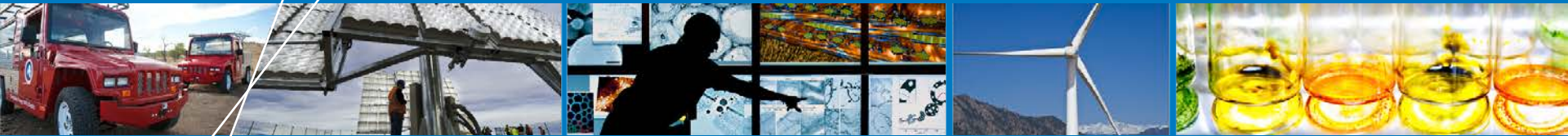


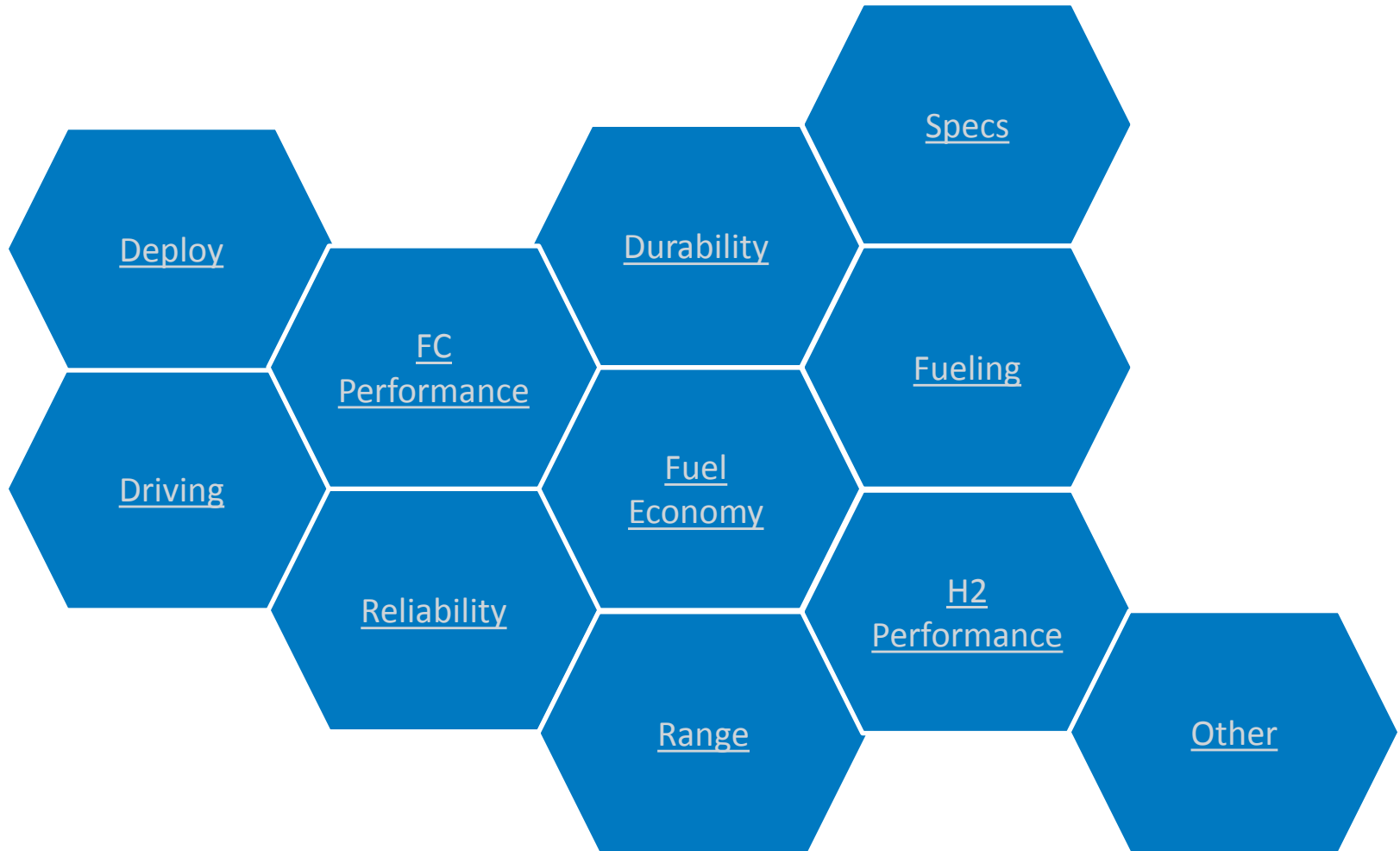
# Fuel Cell Electric Vehicle (FCEV) Performance Composite Data Products Spring 2016

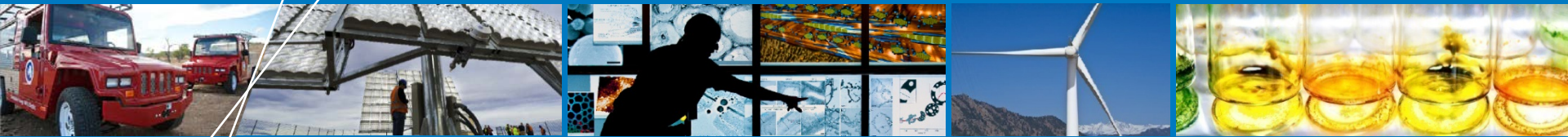


Jennifer Kurtz, Sam Sprik,  
Chris Ainscough, Genevieve  
Saur, and Matthew Jeffers

May 2016

# Analysis Categories

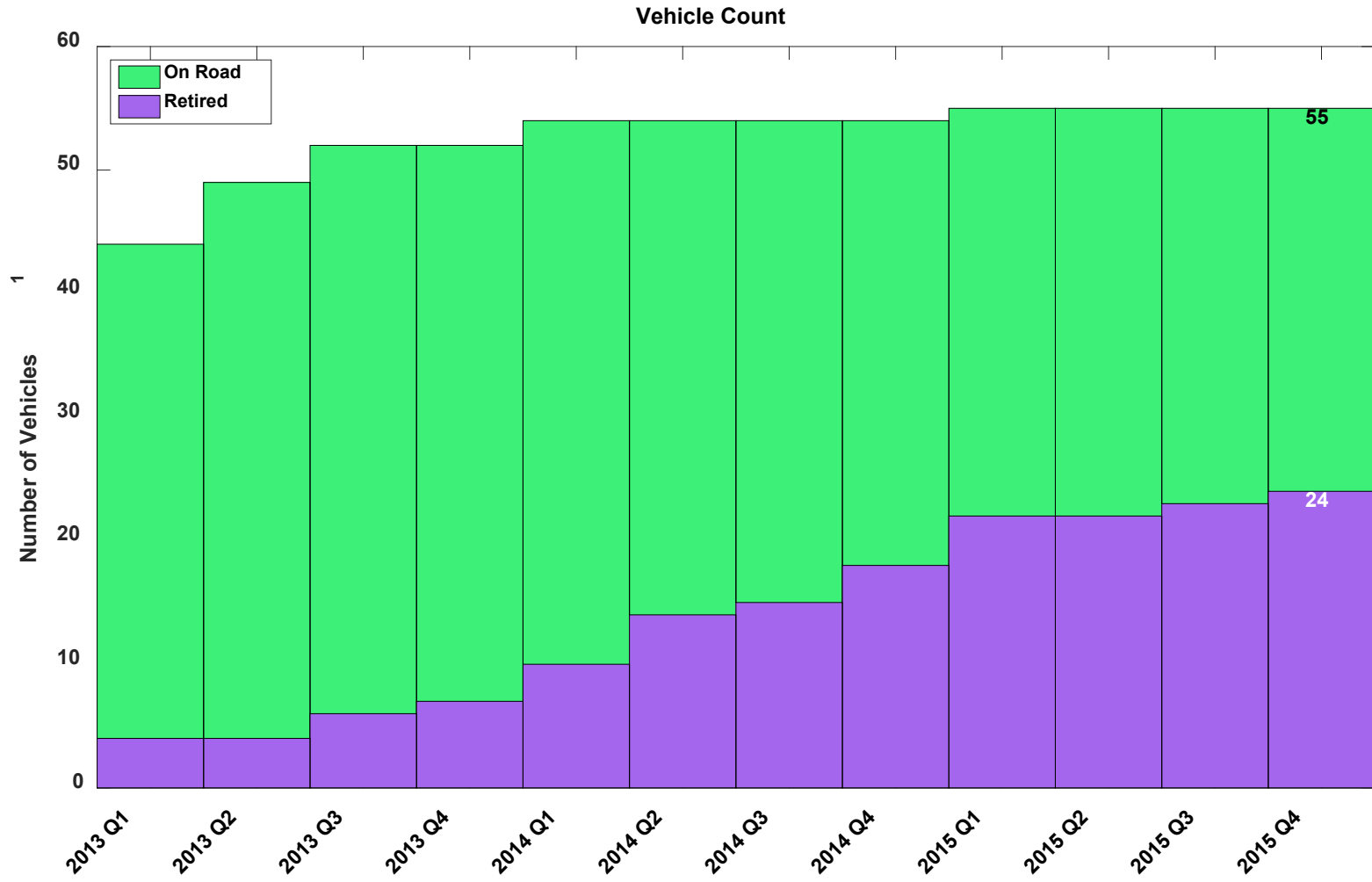




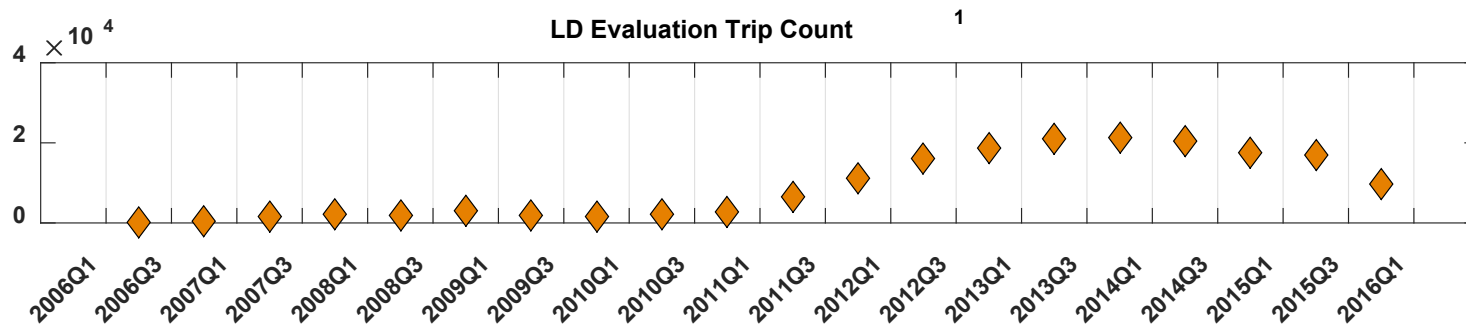
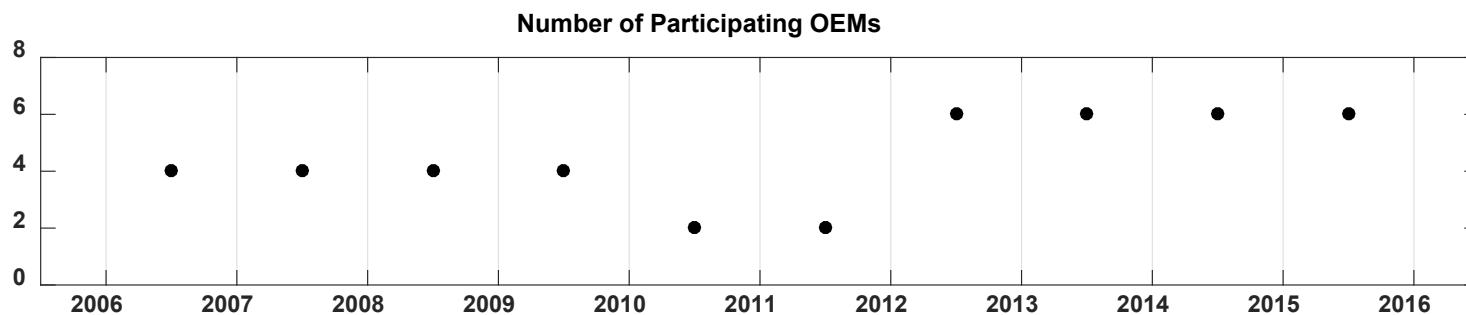
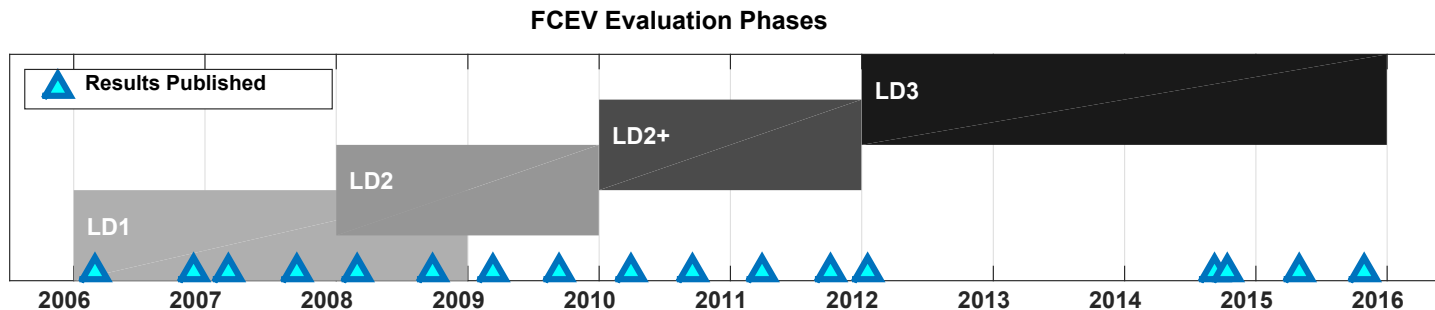
# Deployment

# CDP-FCEV-01

## Vehicle Count

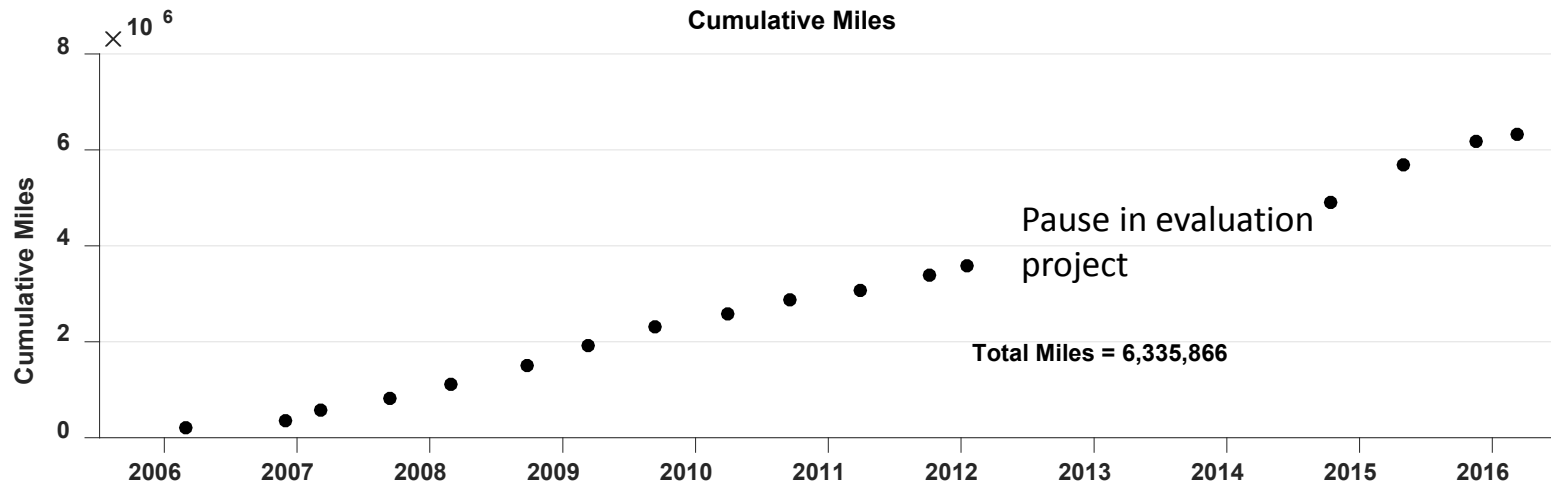
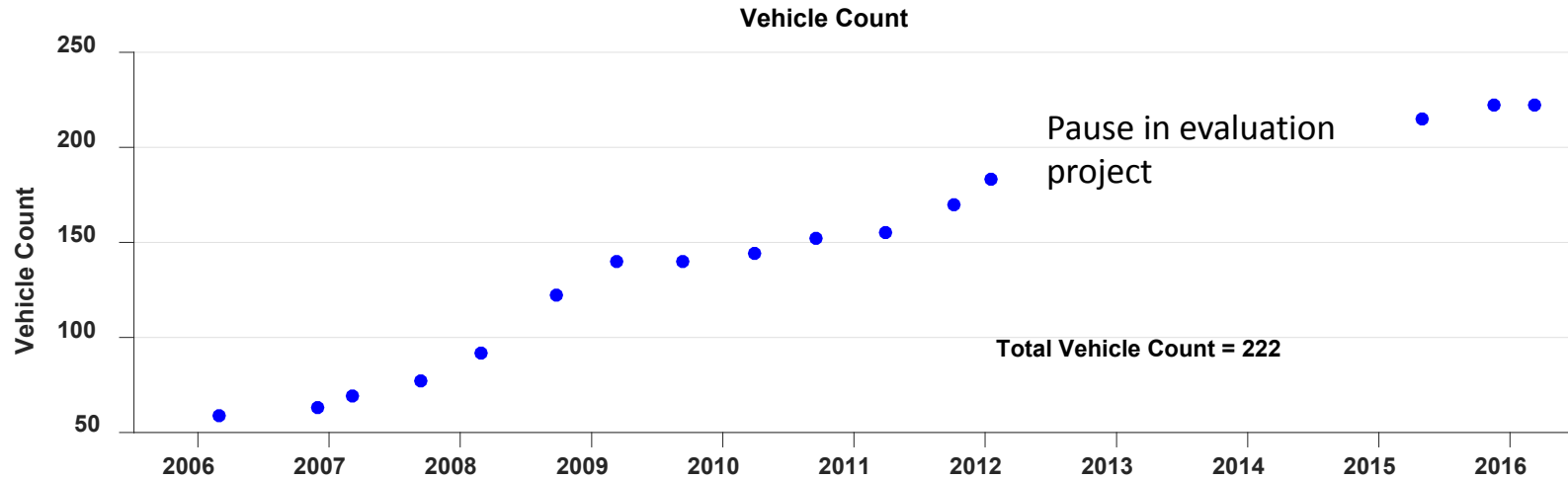


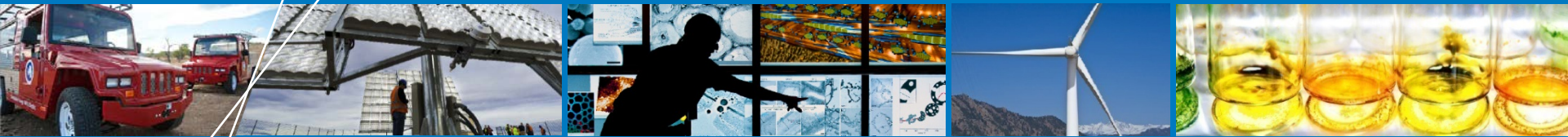
## Evaluation Phases and OEM Participant Trend



# CDP-FCEV-53

## Cumulative Vehicle Count and Miles Since 2006

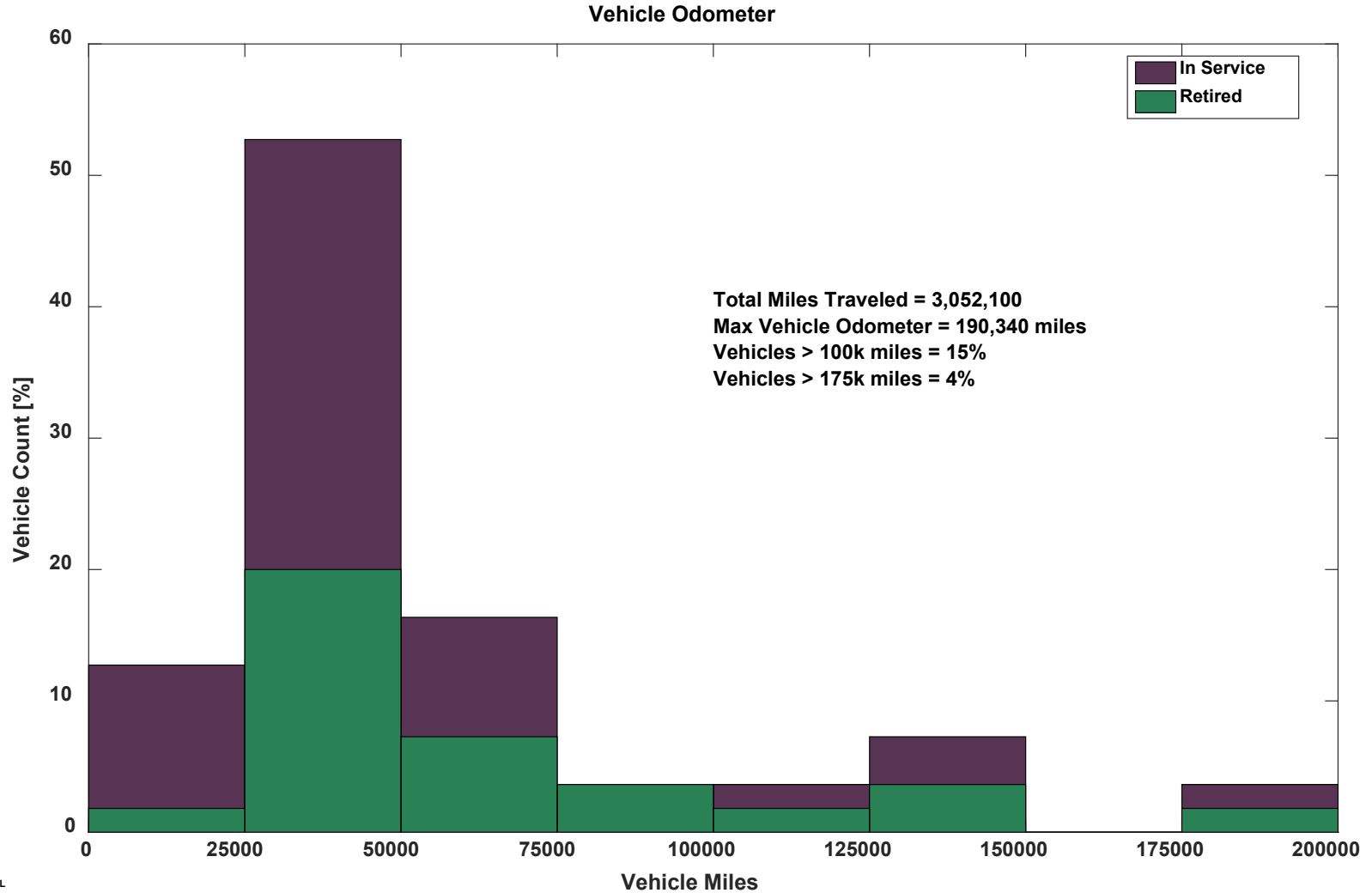




# Driving Behavior

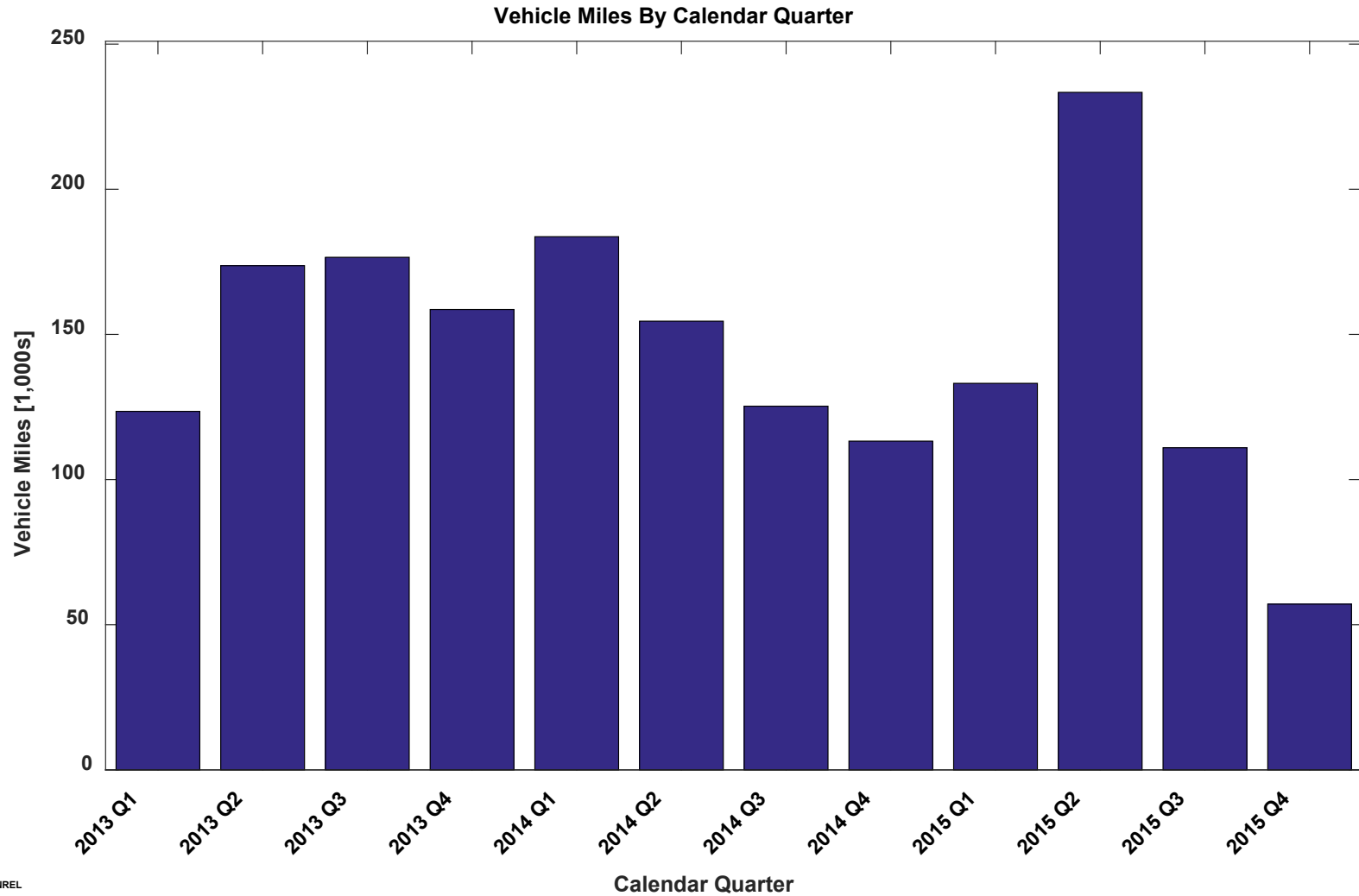
# CDP-FCEV-02

## Vehicle Miles



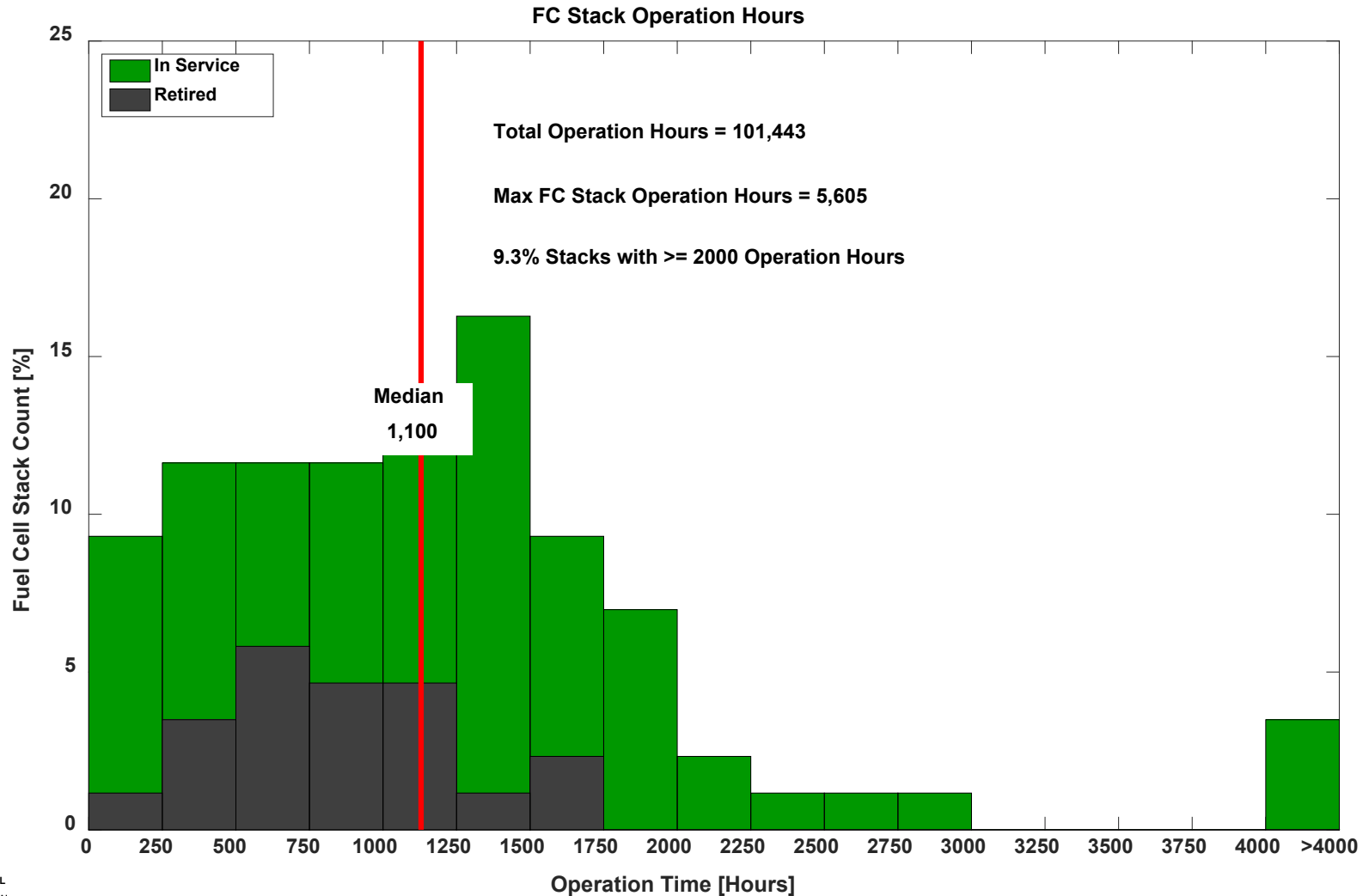


## FCEV Miles Driven by Calendar Quarter

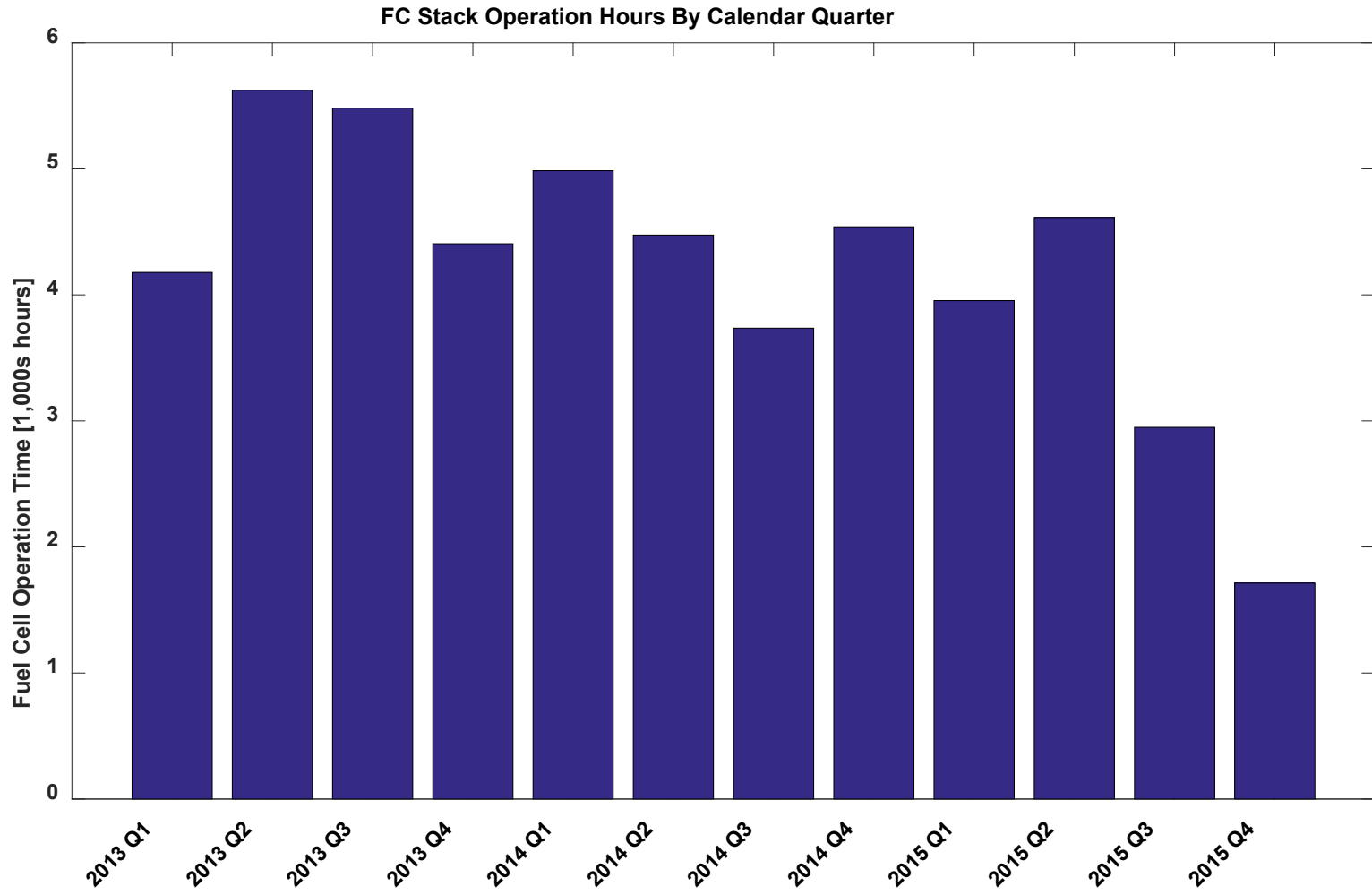


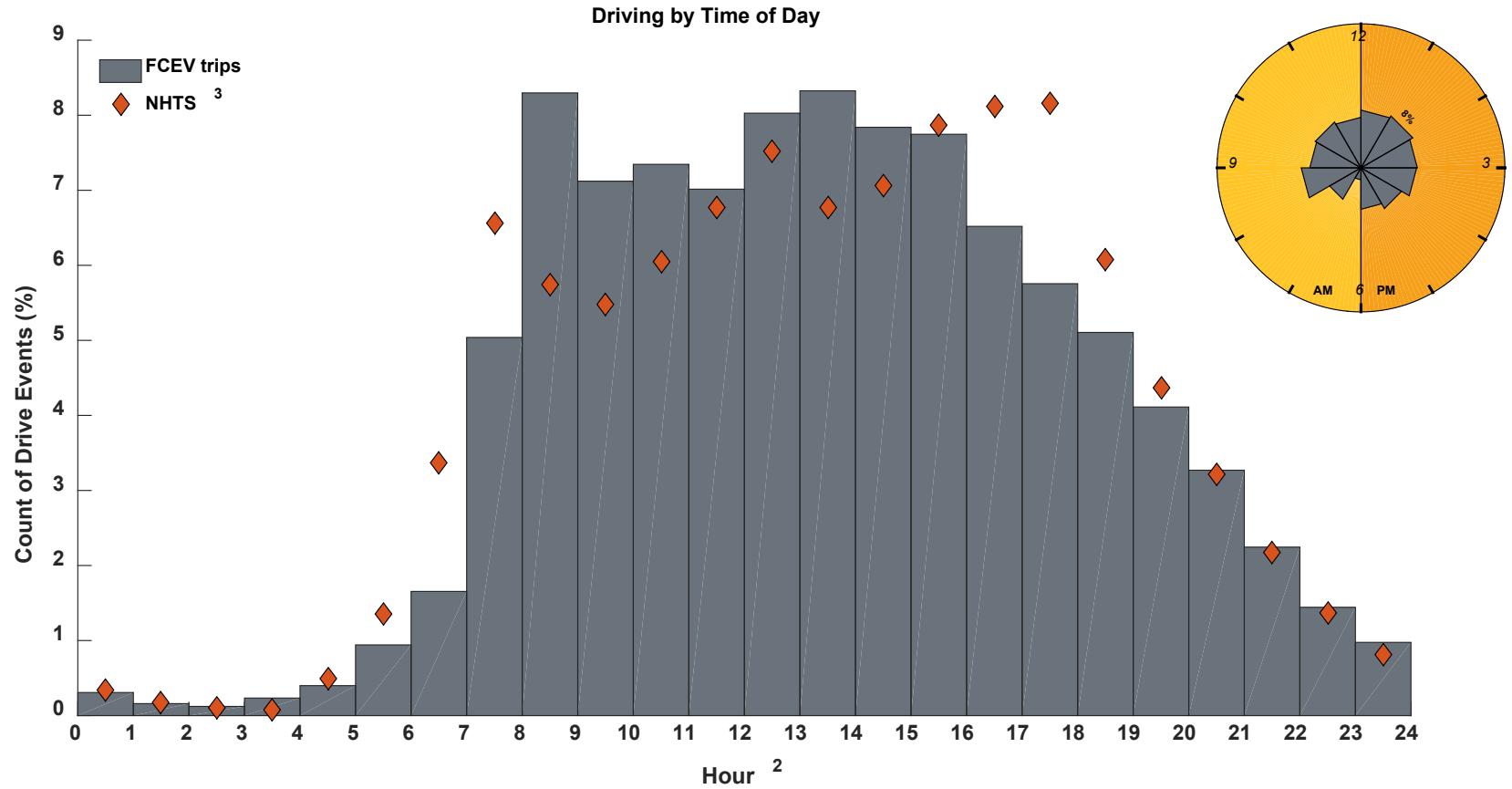
# CDP-FCEV-04

## Fuel Cell Stack Hours

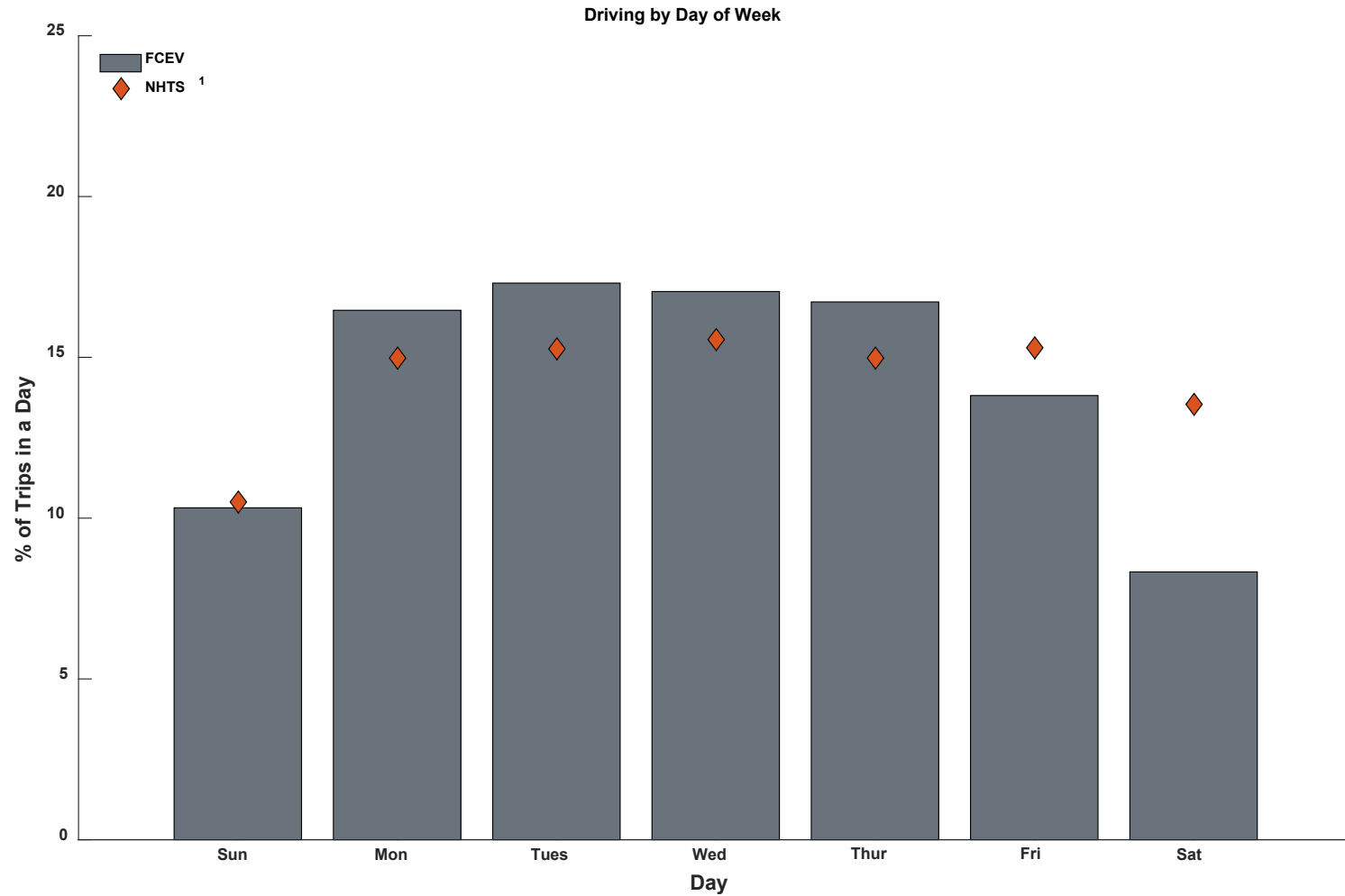


## Fuel Cell Stack Operation Hours by Calendar Quarter

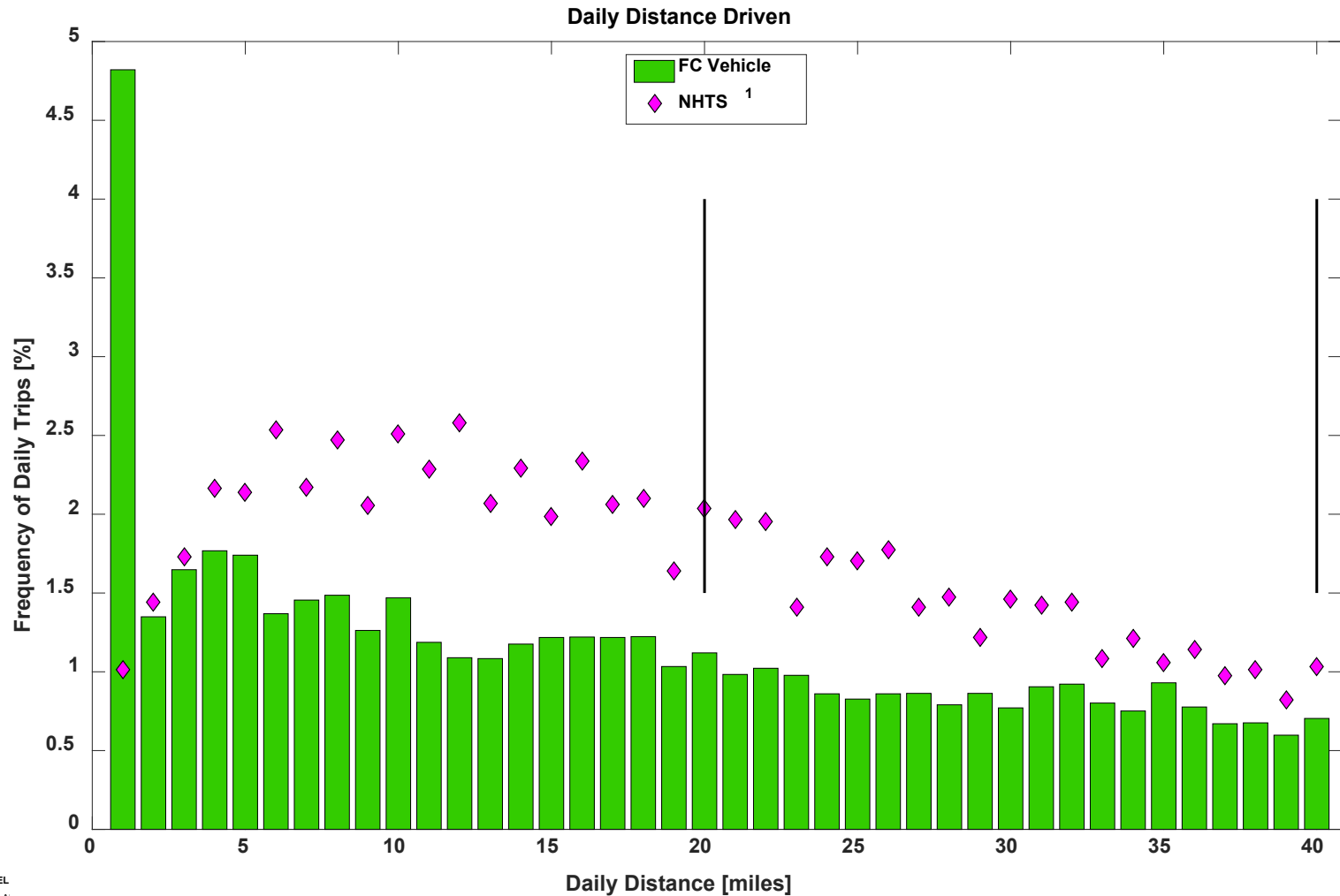


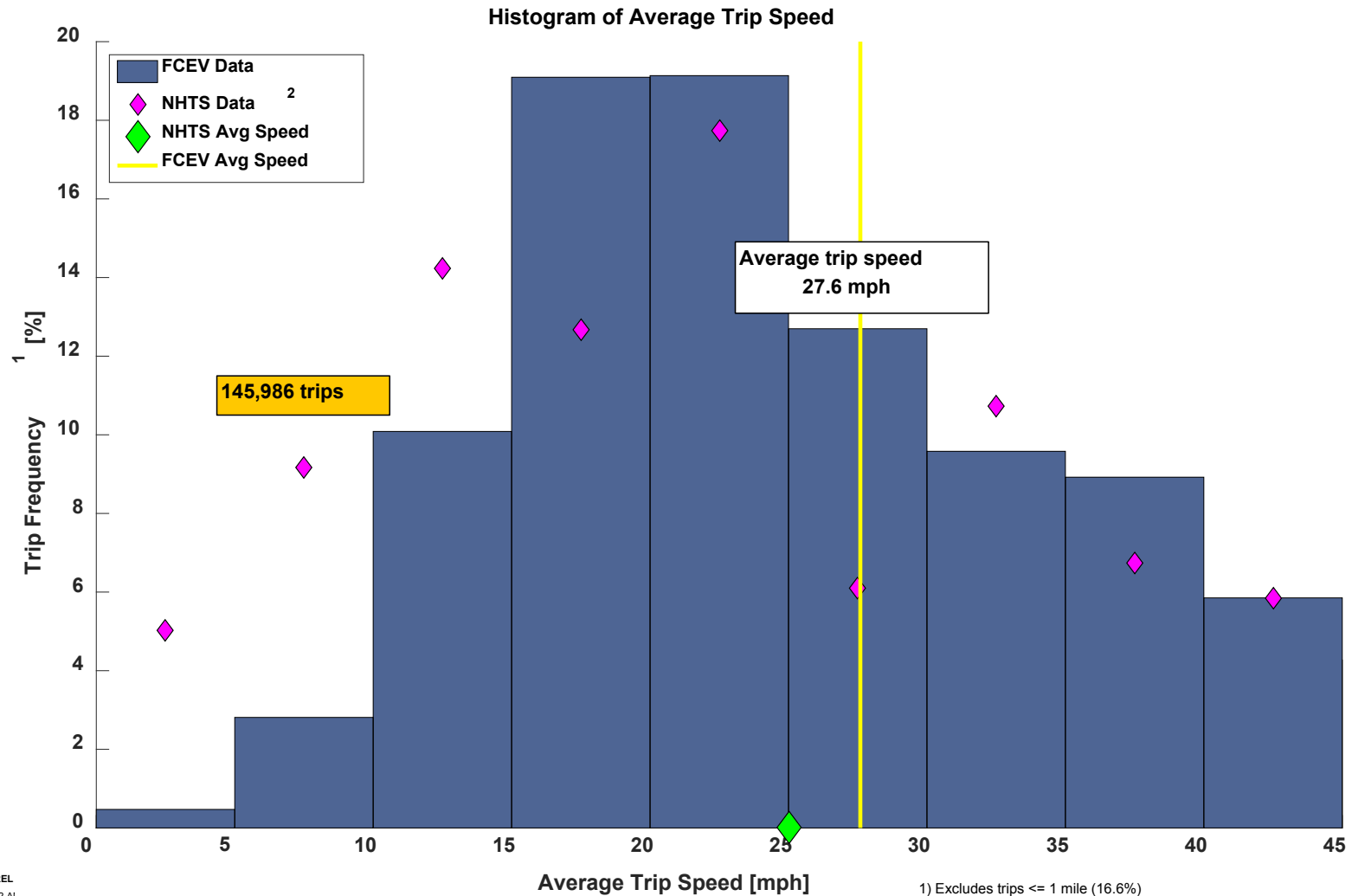


## Driving by Day of Week

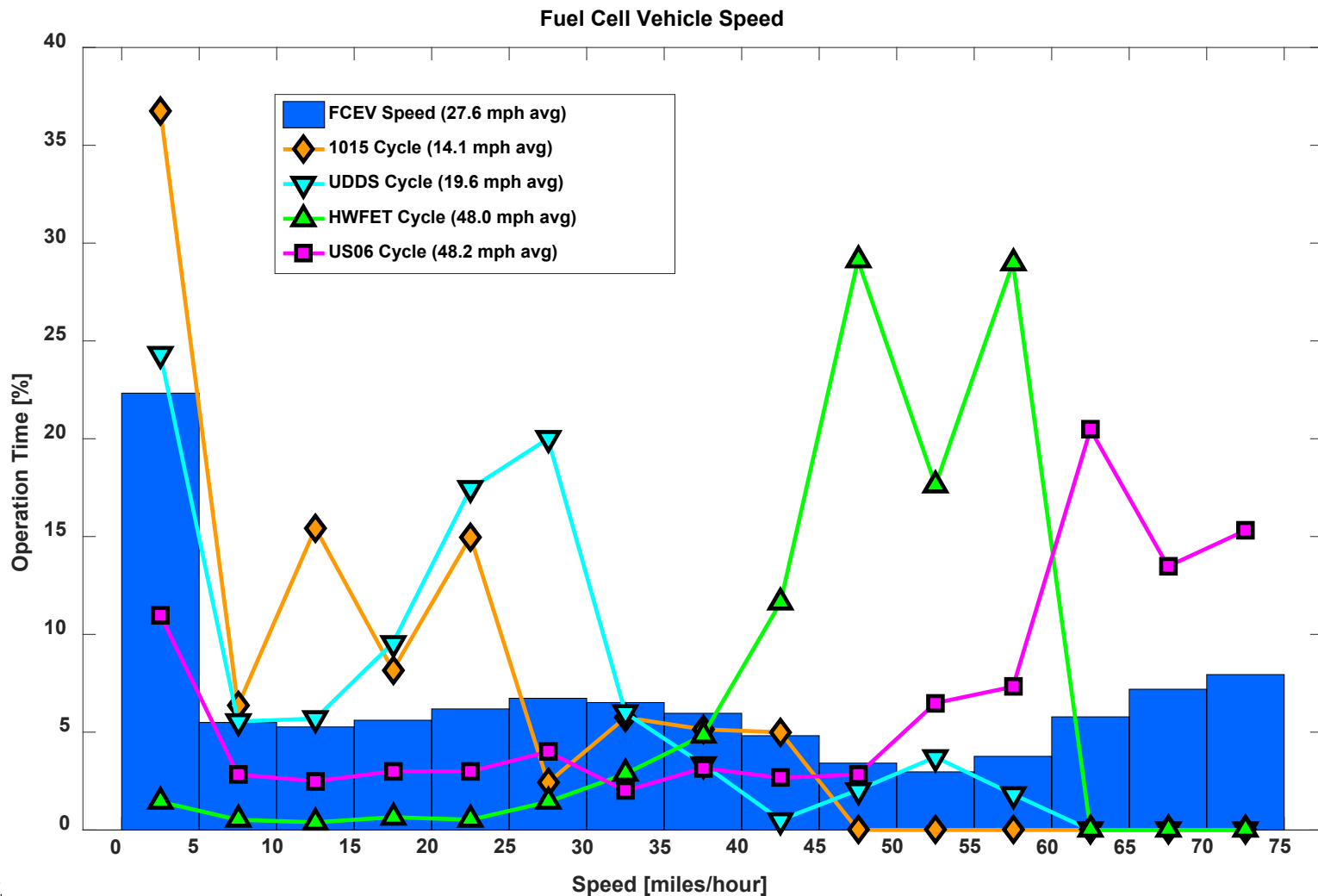


## Daily Driving Distance





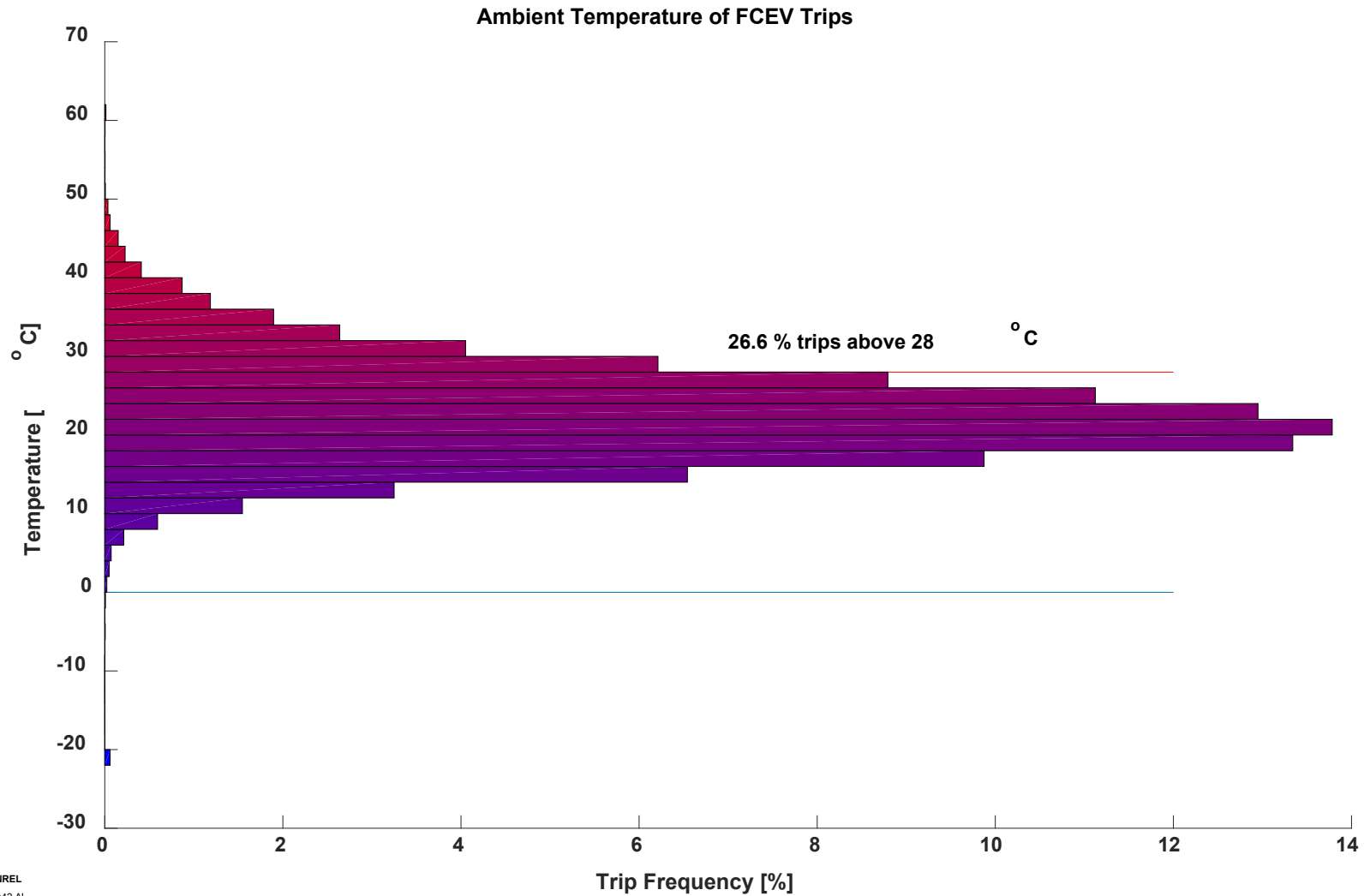
## Trip Speed Comparison with Standard Drive Cycles





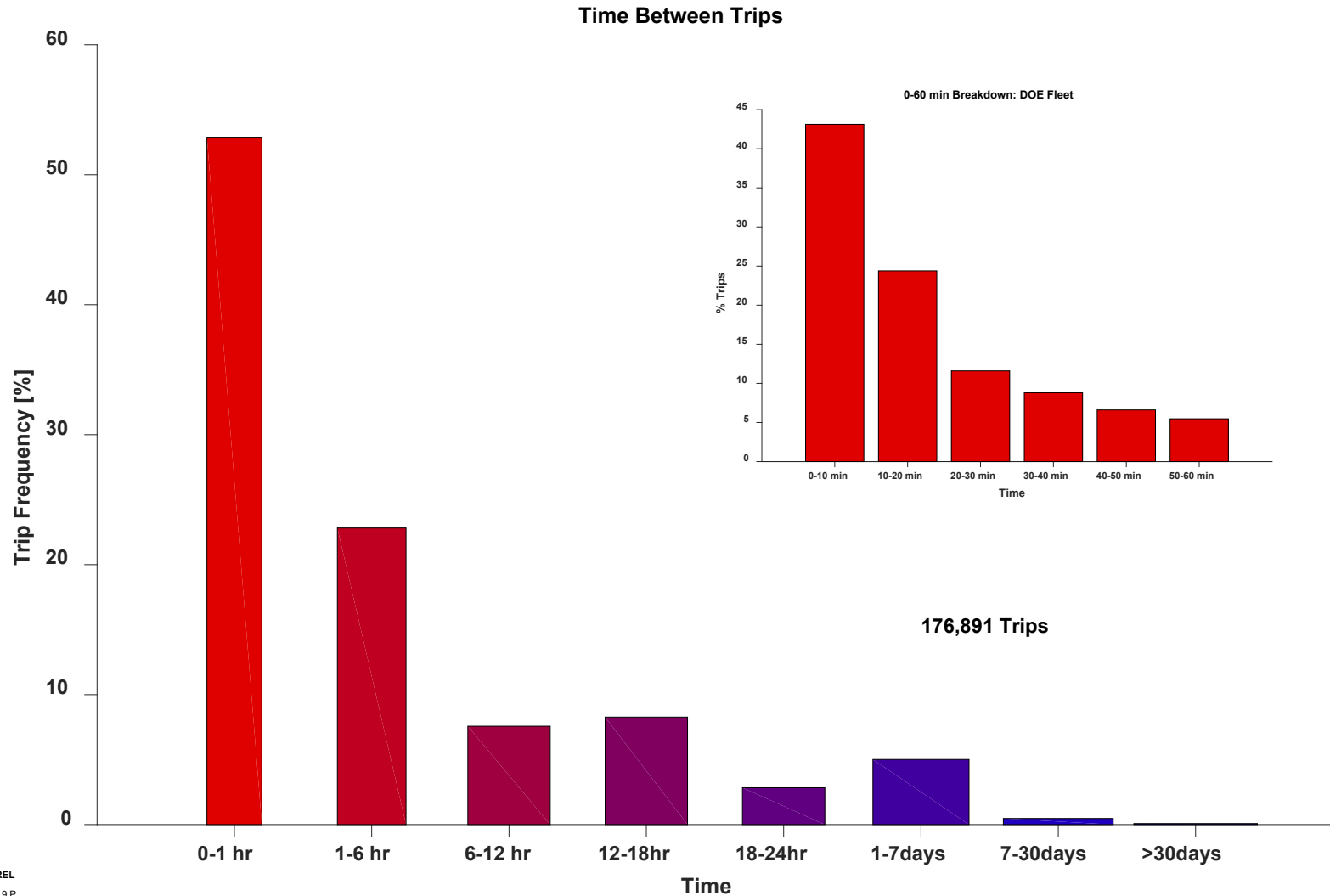
# CDP-FCEV-35

## Trip Ambient Temperature

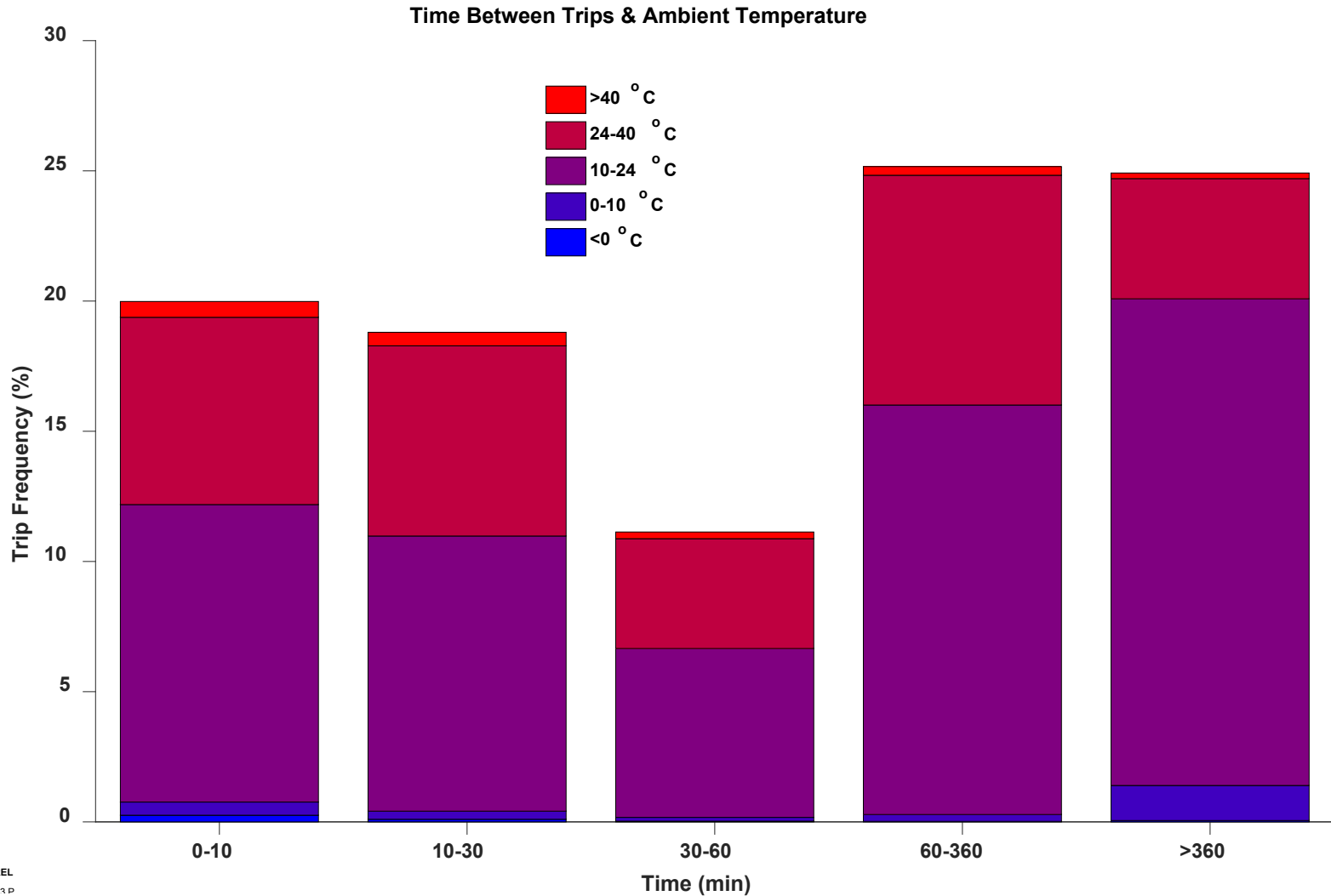


# CDP-FCEV-36

## Time Between Trips

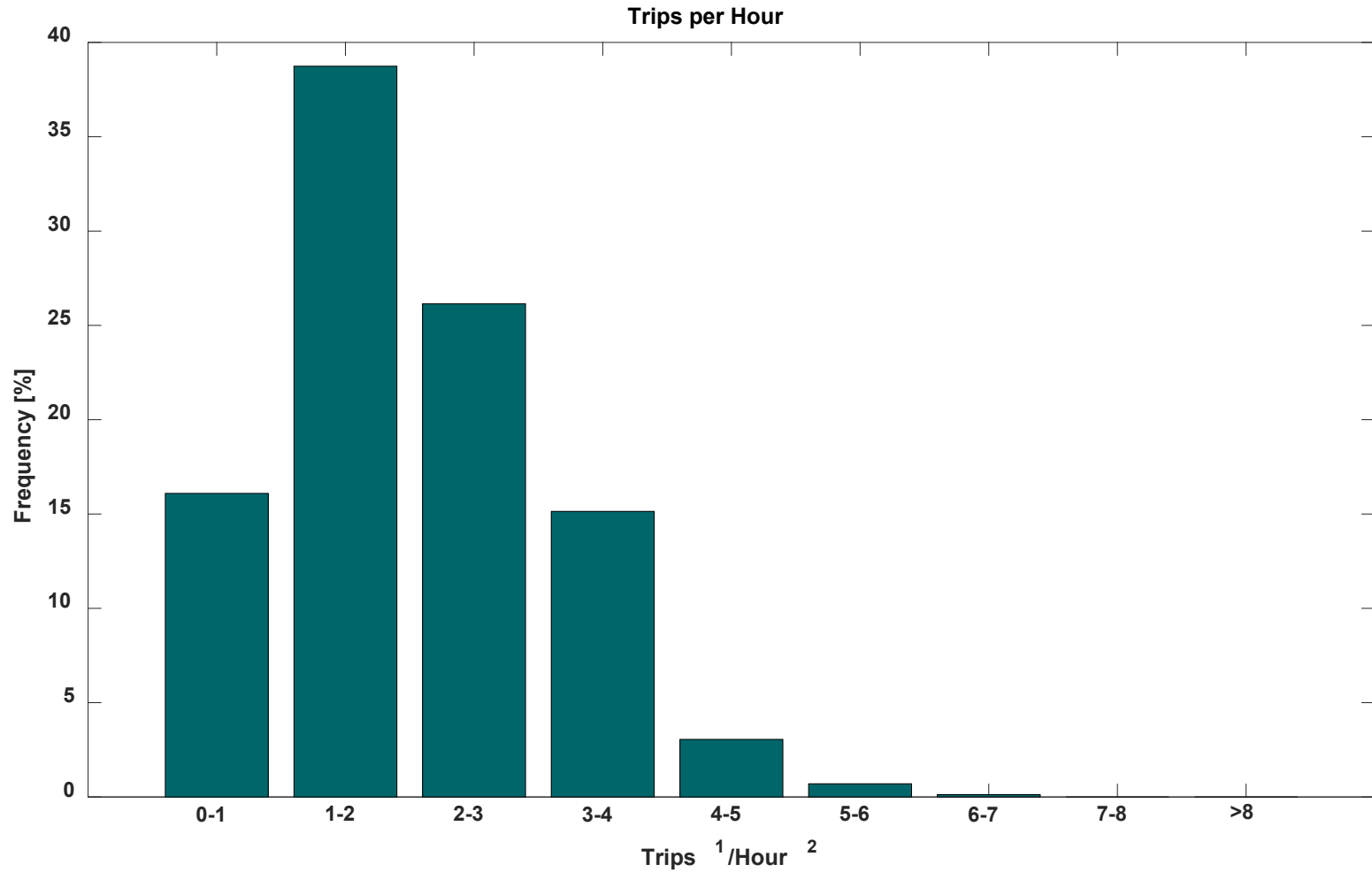


## Time Between Trips and Trip Ambient Temperatures



# CDP-FCEV-38

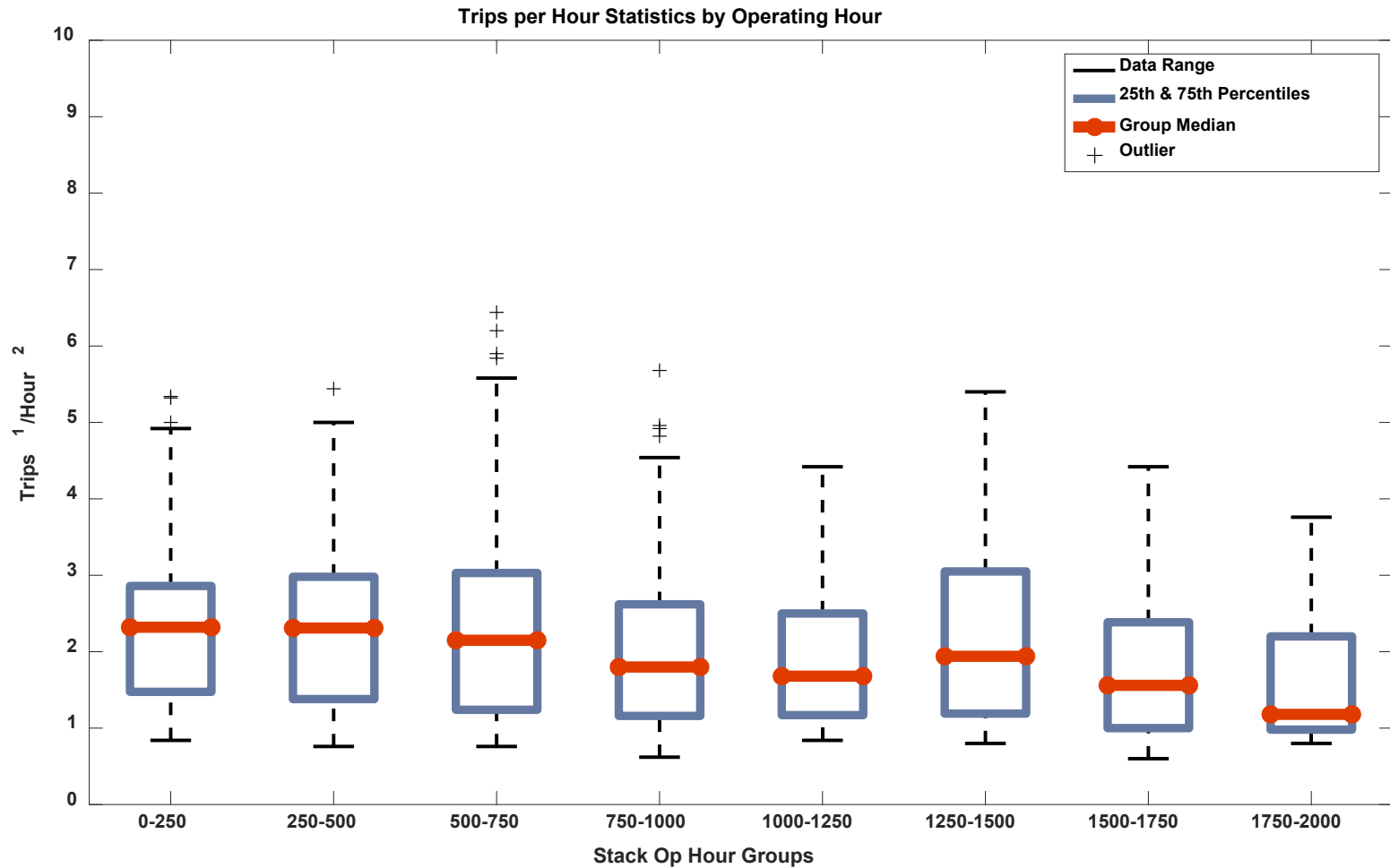
## Trips per Hour



1) A trip is counted when the fuel cell has successfully started.

2) Trips/Hour based on 50 hour segments spanning stack operating period for stacks with greater than 100 operating hours.

## Trips per Hour by Fuel Cell Operation Hour Groups

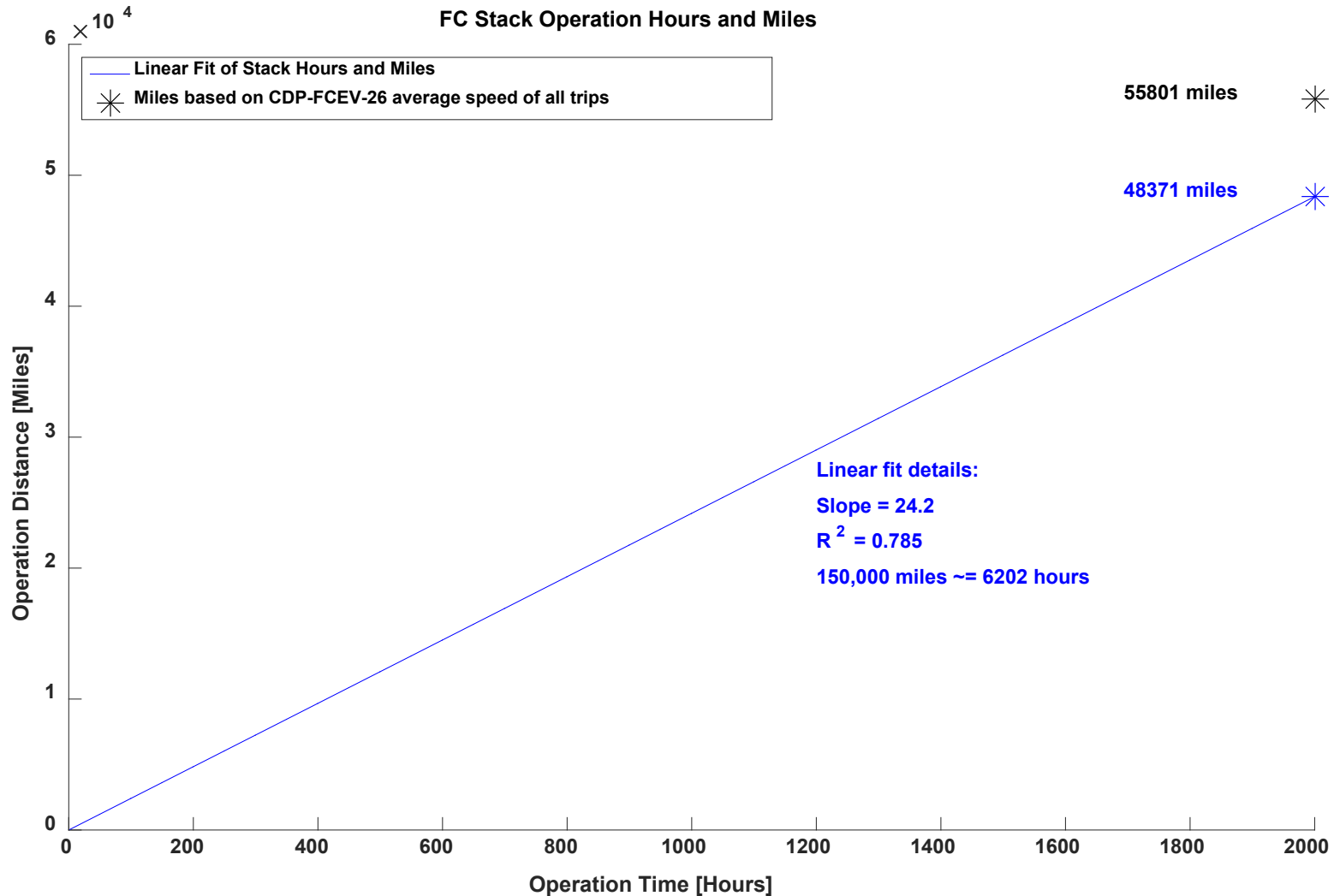


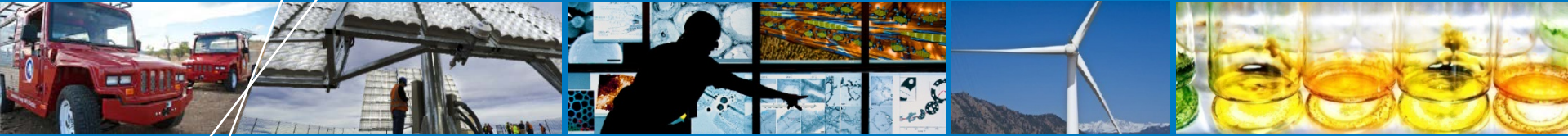
1) A trip is counted when the fuel cell has successfully started.

2) Trips/Hour based on 50 hour segments spanning stack operating period for stacks with greater than 100 operating hours.

# CDP-FCEV-51

## Comparison of FC Stack Operation Hours and Miles Traveled

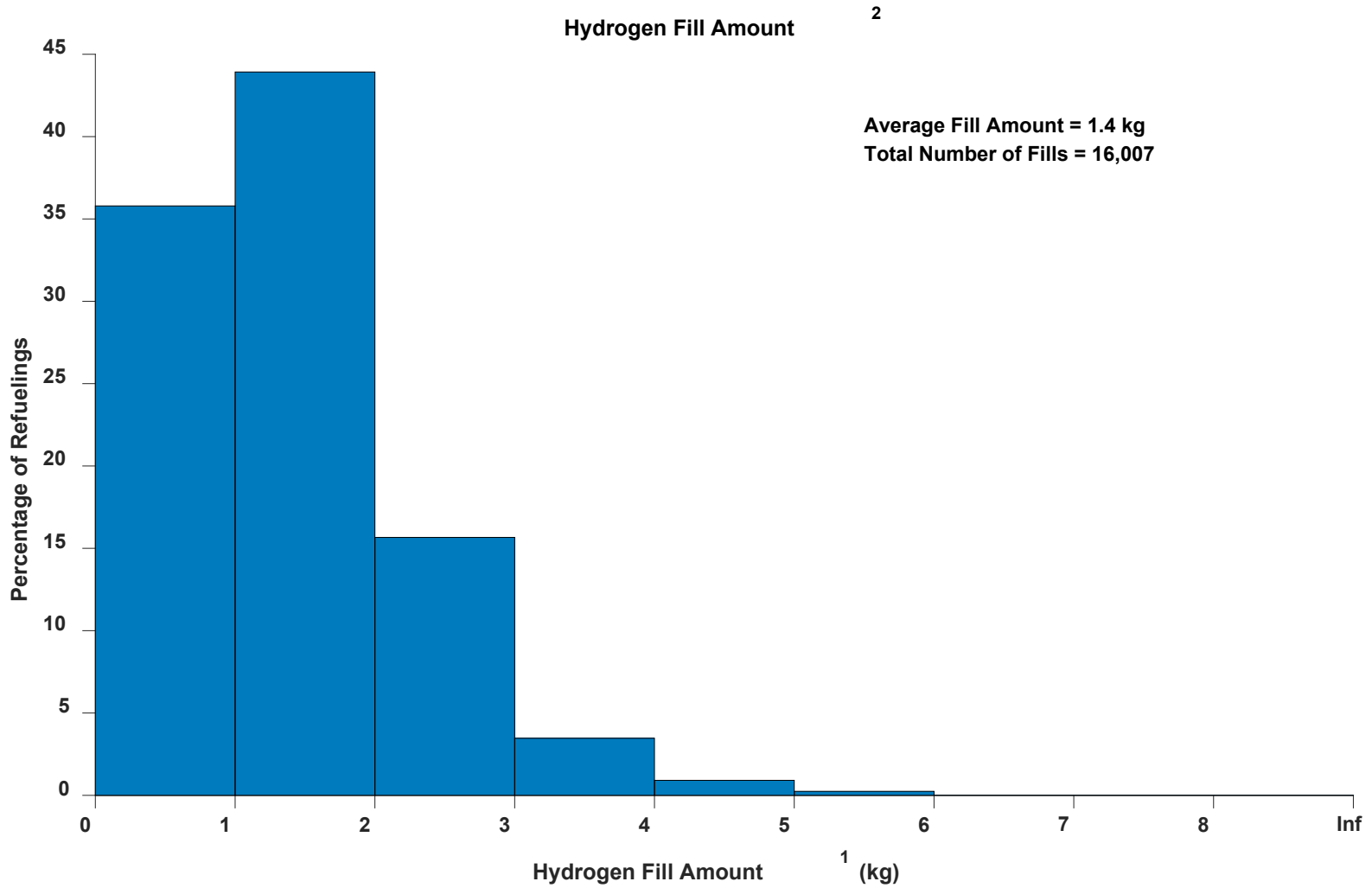




# Fuel Economy

# CDP-FCEV-08

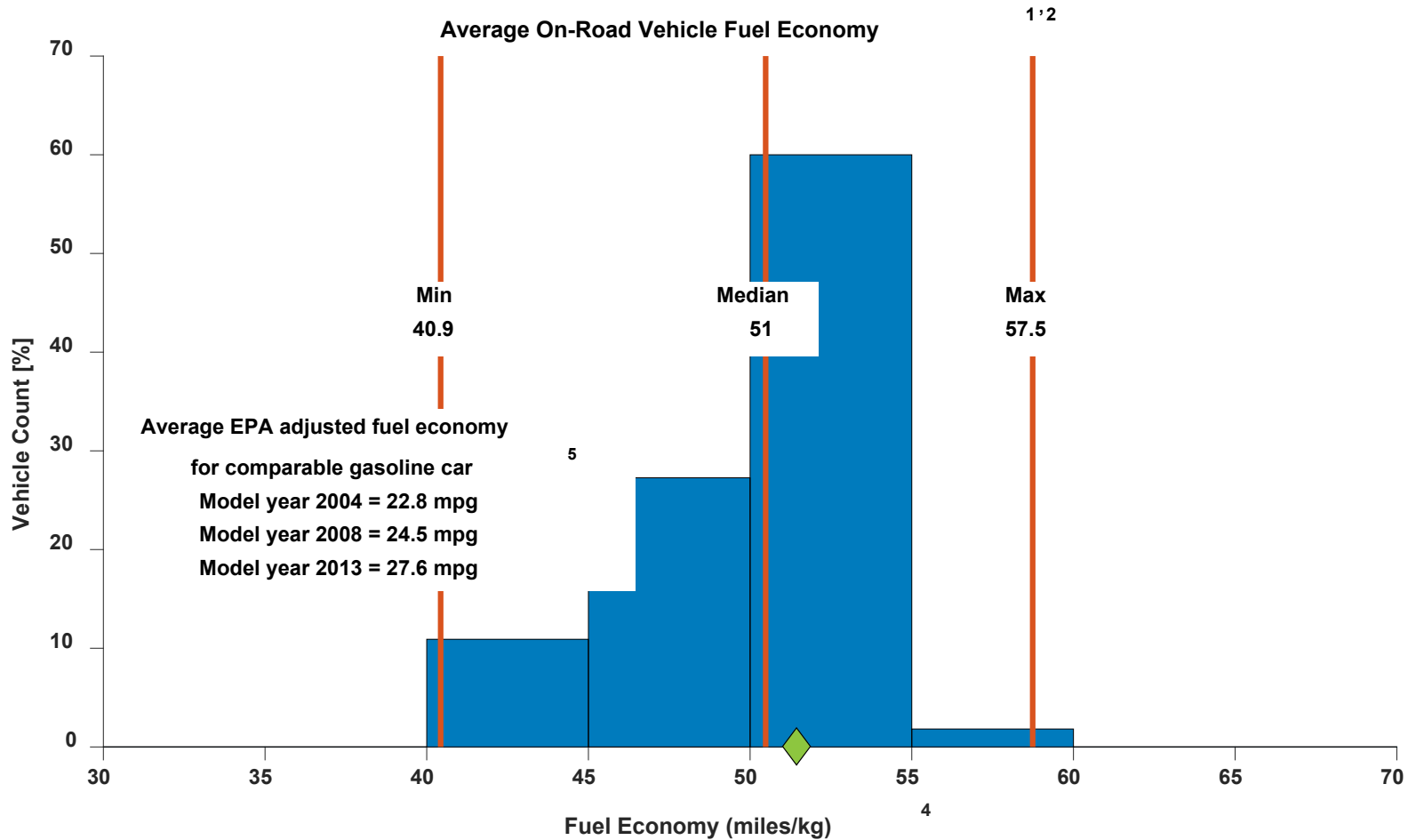
## FCEV Fill Amounts



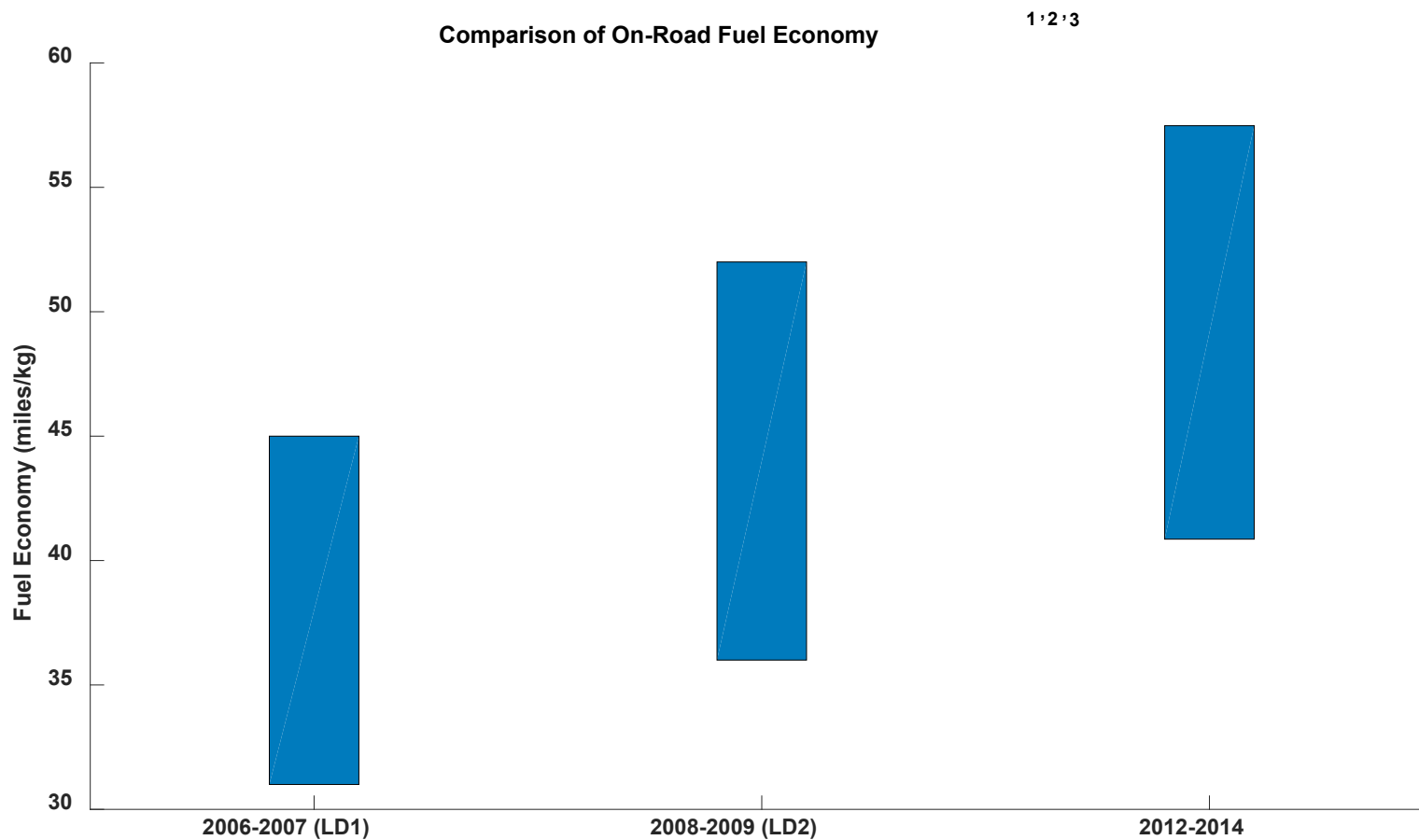


# CDP-FCEV-14

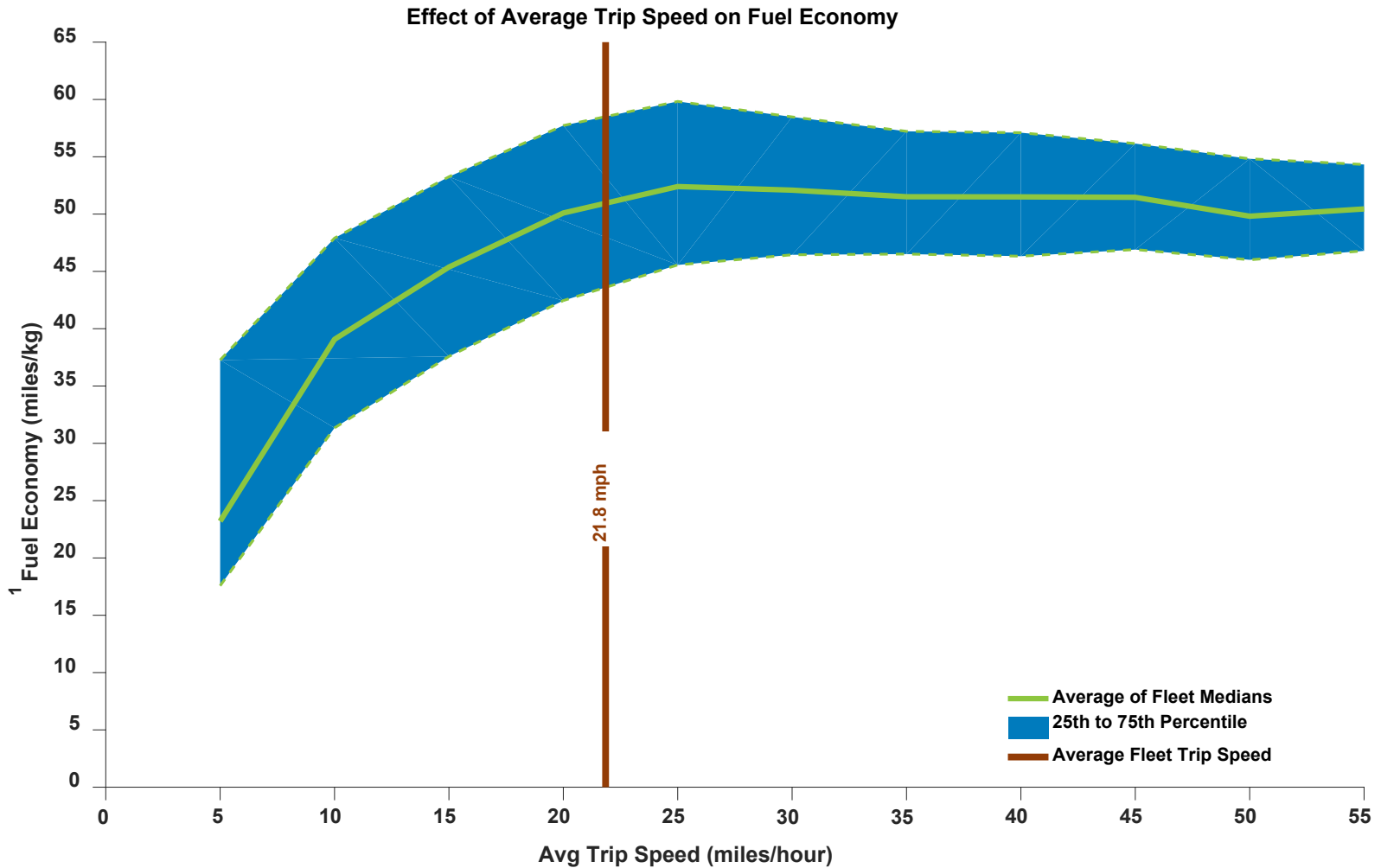
## Average Vehicle Fuel Economy



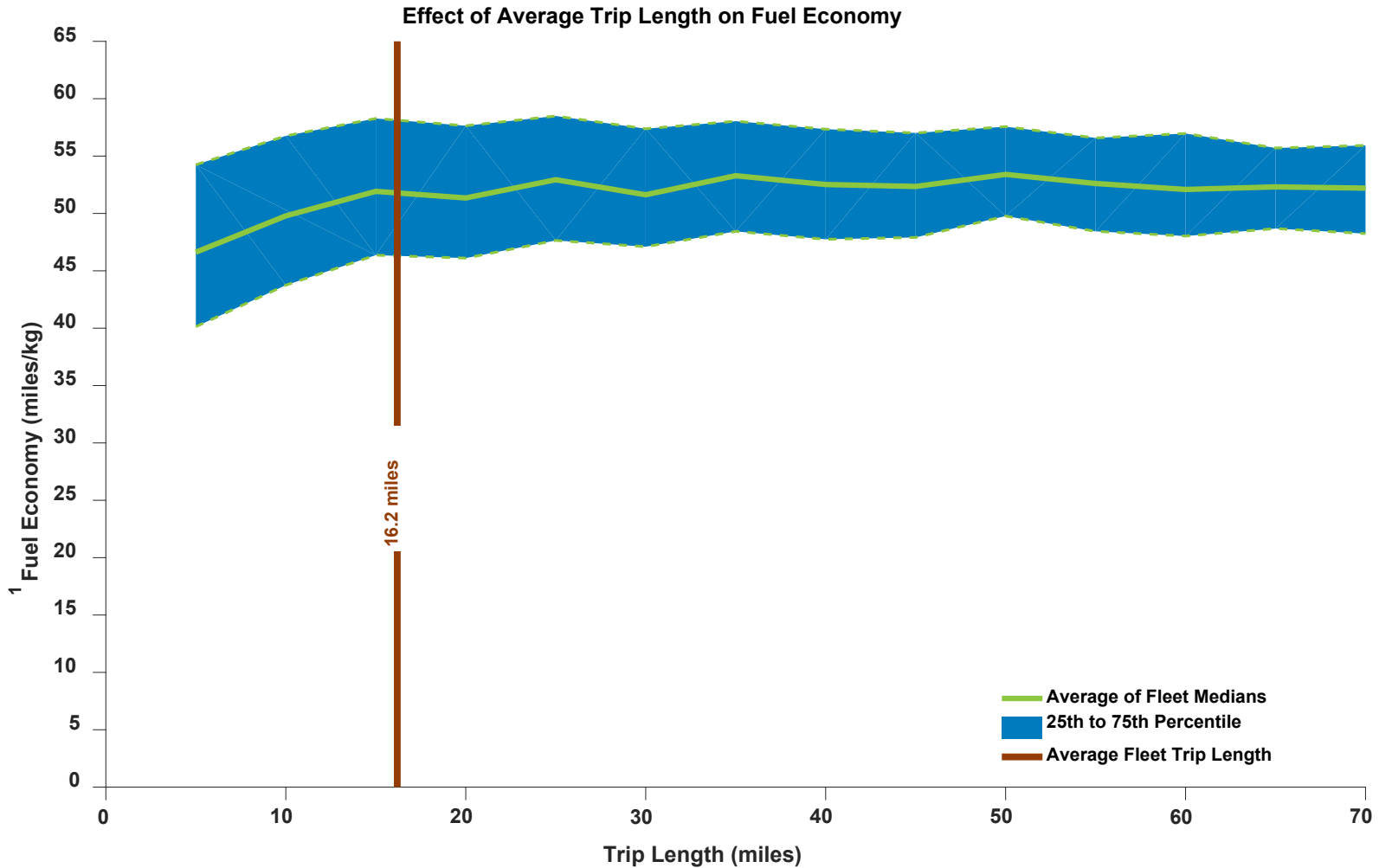
## On-Road Fuel Economy Trends



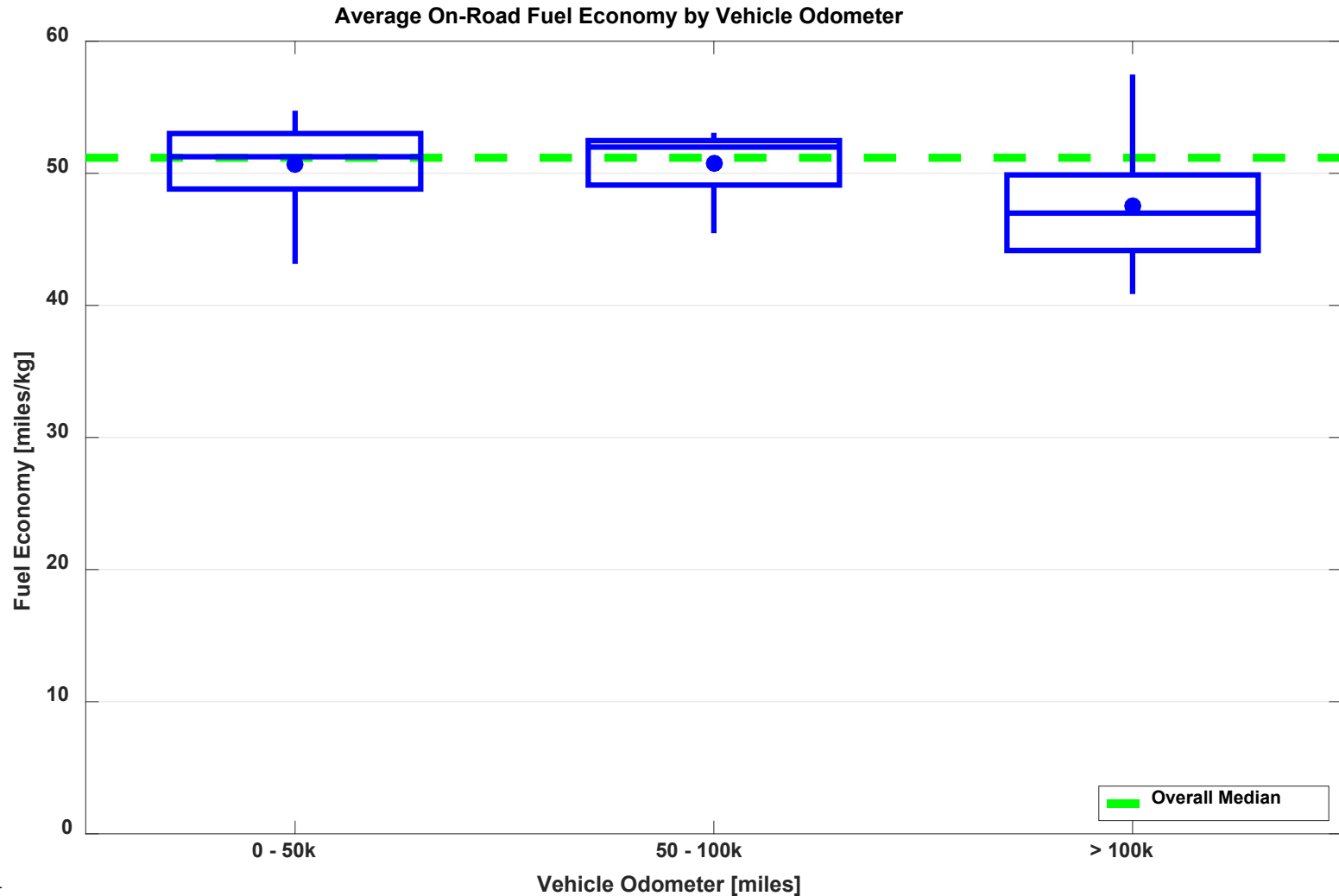
## Effect of Average Trip Speed on Fuel Economy



## Effect of Average Trip Length on Fuel Economy

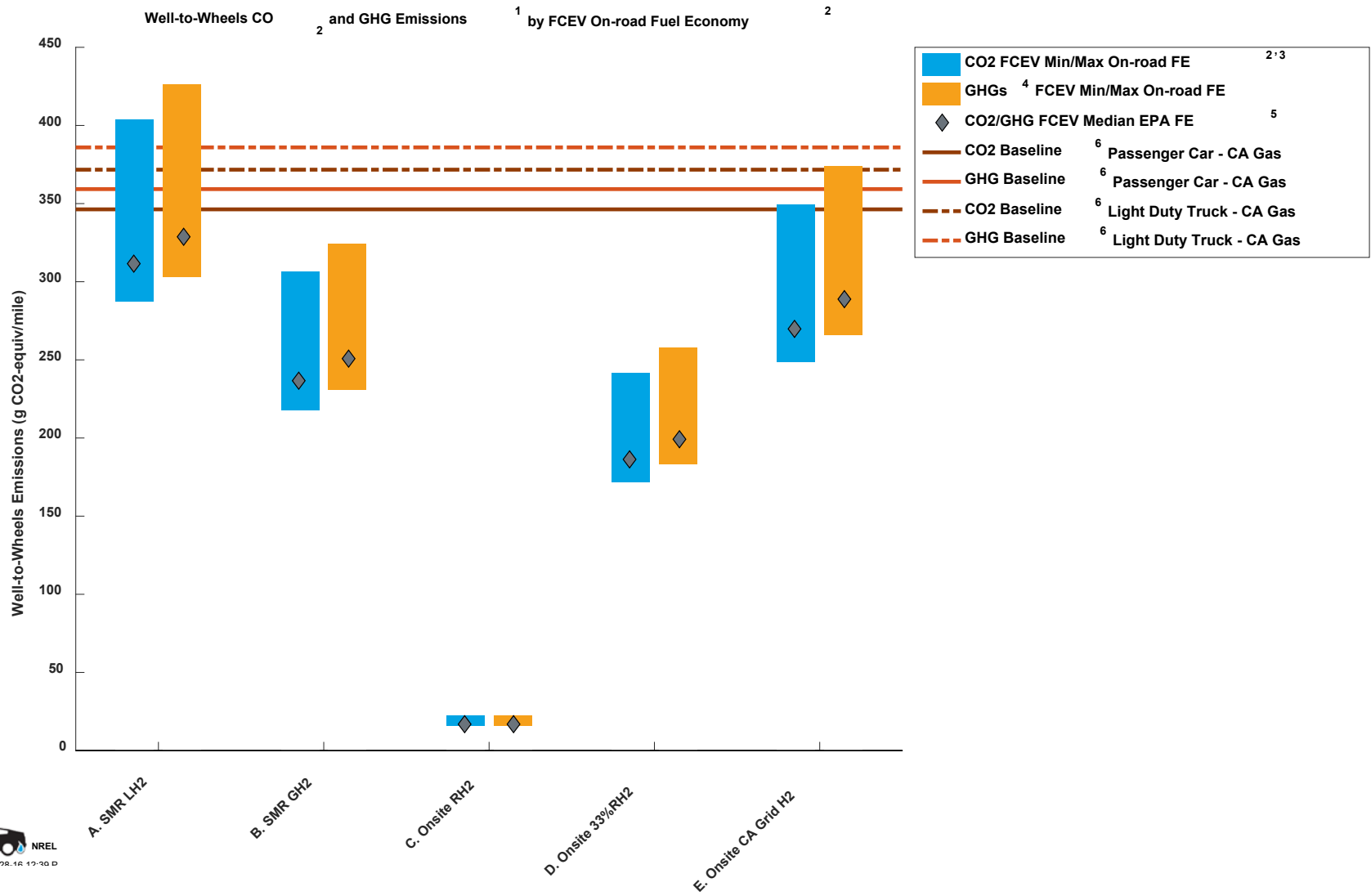


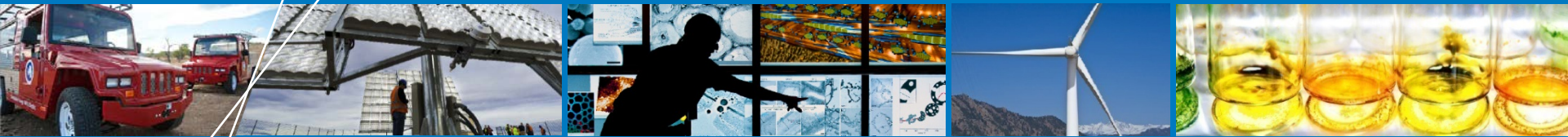
## Average On-Road Fuel Economy by Vehicle Odometer



# CDP-FCEV-69

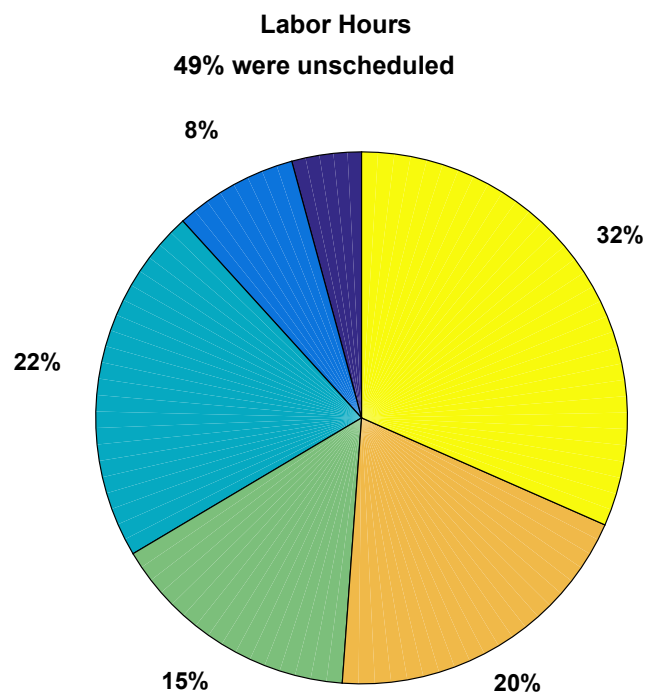
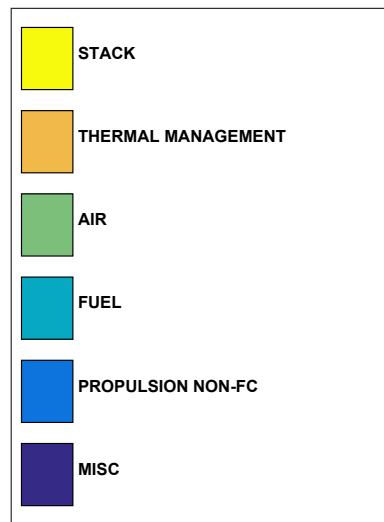
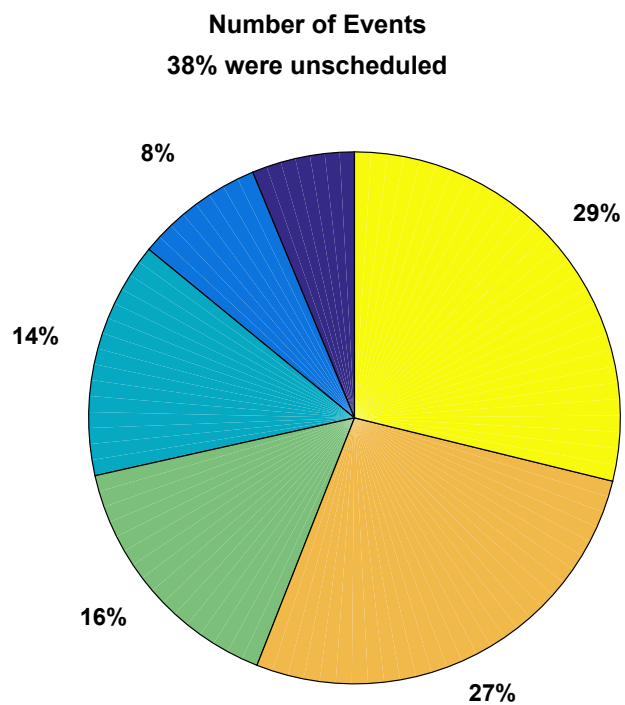
## Greenhouse Gas (GHG) Emissions by Fuel Economy





# Reliability

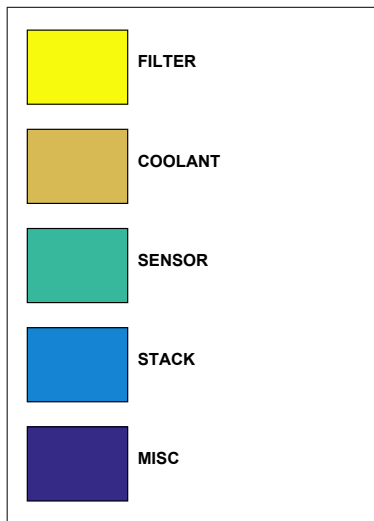
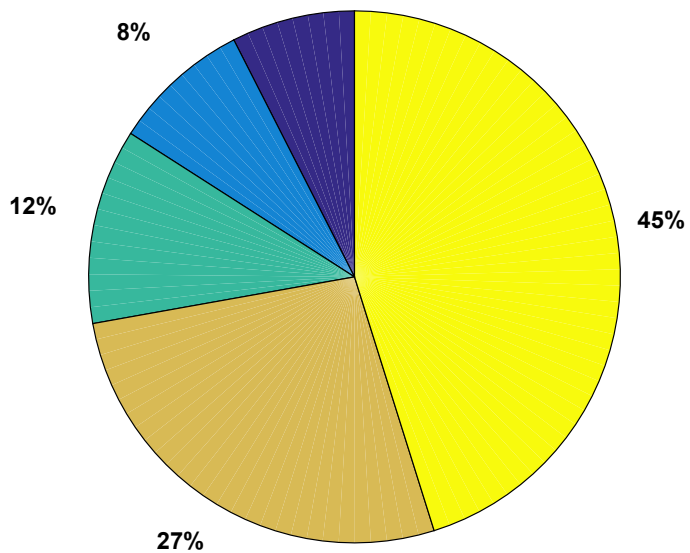
## Maintenance by Subsystem Category



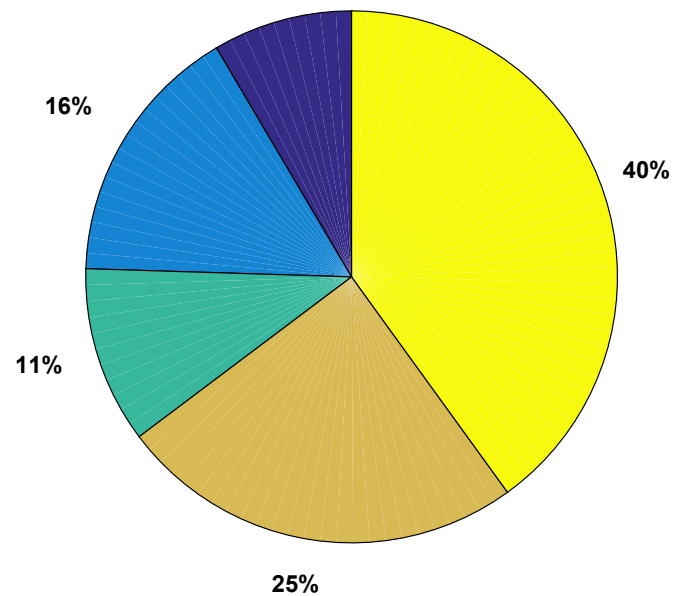


## Maintenance by Component Category

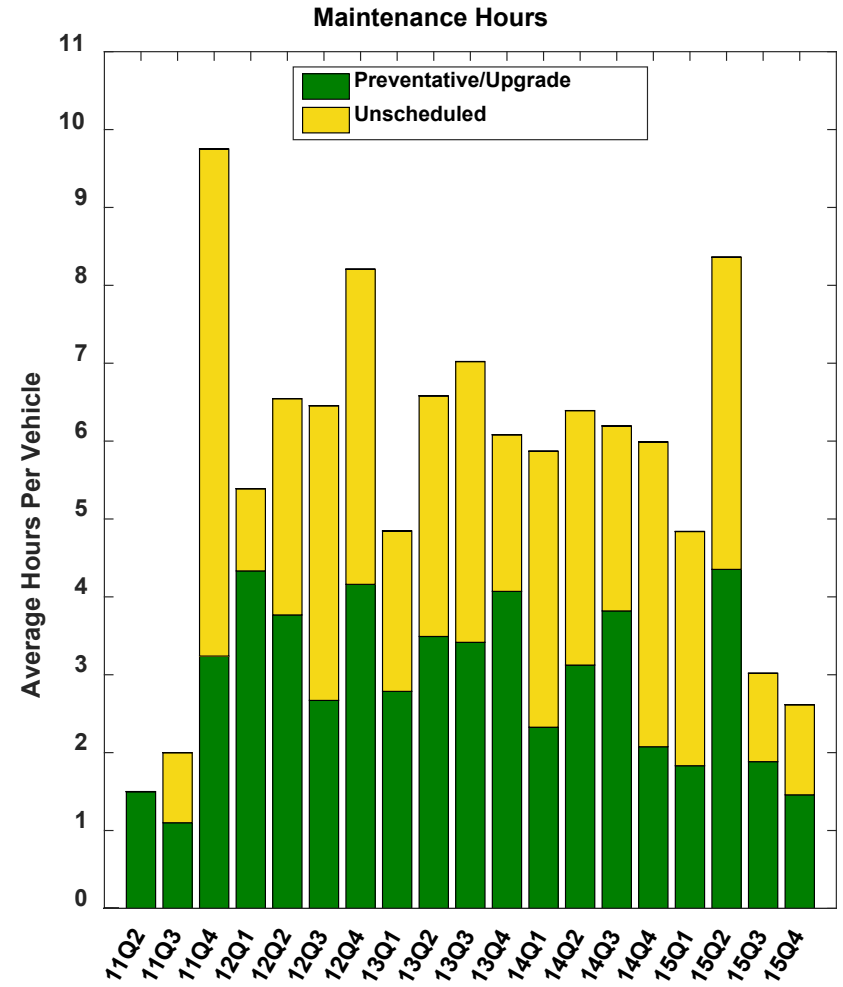
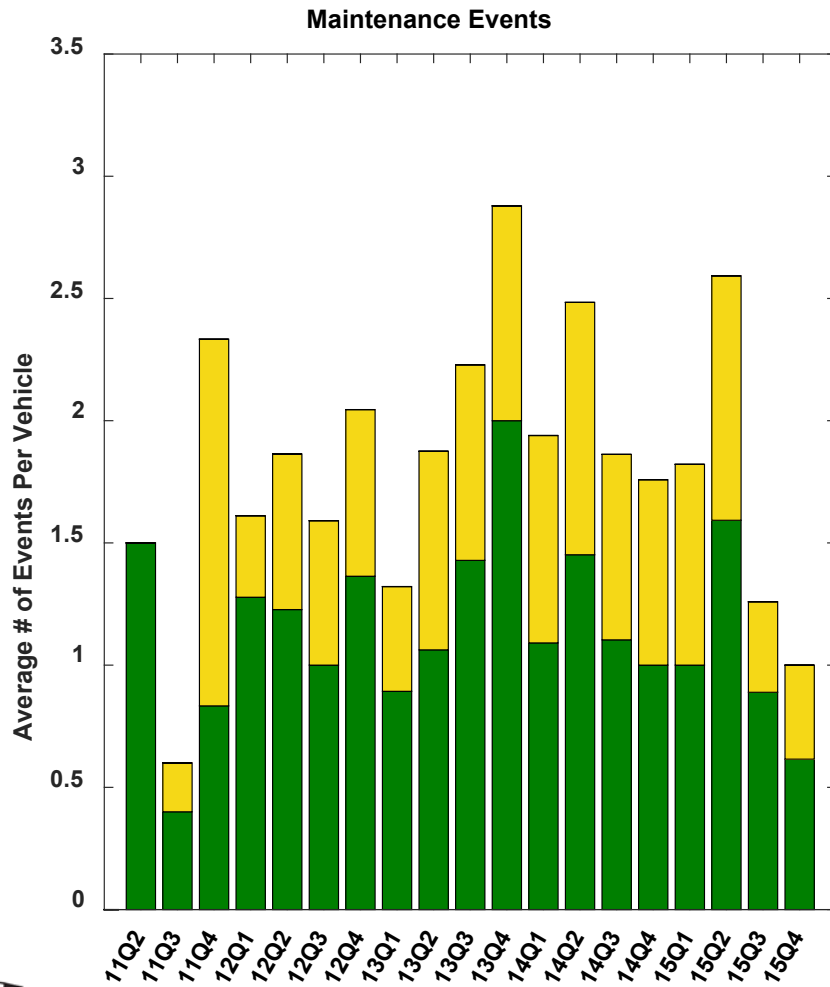
**Number of Events**  
26% were unscheduled



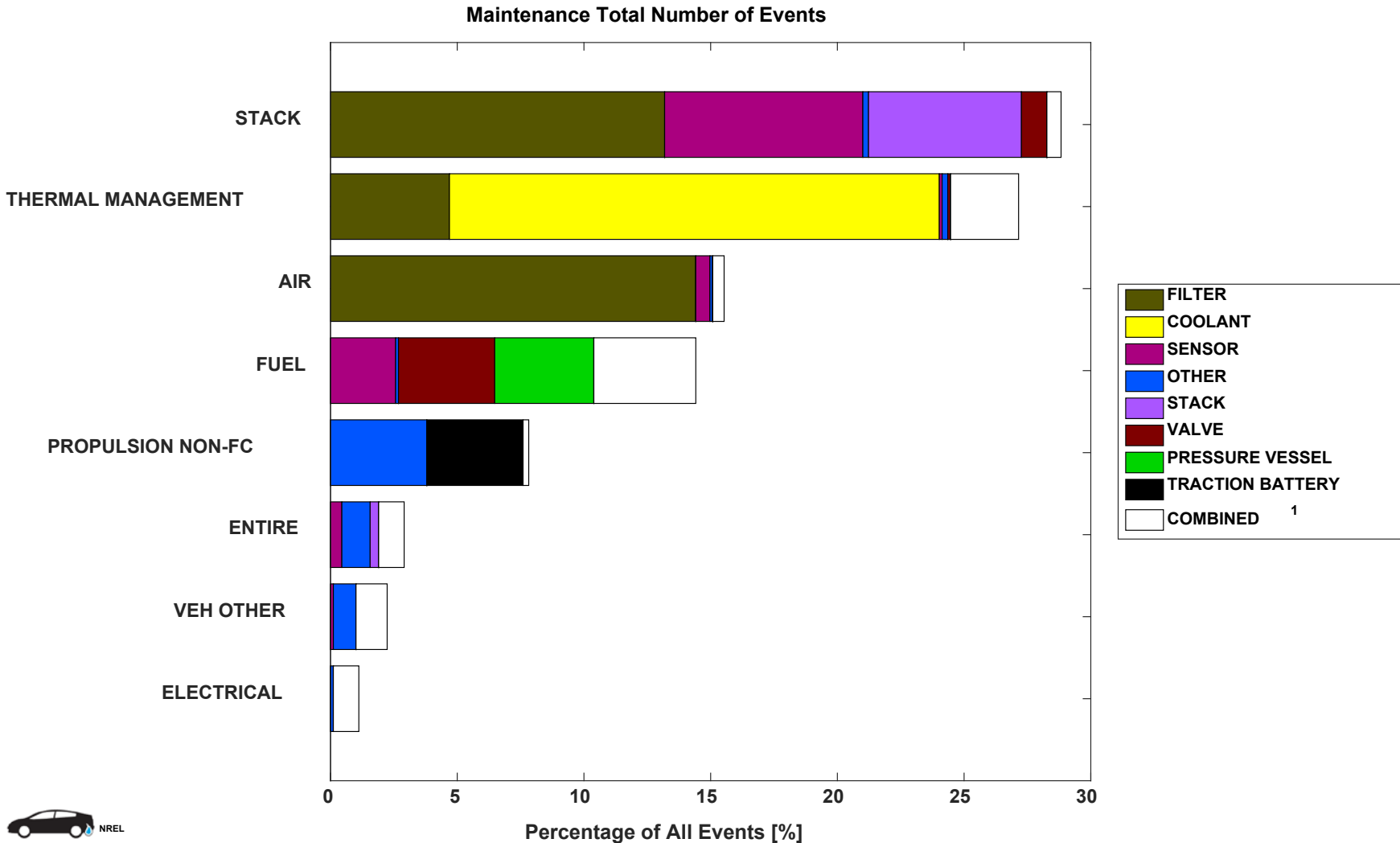
**Labor Hours**  
34% were unscheduled



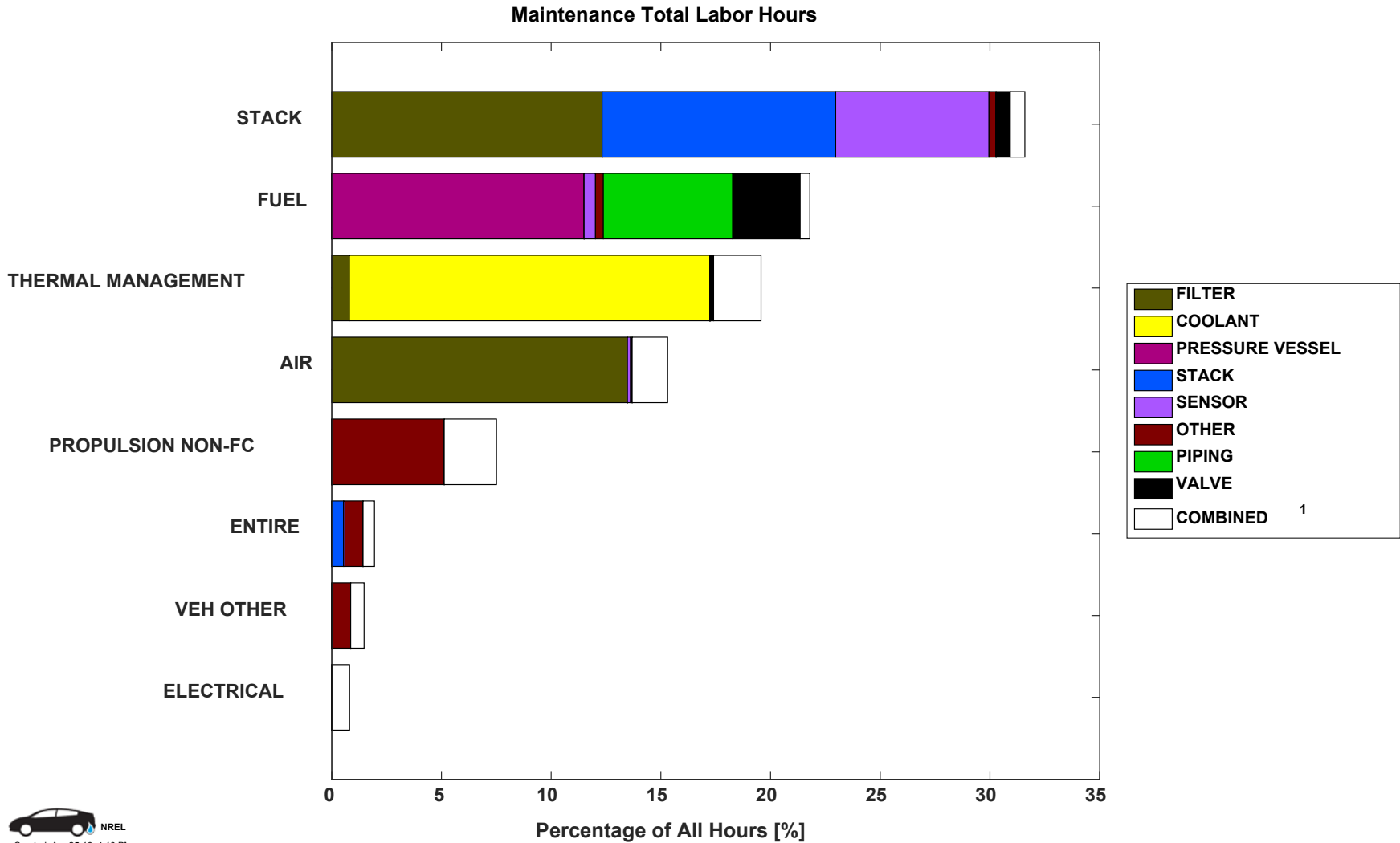
## Maintenance by Component Category by Quarter



## Maintenance Total Number of Events

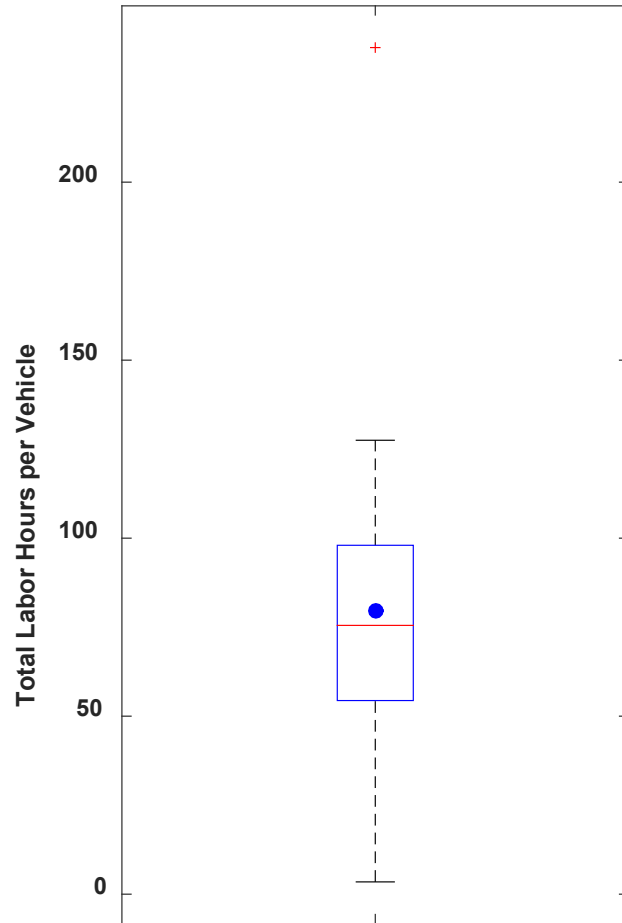


## Maintenance Total Labor Hours

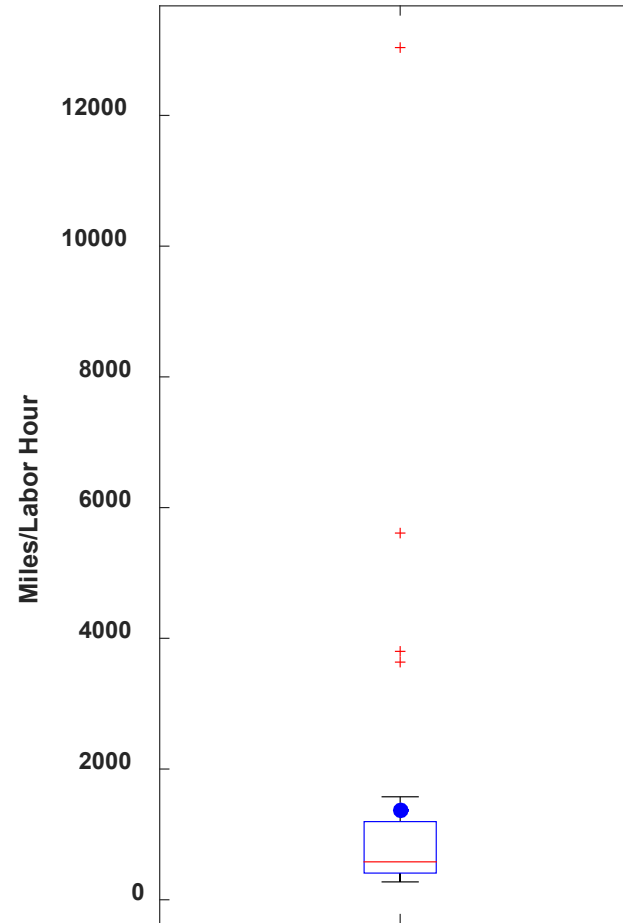


## Maintenance per Vehicle

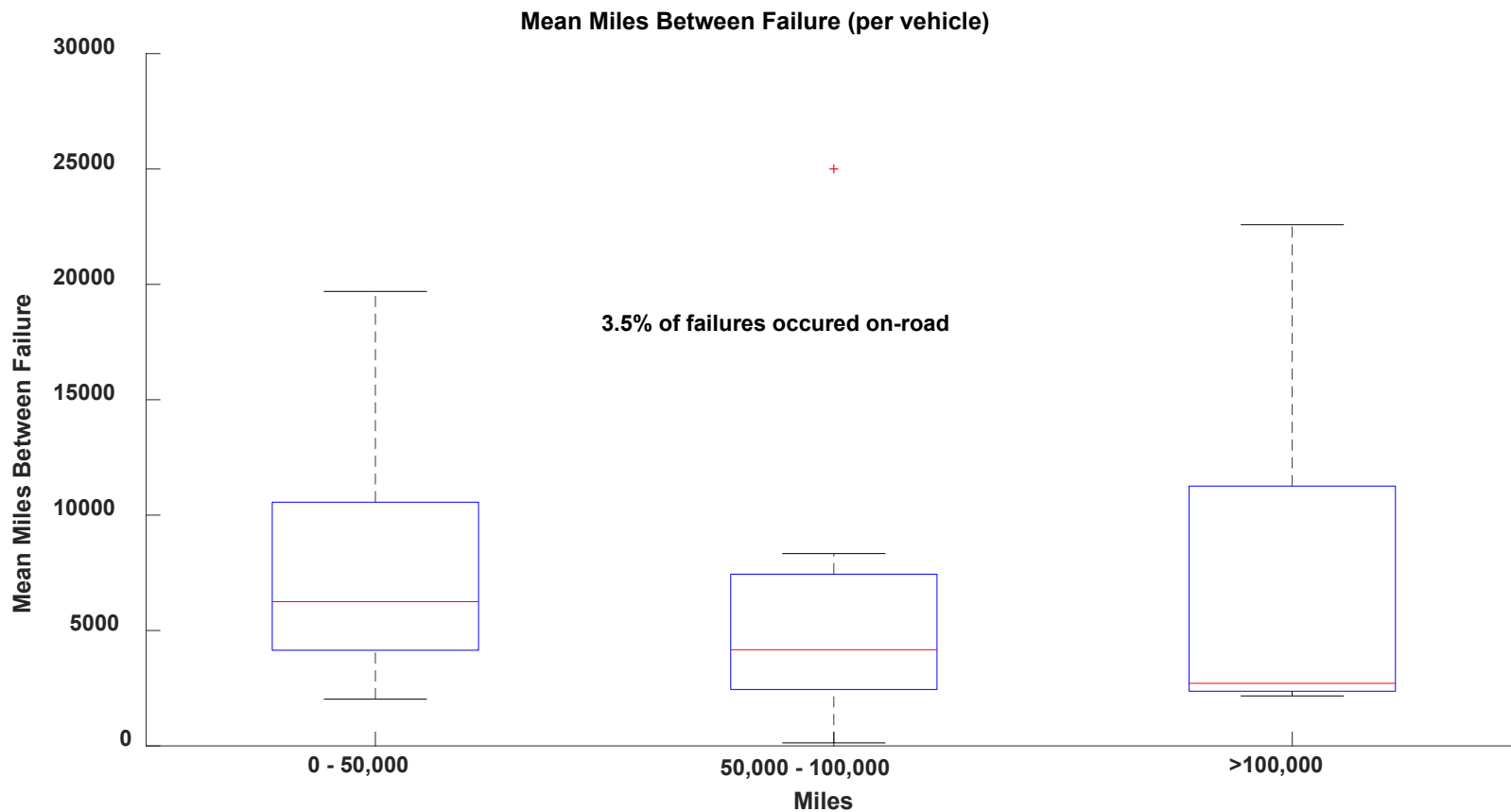
Maintenance Labor Hours (per vehicle)



Miles per Labor Hour

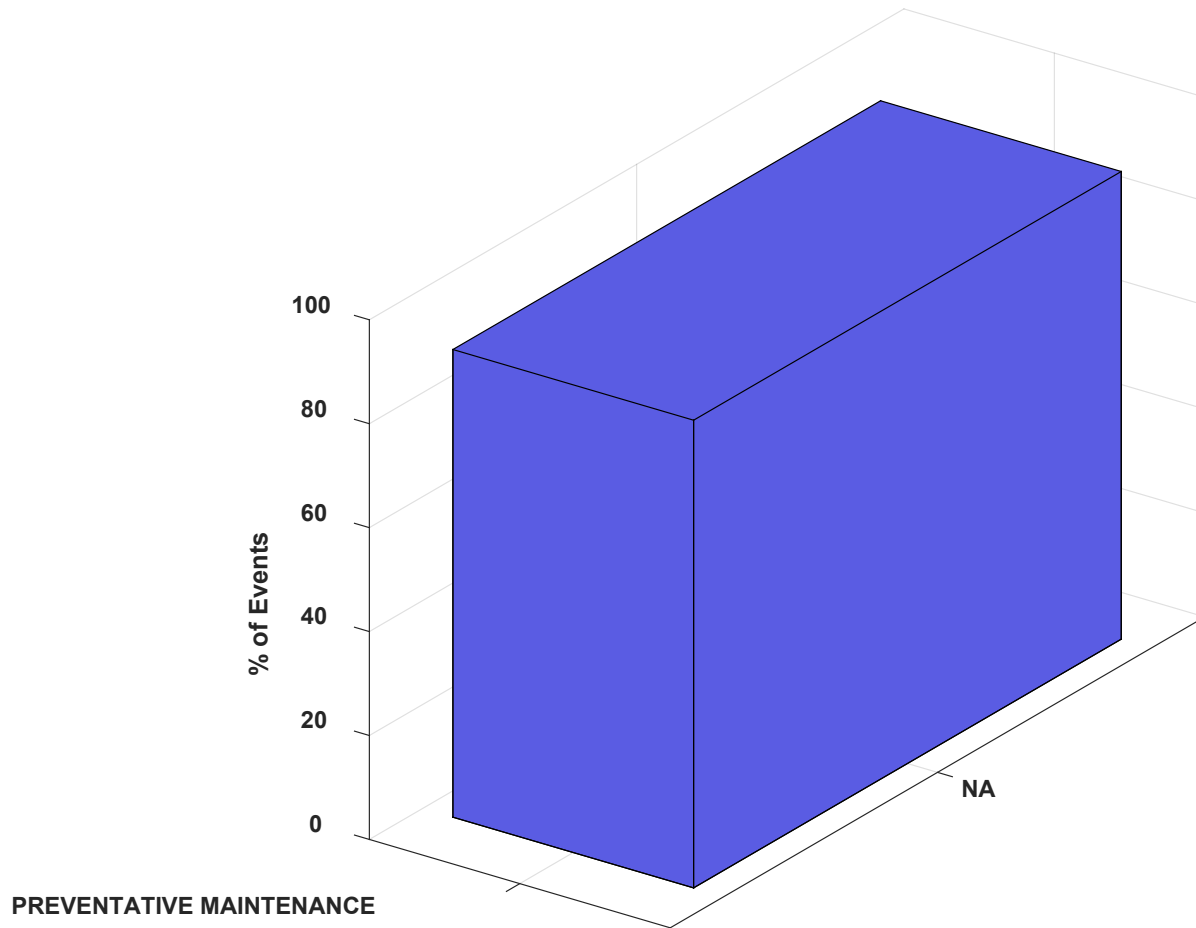


## Mean Miles Between Failure



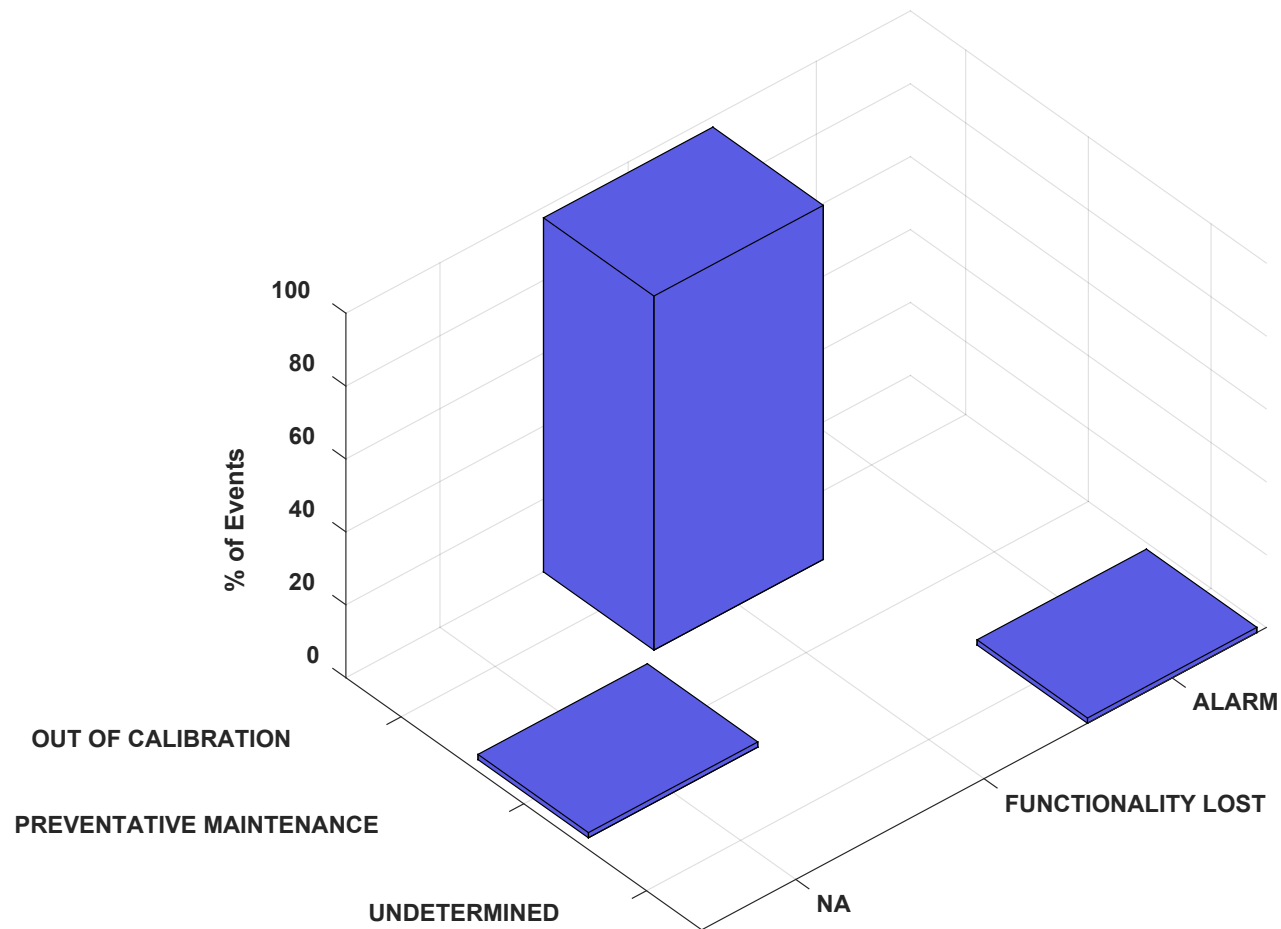
# CDP-FCEV-57

## Maintenance Causes and Effects—Stack Subsystem, Filter Component



# CDP-FCEV-58

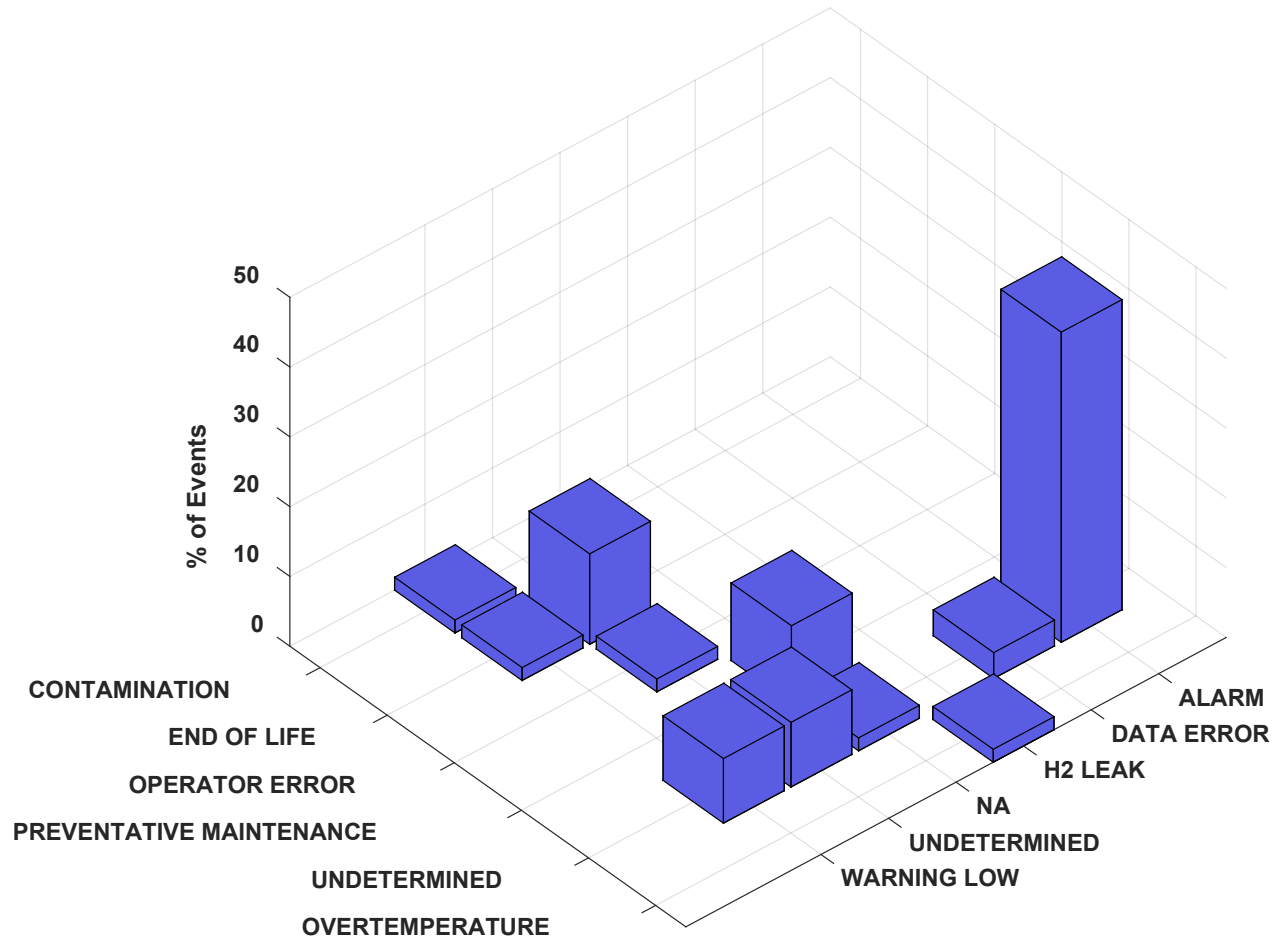
## Maintenance Causes and Effects—Stack Subsystem, Sensor Component





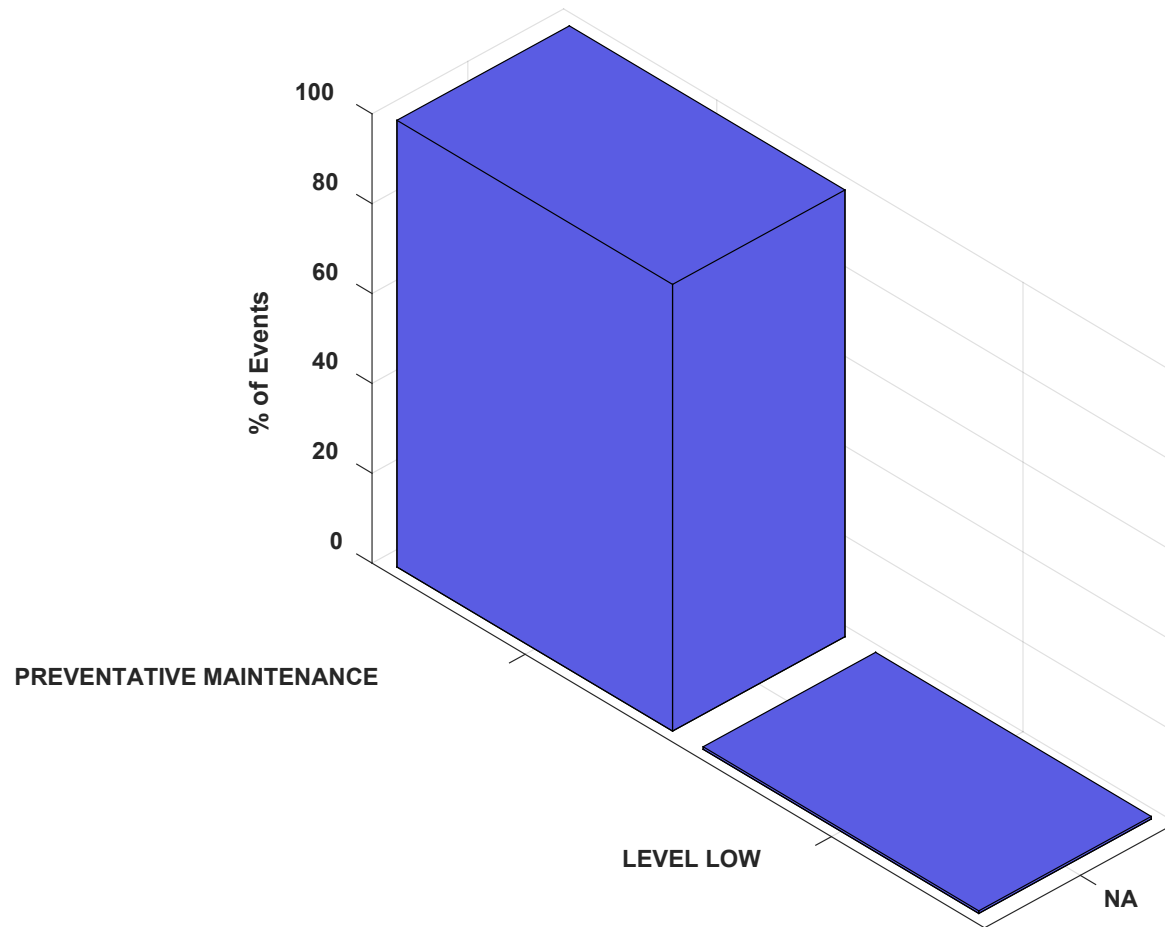
# CDP-FCEV-59

## Maintenance Causes and Effects—Stack Subsystem, Stack Component



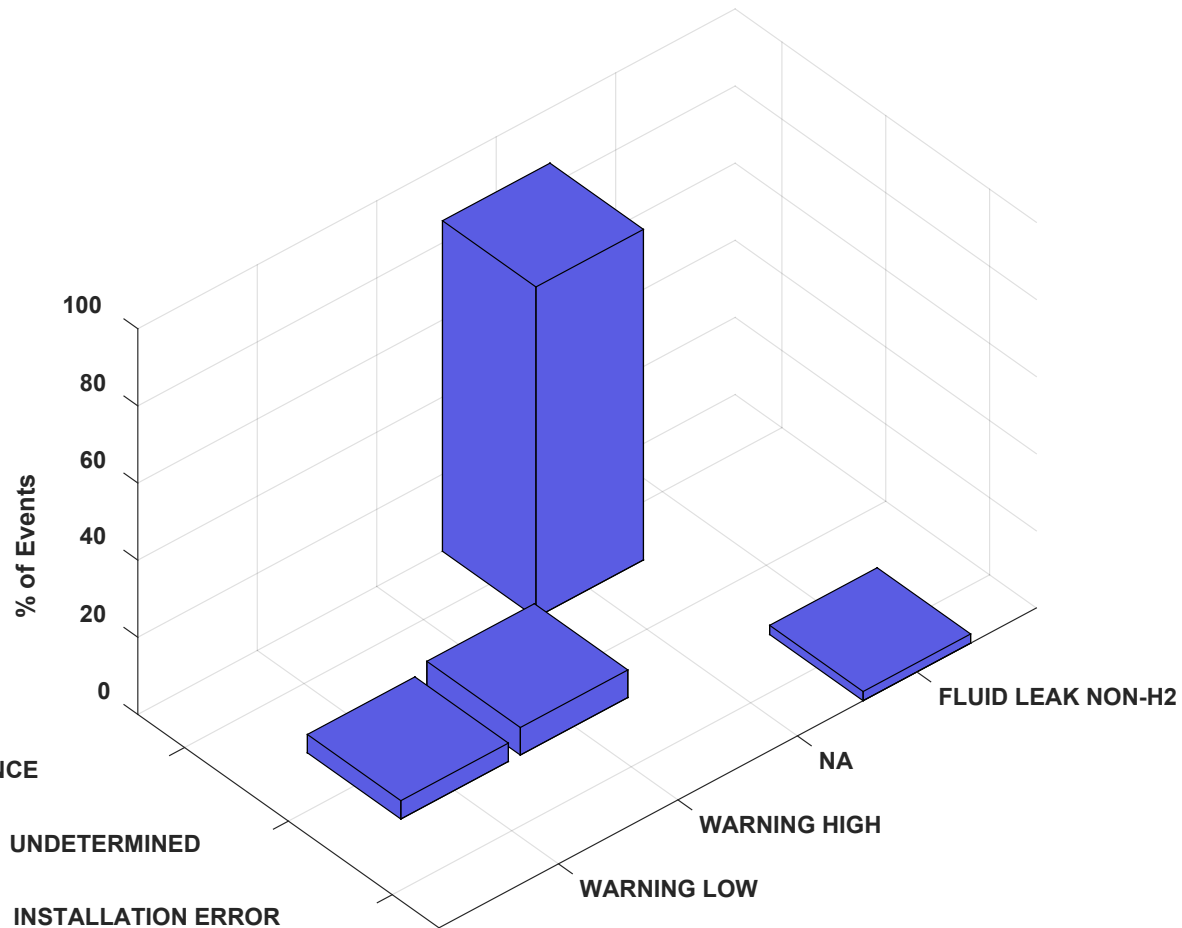
# CDP-FCEV-60

## Maintenance Causes and Effects—Thermal Management Subsystem, Coolant Component



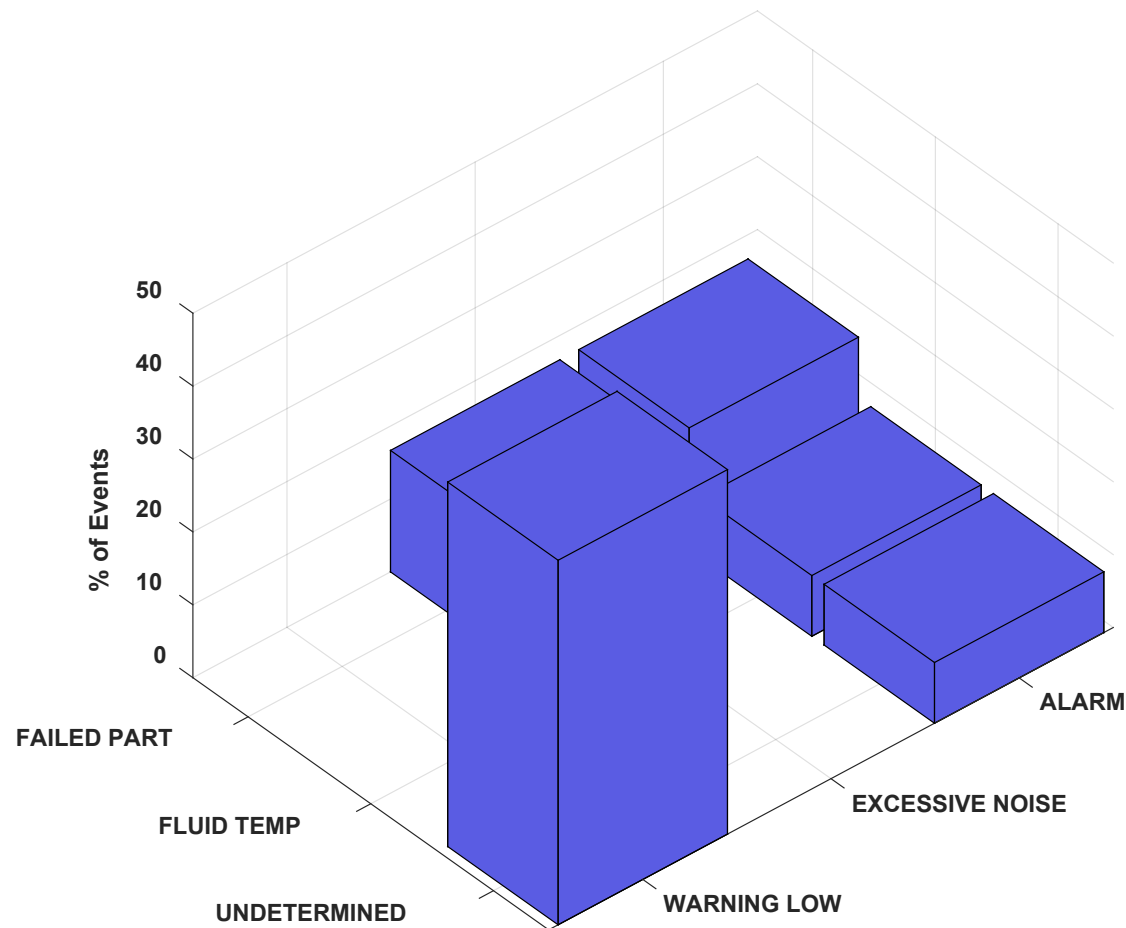
# CDP-FCEV-61

## Maintenance Causes and Effects—Thermal Management Subsystem, Filter Component



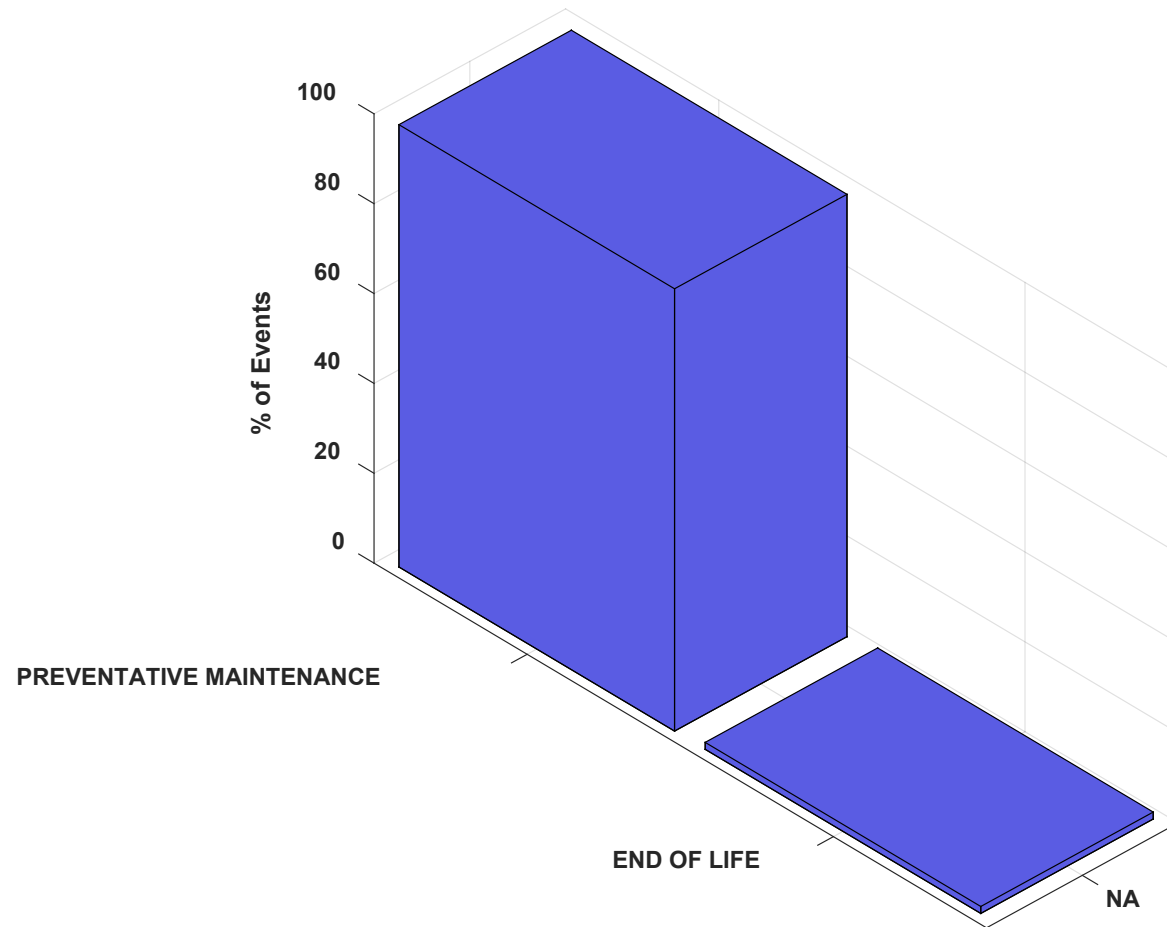
# CDP-FCEV-62

## Maintenance Causes and Effects—Thermal Management Subsystem, Pump Component



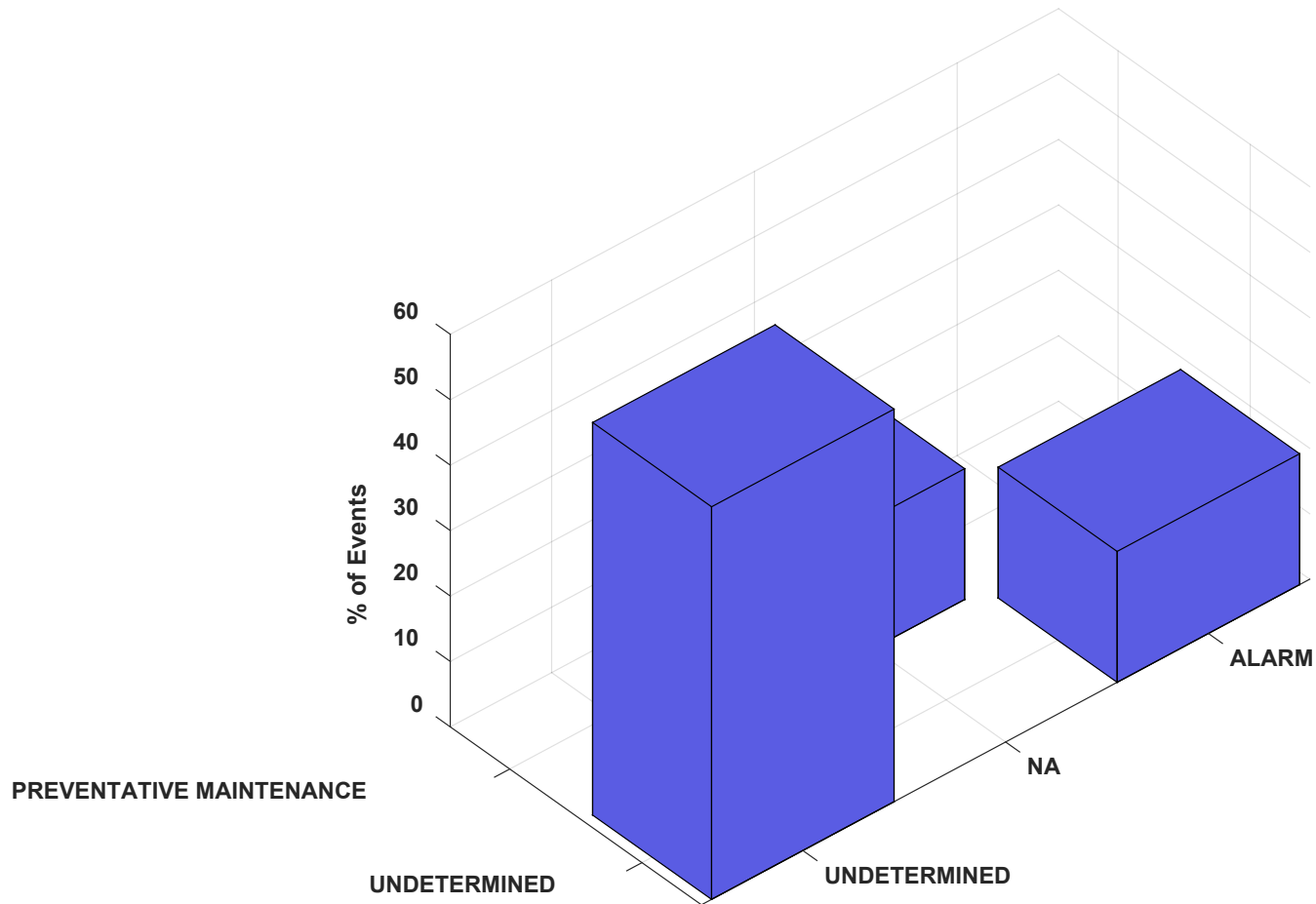
# CDP-FCEV-63

## Maintenance Causes and Effects—Air Subsystem, Filter Component



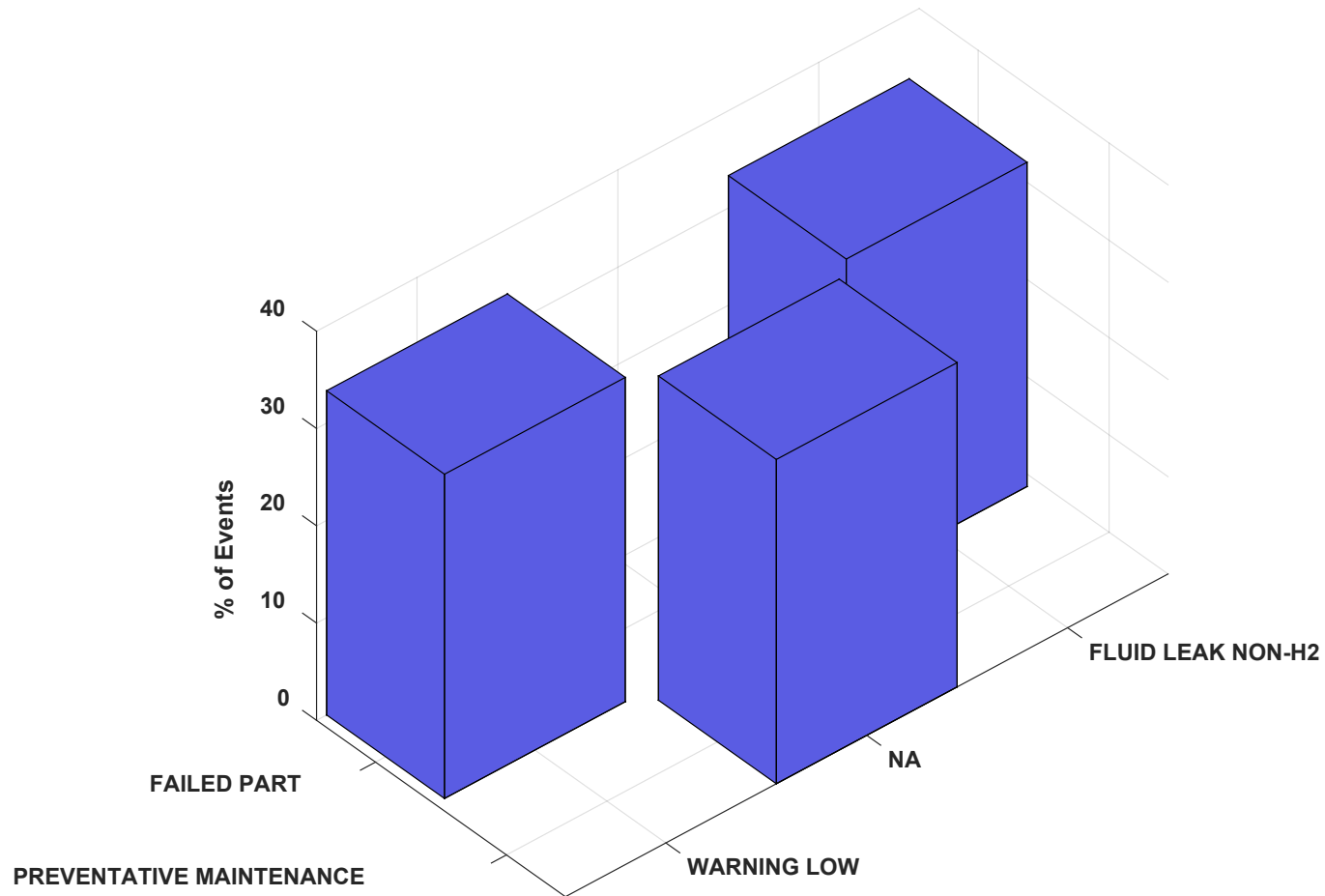
# CDP-FCEV-64

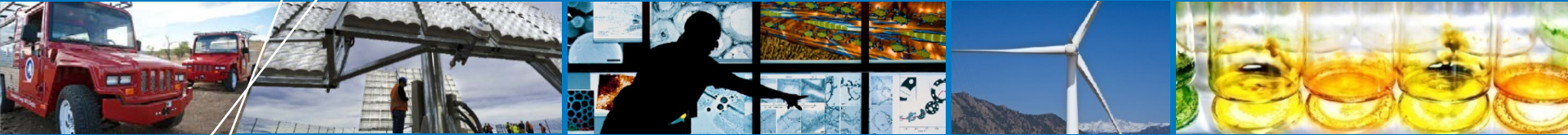
## Maintenance Causes and Effects—Air Subsystem, Sensor Component



# CDP-FCEV-65

## Maintenance Causes and Effects—Air Subsystem, Humidifier Component



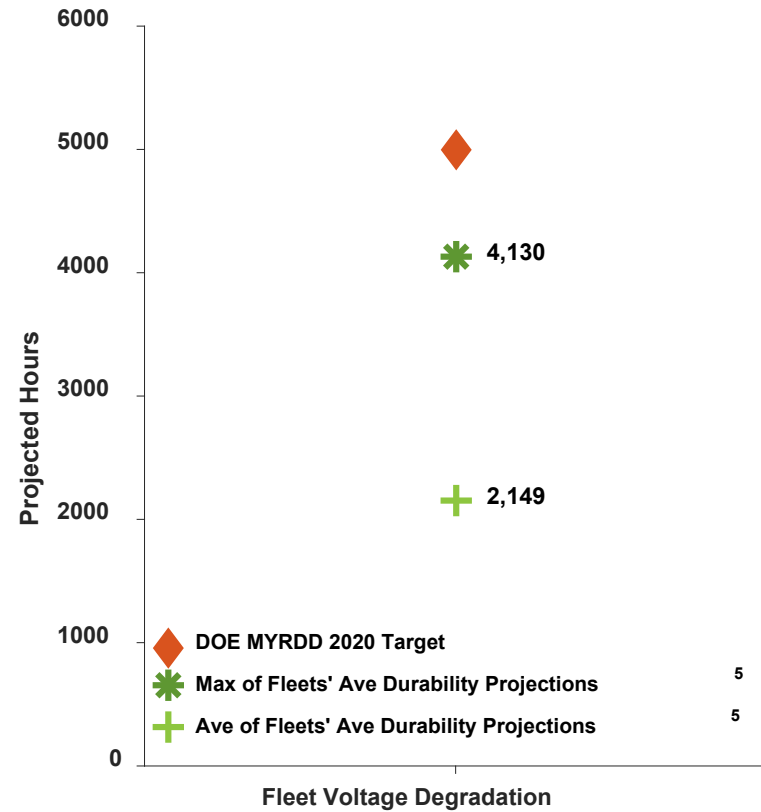
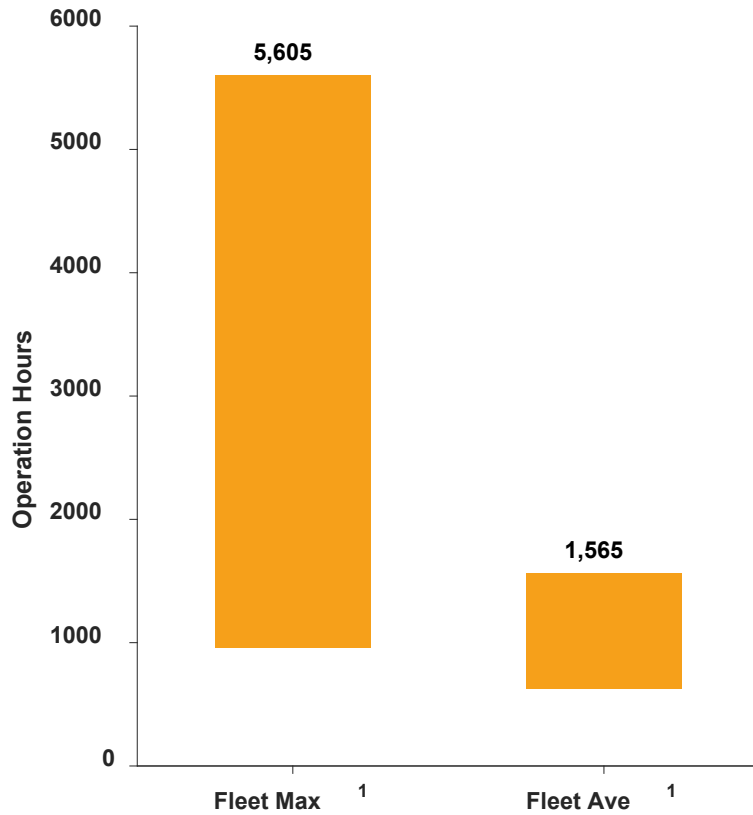


# Durability



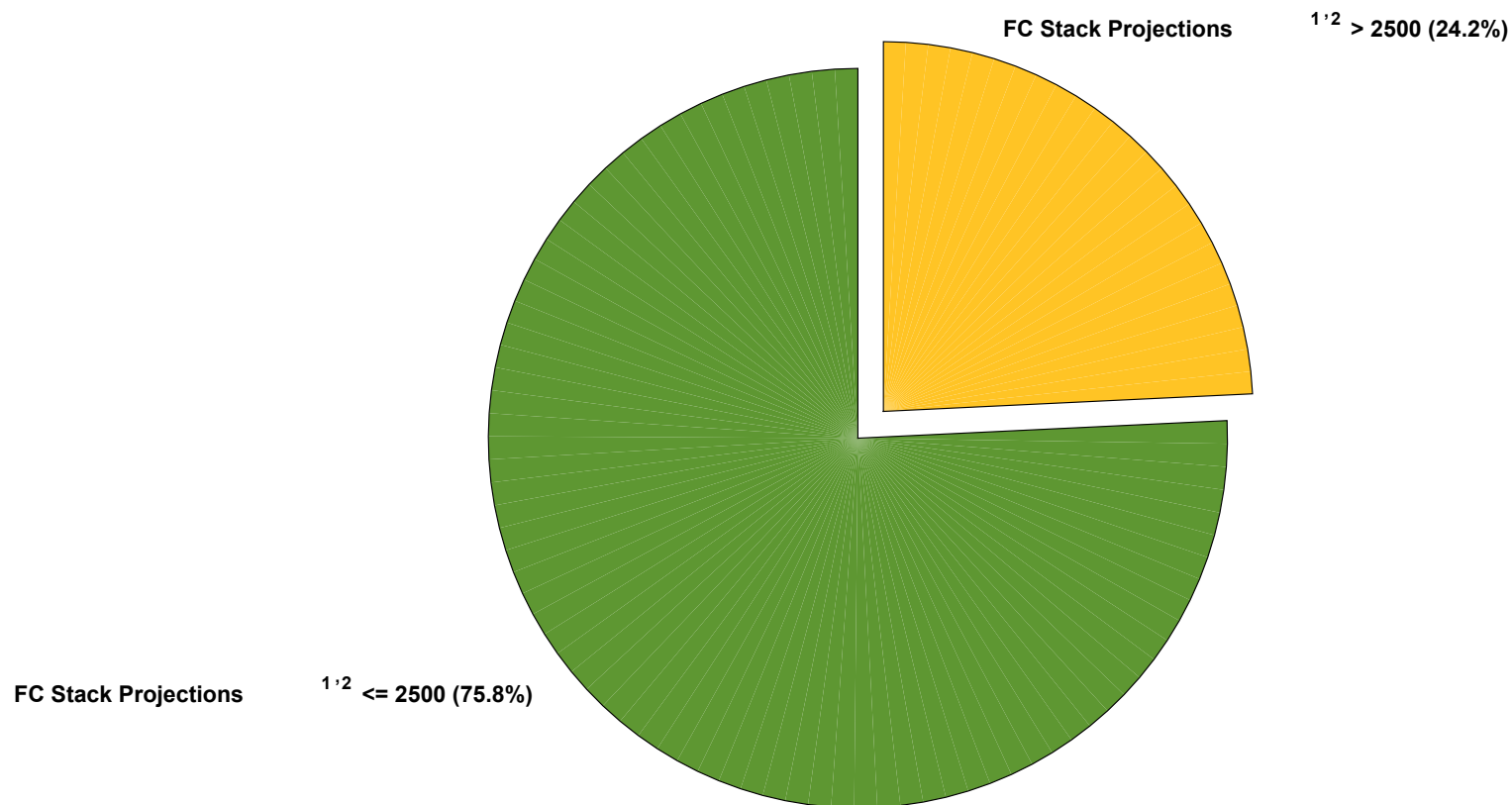
# CDP-FCEV-21

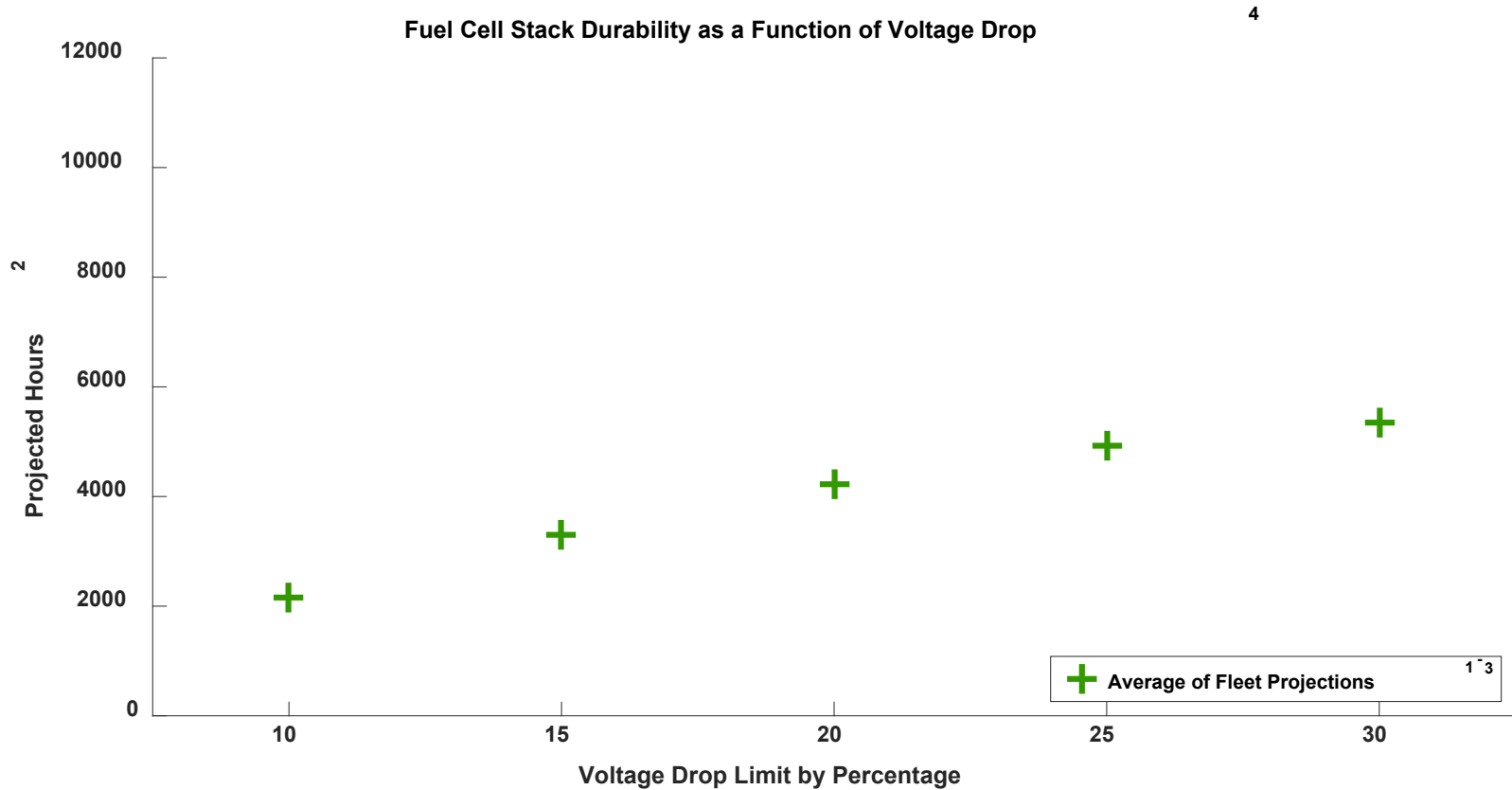
## Operation Hours and Voltage Durability



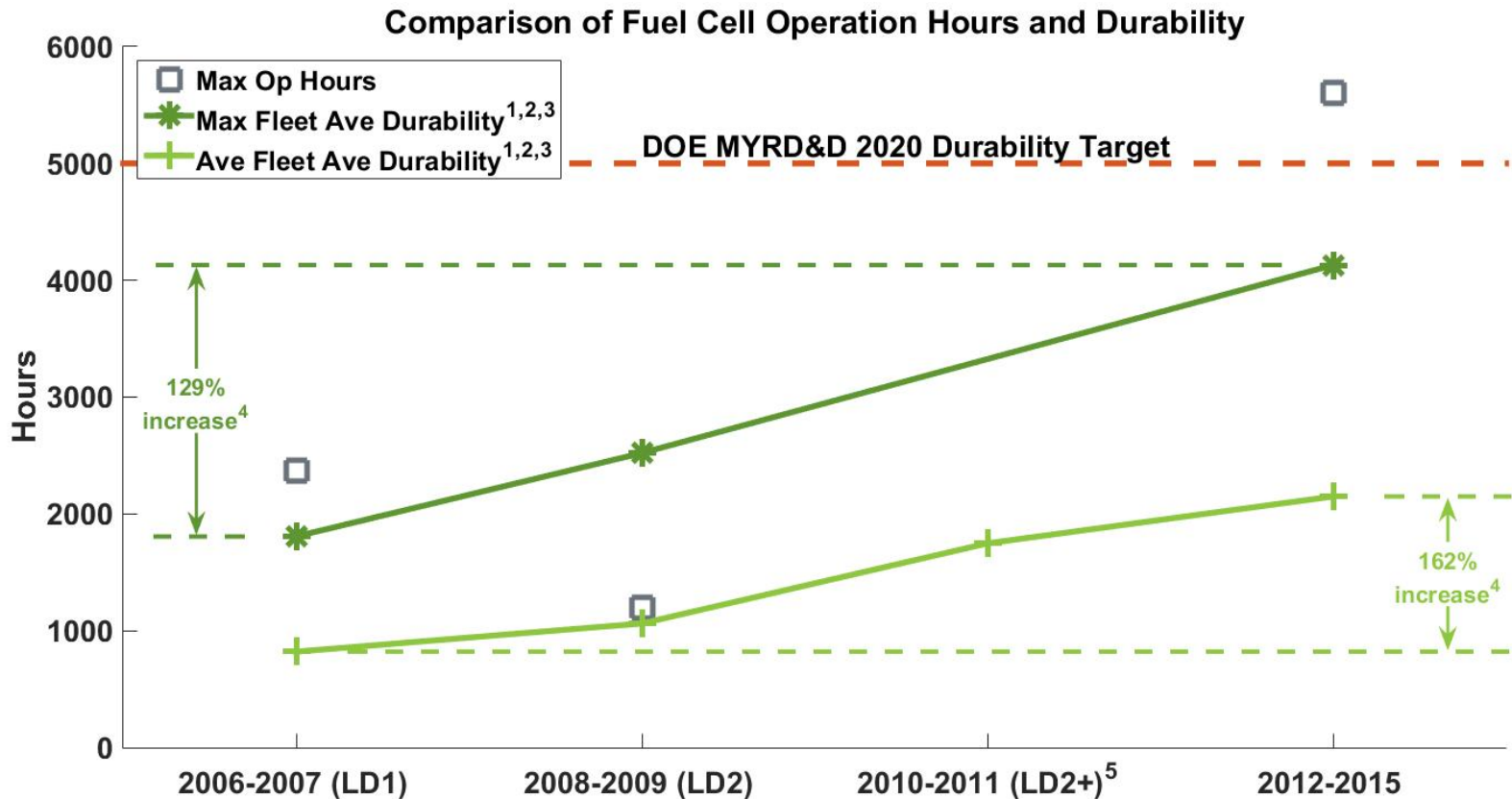
## Projected Hours to 10% Voltage Degradation

Fuel Cell 10% Voltage Degradation Against 2,500 Hour Benchmark





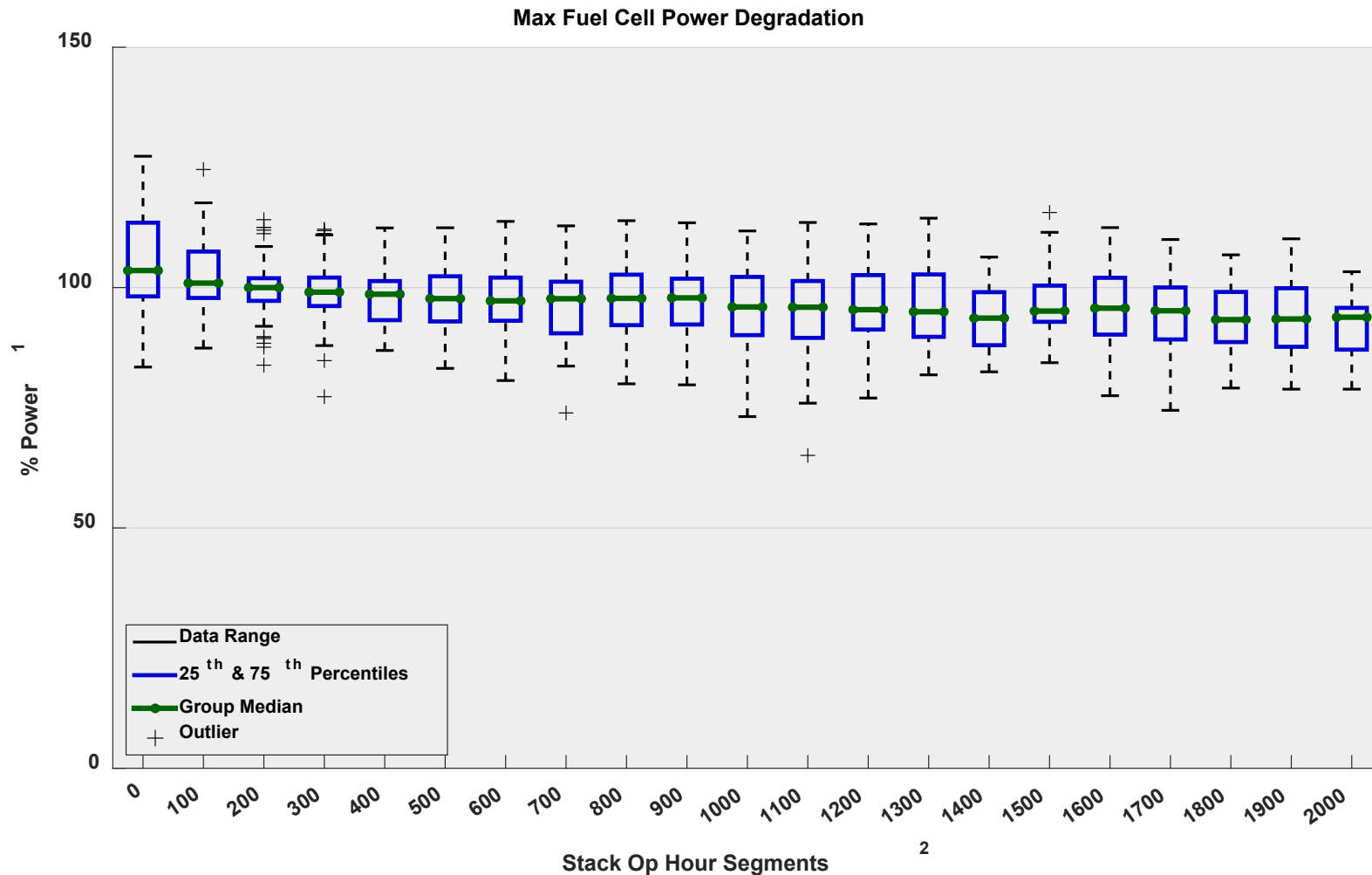
## Fuel Cell Operation Hours and Voltage Degradation Trend



1. Durability based on voltage degradation to 10% lower than beginning of life voltage. 10% voltage drop level is a DOE metric for assessing fuel cell durability.
2. Projections using on-road data are calculated at approximately 55%-65% rated stack current.
3. 10% voltage drop is NOT an indication of an OEM's end-of-life criteria and projections do not address catastrophic stack failure.
4. Percent increases are calculated relative to Learning Demonstration 1 (LD1) (2006-2007).
5. Maximum operational hours not reported in Learning Demonstration 2 continuation (LD2+) (2010-2011).



NREL cdp\_fcev\_31  
 Created: May-03-16 12:38 PM | Data Range: 2009Q1-2015Q4  
 Included Vehicles: Partial

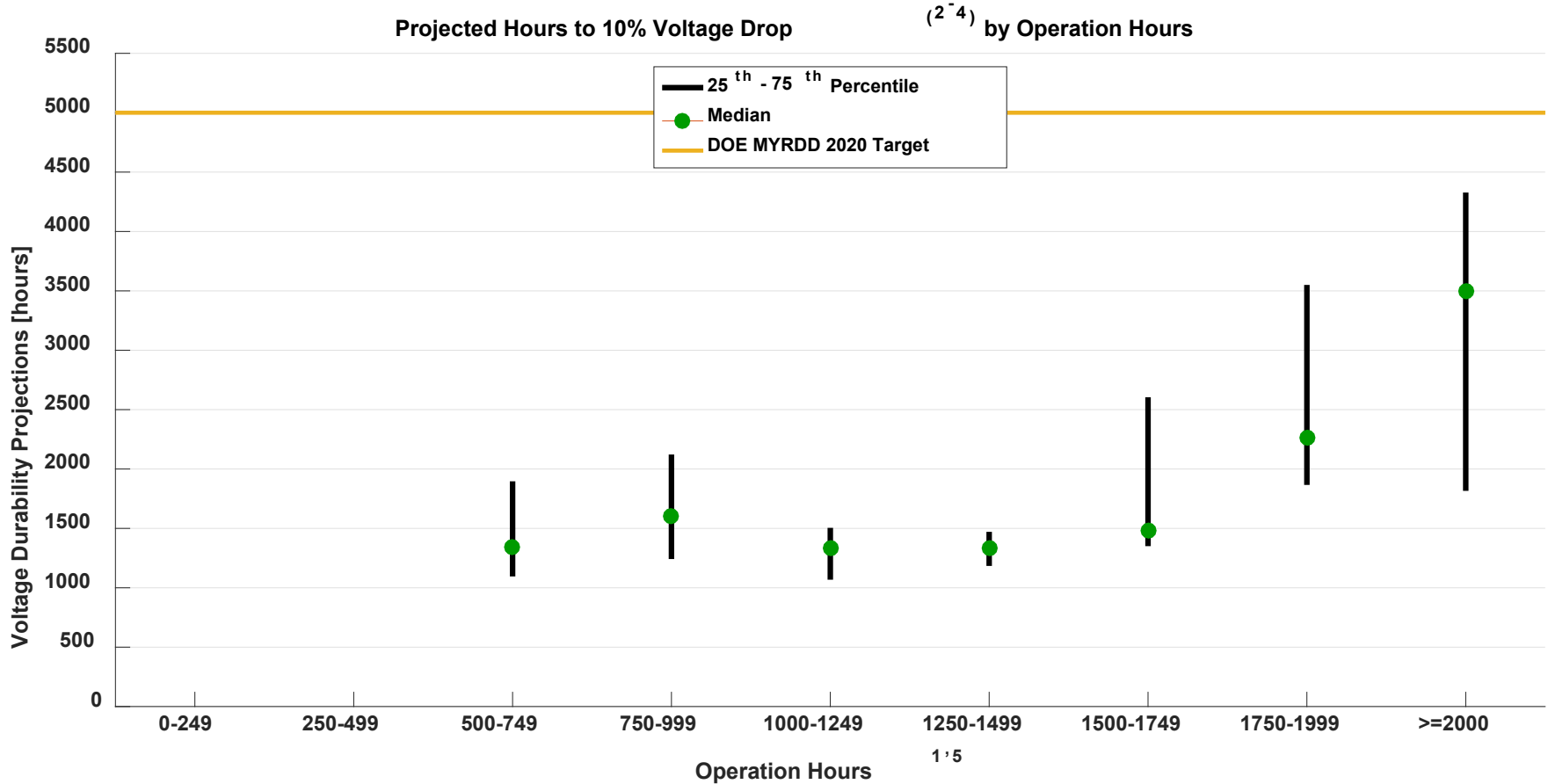


1) Normalized by fleet median value at 200 hours.

2) Each segment point is median FC power (+/-50 hrs). Box not drawn if fewer than 3 points in segment.

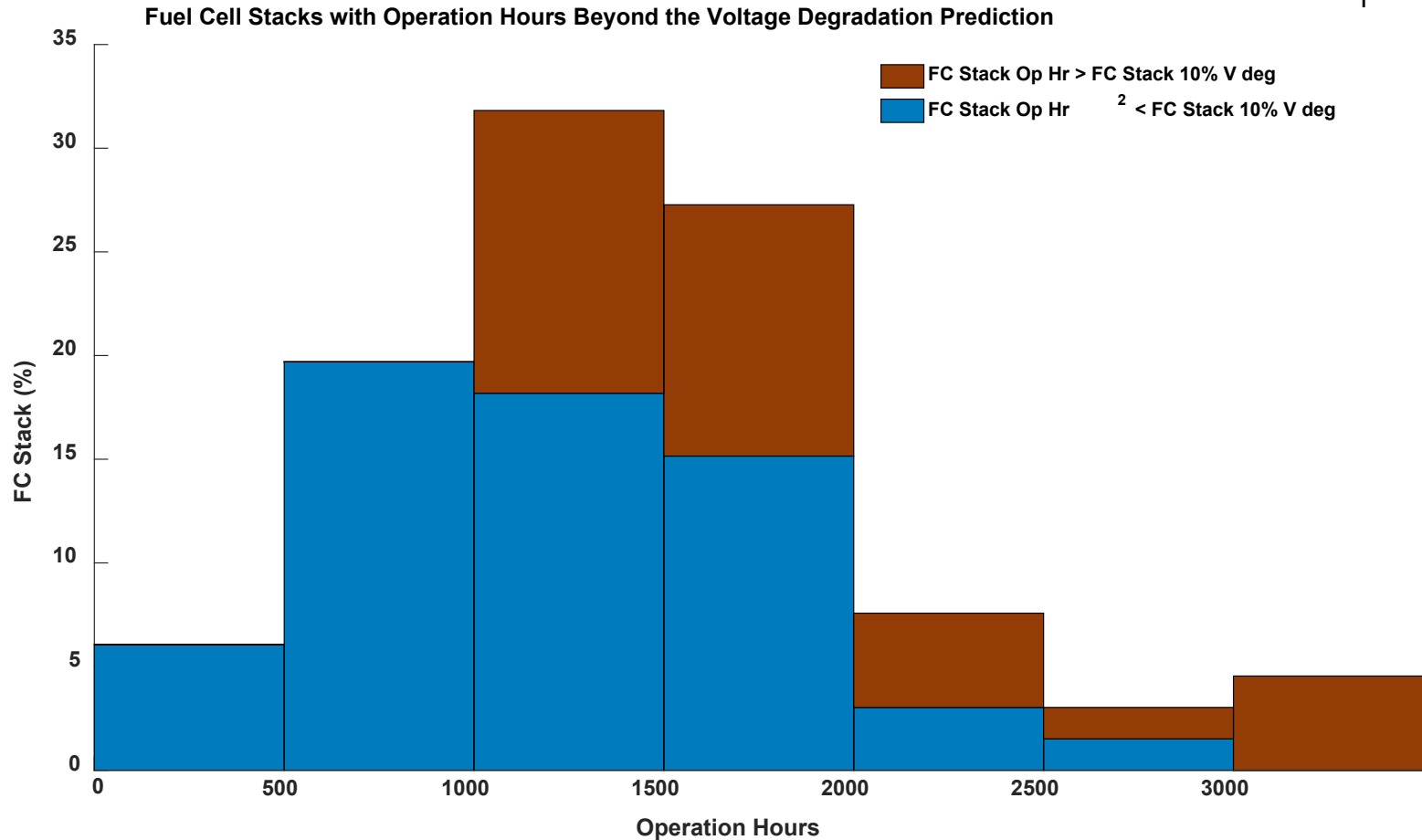
# CDP-FCEV-50

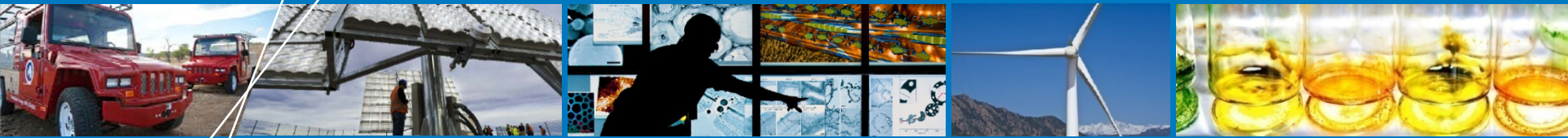
## Voltage Degradation Projection by Operation Hours



## Fuel Cell Operation Hours Beyond 10% Voltage Degradation

1

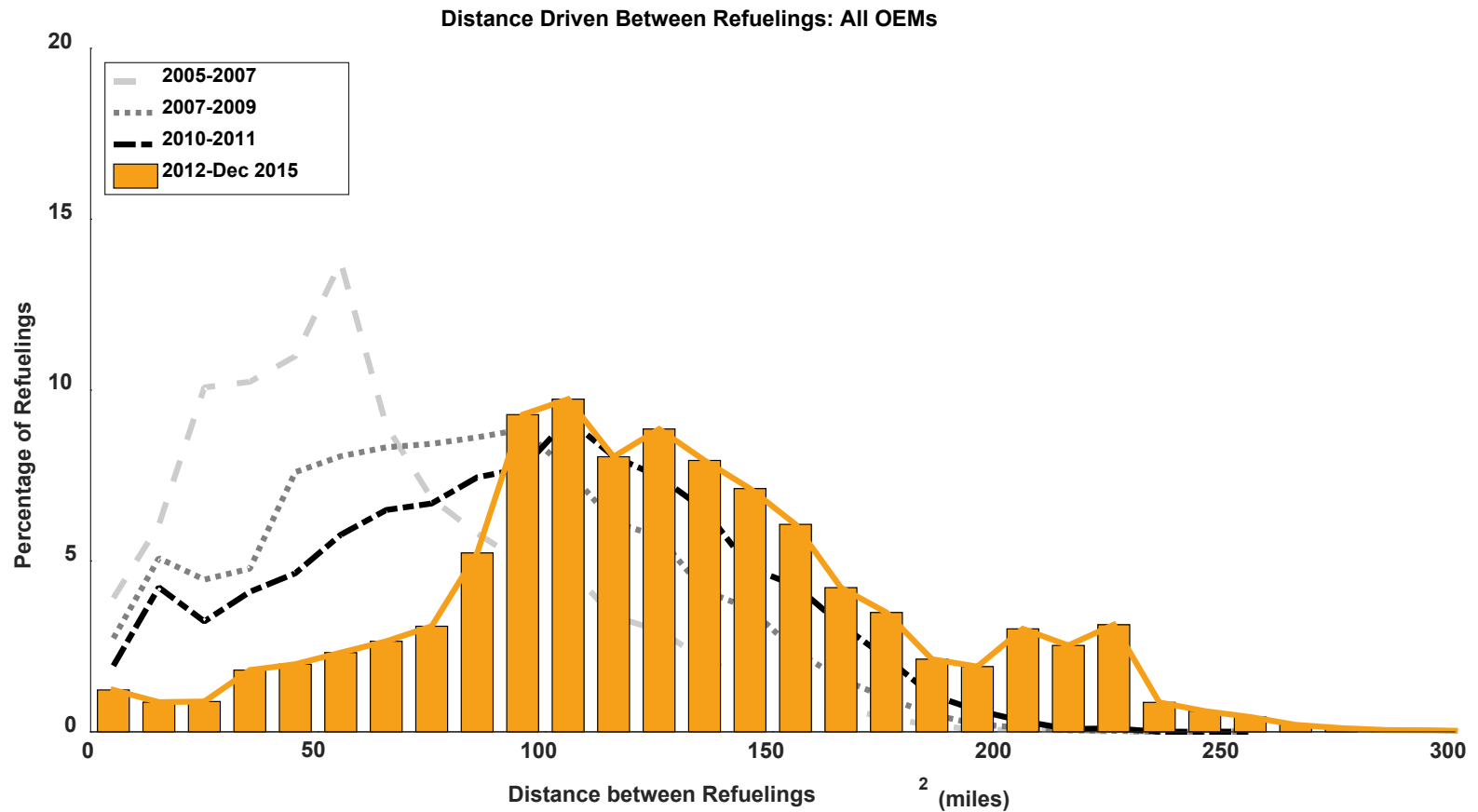




# Range

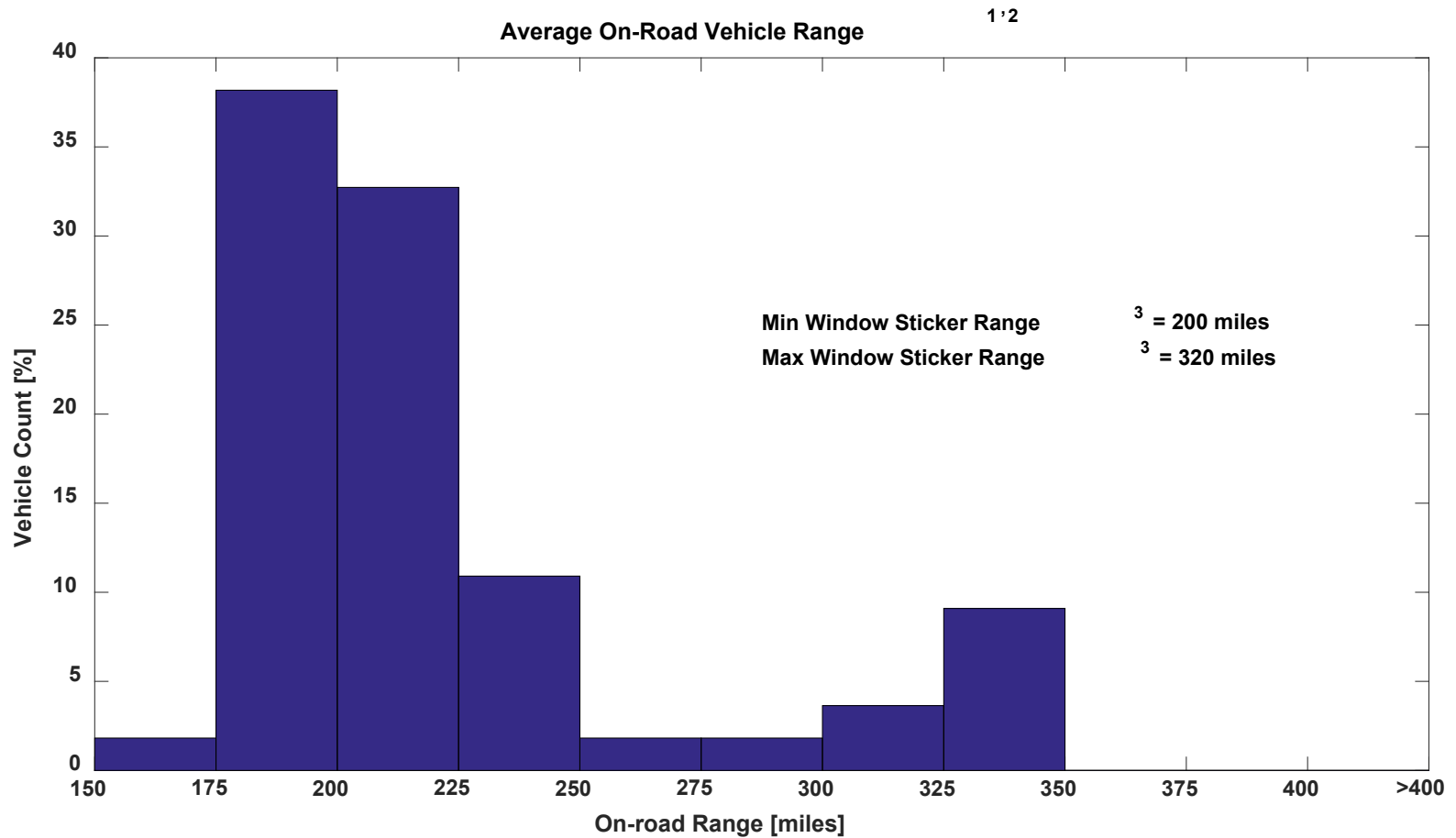


## Distance Driven Between Refueling

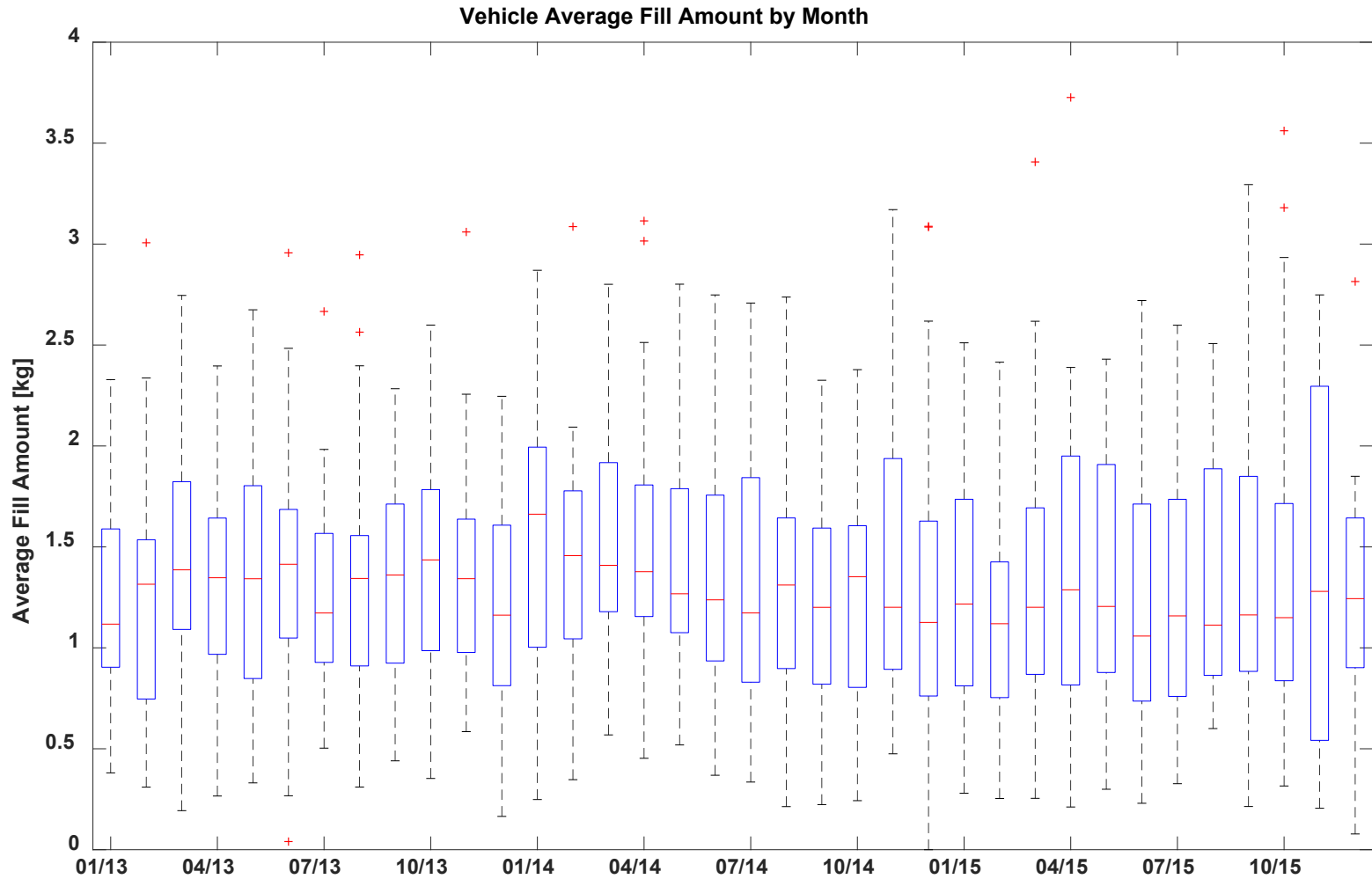


# CDP-FCEV-47

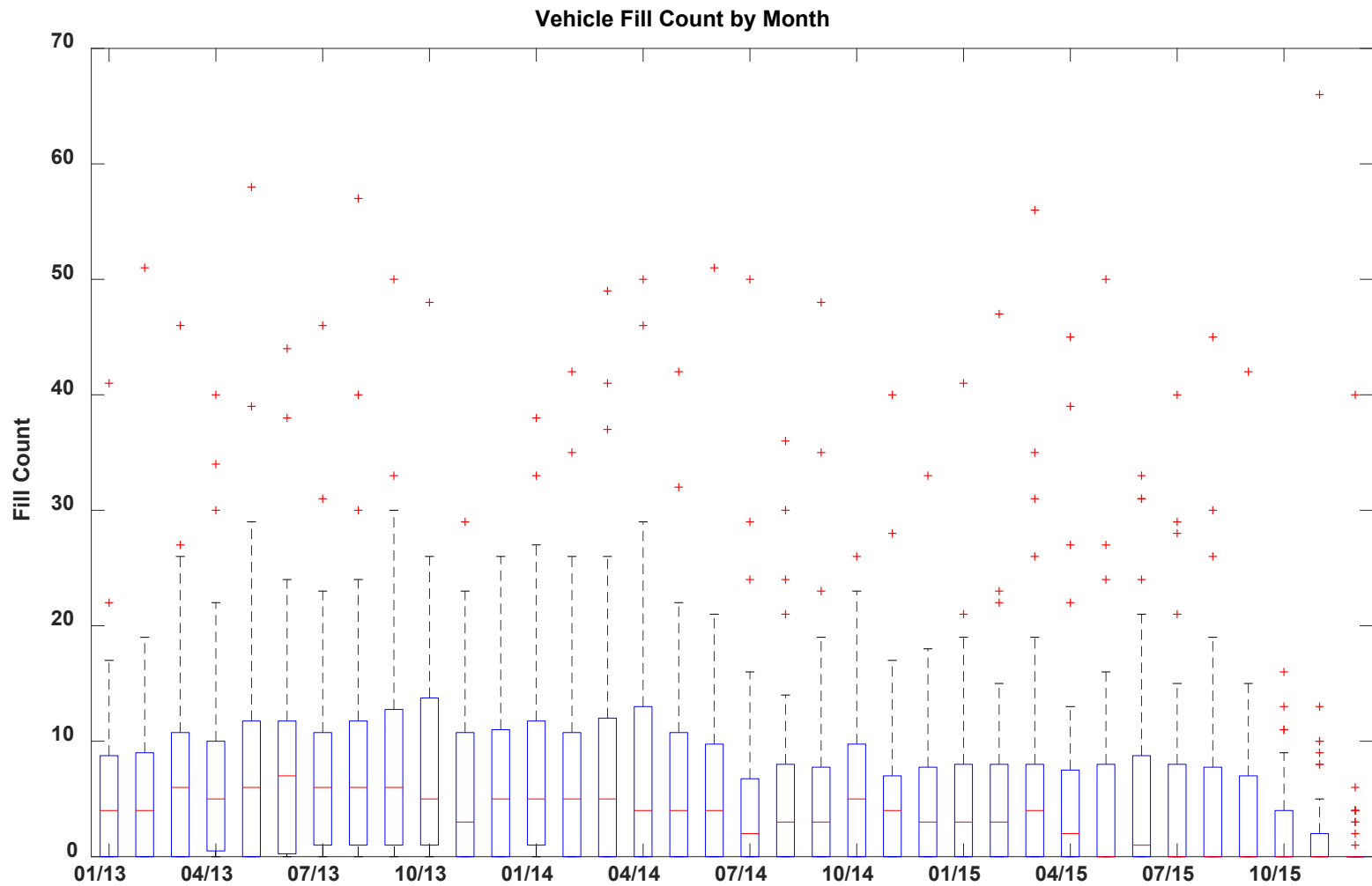
## Average On-Road Vehicle Range



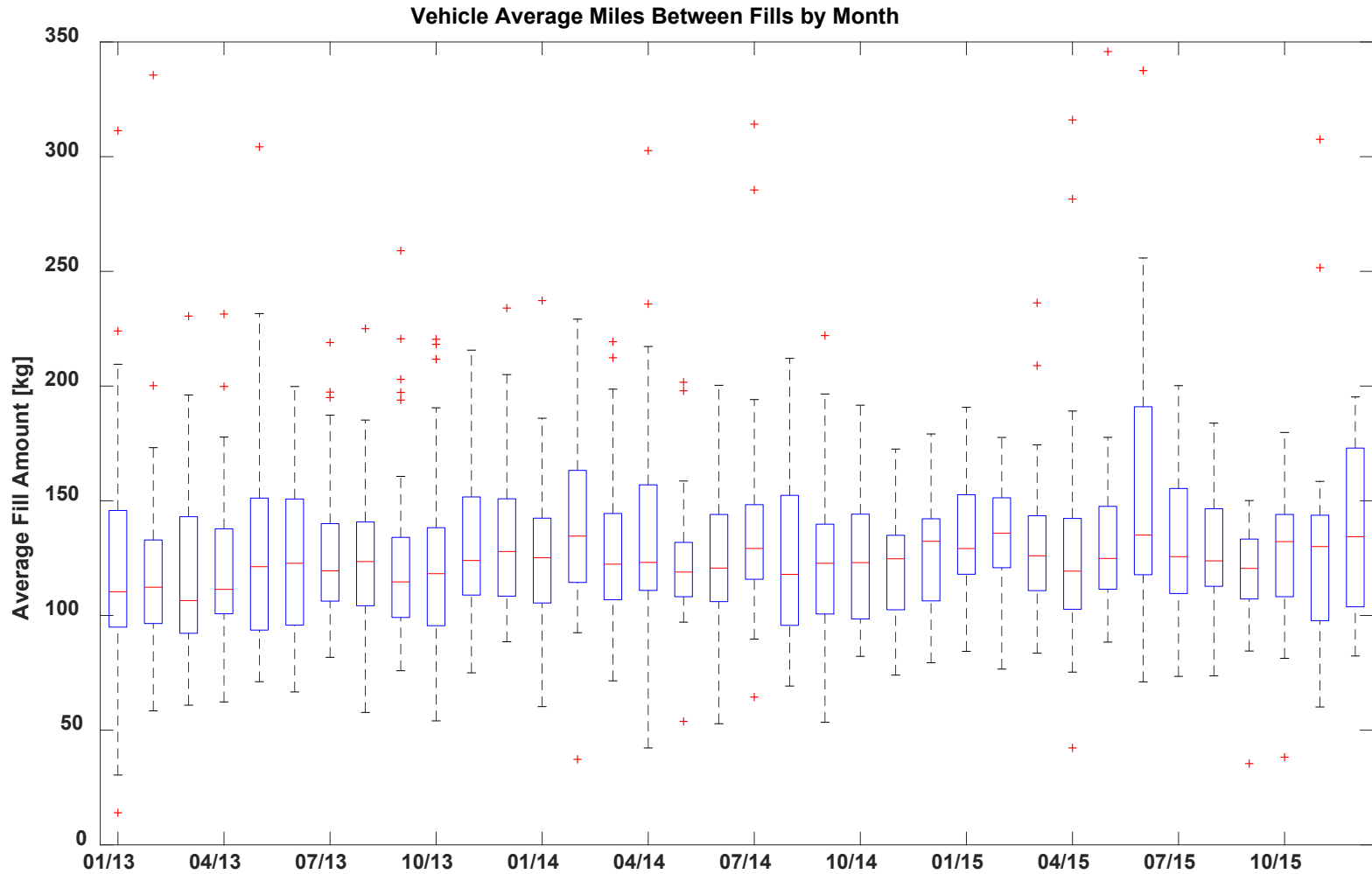
## Vehicle Average Fill Amount by Month

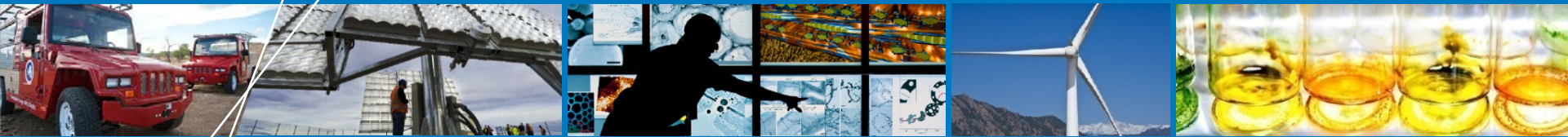


## Vehicle Fill Count by Month



## Average Vehicle Miles Between Fills by Month

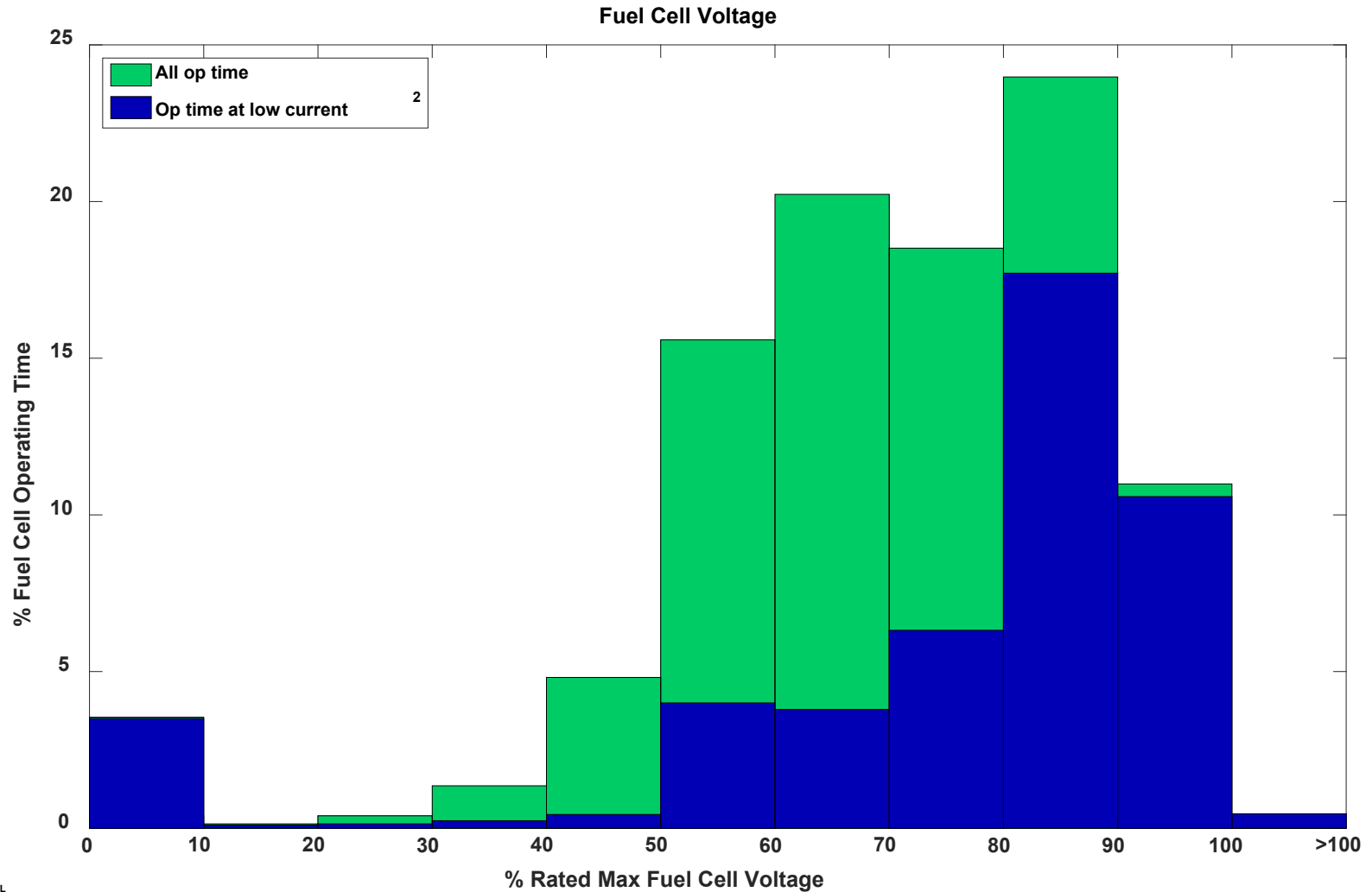




# Fuel Cell Performance

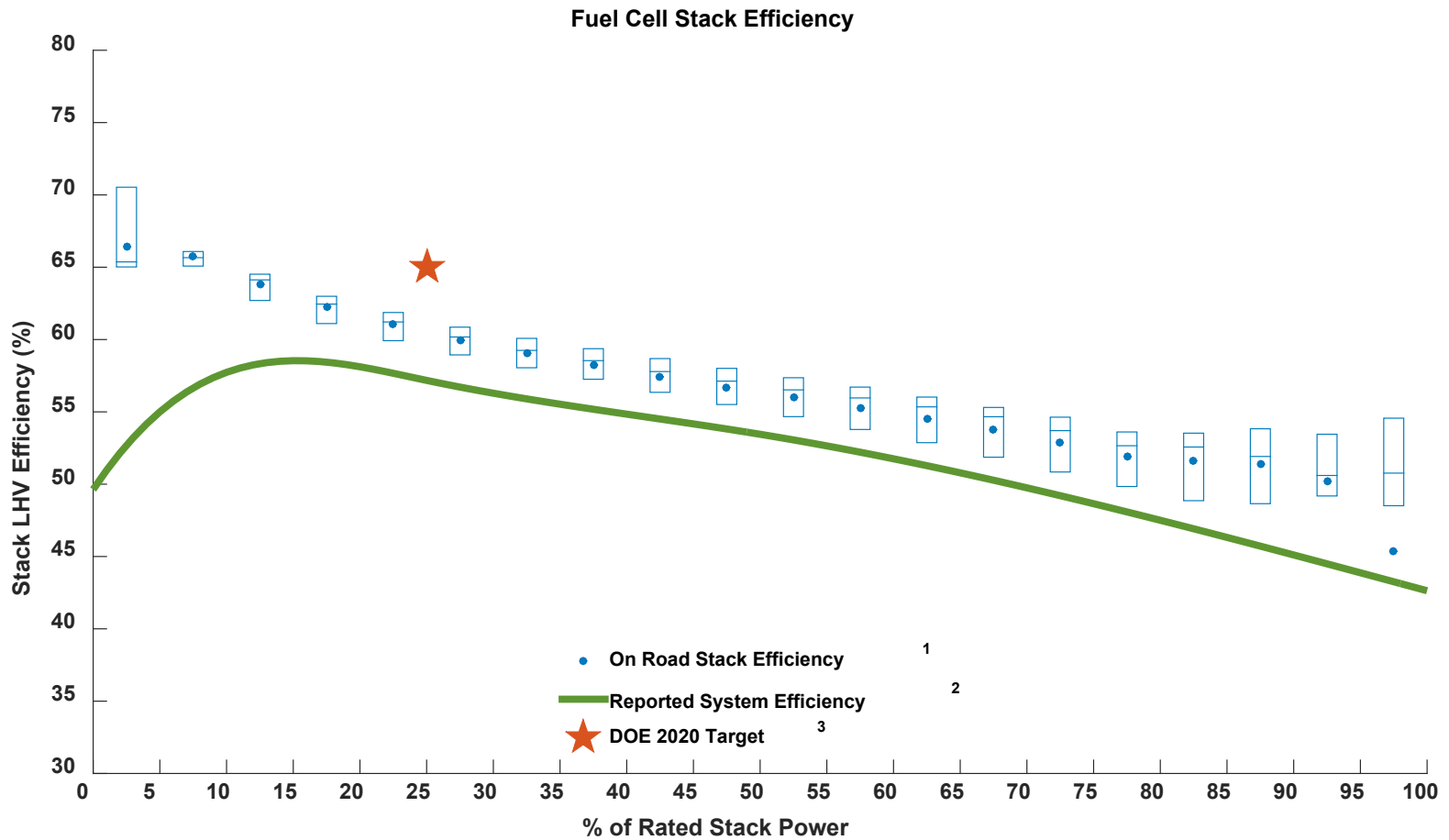
# CDP-FCEV-40

## Fuel Cell Voltage



# CDP-FCEV-45

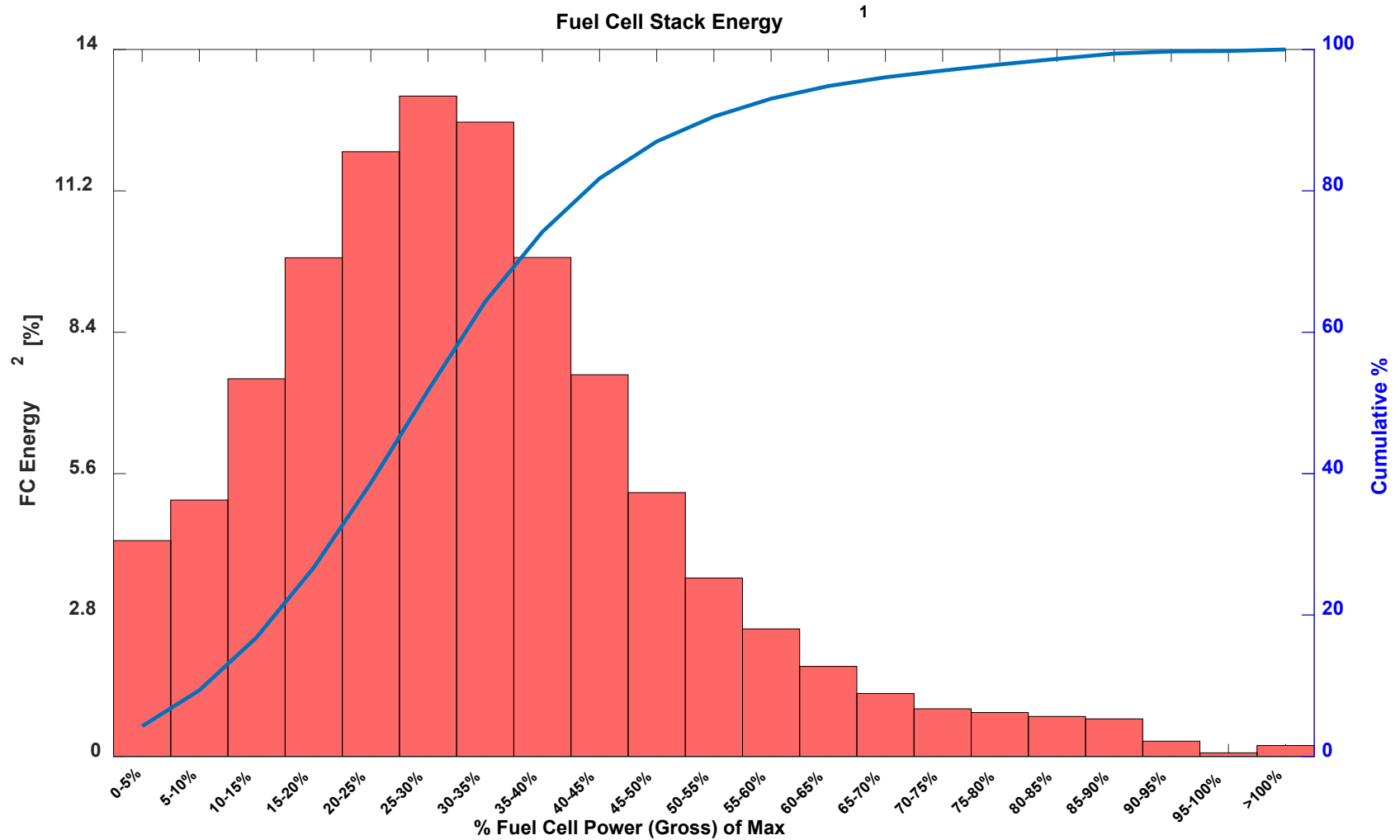
## On-Road Fuel Cell Stack Efficiency



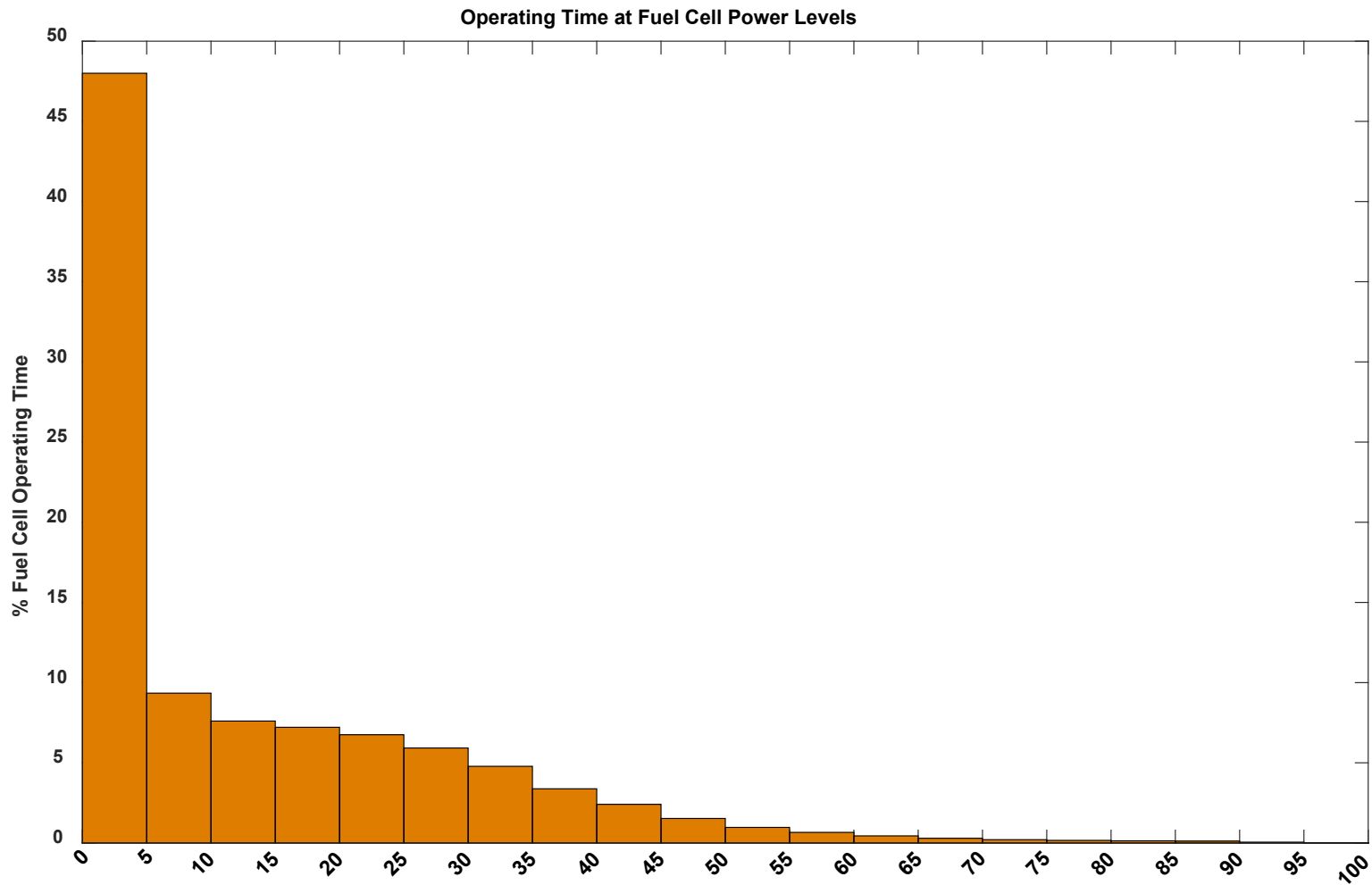


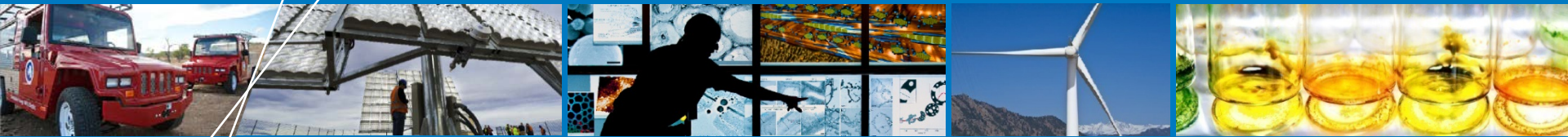
# CDP-FCEV-52

## Fuel Cell Stack Energy at Power Levels



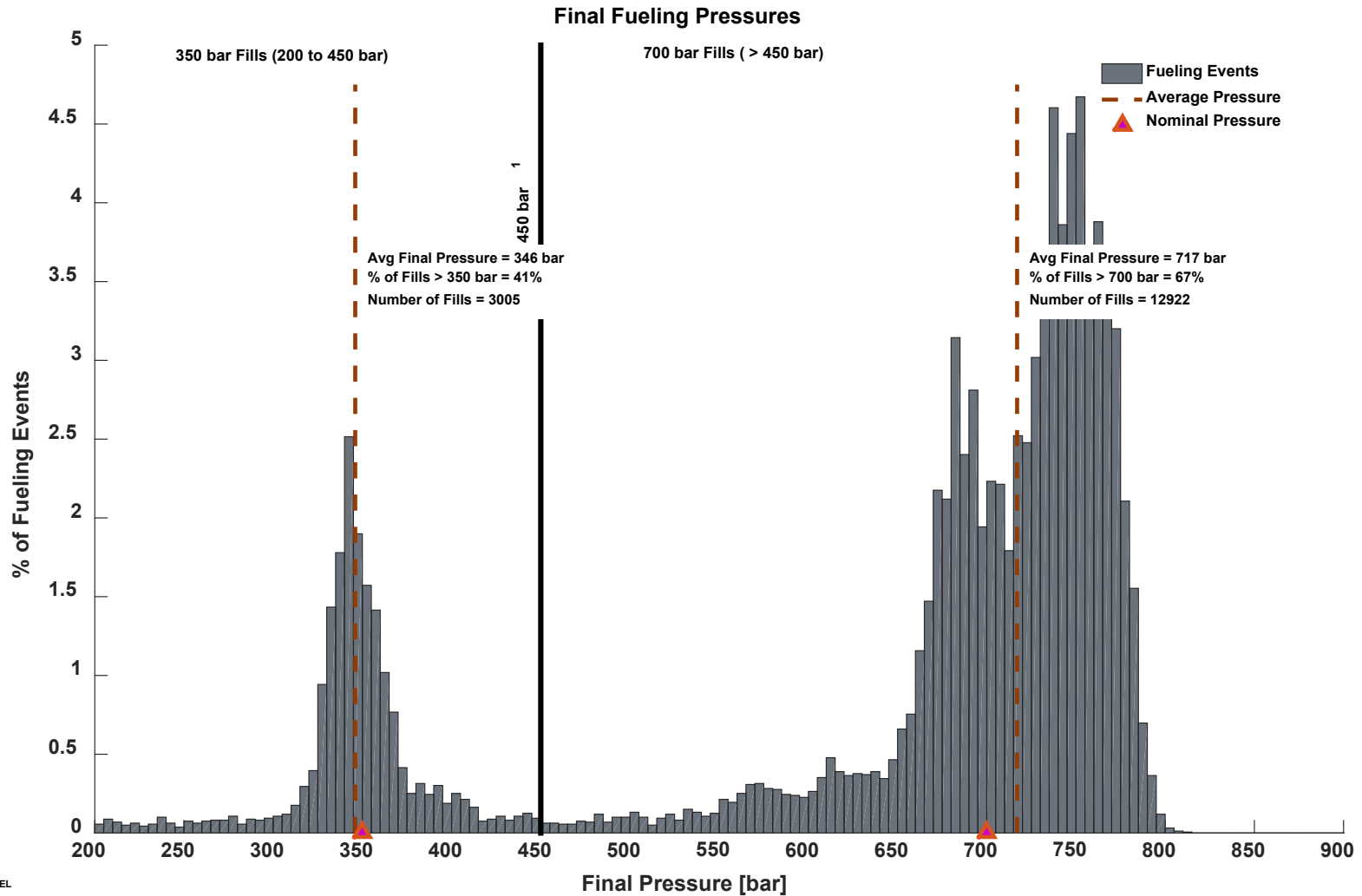
## Fuel Cell Stack Power Level Operation Time



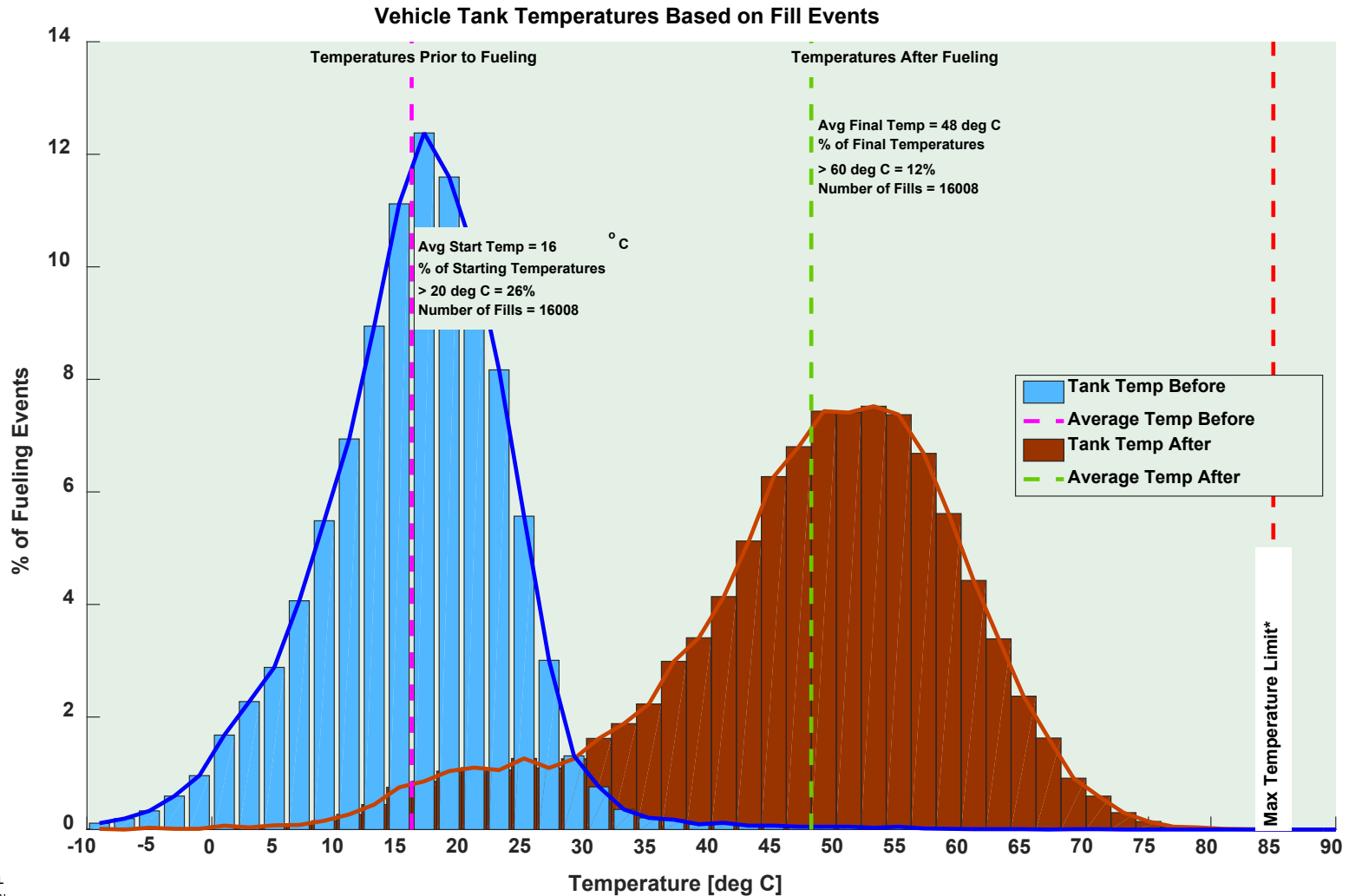


# Hydrogen Performance

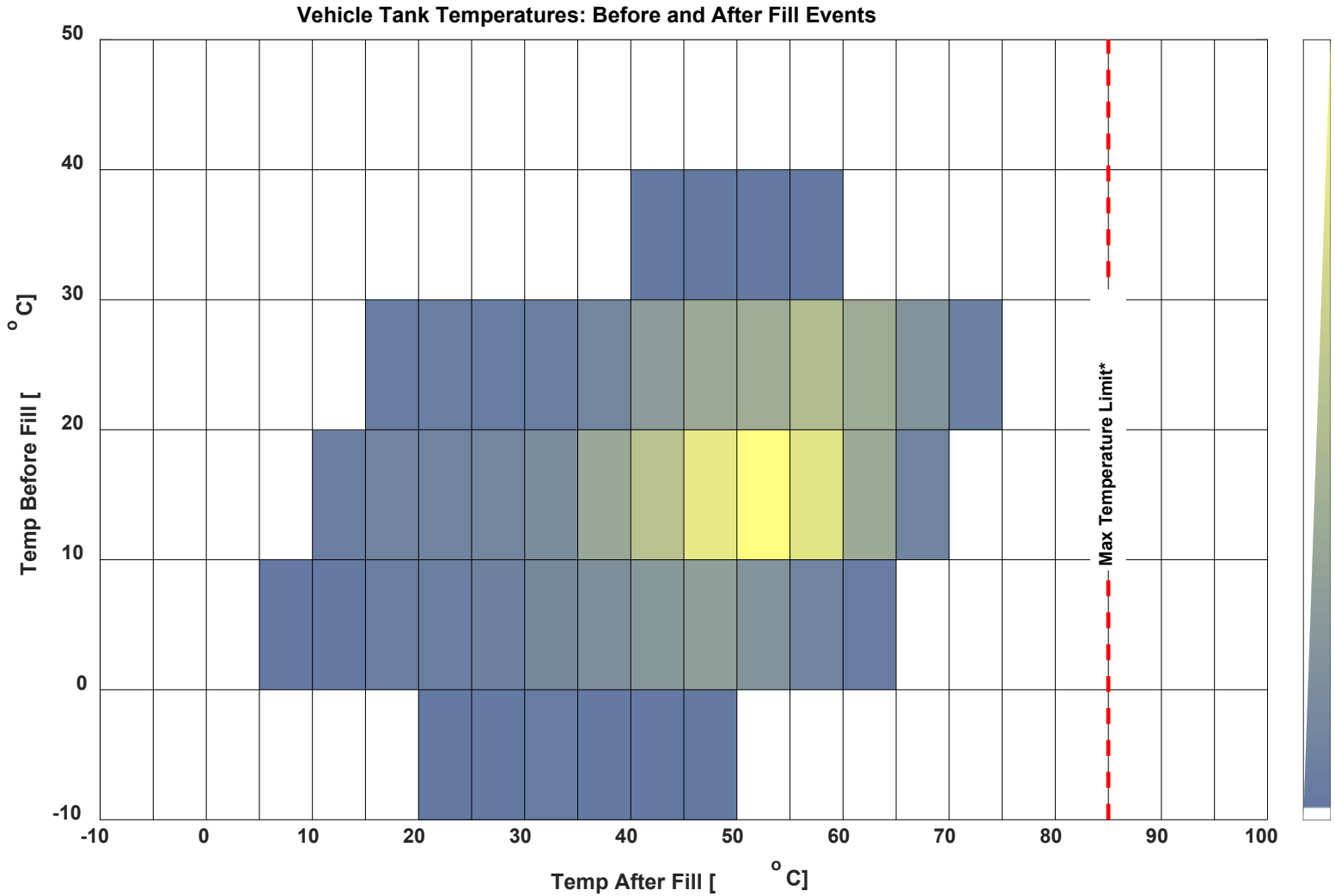
## Final Fueling Pressure—FCEV Onboard Sensors



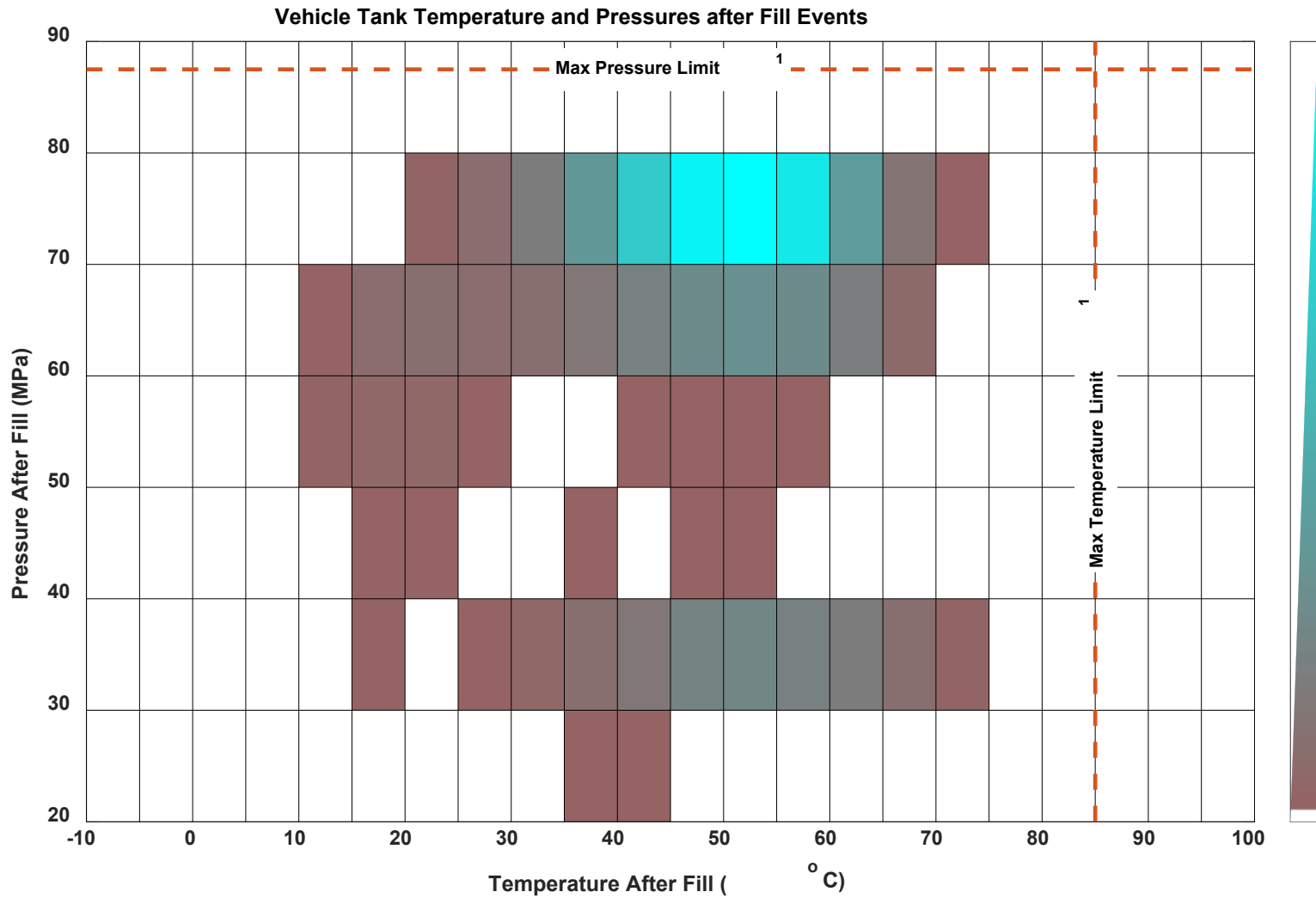
## Vehicle Tank Temperatures Before and After Fueling

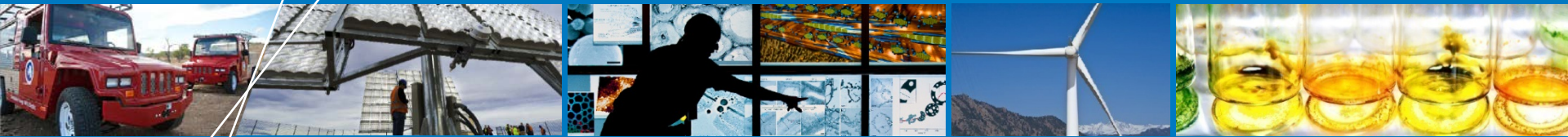


## Vehicle Tank Temperatures: Before and After a Fill



## Vehicle Tank Temperatures and Pressures After Fill Events

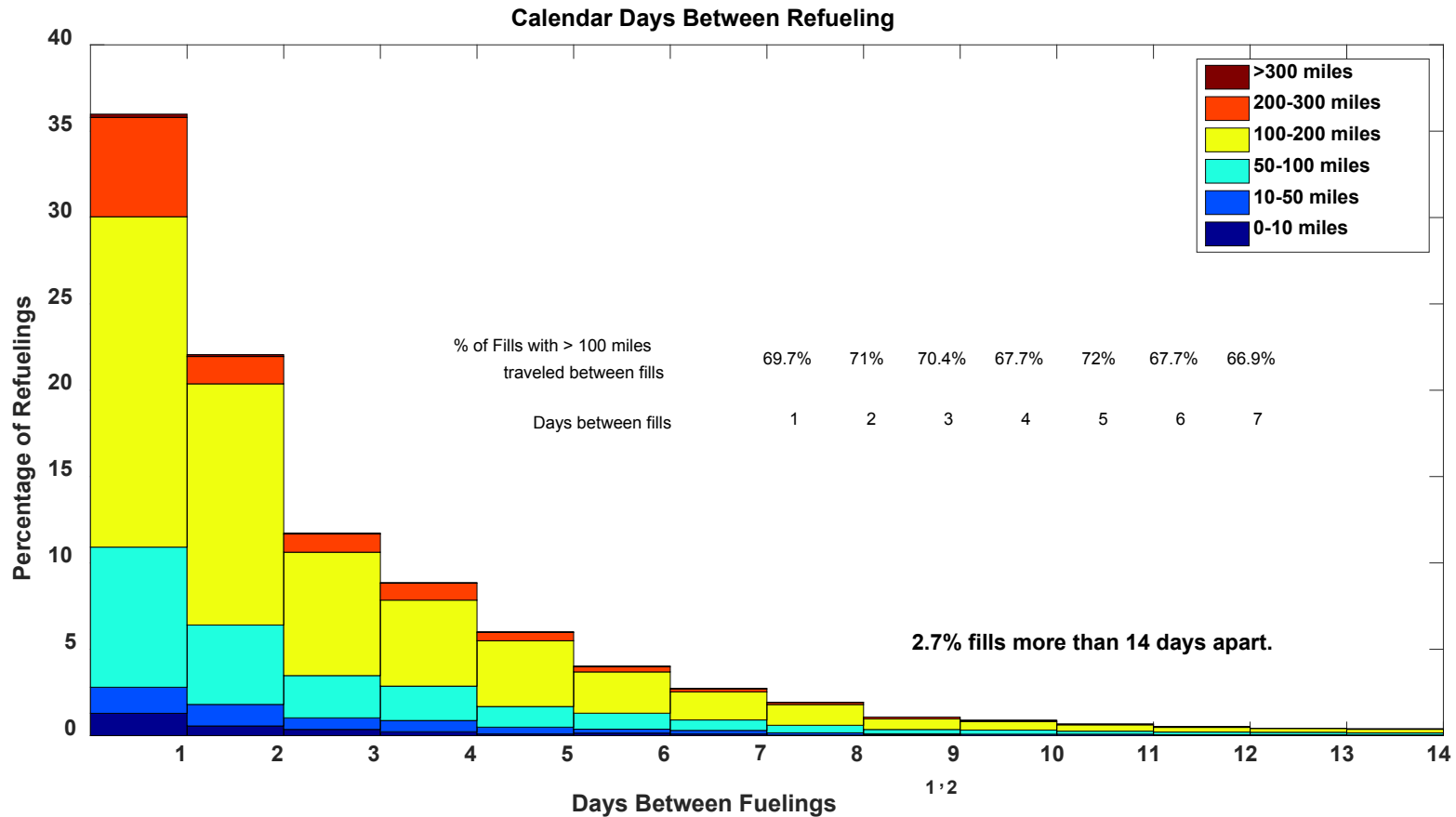


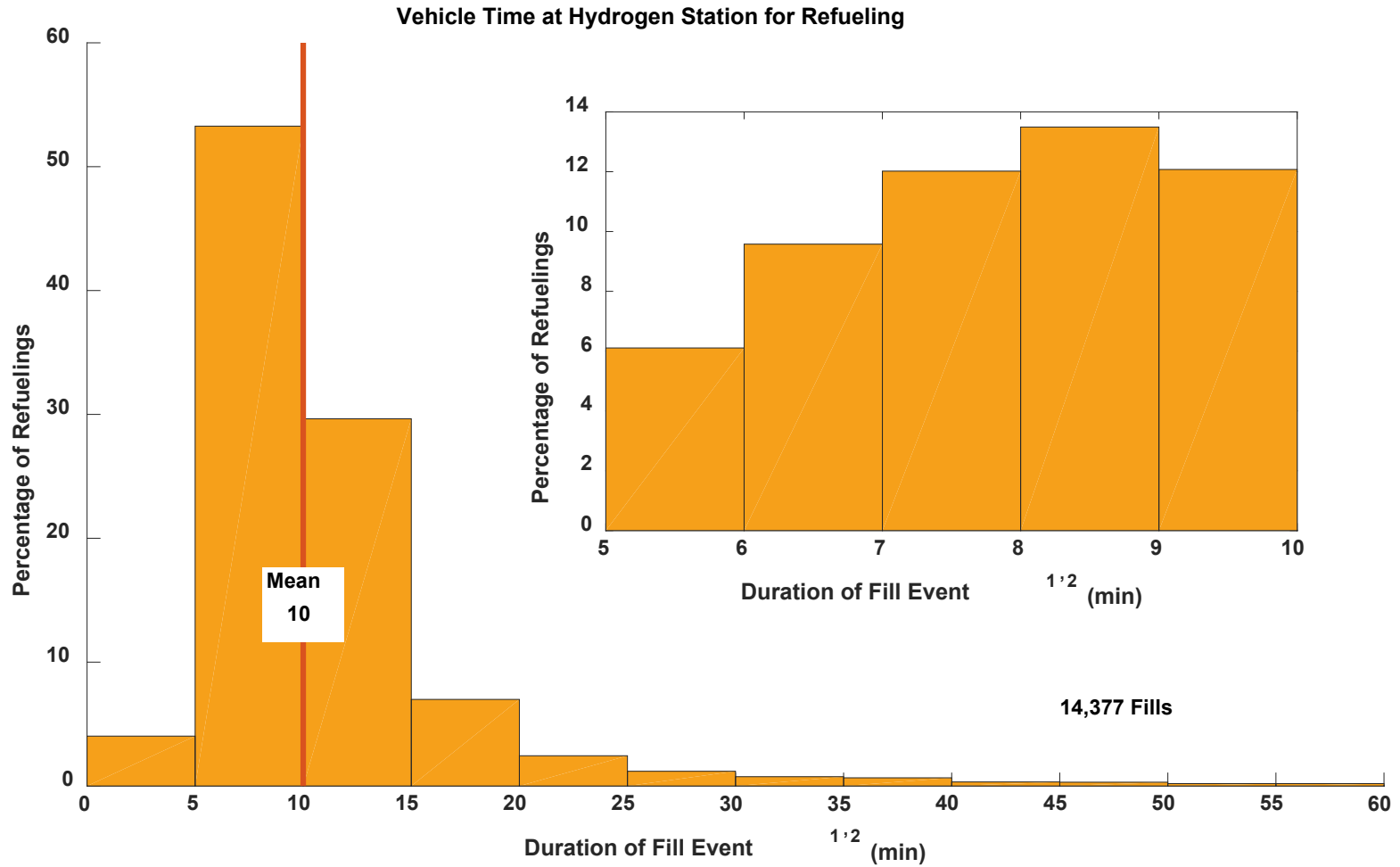


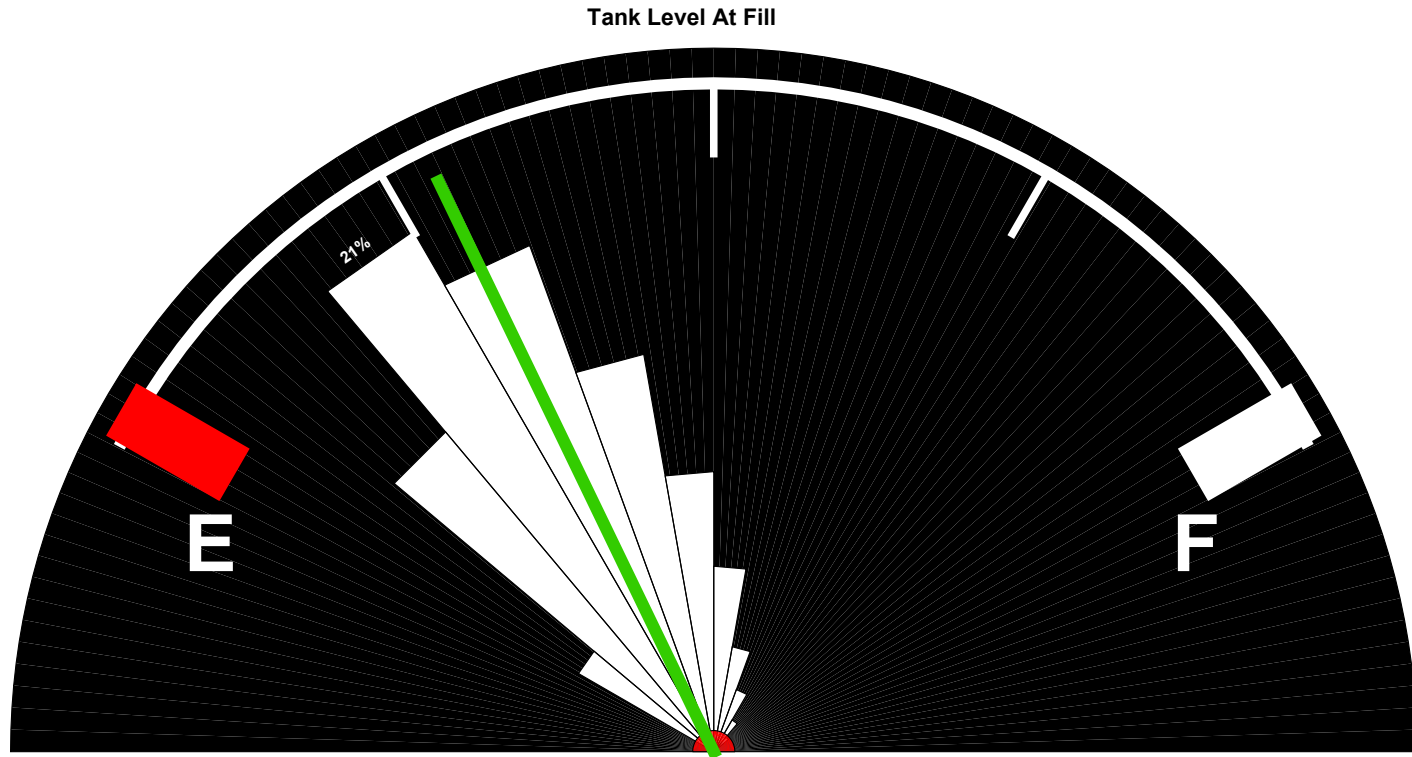
# Fueling Behavior



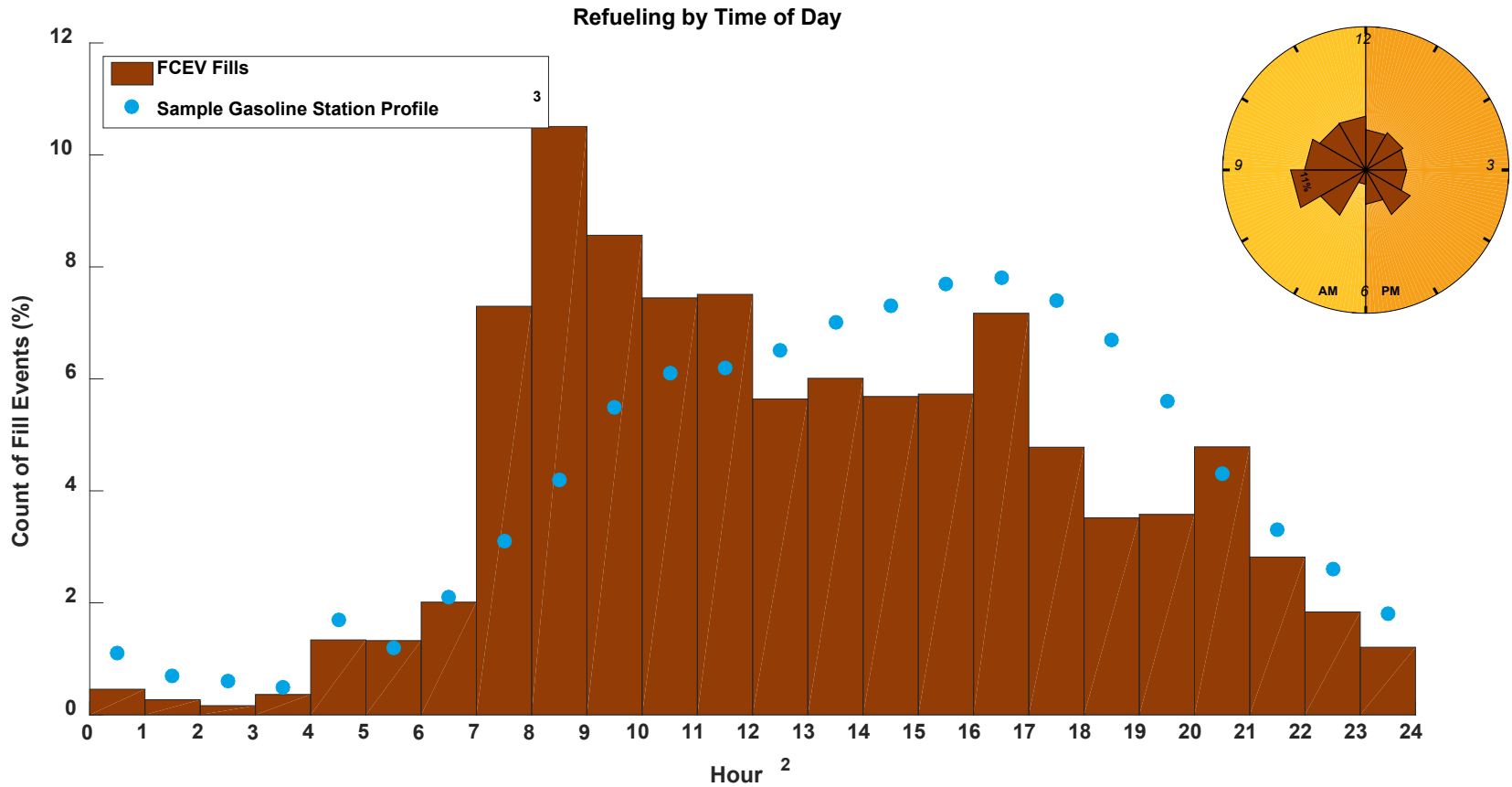
## Average Calendar Days Between Refueling per Vehicle





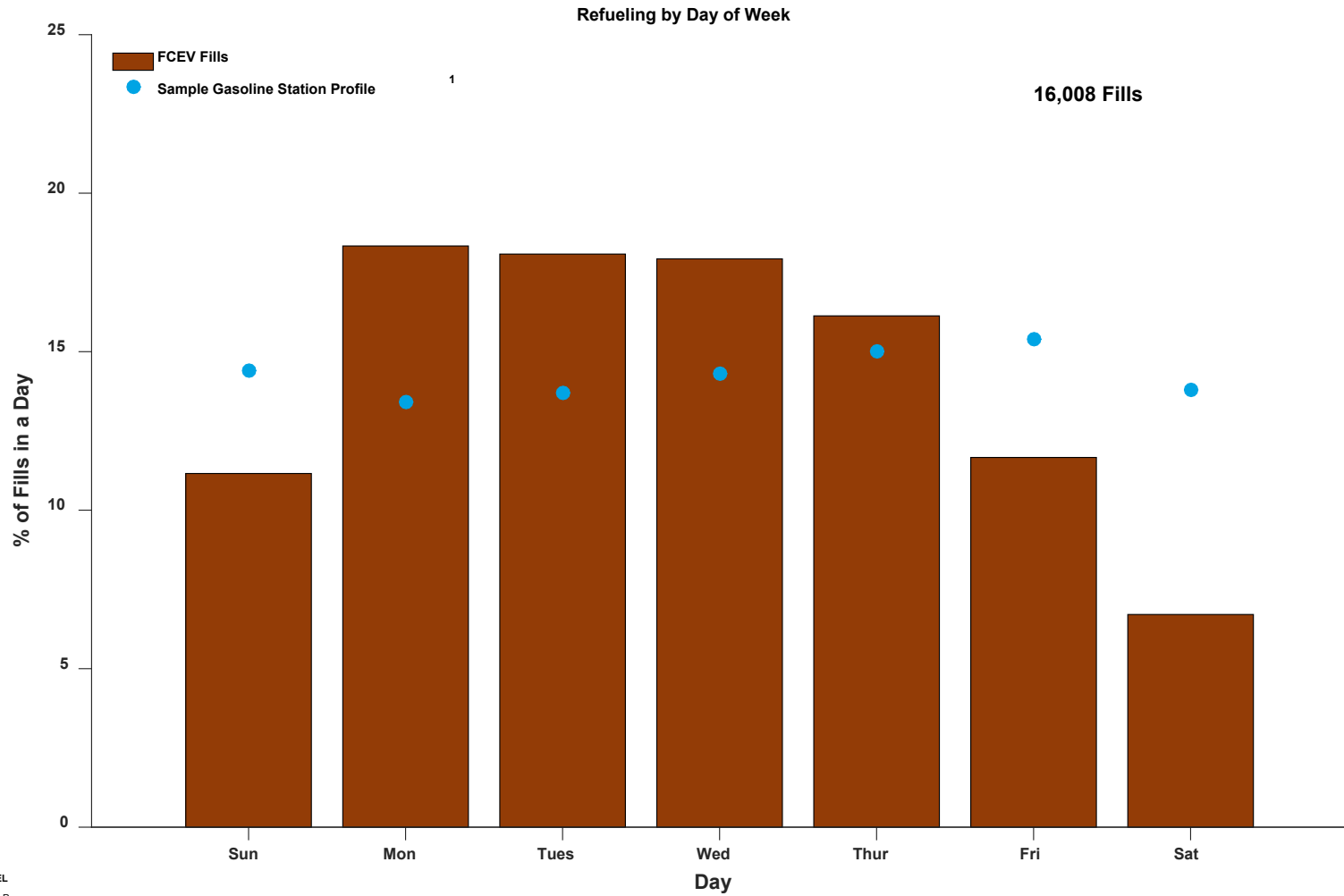


## Refueling by Time of Day



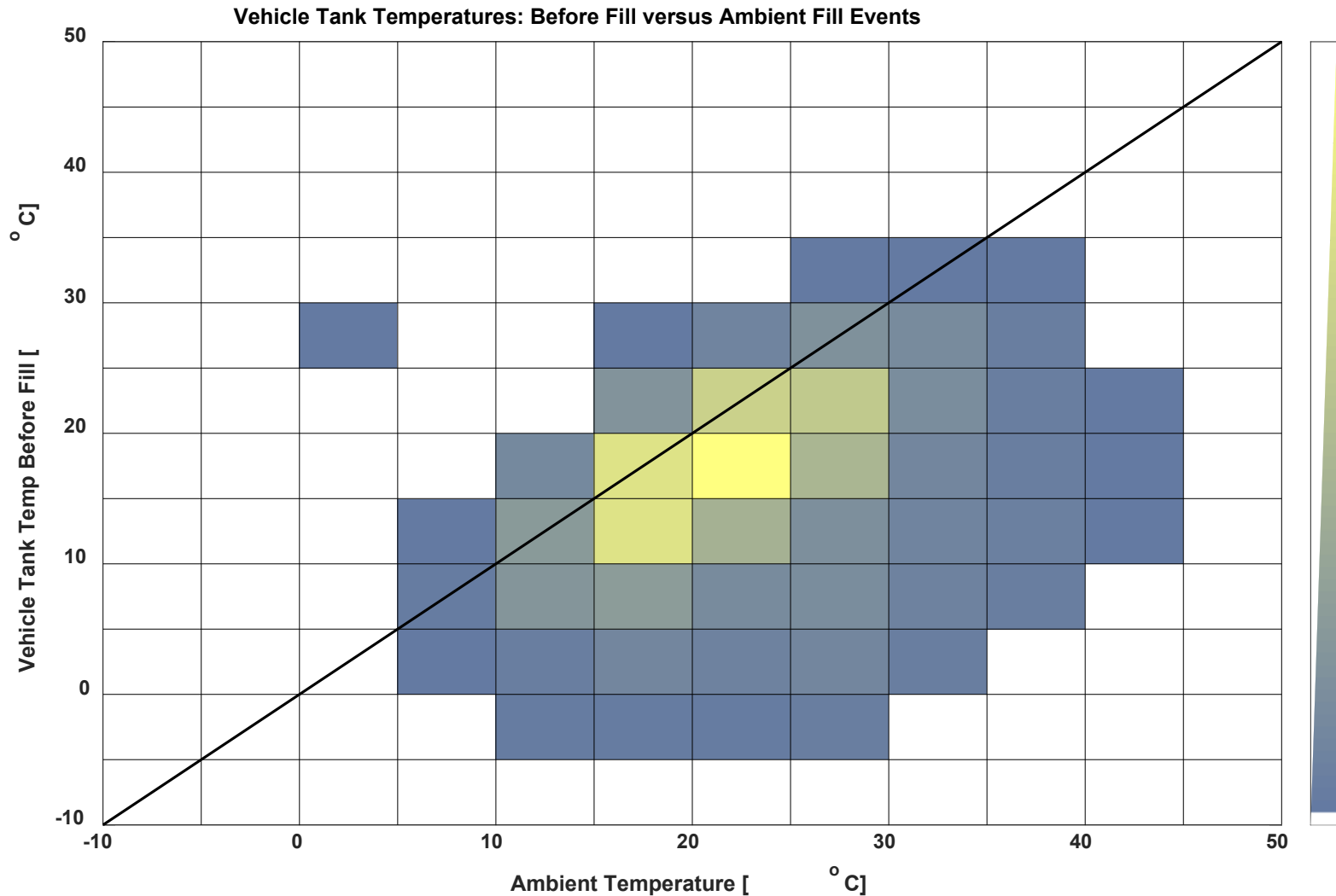
# CDP-FCEV-17

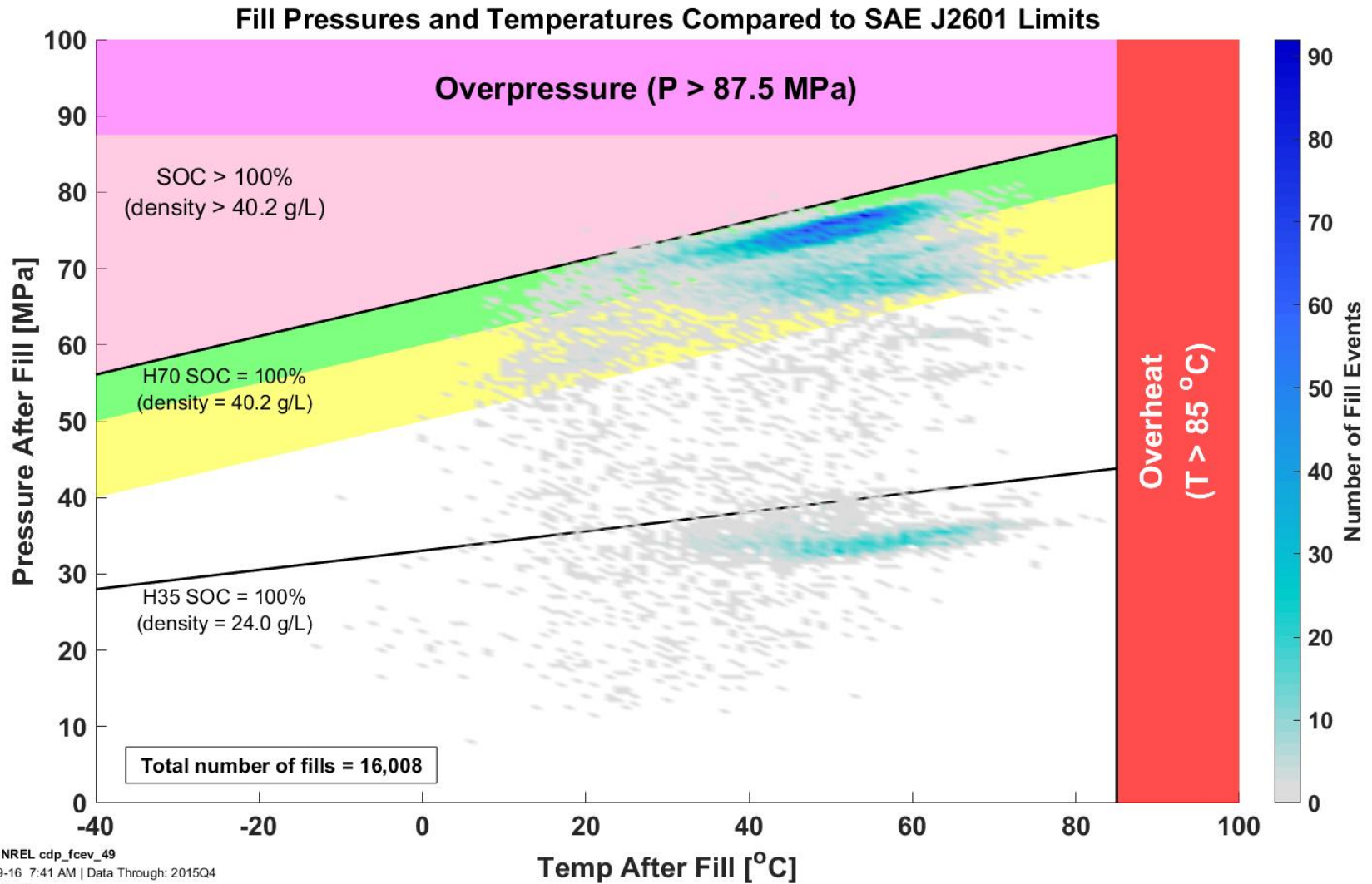
## Refueling by Day of Week

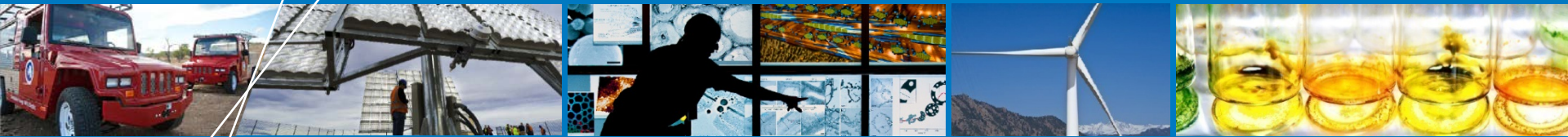


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## Vehicle Tank Temperatures versus Ambient Temperatures







# Specifications



# CDP-FCEV-11

## Vehicle Size Parameters

### Fuel Cell Electric Vehicle (FCEV) Size Metrics in Evaluation Project

Range of FCEV Model Years



Range of FCEV Curb Weight



kg

1500

1600

1700

1800

1900

2000

2100



Range of FCEV Coefficient of Drag



0.1

0.2

0.3

0.4

0.5



Range of FCEV Frontal Area



1

2

3

4

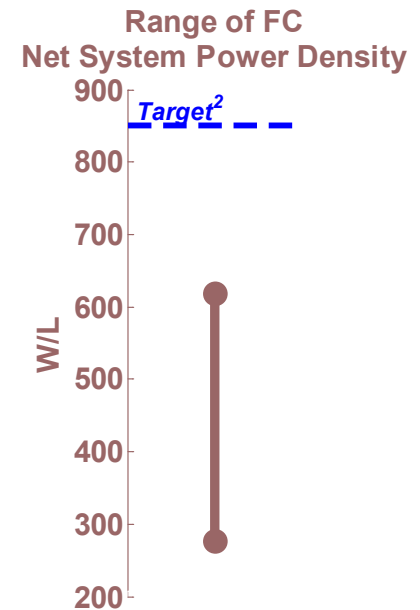
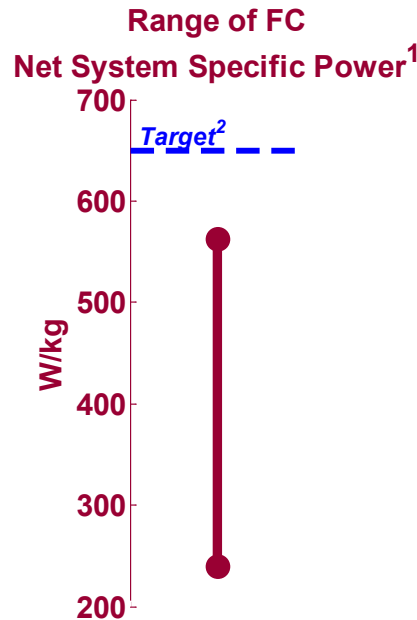
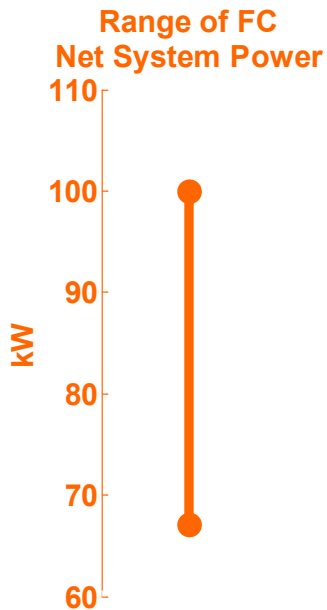


# CDP-FCEV-12

## Fuel Cell System Power Parameters

### Fuel Cell Electric Vehicle (FCEV) Power Metrics in Evaluation Project

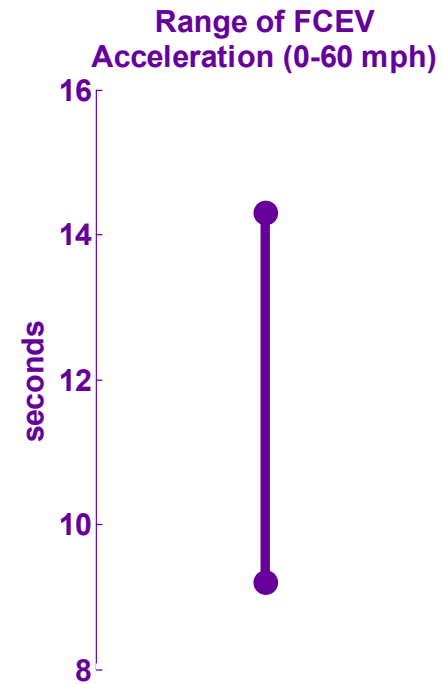
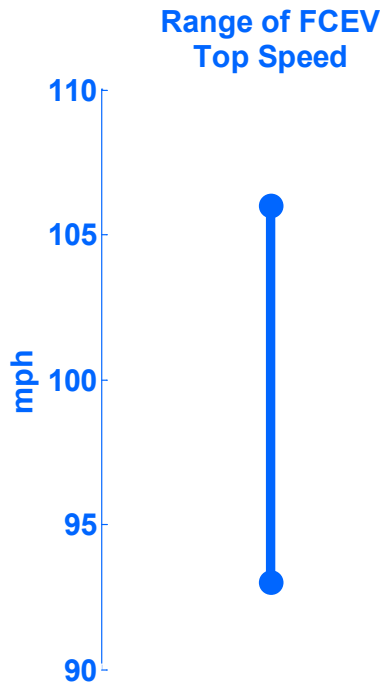
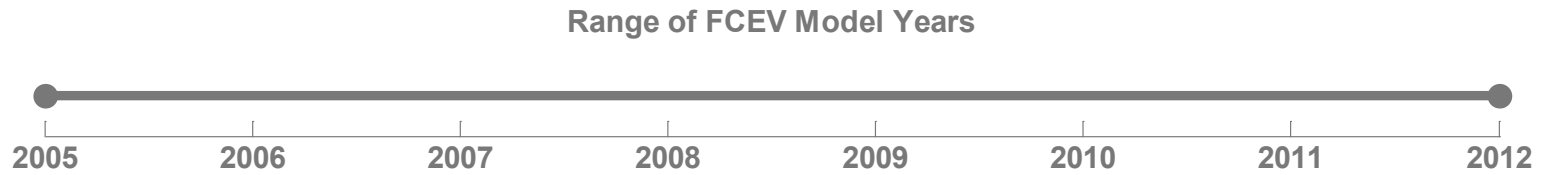
Range of FCEV Model Years



1) Fuel cell system includes fuel cell stack and balance of plant. Hydrogen storage, battery storage, power electronics, and electric drive are not included.  
 2) 2020 DOE technical target Table 3.4.3  
 ([www.energy.gov/sites/prod/files/2014/12/f19/fcto\\_myrrdd\\_fuel\\_cells.pdf](http://www.energy.gov/sites/prod/files/2014/12/f19/fcto_myrrdd_fuel_cells.pdf))

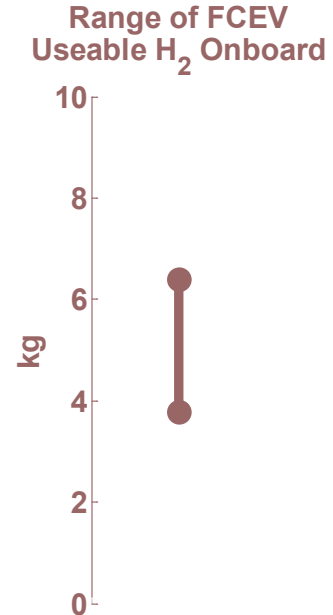
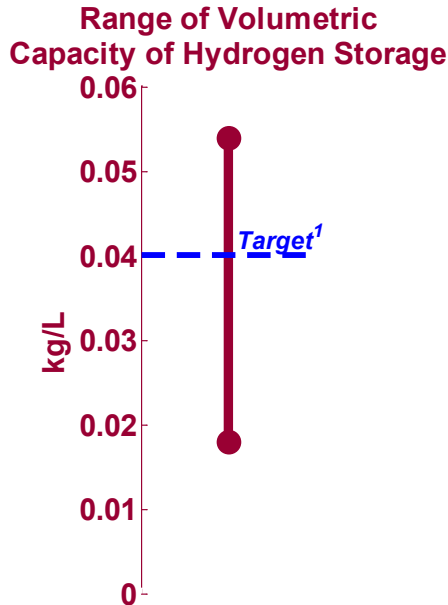
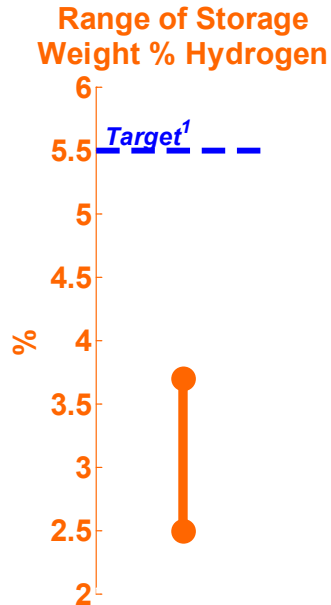
## Vehicle Speed and Acceleration Parameters

### Fuel Cell Electric Vehicle (FCEV) Speed & Acceleration Metrics in Evaluation Project

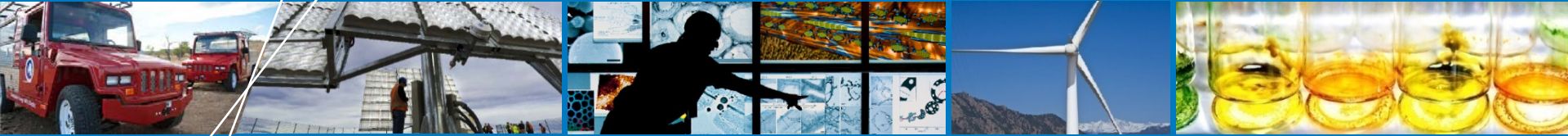


### Fuel Cell Electric Vehicle (FCEV) Power Metrics in Evaluation Project

Range of FCEV Model Years



1) 2020 DOE technical target Table 3.3.3  
([www.energy.gov/sites/prod/files/2015/05/f22/fcto\\_m\\_yrdd\\_storage.pdf](http://www.energy.gov/sites/prod/files/2015/05/f22/fcto_m_yrdd_storage.pdf))



# Other

# CDP-FCEV-10

## Data File Count and Size

