 3. Some events not recorded/detected due to data noise or incompleteness.

# CDP#51: Driving Start Time – Night

Driving Start Time - Night: DOE Fleet

% of driving trips b/t 6 PM & 6 AM: 14.7%  
 % of NHTS trips b/t 6 PM & 6 AM: 18.4%

Total Driving<sup>3</sup> Events = 295222

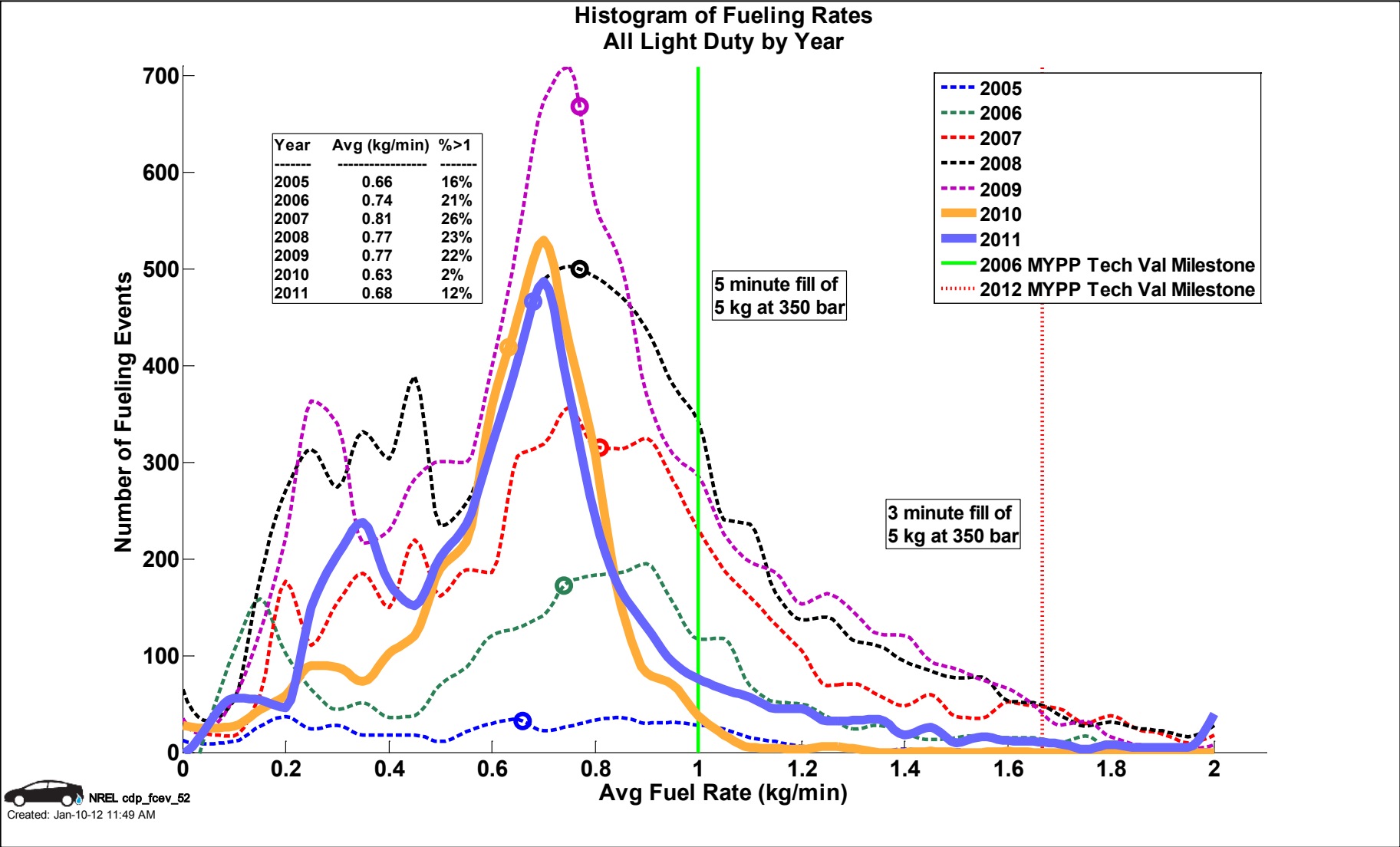


■ DOE Fleet  
 ◆ NHTS

- 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.

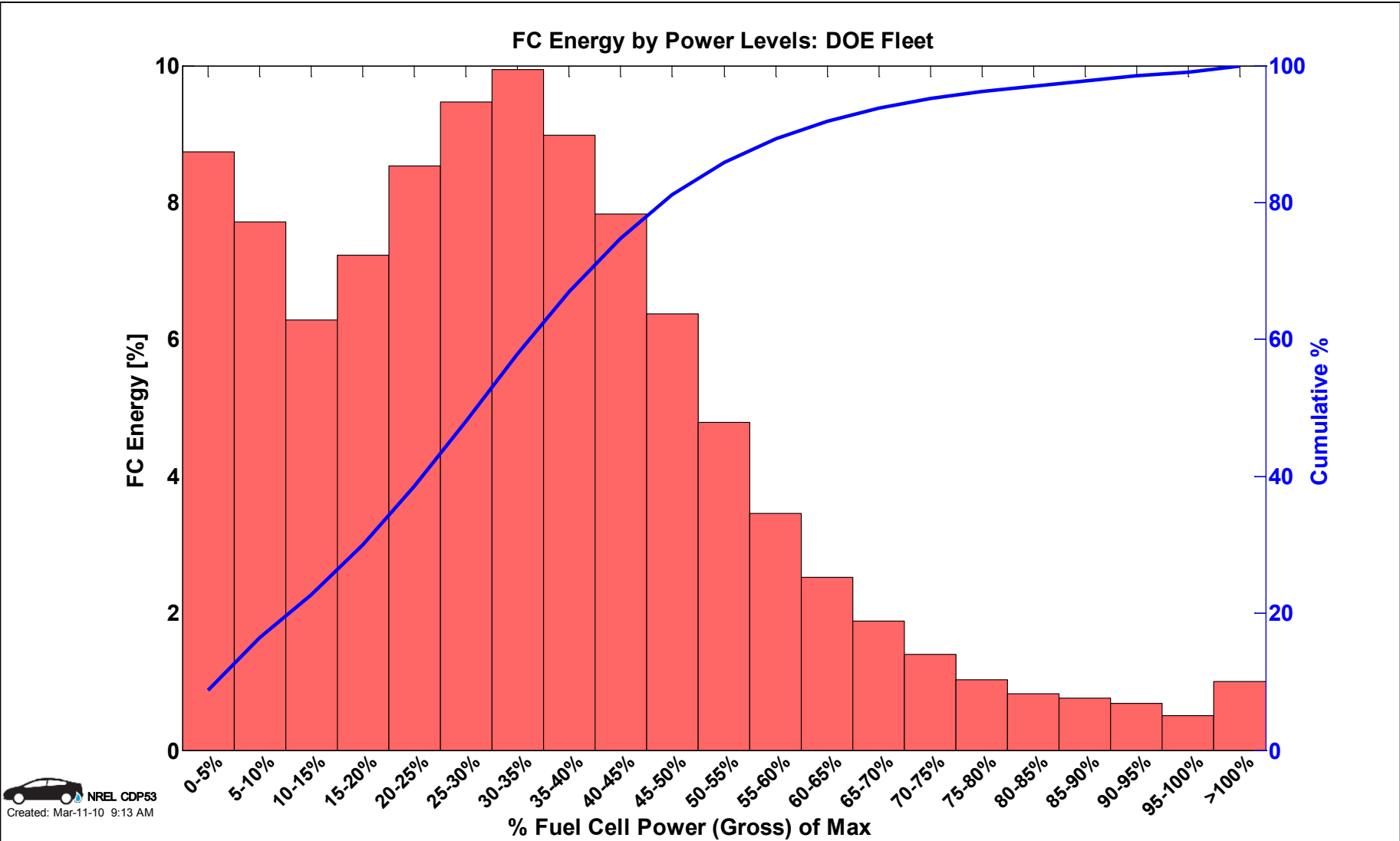
2001 NHTS Data Includes Car, Truck, Van, & SUV day trips  
 ASCII.csv Source: <http://nhts.ornl.gov/download.shtml#2001>

# CDP#52: Fueling Rates by Year



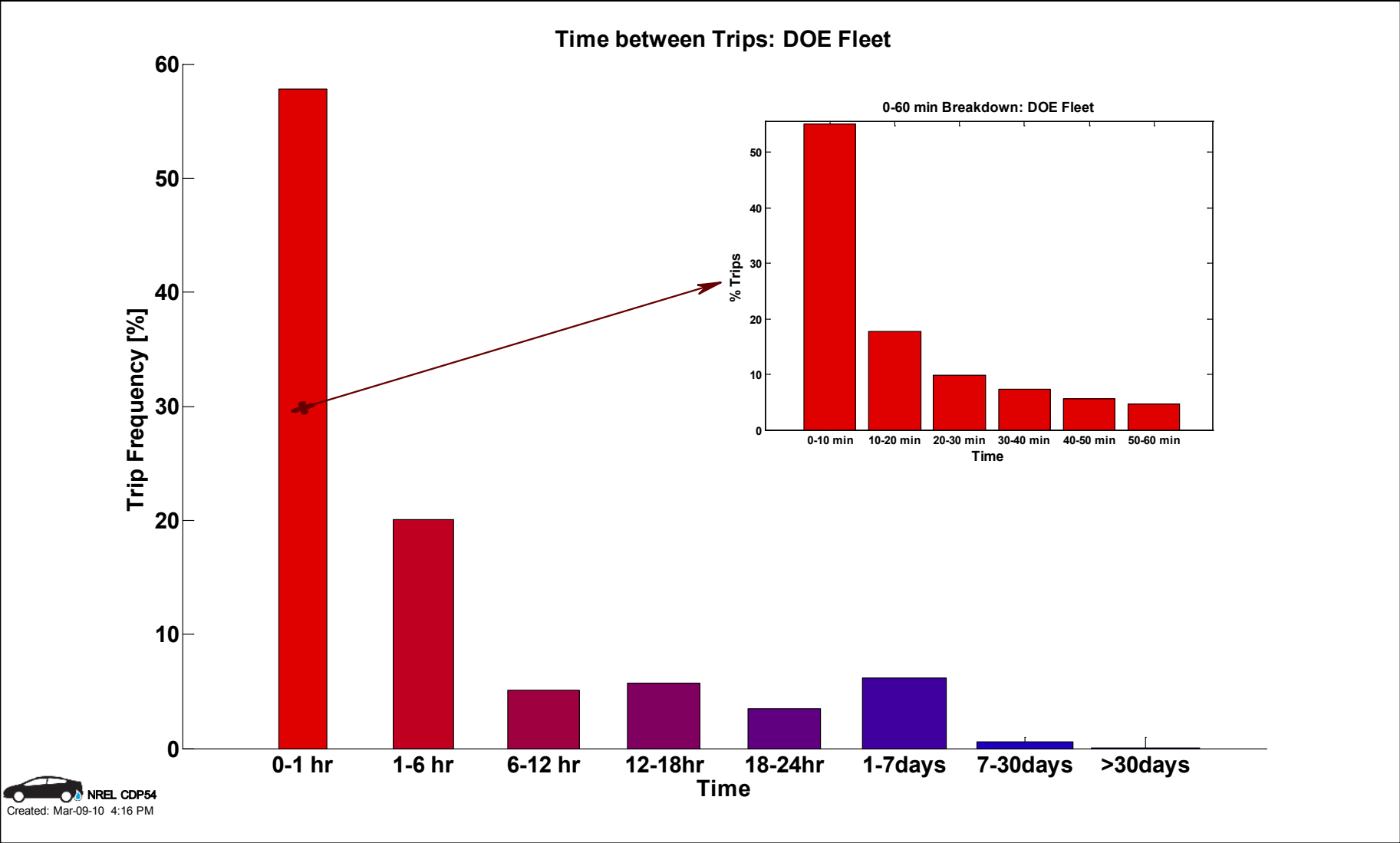


# CDP#53: Fuel Cell System Energy within Power Levels

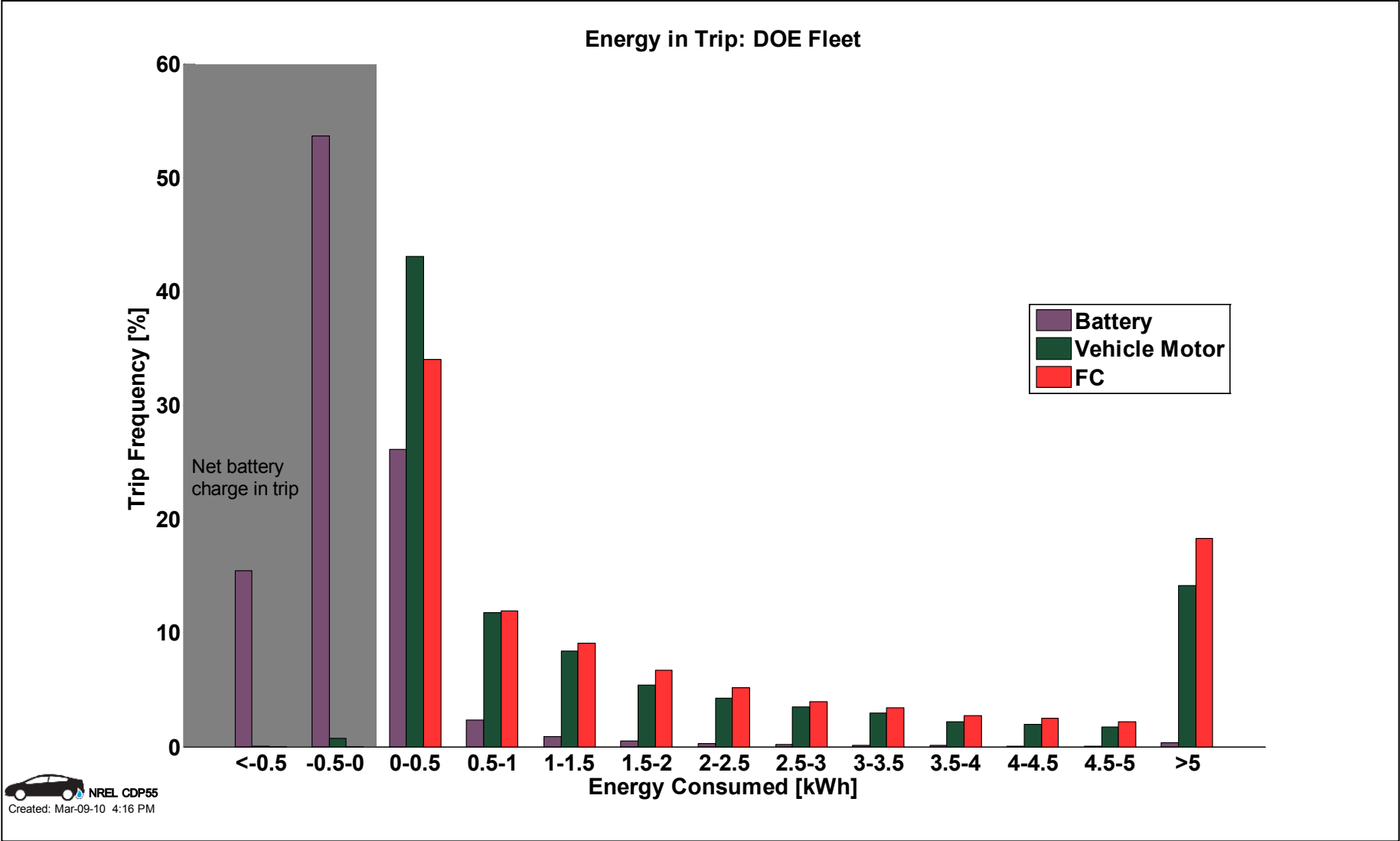


 NREL CDP53  
Created: Mar-11-10 9:13 AM

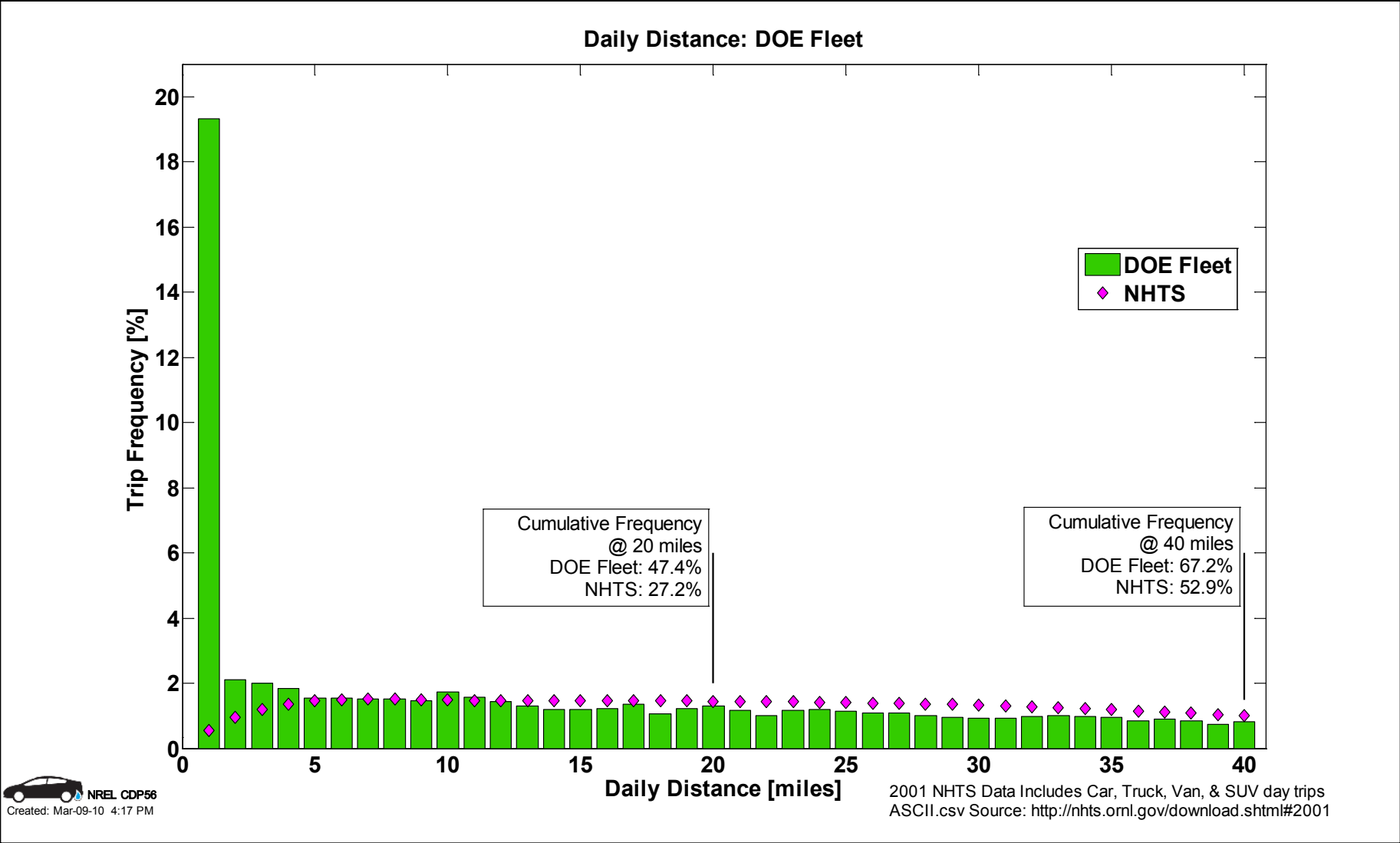
# CDP#54: Time Between Trips



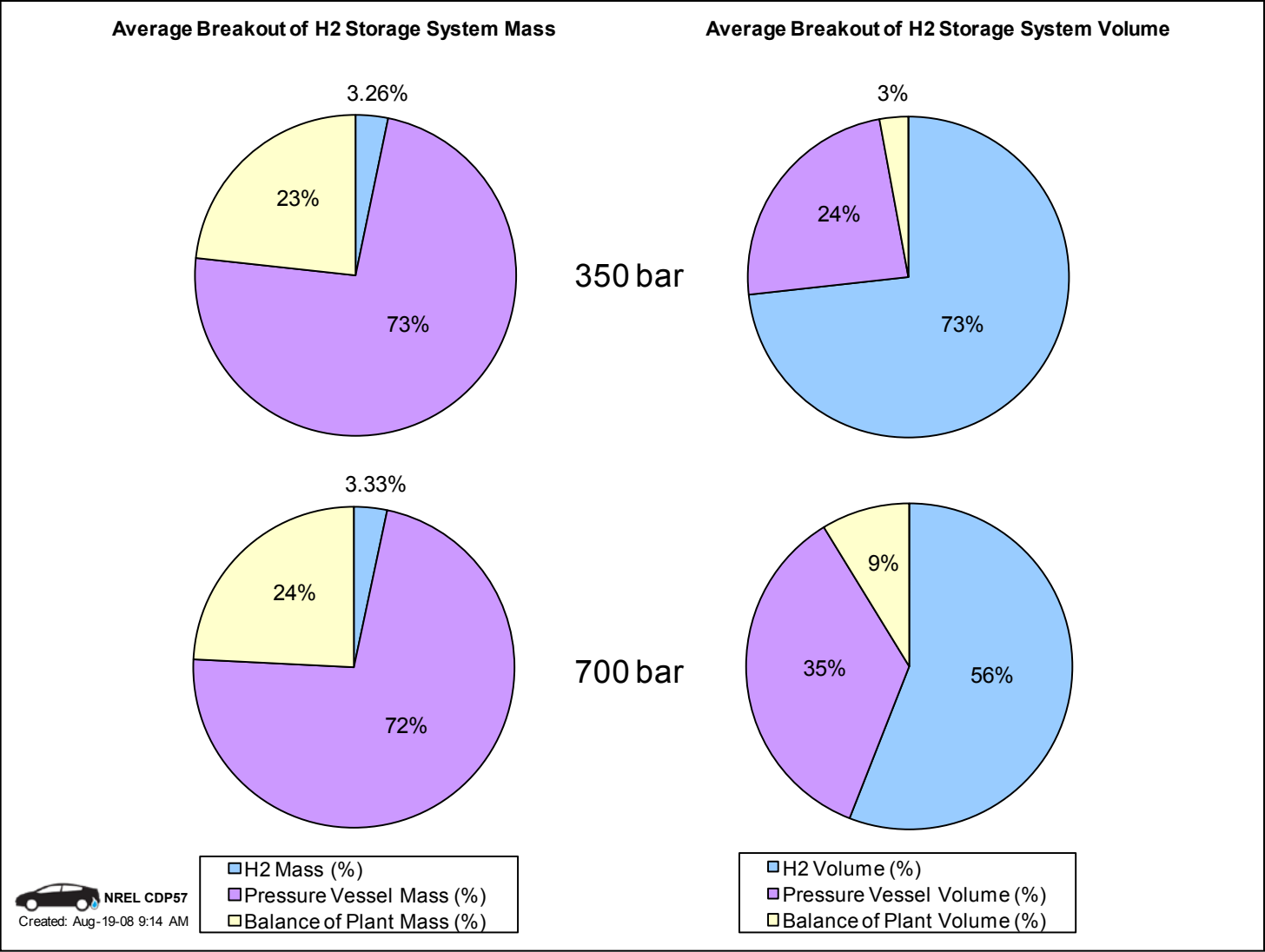
# CDP#55: Fuel Cell System Energy



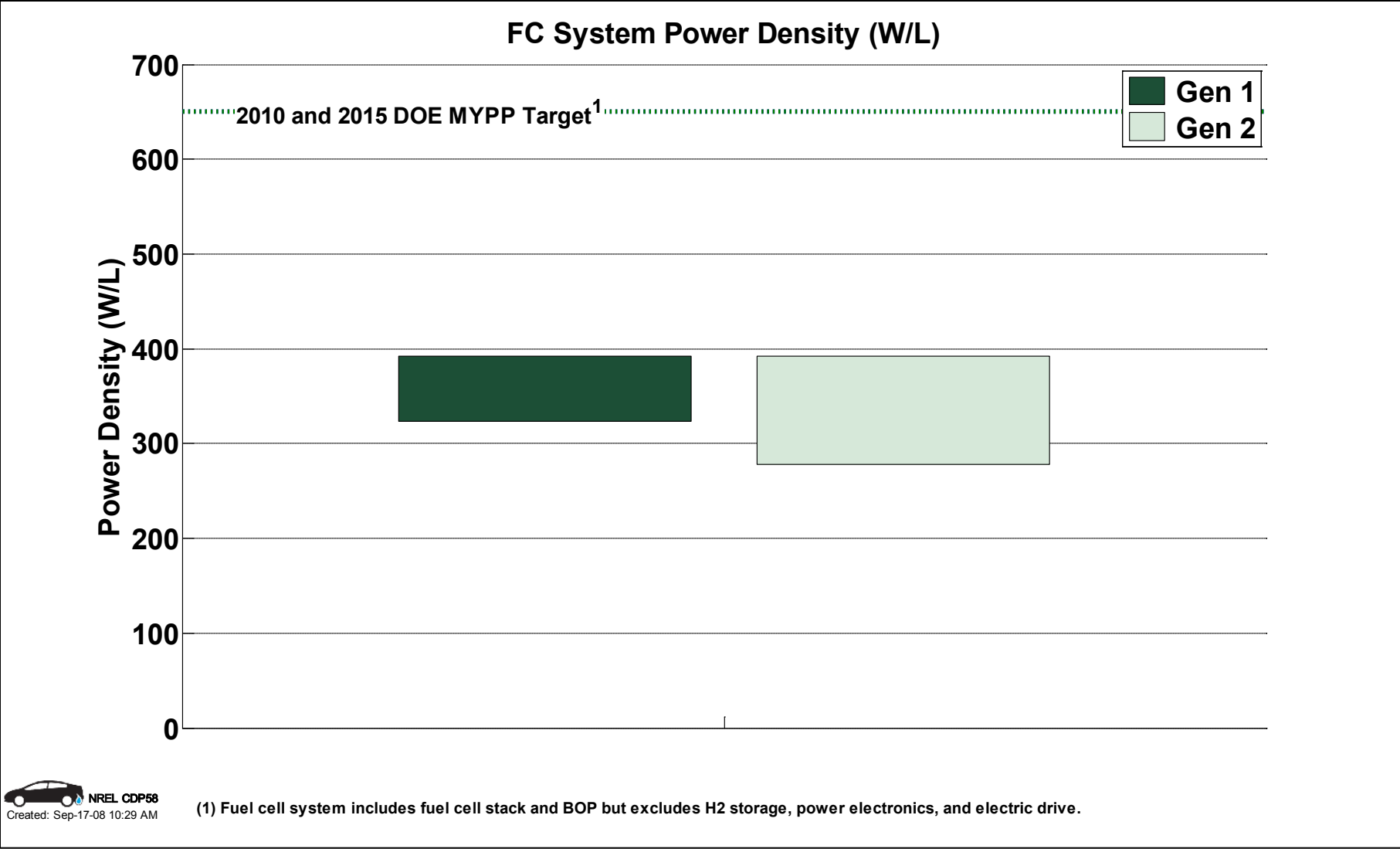
# CDP#56: Daily Driving Distance



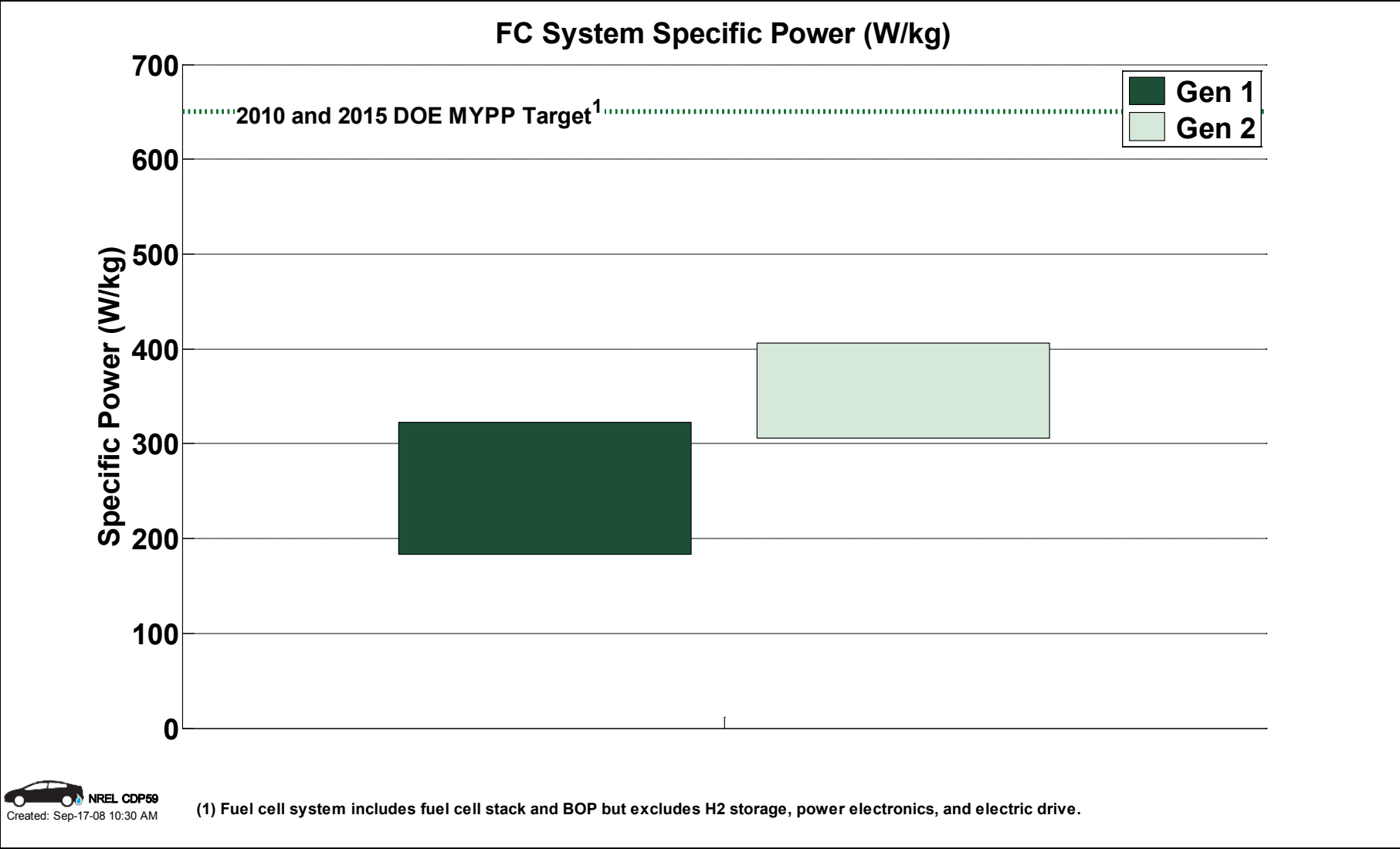
# CDP#57: H2 Storage System Mass and Volume Breakdown



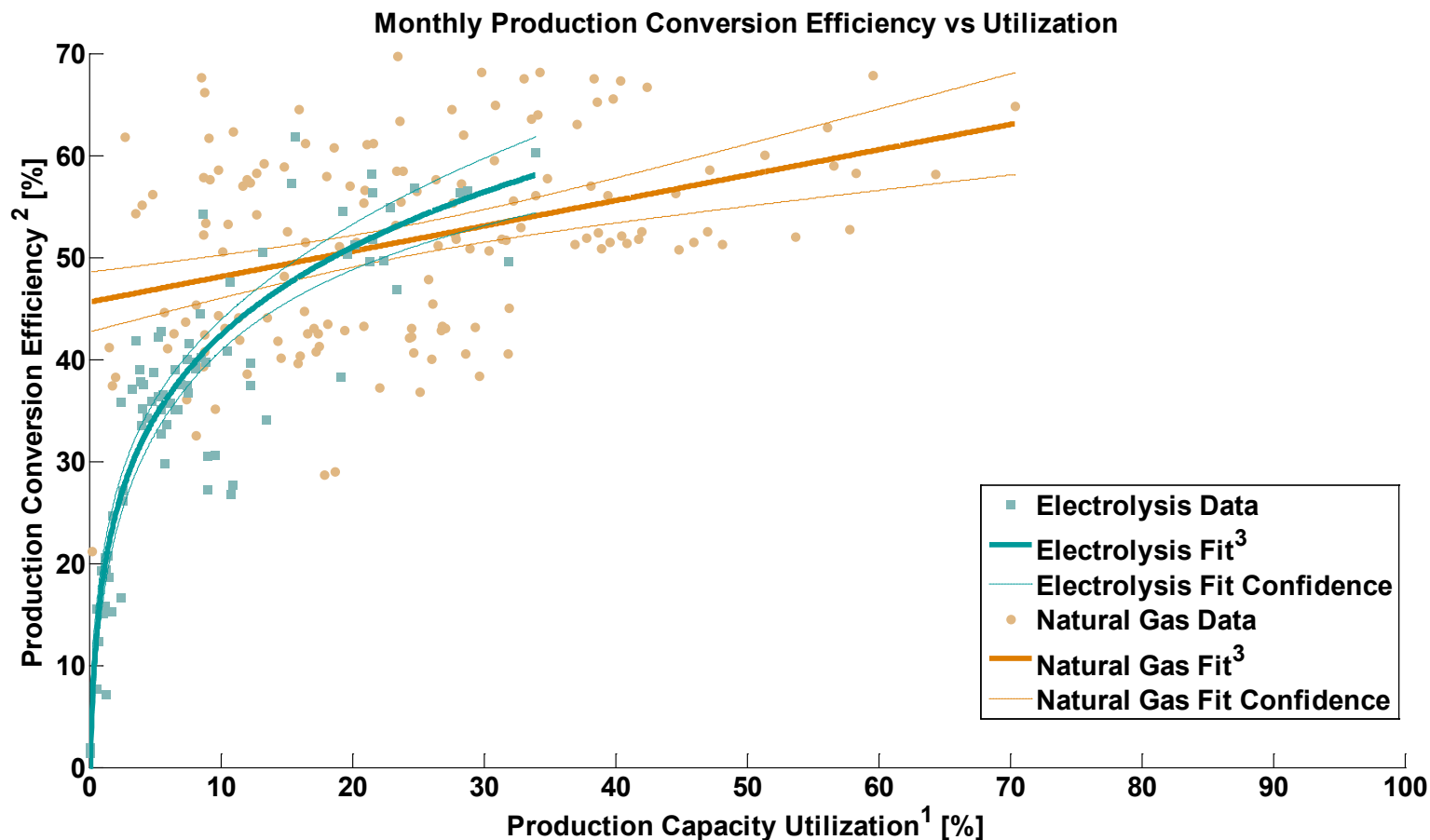
# CDP#58: Fuel Cell System Power Density



# CDP#59: Fuel Cell System Specific Power



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



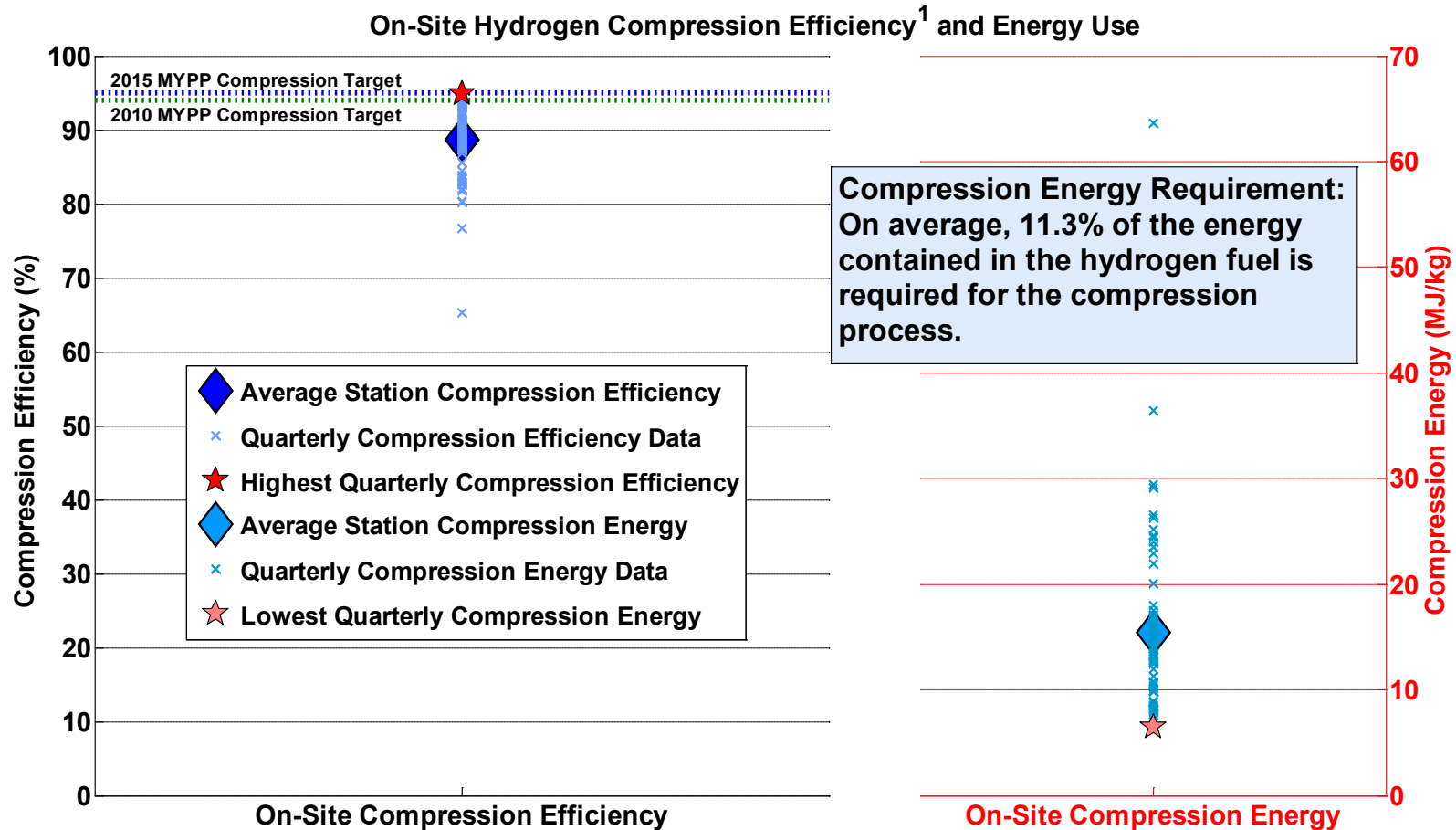
1) 100% production utilization assumes operation 24 hrs a day, 7 days a week

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 ( $R^2 = 0.82$ ) & low correlation with natural gas data ( $R^2 = 0.060$ )



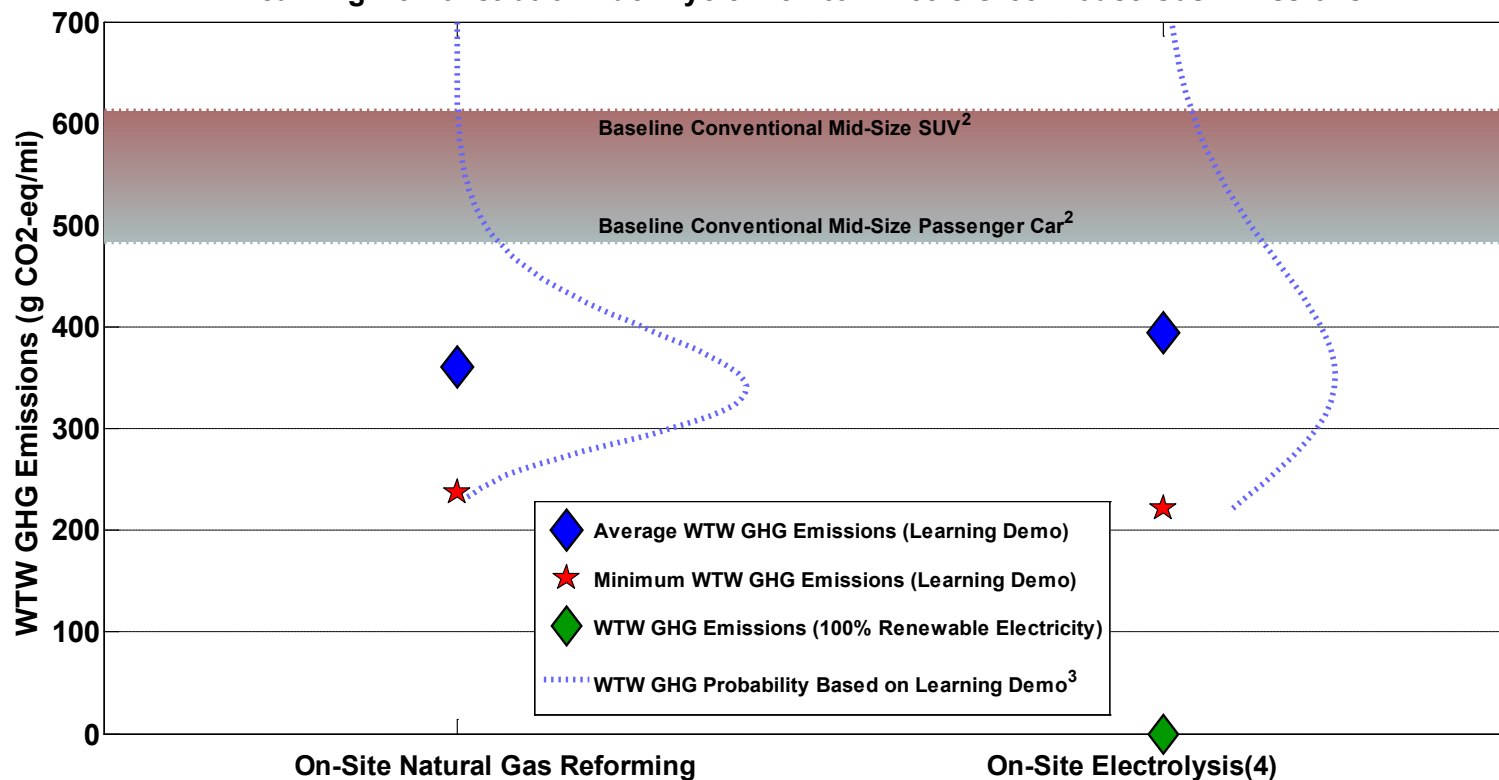
# CDP#61: Refueling Station Compressor Efficiency



<sup>1</sup>Consistent 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.

# CDP#62: Learning Demonstration Vehicle Greenhouse Gas Emissions

Learning Demonstration Fuel Cycle Well-to-Wheels Greenhouse Gas Emissions<sup>1</sup>



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.

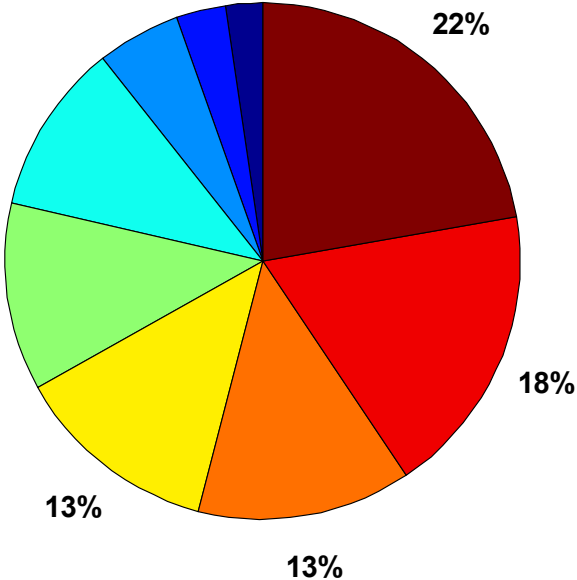
3. The Well-to-Wheels GHG probability distribution represents the range and likelihood of GHG emissions resulting from the hydrogen FCV fleet based on window-sticker fuel economy data and monthly conversion efficiency data from the Learning Demonstration.

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 1330 g/mile.

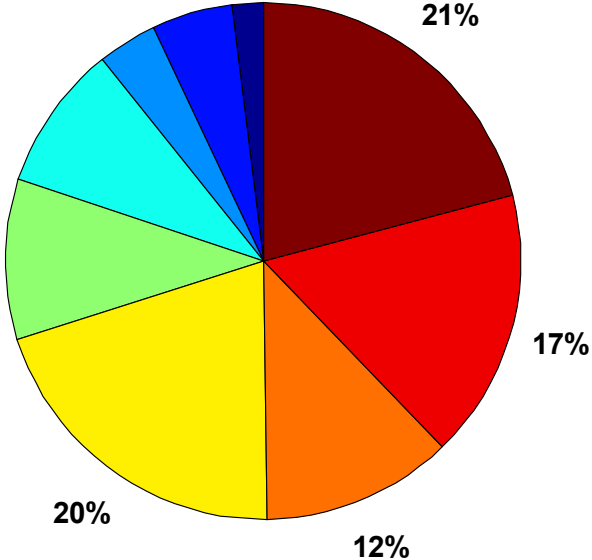
# CDP#63: Hydrogen Fueling Station Maintenance by System

Hydrogen Fueling Station Maintenance

By Number of Events  
Total Number of Events = 2491



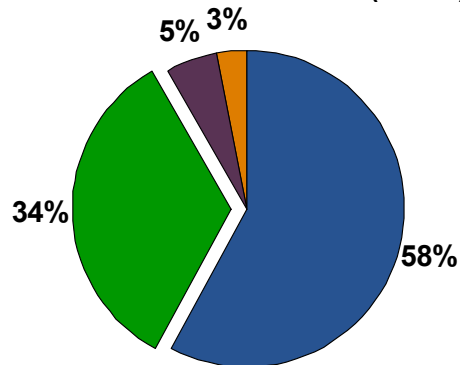
By Labor Hours  
Total Hours = 11430



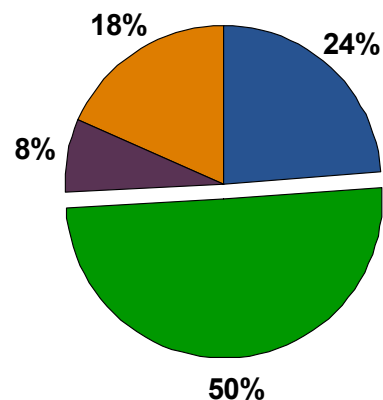
# CDP#64: Fuel Cell Vehicle Maintenance by System

Fuel Cell Vehicle Maintenance Events and Labor Hours

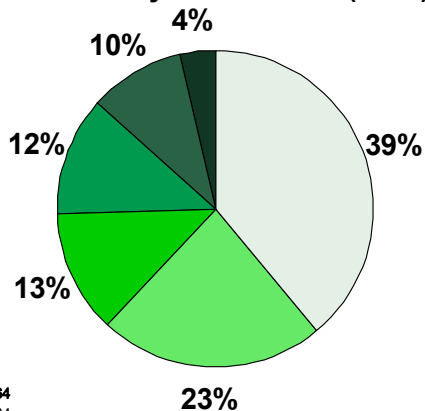
Fuel Cell Vehicle Events (11574)



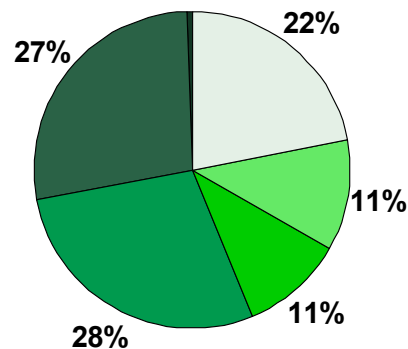
Fuel Cell Vehicle Labor (12522 hours)



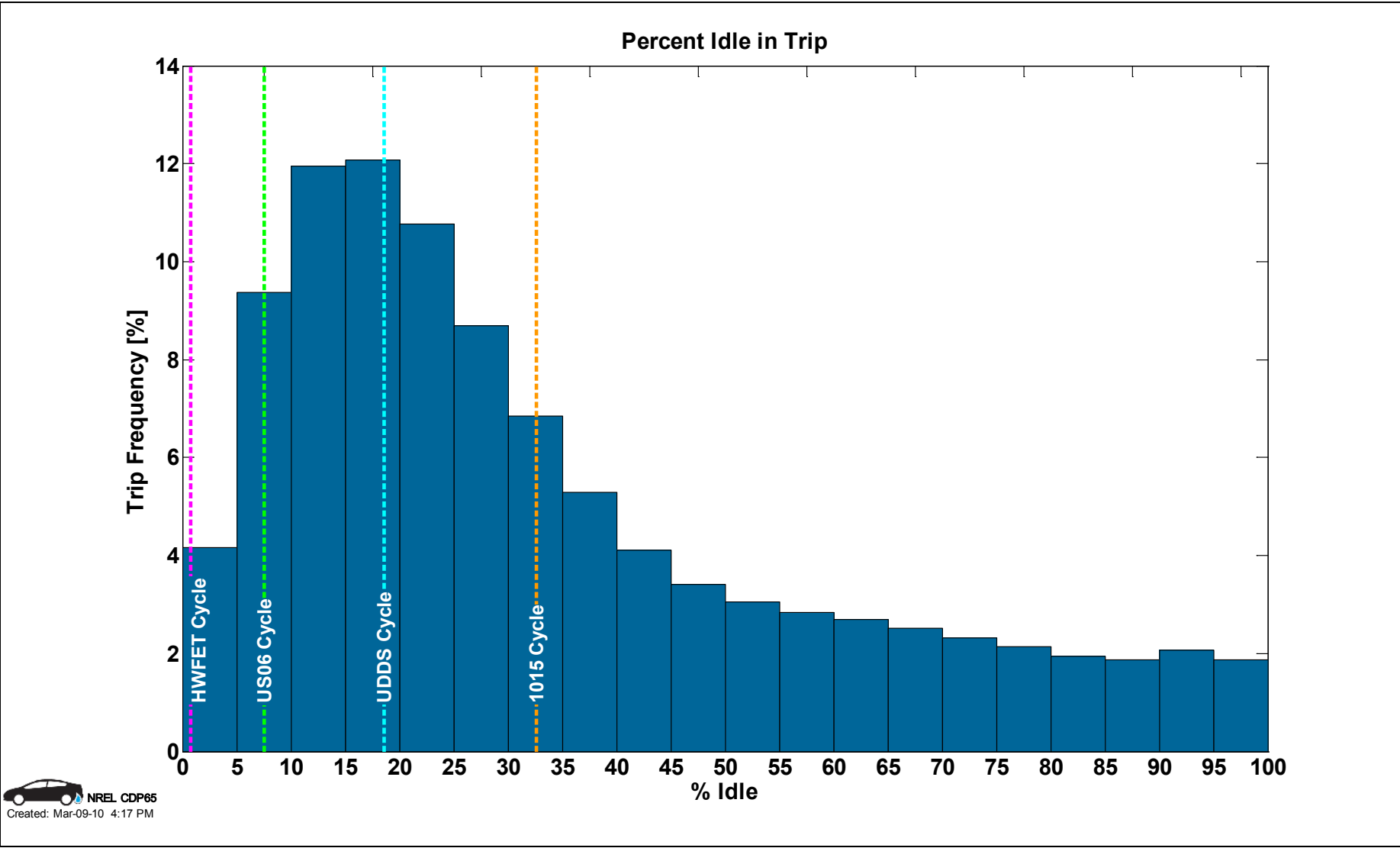
Fuel Cell System Events (3916)



Fuel Cell System Labor (6304 hours)  
< 1%

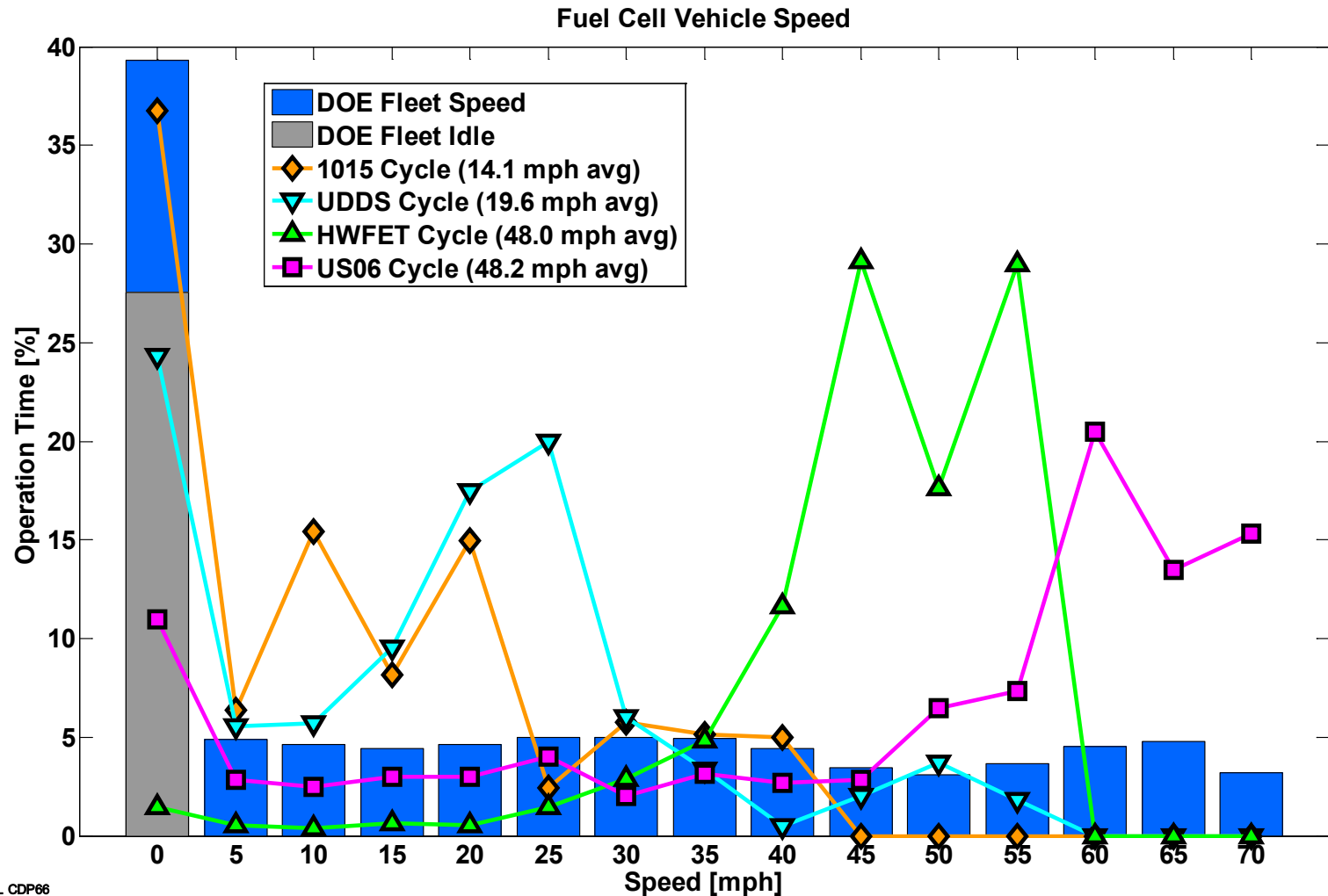


# CDP#65: Percent Idle in Trip with Comparison to Standard Drive Cycles

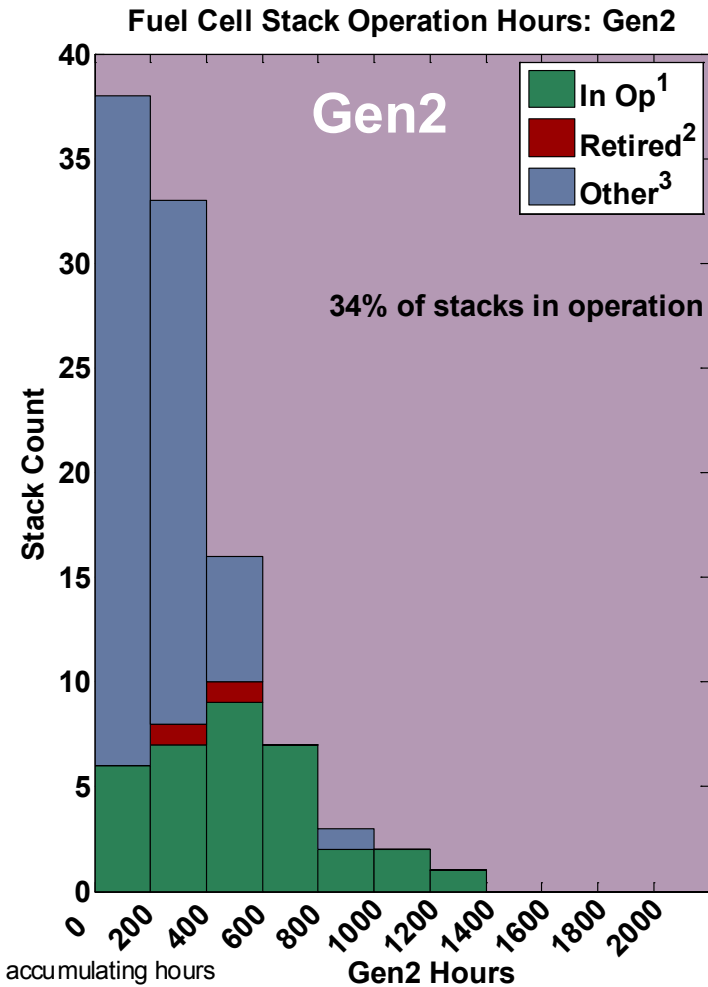
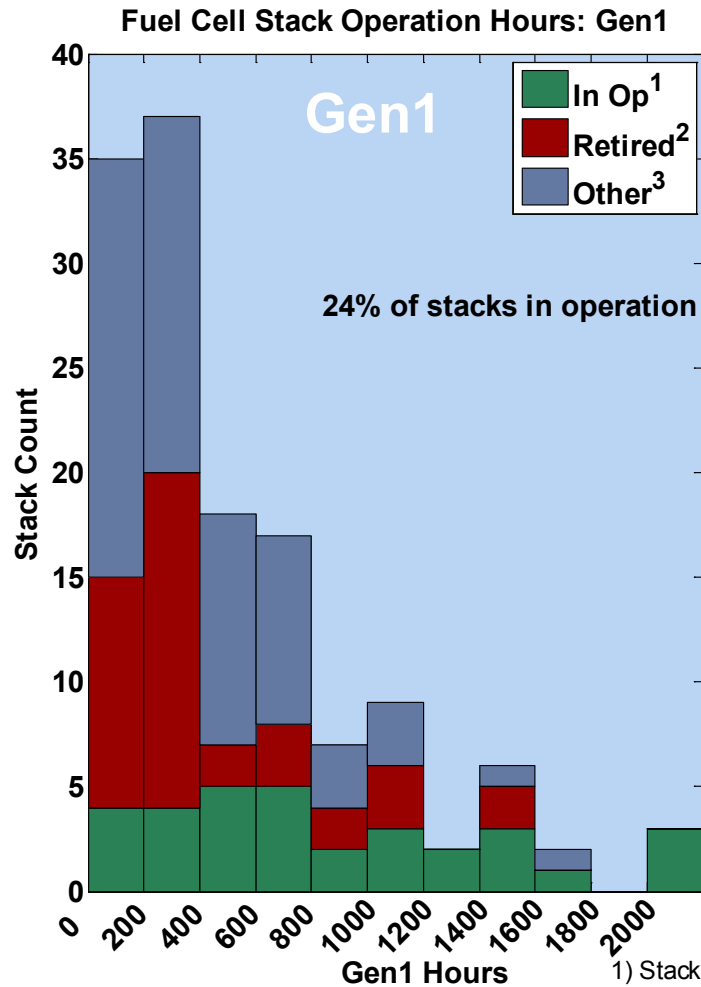


 NREL CDP65  
Created: Mar-09-10 4:17 PM

# CDP#66: FCV Speed with Comparison to Standard Drive Cycles

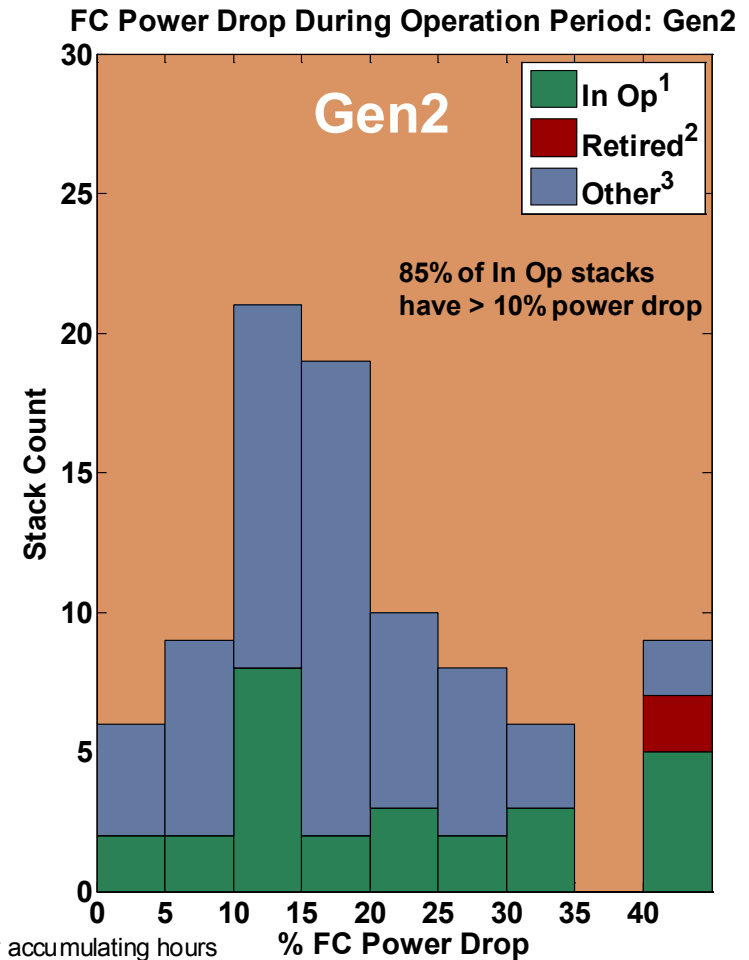
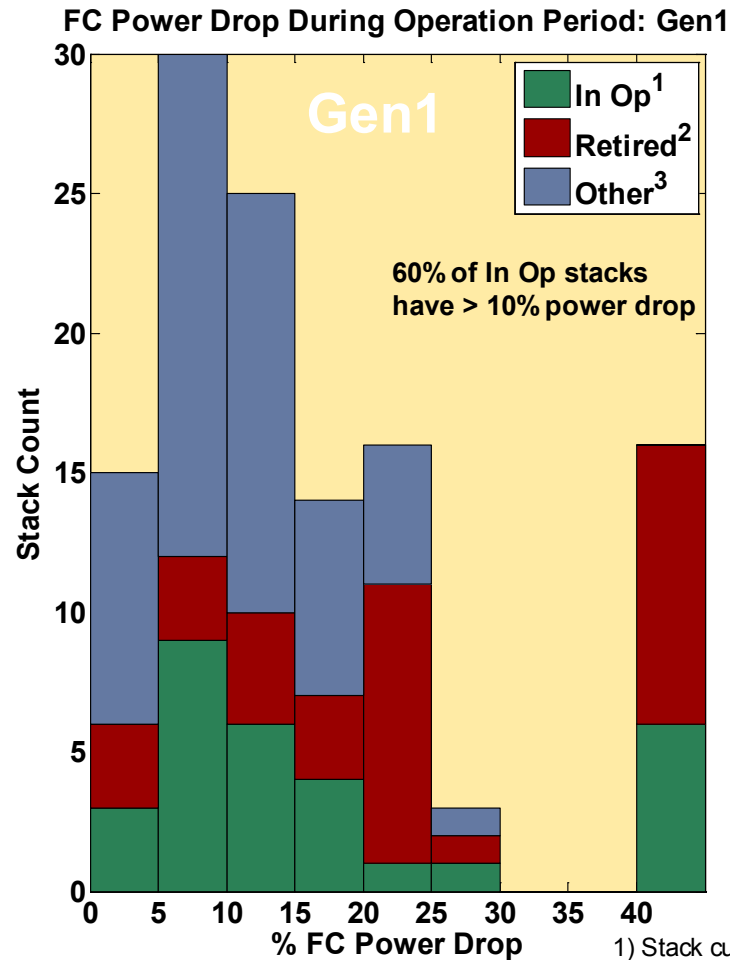


# CDP#67: Fuel Cell Stack Operation Hours



- 1) Stack currently accumulating hours
  - 2) Stack removed for low performance
  - 3) Stack not currently accumulating hours, but not removed because of low performance.
- Some project teams concluded in Fall/Winter 2009

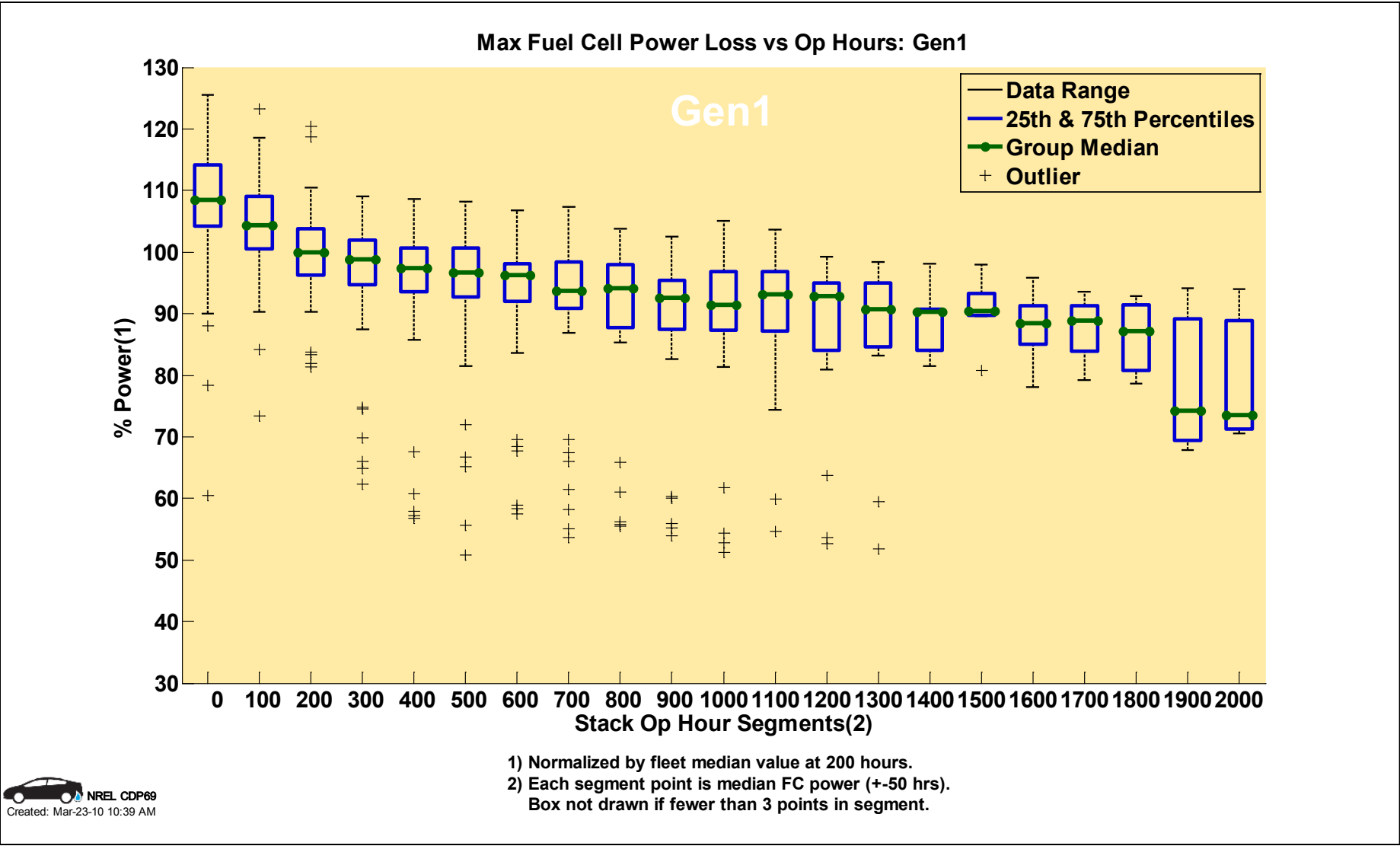
# CDP#68: Power Drop During Fuel Cell Stack Operation Period



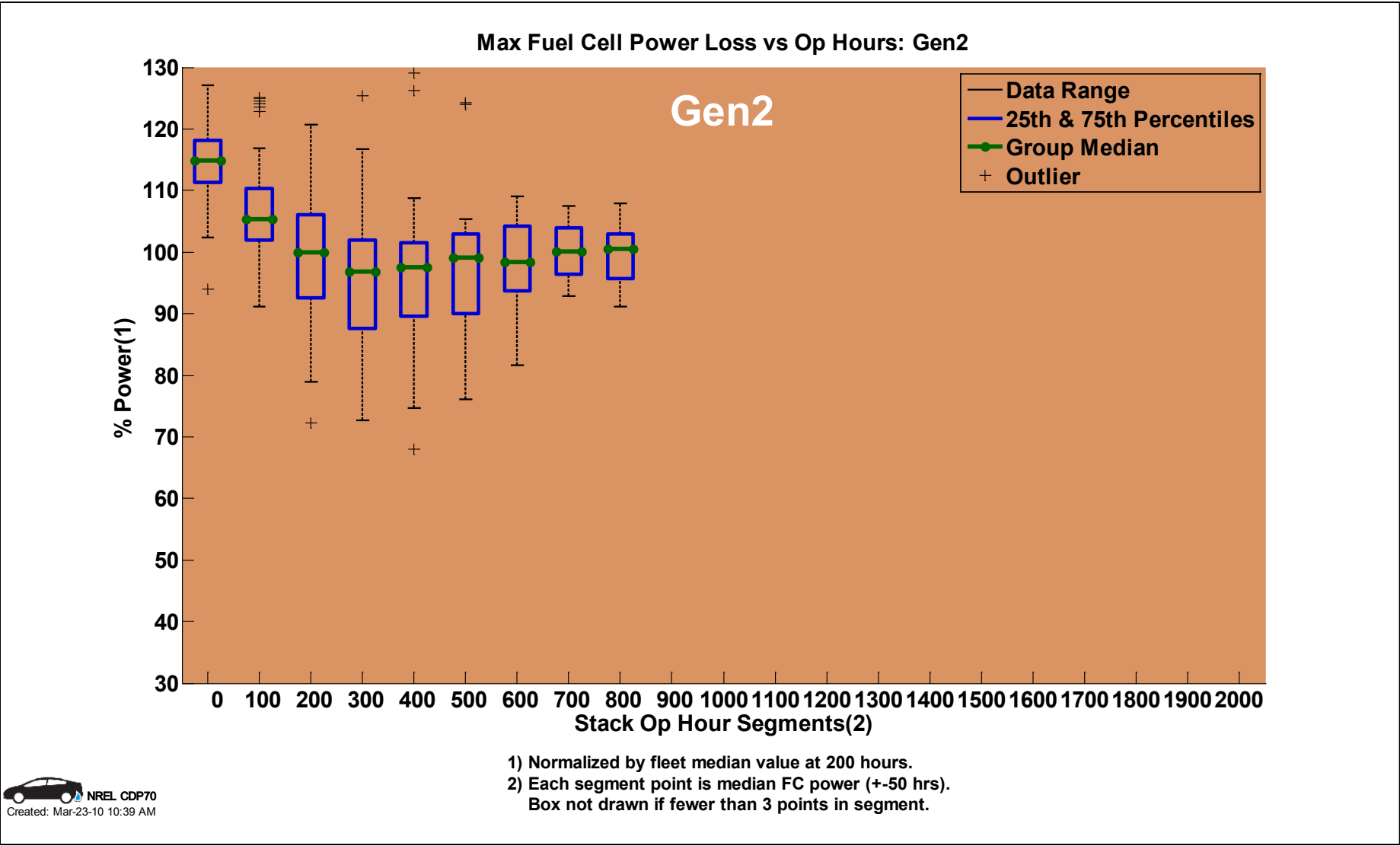
- 1) Stack currently accumulating hours
- 2) Stack removed for low performance
- 3) Stack not currently accumulating hours, but not removed because of low performance. Some project teams concluded in Fall/Winter 2009



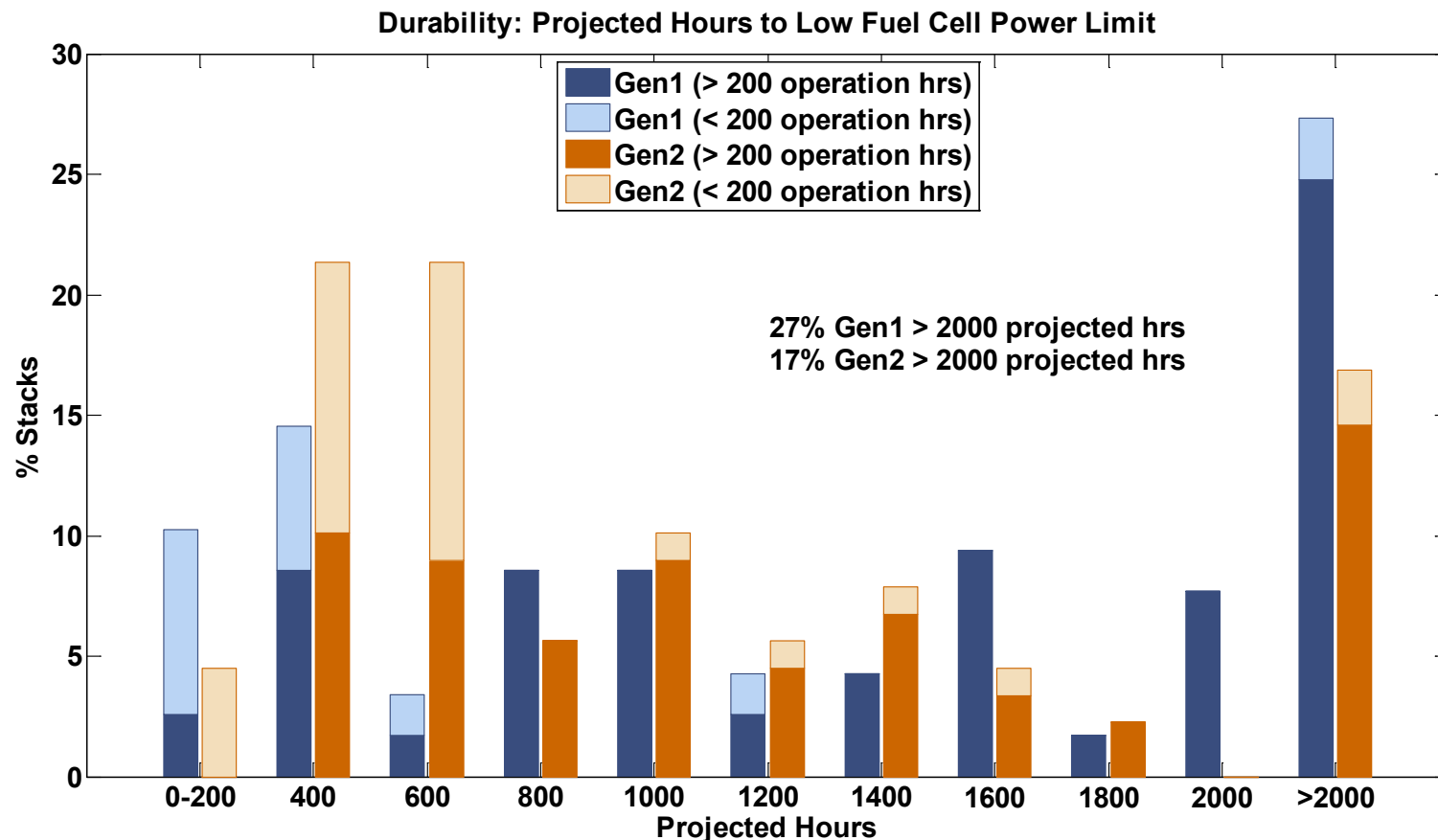
# CDP#69: Max Fuel Cell Power Degradation – Gen 1



# CDP#70: Max Fuel Cell Power Degradation – Gen 2

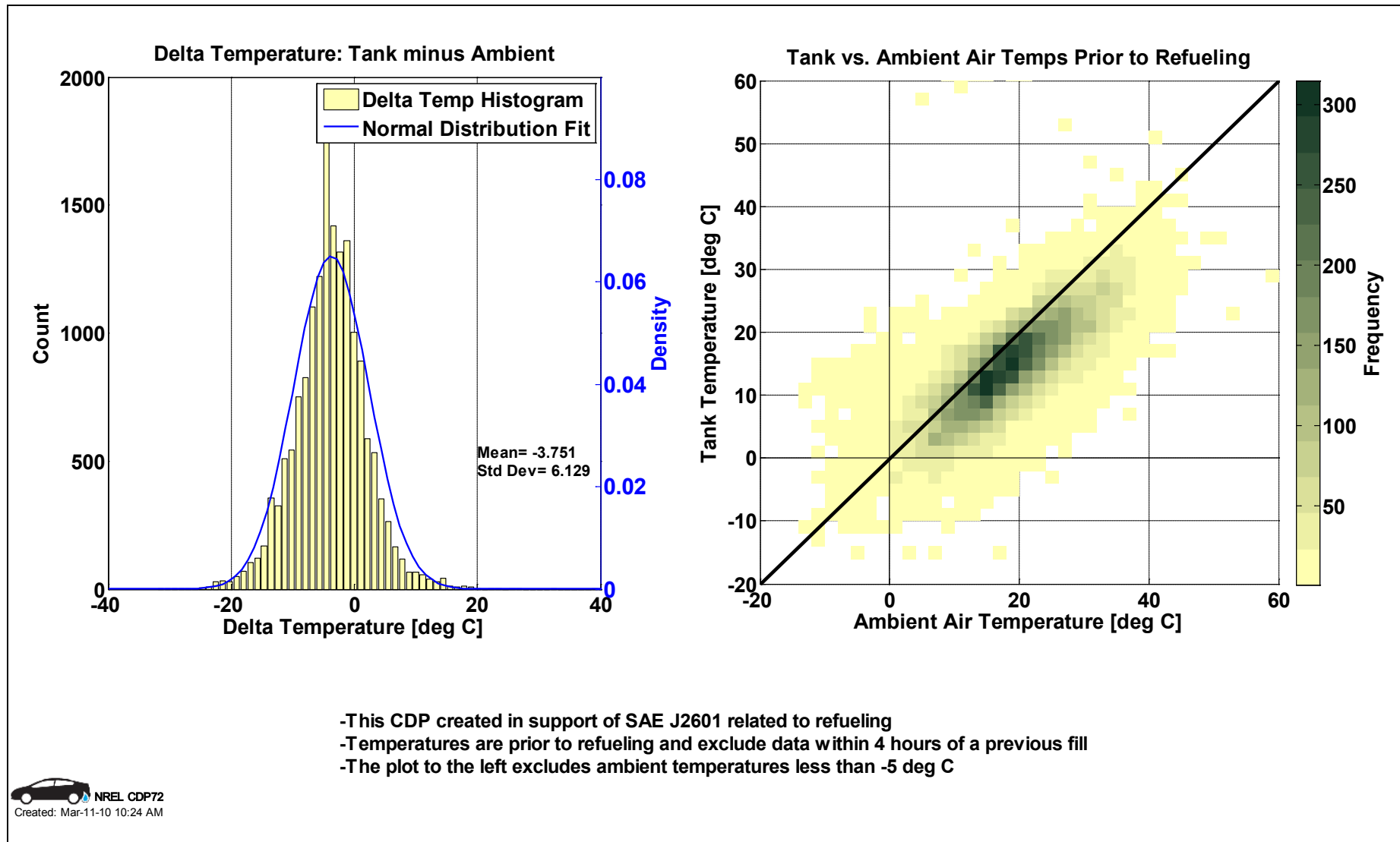


# CDP#71: Projected Hours to OEM Low Power Operation Limit

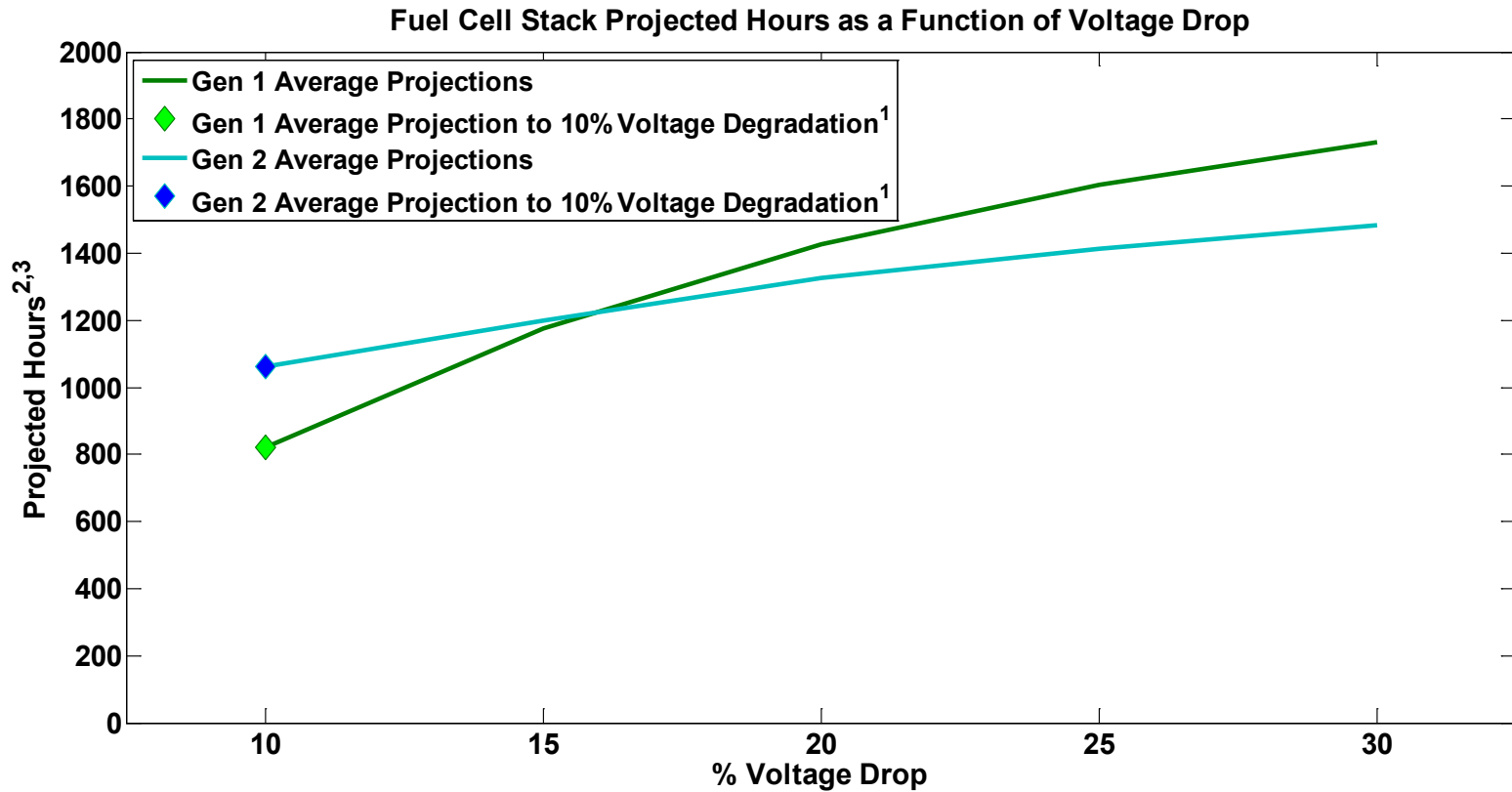


1. Low fuel cell power limit is dependent on the fuel cell vehicle system and is unique to each company in this Learning Demonstration.
2. Acceptable low vehicle performance limit will be determined by retail customer expectations.
3. Power projection method based on the voltage degradation techniques, but uses max fuel cell power instead of voltage at a specific high current.
4. Stacks with less than 200 operation hours are in separate groups because the projection is based on operation data and with operation hours greater than 200 the degradation rate tends to flatten out.

# CDP#72: Difference Between Tank and Ambient Temperature Prior to Refueling

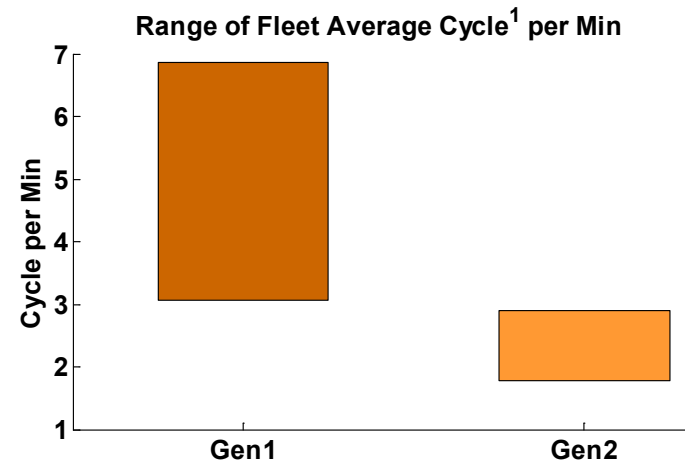
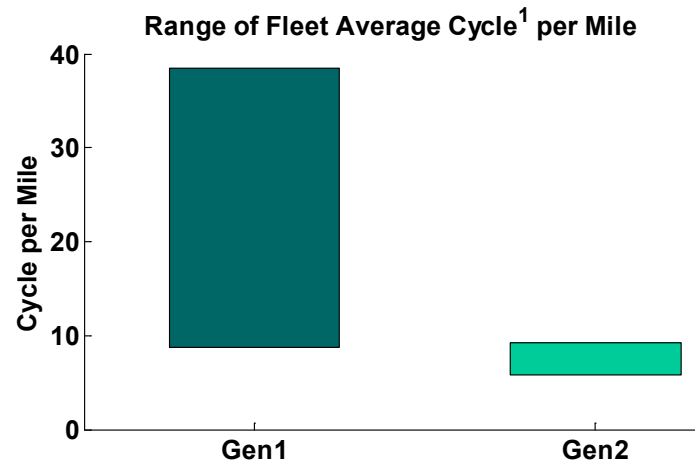
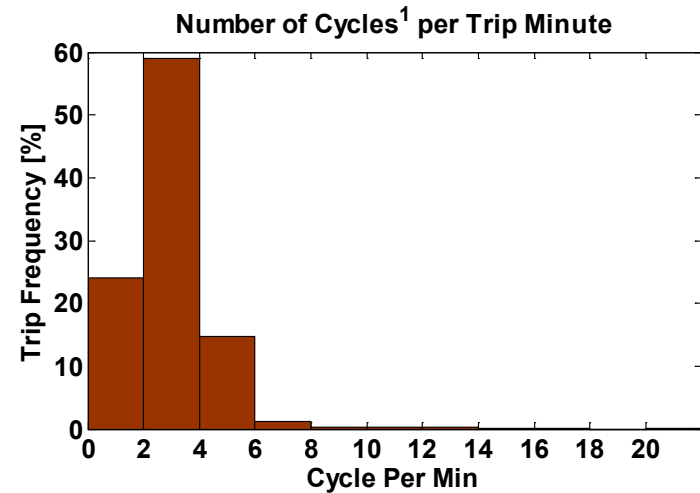
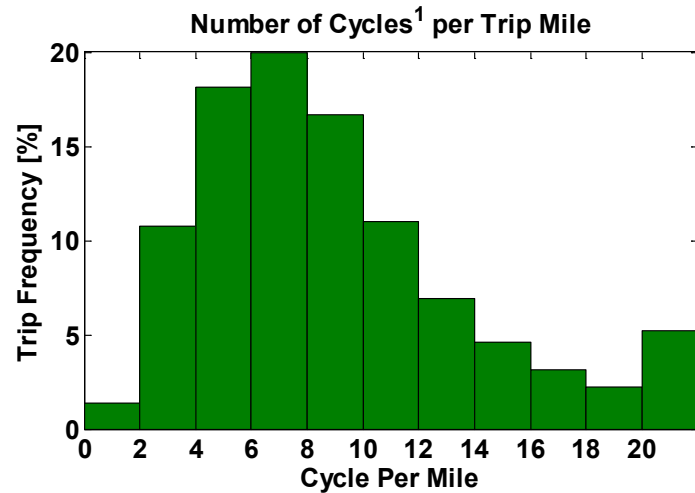


# CDP#73: Fuel Cell Stack Projected Hours as a Function of Voltage Drop



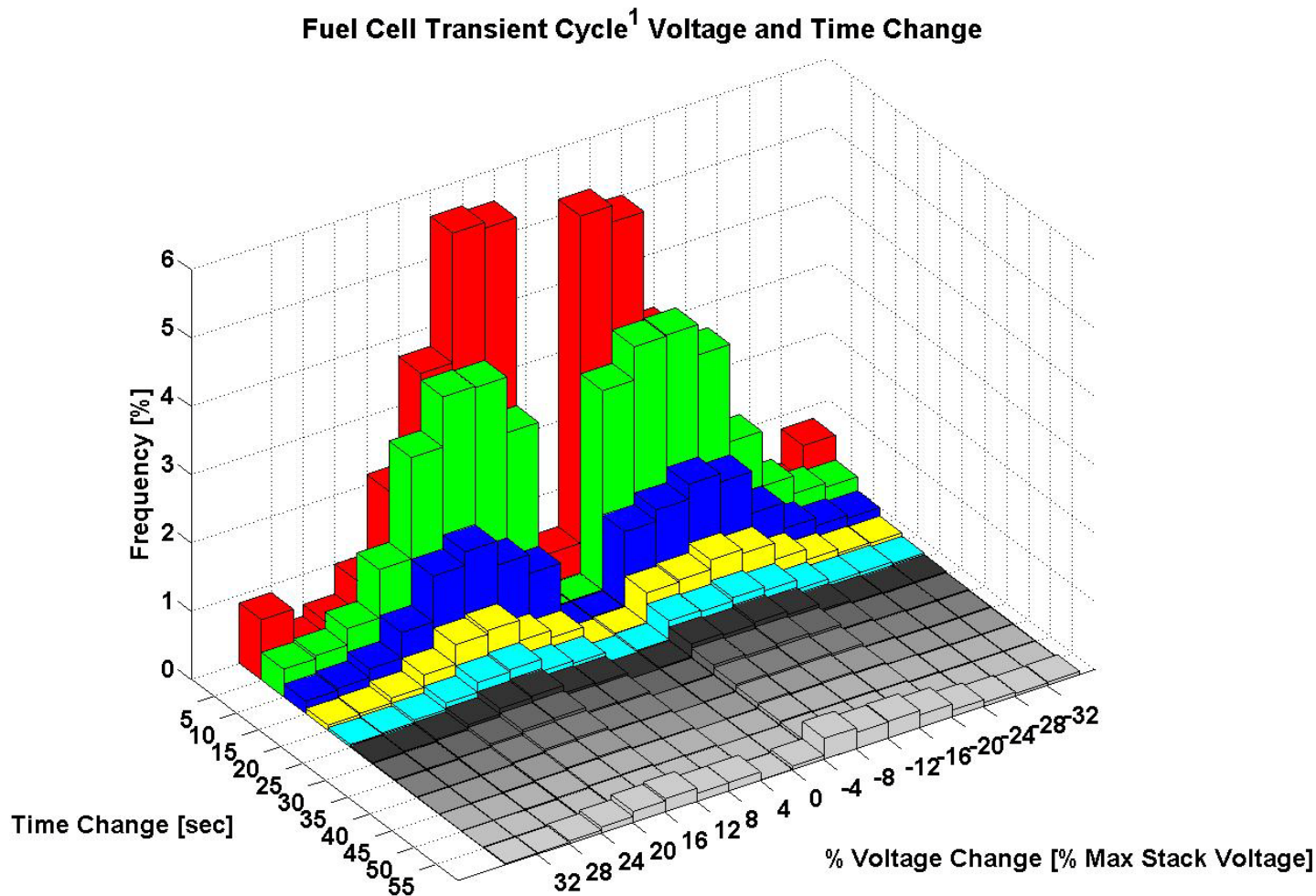
- (1) 10% Voltage degradation is a DOE metric for assessing fuel cell performance.
- (2) Projections using on-road data -- degradation calculated at high stack current.
- (3) Curves generated using the Learning Demonstration average of each individual fleet average at various voltage degradation levels.
- (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) 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.
- (6) All OEM Gen 2 average fleet projections are higher than Gen1 projections, however due to less operation data for Gen 2, these projections are limited by demonstrated operation hours to minimize extrapolations.

# CDP#74: Fuel Cell Transient Cycle Count per Mile and per Minute



1) A fuel cell voltage transient cycle has a decrease and increase with a minimum delta of 5% max stack voltage.

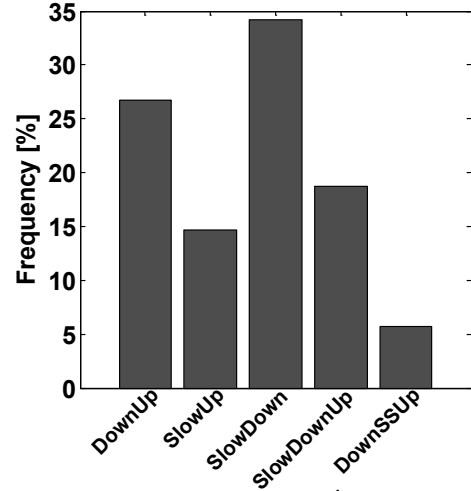
# CDP#75: Fuel Cell Transient Voltage and Time Change



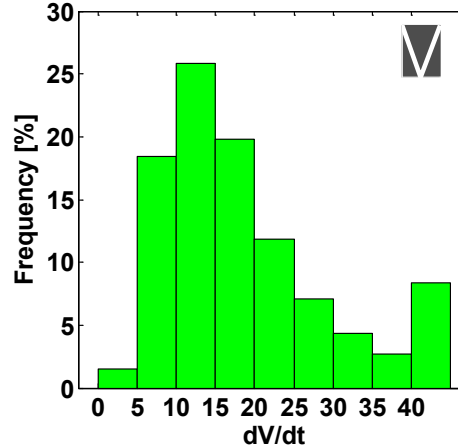
1) A fuel cell voltage transient cycle has a decrease and increase with a minimum delta of 5% max stack voltage.

# CDP#76: Fuel Cell Transient Rate by Cycle Category

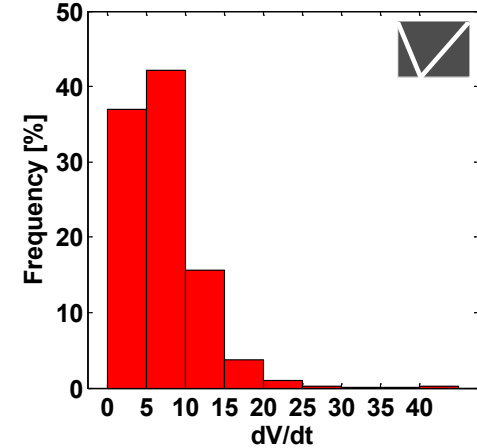
Transient Cycle<sup>1</sup> Count by Category<sup>2</sup>



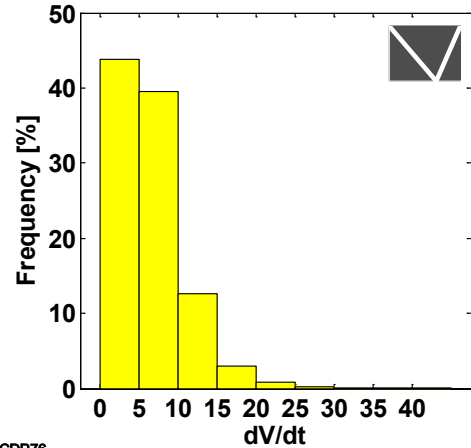
DownUp Cycle<sup>1</sup> dV/dT



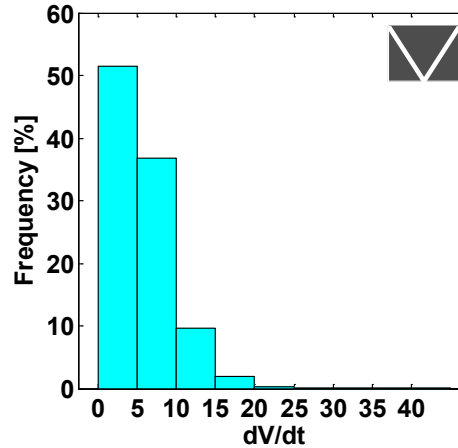
SlowUp Cycle<sup>1</sup> dV/dT



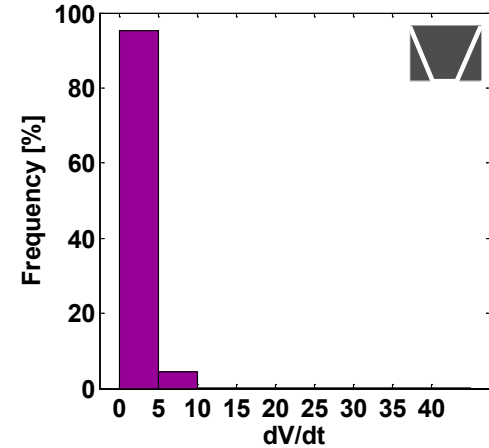
SlowDown Cycle<sup>1</sup> dV/dT



SlowDownUp Cycle<sup>1</sup> dV/dT



DownSSUp Cycle<sup>1</sup> dV/dT

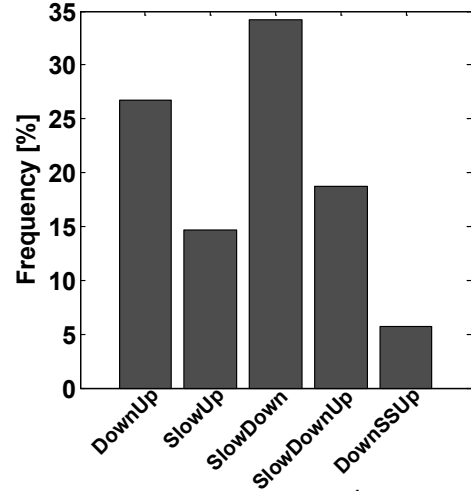


1) A fuel cell voltage transient cycle has a decrease and increase with a minimum delta of 5% max stack voltage.  
2) Cycle categories based on cycle up and down times. A slow up or down transient has a time change  $\geq 5$  seconds.  
SS = Steady State, where the time change is  $\geq 10$  seconds and the voltage change is  $\leq 2.5\%$  max stack voltage.

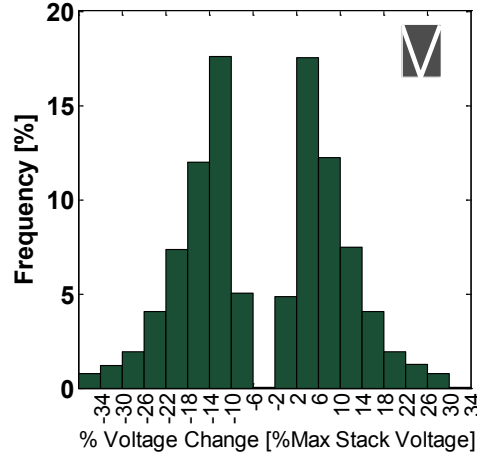


# CDP#77: Fuel Cell Transient Voltage Changes by Cycle Category

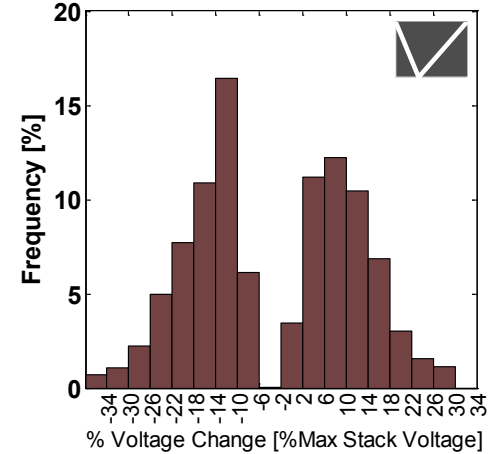
Transient Cycle<sup>1</sup> Count by Category<sup>2</sup>



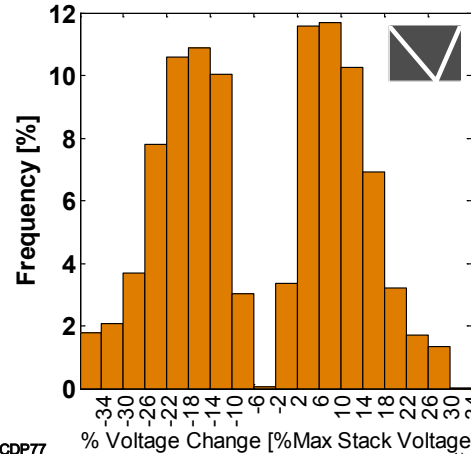
DownUp Cycle<sup>1</sup> dV



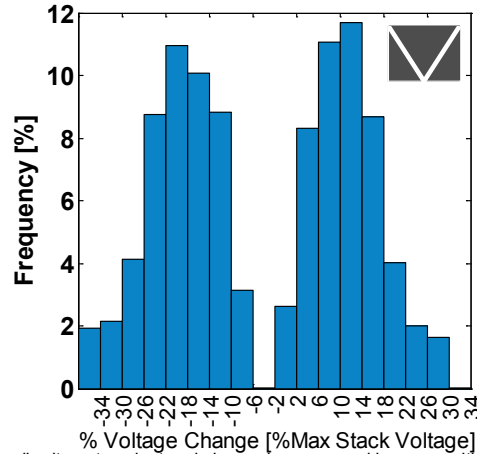
SlowUp Cycle<sup>1</sup> dV



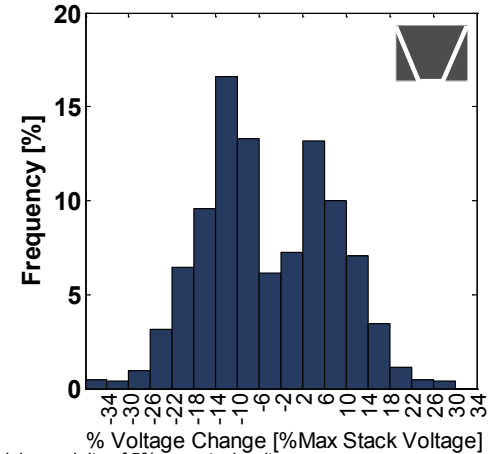
SlowDown Cycle<sup>1</sup> dV



SlowDownUp Cycle<sup>1</sup> dV

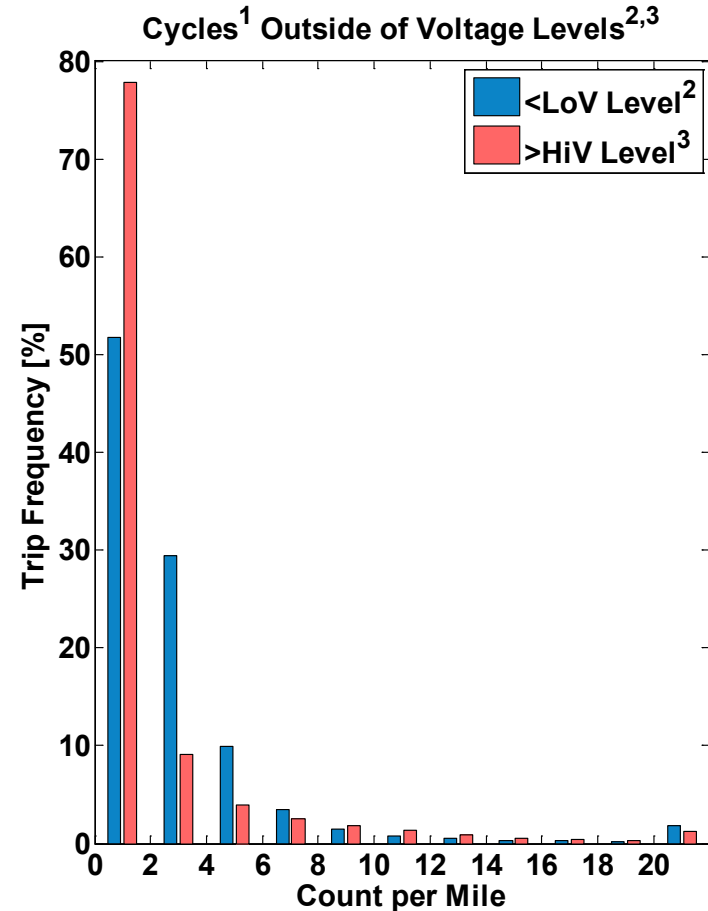
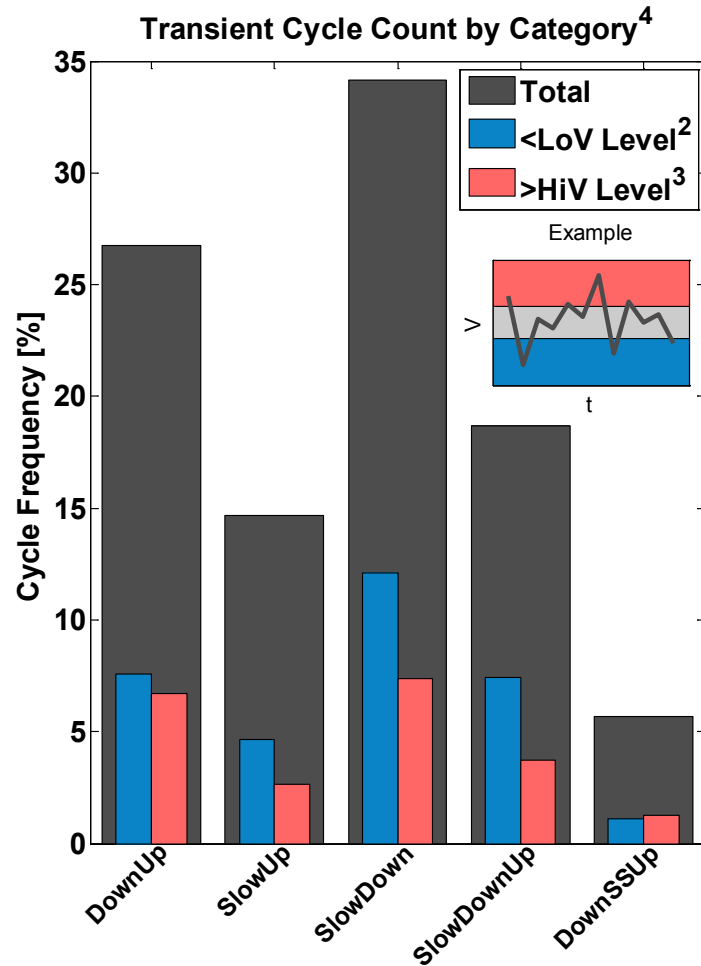


DownSSUp Cycle<sup>1</sup> dV



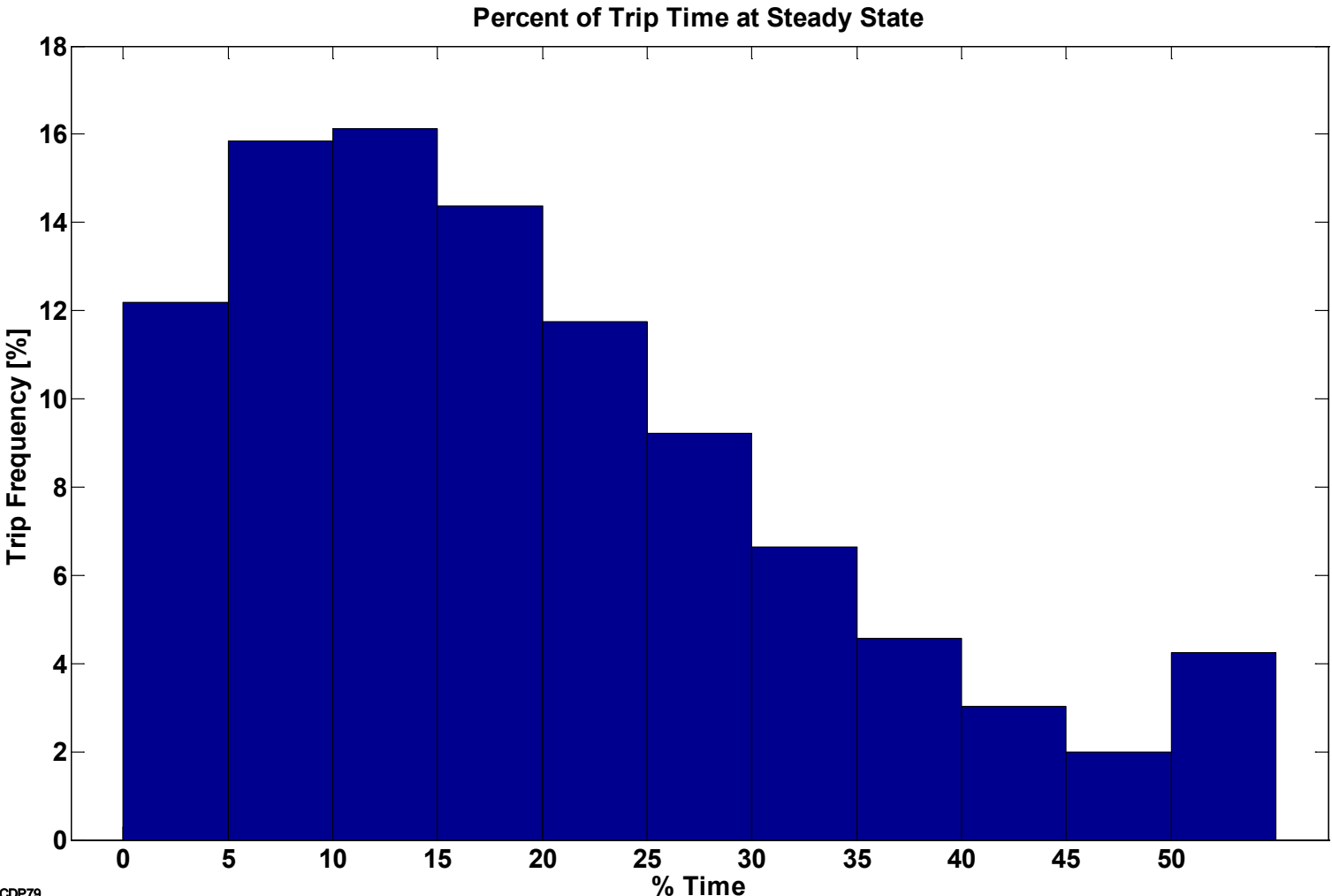
1) A fuel cell voltage transient cycle has a decrease and increase with a minimum delta of 5% max stack voltage.  
2) Cycle categories based on cycle up and down times. A slow up or down transient has a time change  $\geq 5$  seconds.  
SS = Steady State, where the time change is  $\geq 10$  seconds and the voltage change is  $\leq 2.5\%$  max stack voltage.

# CDP#78: Fuel Cell Transient Cycles Outside of Specified Voltage Levels



- 1) A fuel cell voltage transient cycle has a decrease and increase with a minimum delta of 5% max stack voltage.
- 2) The low voltage level is 70% Max Stack Voltage
- 3) The high voltage level is 90% Max Stack Voltage
- 4) Cycle categories based on cycle up and down times. A slow up or down transient has a time change  $\geq 5$  seconds.  
SS = Steady State, where the time change is  $\geq 10$  seconds and the voltage change is  $\leq 2.5\%$  max stack voltage.

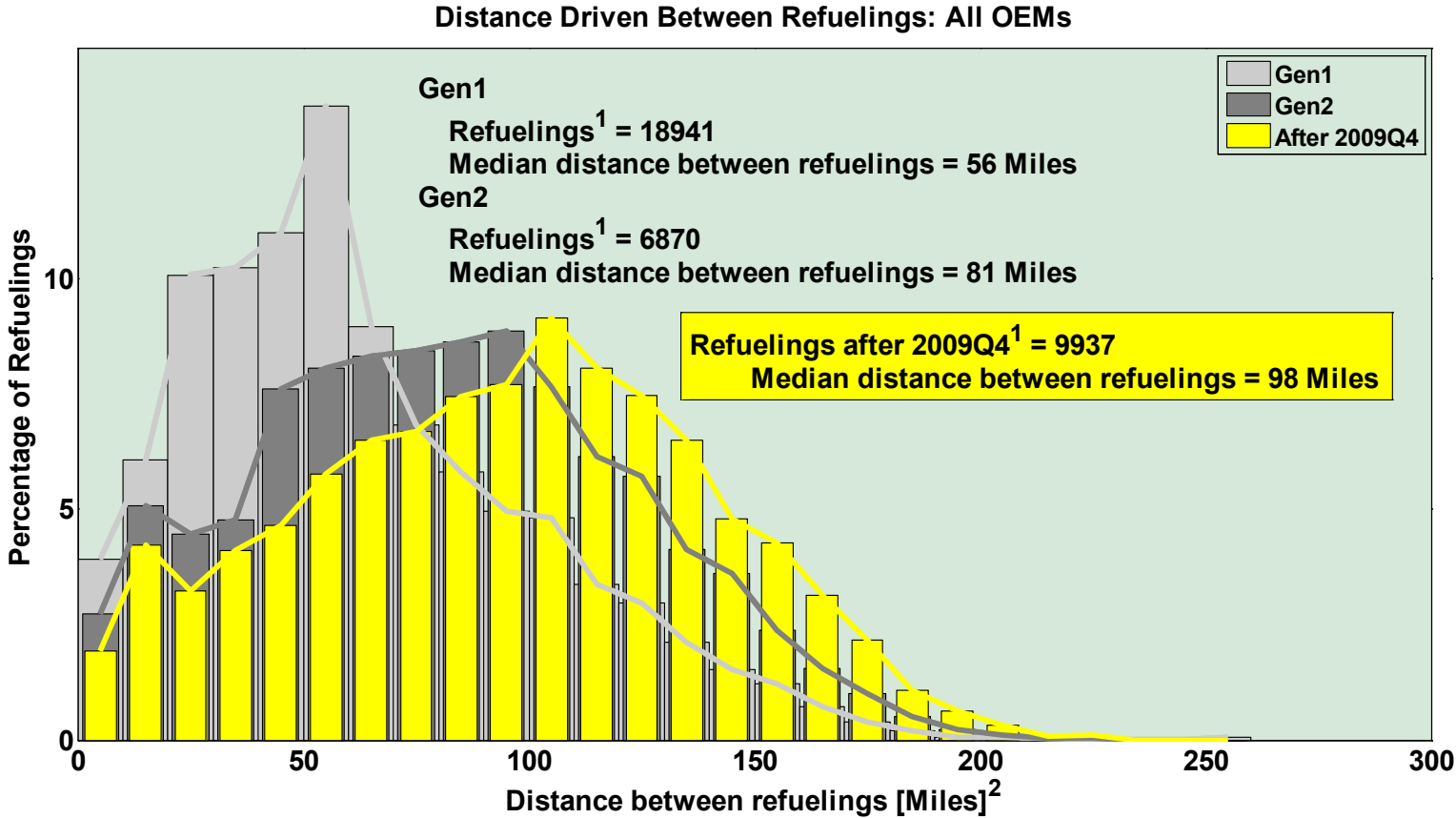
# CDP#79: Percentage of Trip Time at Steady State



 NREL CDP79  
Created: Mar-22-10 4:46 PM

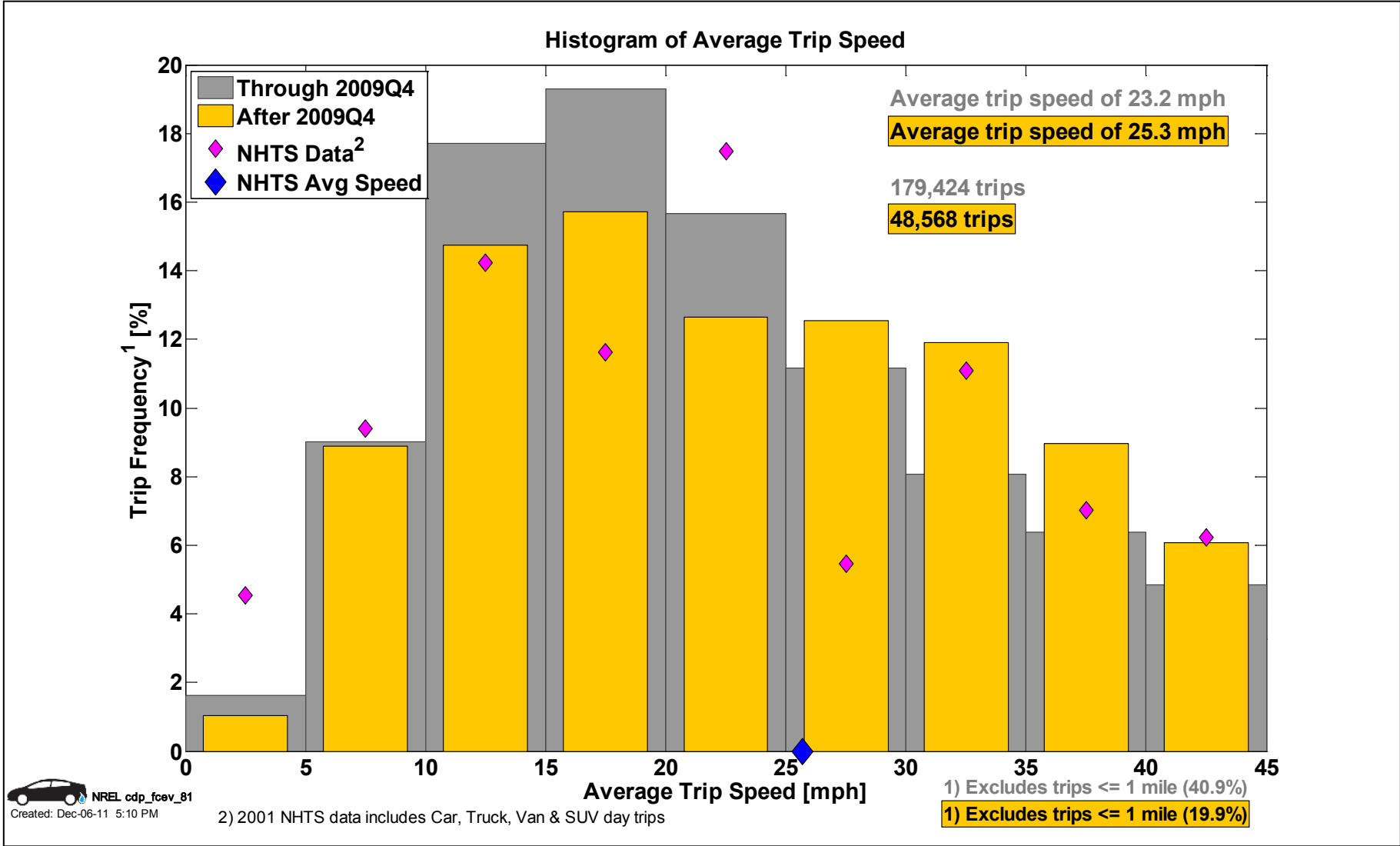
1) SS = Steady State, where the time change is  $\geq 10$  seconds and the voltage change is  $\leq 2.5\%$  max stack voltage.

# CDP#80: Miles Between Refuelings

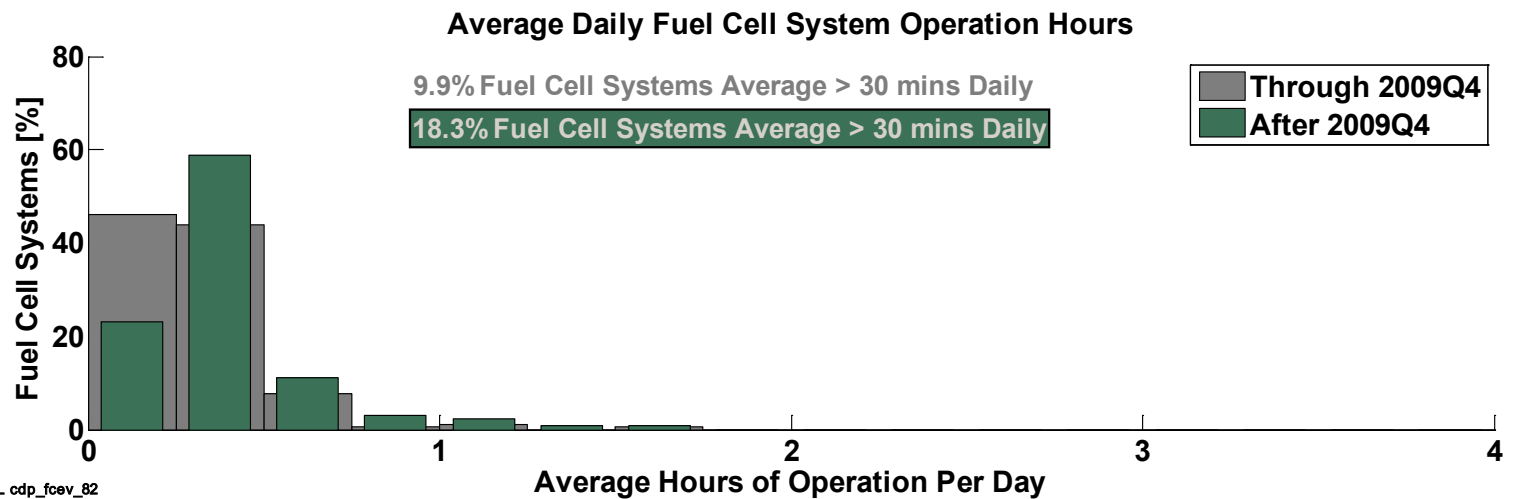
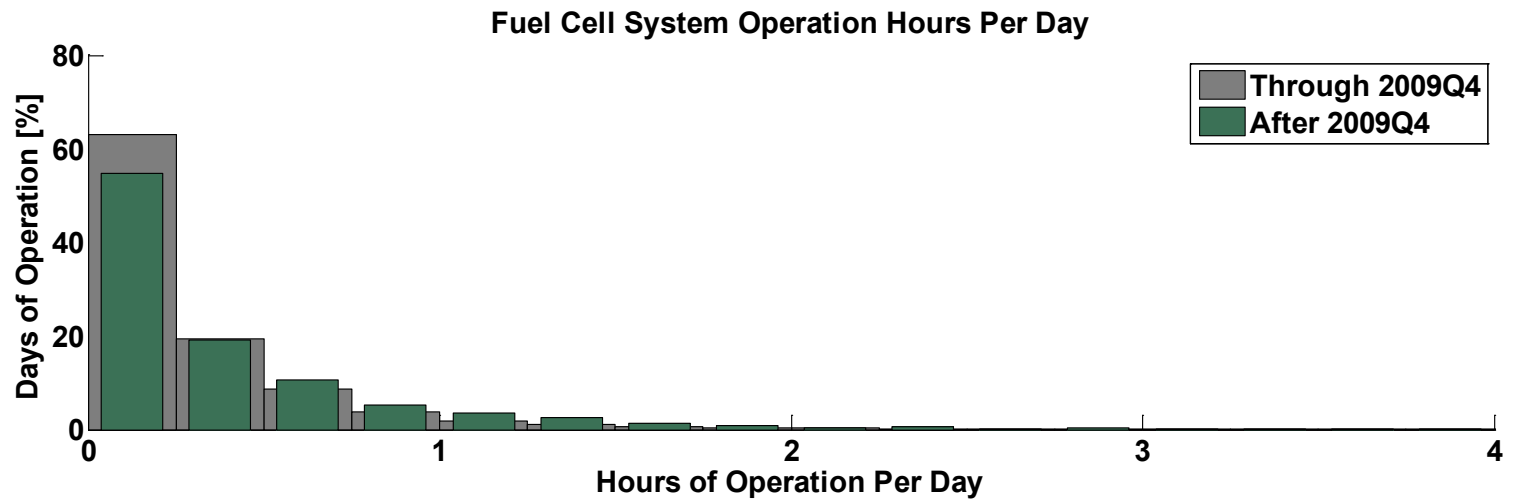


1. Some refueling events are not detected/reported due to data noise or incompleteness.  
 2. Distance driven between refuelings is indicative of driver behavior and does not represent the full range of the vehicle.

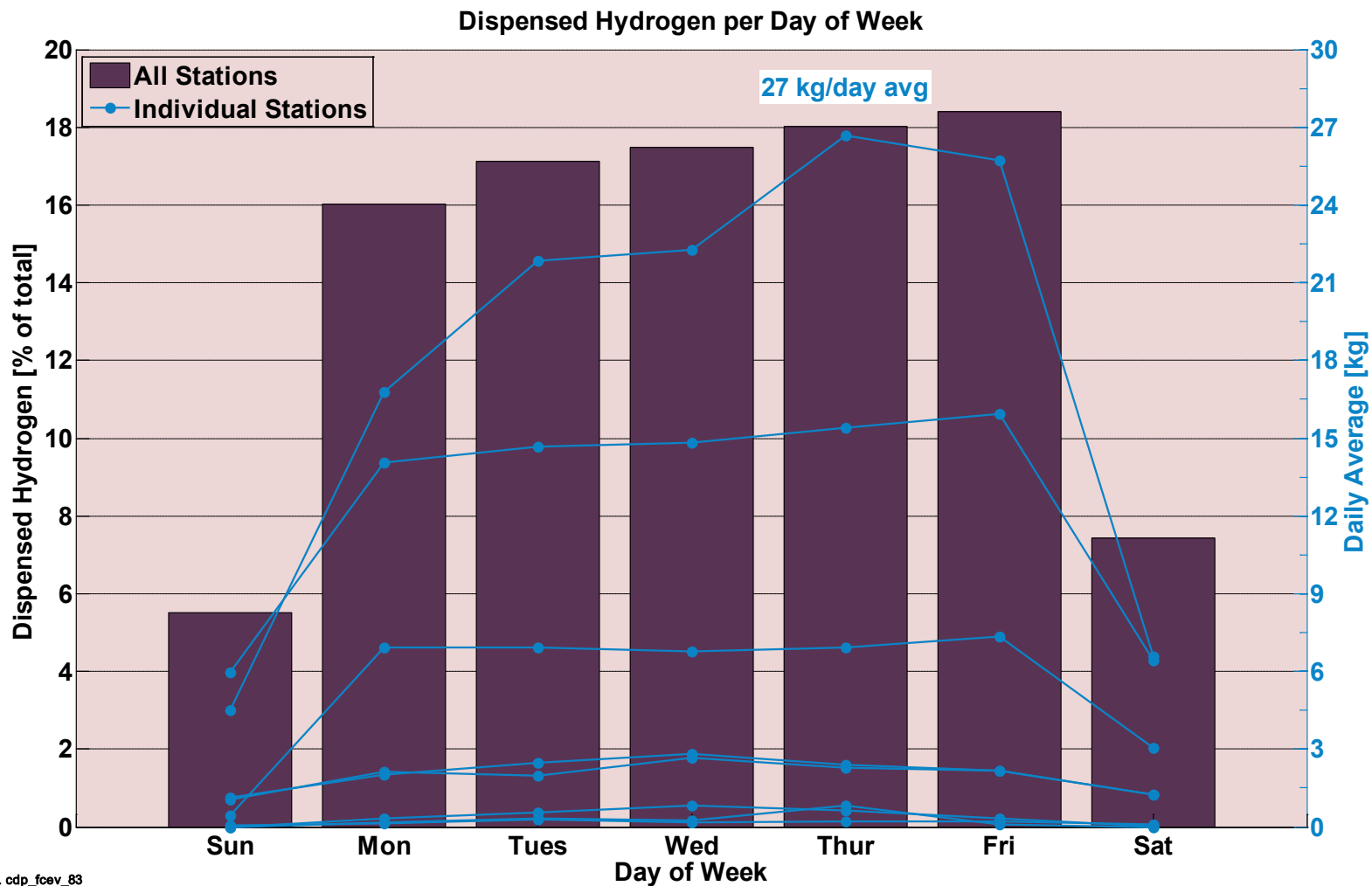
# CDP#81: Average Trip Speed



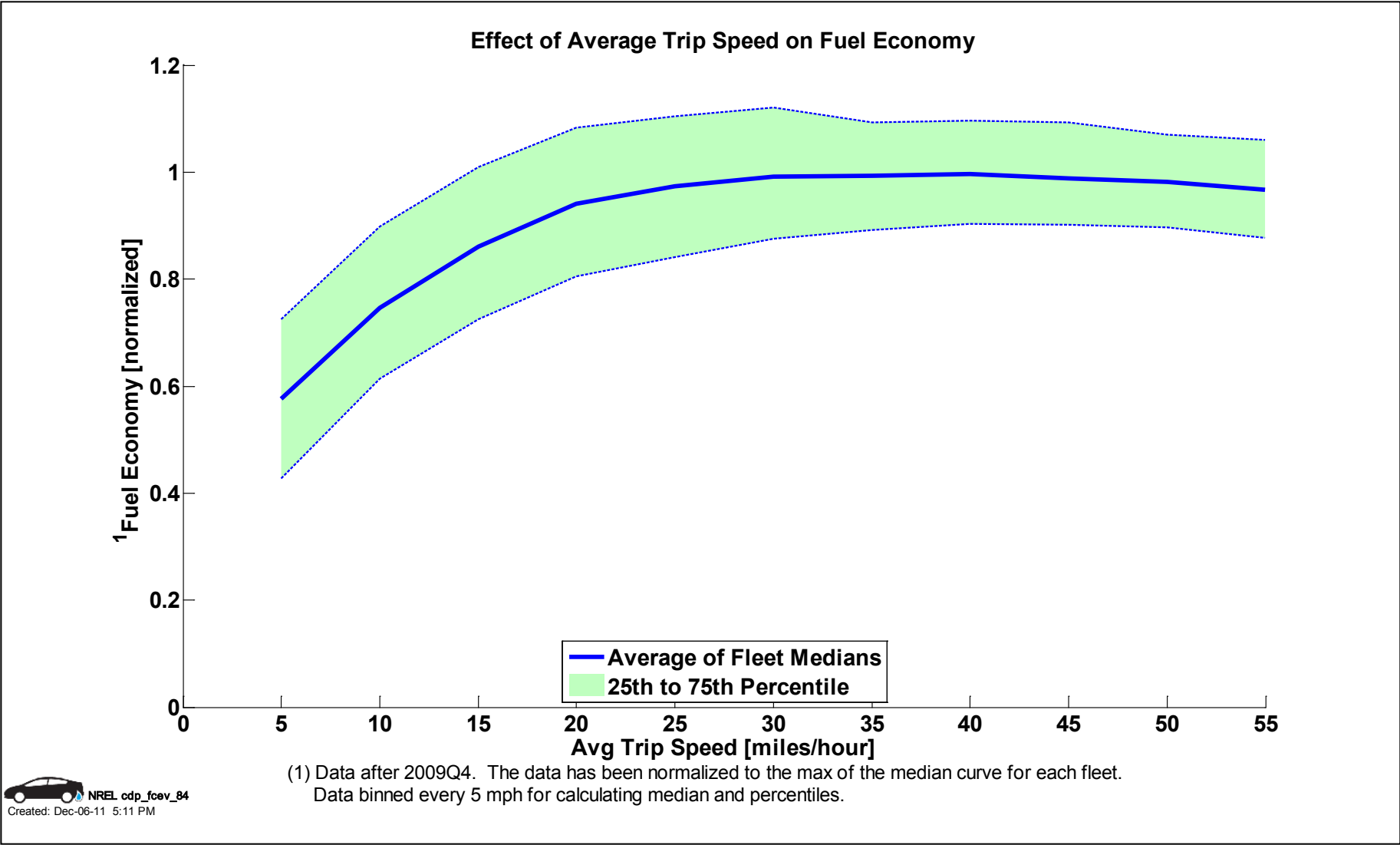
# CDP#82: Daily FC Operation Hours in Automotive Application



# CDP#83: Hydrogen Dispensed by Day of Week

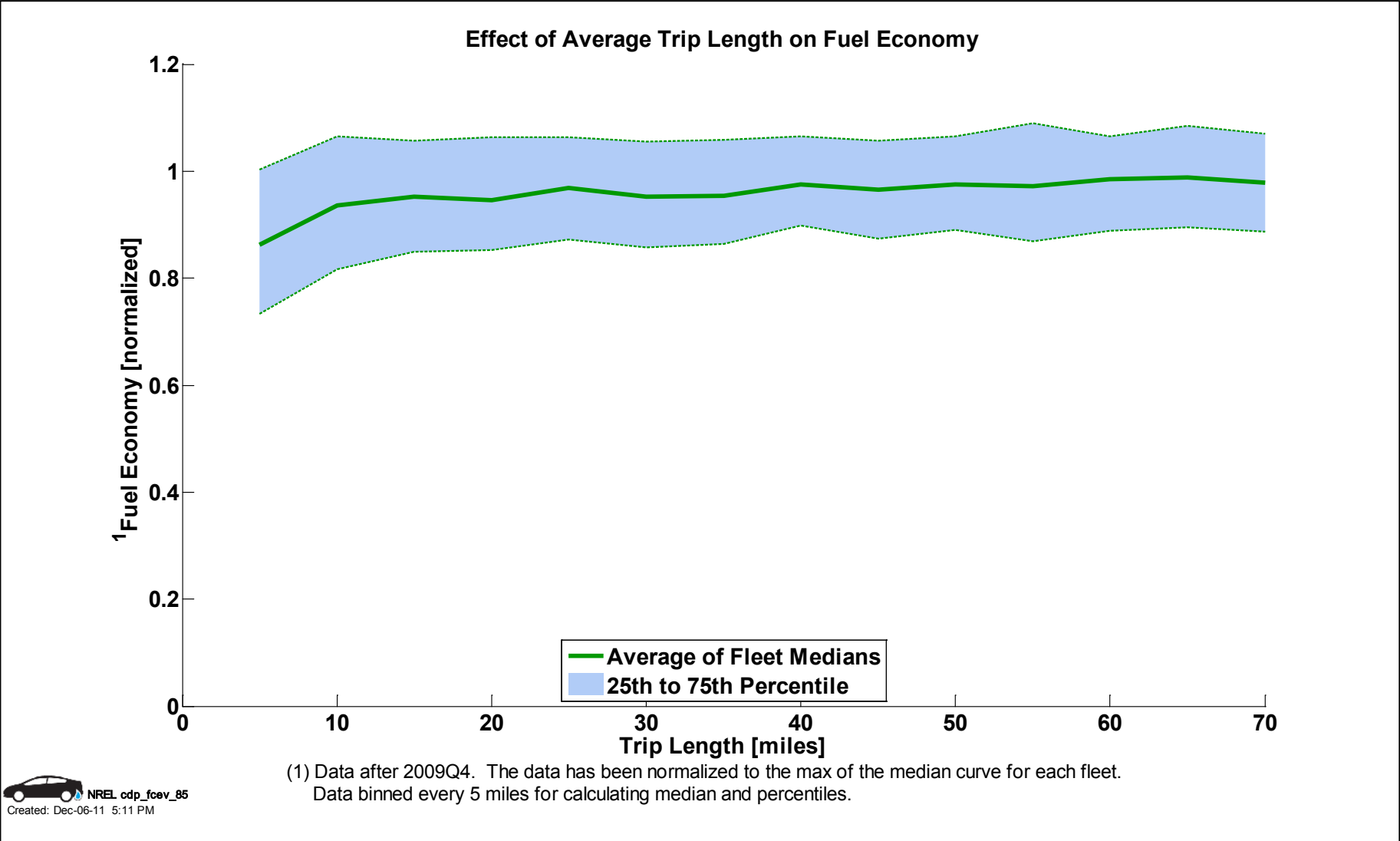


# CDP#84: Effect of Average Trip Speed on Fuel Economy

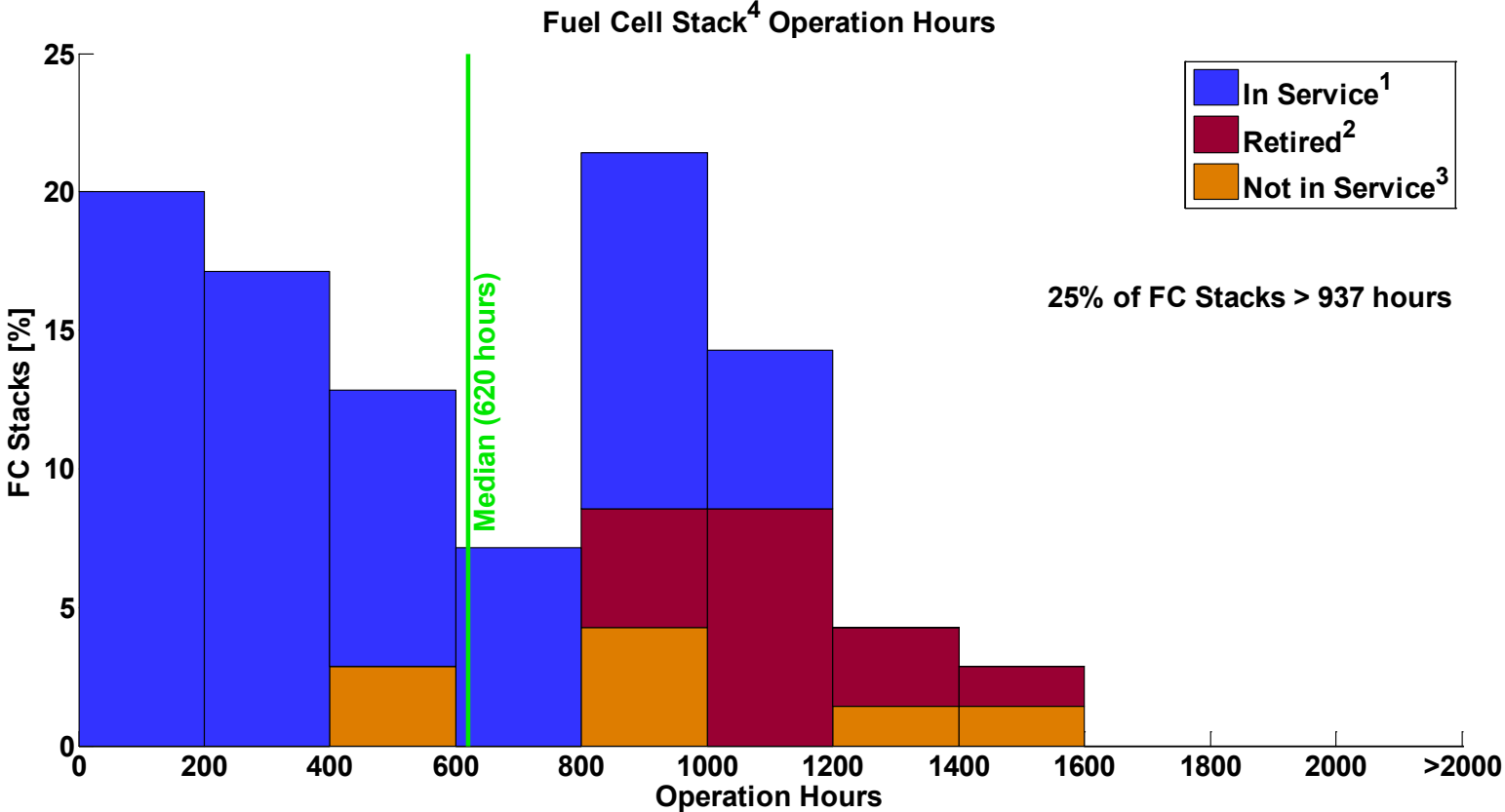




# CDP#85: Effect of Trip Length on Fuel Economy

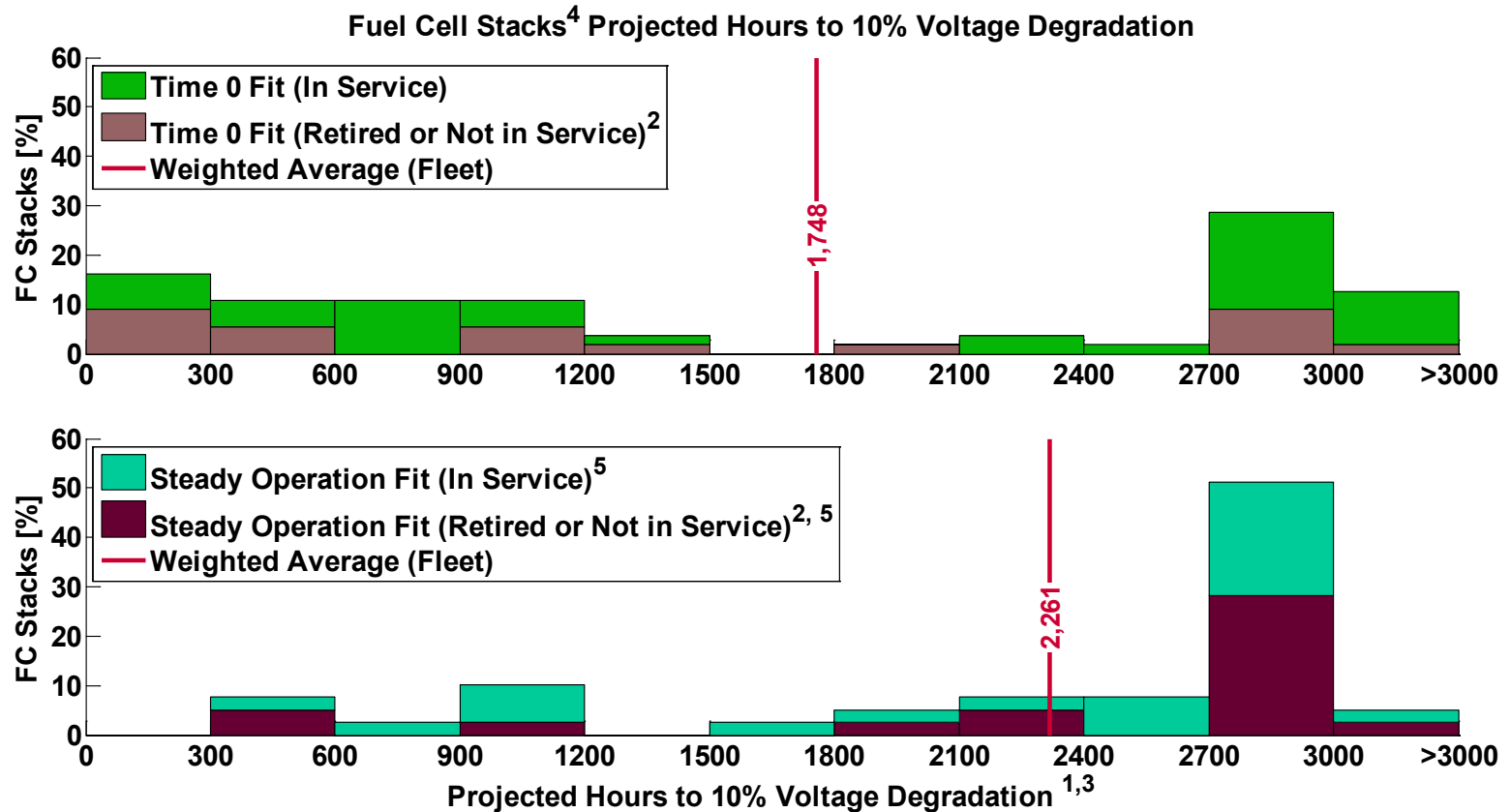


# CDP#86: Fuel Cell Stack Operation Hours



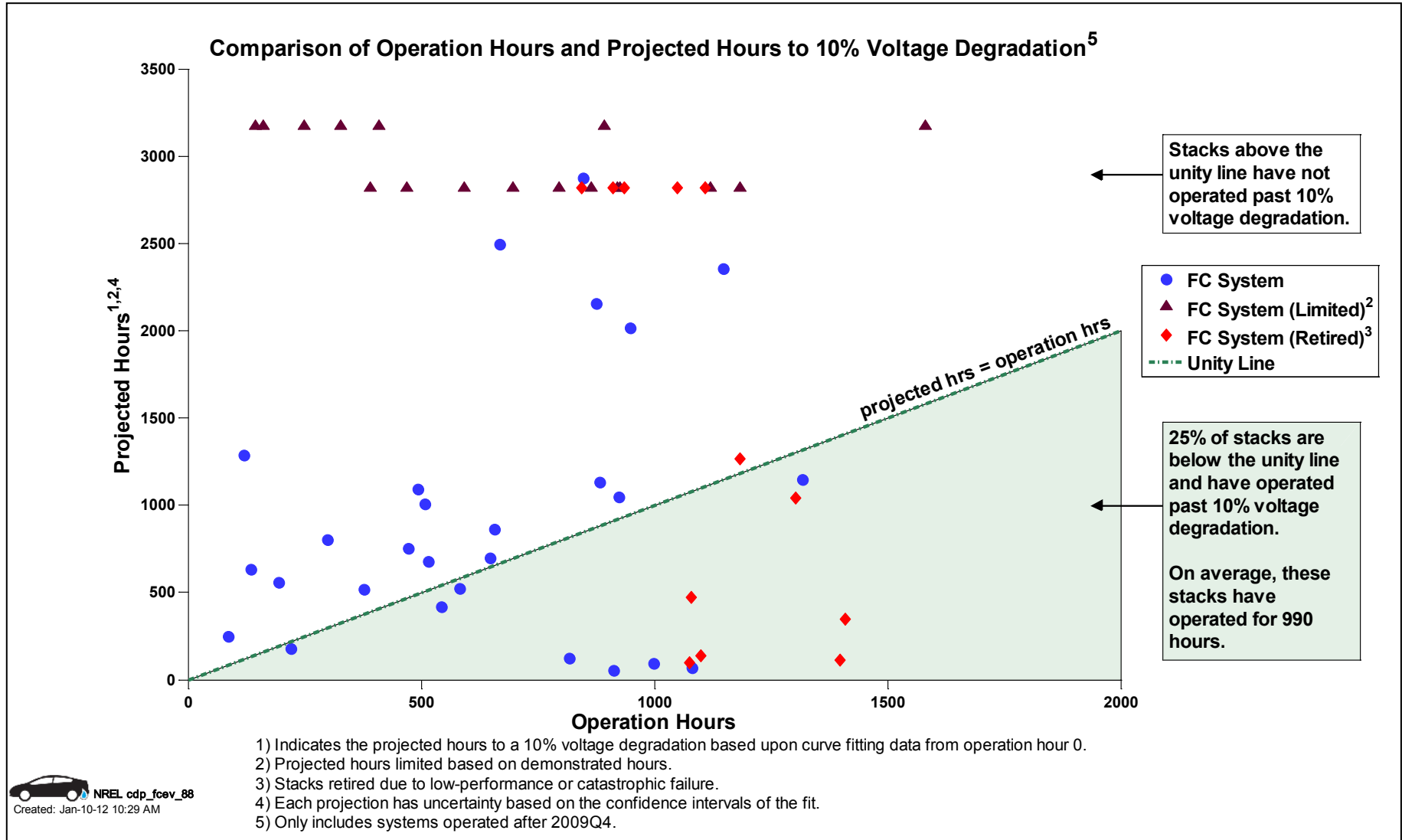
- 1) Stacks that are in service and accumulating operation hours.
- 2) Stacks retired due to low-performance or catastrophic failure.
- 3) Indicates stacks that are no longer accumulating hours either a) temporarily or b) have been retired for non- stack performance related issues or c) removed from DOE program.
- 4) Only includes systems operating after 2009Q4.

# CDP#87: Fuel Cell Stacks Projected Hours to 10% Voltage Degradation with Two Fits

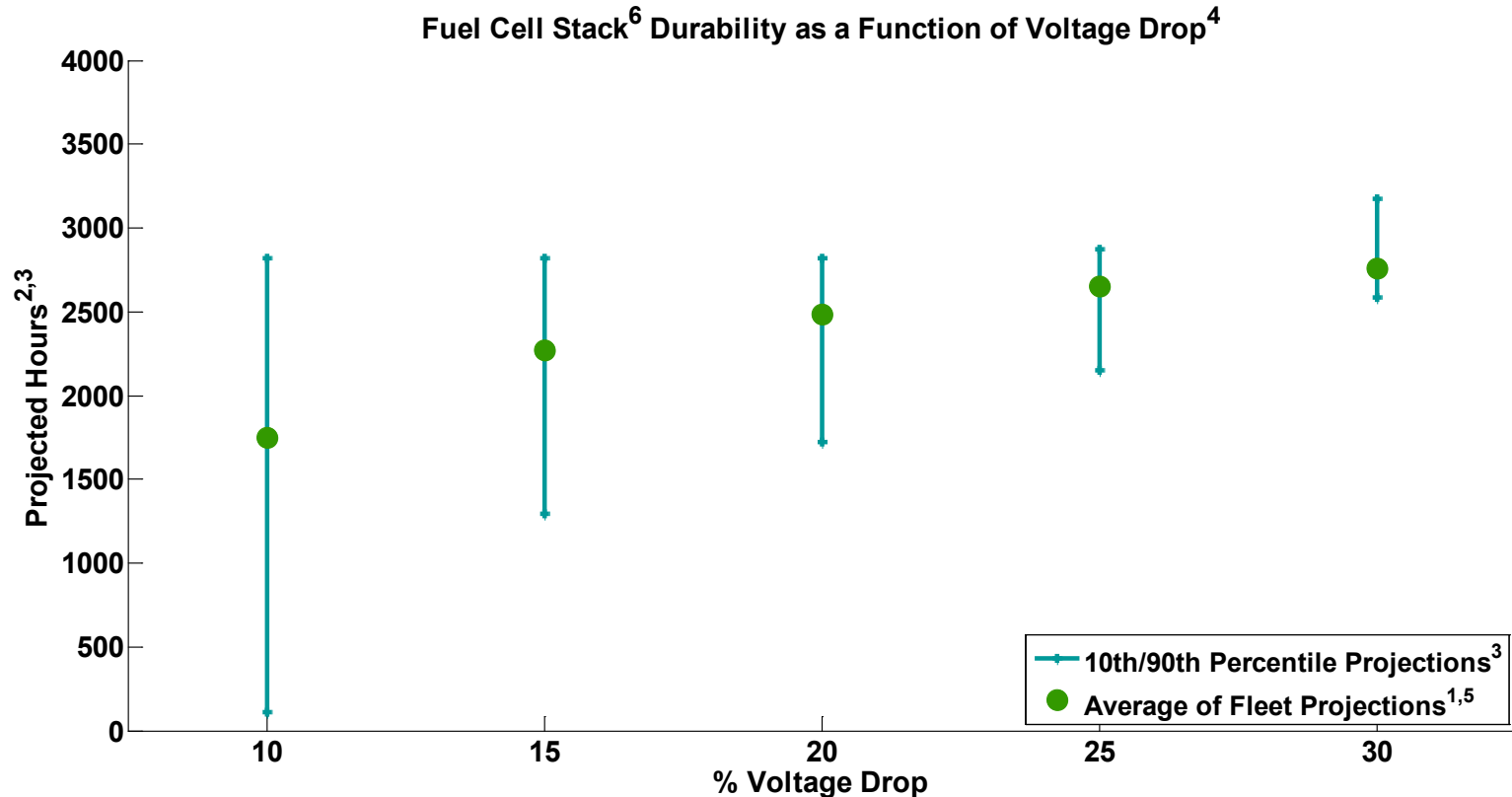


- 1) Projection using field data, calculated at high stack current, from operation hour 0 or a steady operation period. Projected hours may differ from an OEM's end-of-life criterion and does not address "catastrophic" failure modes.
- 2) Indicates stacks that are no longer accumulating hours either a) temporarily or b) have been retired for non- stack performance related issues or c) removed from DOE program.
- 3) Projected hours limited based on demonstrated hours.
- 4) Only includes systems operating after 2009Q4.
- 5) Not all stacks have a steady operation fit which is calculated from data after 200 hr break-in period. The steady operation starting hour is an approximation of the period after initial break-in where degradation levels to a more steady rate.

# CDP#88: Comparison of Fuel Cell Operation Hours and Projected Hours to 10% Voltage Degradation

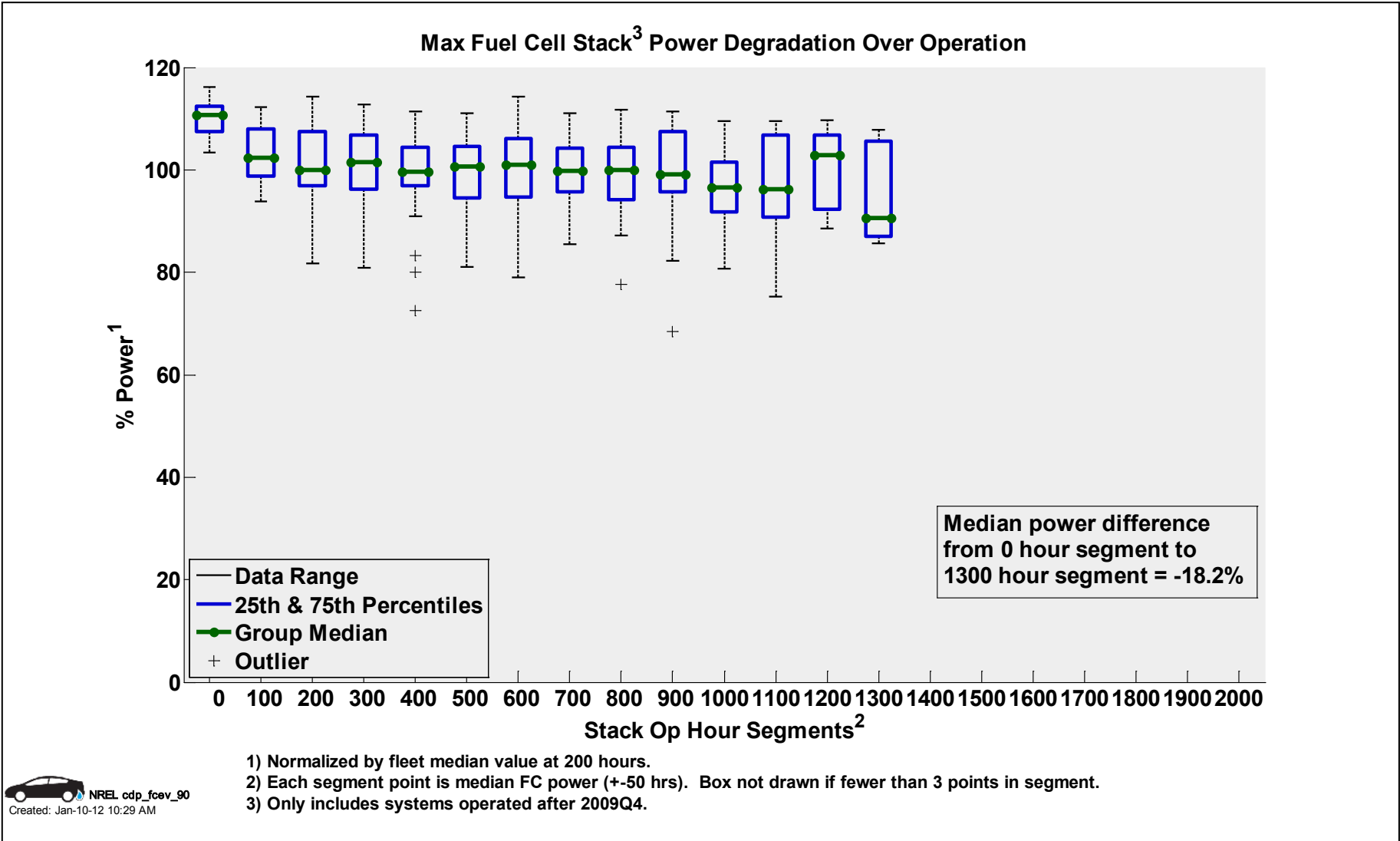


# CDP#89: Fuel Cell Stack Durability as a Function of Voltage Drop

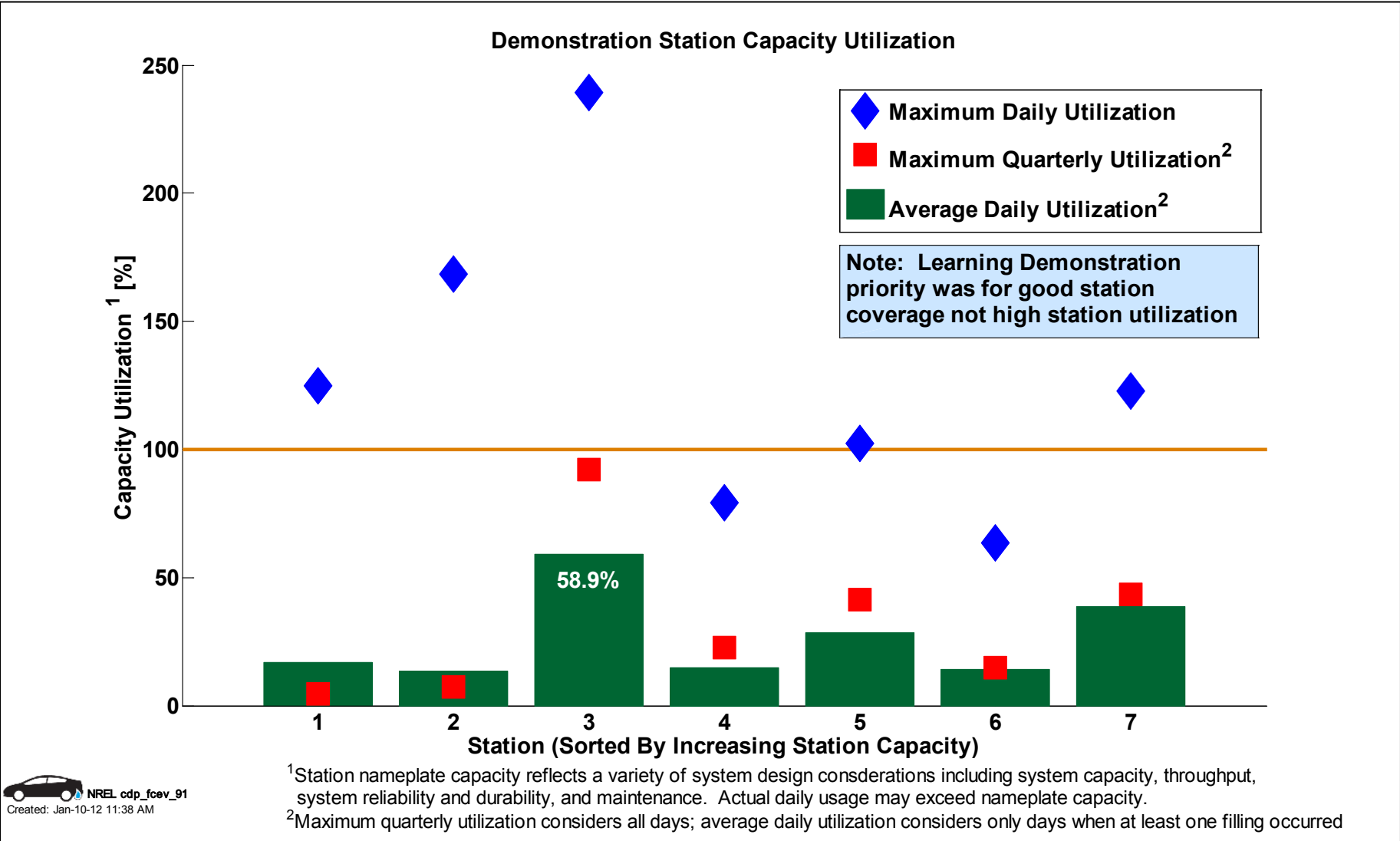


- 1) 10% Voltage degradation is a DOE metric for assessing fuel cell performance not an indication of an OEM's end-of-life criteria.
- 2) Projections using field data and calculated at high stack current.
- 3) 10<sup>th</sup> and 90<sup>th</sup> percentiles spans the range of stack projection. The included stacks satisfy a minimum number of operation hours and weighting factor.
- 4) The projected hours vary based on the percentage of voltage degradation, but the projected hours do not imply that all stacks will (or do) operate to these voltage degradation levels.
- 5) Each fleet has one voltage projection value that is the weighted average of the fleet's fuel cell stack projections.
- 6) Only includes systems operated after 2009Q4.

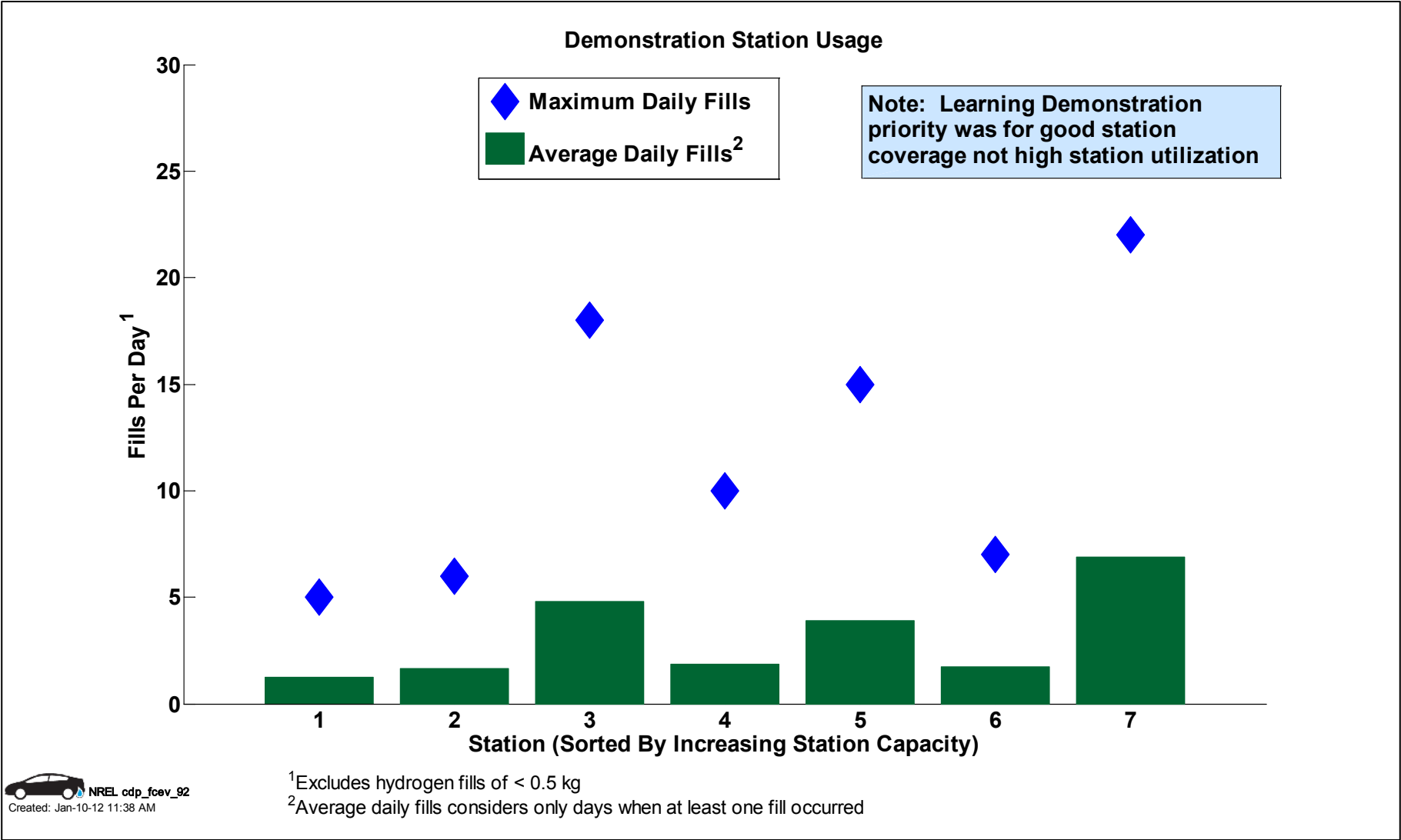
# CDP#90: Max Fuel Cell Stack Power Degradation Over Operation



# CDP#91: Station Capacity Utilization

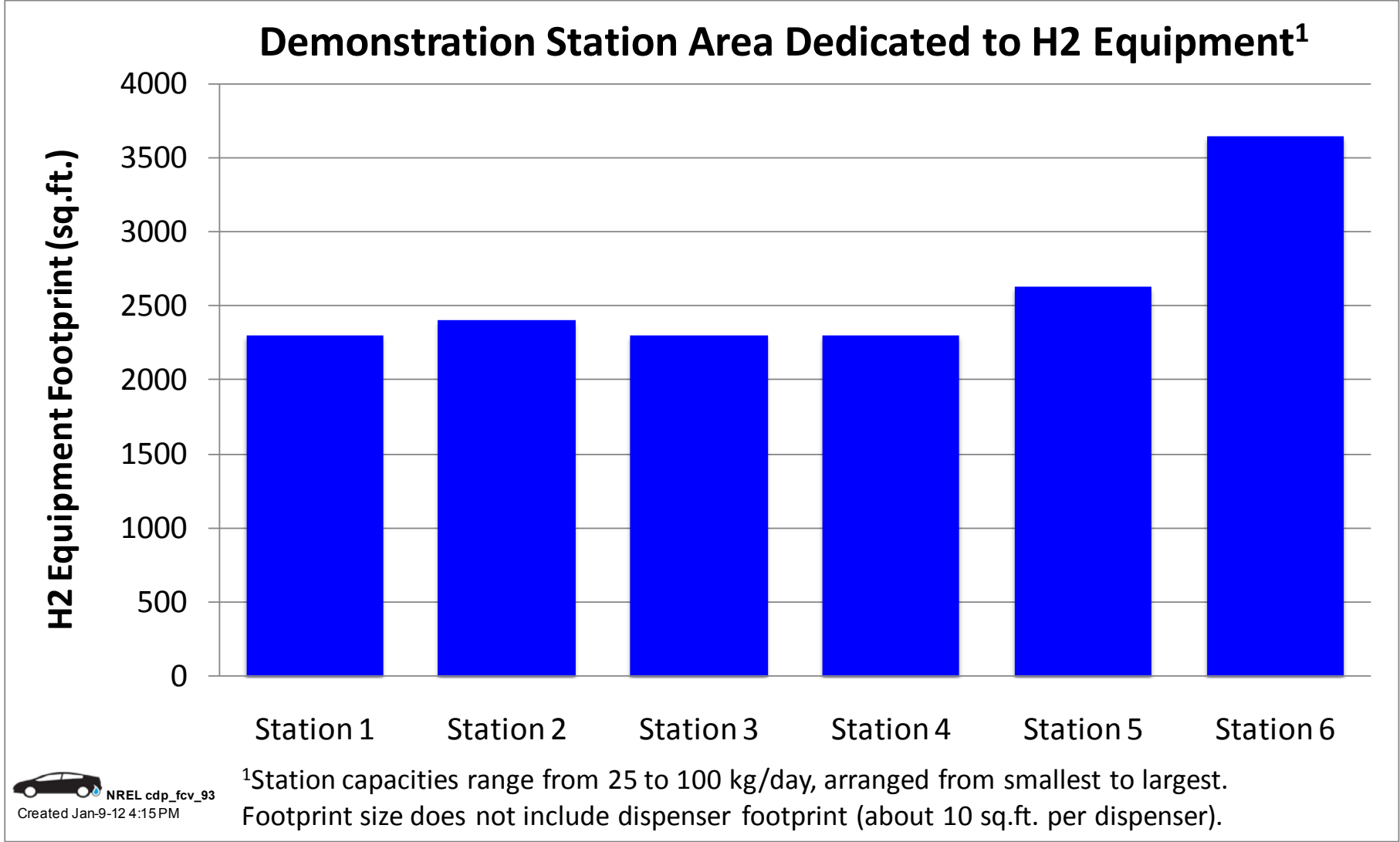


# CDP#92: Station Usage (fills per day)



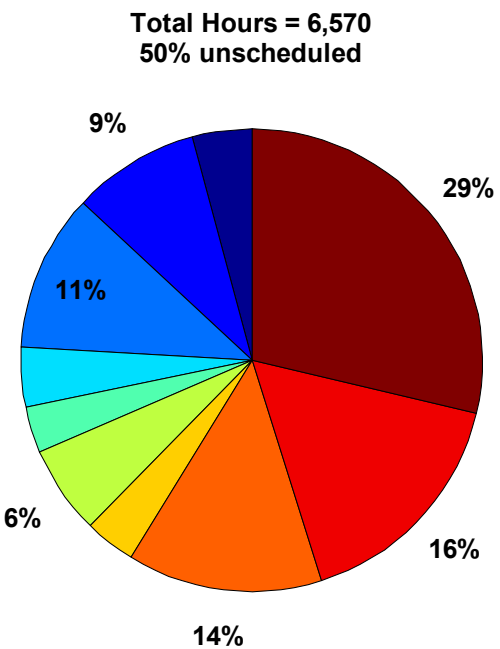
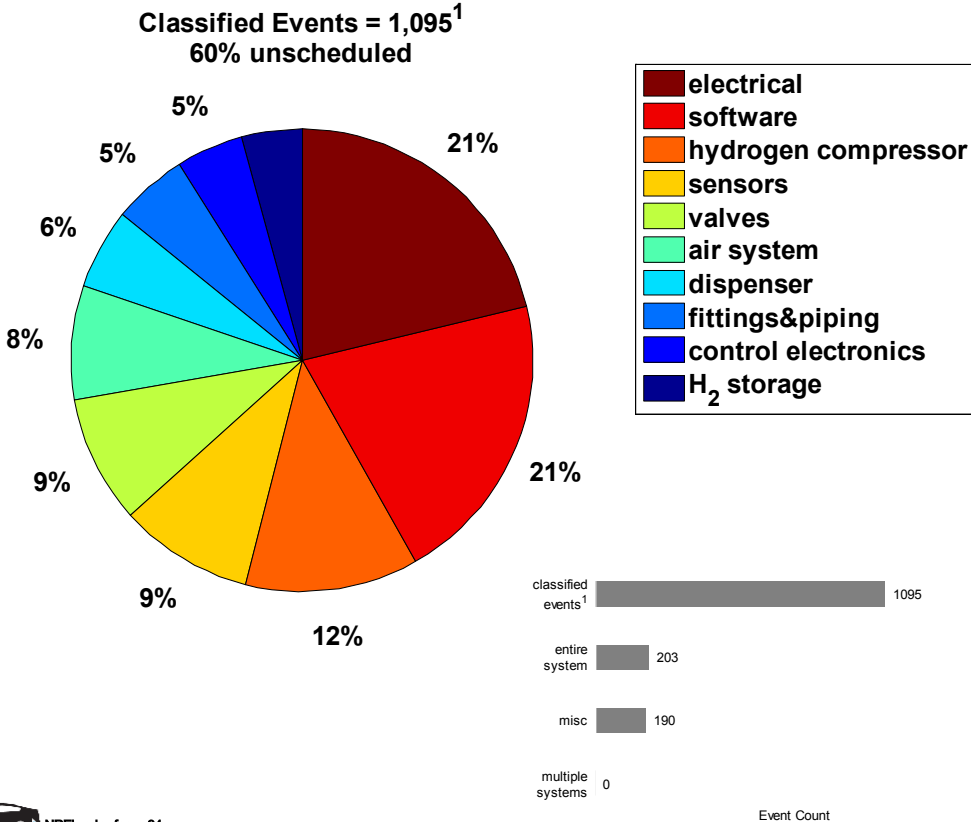


# CDP#93: Hydrogen Equipment Footprint



# CDP#94 Infrastructure Maintenance by Category

Infrastructure Maintenance By Equipment Type<sup>2</sup>

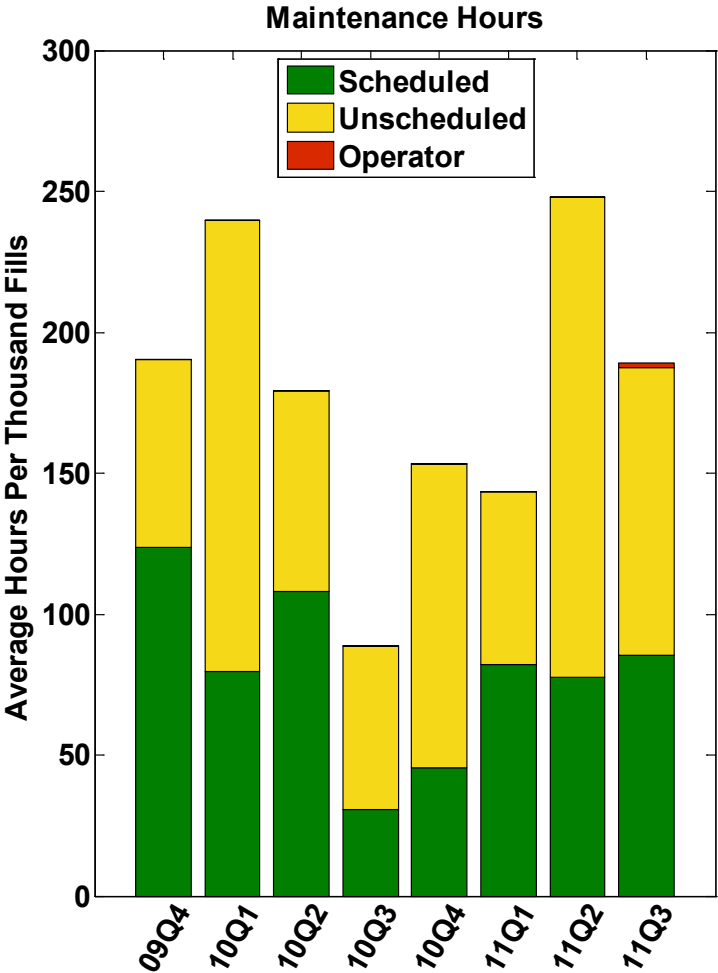
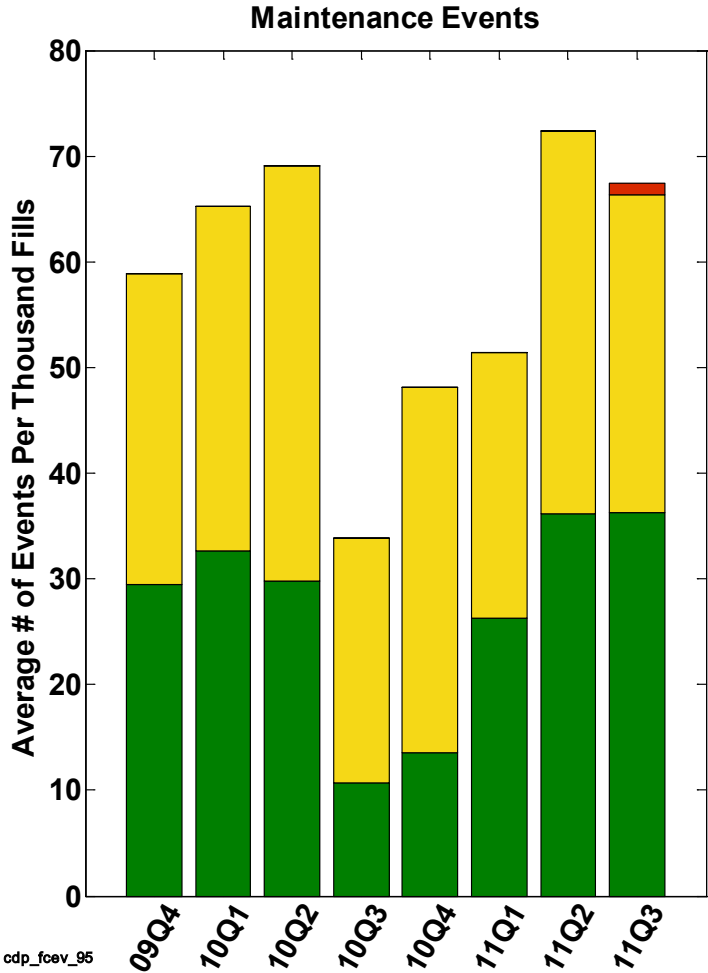


MISC includes the following failure modes: purifier, nitrogen system, feedwater system, seal, safety, reformer, electrolyzer, thermal management, other

2. Includes data from stations operating after 2009 Q4. For legacy results refer to CDP #63.

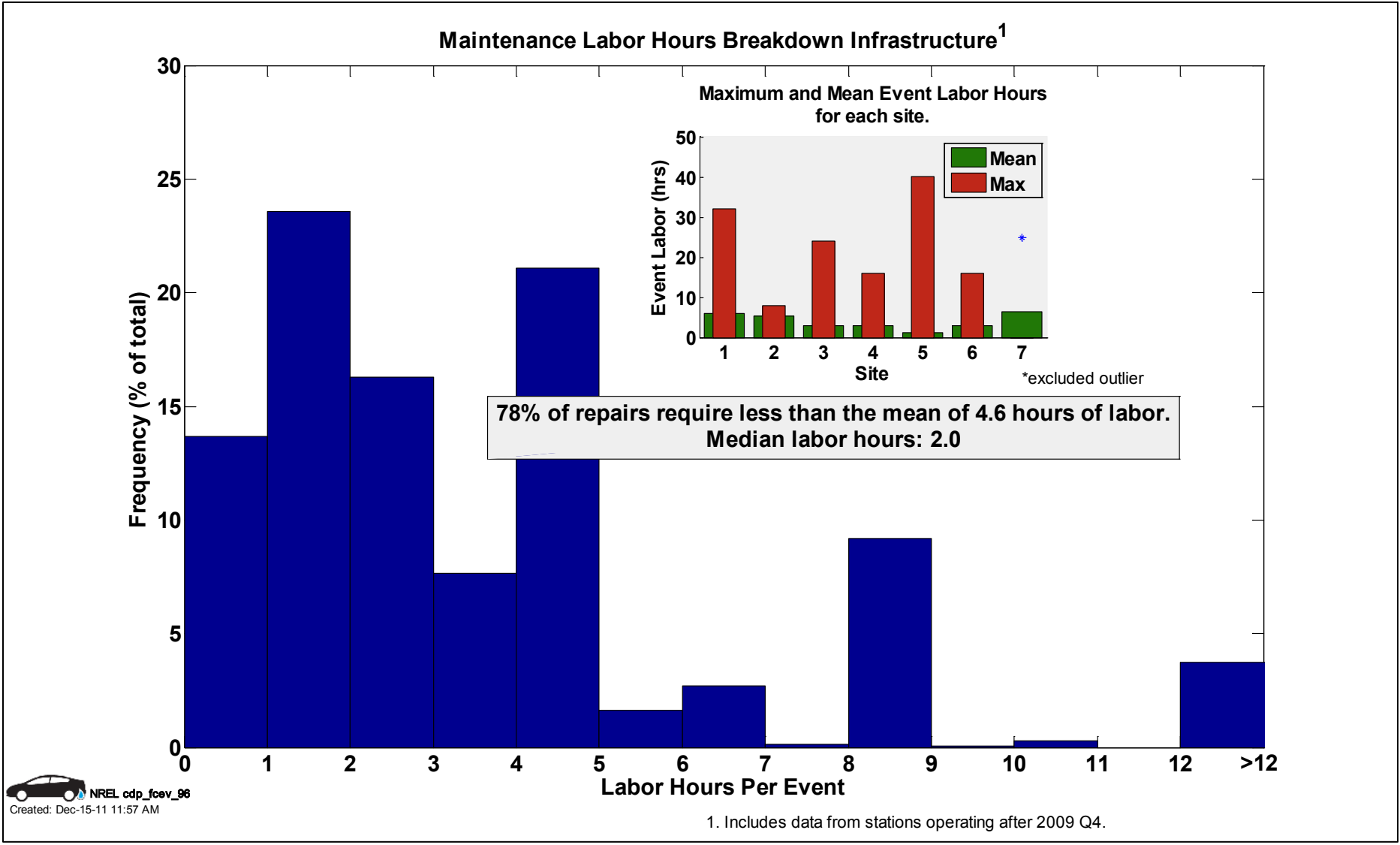
# CDP#95 Infrastructure Maintenance By Quarter

Infrastructure Maintenance by Quarter<sup>1</sup>



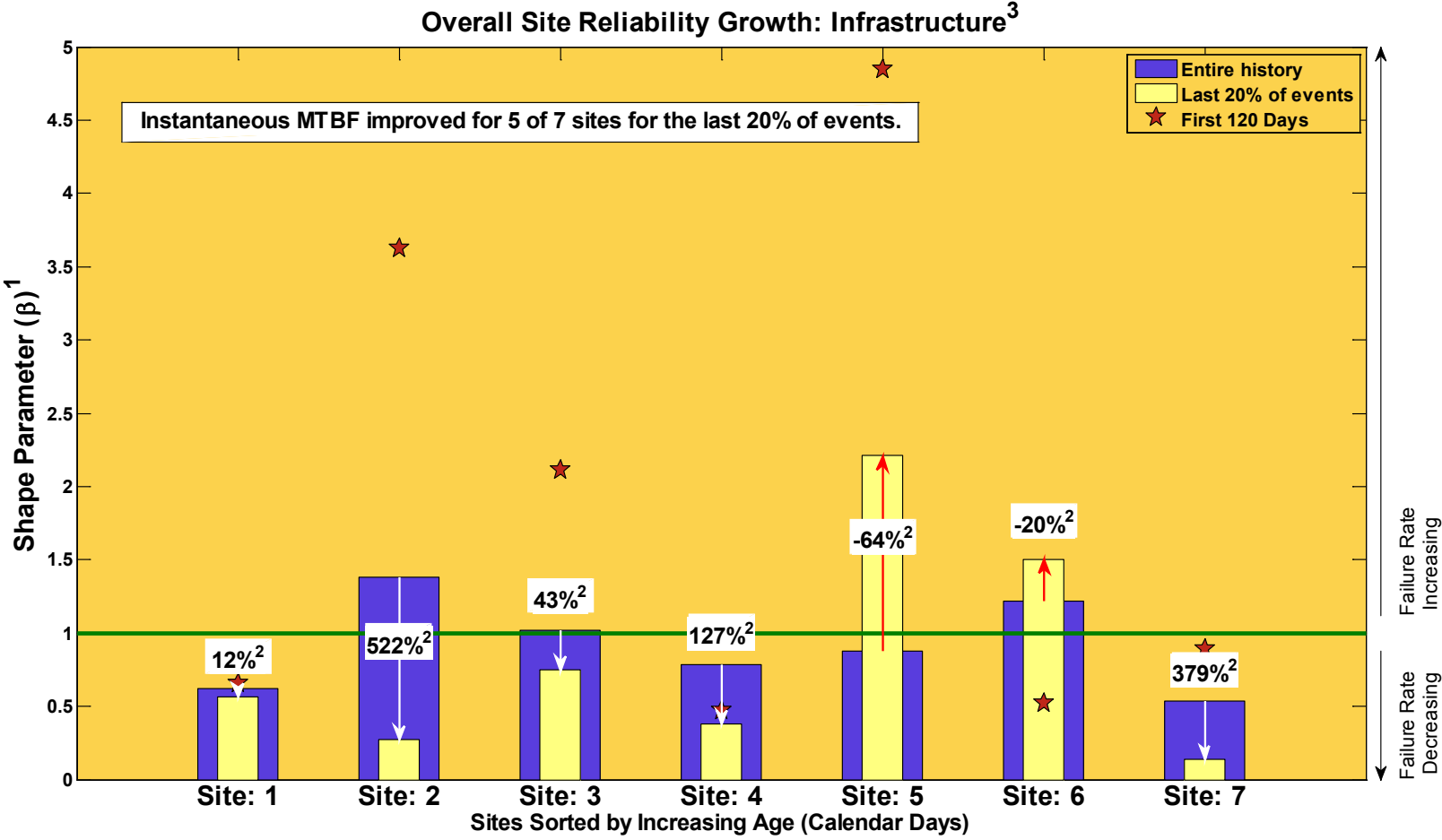
1. Includes data from stations operating after 2009 Q4.

# CDP#96 Infrastructure Maintenance Labor Hours



1. Includes data from stations operating after 2009 Q4.

# CDP#97 Infrastructure Reliability Growth

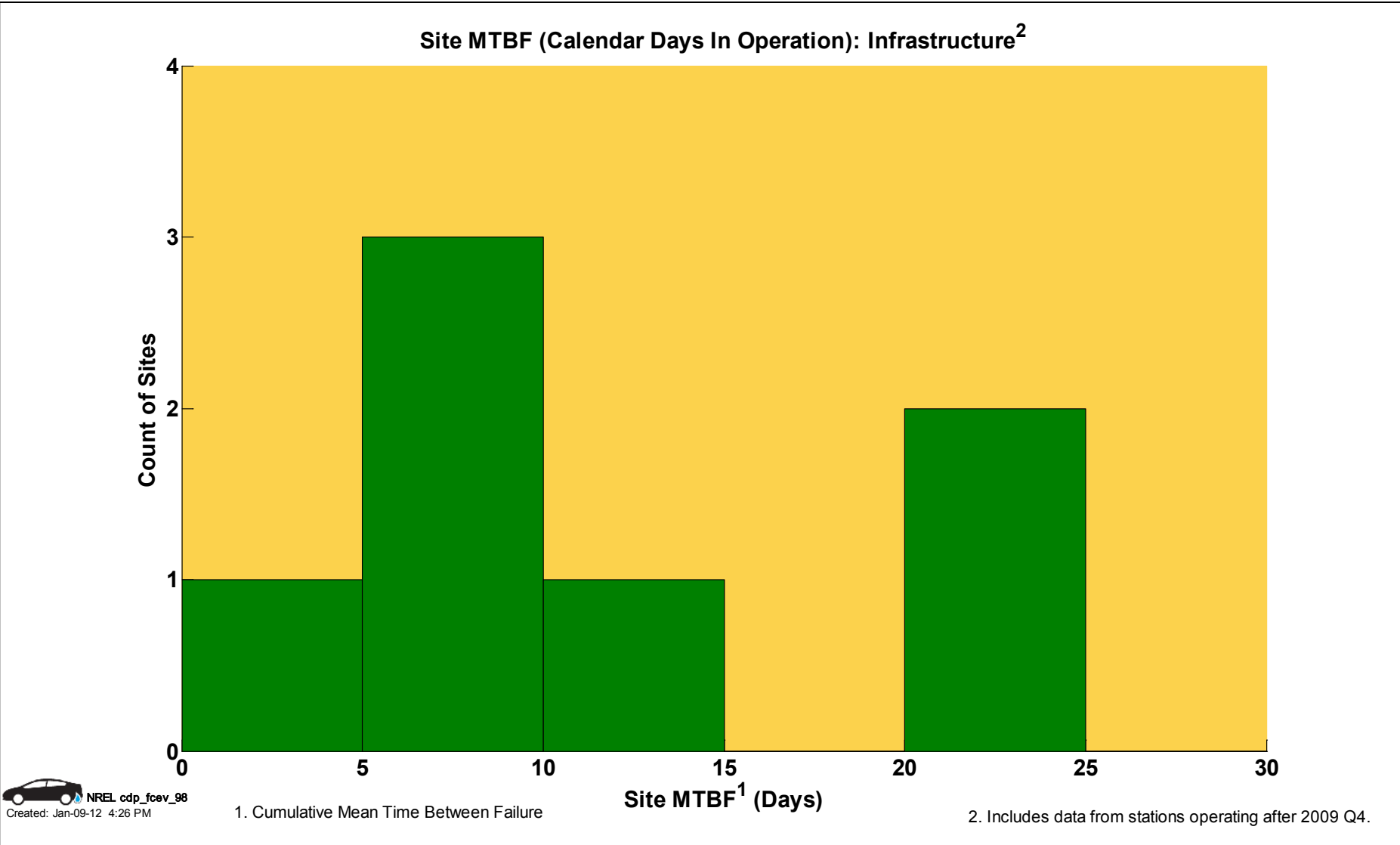


1. IEC 61164:2004(E), Reliability Growth - Statistical Test and Evaluation Methods, IEC. 2004.

2. % change in instantaneous MTBF

3. Includes data from stations operating after 2009 Q4.

# CDP#98 Infrastructure MTBF (based on Calendar Days of Operation)



# CDP#99 Infrastructure Mean Time between Scheduled Maintenance

