



**Technical Report**  
NREL/TP-5400-60795  
November 2013

# ARRA Material Handling Equipment Composite Data Products

## Data through Quarter 2 of 2013

J. Kurtz, S. Sprik, C. Ainscough, G. Saur, M. Post, and M. Peters

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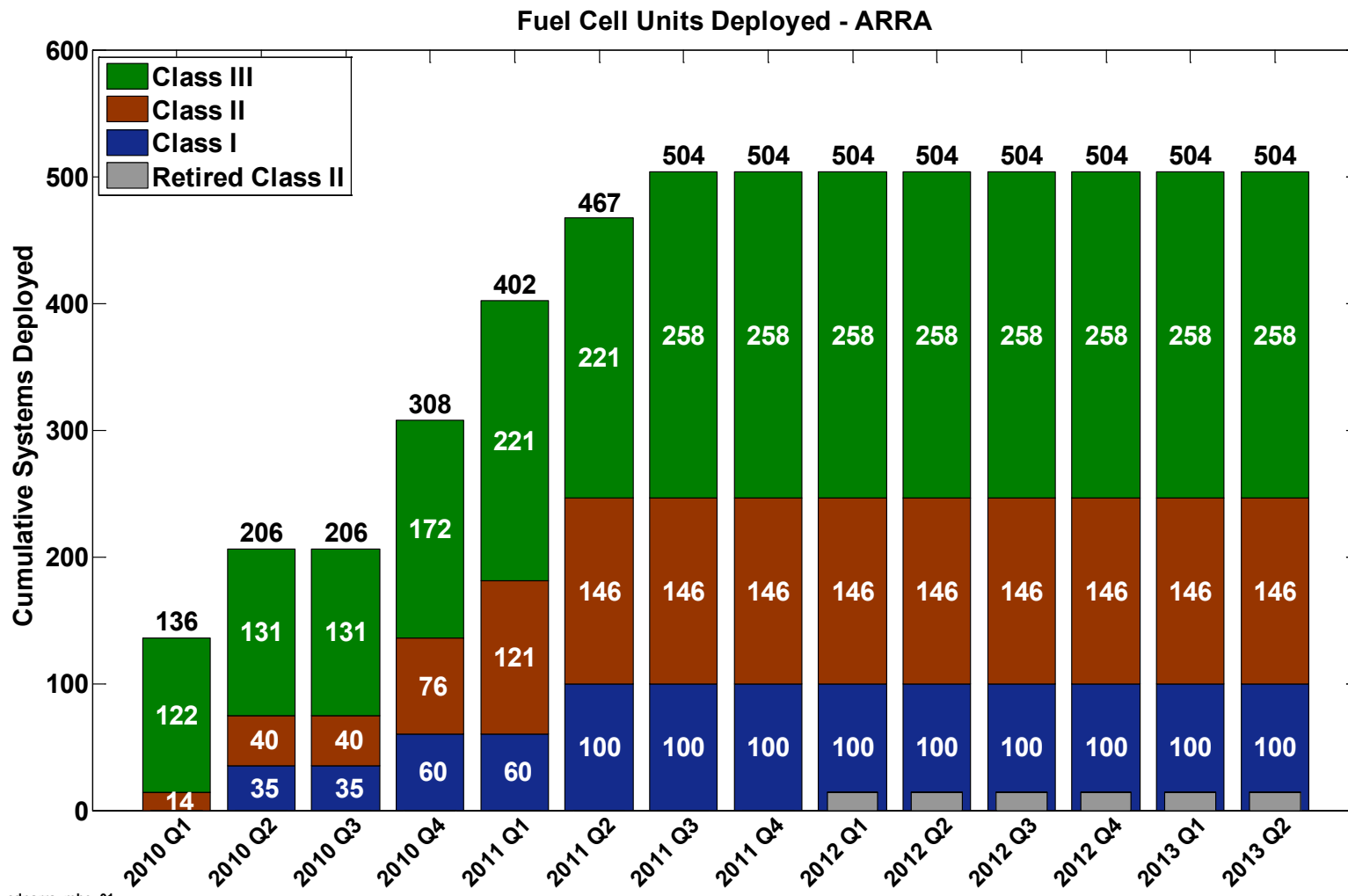
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Cover Photos: (left to right) PIX 16416, PIX 17423, PIX 16560, PIX 17613, PIX 17436, PIX 17721



Printed on paper containing at least 50% wastepaper, including 10% post consumer waste.

## Fuel Cell MHE Systems Deployed

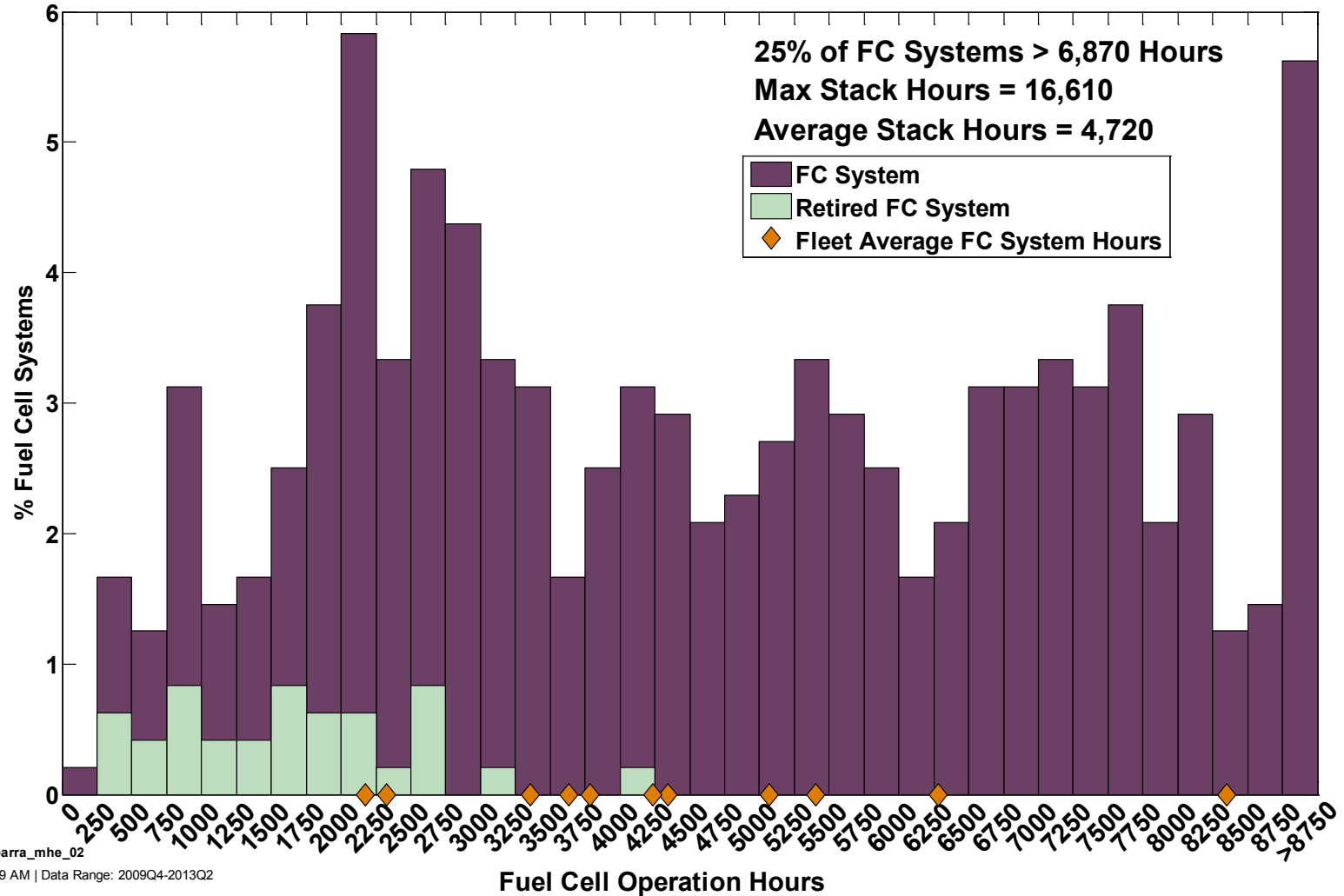


NREL cdparra\_mhe\_01

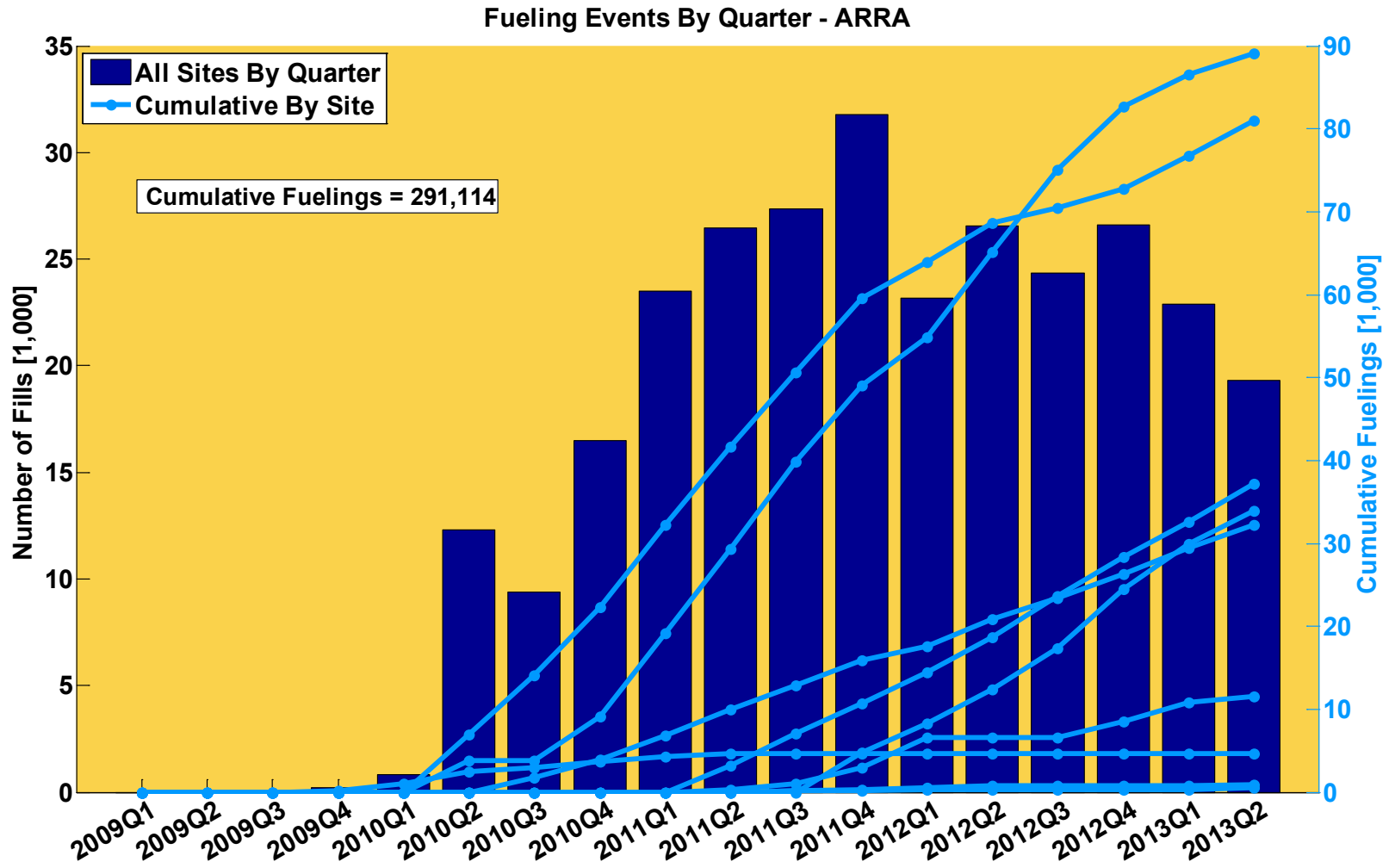
Created: Sep-27-13 3:34 PM | Data Range: 2010Q1-2013Q2

## Fuel Cell System Operation Hours

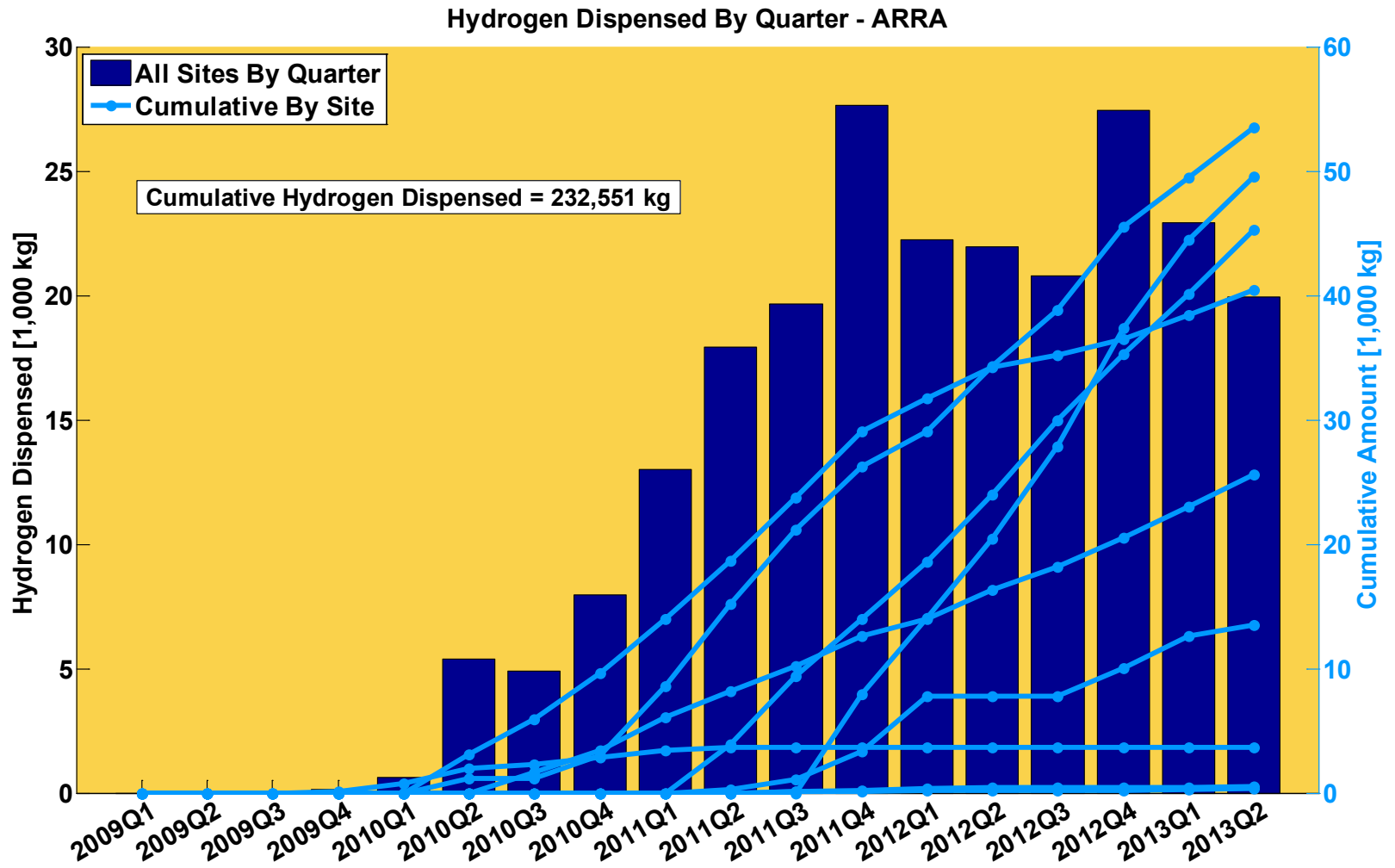
Cumulative Fuel Cell Operation Hours - ARRA  
Combined Fleet Through 2013Q2

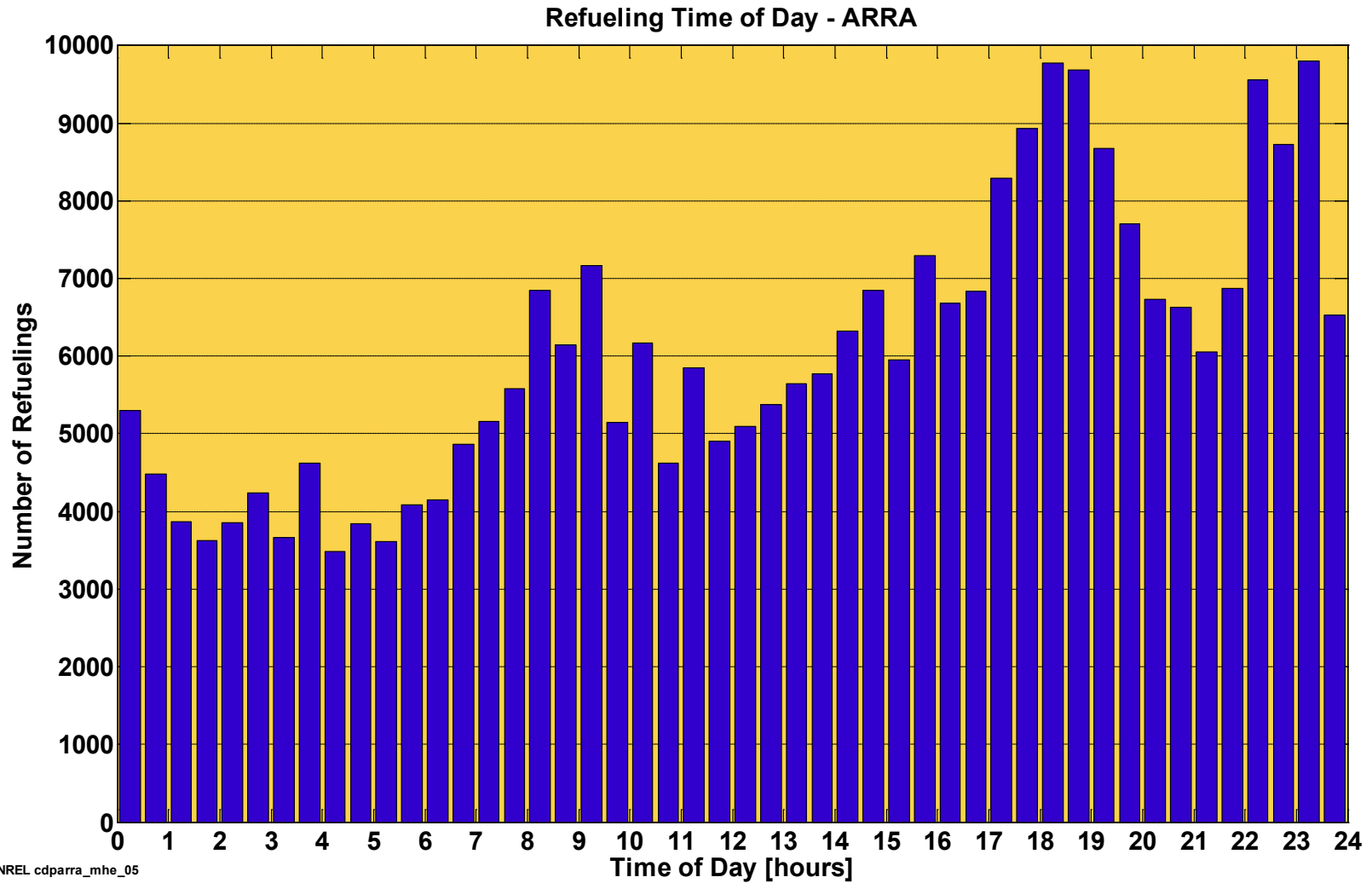


## Fueling Events by Quarter



## Hydrogen Dispensed by Quarter



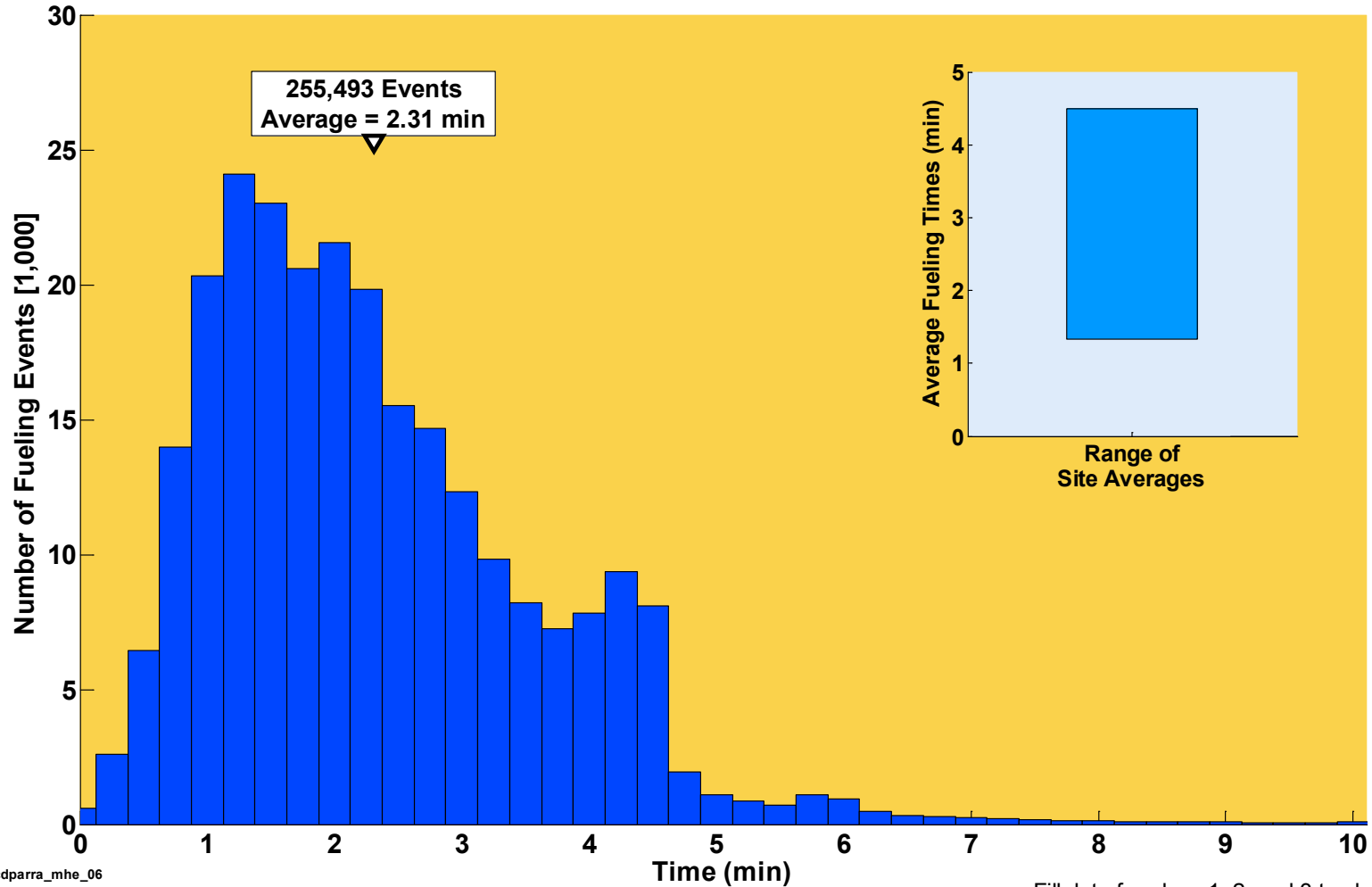


NREL cdparra\_mhe\_05

Created: Sep-27-13 4:10 PM | Data Range: 2009Q4-2013Q2

## Histogram of Fueling Times

Histogram of Fueling Times  
ARRA Combined Fleet



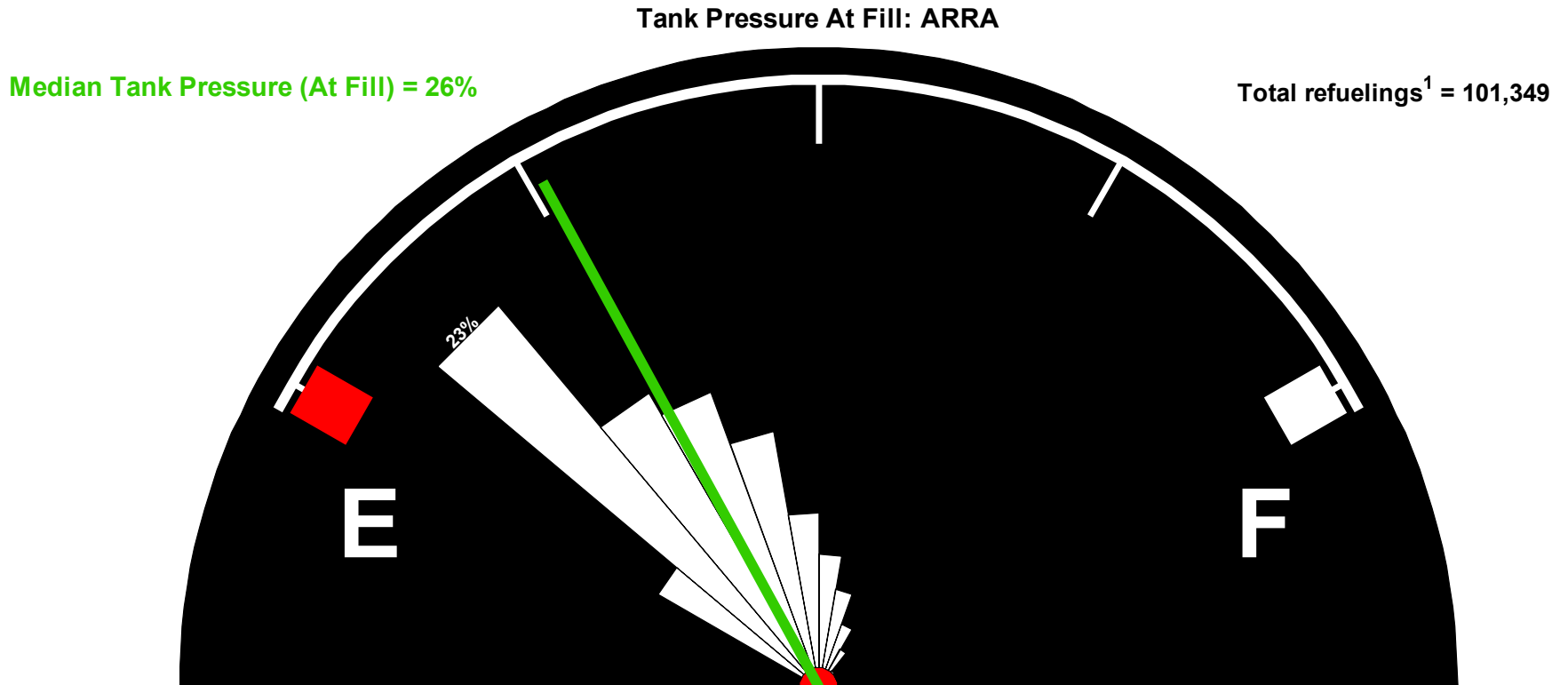
NREL cdparramhe\_06

Created: Sep-26-13 5:13 PM | Data Range: 2009Q4-2013Q2

Fill data for class 1, 2, and 3 trucks



## Tank Pressure Level at Fueling



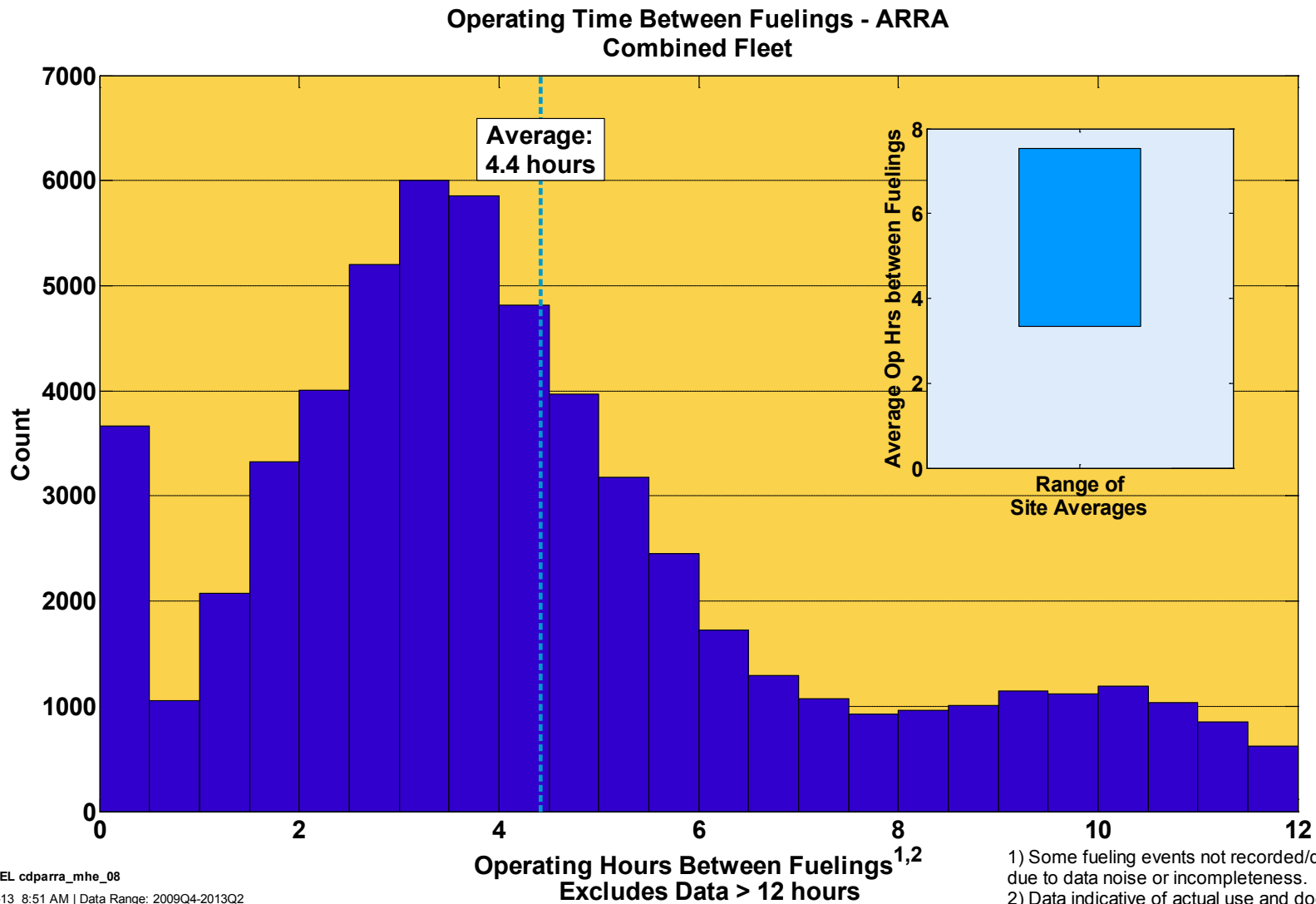
1. Some refueling events not recorded/detected due to data noise or incompleteness.
2. The outer arc is set at 30% total refuelings.
3. Full Pressure is either 3600 psi or 5000 psi.



NREL cdparra\_mhe\_07

Created: Sep-27-13 3:40 PM | Data Range: 2010Q1-2013Q2

## Operation Time Between Fueling



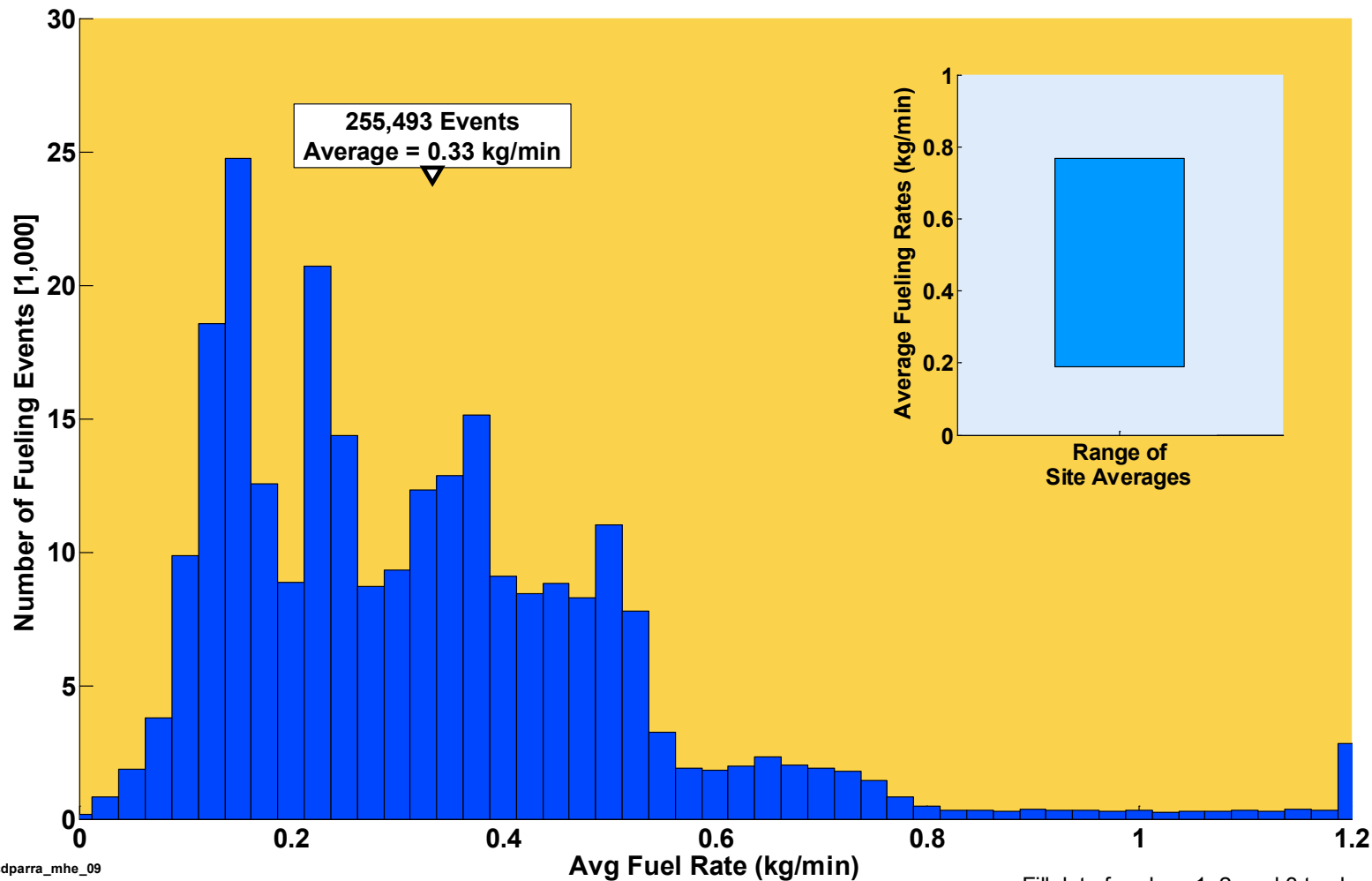
NREL cdparramhe\_08

Created: Sep-26-13 8:51 AM | Data Range: 2009Q4-2013Q2

- 1) Some fueling events not recorded/detected due to data noise or incompleteness.
- 2) Data indicative of actual use and does not represent the max capability of the systems.

## Histogram of Fueling Rates

Histogram of Fueling Rates  
ARRA Combined Fleet



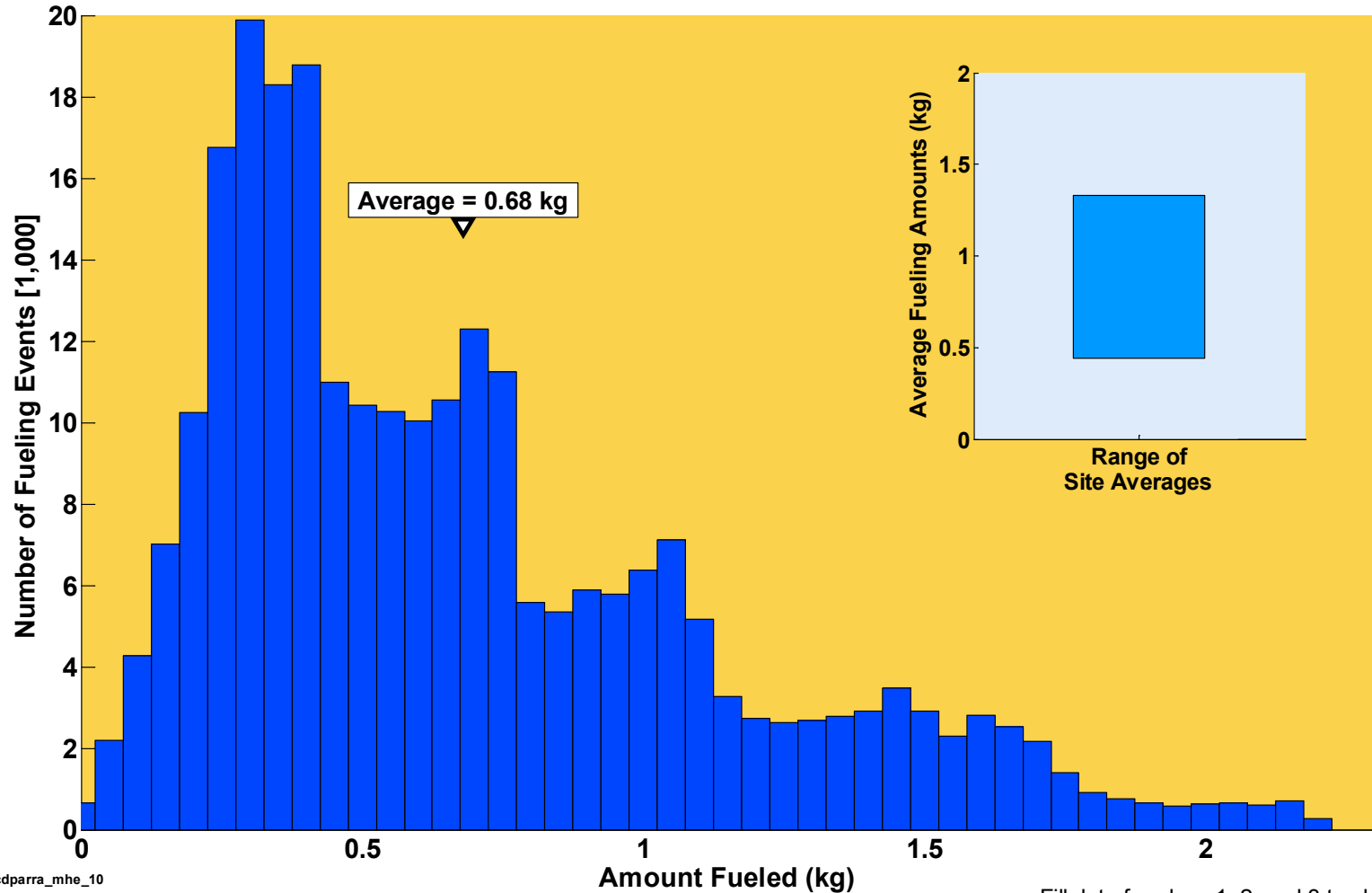
NREL cdparramhe\_09

Created: Sep-28-13 12:00 PM | Data Range: 2009Q4-2013Q2

Fill data for class 1, 2, and 3 trucks

## Histogram of Fueling Amounts

Histogram of Fueling Amounts  
ARRA Combined Fleet



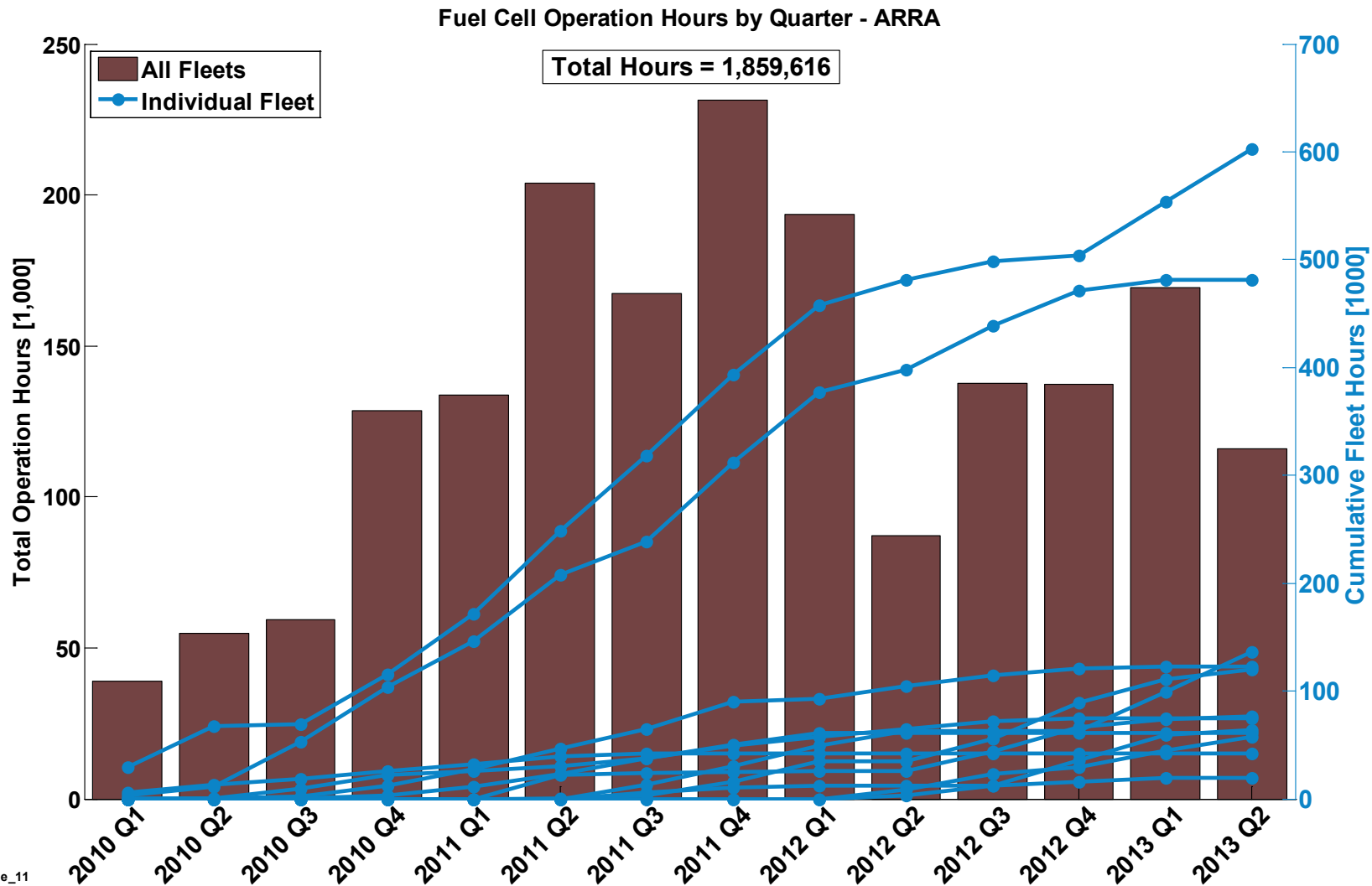
NREL cdparramhe\_10

Created: Sep-28-13 12:10 PM | Data Range: 2009Q4-2013Q2

Fill data for class 1, 2, and 3 trucks

# CDPARRA-MHE-11

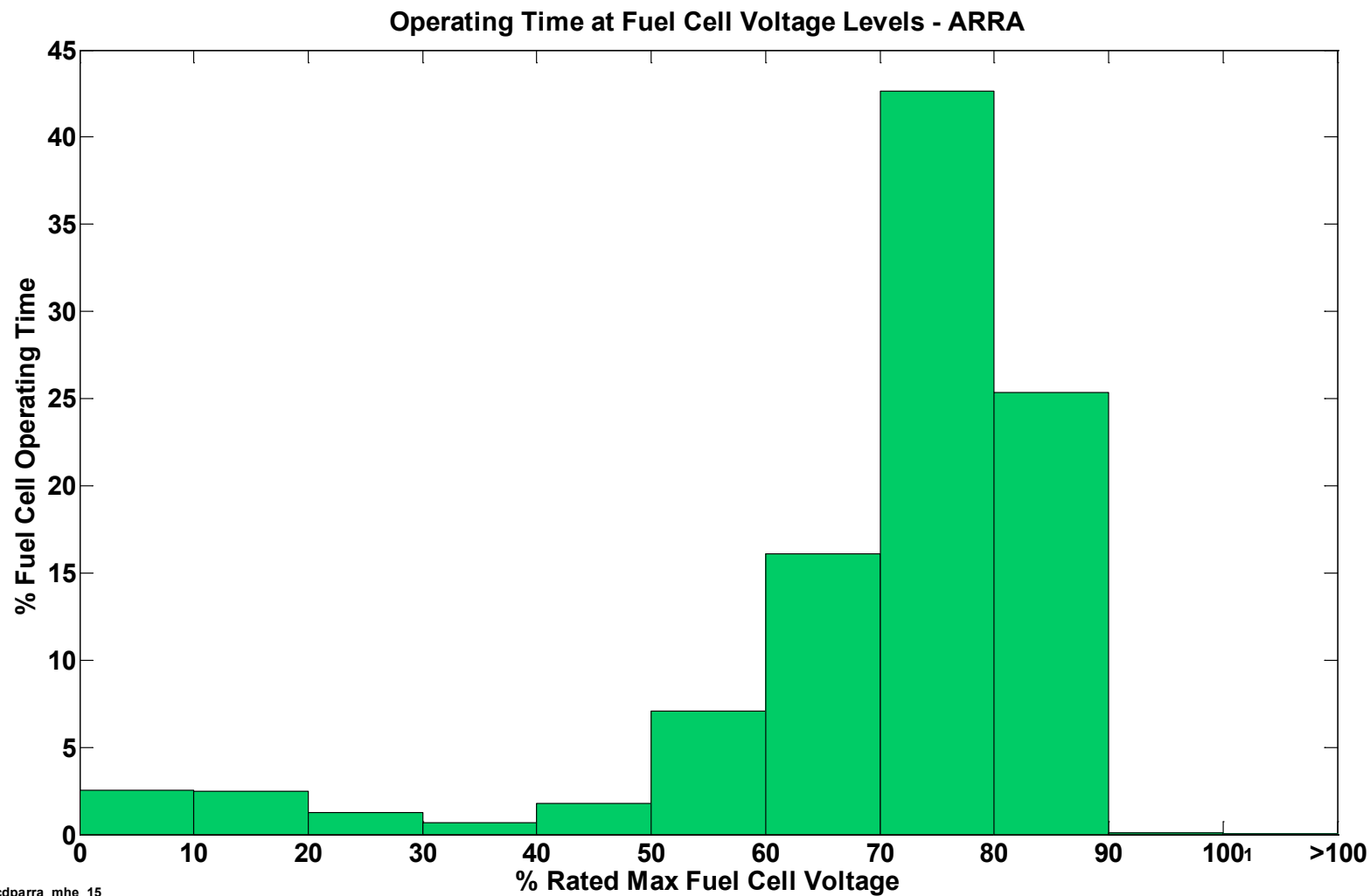
## Fuel Cell Operation Hours by Quarter



NREL cdparra\_mhe\_11

Created: Sep-30-13 9:55 AM | Data Range: 2009Q4-2013Q2

## Operating Time at Fuel Cell Voltage Levels

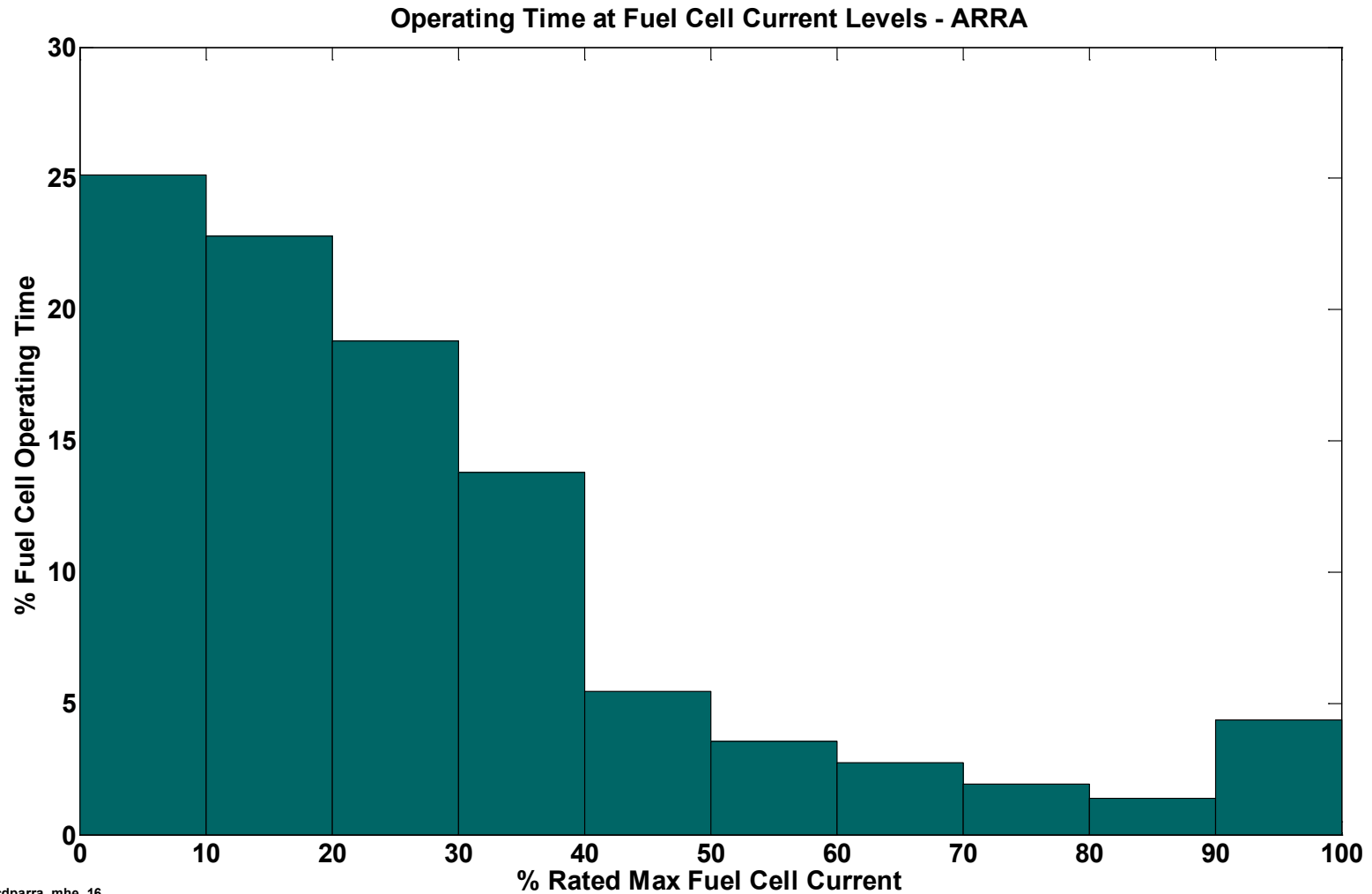


NREL cdparra\_mhe\_15

Created: Sep-30-13 9:58 AM | Data Range: 2009Q4-2013Q2

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

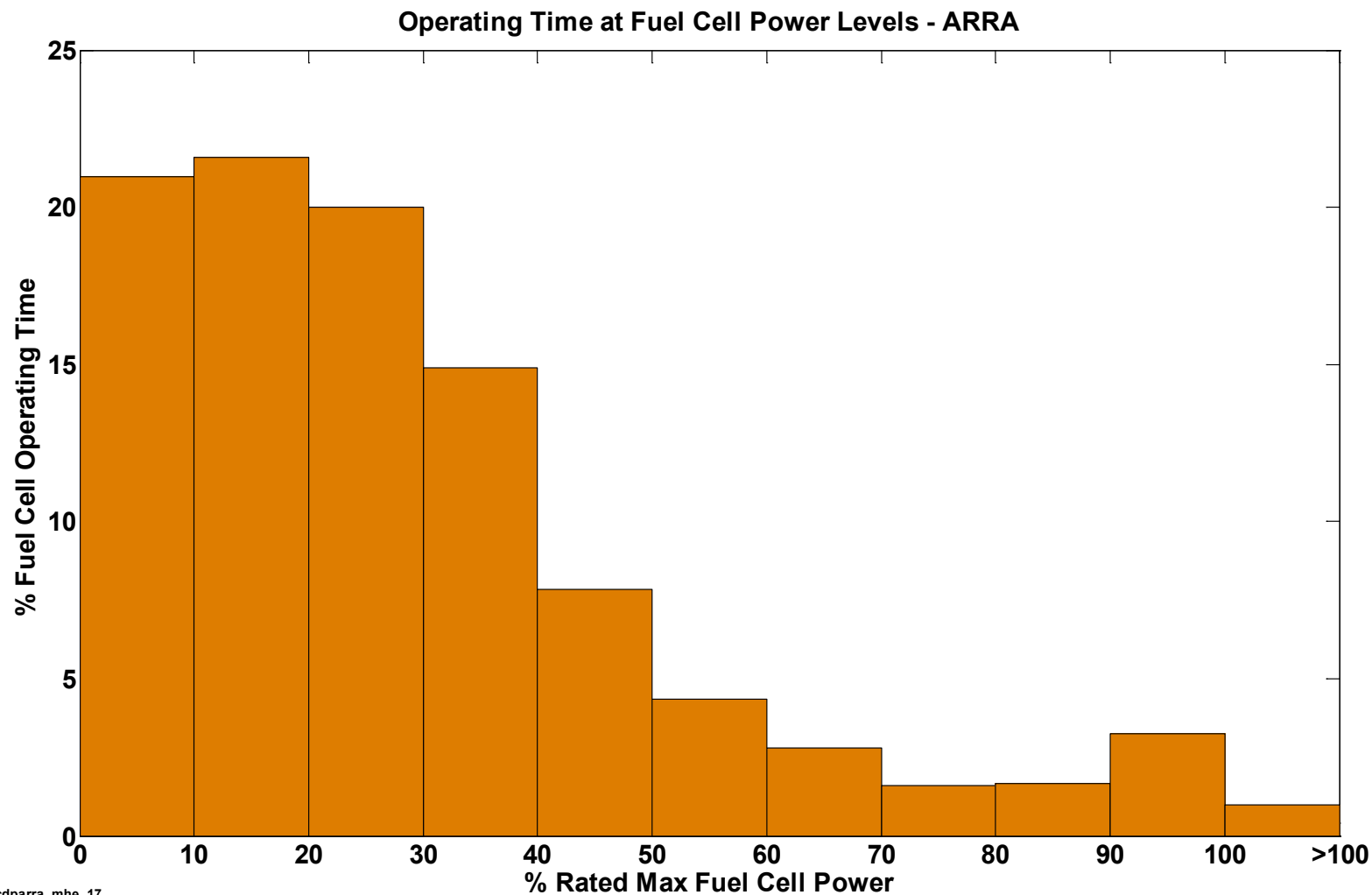
## Operating Time at Fuel Cell Current Levels



NREL cdparra\_mhe\_16

Created: Sep-30-13 9:58 AM | Data Range: 2009Q4-2013Q2

## Operating Time at Fuel Cell Power Levels



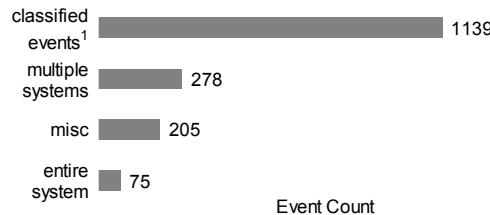
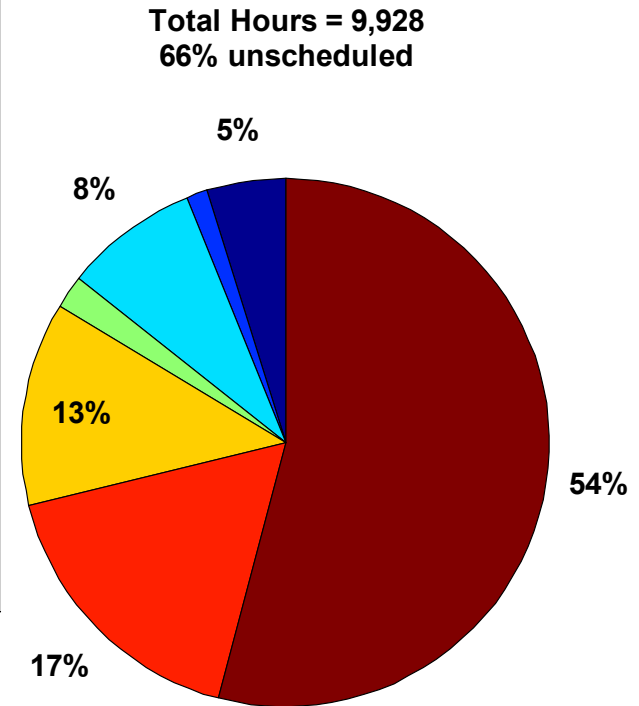
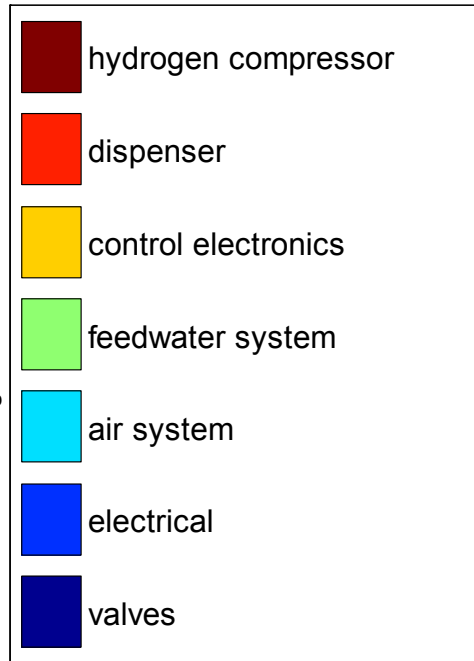
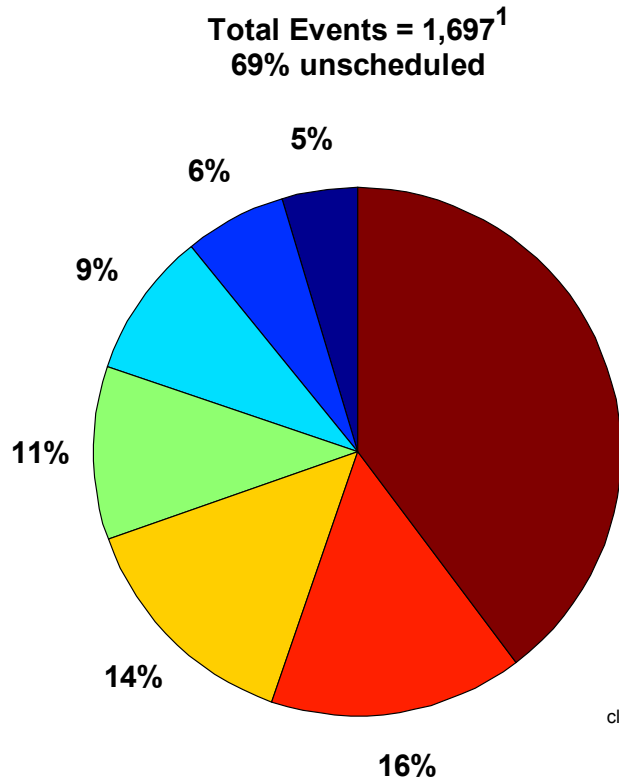
NREL cdparra\_mhe\_17

Created: Sep-30-13 9:59 AM | Data Range: 2009Q4-2013Q2



## Infrastructure Maintenance by Category

### Infrastructure Maintenance By Equipment Type

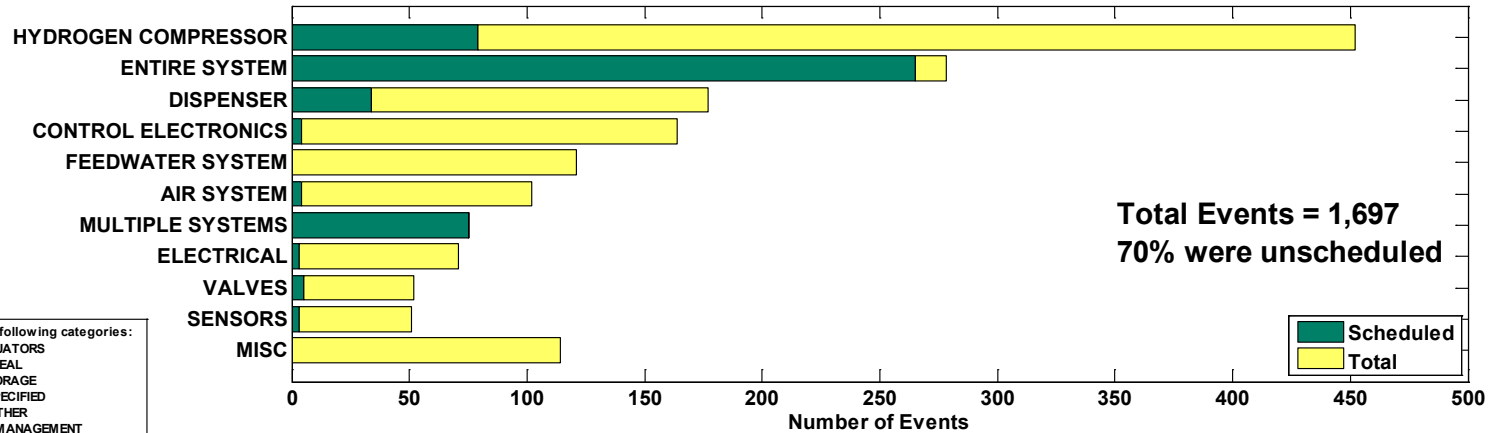


MISC includes the following failure modes: actuators, seal, storage, unspecified, thermal management, safety, software, fuel system, fittings&piping, reformer, sensors, other



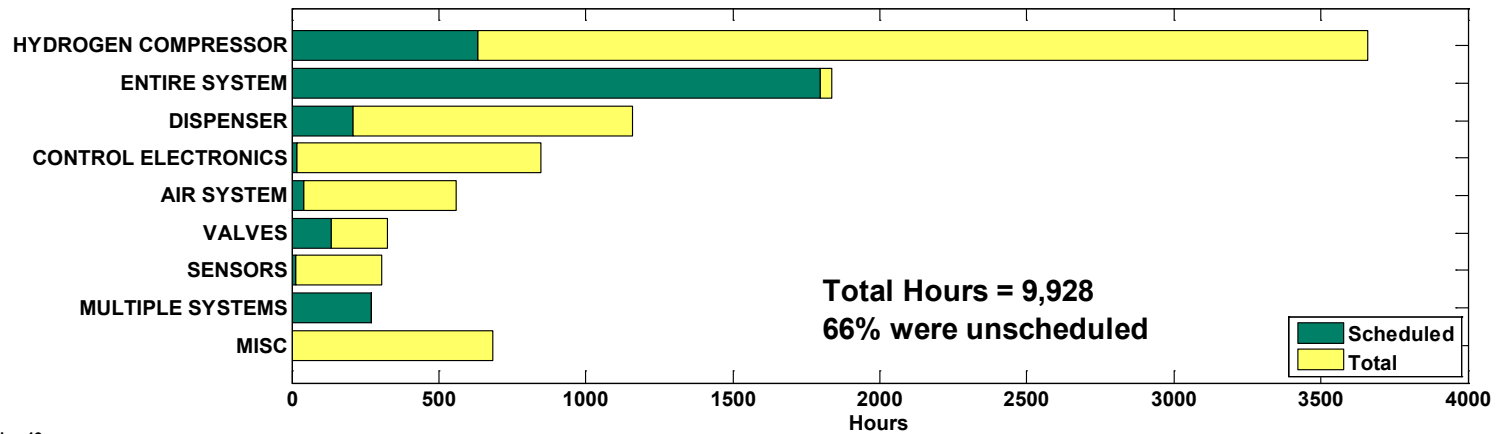
## Infrastructure Scheduled and Unscheduled Maintenance by Category

Infrastructure Maintenance Scheduled vs. Unscheduled  
Number of Maintenance Events by Category

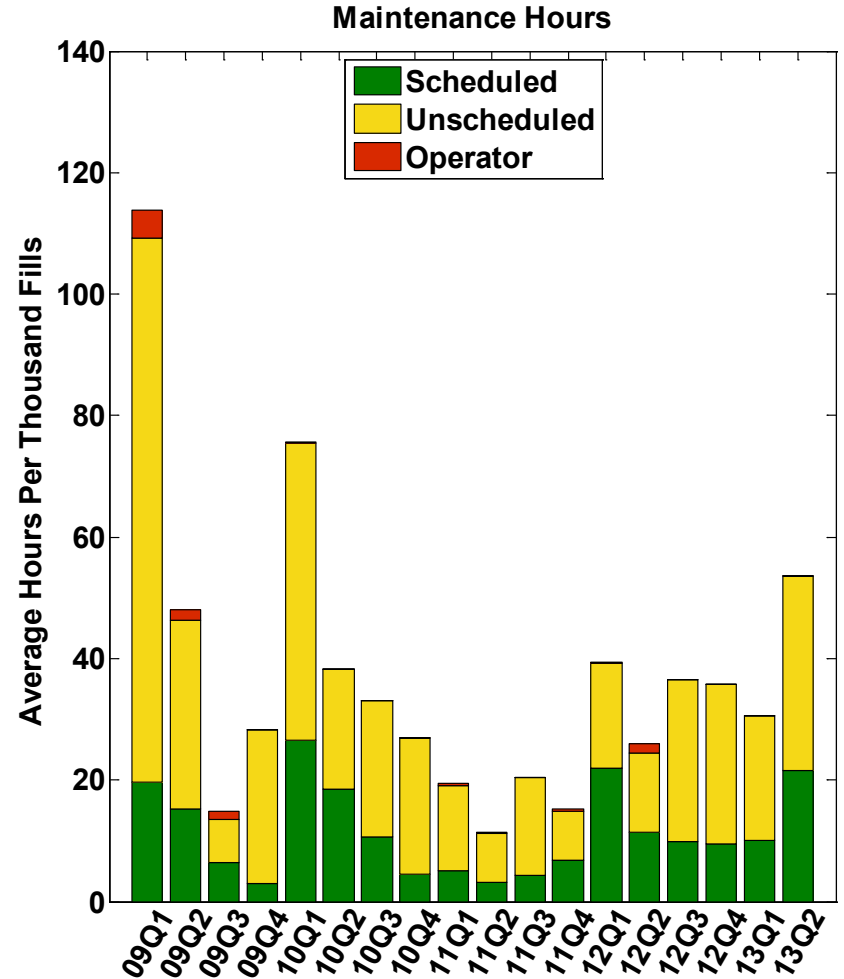
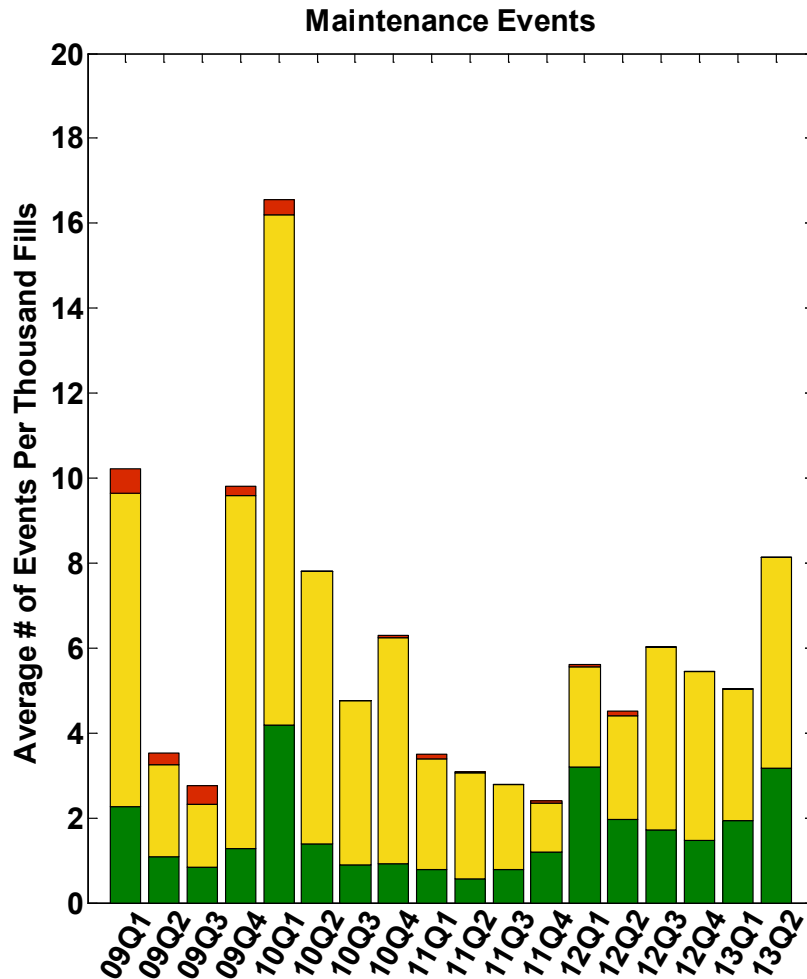


MISC includes the following categories:  
 ACTUATORS  
 SEAL  
 STORAGE  
 UNSPECIFIED  
 OTHER  
 THERMAL MANAGEMENT  
 SAFETY  
 SOFTWARE  
 FUEL SYSTEM  
 FITTINGS&PIPING  
 REFORMER

Number of Labor Hours by Category



### Average Infrastructure Site Quarterly Maintenance



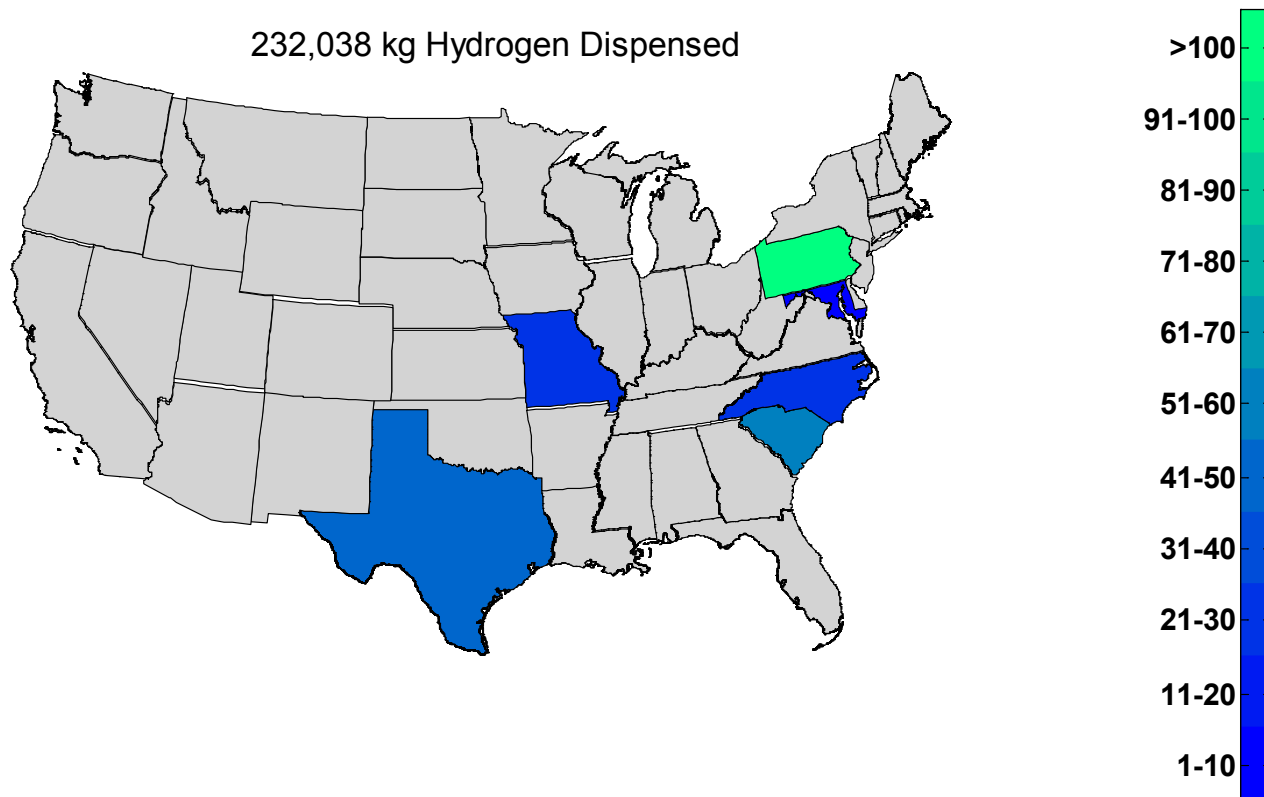
NREL cdp\_mhe\_20

Created: Sep-30-13 9:57 AM | Data Range: 2009Q1-2013Q2

## Average Daily Hydrogen Dispensed by Location

Average Daily Hydrogen Dispensed by Location - ARRA

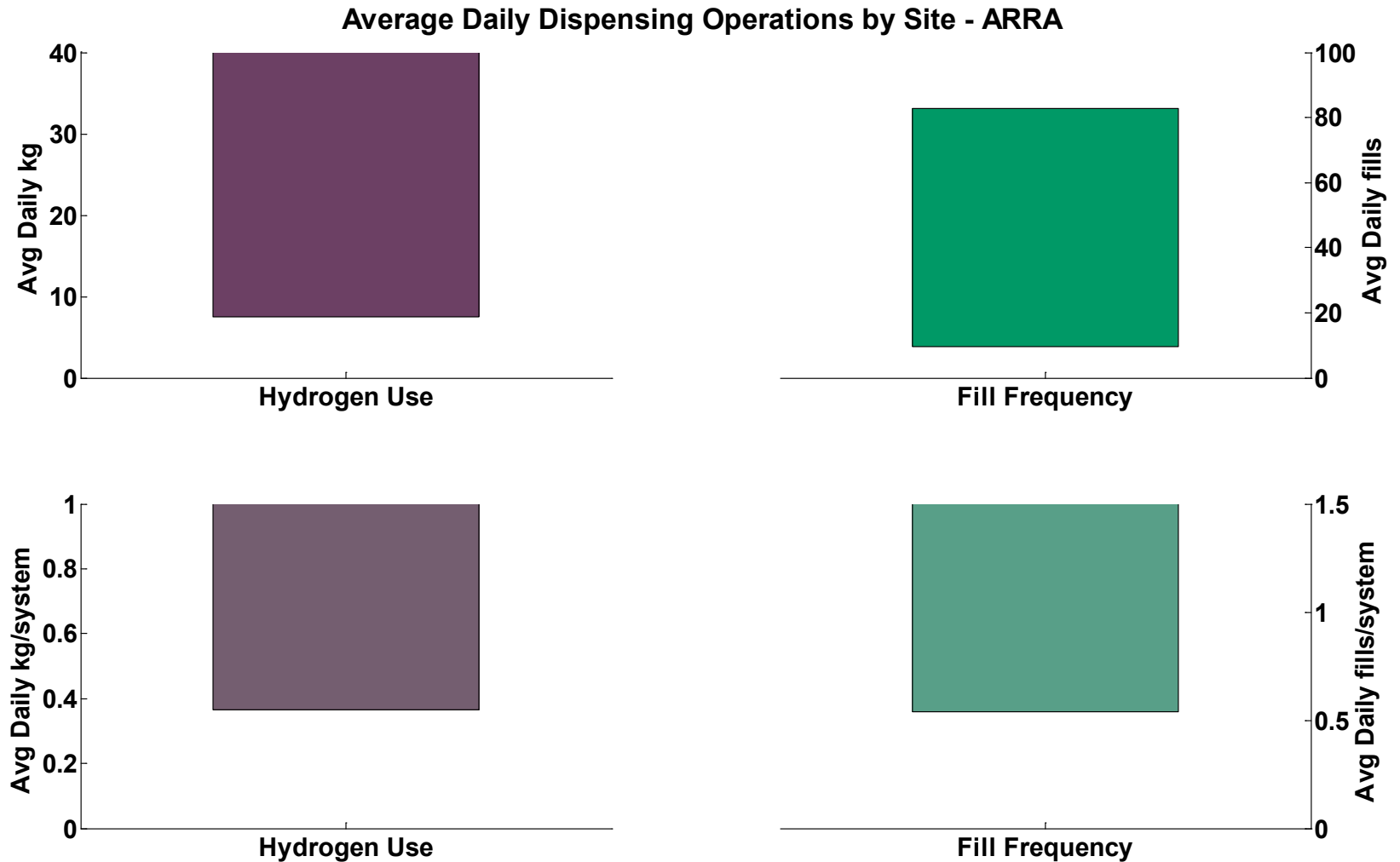
232,038 kg Hydrogen Dispensed



NREL cdparra\_mhe\_21

Created: Sep-26-13 8:52 AM | Data Range: 2010Q1-2013Q2

## Average Daily Dispensing Operations by Site

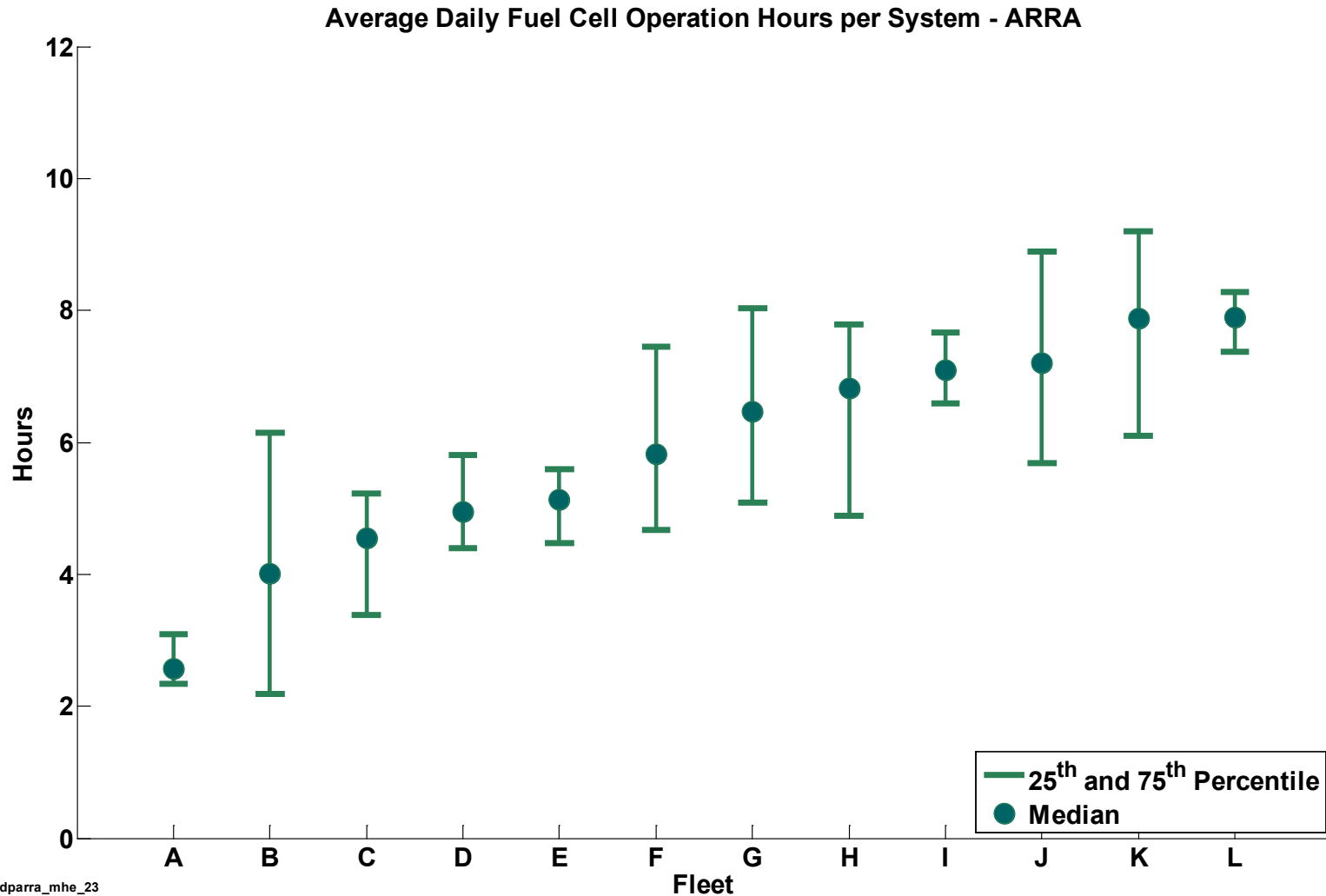


NREL cdparrar\_mhe\_22

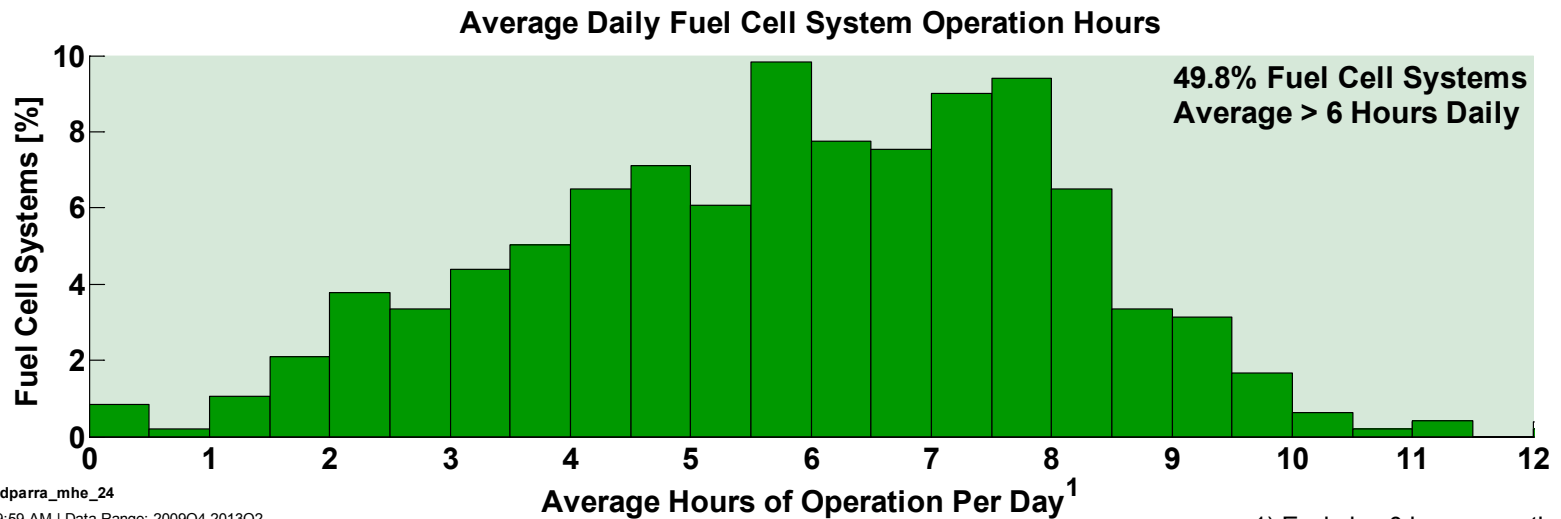
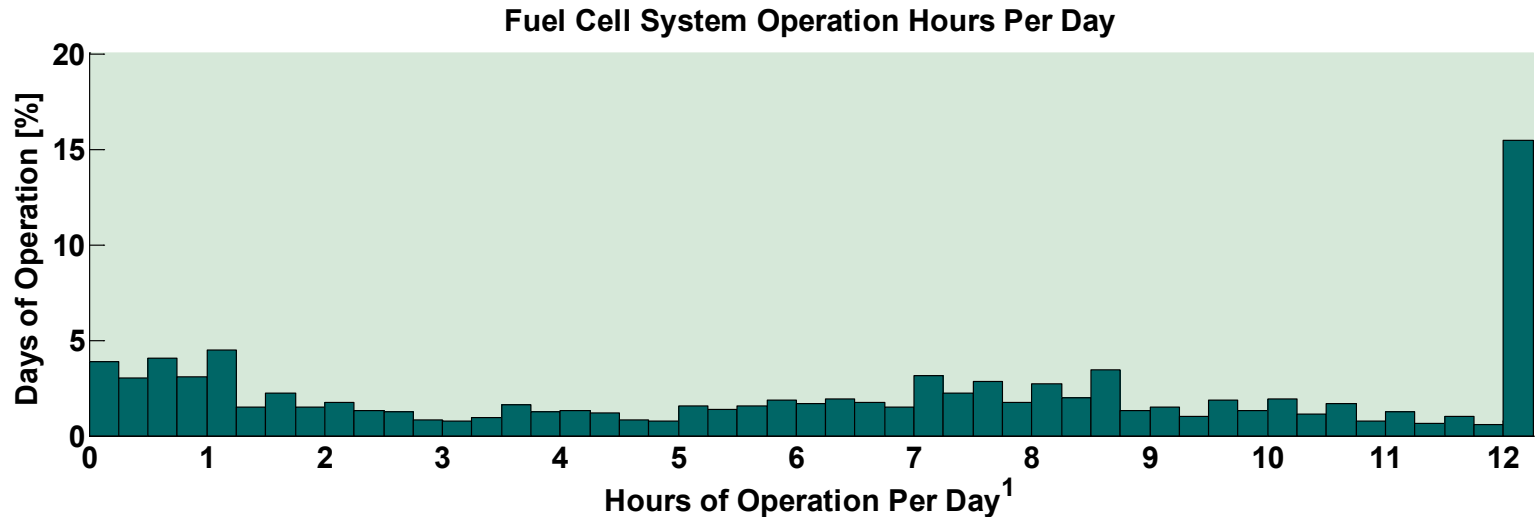
Created: Sep-27-13 11:24 AM | Data Range: 2010Q1-2013Q2

Shaded areas represent the min and max site average hydrogen use and fill frequency

## Average Daily Fuel Cell Operation Hours per Fleet



## Average Daily Fuel Cell Operation Hours per System

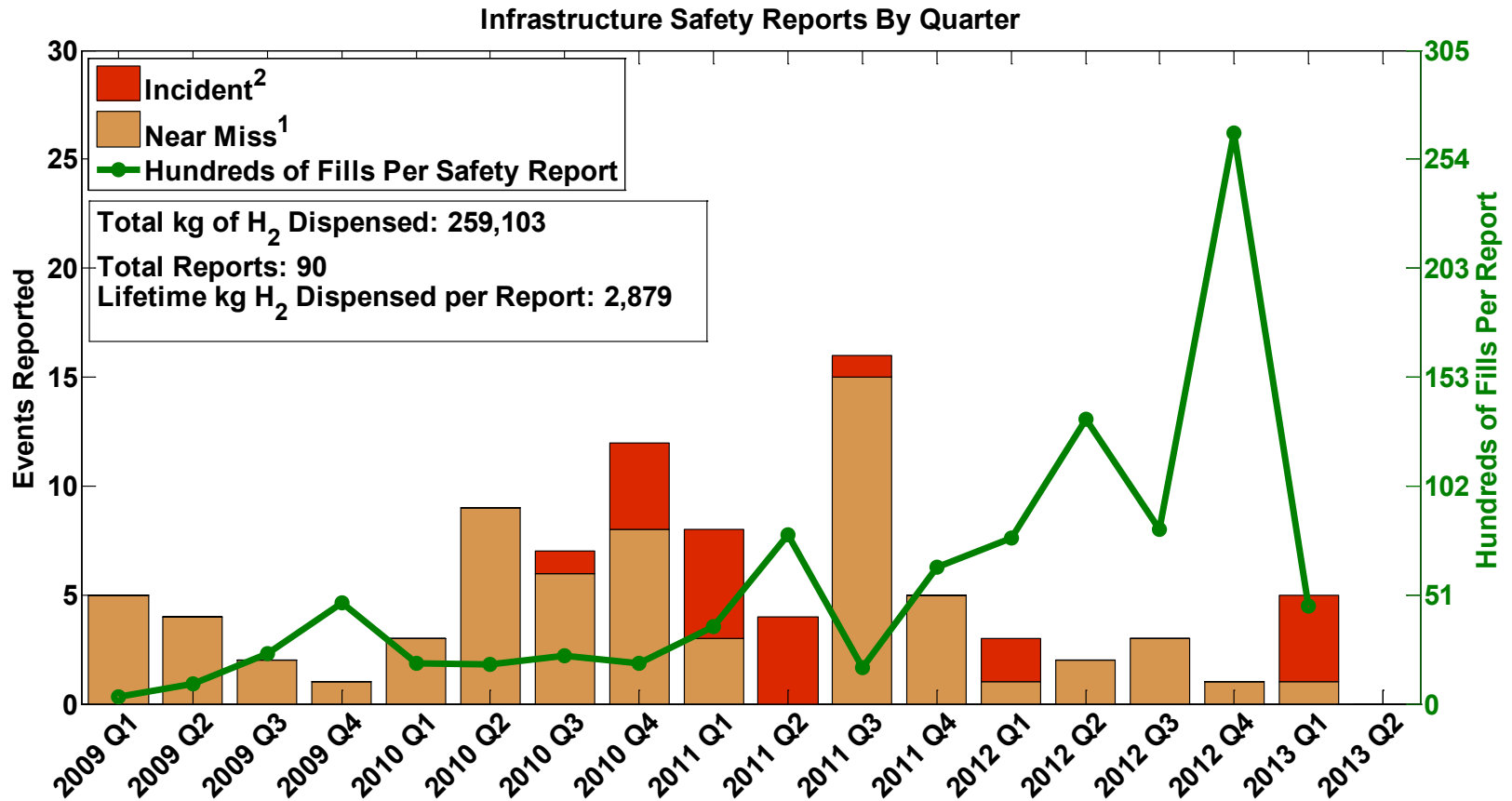


NREL cdparra\_mhe\_24

Created: Sep-30-13 9:59 AM | Data Range: 2009Q4-2013Q2

1) Excludes 0 hour operation days

## Infrastructure Safety Reports by Quarter



1) Near Miss is an event that under slightly different circumstances could have become an incident  
 -unplanned H<sub>2</sub> release insufficient to sustain a flame

2) 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)

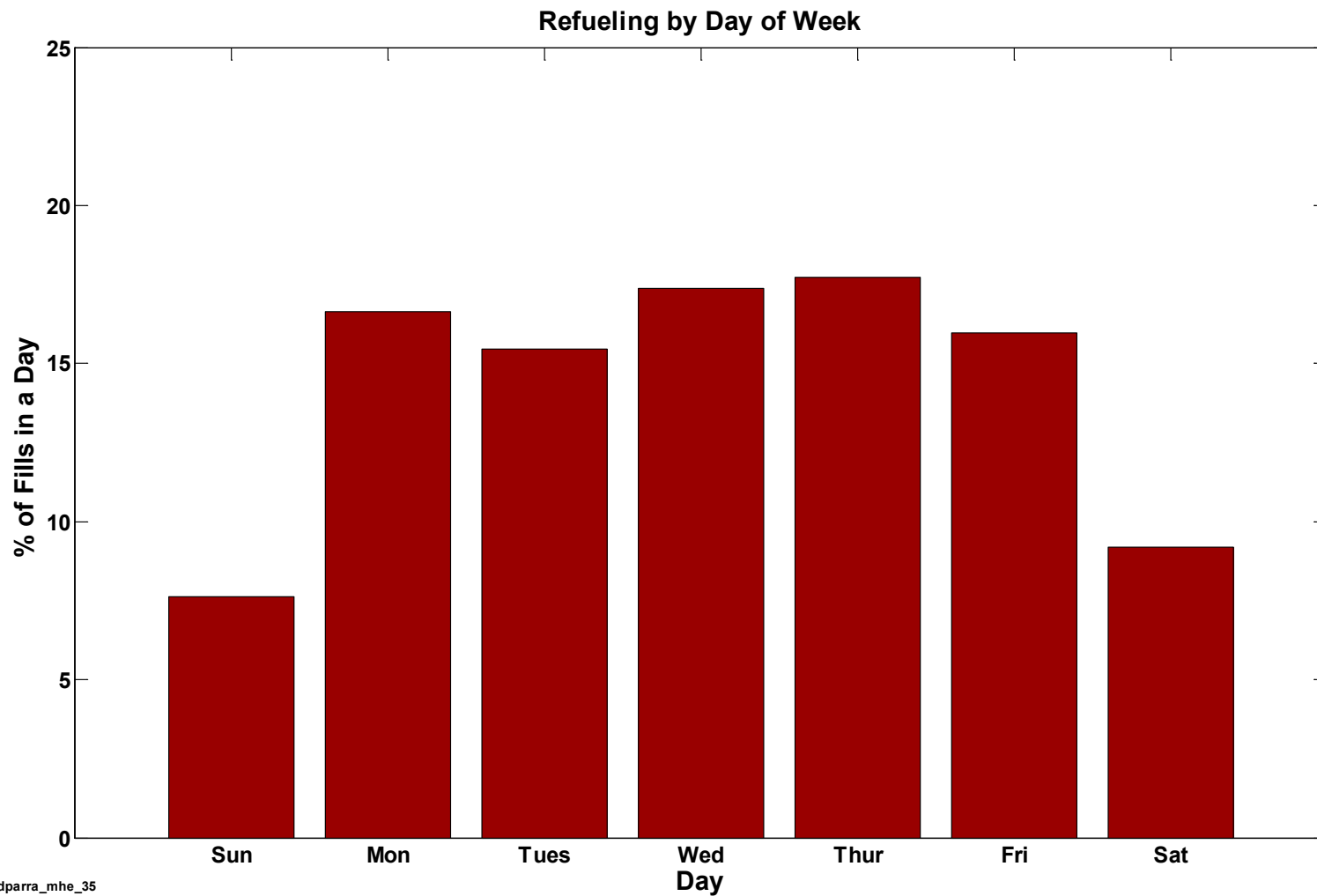


NREL cdp\_mhe\_25

Created: Sep-30-13 9:58 AM | Data Range: 2009Q1-2013Q2



## Refuel Events by Day of Week

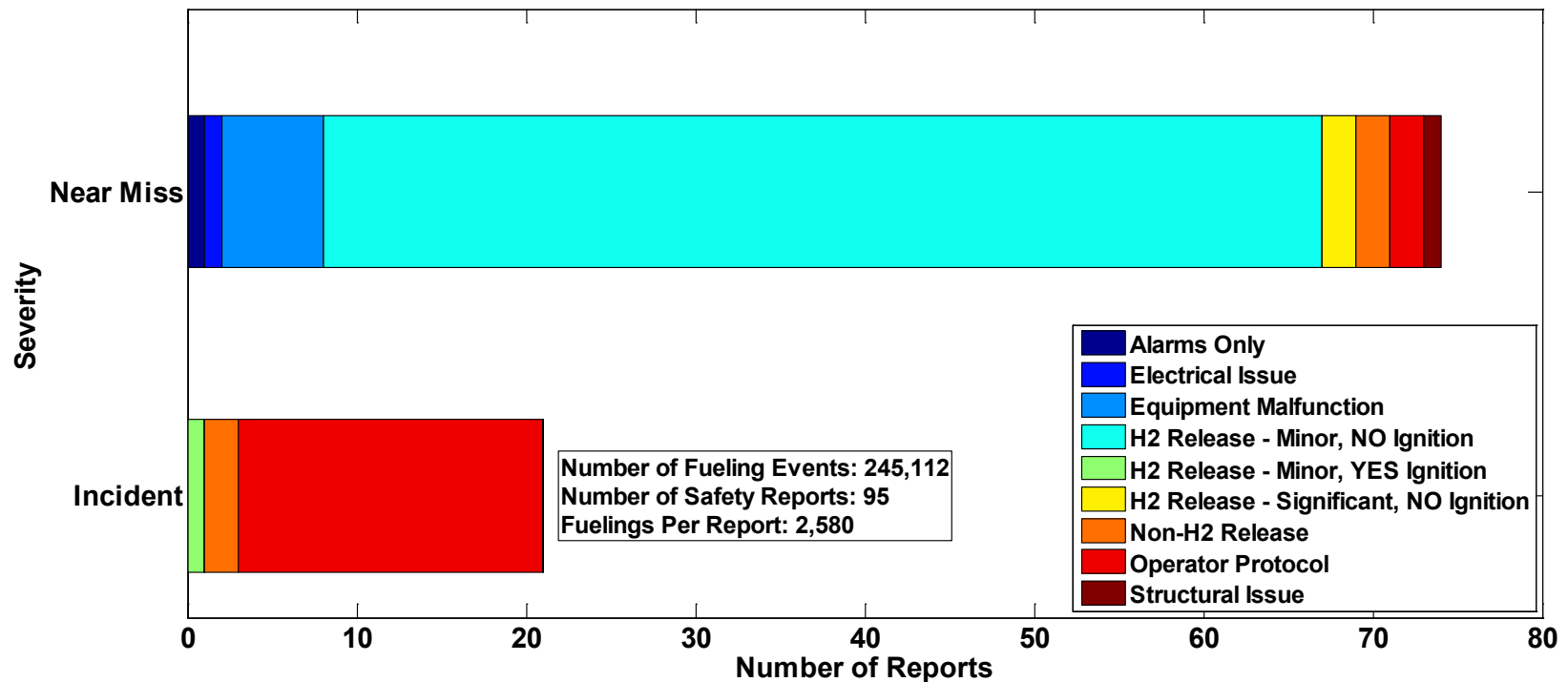


NREL cdparra\_mhe\_35

Created: Sep-26-13 9:13 AM | Data Range: 2009Q4-2013Q2

## Infrastructure Safety Categories

Infrastructure Safety Reports by Severity - All Sites and Report Type



An INCIDENT is an event that results in:

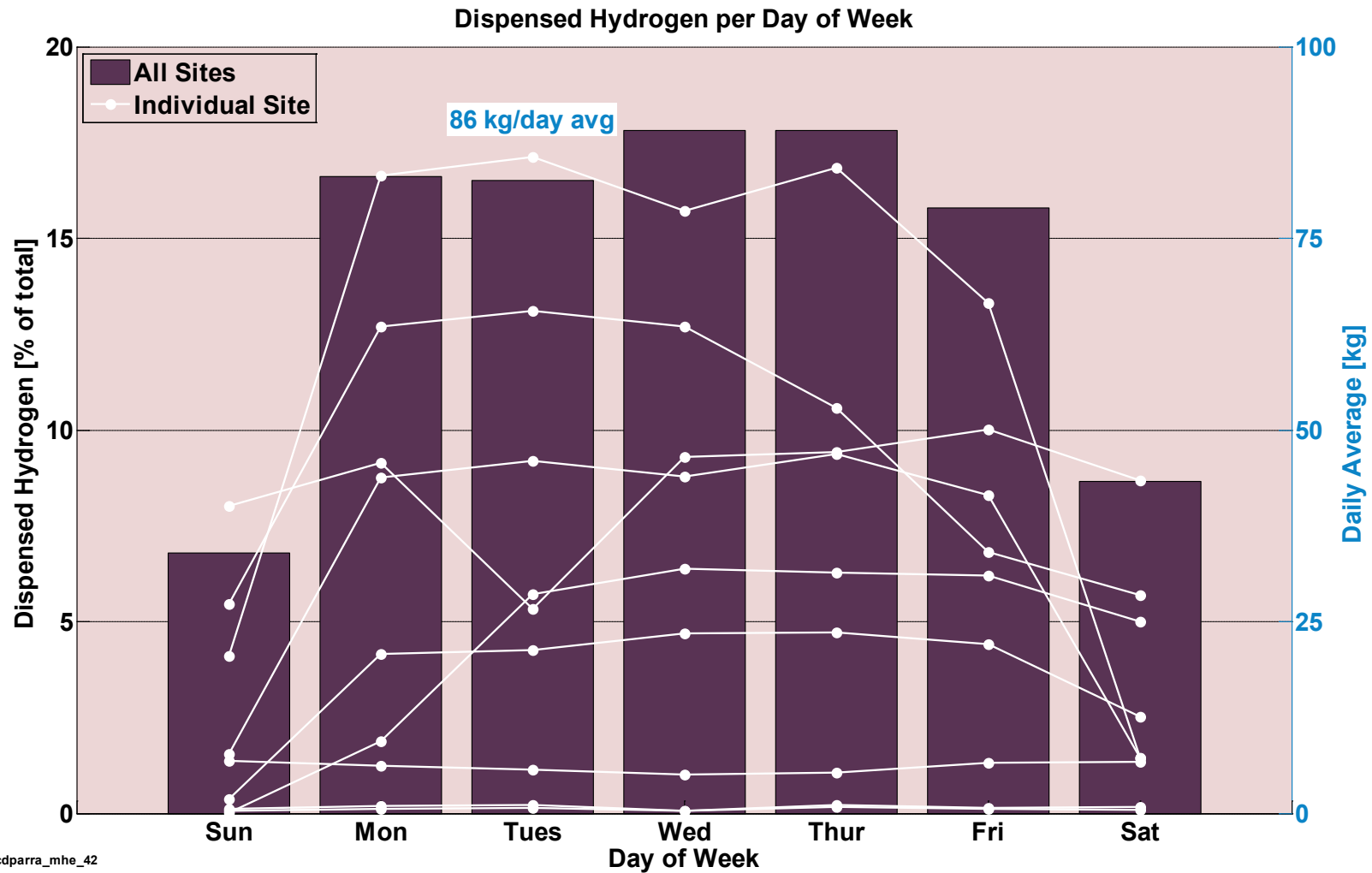
- a lost time accident and/or injury to personnel
- damage/unplanned downtime for project equipment, facilities or property
- impact to the public or environment
- any hydrogen release that unintentionally ignites or is sufficient to sustain a flame if ignited
- release of any volatile, hydrogen containing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

A NEAR-MISS is:

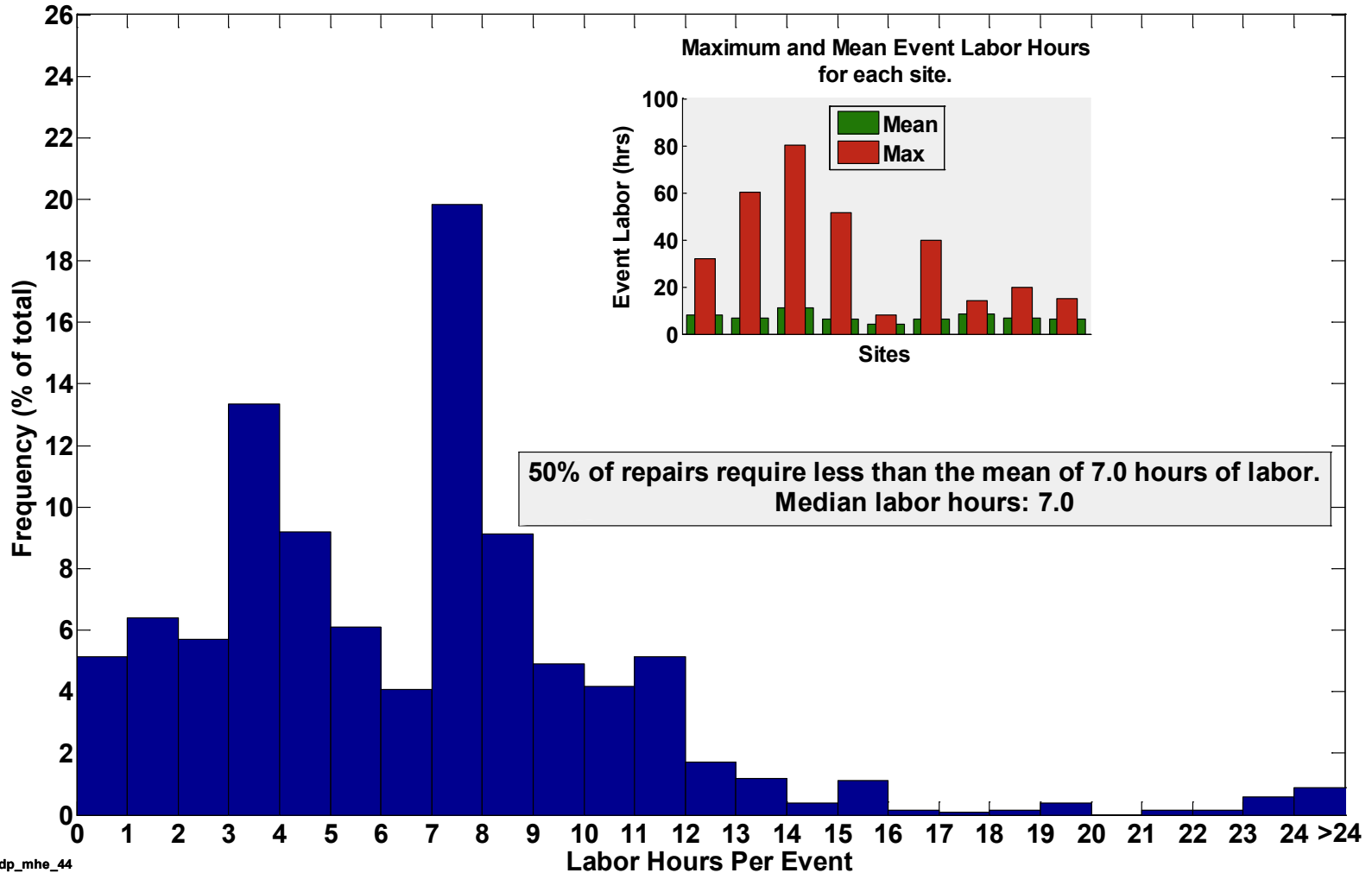
- an event that under slightly different circumstances could have become an incident
- unplanned H2 release insufficient to sustain a flame



## Amount of Hydrogen Dispensed by Day of Week

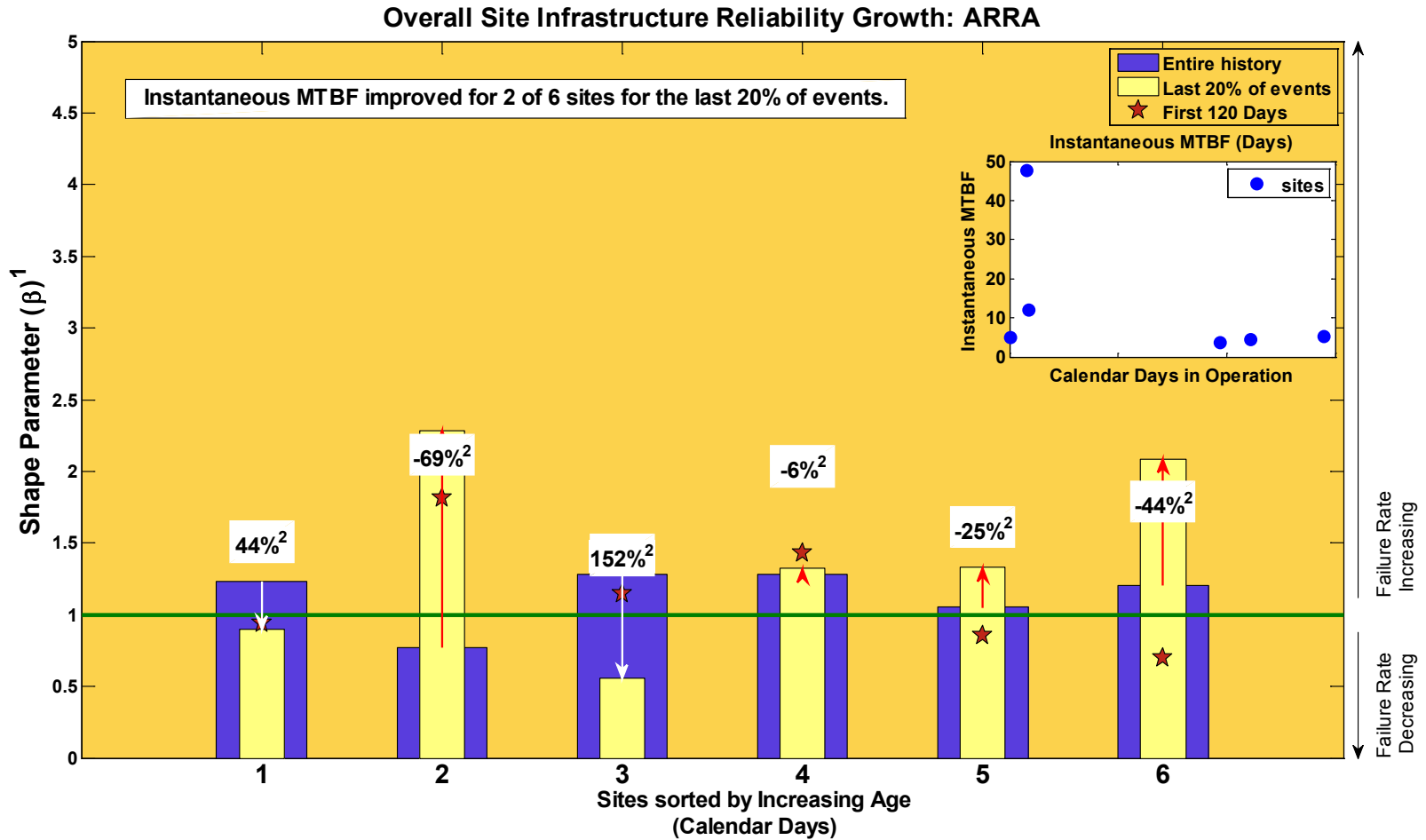


### Breakdown of Maintenance Event Labor Hours: Infrastructure



# CDPARRA-MHE-45

## Infrastructure Reliability Growth



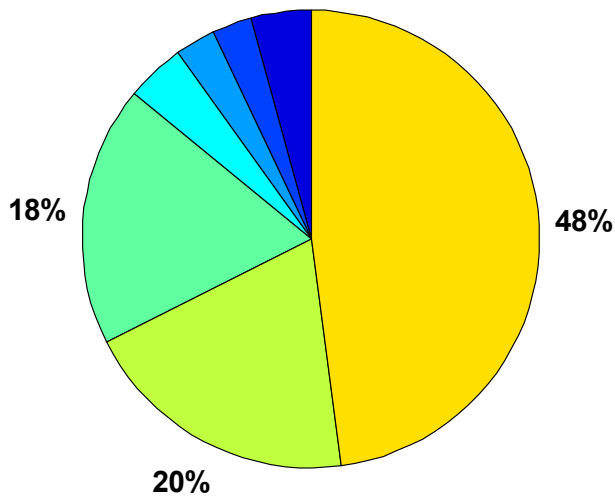
1. IEC 61164:2004(E), Reliability Growth - Statistical Test and Evaluation Methods, IEC. 2004.

2. % change in instantaneous MTBF

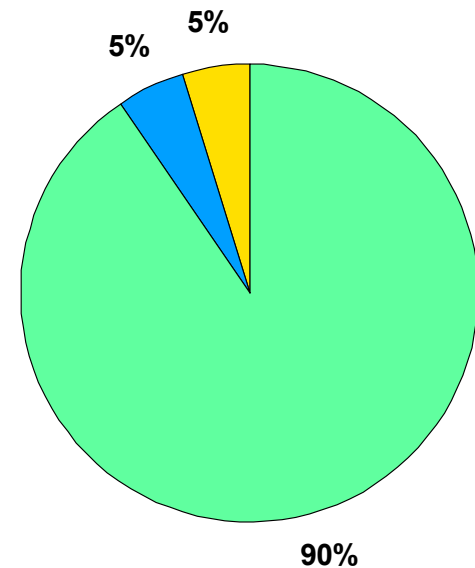


### Safety Reports By Equipment Category: Infrastructure

**By Number of Reports**  
Total Near Miss Reports = 71



**By Number of Incidents**  
Total Incidents = 21



MISC includes the following categories:  
STORAGE  
FUEL SYSTEM  
OTHER

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:

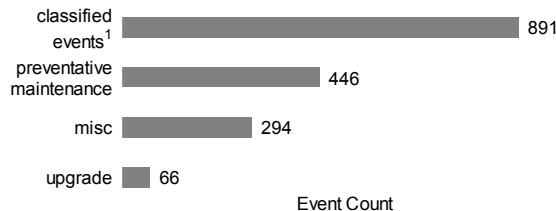
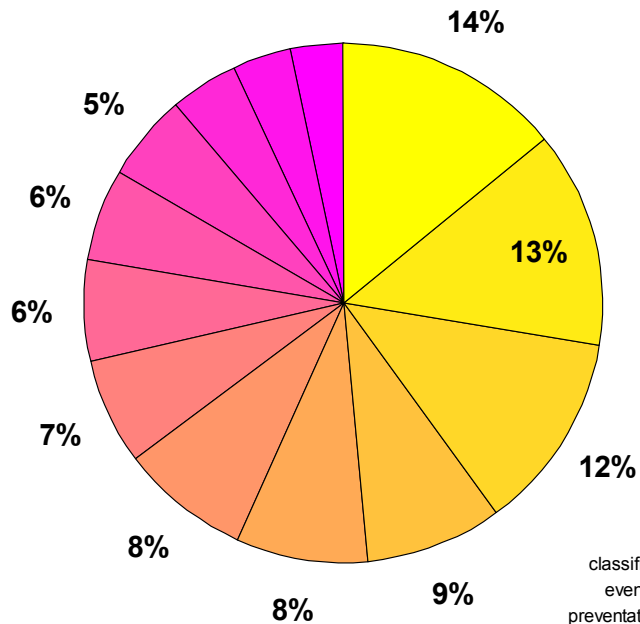
- an event that under slightly different circumstances could have become an incident
- unplanned H2 release insufficient to sustain a flame



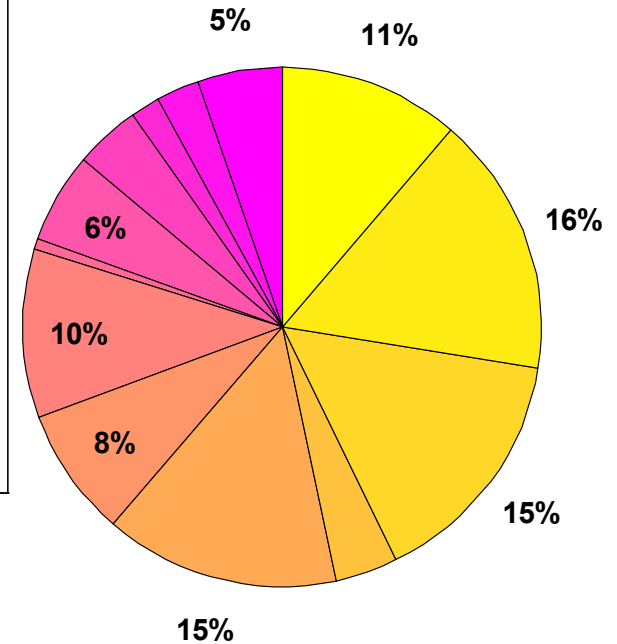
## Infrastructure Maintenance by Mode

Infrastructure Maintenance By Mode

Total Events = 1,697<sup>1</sup>  
70% unscheduled



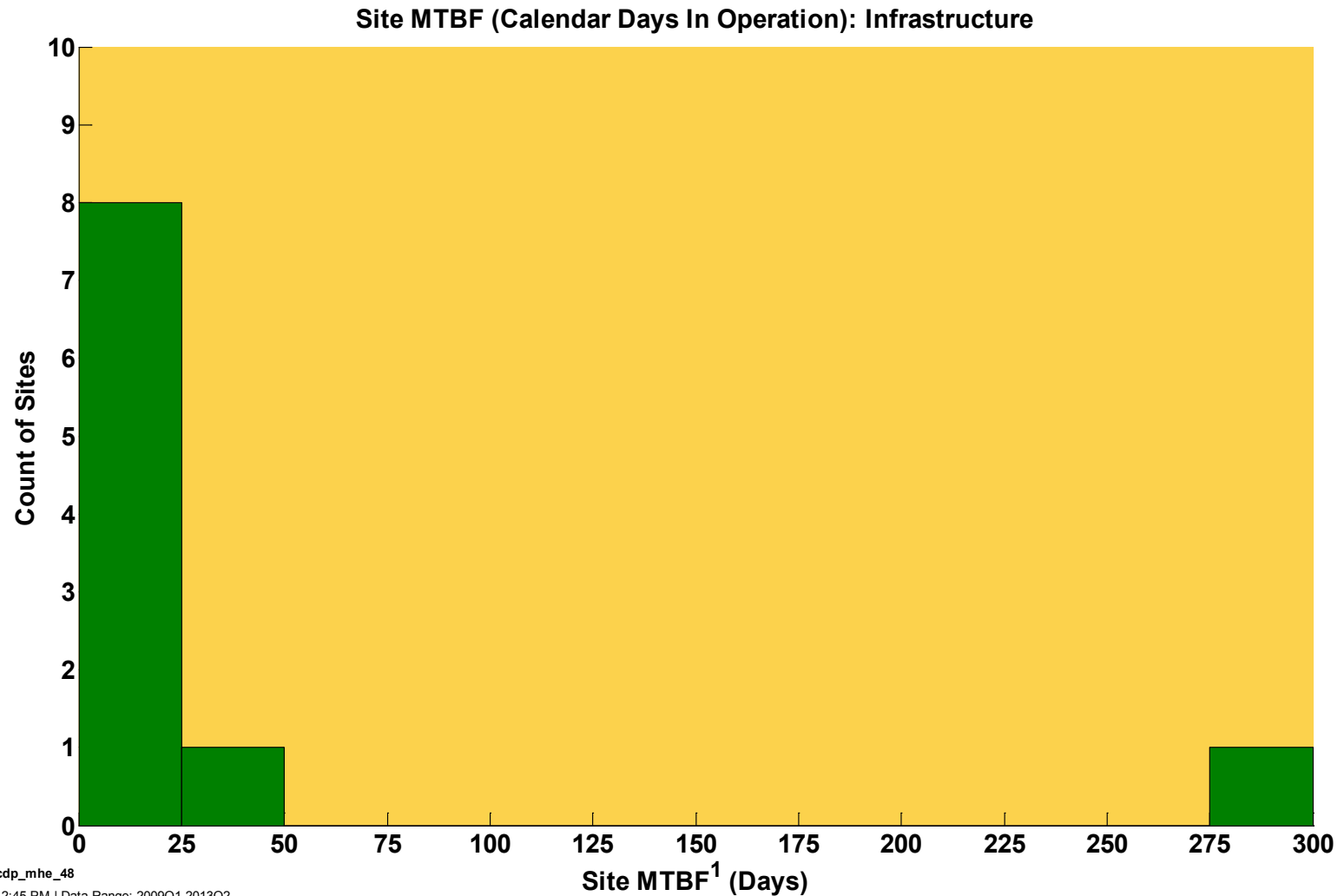
Total Hours = 9,928  
66% unscheduled



MISC includes the following failure modes: animal damage, cavitation, debris infiltration, false alarm, fluid leak non\_hydrogen, vandalism, voltage low, cleanup device failed, electrical short, maintenance error, network malfunction, fluid leak non-hydrogen, broken wire, manufacturing defect, ambient temperature too low, power outage, unspecified electronics failure, failed open, software bug, lightning strike, drive off, moisture infiltration, operator protocol, failed closed, other



## Infrastructure Mean Time Between Failures



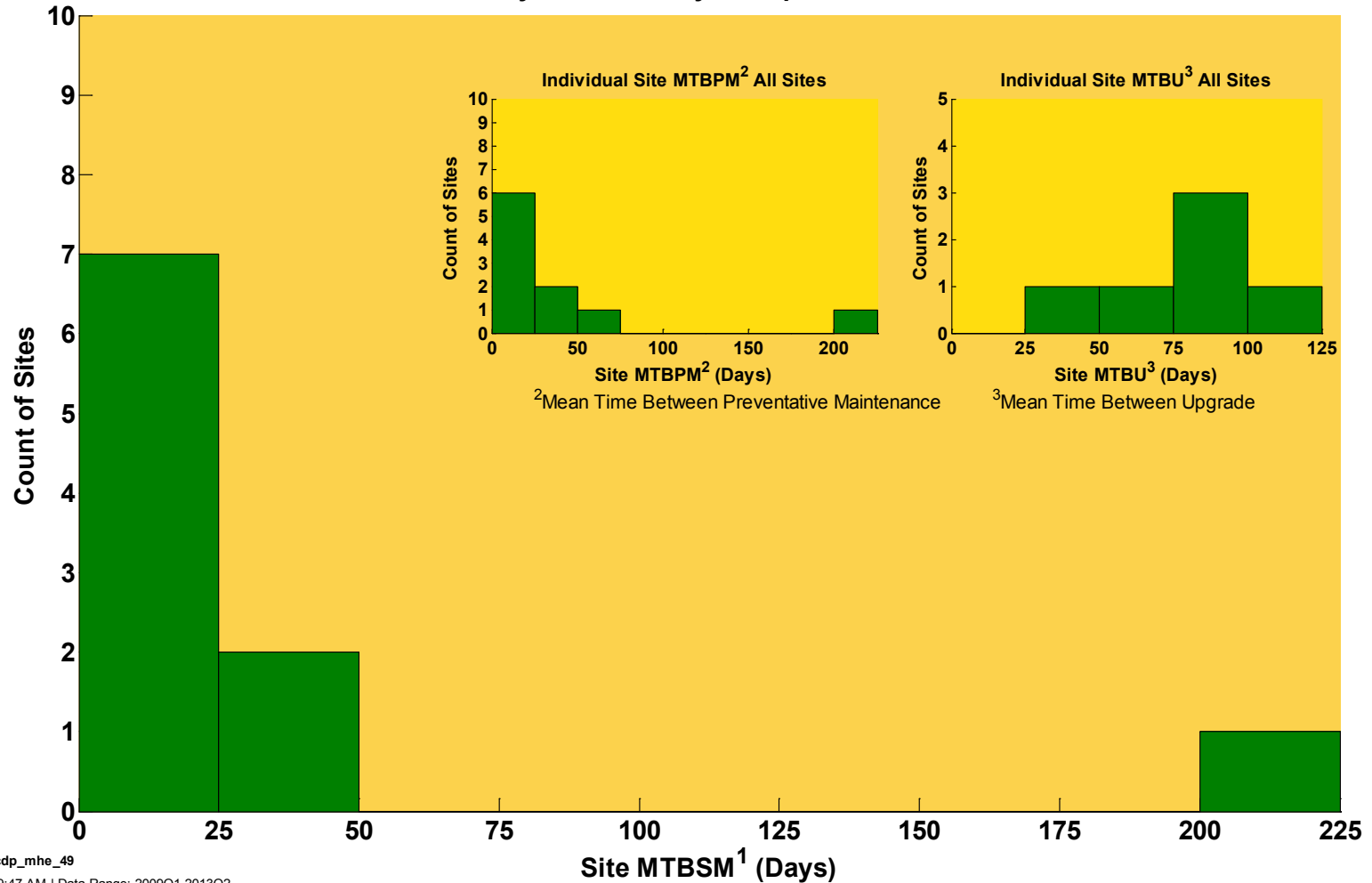
NREL cdp\_mhe\_48

Created: Sep-28-13 12:45 PM | Data Range: 2009Q1-2013Q2

1. Cumulative Mean Time Between Failure



Site MTBSM by Calendar Days In Operation: Infrastructure

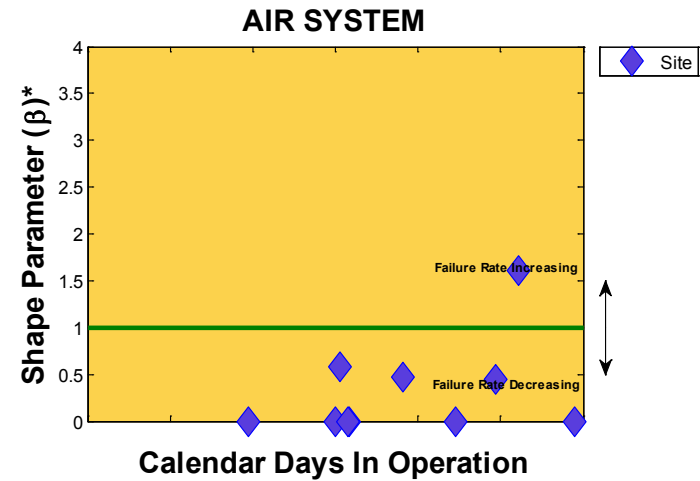
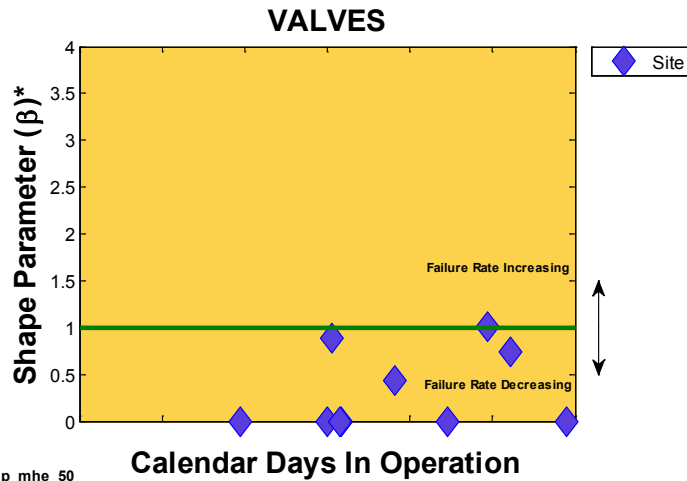
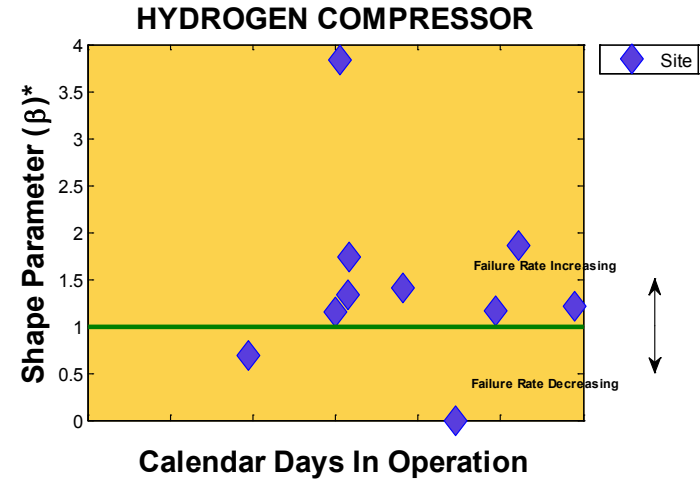
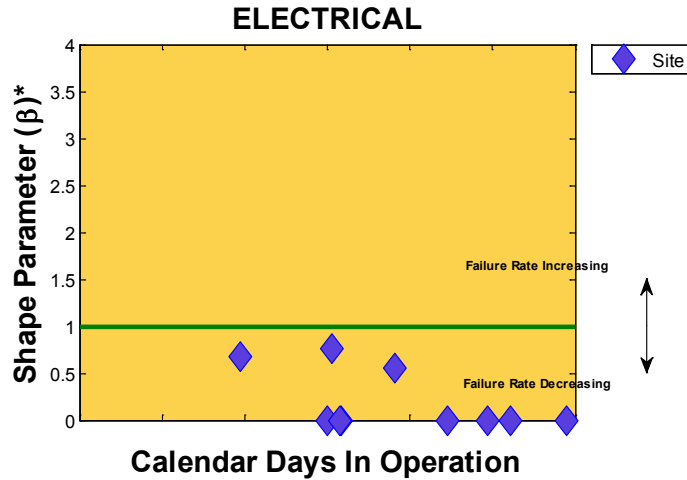


NREL cdp\_mhe\_49

Created: Sep-26-13 9:47 AM | Data Range: 2009Q1-2013Q2

1. Cumulative Mean Time Between Scheduled Maintenance. Includes Preventative and Upgrades

## Infrastructure Reliability Growth by Category



NREL cdp\_mhe\_50

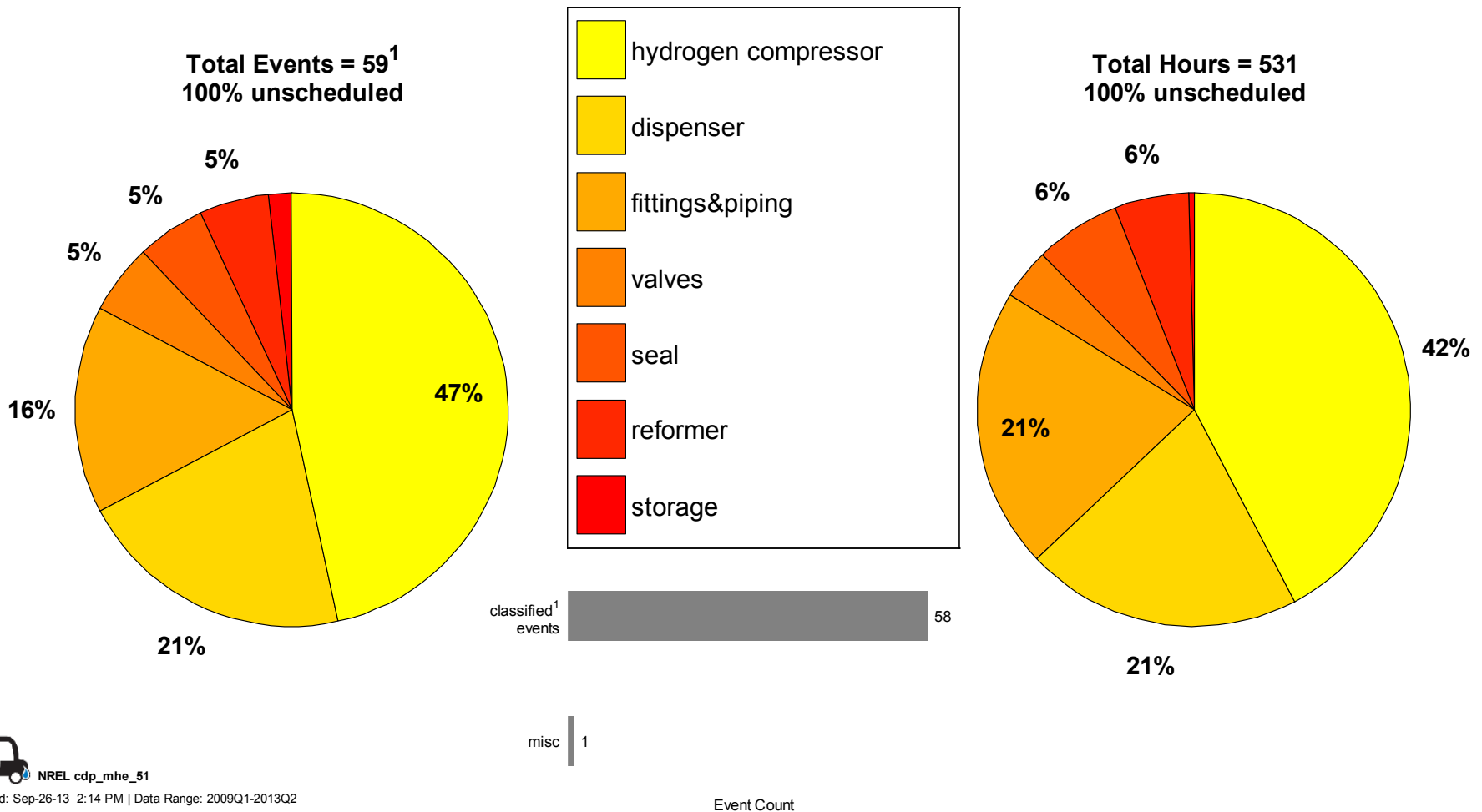
Created: Sep-26-13 9:48 AM | Data Range: 2009Q1-2013Q2

These represent the top four equipment failure categories from all combined data.

\*IEC 61164  $\beta$

## Infrastructure Hydrogen Leaks by Equipment Type

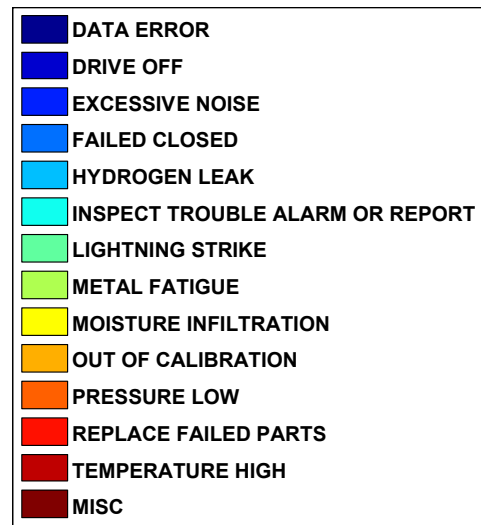
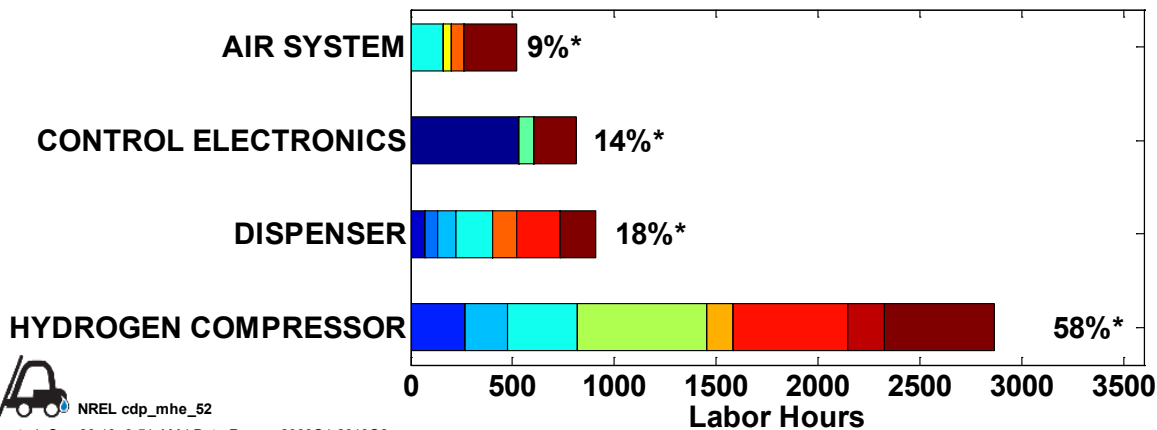
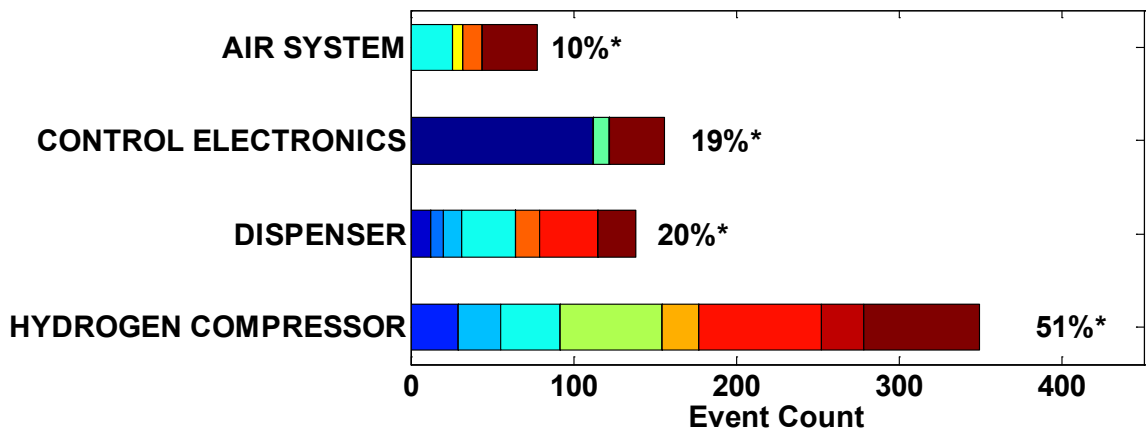
Hydrogen Leaks By Equipment Category: Infrastructure



NREL cdp\_mhe\_51

Created: Sep-26-13 2:14 PM | Data Range: 2009Q1-2013Q2

Failure Modes for Top Four Infrastructure Equipment Categories



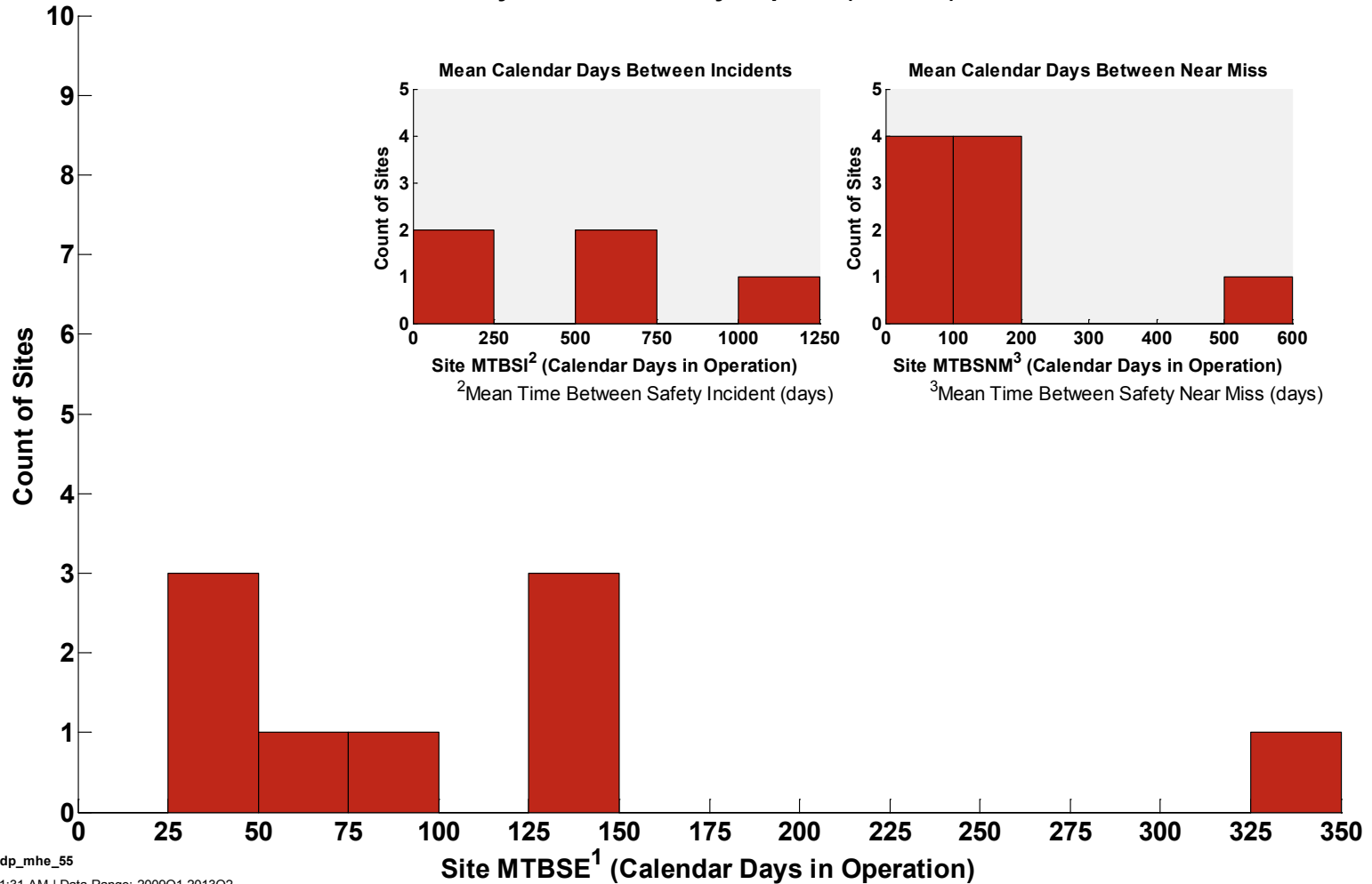
MISC includes the following failure modes: ambient temperature too low, broken wire, cavitation, data error, debris infiltration, electrical short, failed closed, false alarm, flow high, flow low, fluid leak non-hydrogen, fluid leak non\_hydrogen, fluid leak\_non\_hydrogen, inspect trouble alarm or report, maintenance error, manufacturing defect, metal fatigue, moisture infiltration, network malfunction, operator protocol, other, power outage, pressure high, pressure low, replace failed parts, software bug, unspecified electronics failure, vandalism, voltage low, other

\* Percentage of total events or hours, reference CDP 66.



## Infrastructure Mean Time Between Safety Events

Mean Calendar Days Between Safety Reports (MTBSR): Infrastructure

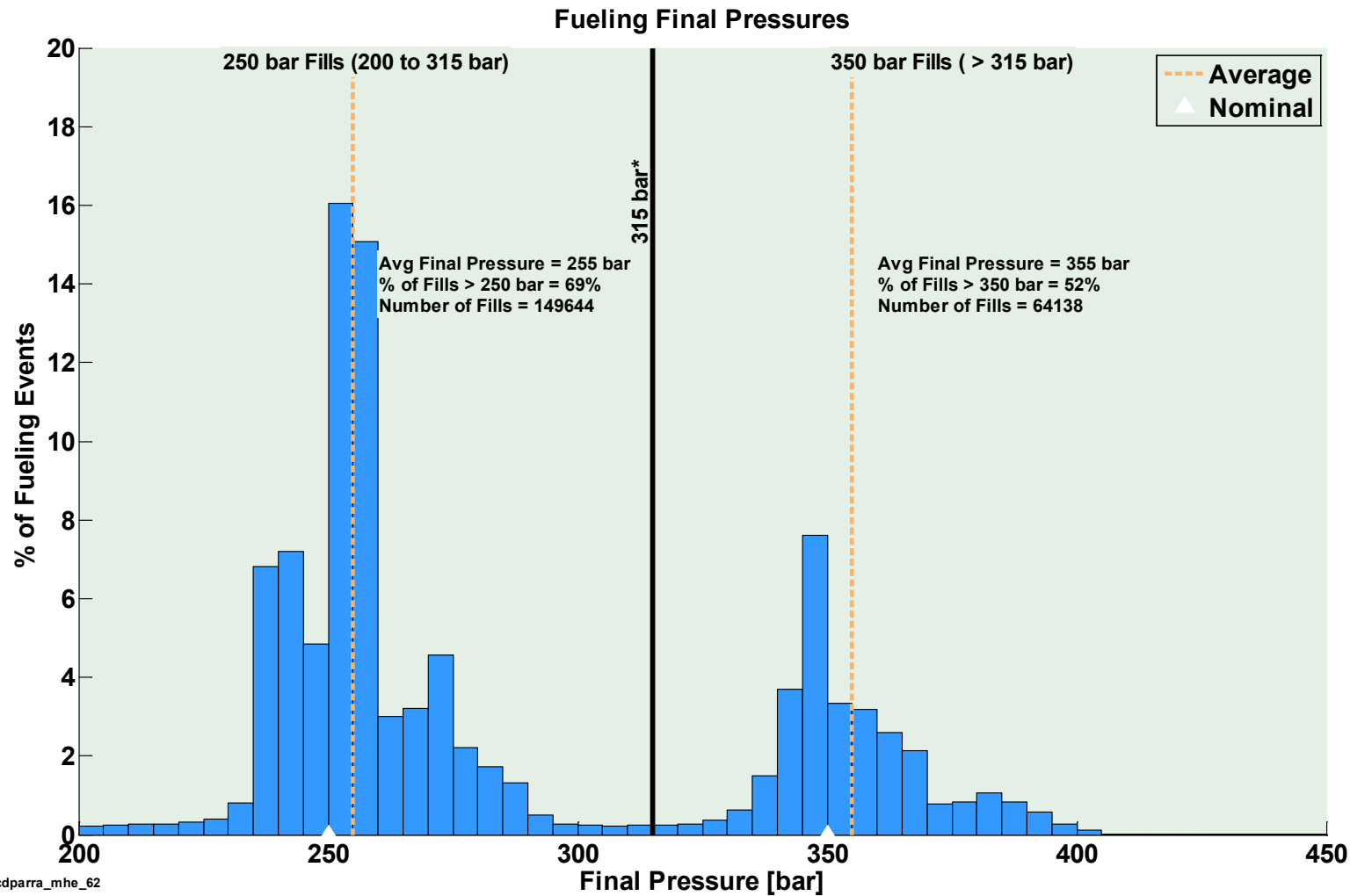


NREL cdp\_mhe\_55

Created: Sep-27-13 11:31 AM | Data Range: 2009Q1-2013Q2

1. Cumulative Mean Time Between Safety Report (days)

## Final Pressure of Hydrogen Fills

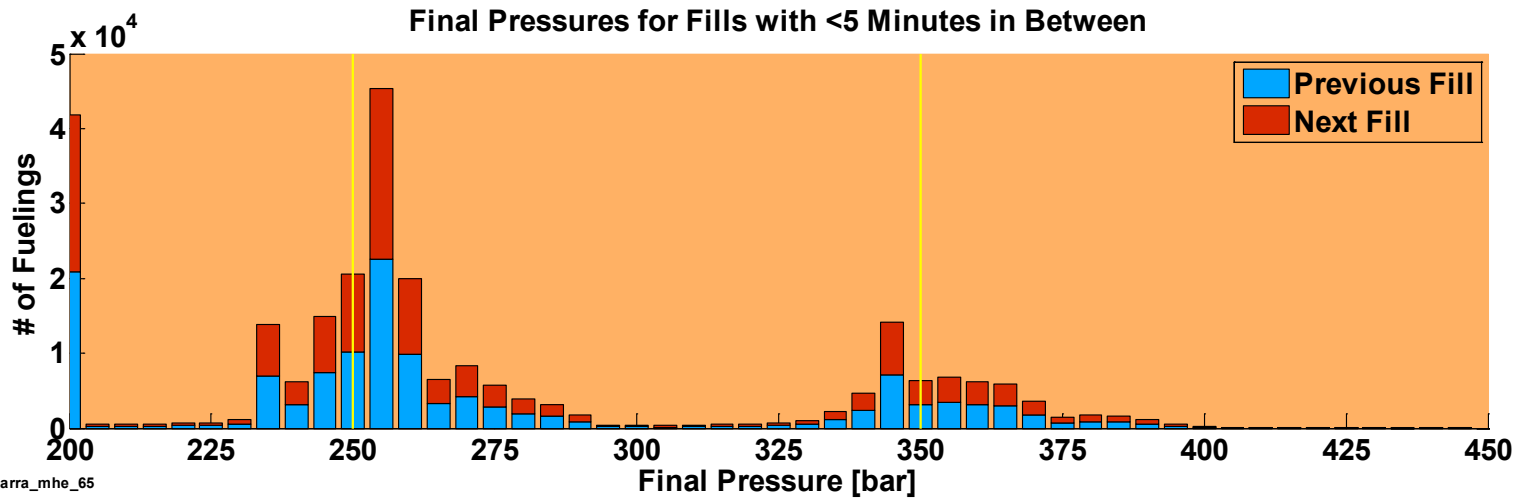
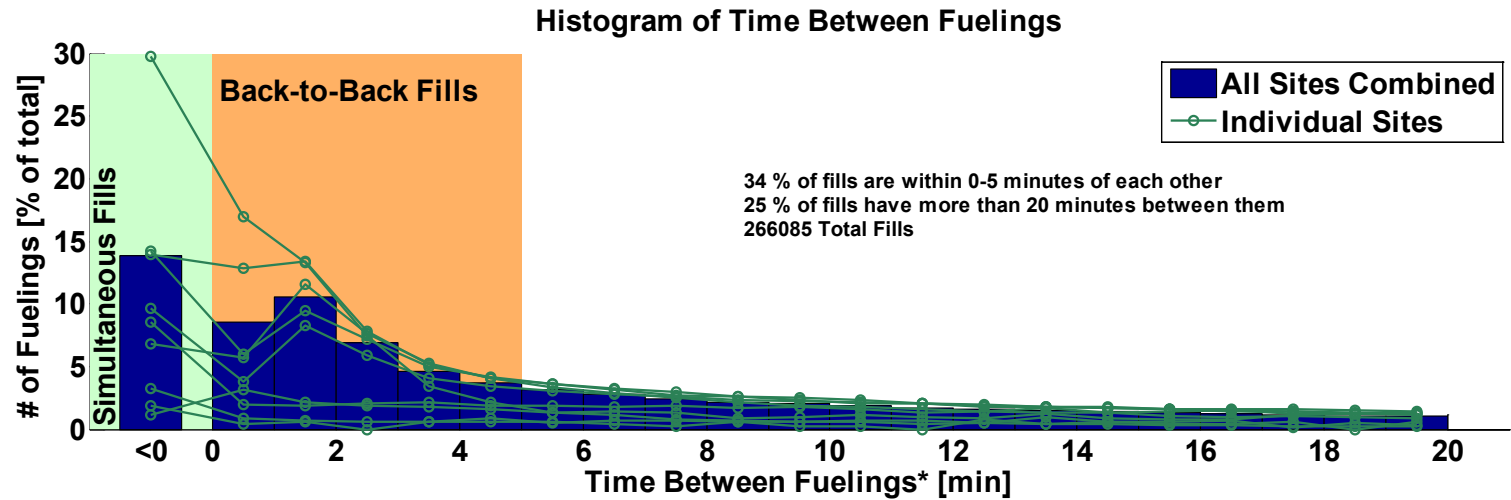


NREL cdparra\_mhe\_62

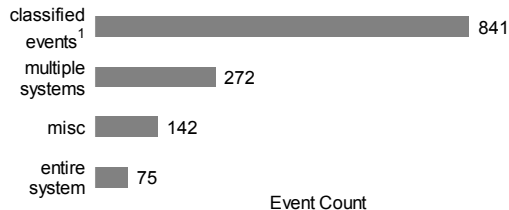
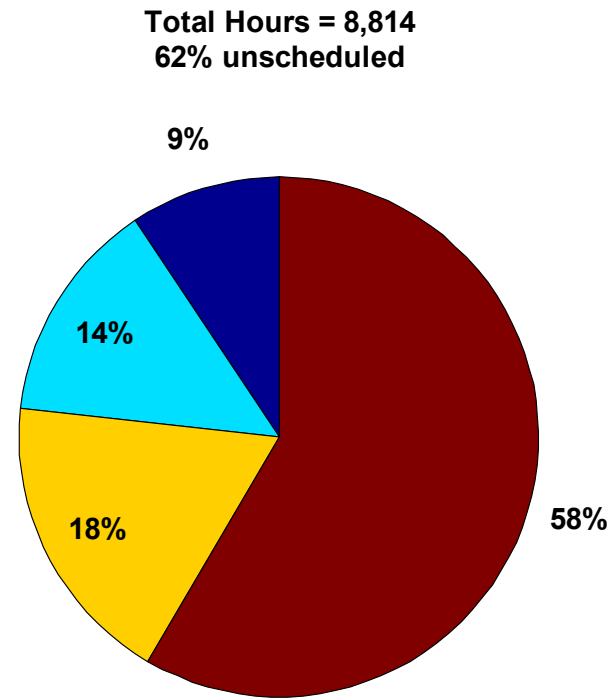
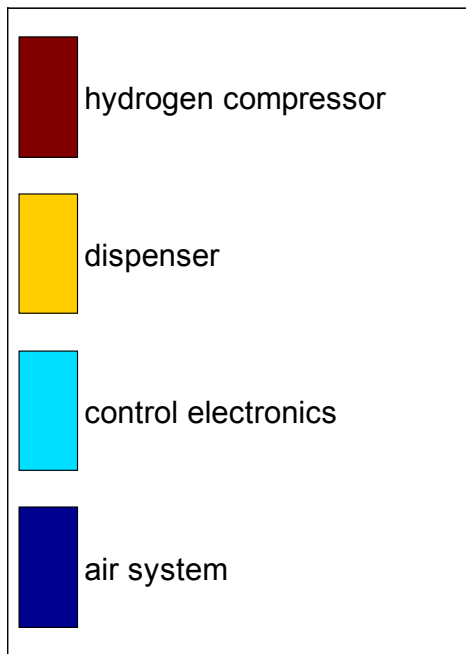
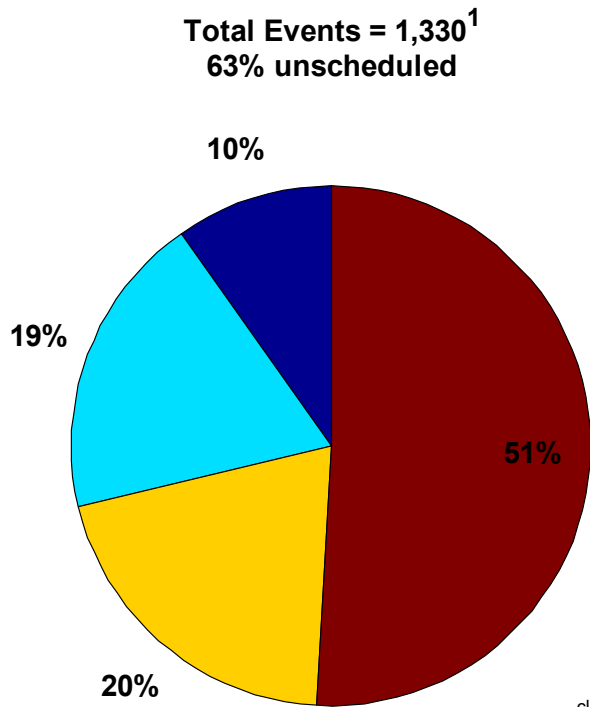
Created: Sep-26-13 9:26 AM | Data Range: 2009Q4-2013Q2

\*The line at 315 bar separates 250 bar fills from 350 bar fills. It is slightly over the allowable 125% of nominal pressure (312.5 bar) from SAE J2601.

## Details of Back-to-Back Fills



### Delivered Hydrogen Infrastructure Maintenance By Equipment Type

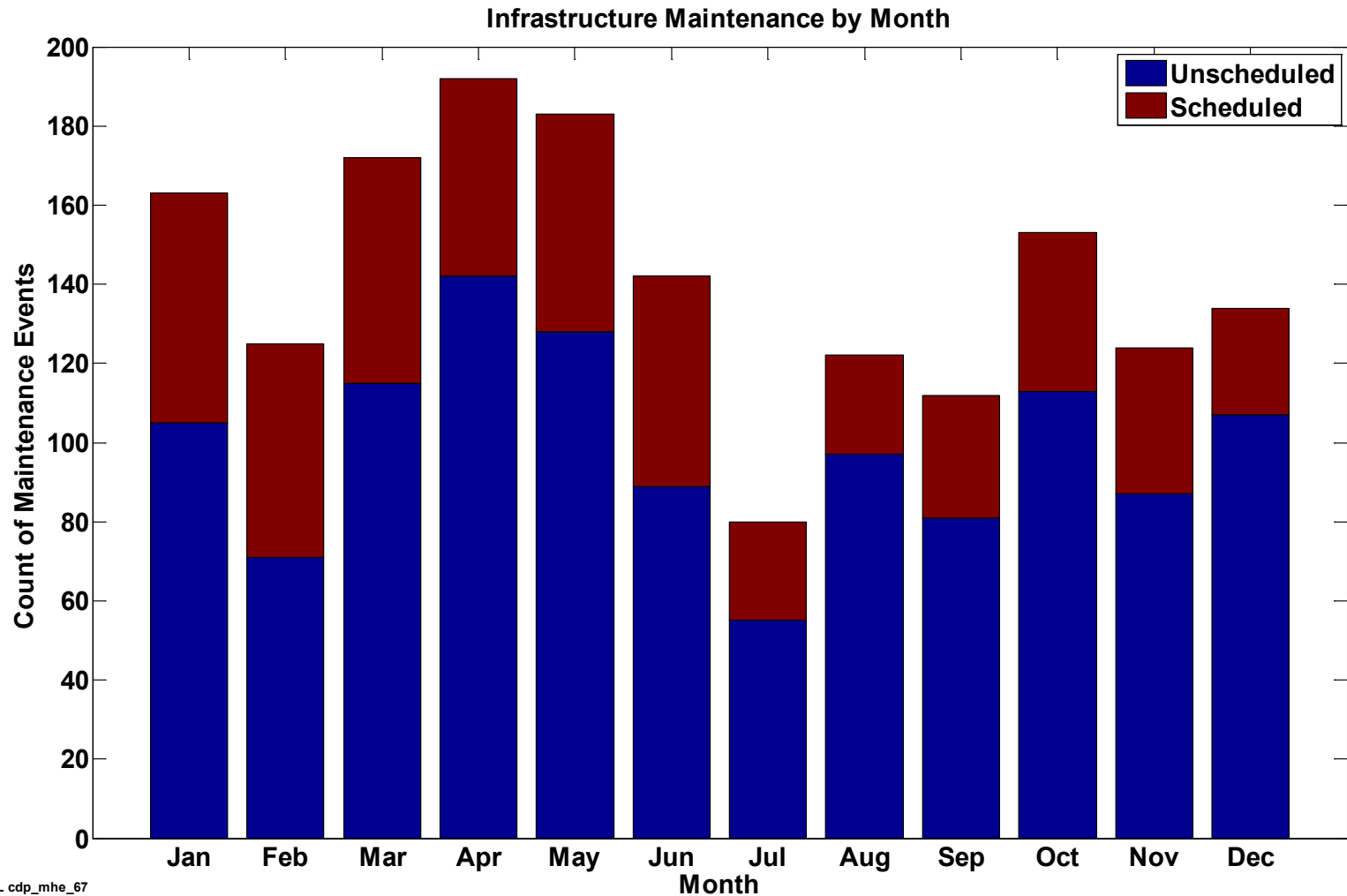


MISC includes the following failure modes: seal, fuel system, thermal management, storage, electrical, fittings&pipng, safety, software, valves, sensors, other





## Infrastructure Maintenance by Month

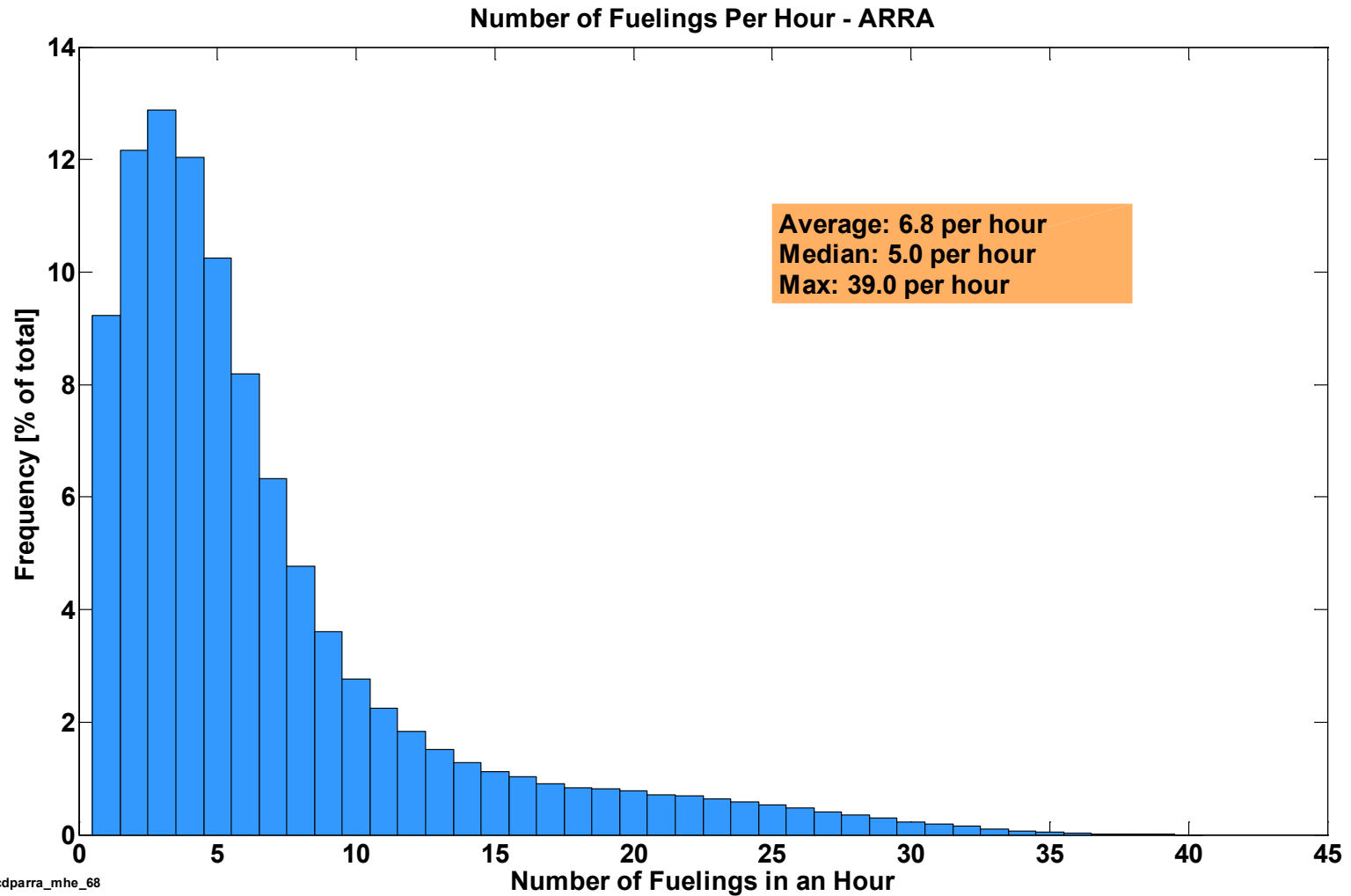


NREL cdp\_mhe\_67

Created: Sep-26-13 9:51 AM | Data Range: 2009Q1-2013Q2

# CDPARRA-MHE-68

## Fill Counts per Hour

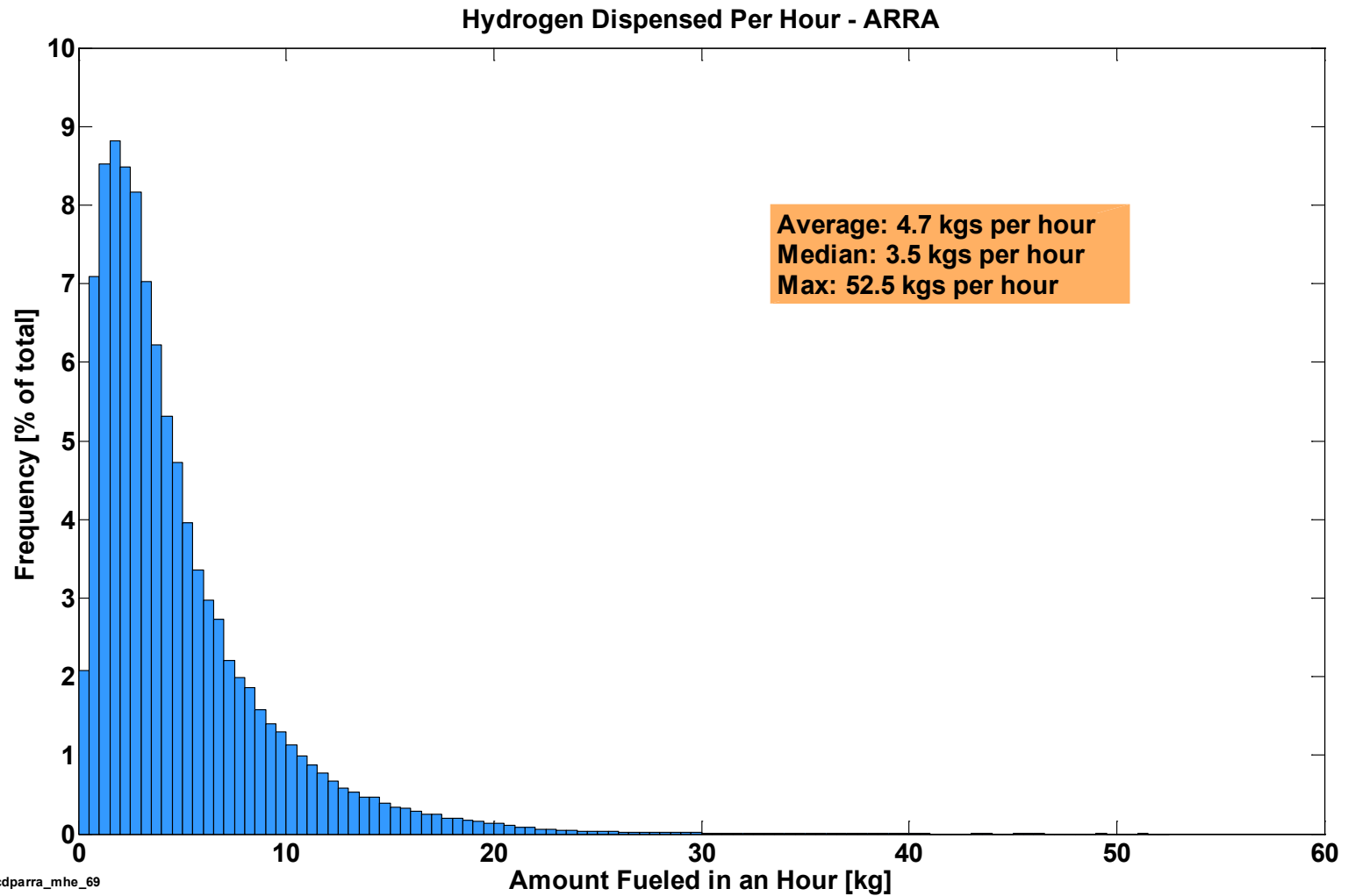


NREL cdparra\_mhe\_68

Created: Sep-26-13 9:51 AM | Data Range: 2009Q4-2013Q2

# CDPARRA-MHE-69

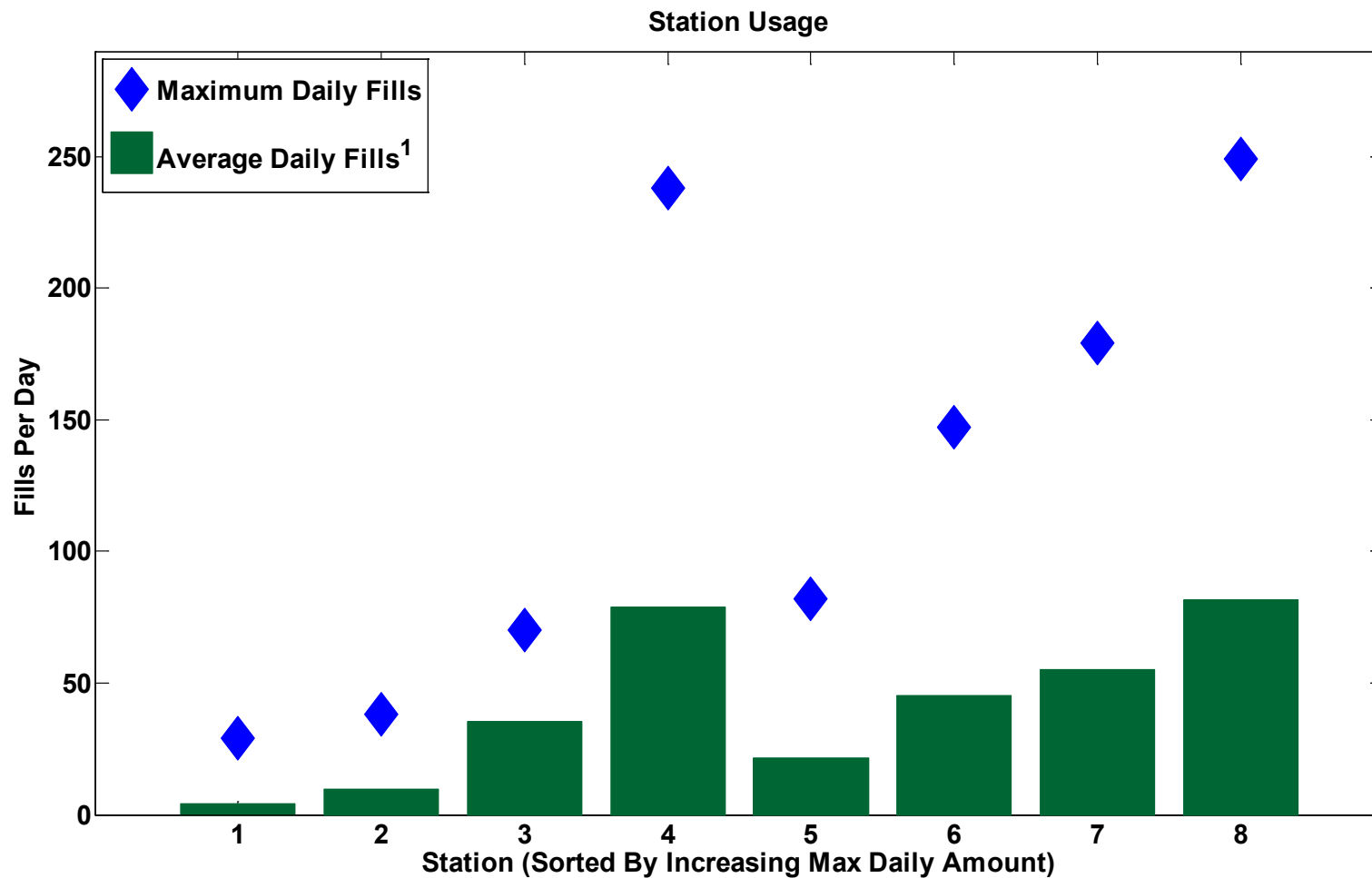
## Fill Amount per Hour



NREL cdparra\_mhe\_69

Created: Sep-26-13 10:08 AM | Data Range: 2009Q4-2013Q2

## Station Usage



<sup>1</sup>Average daily fills considers only days when at least one fill occurred

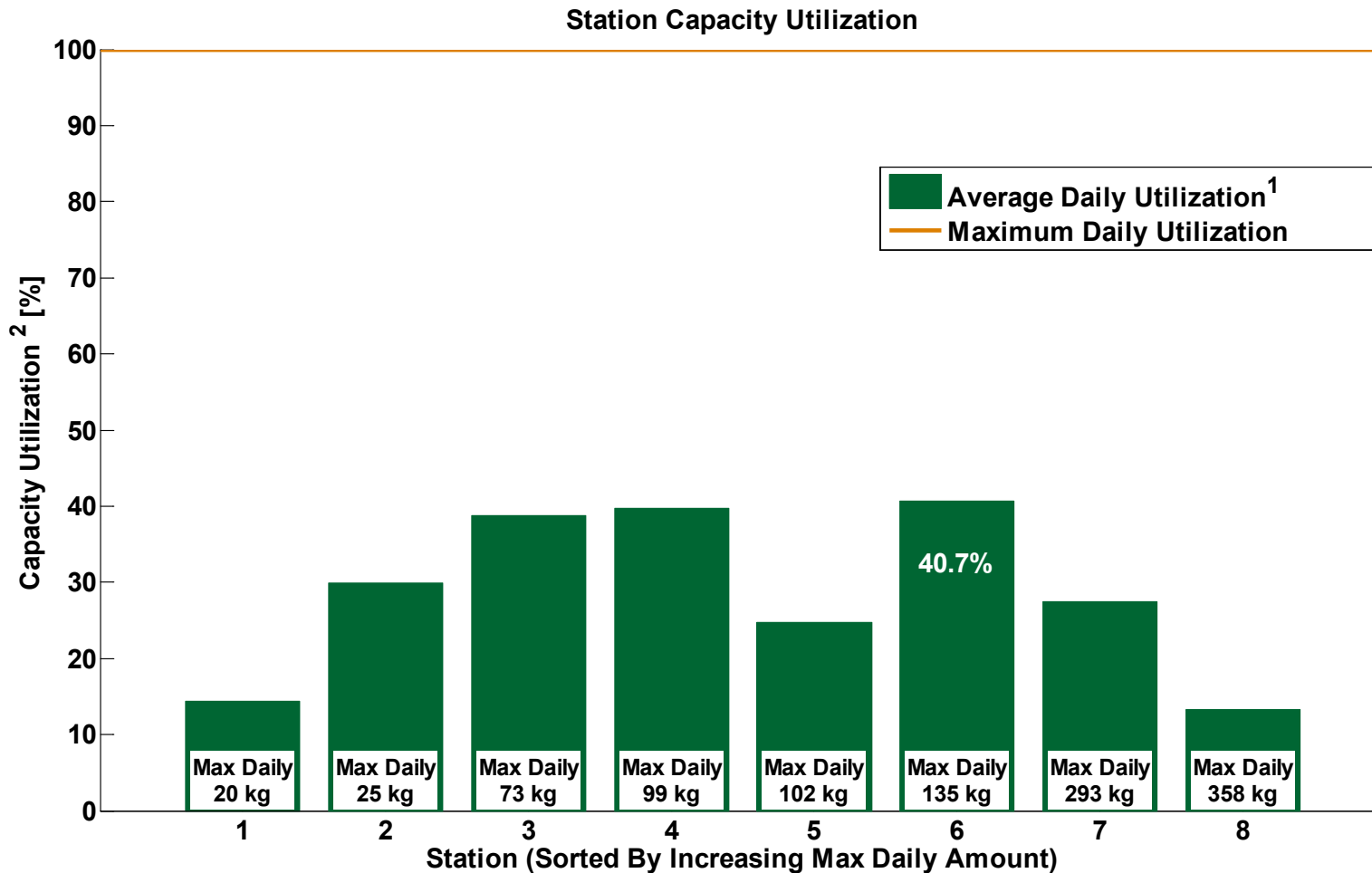


NREL cdparra\_mhe\_70

Created: Sep-26-13 10:20 AM | Data Range: 2009Q4-2013Q2

# CDPARRA-MHE-71

## Station Capacity Utilization

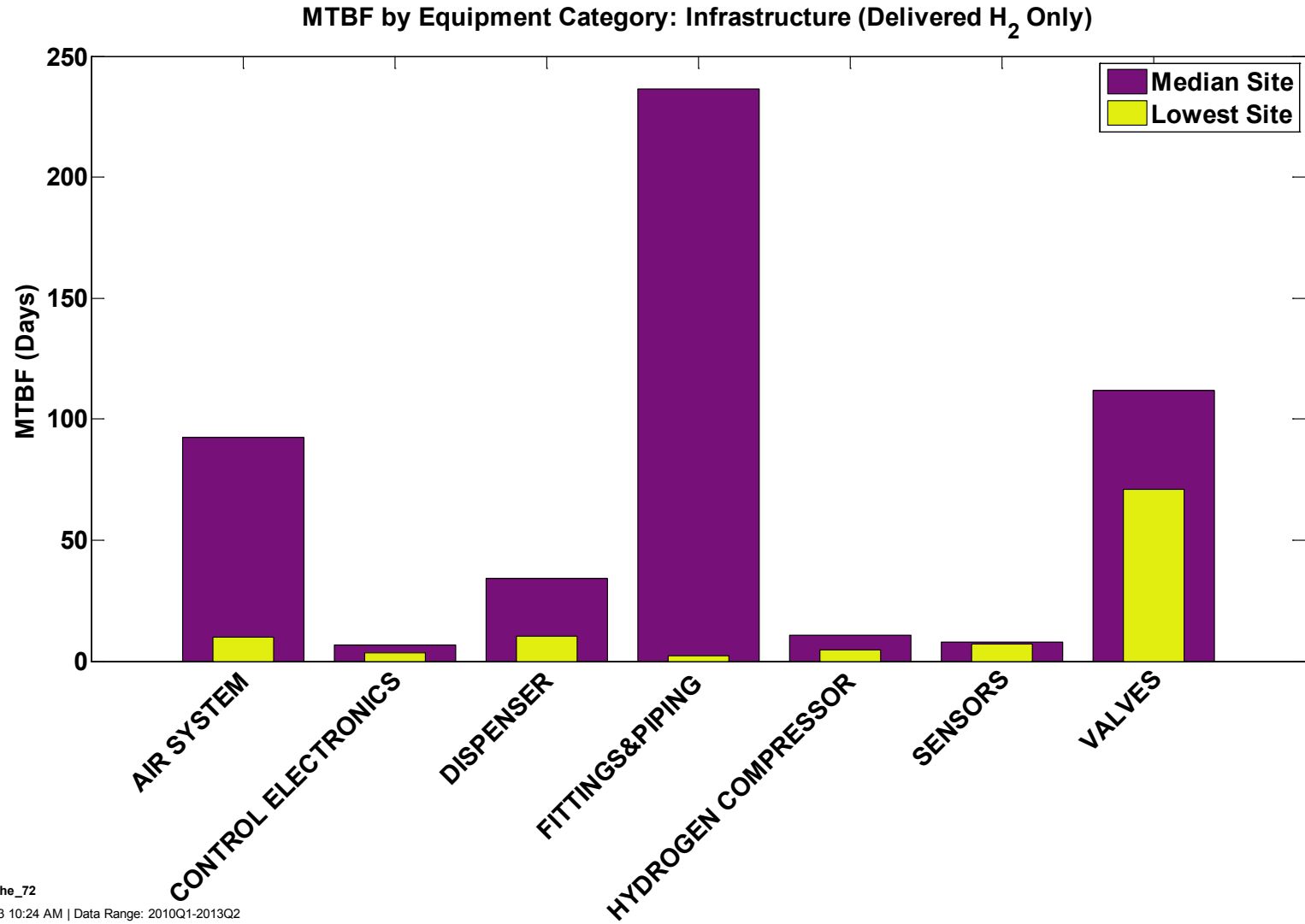


<sup>1</sup>Maximum quarterly utilization considers all days; average daily utilization considers only days when at least one filling occurred

<sup>2</sup>100% represents maximum daily amount dispensed for each individual site



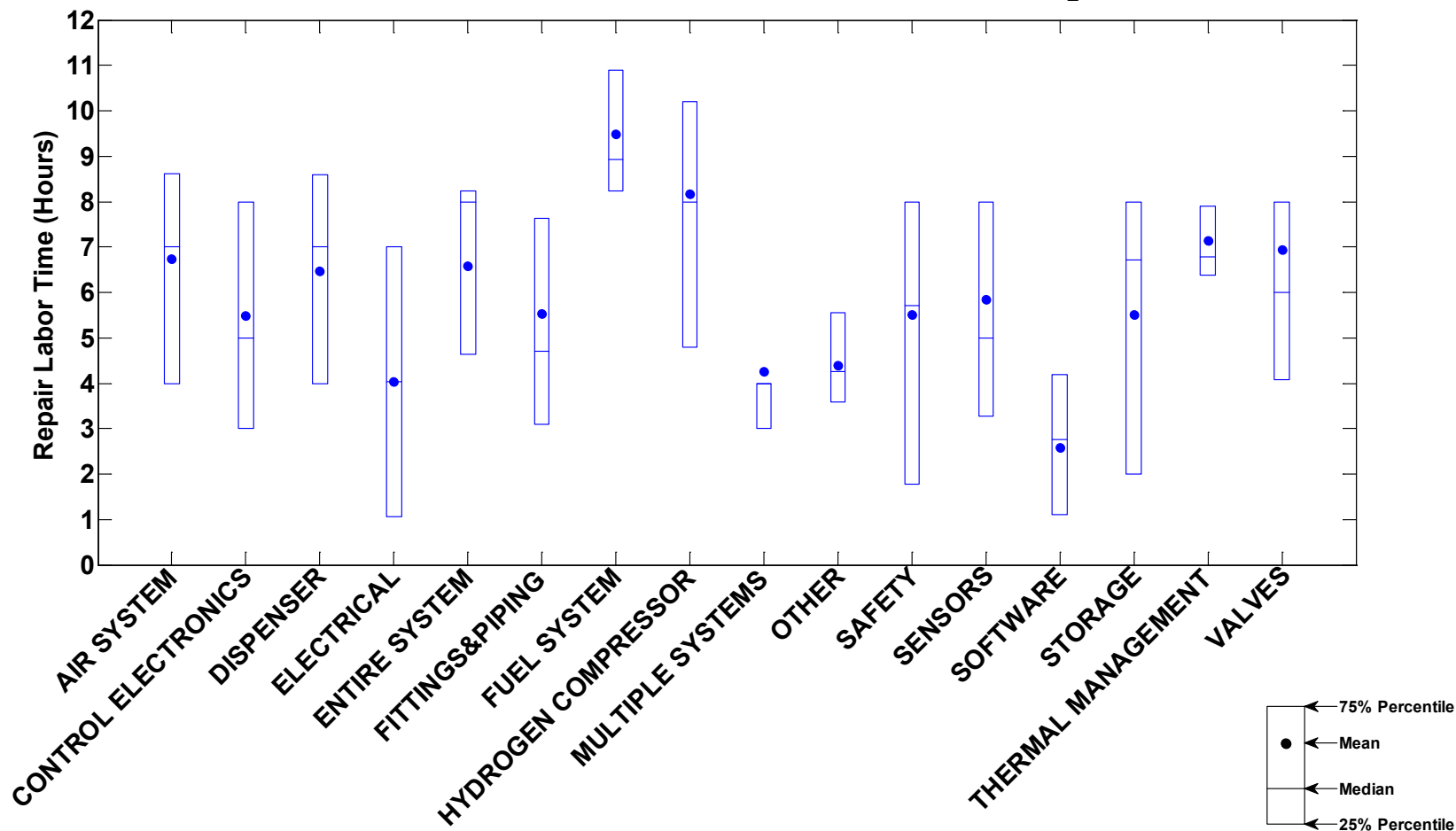
## Component Mean Time Between Failures



# CDPARRA-MHE-76

## Component Repair Time

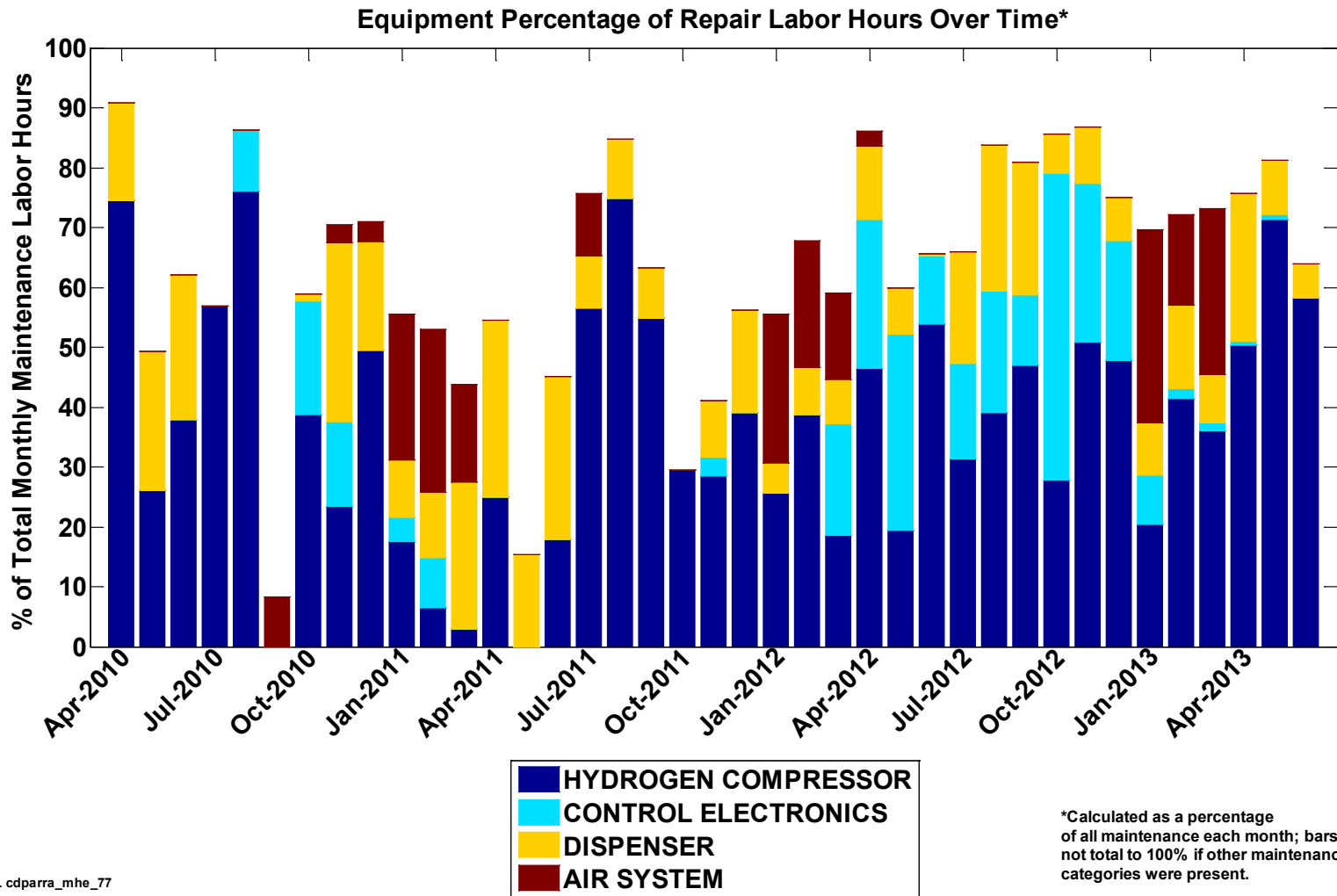
Equipment Category Repair Time: Infrastructure (Delivered H<sub>2</sub> Only)



NREL cdparra\_mhe\_76

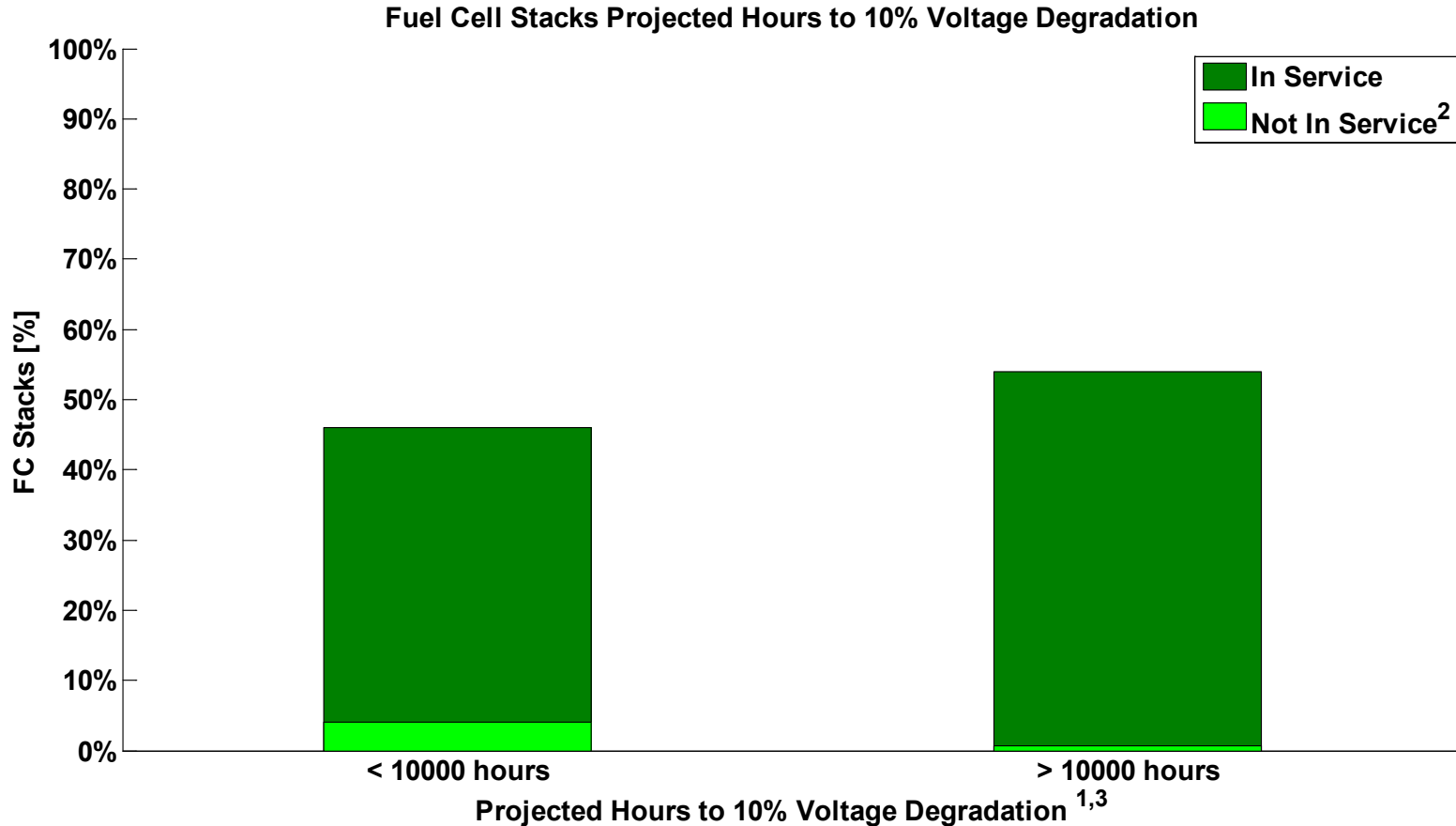
Created: Sep-28-13 10:08 AM | Data Range: 2010Q10-2013Q2

## Equipment Percentage of Monthly Repair Labor Hours





## Projected Hours to 10% Voltage Degradation



1) Projection using field data, calculated at high stack current, from operation hour 0.

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.



NREL cdp\_mhe\_97

Created: Sep-28-13 12:46 PM | Data Range: 2009Q1-2013Q2