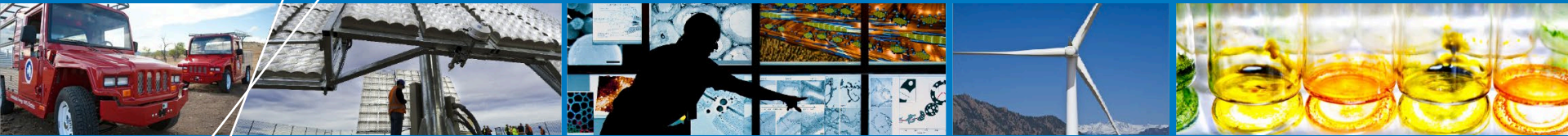


Fuel Cell Electric Vehicle (FCEV) Performance Composite Data Products

Fall 2015

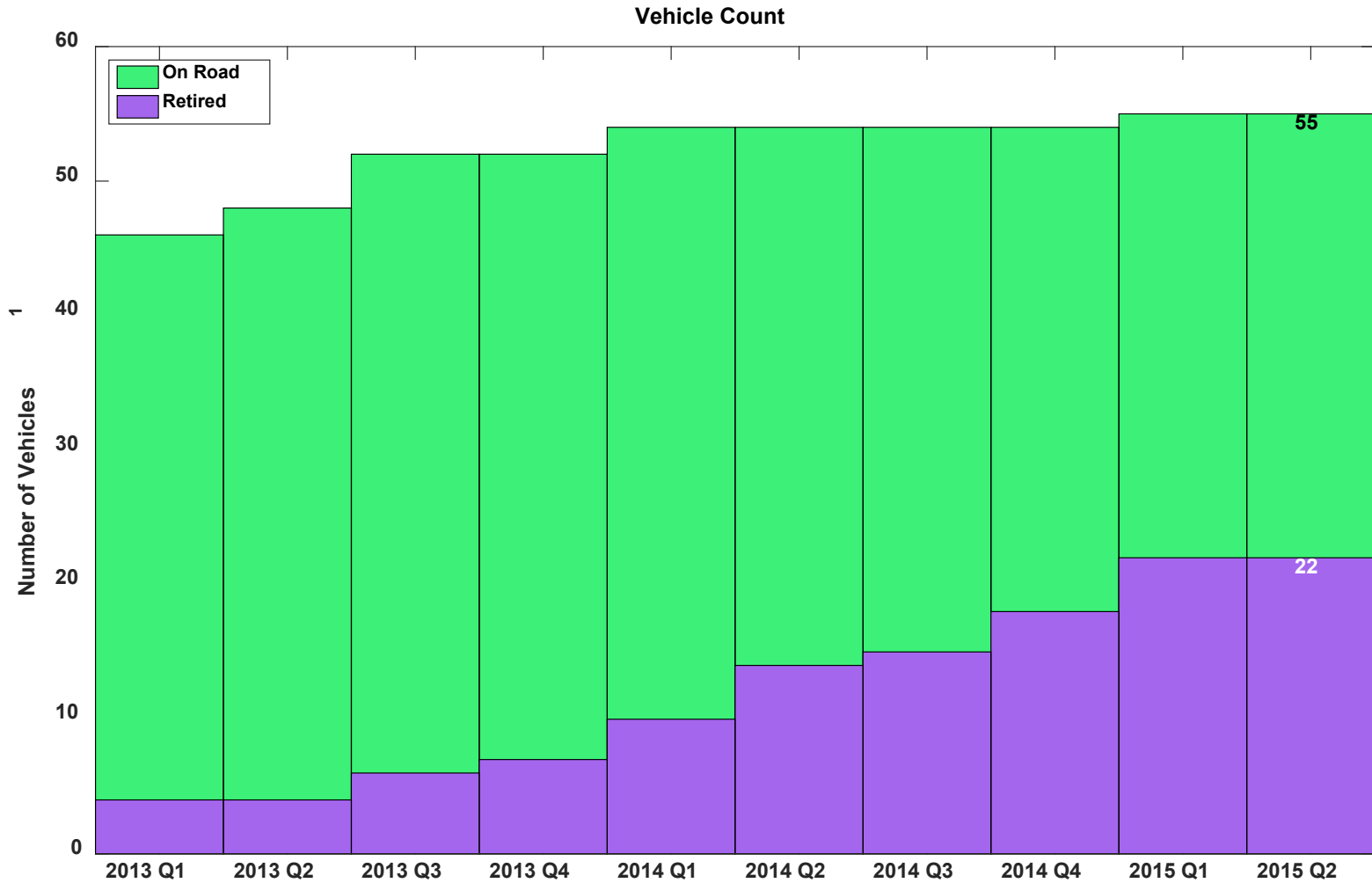


Jennifer Kurtz, Sam Sprik,
Chris Ainscough, Genevieve
Saur, and Mike Peters

November 2015

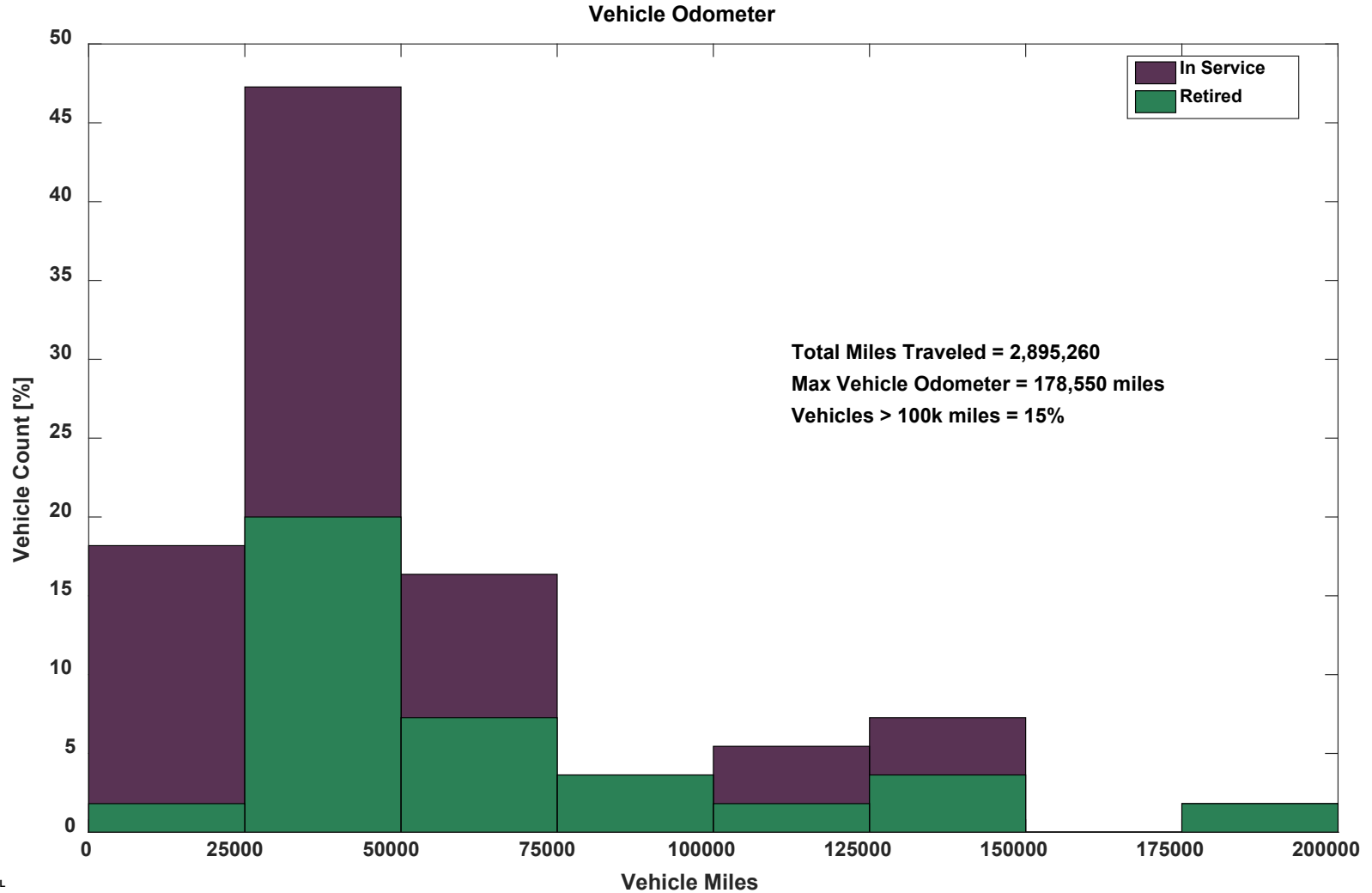
CDP-FCEV-01

Vehicle Count

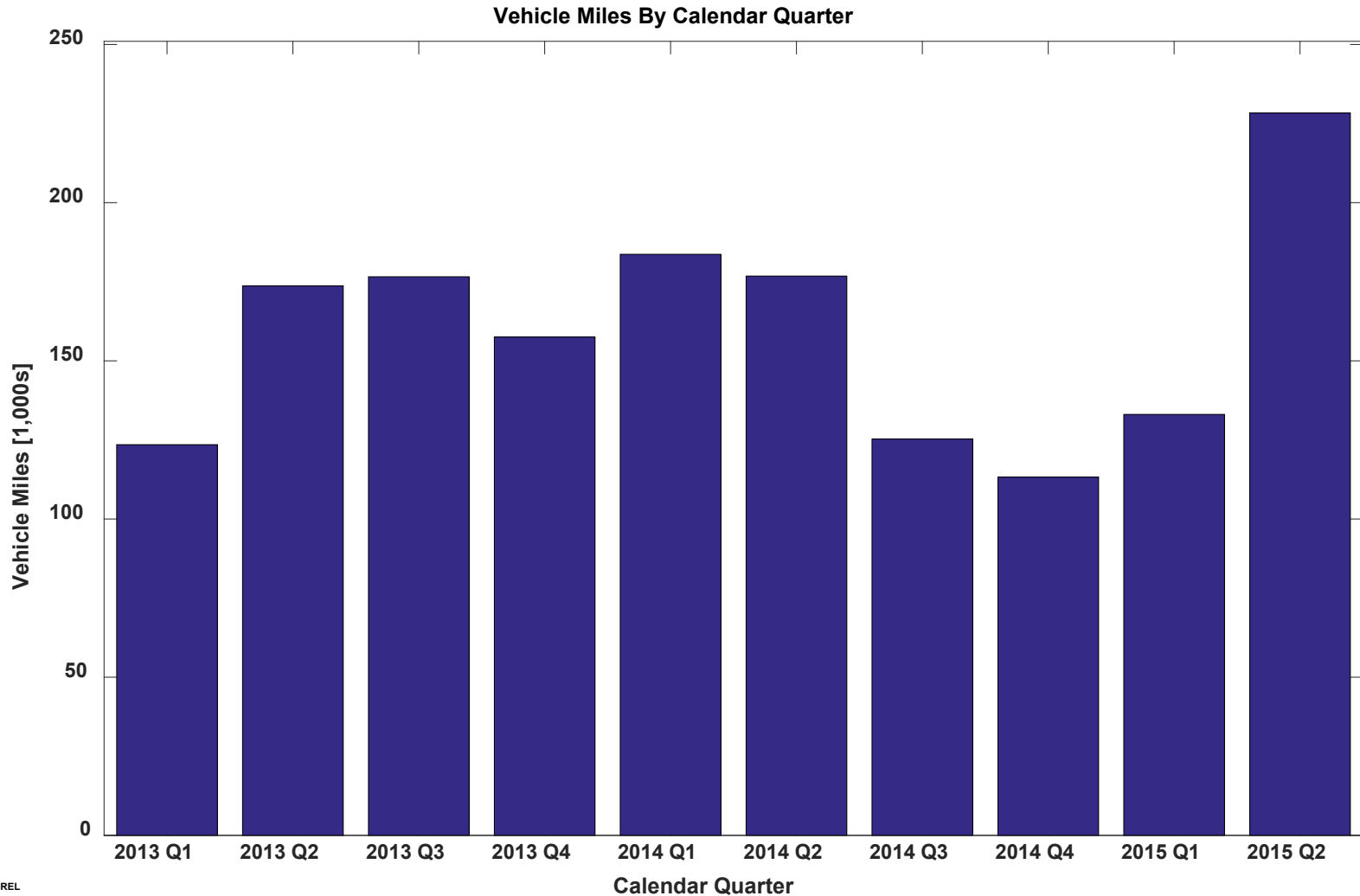


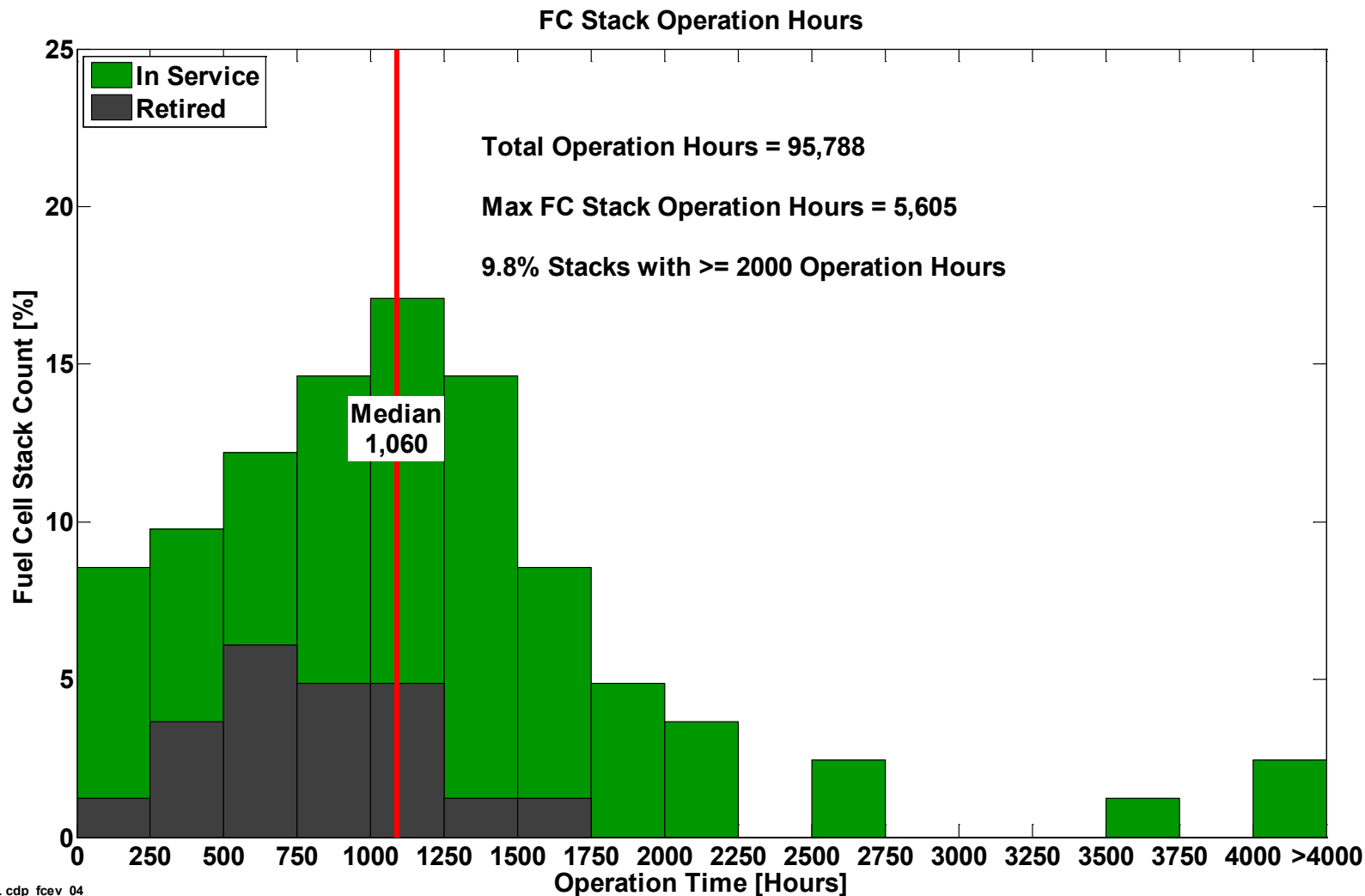
CDP-FCEV-02

Vehicle Miles



FCEV Miles Driven by Calendar Quarter



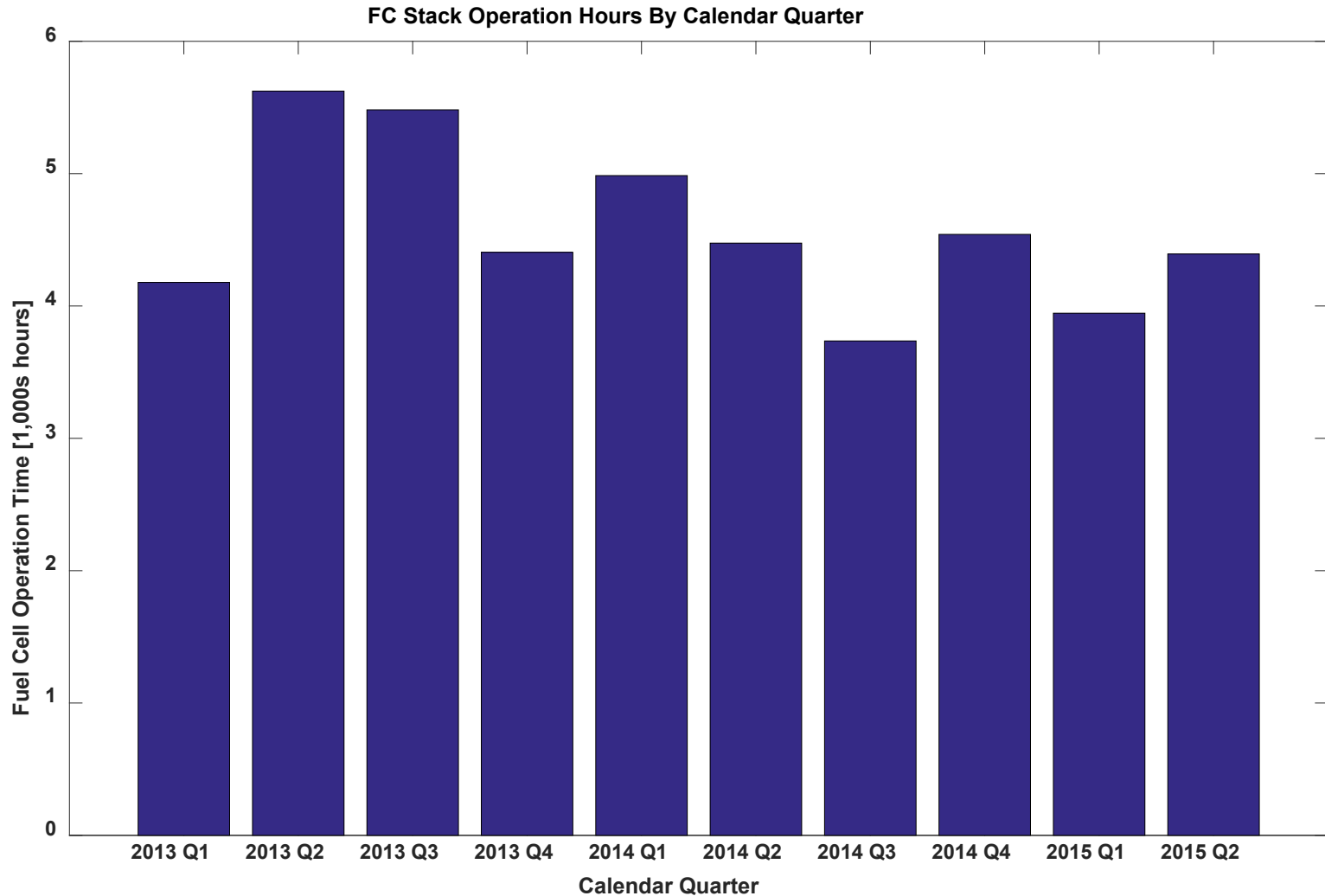


NREL cdp_fcev_04

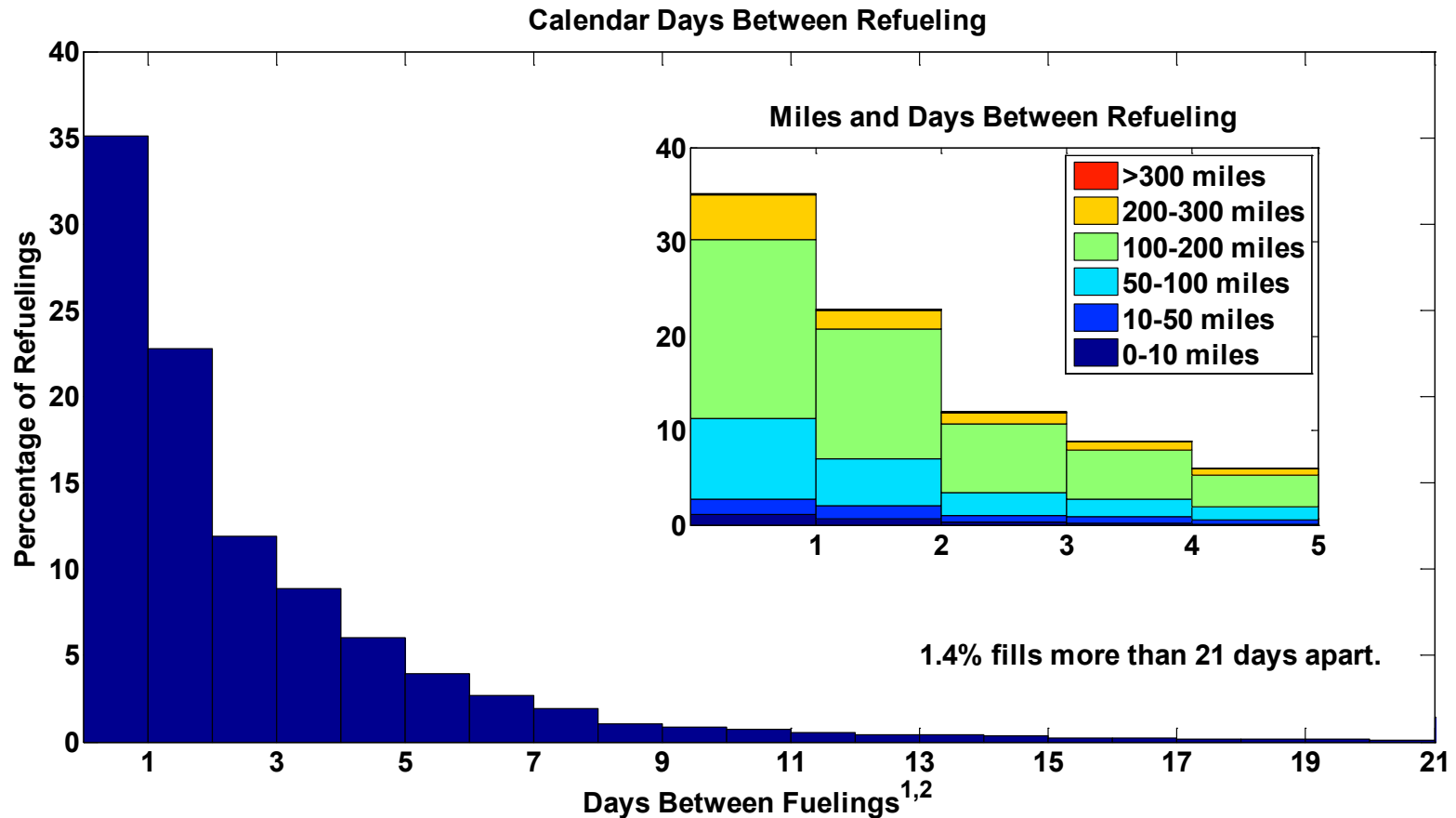
Created: Oct-31-15 11:25 AM | Data Through: 2015Q2

Included Vehicles: Partial

Fuel Cell Stack Operation Hours by Calendar Quarter

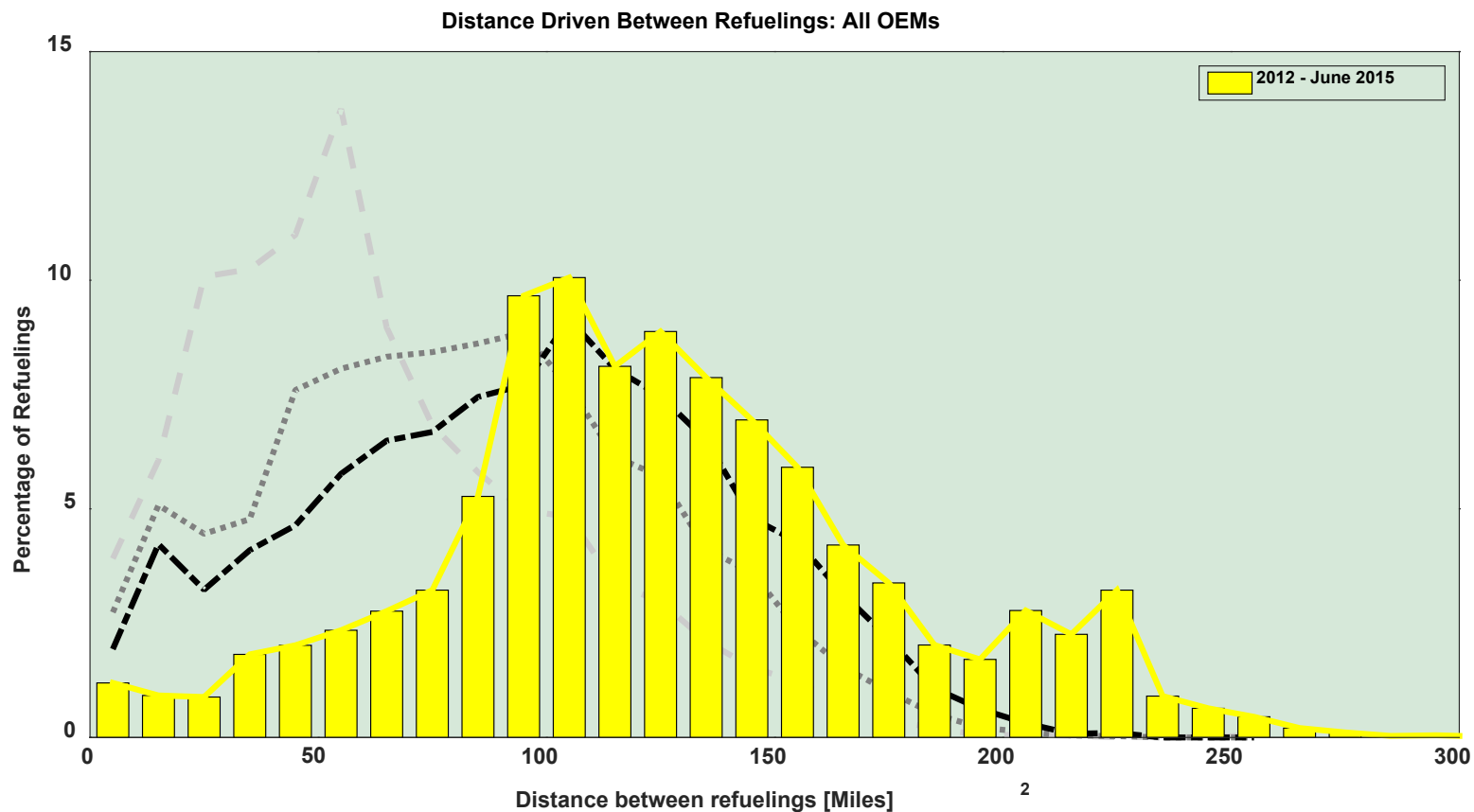


Average Calendar Days Between Refueling per Vehicle



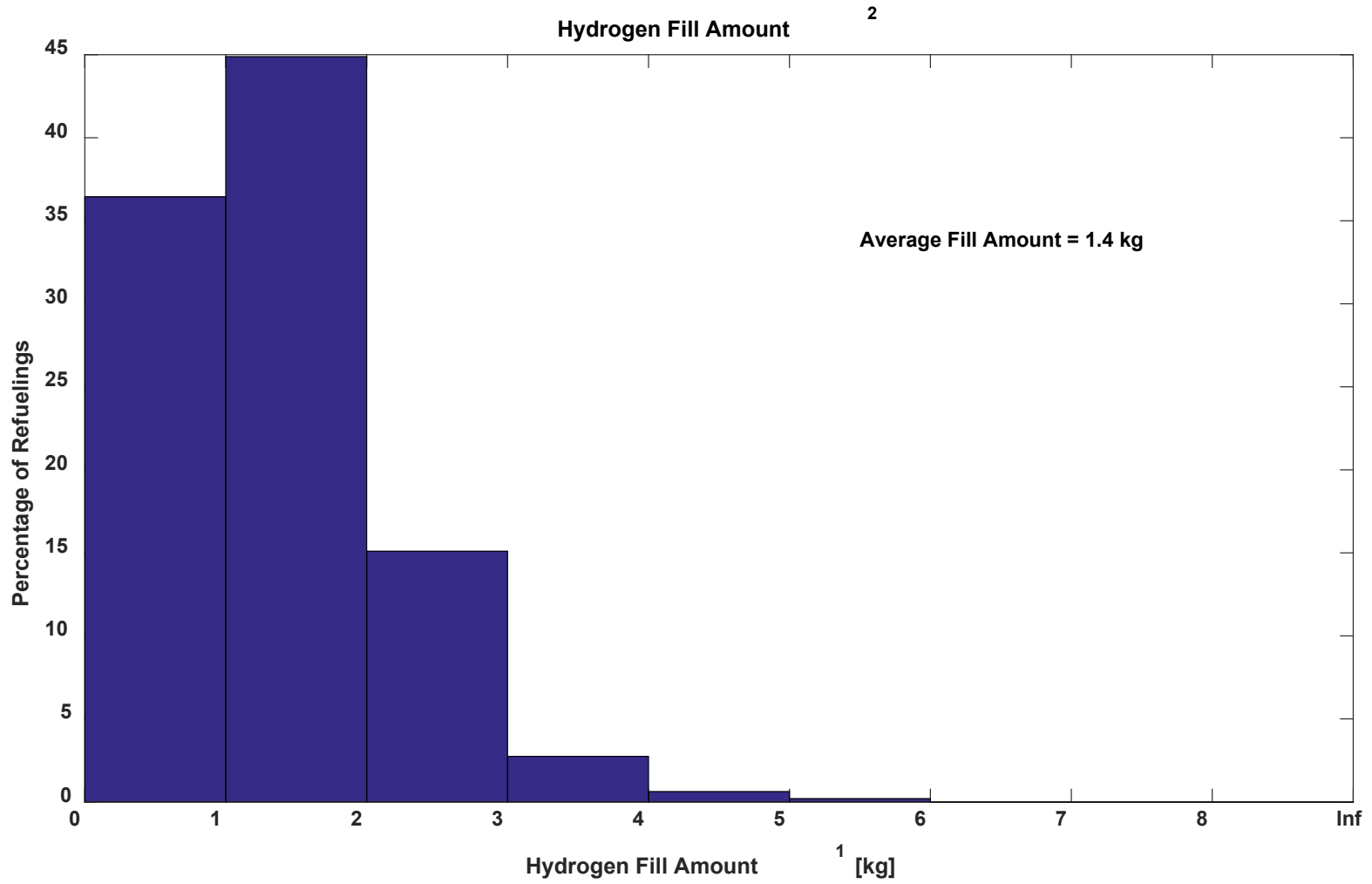
1. Data includes fills from 2012 - 2014. Fills < 1 hour apart are excluded
2. Some vehicles included in the data have scheduled driving aimed at accumulating high miles and operation time over a variety of conditions. These vehicles typically fill at least once a day. These vehicles are operated on public roads and driving is typical for the region.

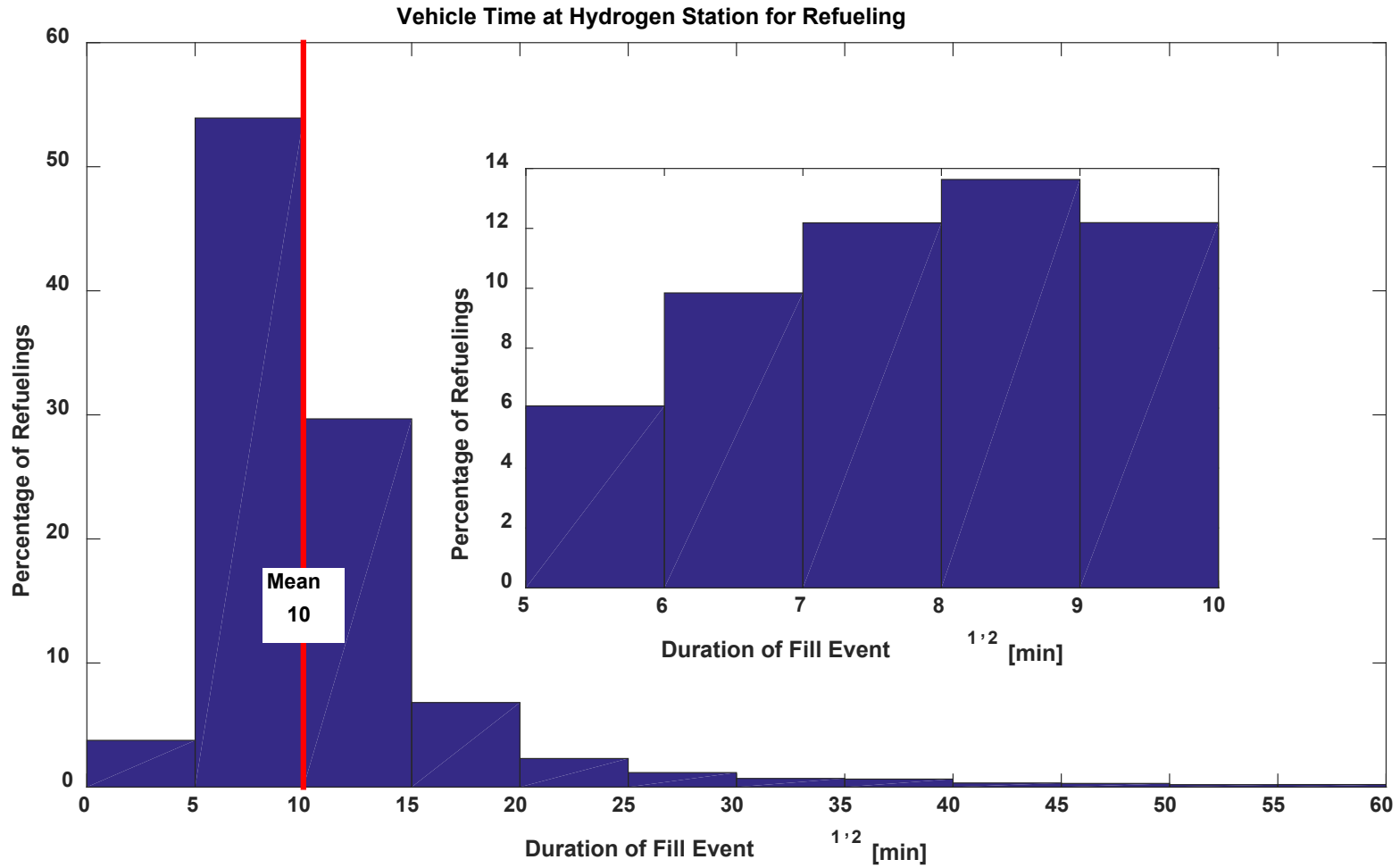
Distance Driven Between Refueling



CDP-FCEV-08

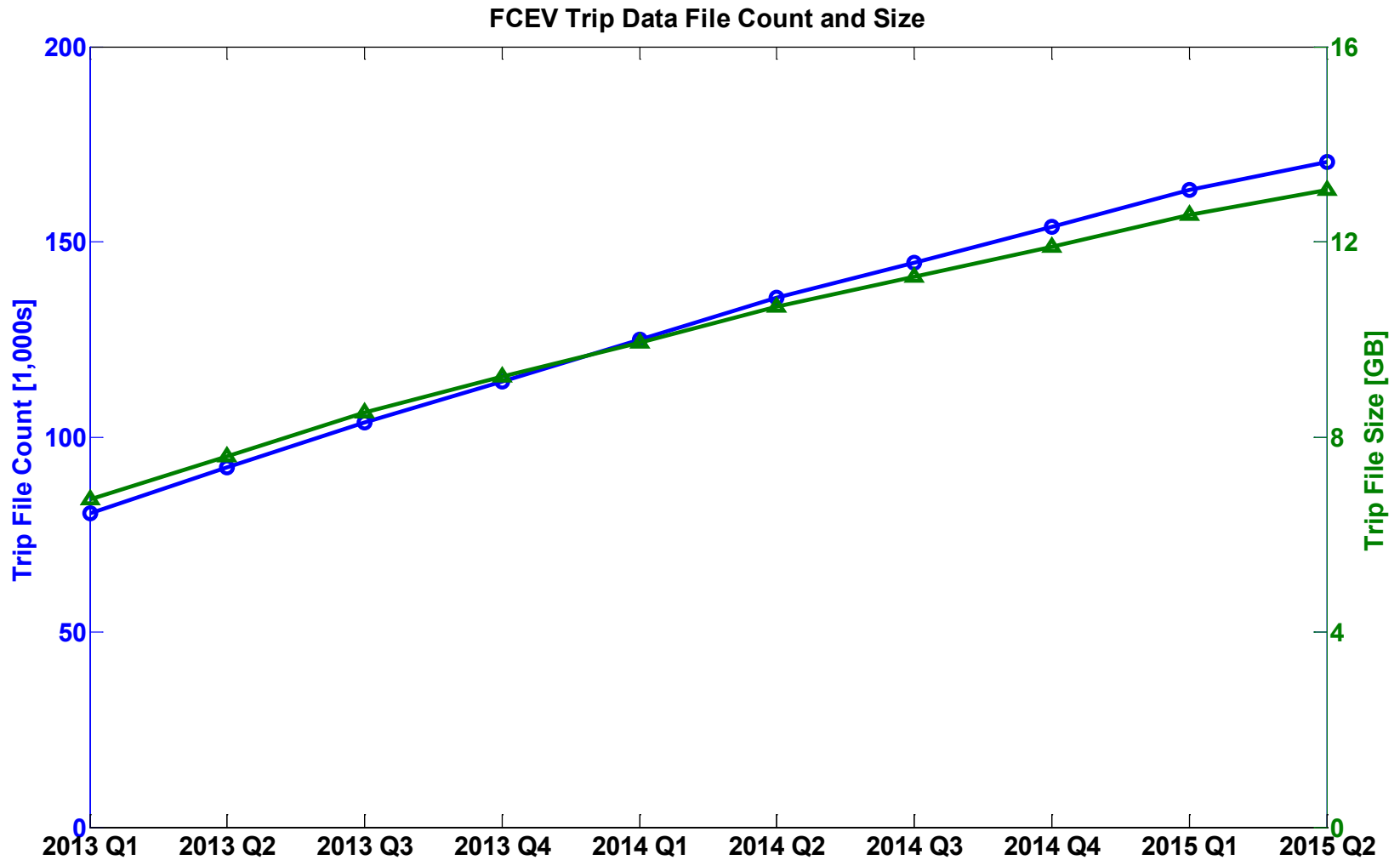
FCEV Fill Amounts





CDP-FCEV-10

Data File Count and Size



NREL cdp_fcev_10

Created: Oct-30-15 12:00 PM | Data Through: 2015Q2

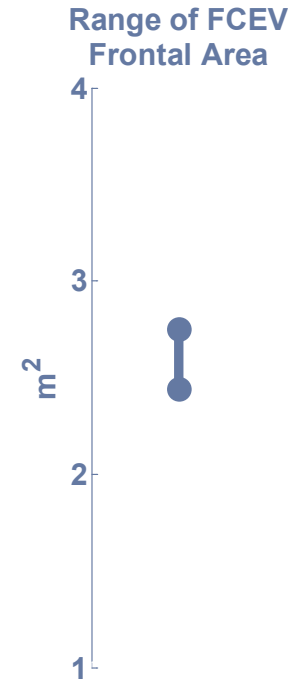
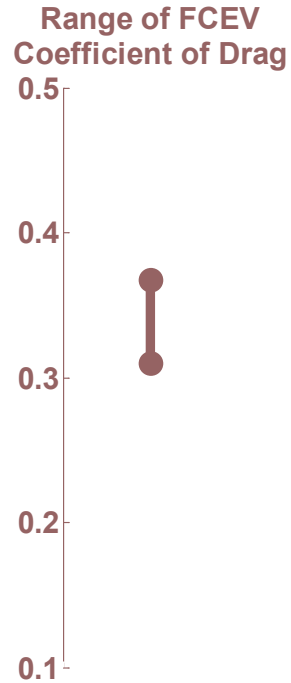
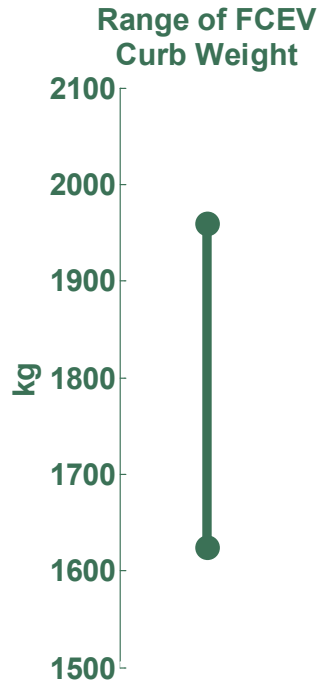
Included Vehicles: All

CDP-FCEV-11

Vehicle Size Parameters

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

Range of FCEV Model Years

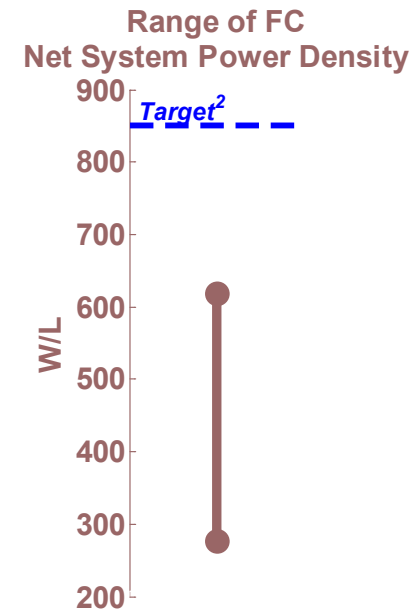
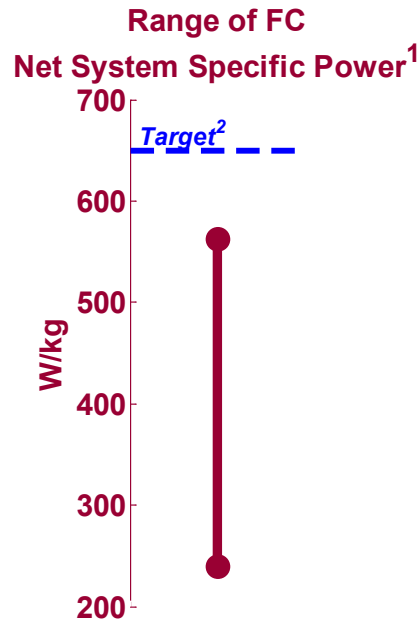
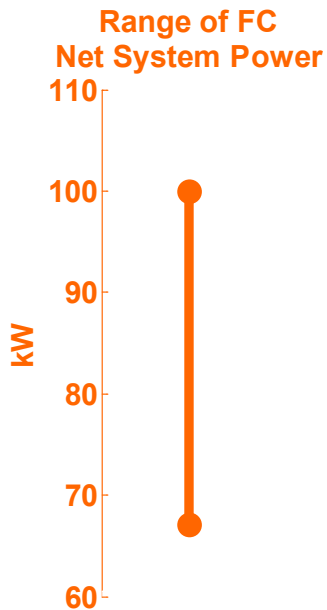


CDP-FCEV-12

Fuel Cell System Power Parameters

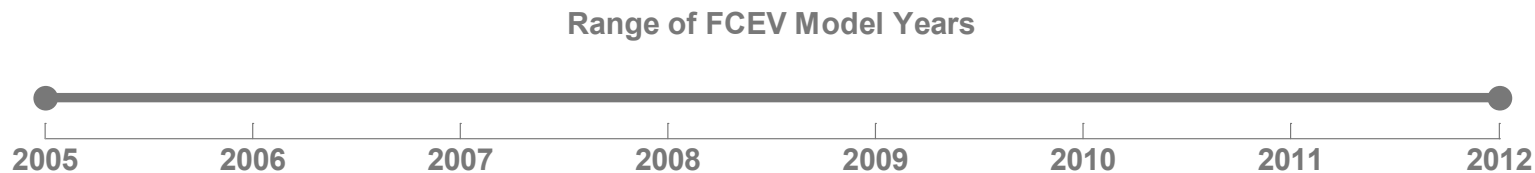
Fuel Cell Electric Vehicle (FCEV) Power Metrics in Evaluation Project

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)

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



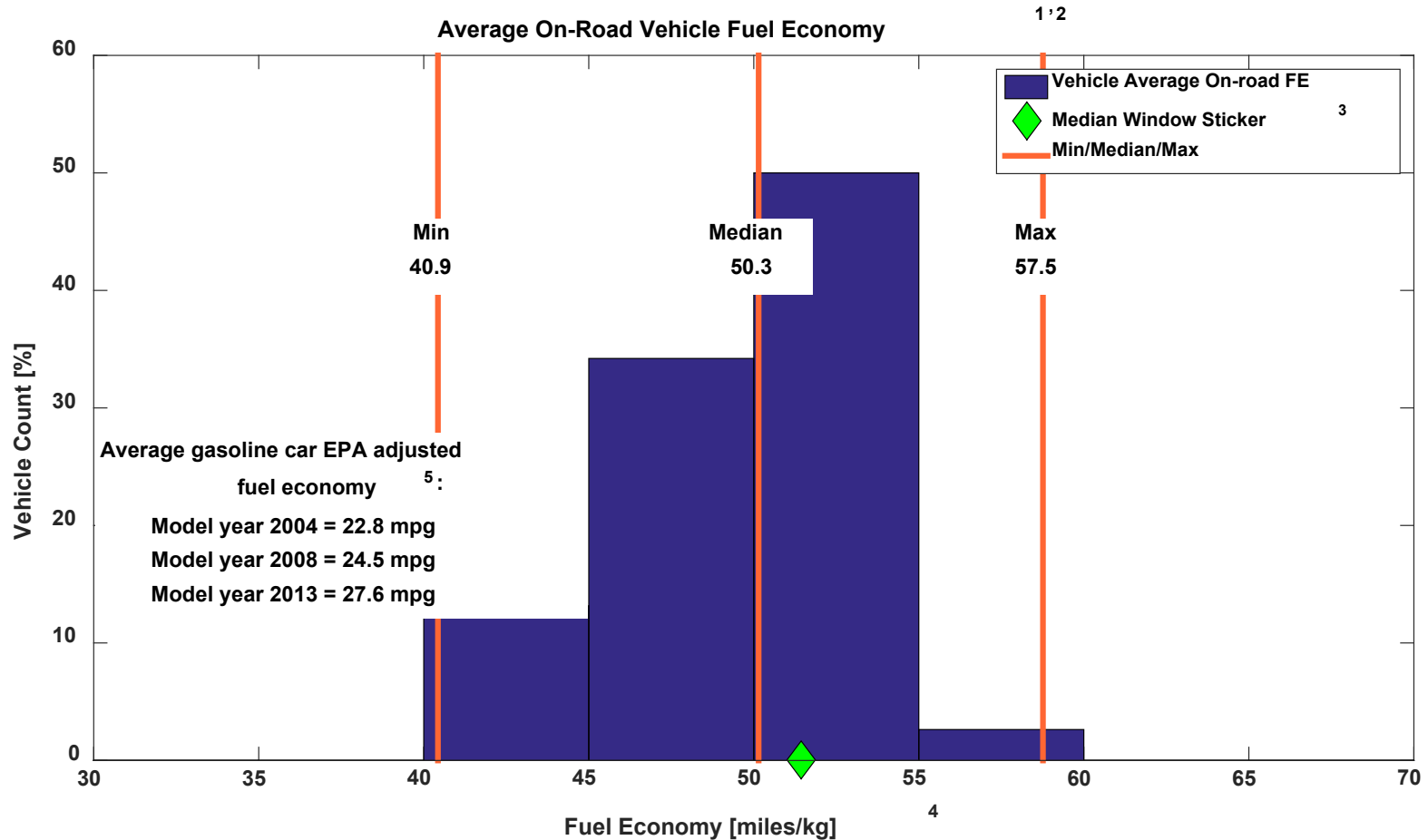
Range of FCEV Top Speed



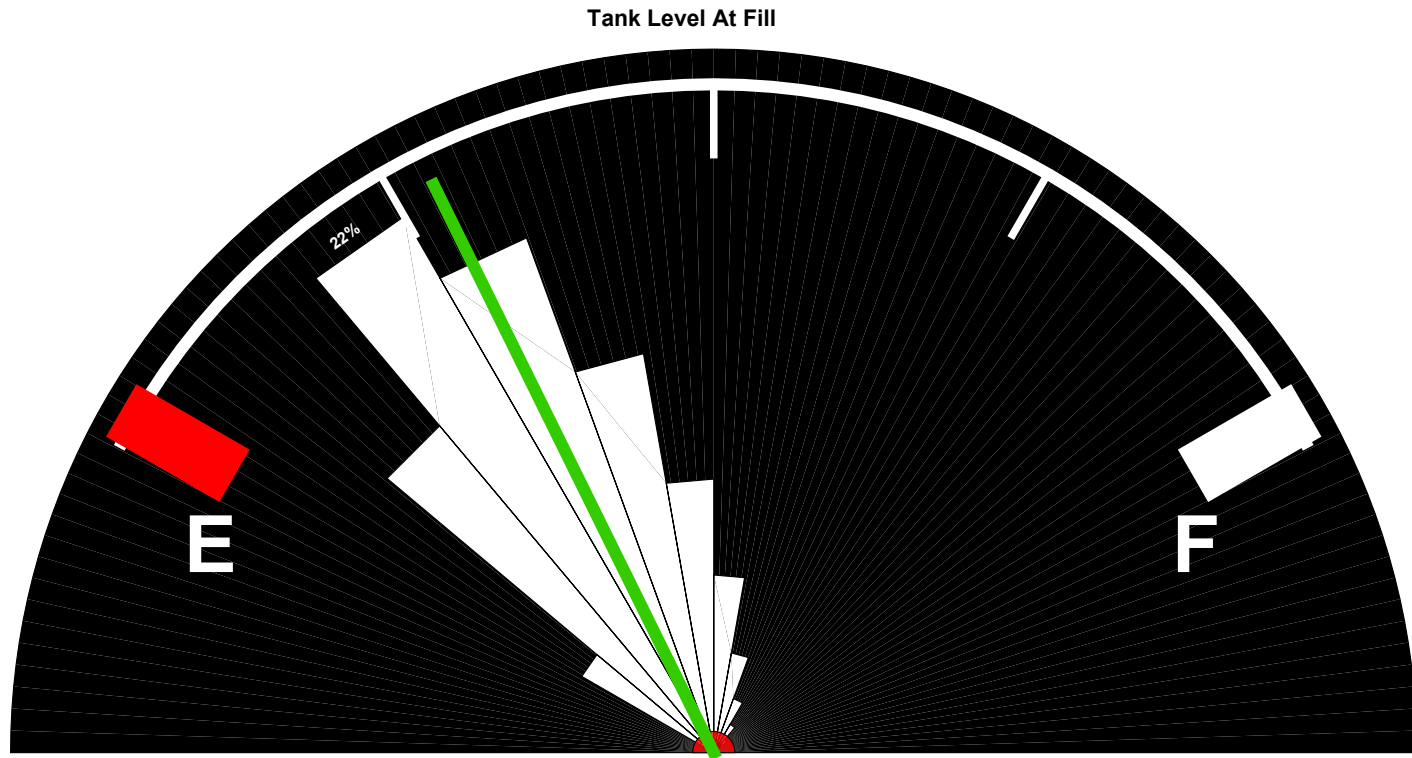
Range of FCEV Acceleration (0-60 mph)



Average Vehicle Fuel Economy

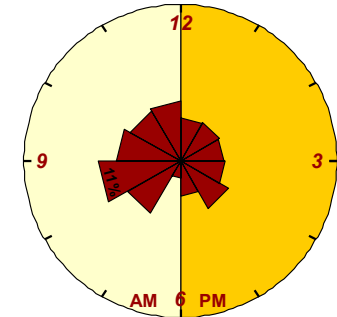
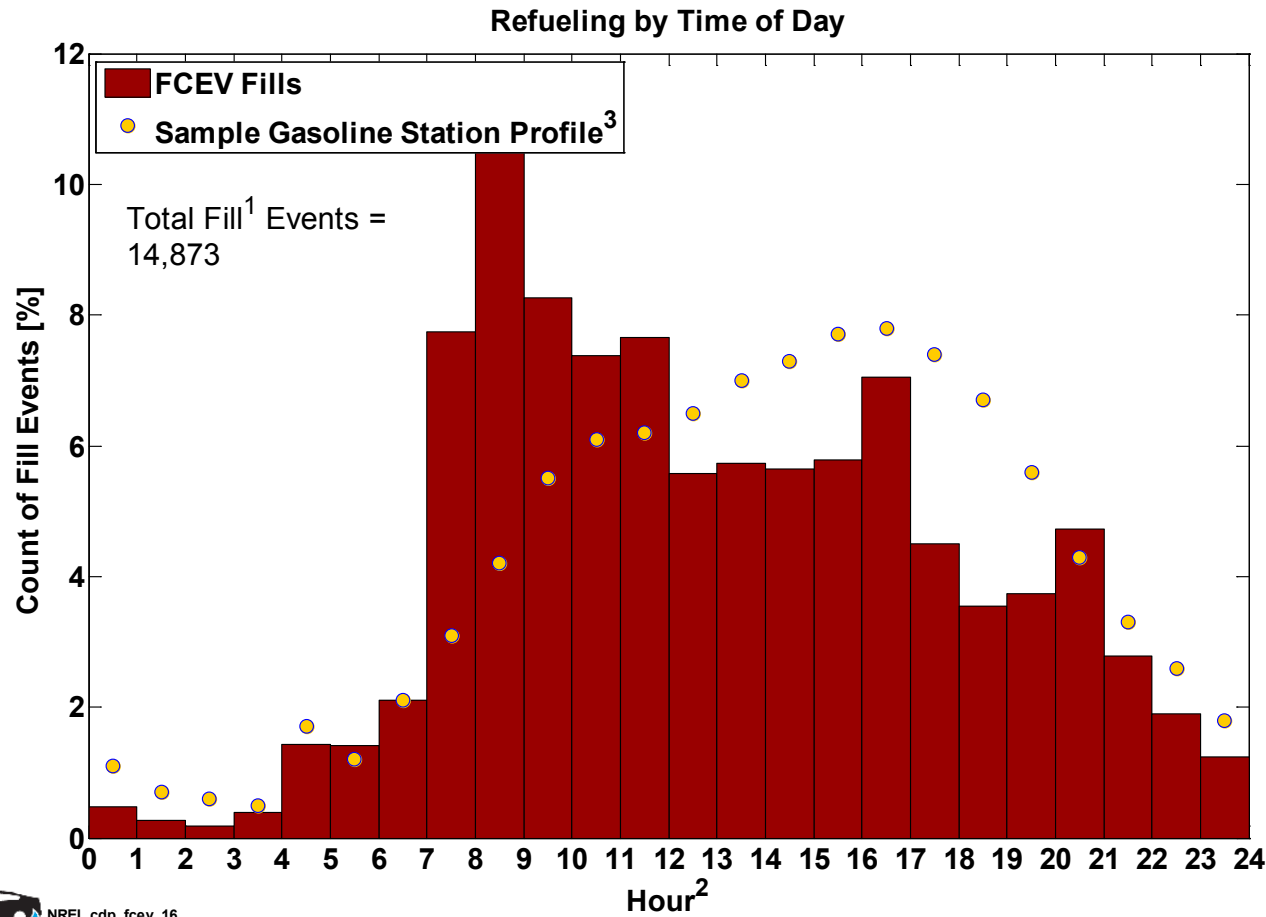


Hydrogen Tank Level at Refueling



CDP-FCEV-16

Refueling by Time of Day



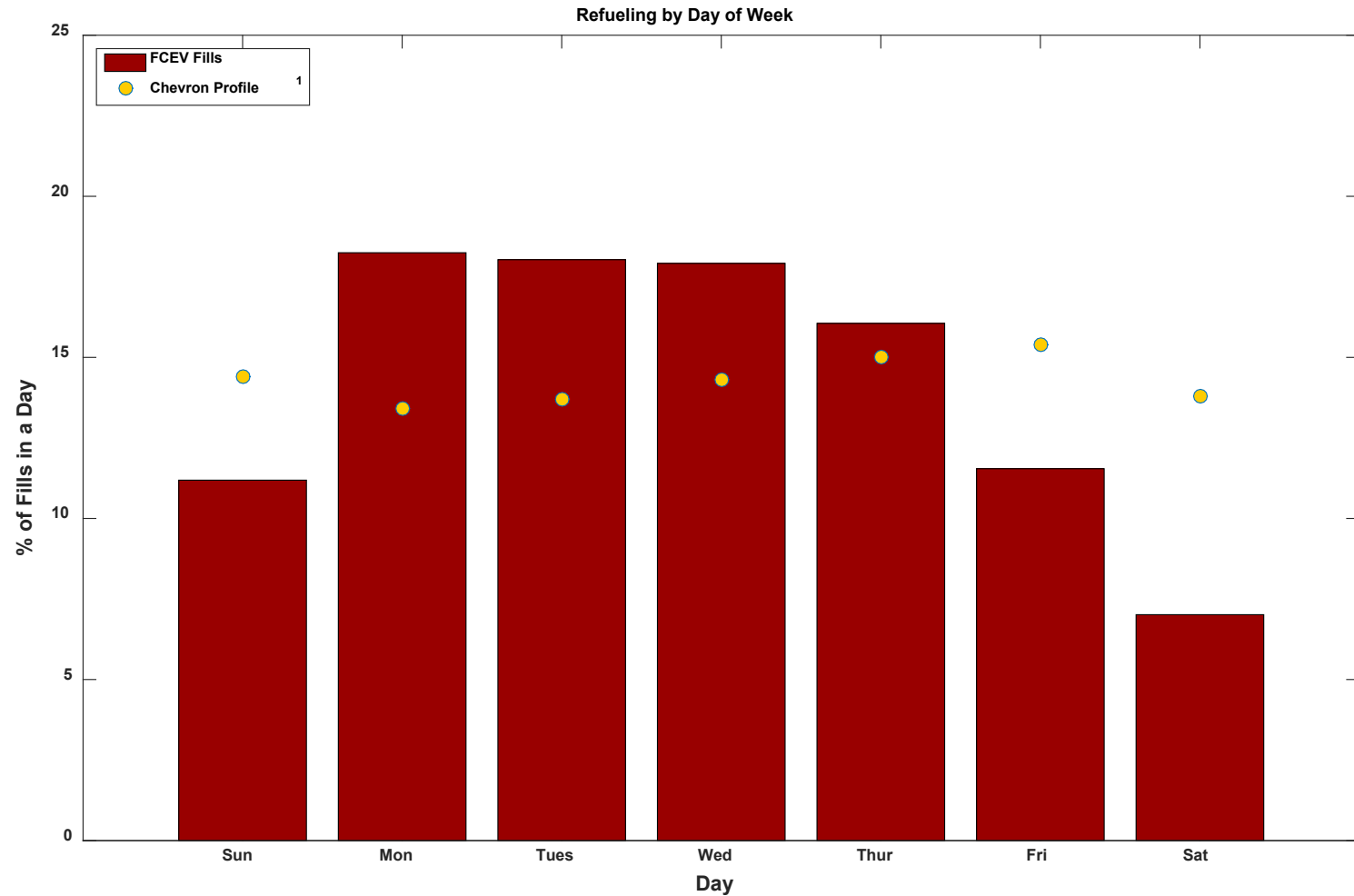
77.9% of fills b/t 6 AM & 6 PM

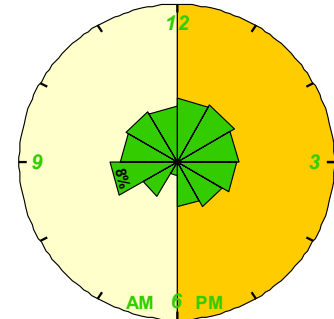
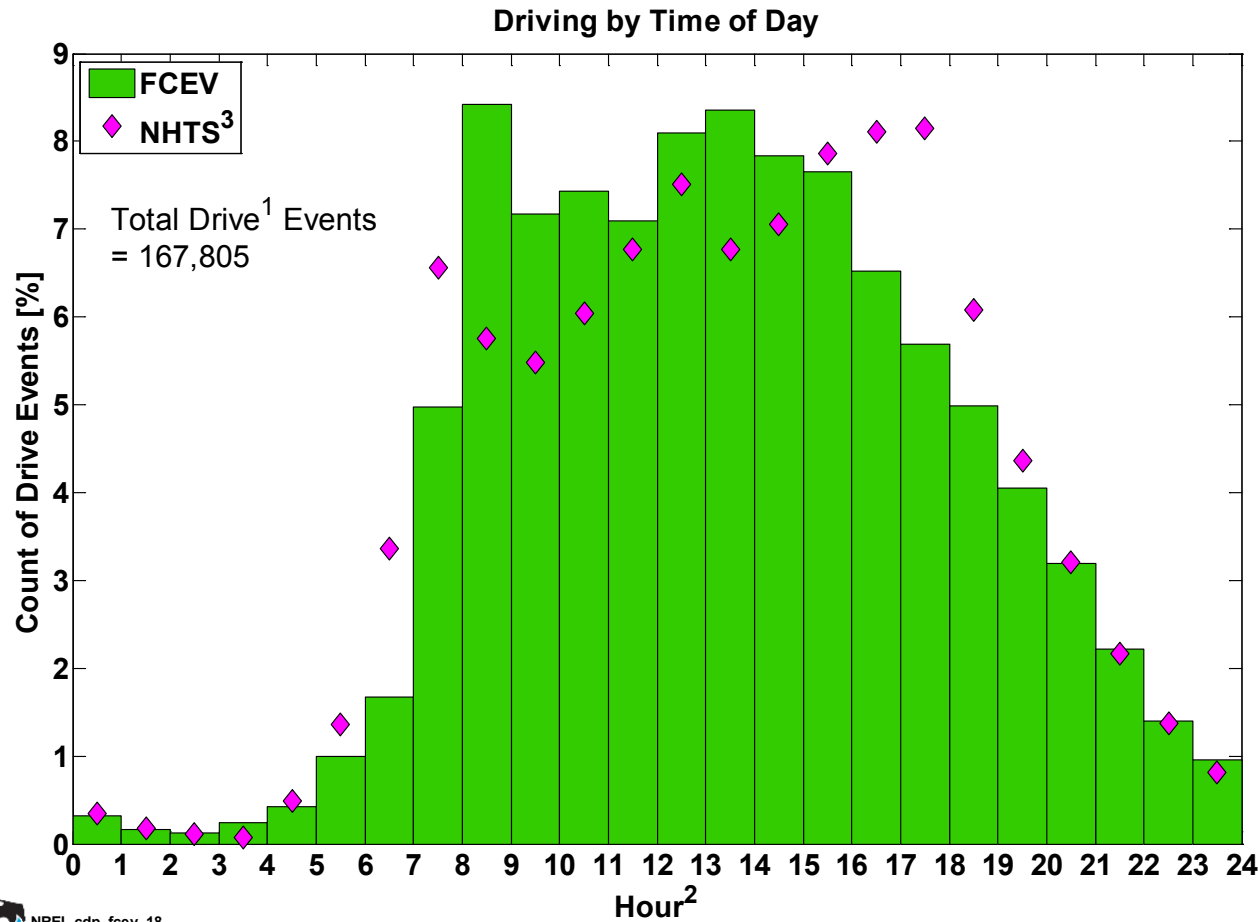
1. Some events not recorded/detected due to data noise or incompleteness.
2. UTC adjusted to local time using meridian-based adjustments and does not account for statutory deviations from the meridian-based system.
3. Friday Chevron profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.



NREL cdp_fcev_16
Created: Oct-30-15 11:43 AM | Data Through: 2015Q2
Included Vehicles: All

Refueling by Day of Week





80.9% of driving trips b/t 6 AM & 6 PM

84.4% of NHTS trips b/t 6 AM & 6 PM

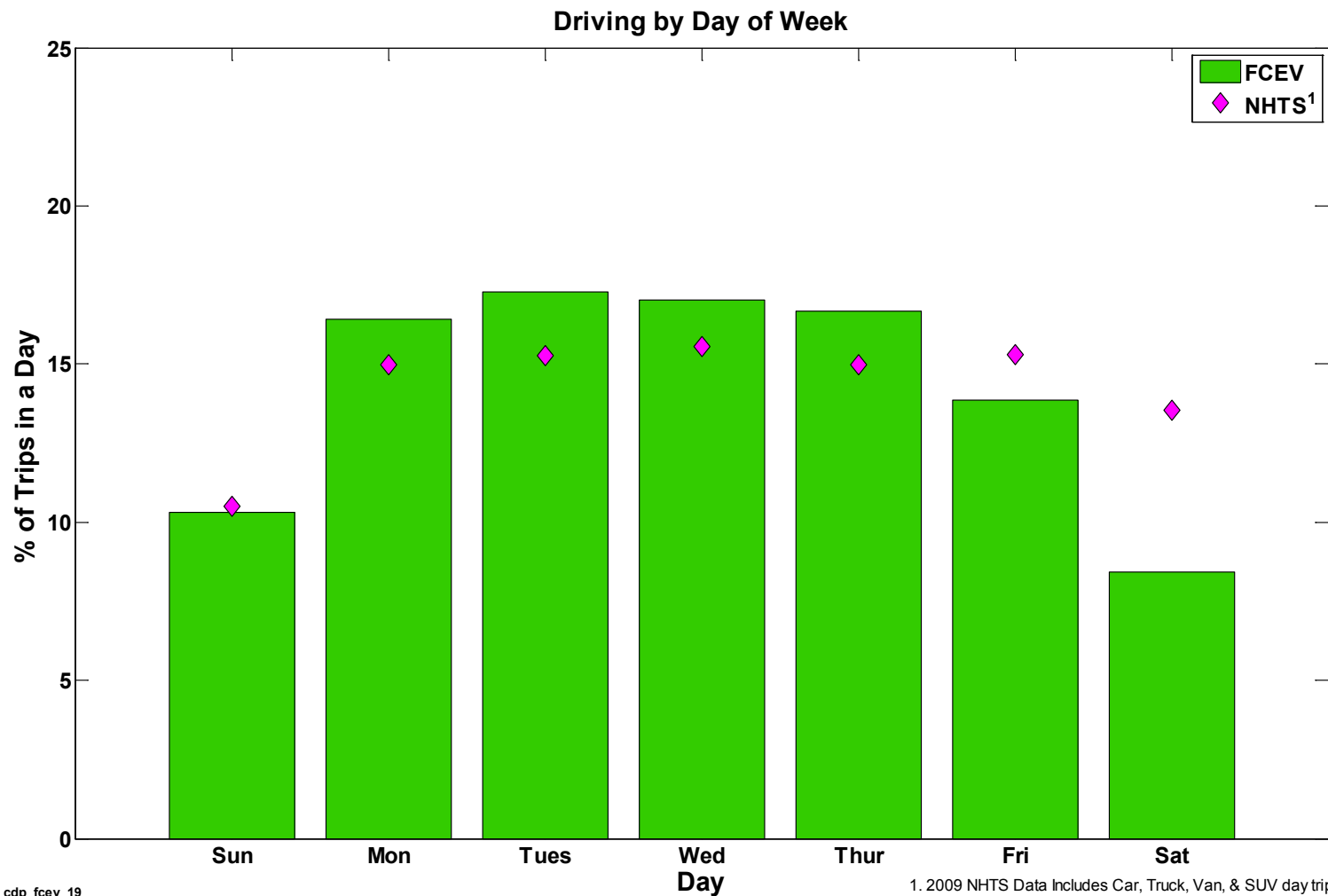
1. Some events not recorded/detected due to data noise or incompleteness.
2. UTC adjusted to local time using meridian-based adjustments and does not account for statutory deviations from the meridian-based system.
3. 2009 NHTS Data Includes Car, Truck, Van, & SUV day trips
ASCII.csv Source: <http://nhts.ornl.gov/download.shtml#2009>



NREL cdp_fcev_18
Created: Oct-31-15 11:27 AM | Data Through: 2015Q2
Included Vehicles: All

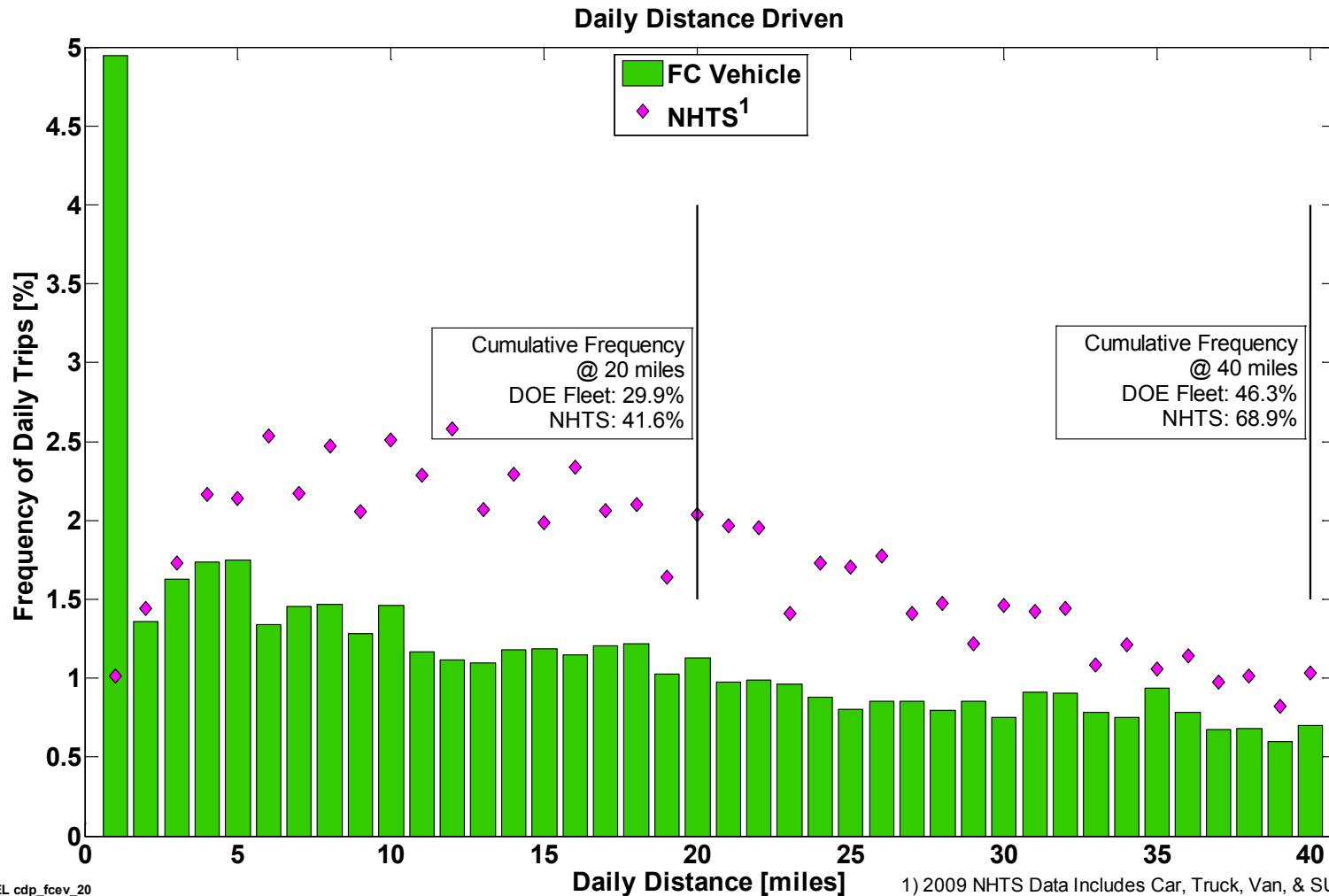
CDP-FCEV-19

Driving by Day of Week

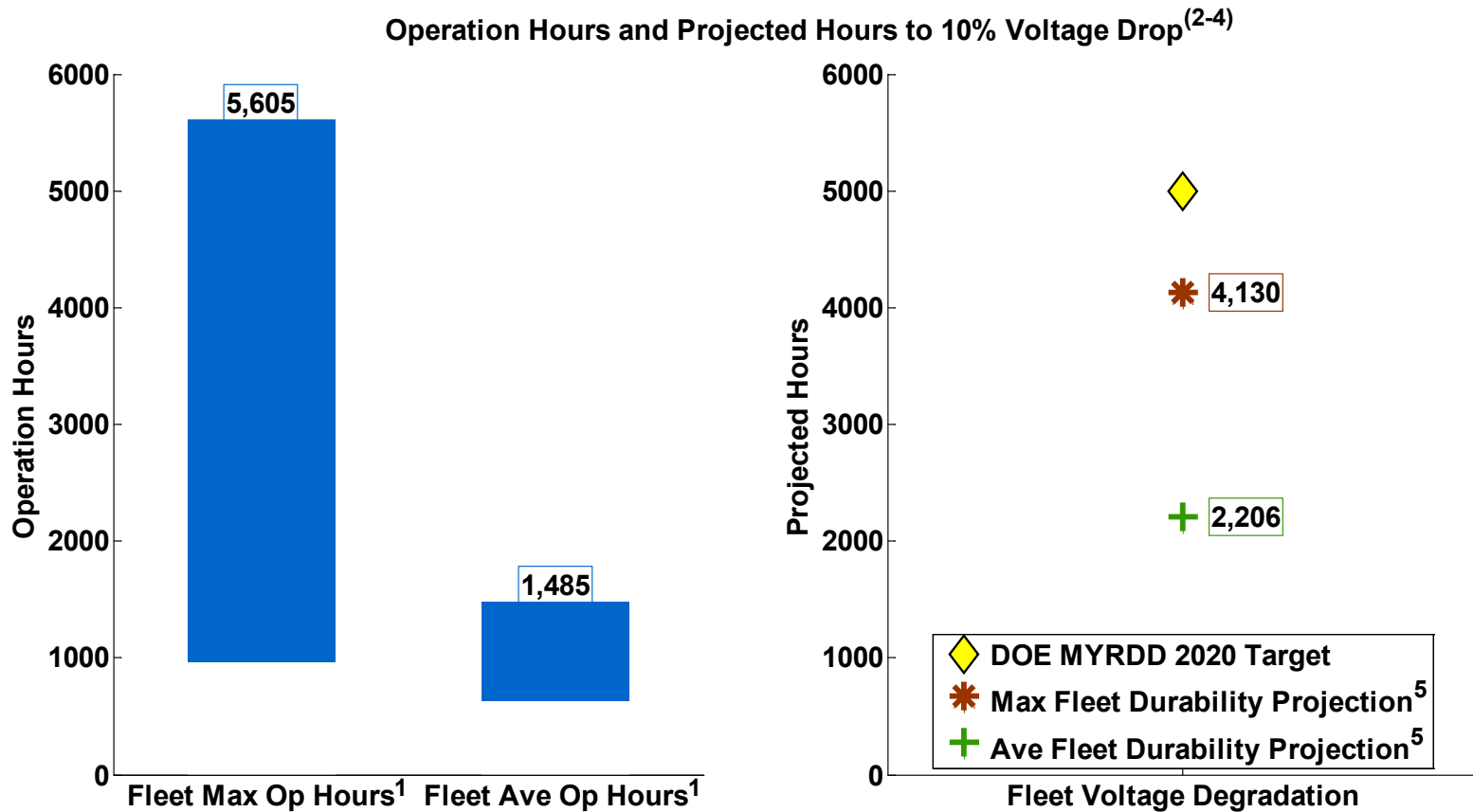


NREL cdp_fcev_19
Created: Oct-31-15 11:27 AM | Data Through: 2015Q2
Included Vehicles: All

1. 2009 NHTS Data Includes Car, Truck, Van, & SUV day trips
ASCII.csv Source: <http://nhts.ornl.gov/download.shtml#2009>



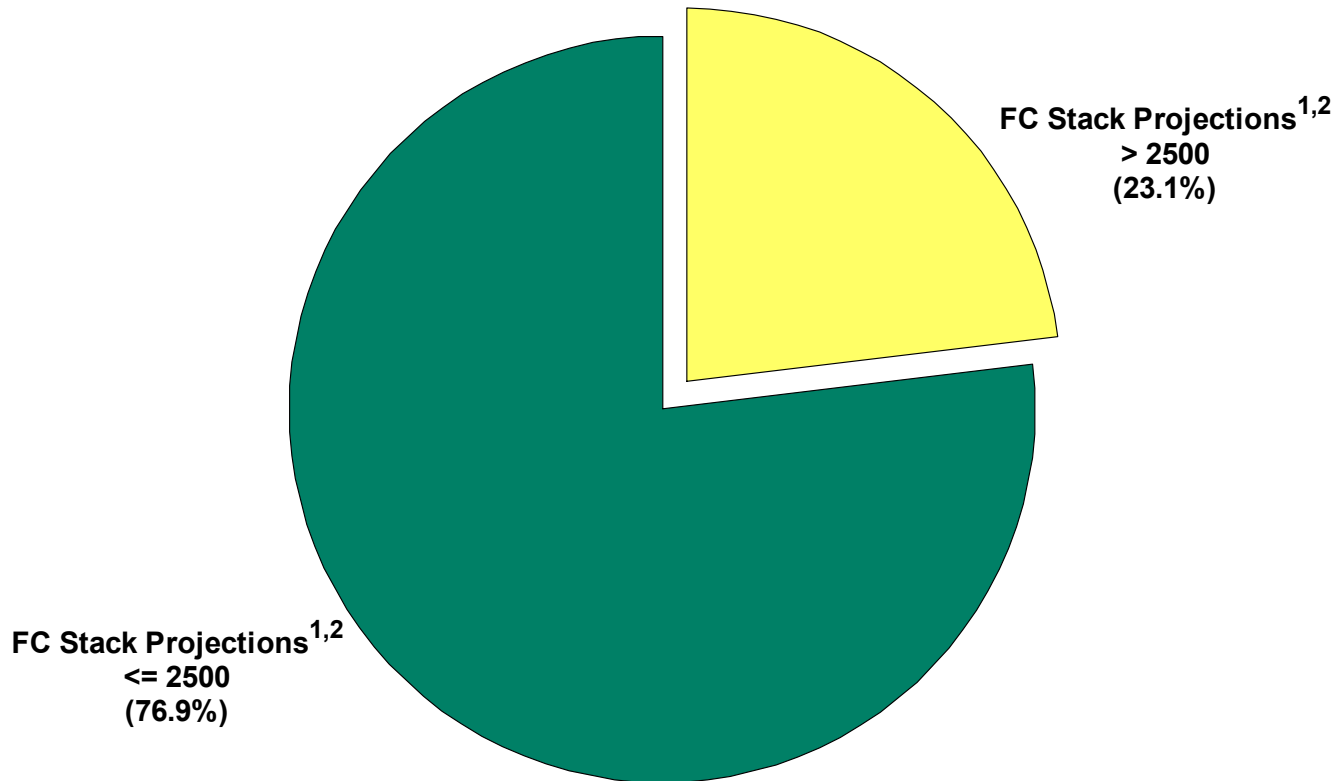
Fuel Cell Stack Operation Hours and Voltage Durability



- 1) Range bars created using one data point for each fleet. Some stacks have accumulated hours beyond 10% voltage degradation.
- 2) Voltage degradation is measured based on a projected time to a voltage drop, at a high current, level 10% lower than beginning of life voltage. 10% voltage drop level is a DOE metric for assessing fuel cell durability.
- 3) Projections using on-road data are calculated at approximately 55 - 65% rated stack current.
- 4) 10% voltage drop is NOT an indication of an OEM's end-of-life criteria and projections do not address catastrophic stack failure.
- 5) Each fleet has one voltage projection value that is the weighted average of the fleet's fuel cell stack projections.

Projected Hours to 10% Voltage Degradation

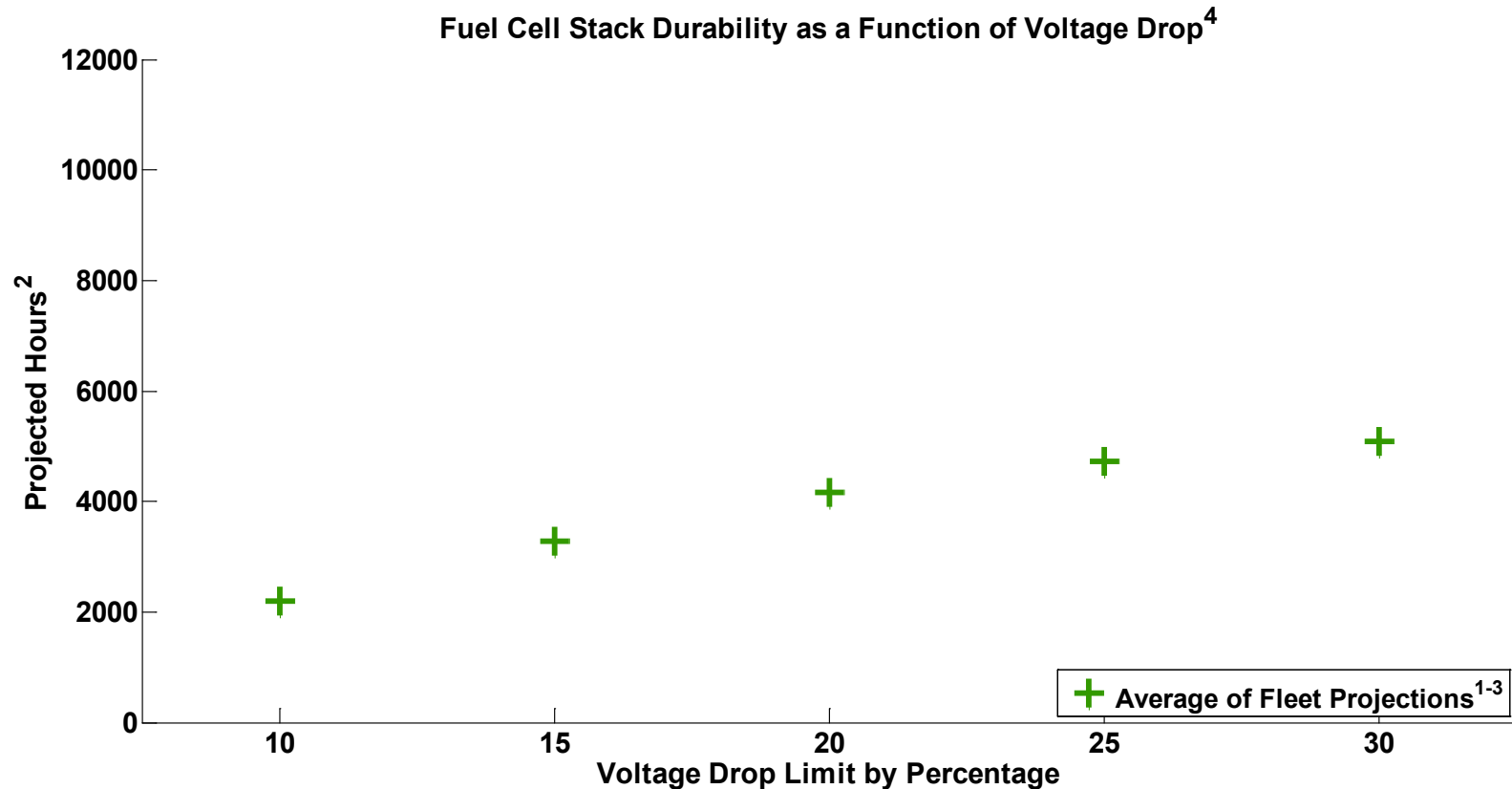
Fuel Cell 10% Voltage Degradation Against 2,500 Hour Benchmark



1) Voltage degradation is measured based on a projected time to a voltage drop, at a high current, level 10% lower than beginning of life voltage. 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.

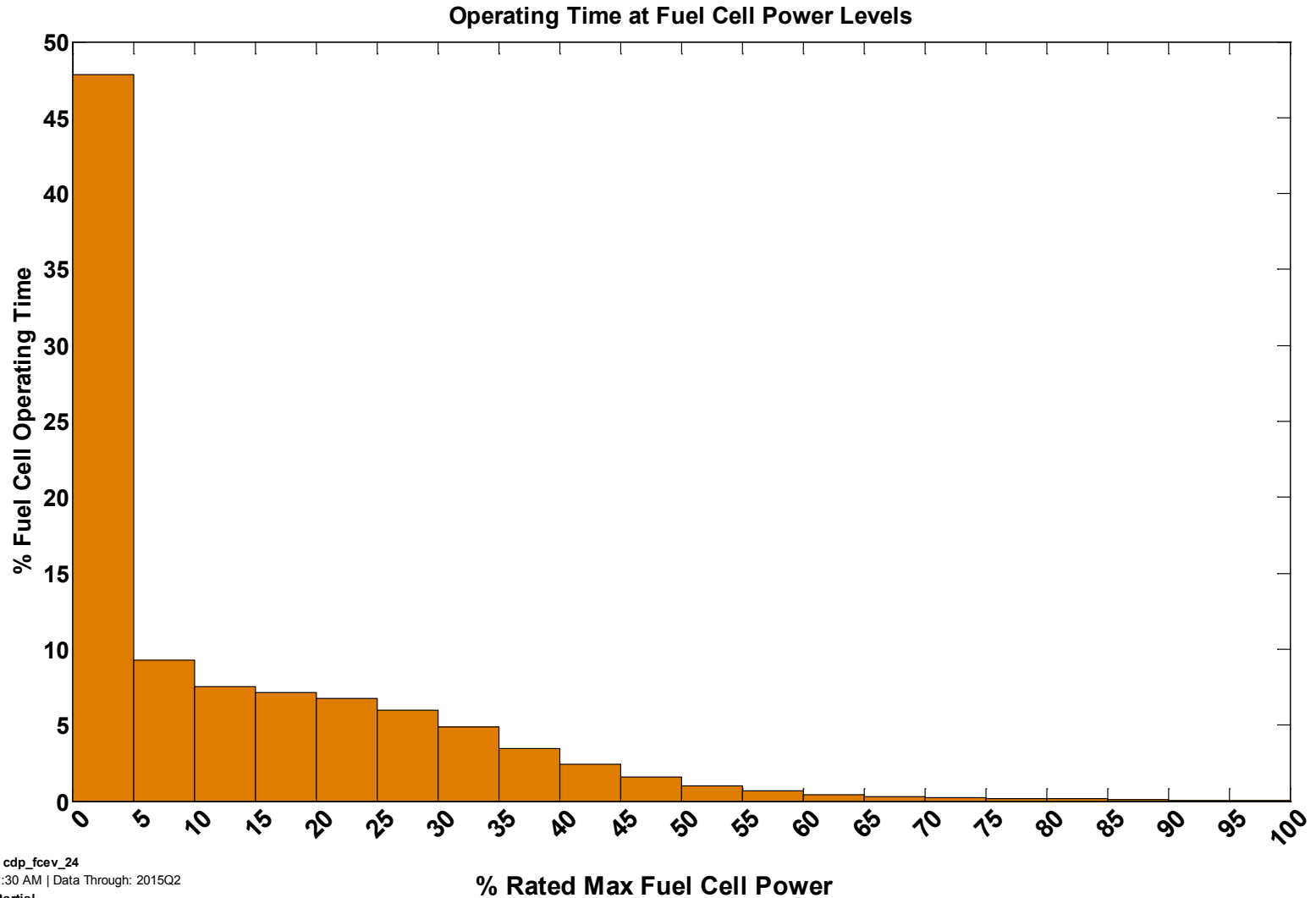




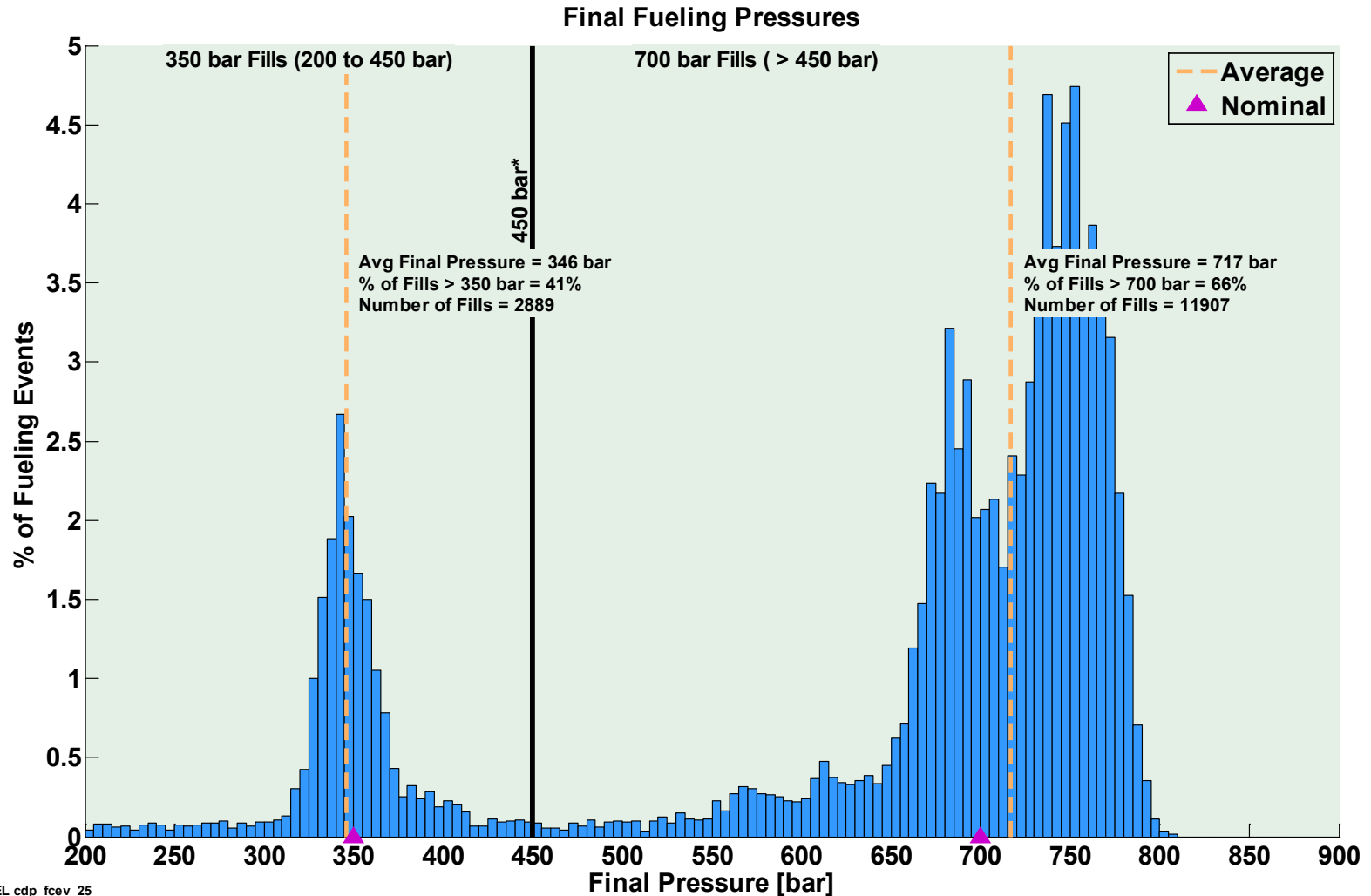
- 1) Voltage degradation is measured based on a projected time to a voltage drop, at a high current, level 10% lower than beginning of life voltage. 10% Voltage degradation is a DOE metric for assessing fuel cell performance not an indication of an OEM's end-of-life criteria.
- 2) Projections using on-road data are calculated at high stack current.
- 3) Each fleet has one voltage projection value that is the weighted average of the fleet's fuel cell stack projections.
- 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.



Fuel Cell Stack Power Level Operation Time



Final Fueling Pressure—FCEV Onboard Sensors

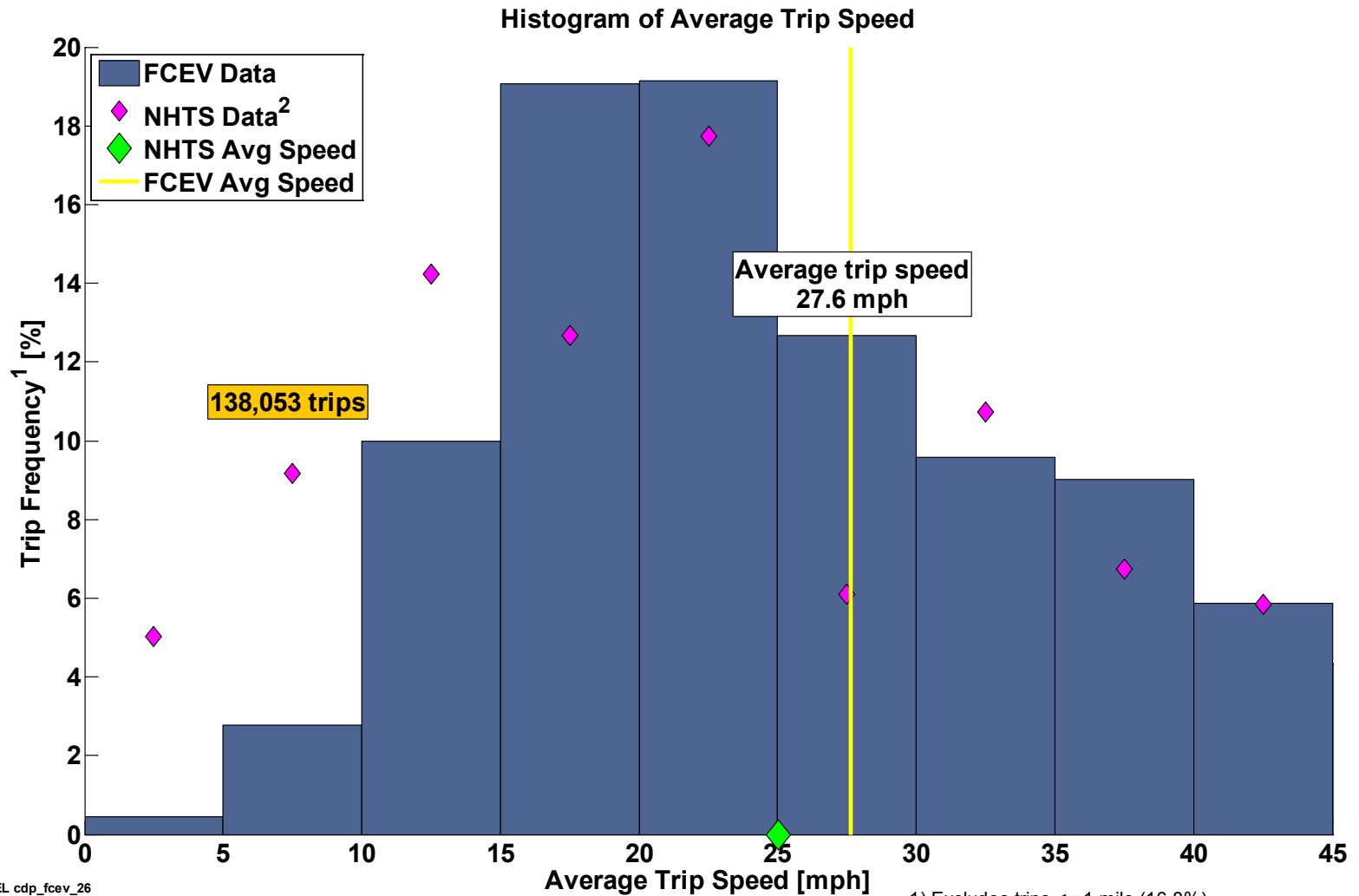


 NREL cdp_fcev_25
 Created: Oct-30-15 12:03 PM | Data Through: 2015Q2
 Included Vehicles: All

*The line at 450 bar separates 350 bar fills from 700 bar fills. It is slightly over the allowable 125% of nominal pressure (437.5 bar) from SAE J2601.

CDP-FCEV-26

Average Trip Speed

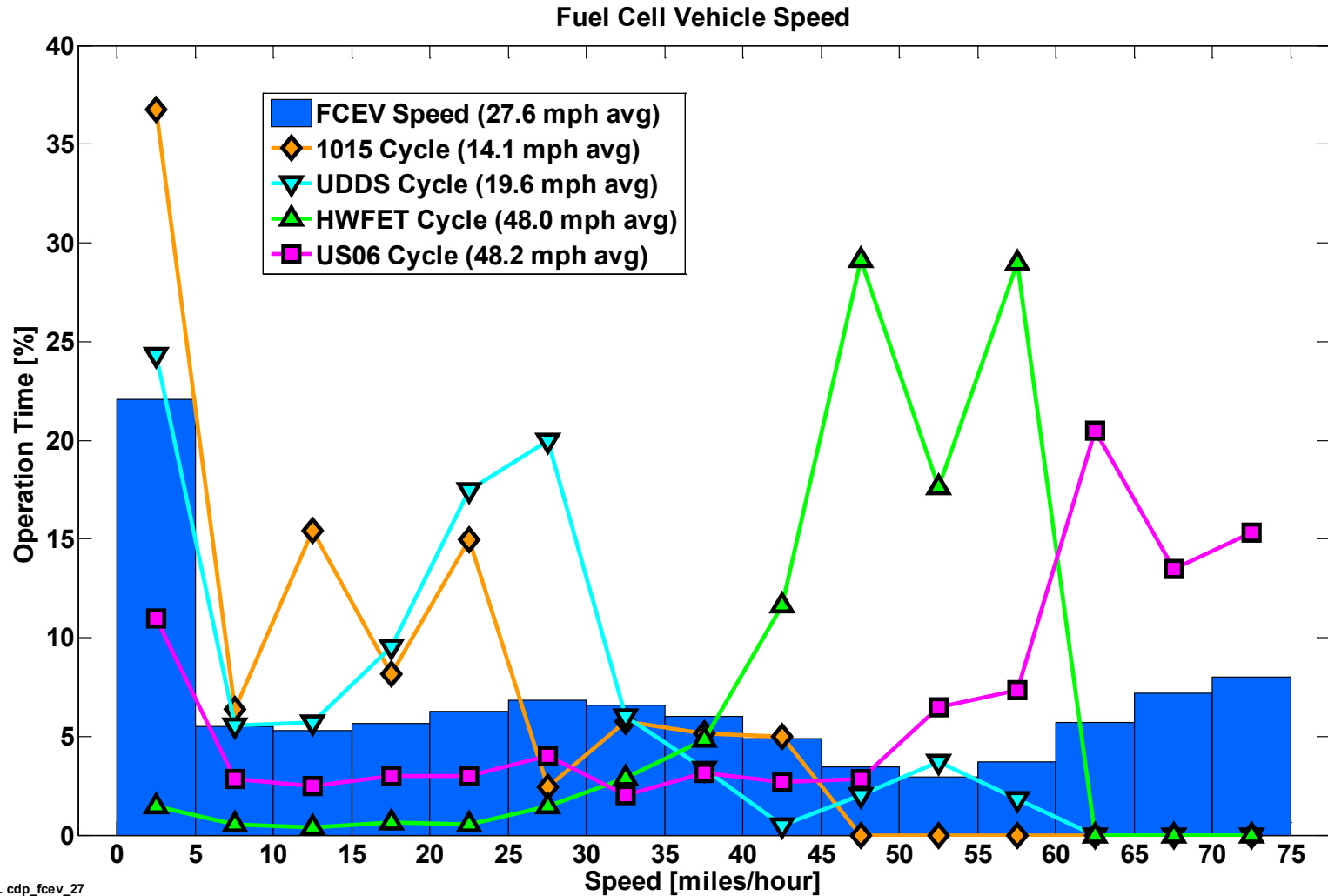


NREL cdp_fcev_26
Created: Oct-31-15 11:30 AM | Data Through: 2015Q2
Included Vehicles: All

1) Excludes trips <= 1 mile (16.8%)
2) 2009 NHTS data includes Car, Truck, Van & SUV day trips

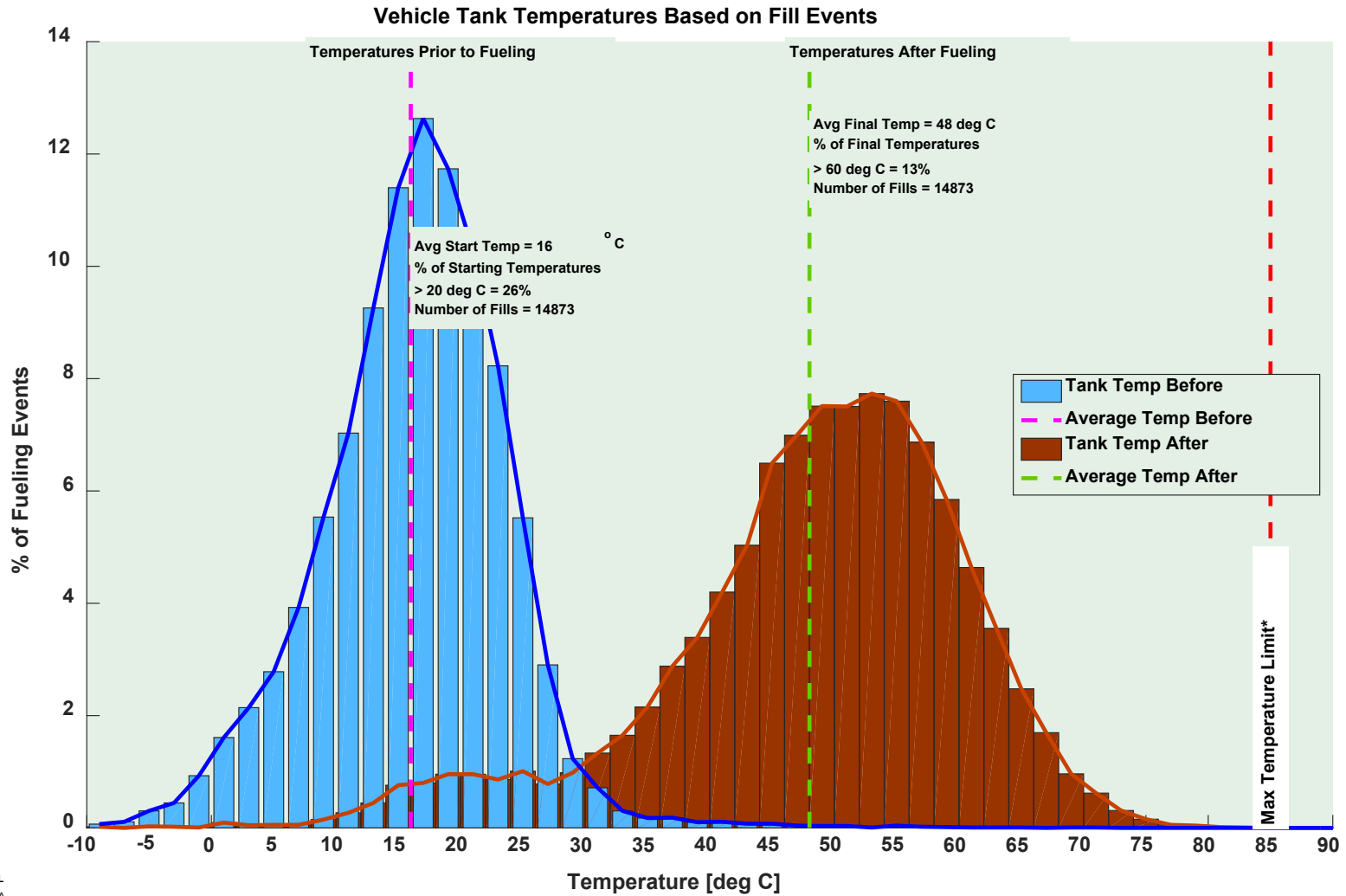
CDP-FCEV-27

Trip Speed Comparison with Standard Drive Cycles

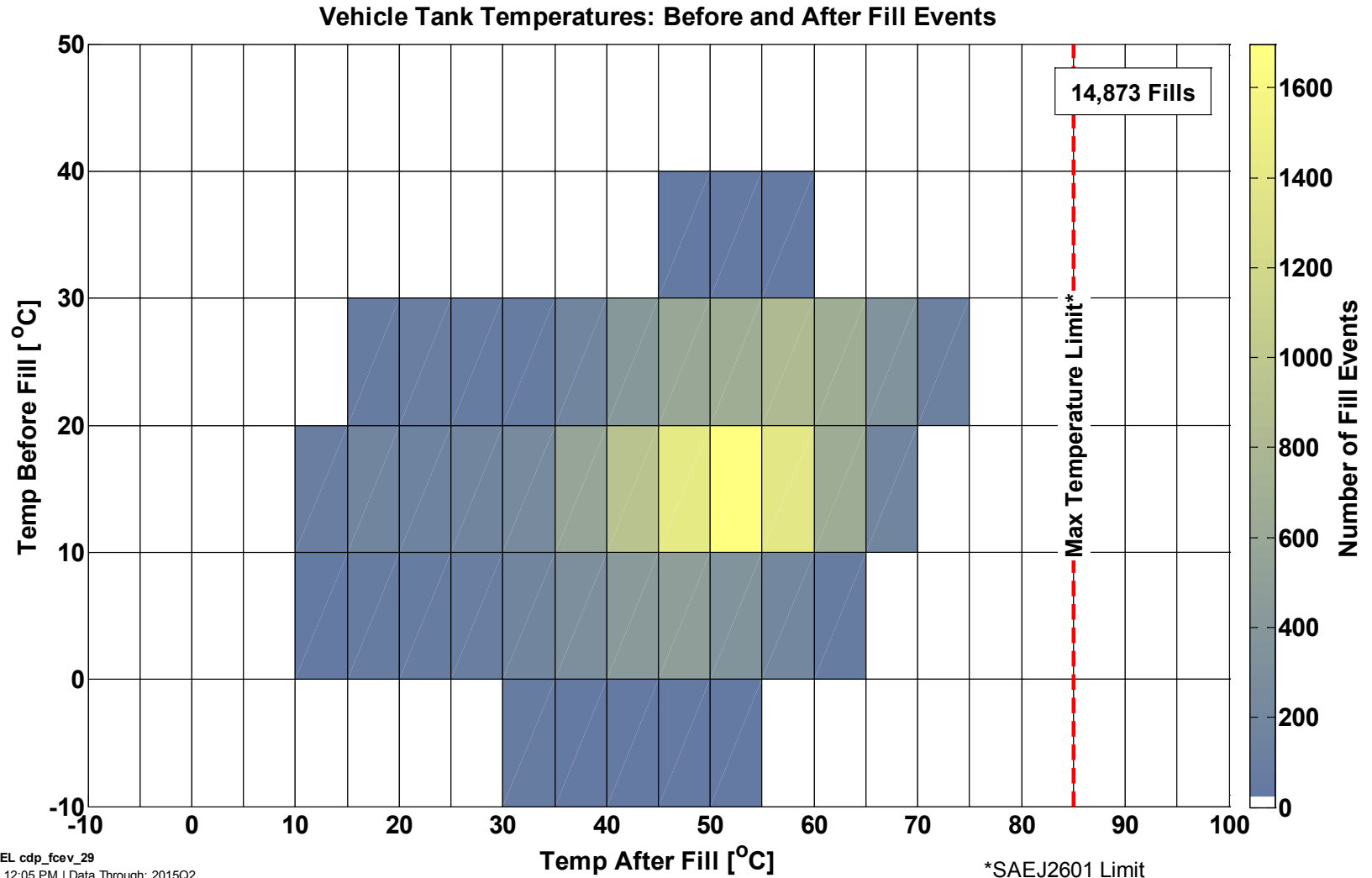


NREL cdp_fcev_27
Created: Oct-31-15 11:31 AM | Data Through: 2015Q2
Included Vehicles: All

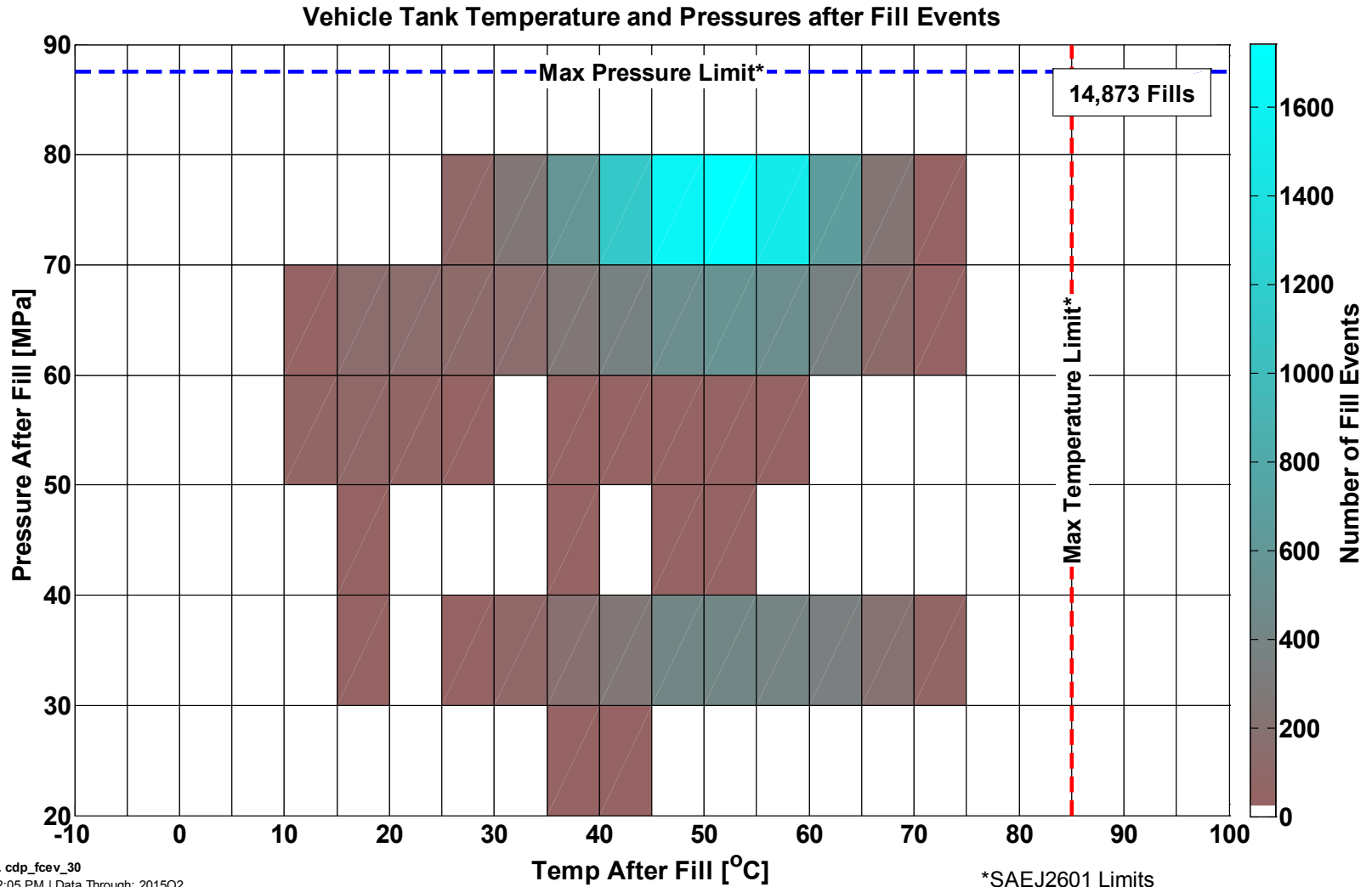
Vehicle Tank Temperatures Before and After Fueling



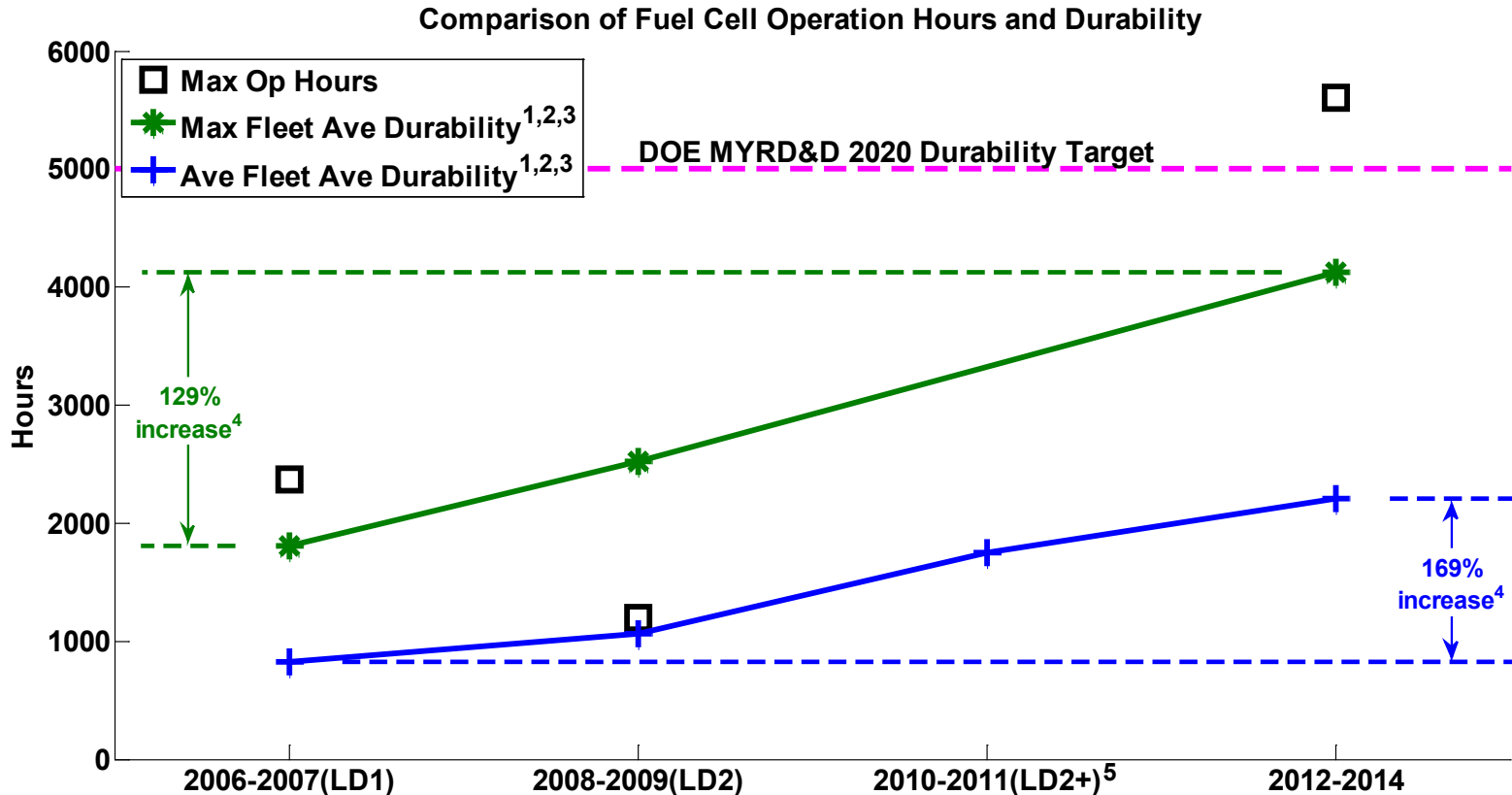
Vehicle Tank Temperatures: Before and After a Fill



Vehicle Tank Temperatures and Pressures after Fill Events

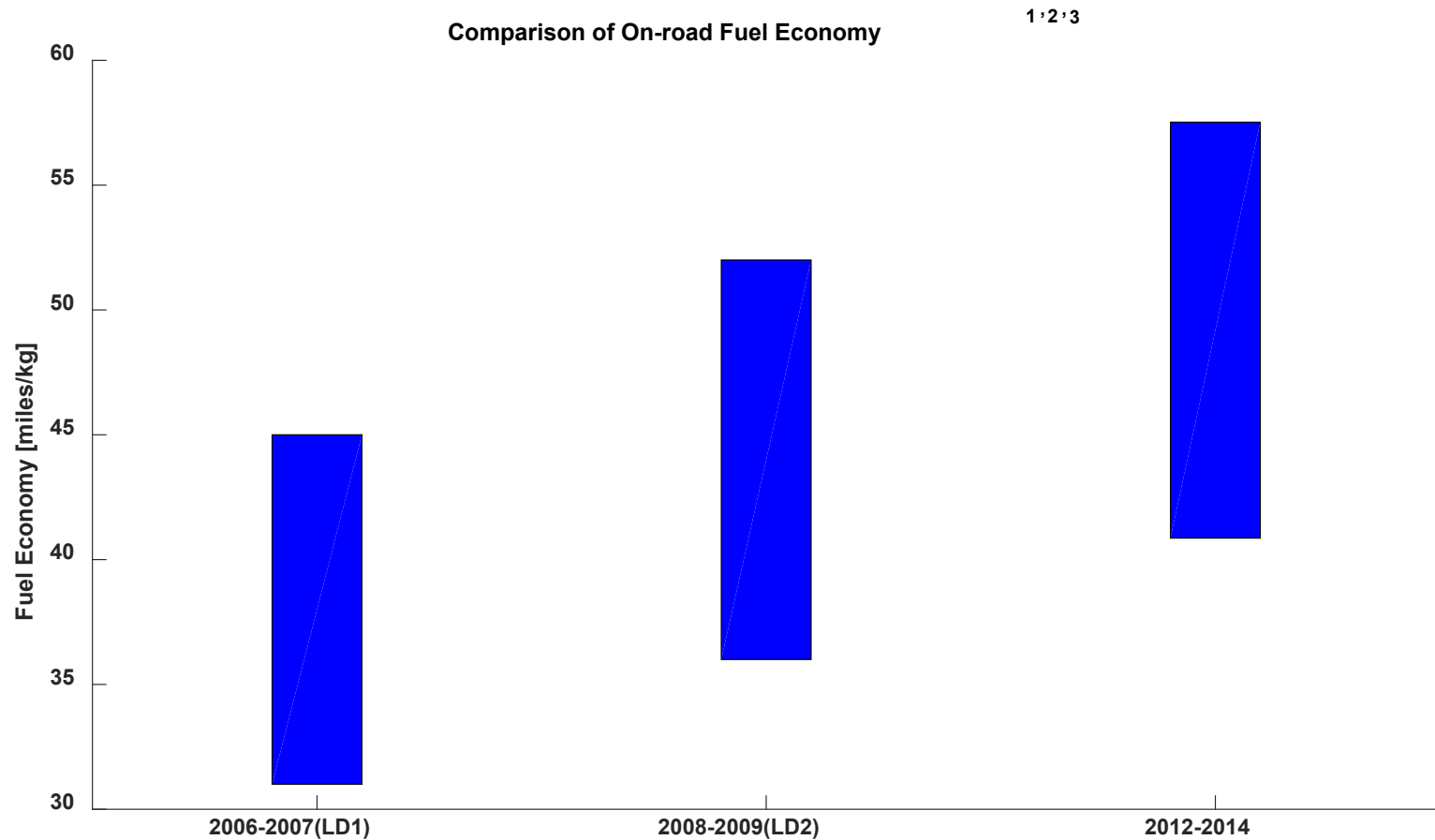


Fuel Cell Operation Hours and Voltage Degradation Trend

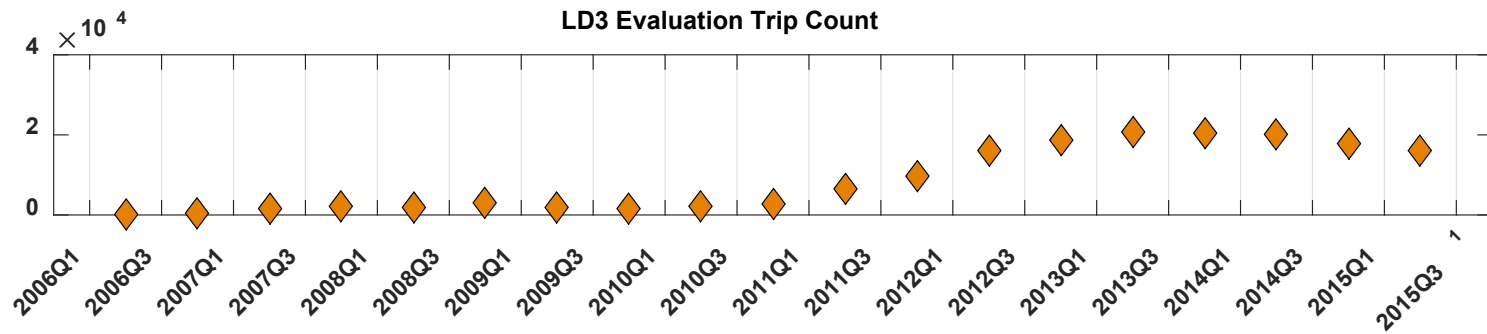
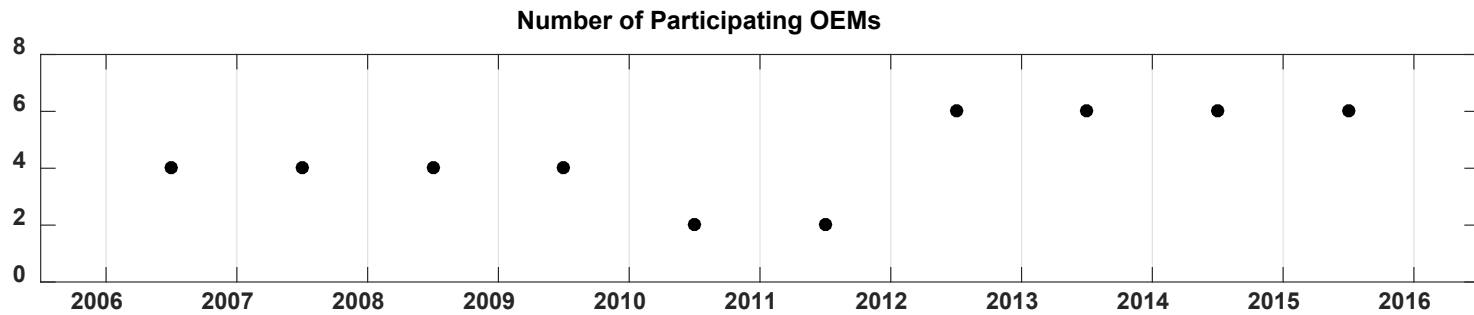
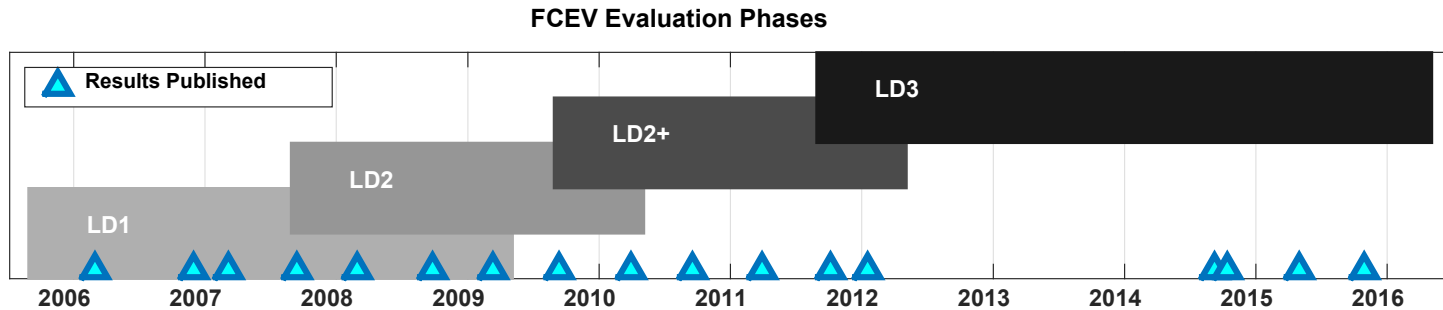


- 1) Durability based on voltage degradation to 10% lower than beginning of life voltage. 10% voltage drop level is a DOE metric for assessing fuel cell durability.
- 2) Projections using on-road data are calculated at approximately 55 - 65% rated stack current.
- 3) 10% voltage drop is NOT an indication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

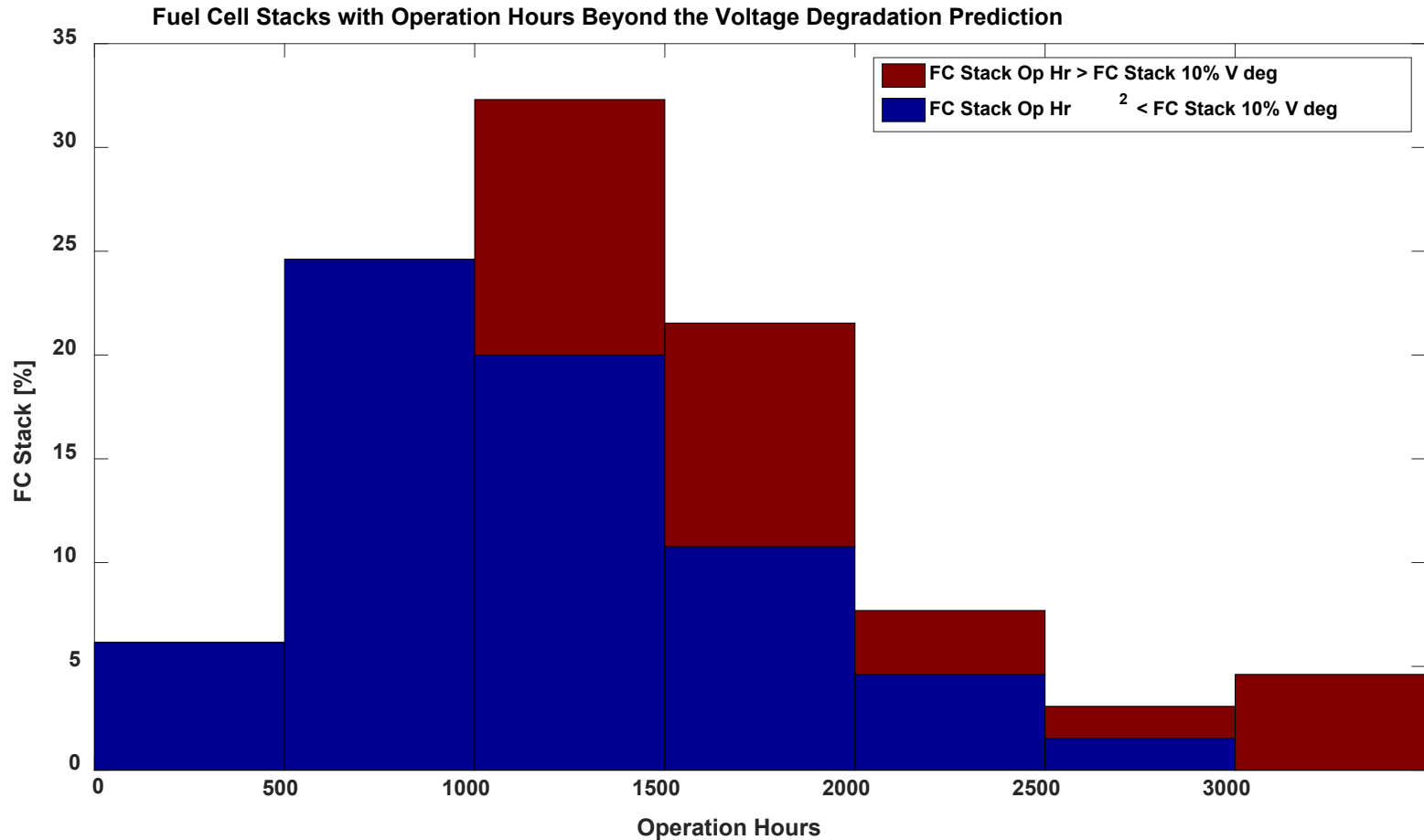
On-Road Fuel Economy Trends



Evaluation Phases and OEM Participation Trend

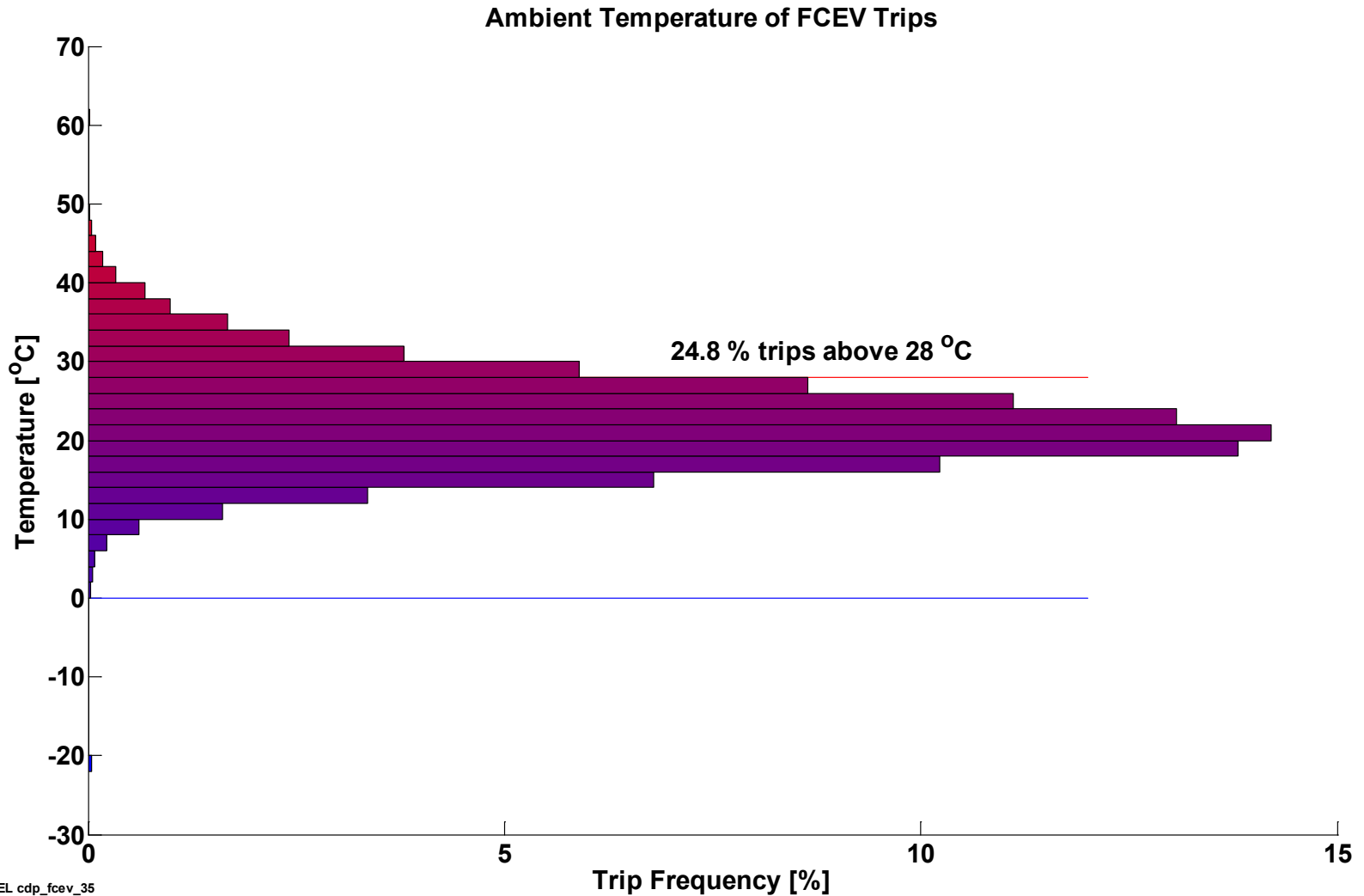


Fuel Cell Operation Hours Beyond 10% Voltage Degradation

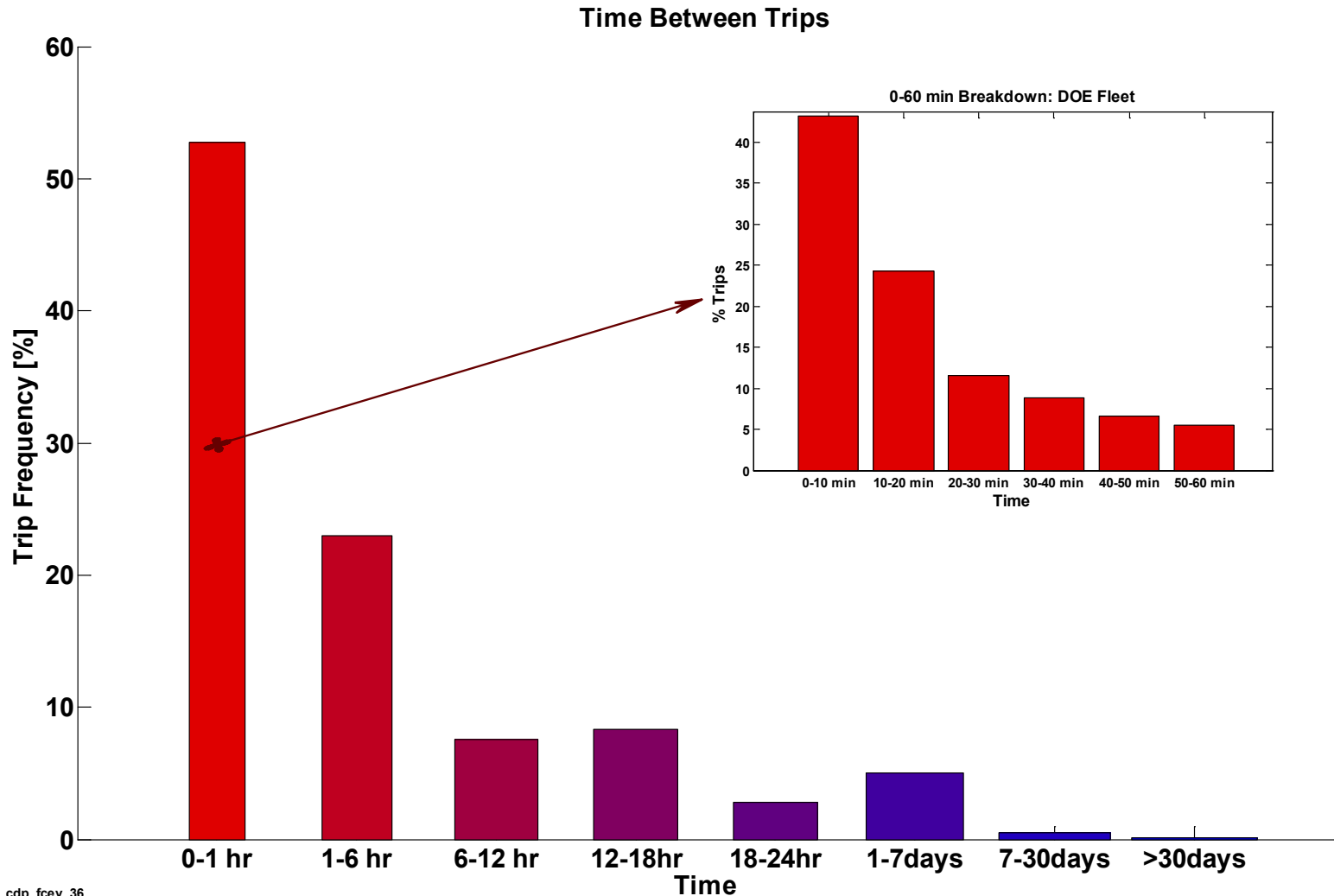


CDP-FCEV-35

Trip Ambient Temperature



Time Between Trips

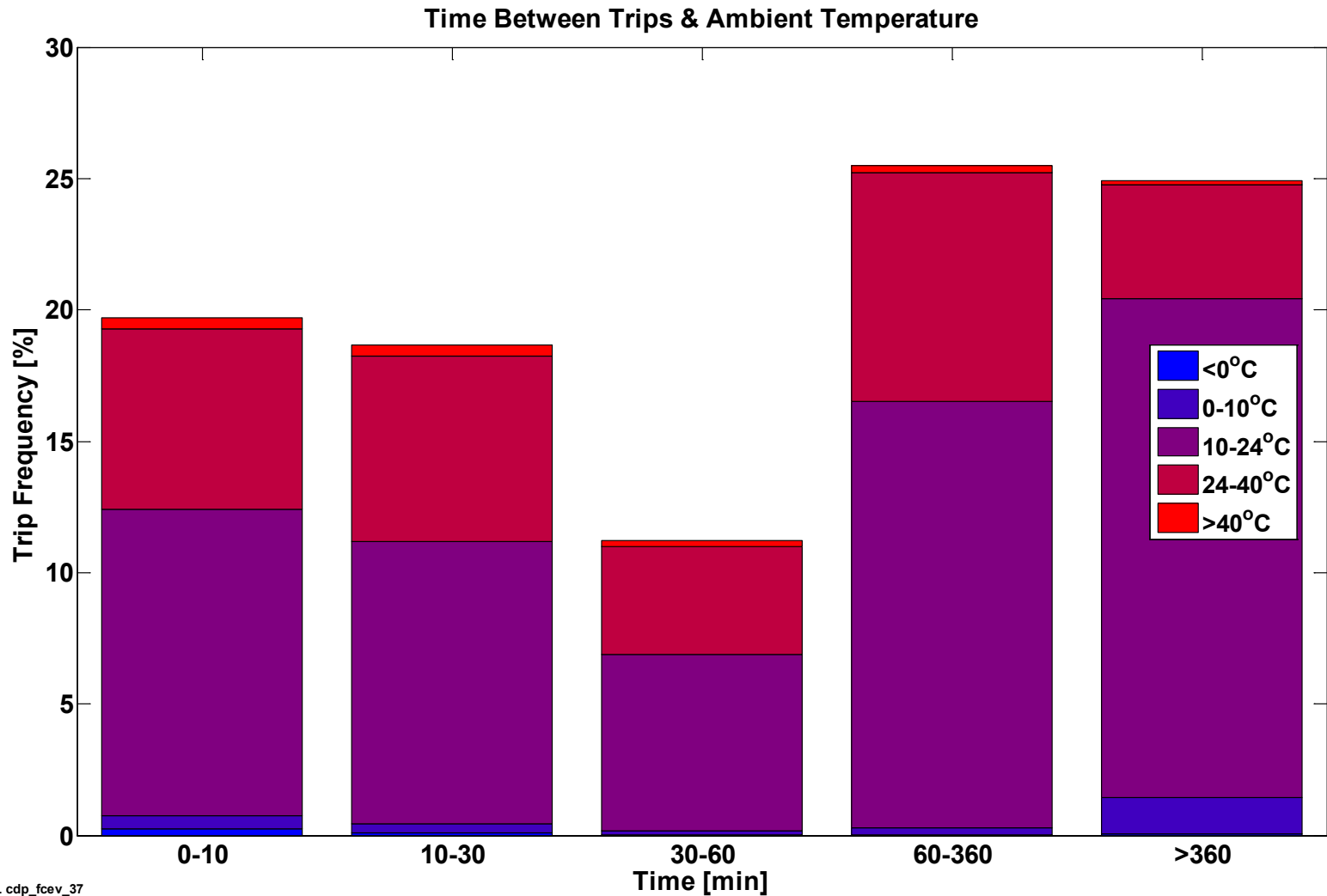


NREL cdp_fcev_36

Created: Oct-31-15 12:52 PM | Data Through: 2015Q2

Included Vehicles: All

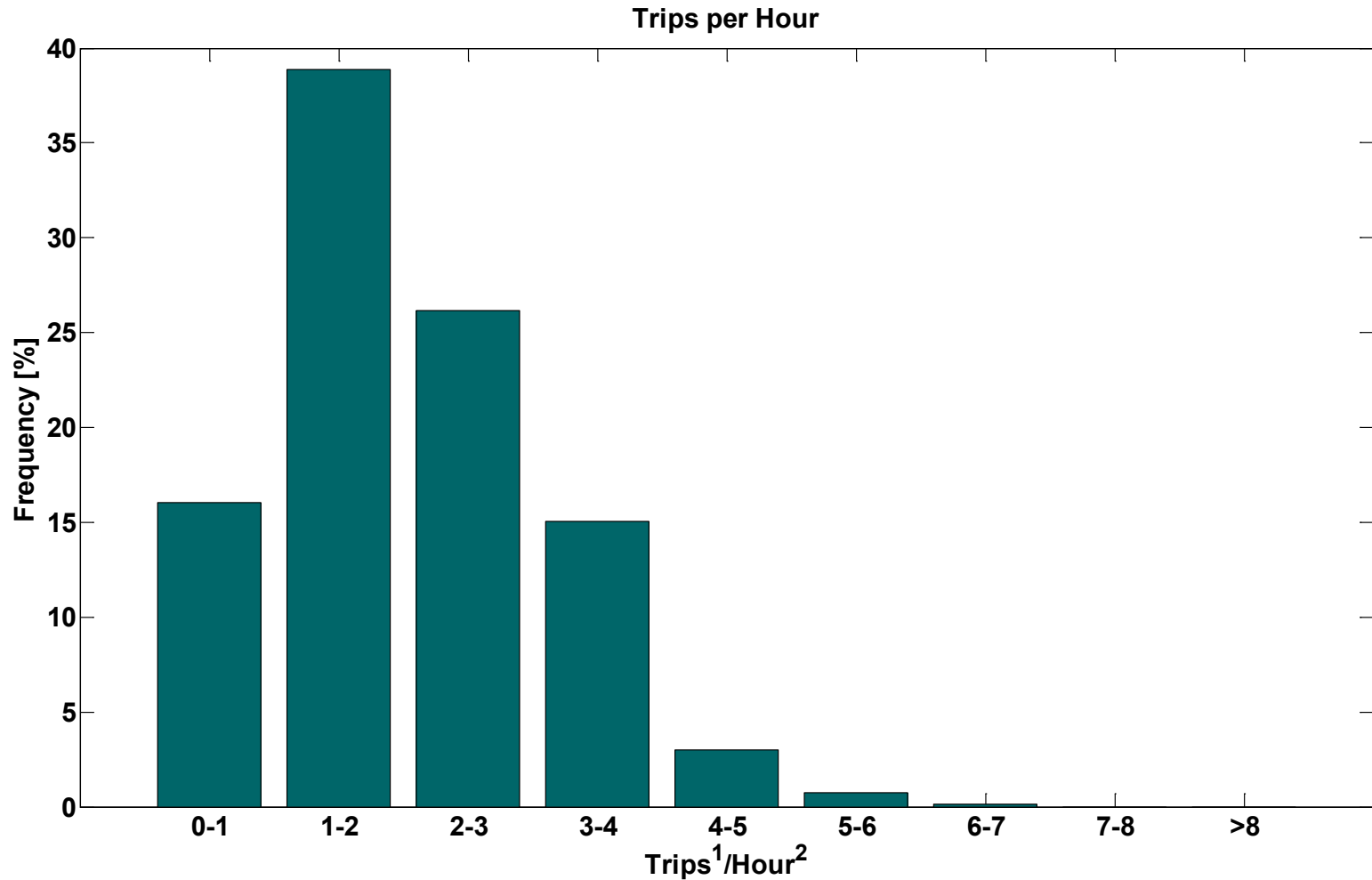
Time Between Trips and Trip Ambient Temperature



NREL cdp_fcev_37

Created: Oct-31-15 12:52 PM | Data Through: 2015Q2

Included Vehicles: Partial



NREL cdp_fcev_38

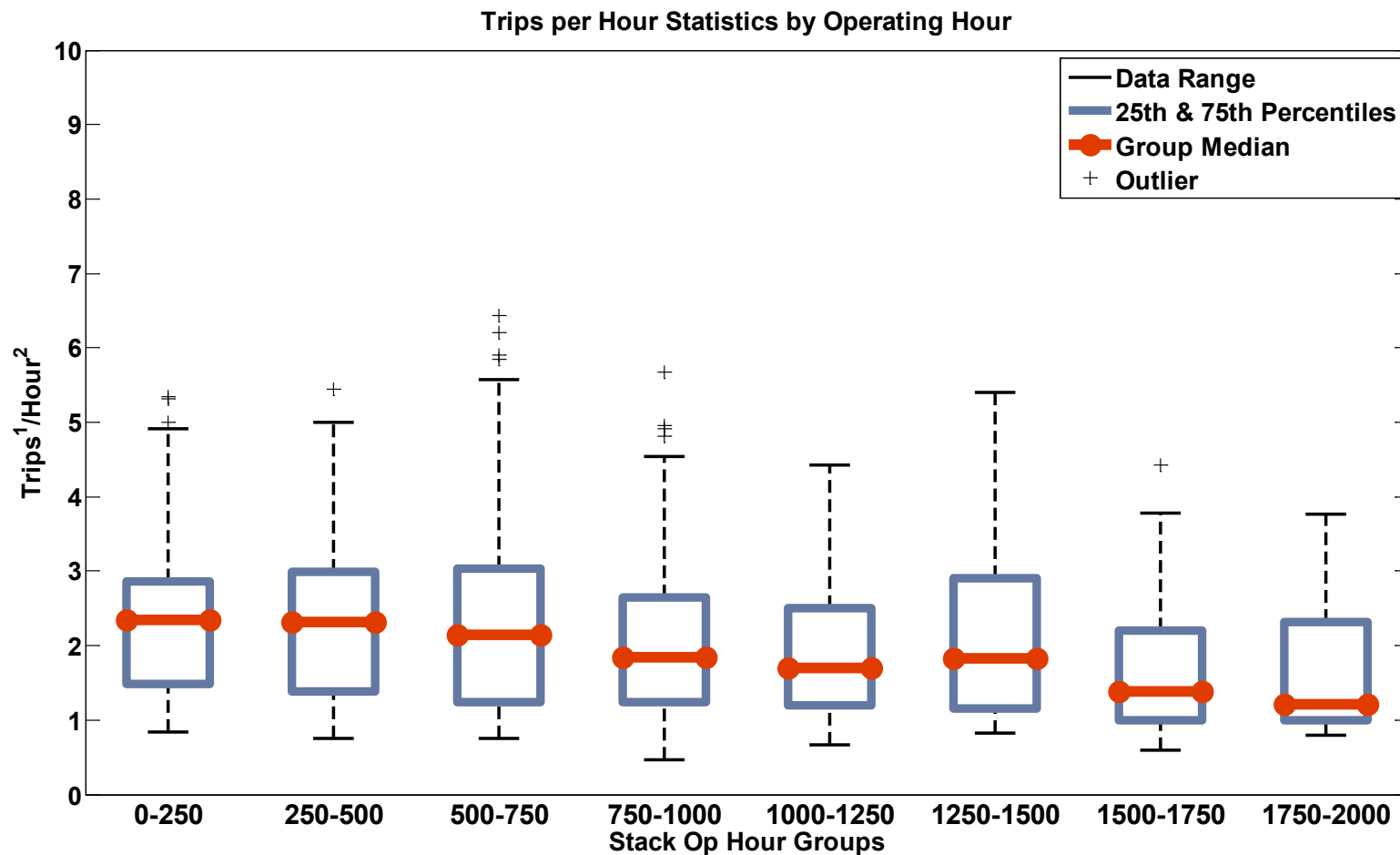
Created: Oct-31-15 12:52 PM | Data Through: 2015Q2

Included Vehicles: Partial

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.



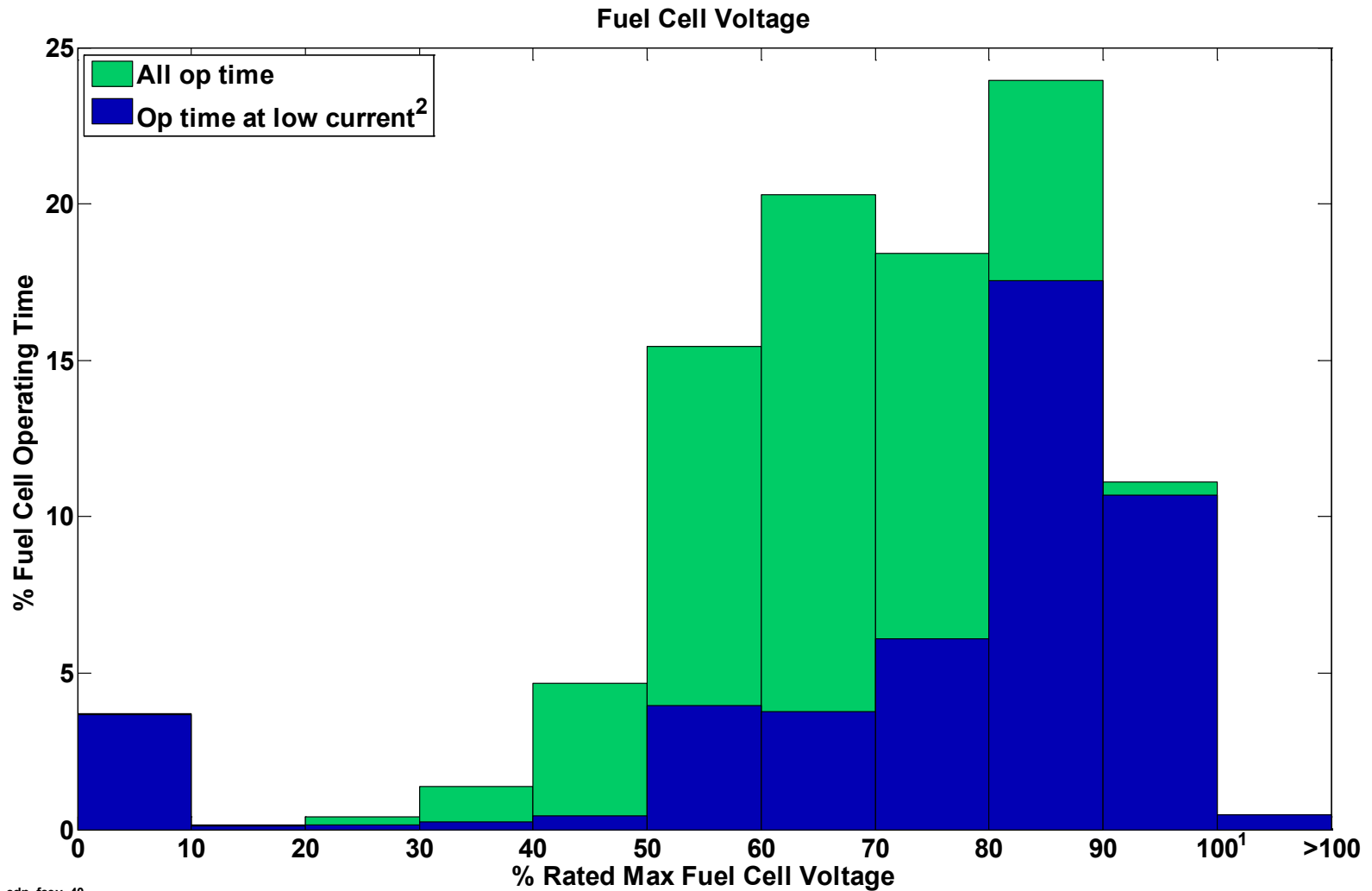
NREL cdp_fcev_39

Created: Oct-31-15 12:53 PM | Data Through: 2015Q2

Included Vehicles: Partial

CDP-FCEV-40

Fuel Cell Voltage



NREL cdp_fcev_40

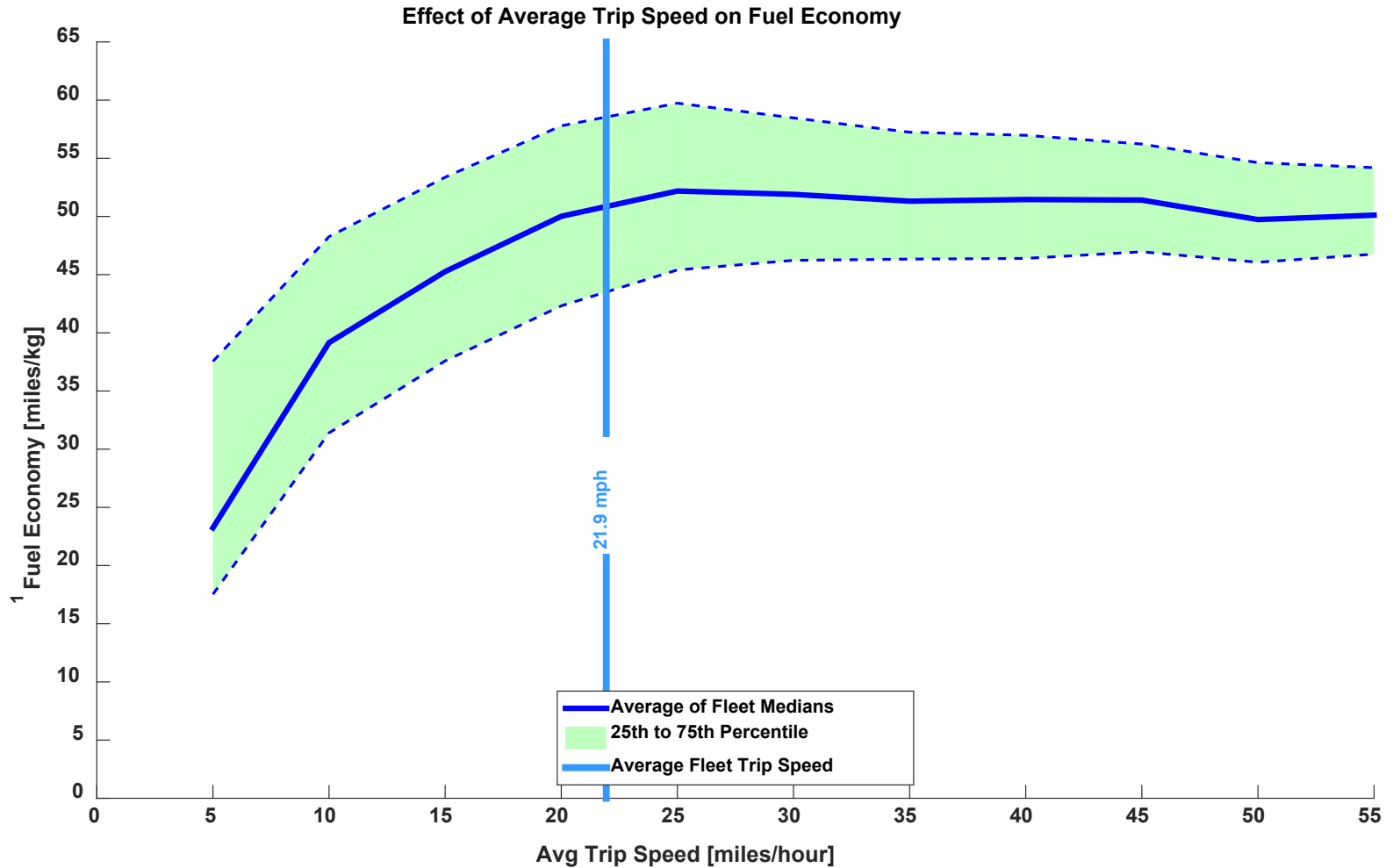
Created: Oct-31-15 12:53 PM | Data Through: 2015Q2

Included Vehicles: Partial

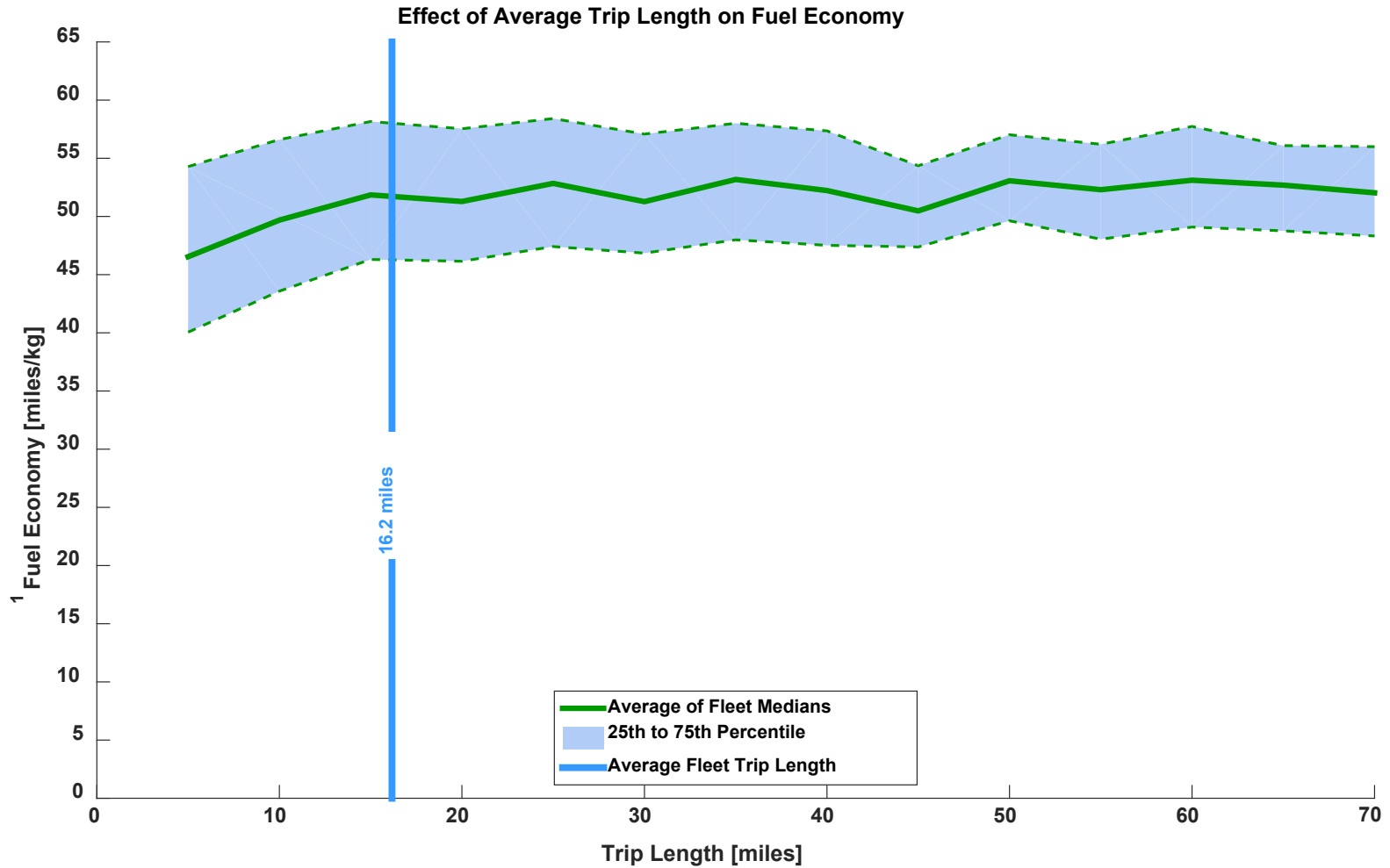
1) 100% max fuel cell voltage is approximately open-circuit voltage

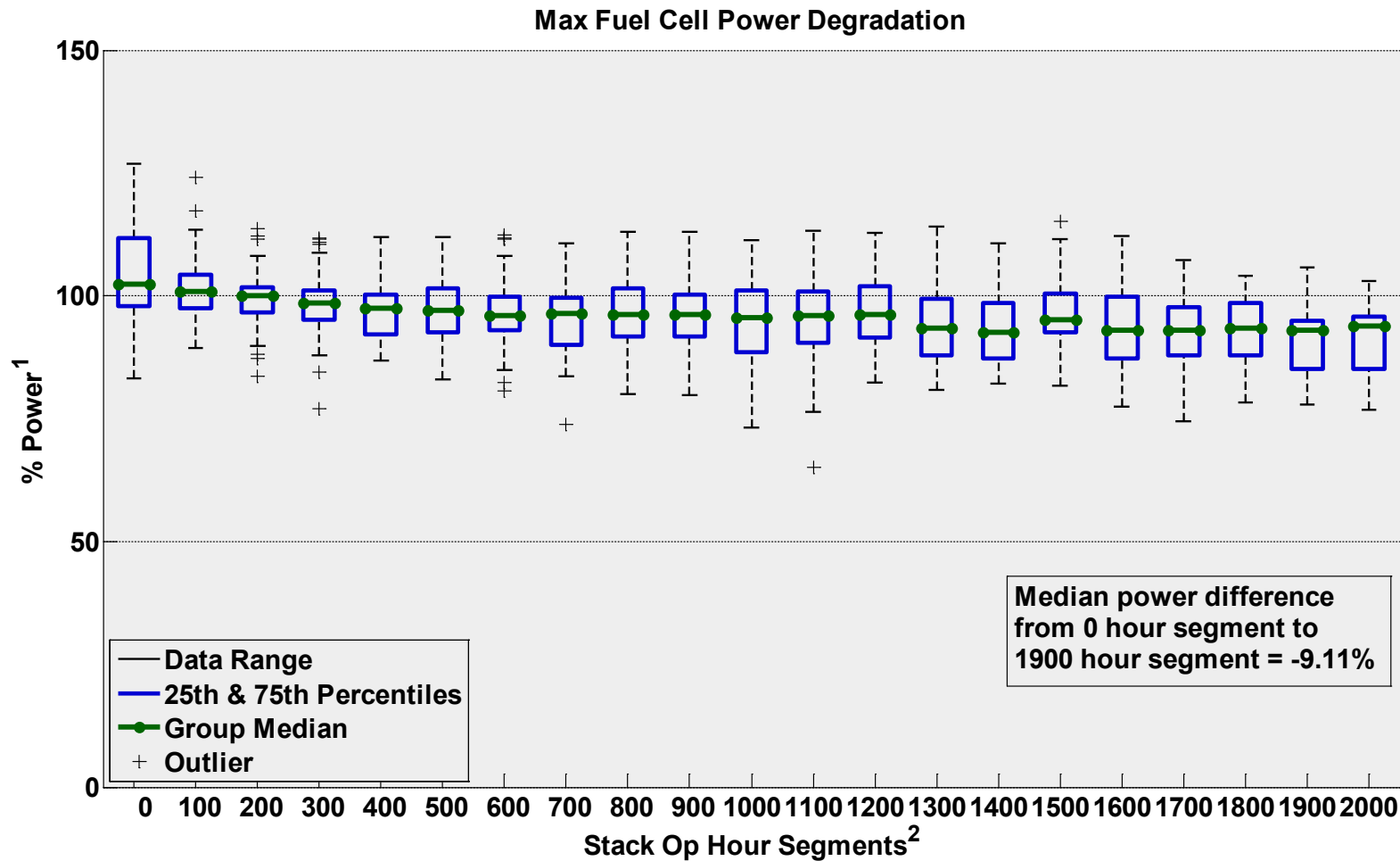
2) Low current is < 10 A.

Effect of Average Trip Speed on Fuel Economy



Effect of Average Trip Length on Fuel Economy





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.

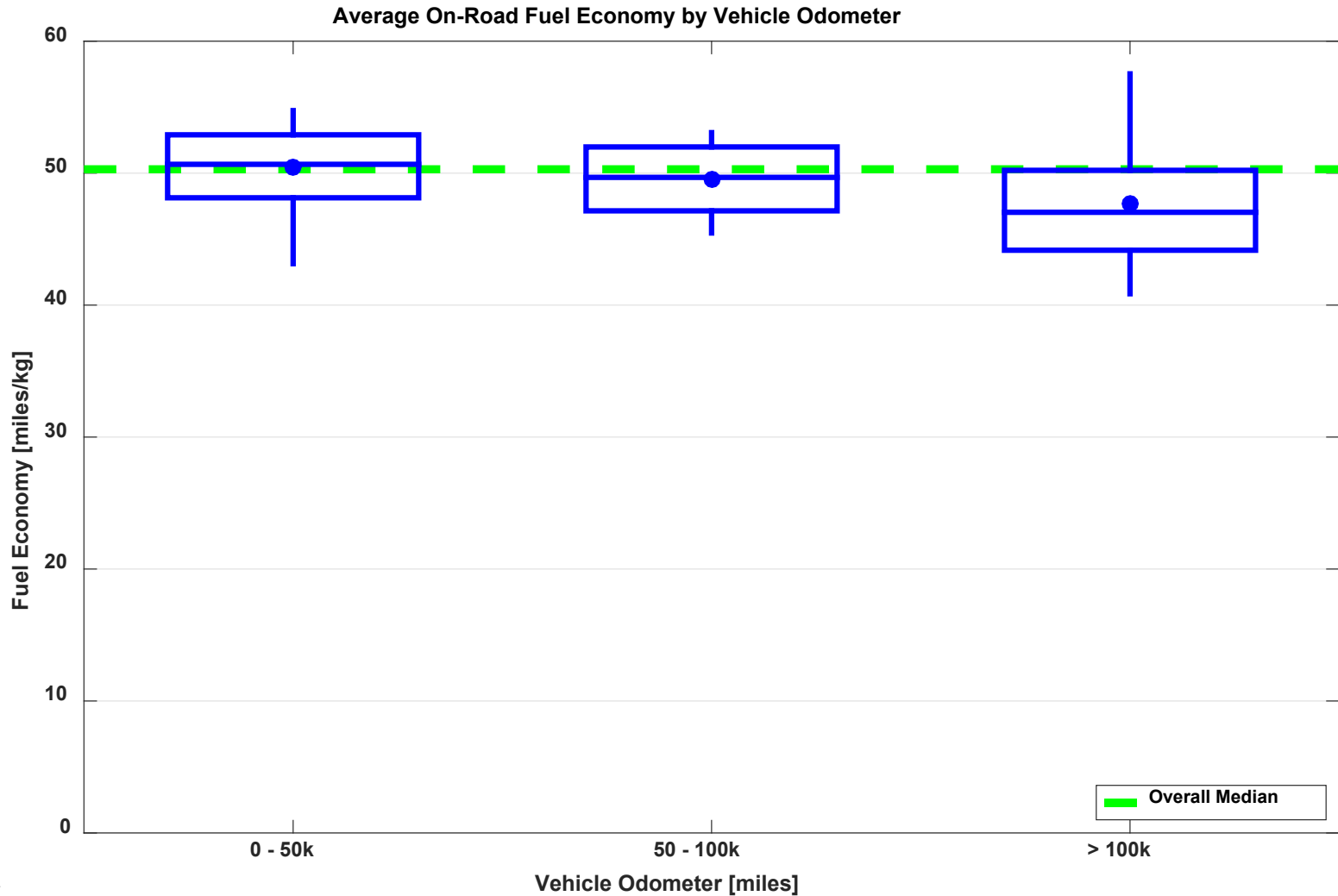


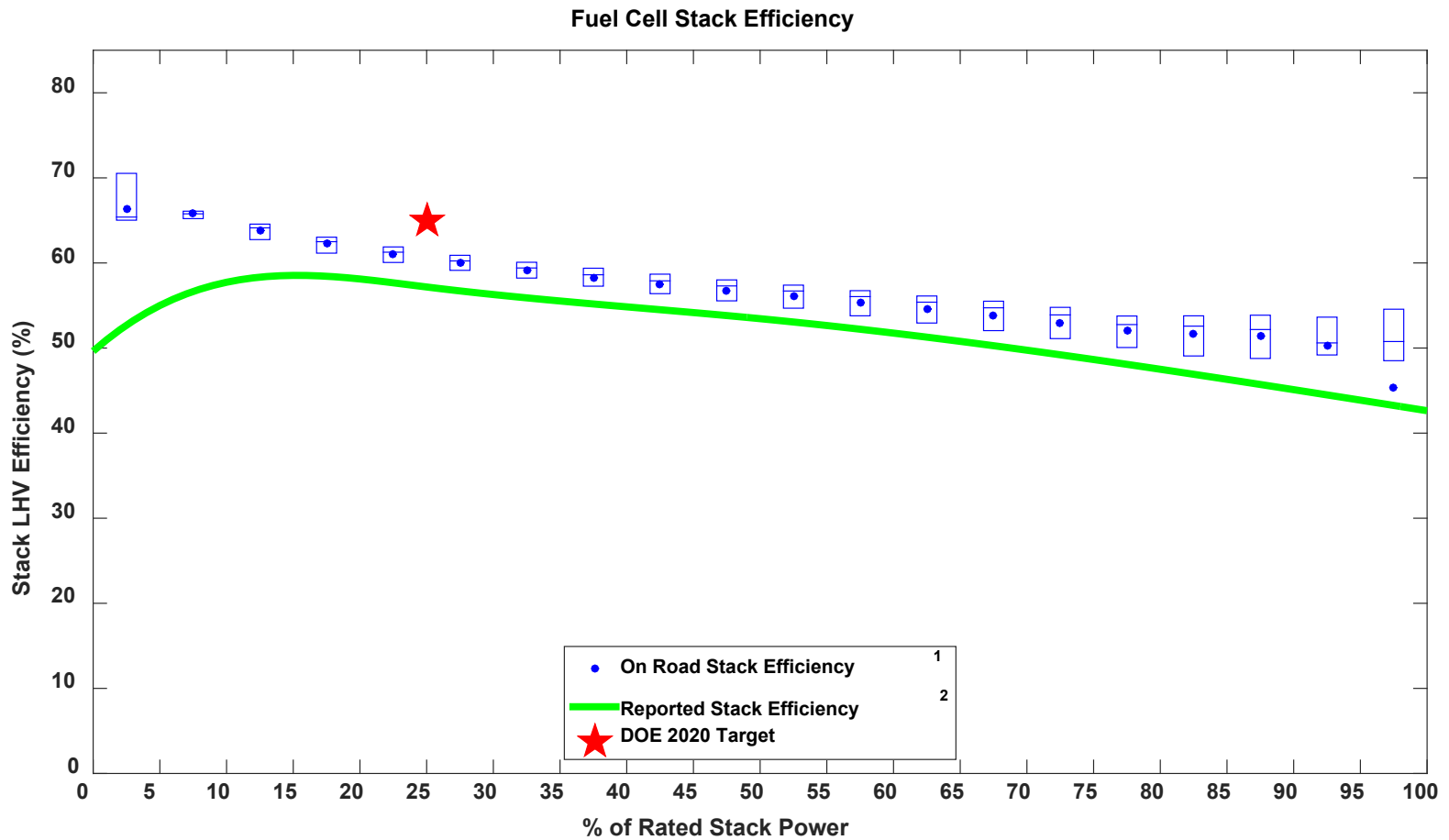
NREL cdp_fcev_43

Created: Oct-31-15 12:54 PM | Data Through: 2015Q2

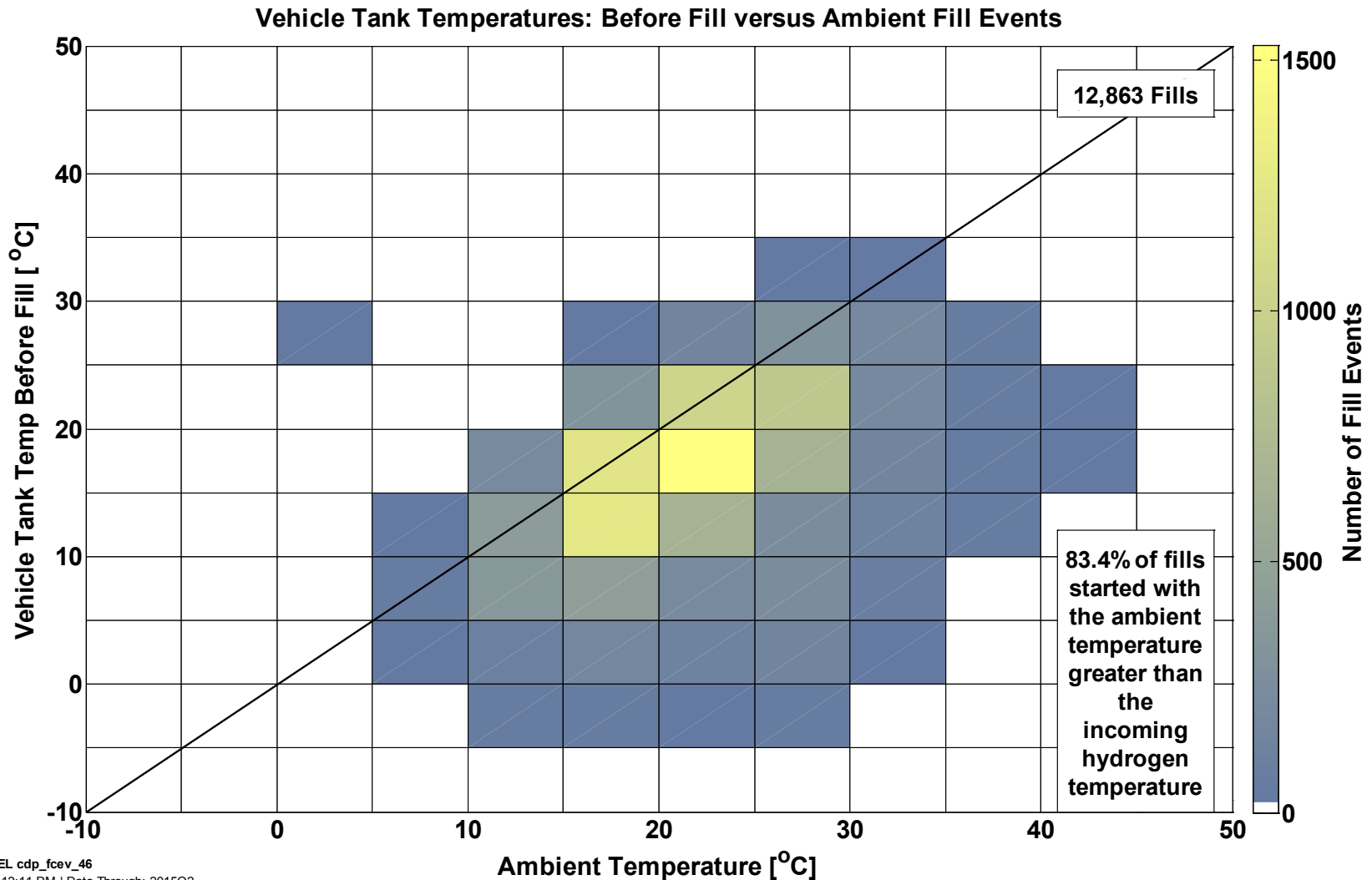
Included Vehicles: Partial

Average On-Road Fuel Economy by Vehicle Odometer





Vehicle Tank Temperatures versus Ambient Temperatures

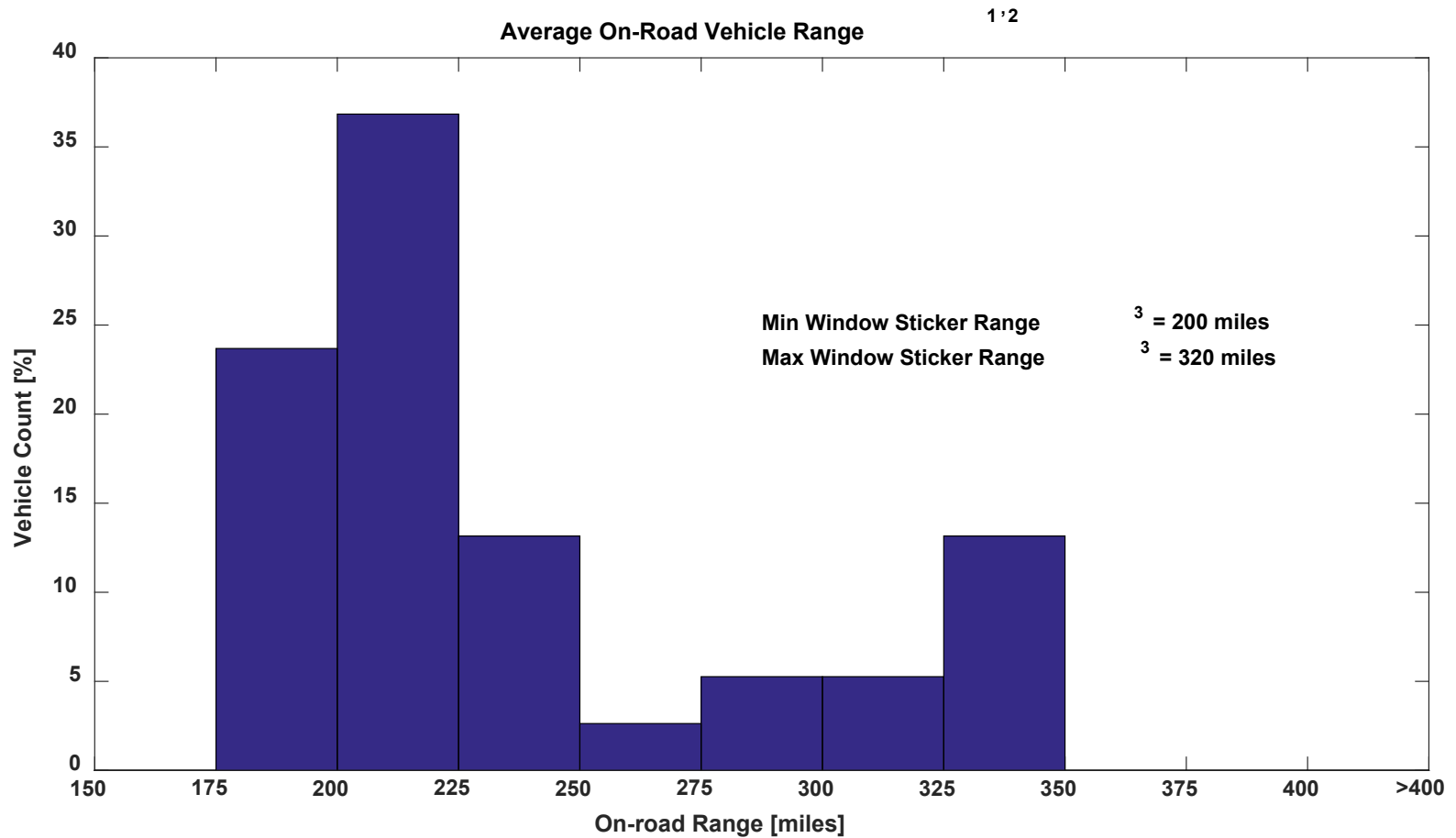


NREL cdp_fcev_46

Created: Oct-30-15 12:11 PM | Data Through: 2015Q2

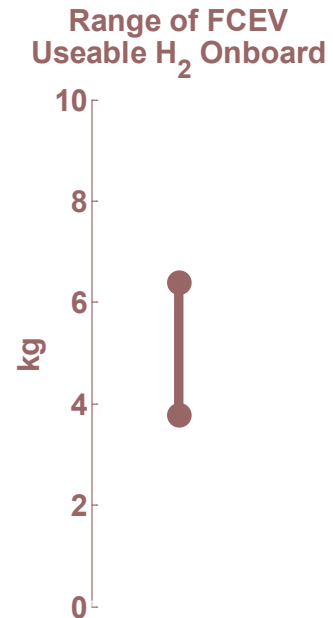
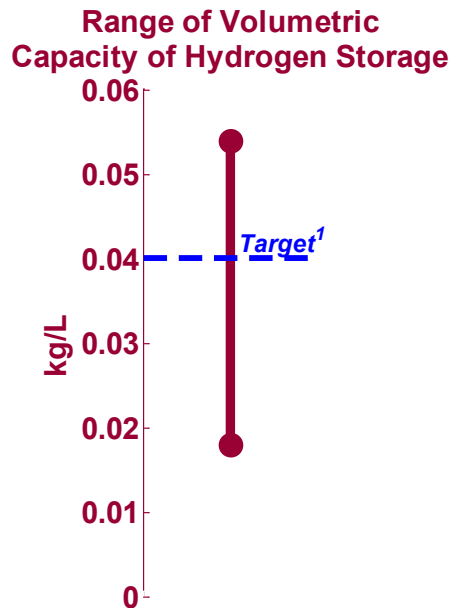
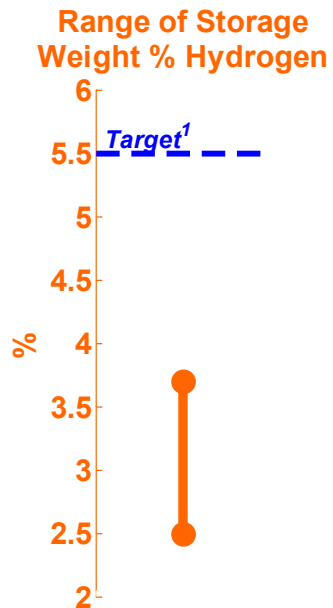
Included Vehicles: Partial

Average On-Road Vehicle Range



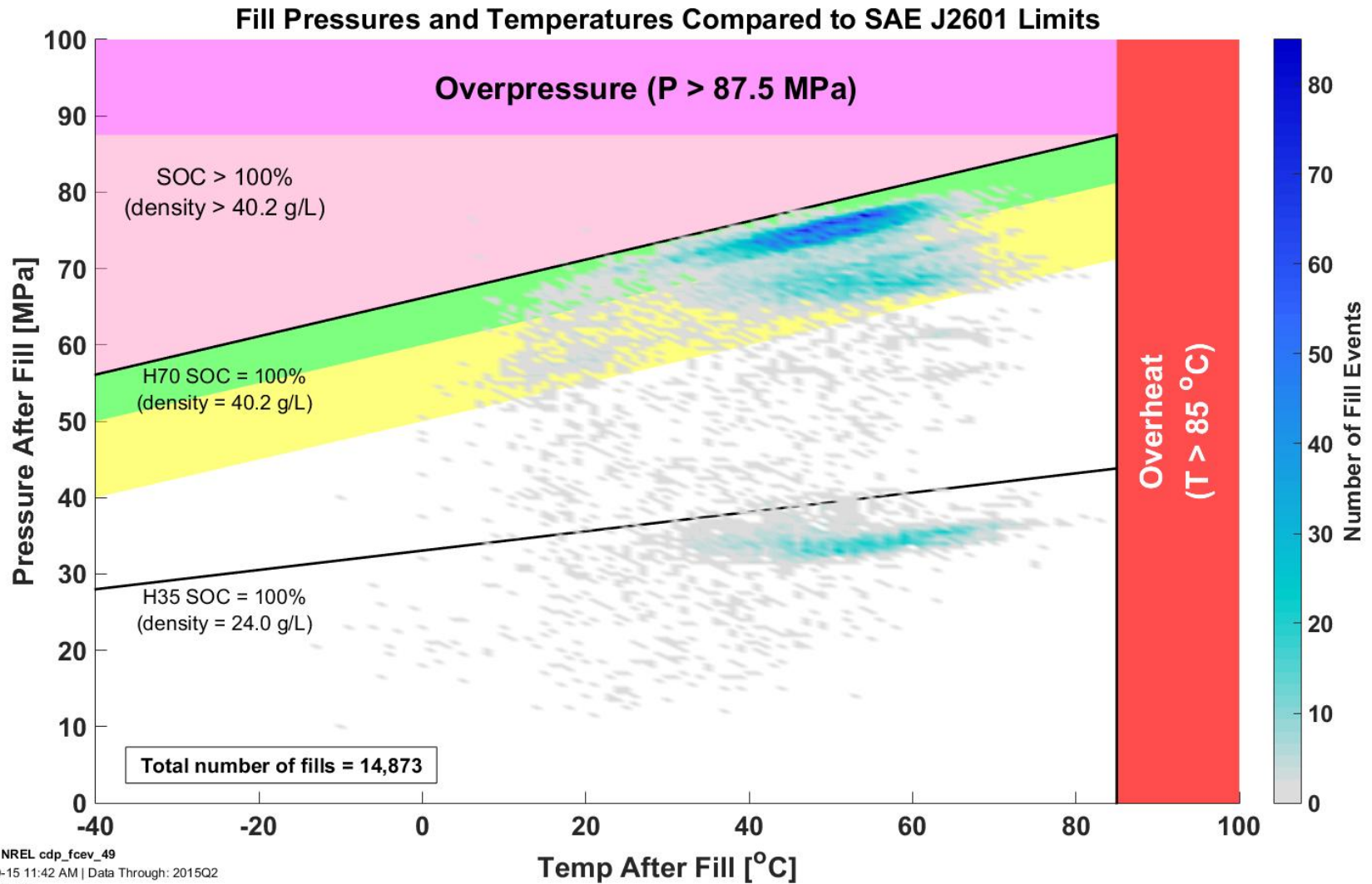
Fuel Cell Electric Vehicle (FCEV) Power Metrics in Evaluation Project

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)

Fill Pressures and Temperatures Compared with SAE J2601 Limits

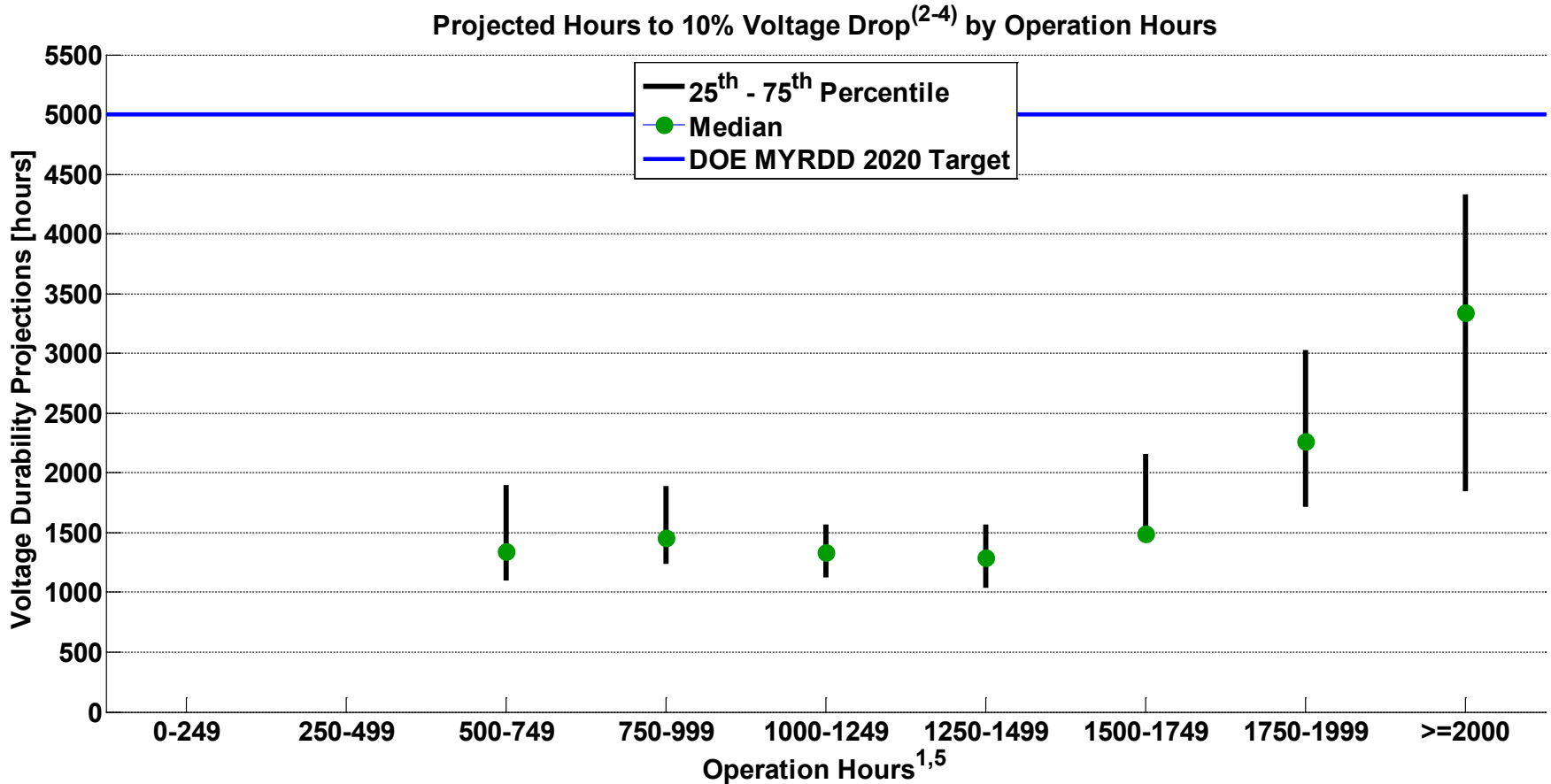


NREL cdp_fcev_49

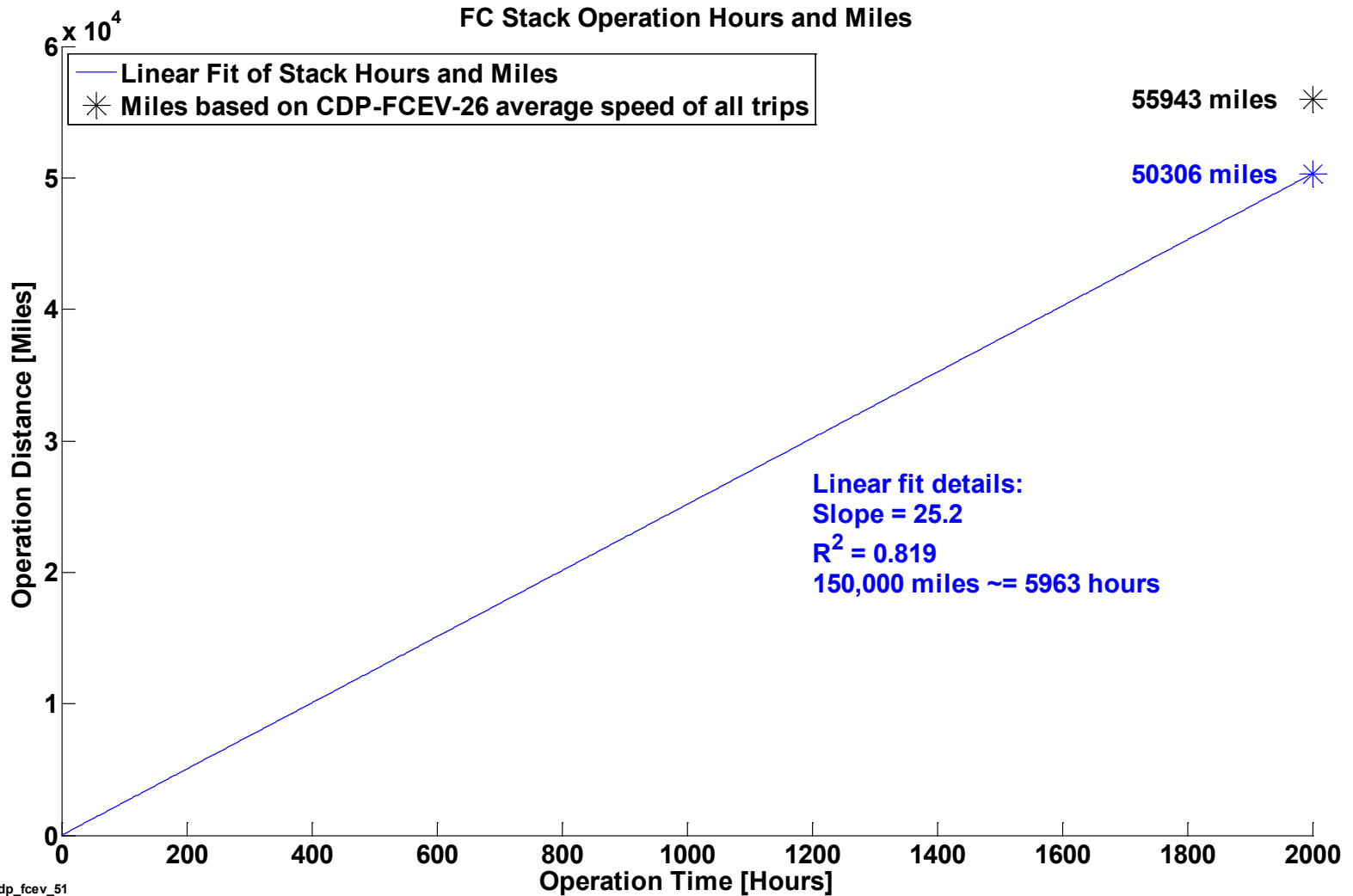
Created: Oct-30-15 11:42 AM | Data Through: 2015Q2

Included Vehicles: All

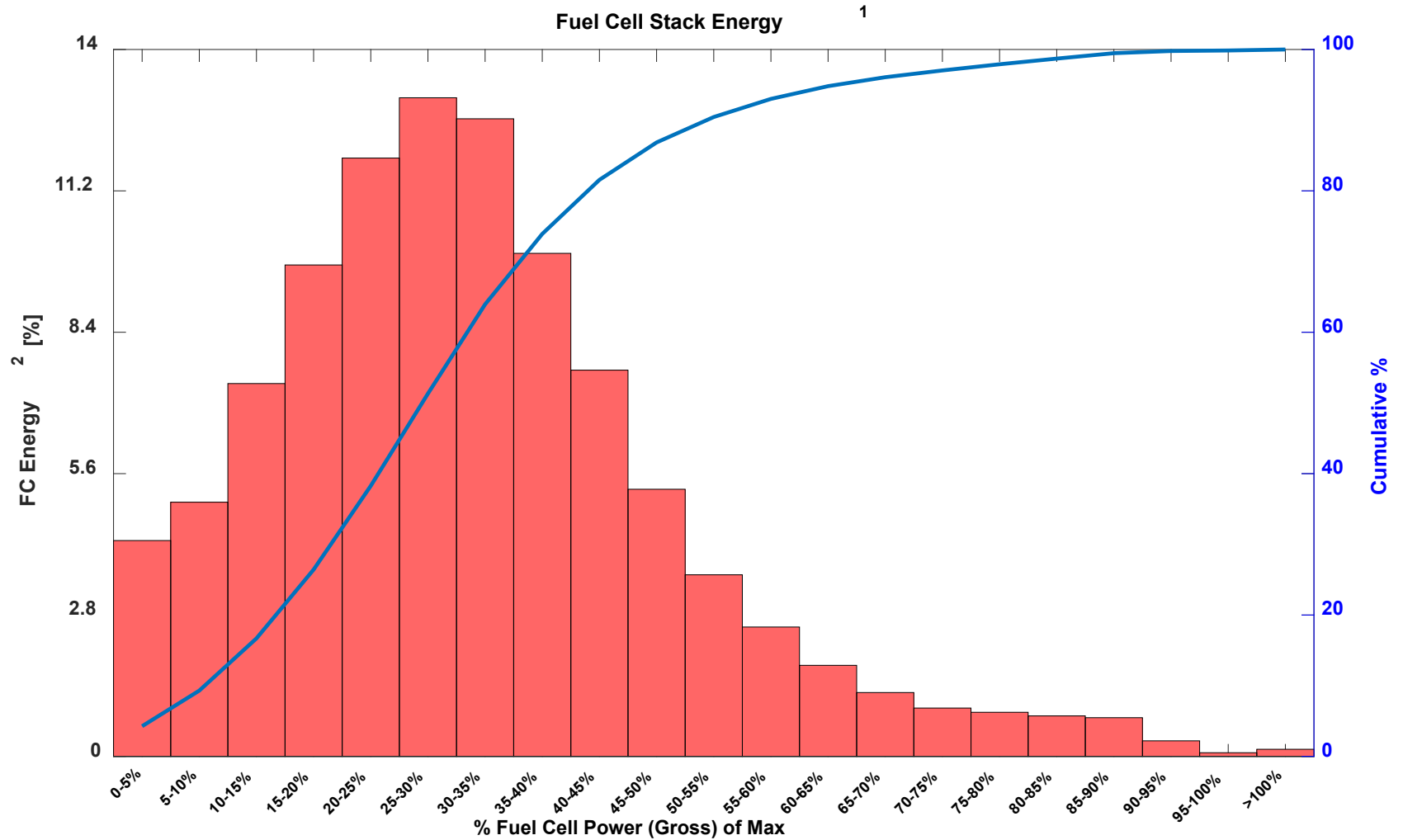
Voltage Degradation Projection by Operation Hours



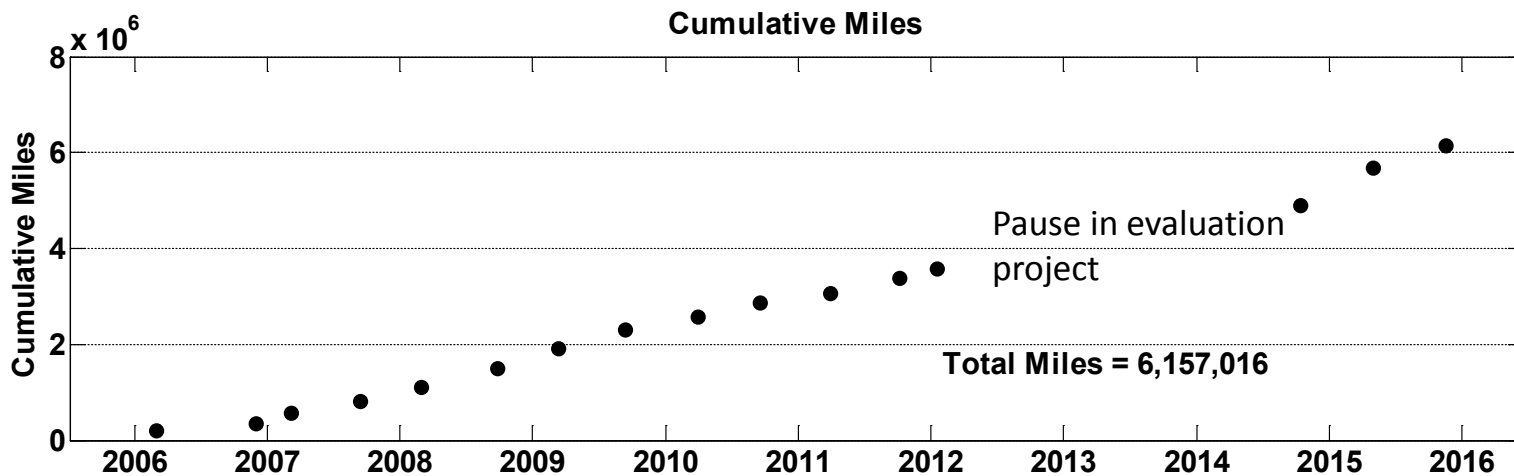
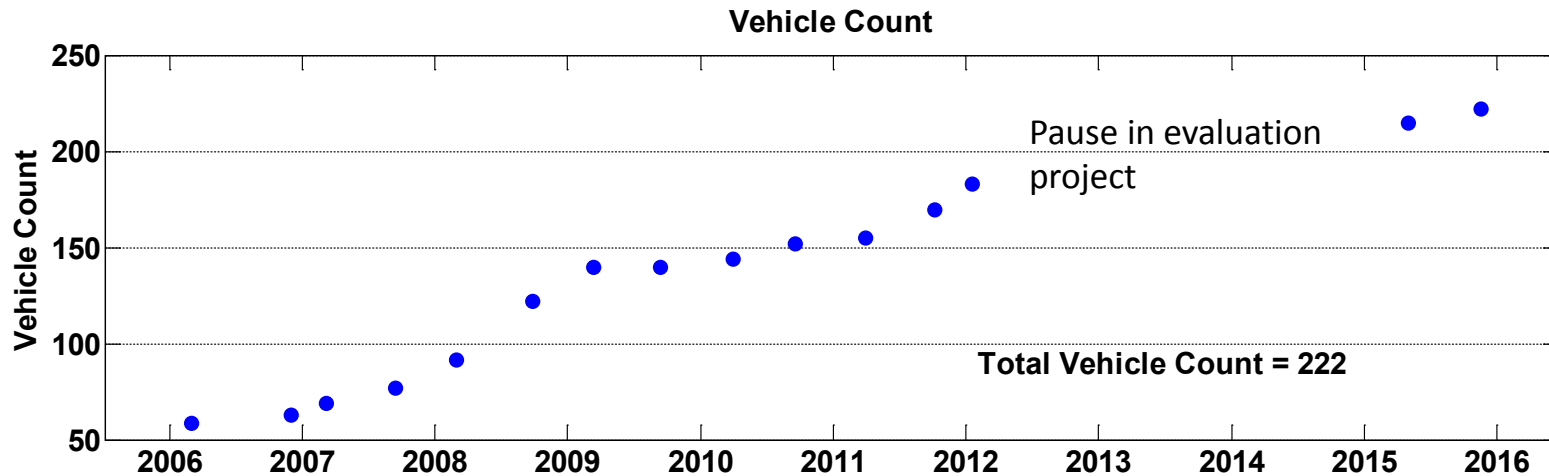
- 1) Statistics by operation hours for individual stacks displayed as long as there were at least 3 stacks in the operation hour group.
- 2) Voltage degradation is measured based on a projected time to a voltage drop, at a high current, level 10% lower than beginning of life voltage. 10% voltage drop level is a DOE metric for assessing fuel cell durability.
- 3) Projections using on-road data are calculated at approximately 55 - 65% rated stack current.
- 4) 10% voltage drop is NOT an indication of an OEM's end-of-life criteria. Projections do not address catastrophic stack failure.
- 5) Maximum FC stack operation hours is 5605. 15.4% stacks with more than 2,000 hours.



Fuel Cell Stack Energy at Power Levels



Cumulative Vehicle Count and Miles Since 2006



NREL cdp_fcev_53

Created: Oct-30-15 10:45 AM | Data Through: 2015Q2

Included Vehicles: All