



**Technical Report**  
NREL/TP-5600-58612  
May 2013

# ARRA Material Handling Equipment Composite Data Products

## Data Through Quarter 4 of 2012

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M. Peters, and T. Ramsden

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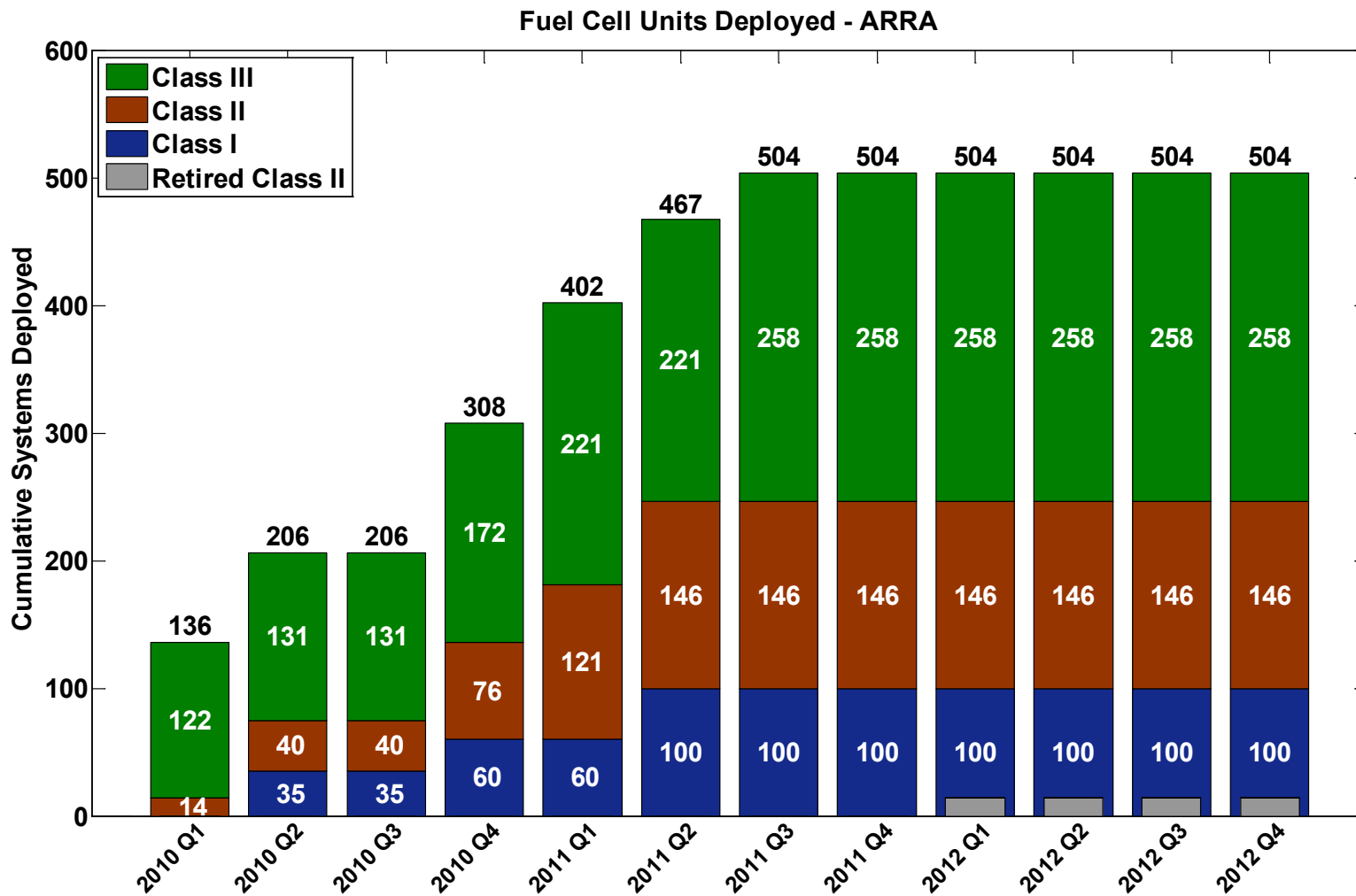
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Cover Photos: (left to right) PIX 16416, PIX 17423, PIX 16560, PIX 17613, PIX 17436, PIX 17721



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

## Fuel Cell MHE Systems Deployed

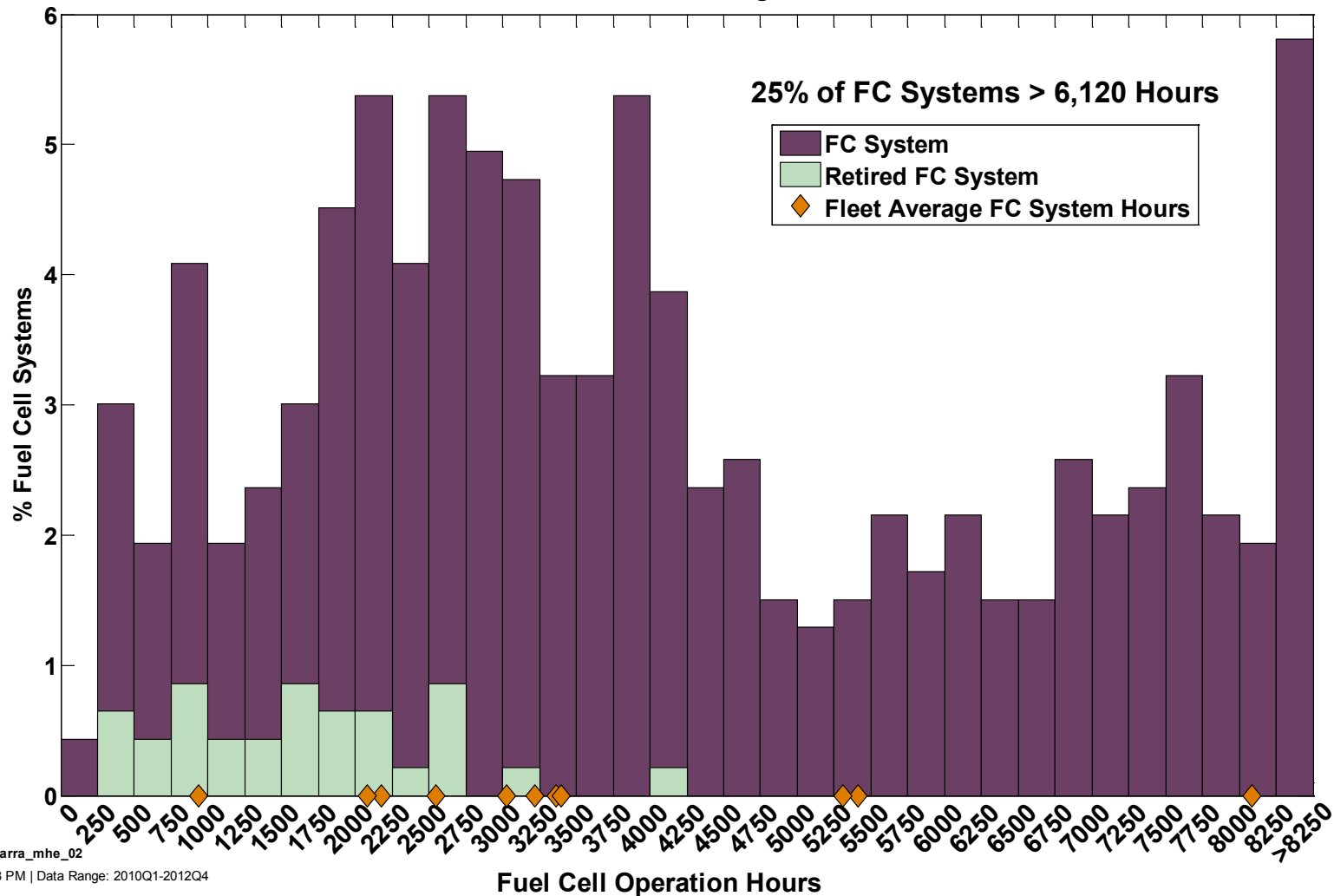


NREL cdparra\_mhe\_01

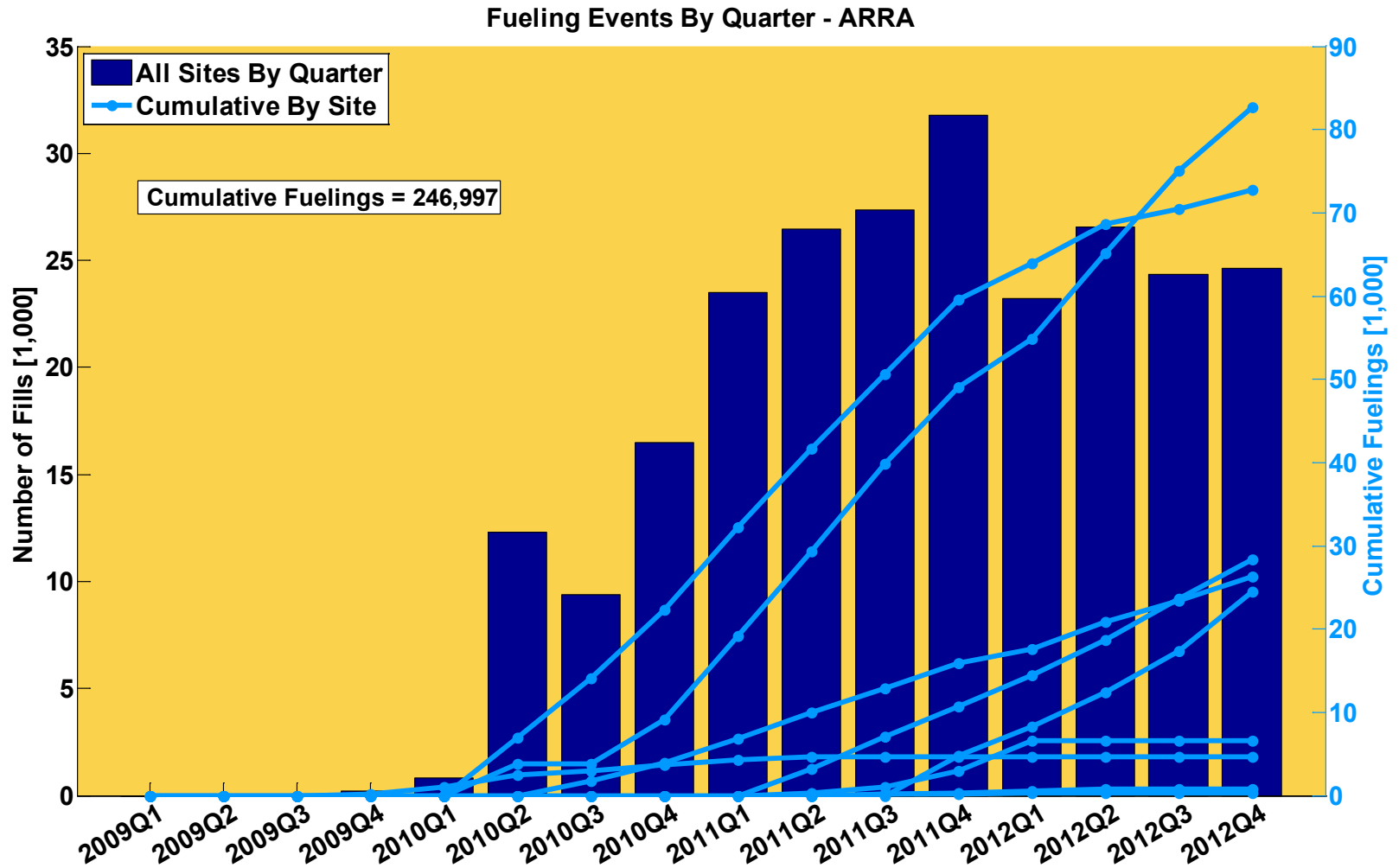
Created: Apr-01-13 3:18 PM | Data Range: 2010Q1-2012Q4

## Fuel Cell System Operation Hours

Cumulative Fuel Cell Operation Hours - ARRA  
Combined Fleet Through 2012Q4



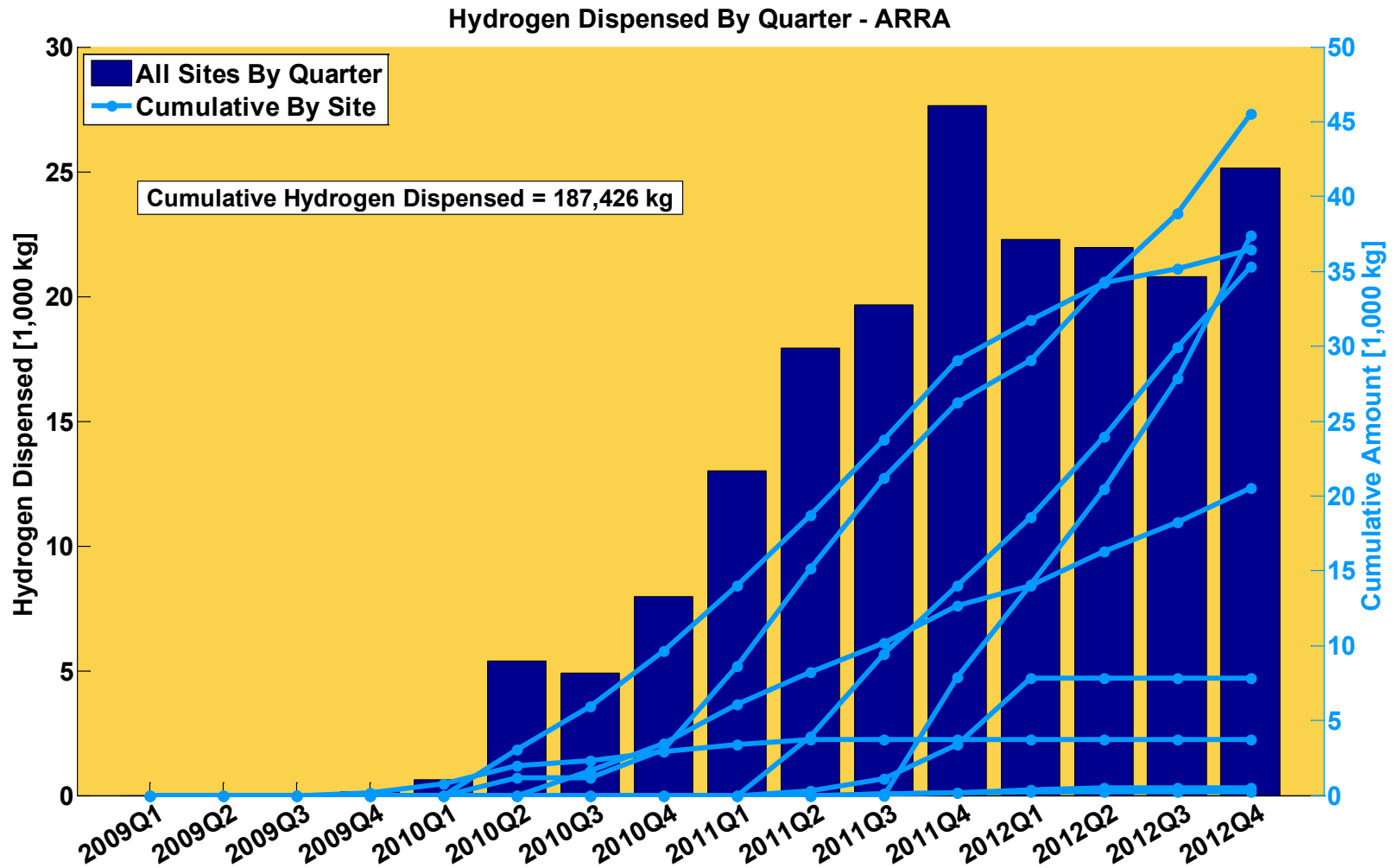
## Fueling Events by Quarter



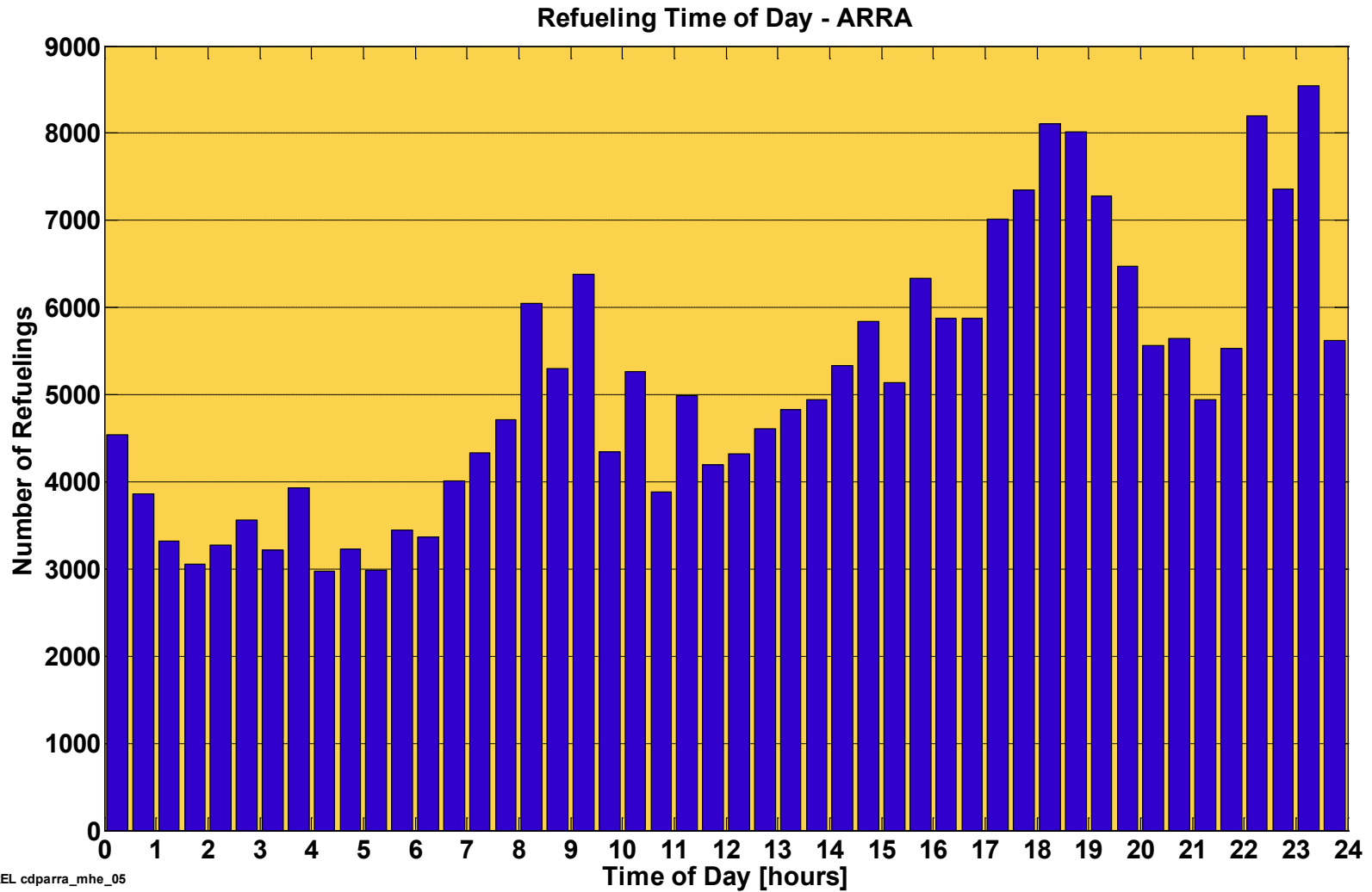
NREL cdparra\_mhe\_03

Created: Apr-01-13 3:22 PM | Data Range: 2010Q1-2012Q4

## Hydrogen Dispensed by Quarter



## Refueling Time of Day

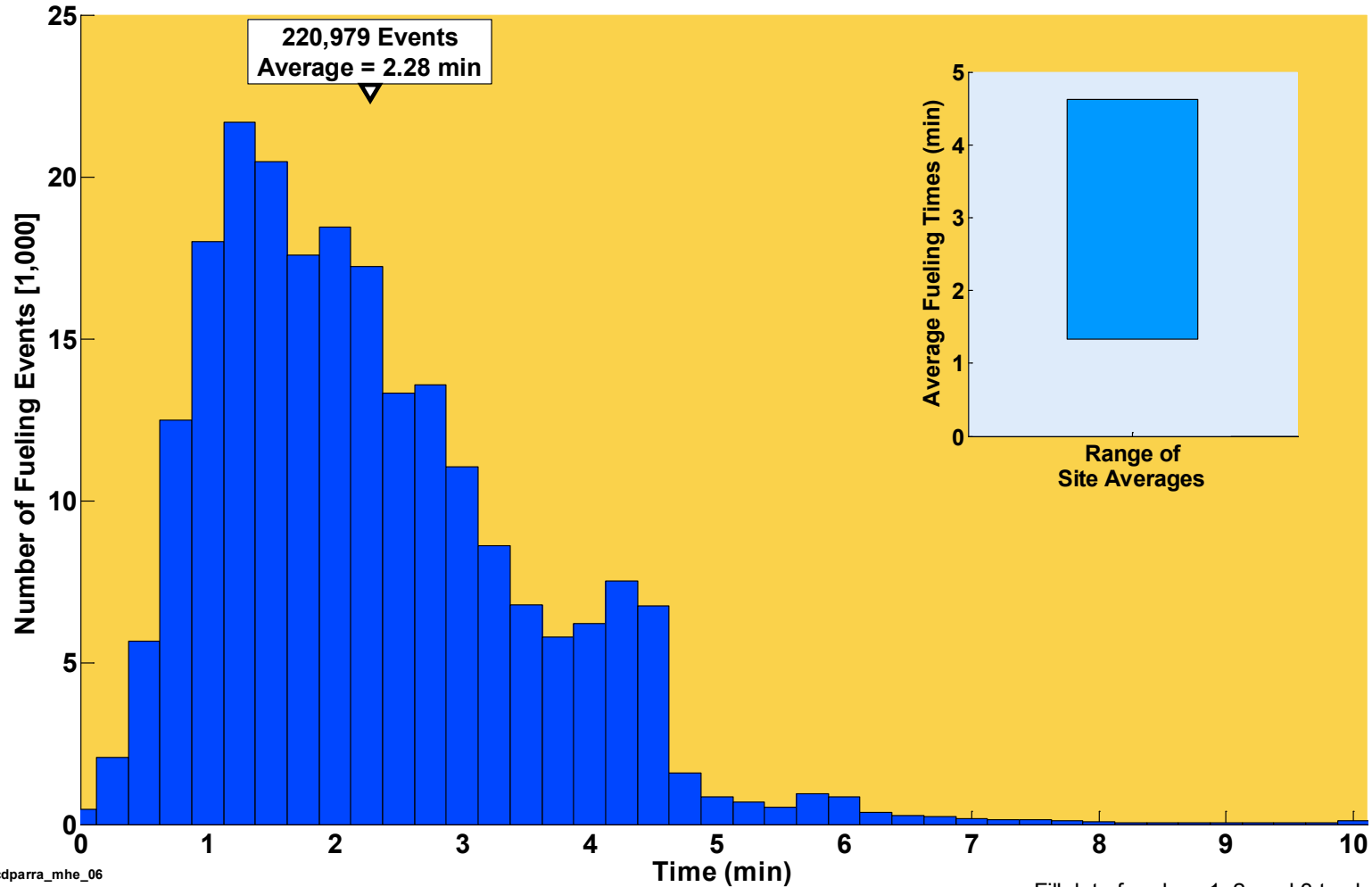


NREL cdparrar\_mhe\_05

Created: Apr-01-13 3:28 PM | Data Range: 2010Q1-2012Q4

## Histogram of Fueling Times

Histogram of Fueling Times  
ARRA Combined Fleet



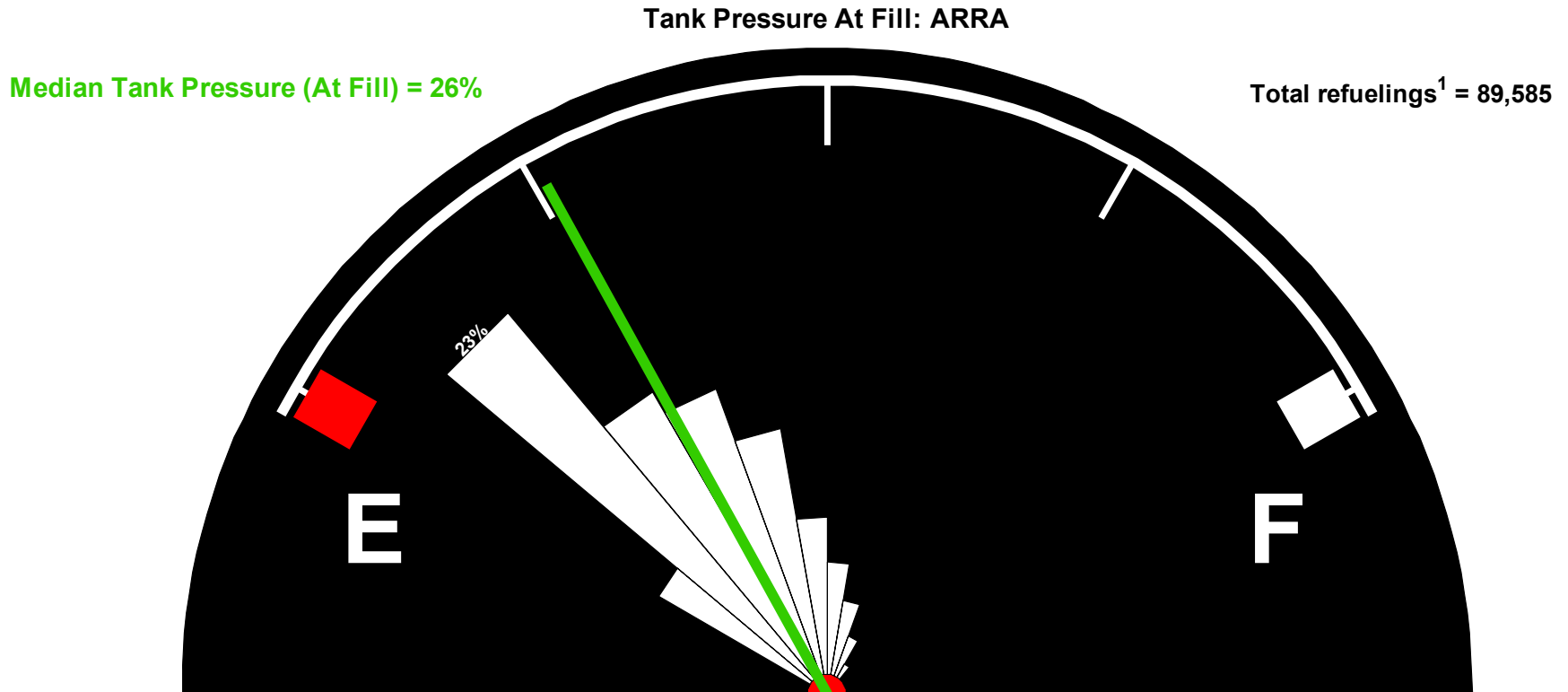
NREL cdparramhe\_06

Created: Apr-01-13 3:35 PM | Data Range: 2010Q1-2012Q4

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.

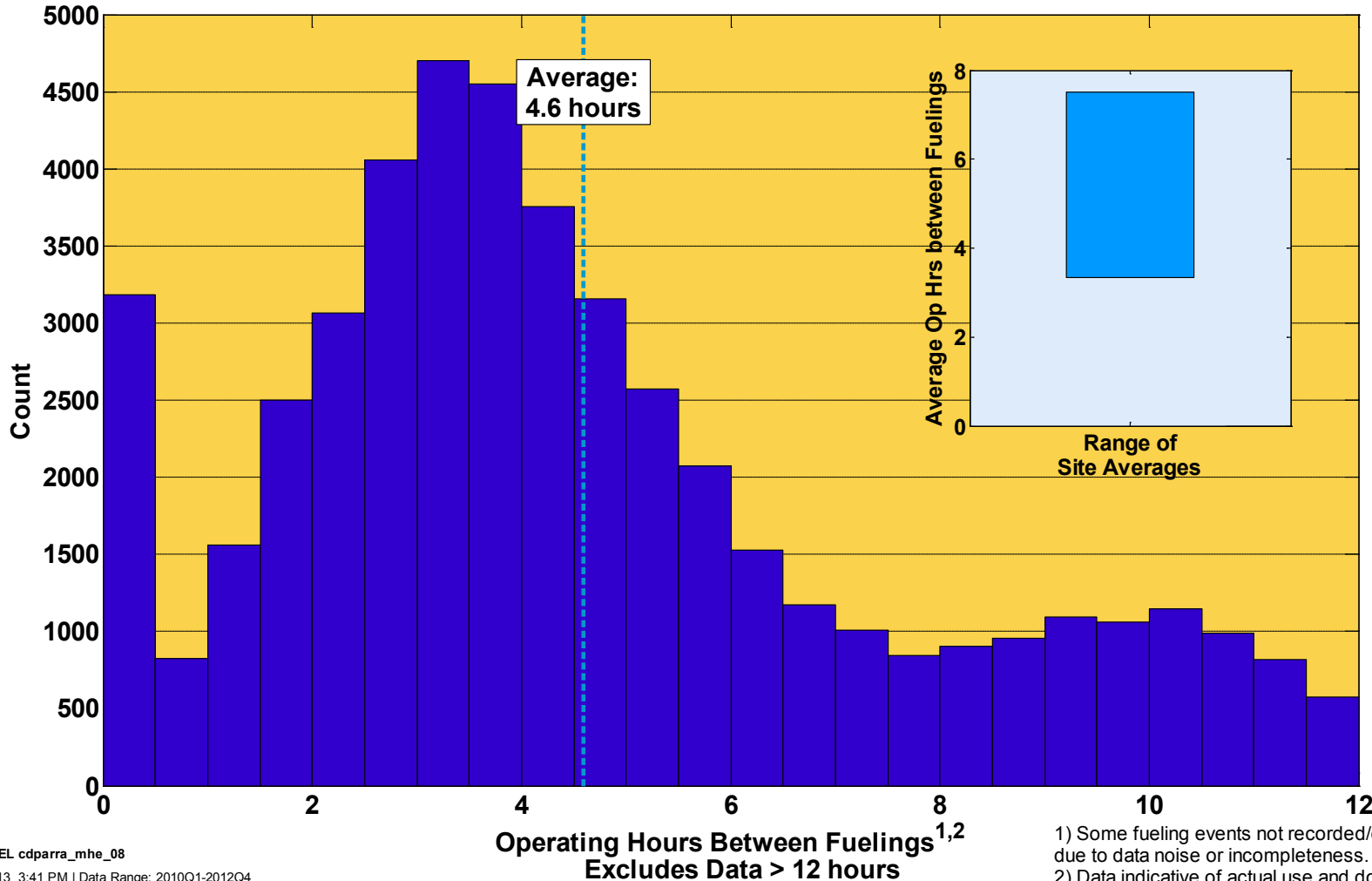


NREL cdparra\_mhe\_07

Created: Apr-01-13 3:40 PM | Data Range: 2010Q1-2012Q4

## Operation Time between Fueling

### Operating Time Between Fuelings - ARRA Combined Fleet



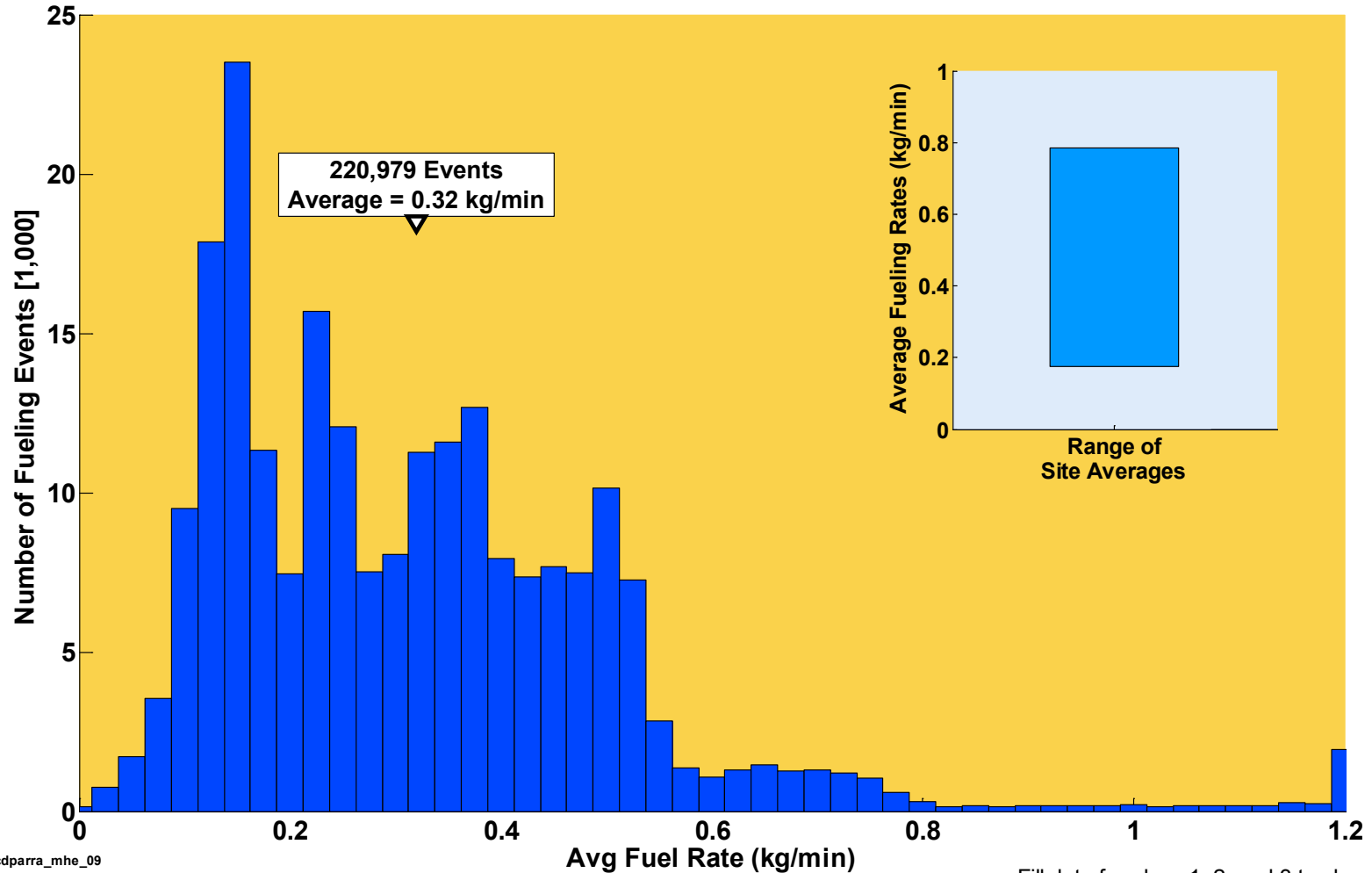
NREL cdparra\_mhe\_08

Created: Apr-01-13 3:41 PM | Data Range: 2010Q1-2012Q4

- 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



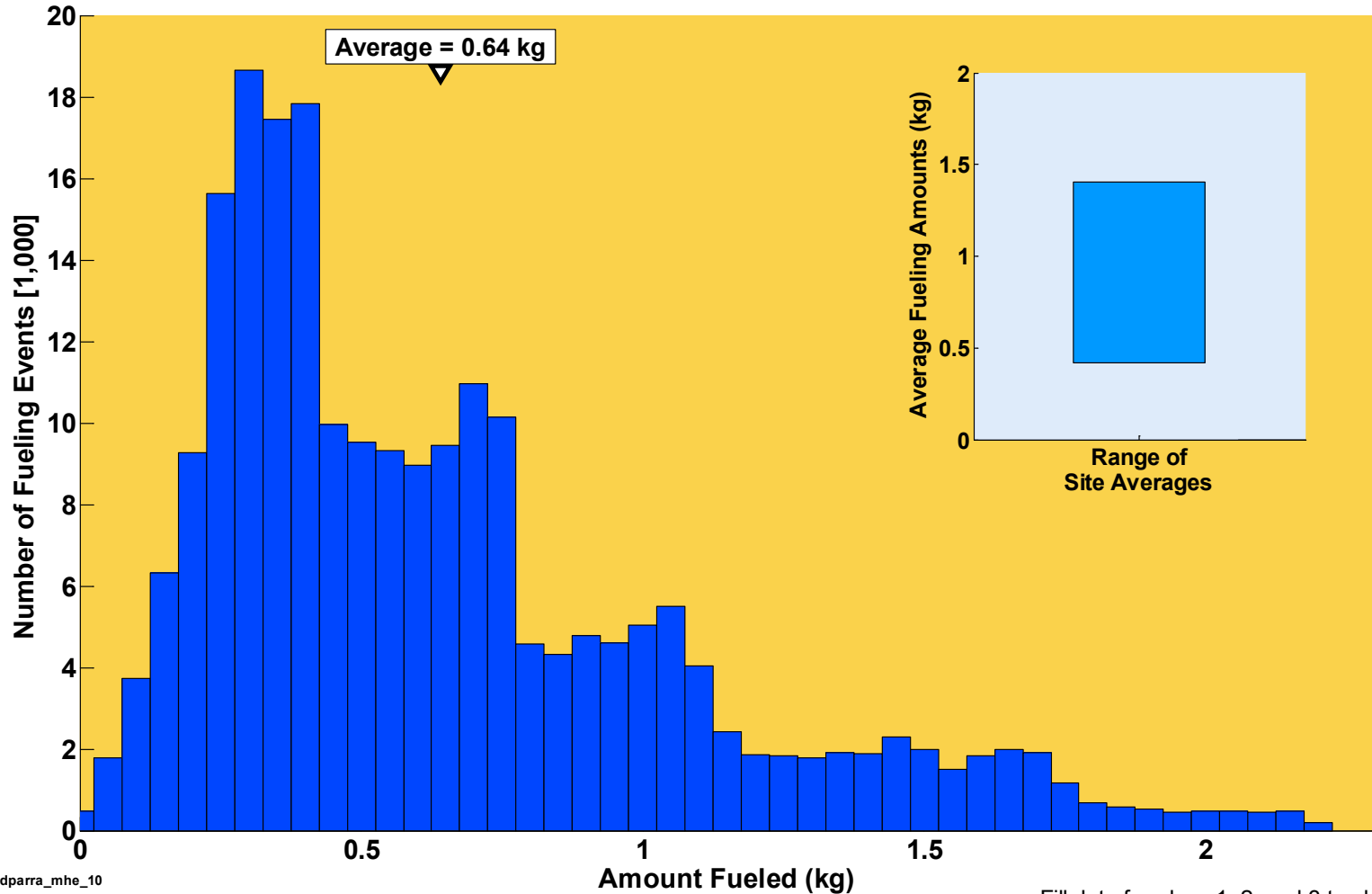
NREL cdparrar\_mhe\_09

Created: Apr-01-13 3:46 PM | Data Range: 2010Q1-2012Q4

Fill data for class 1, 2, and 3 trucks

## Histogram of Fueling Amounts

Histogram of Fueling Amounts  
ARRA Combined Fleet



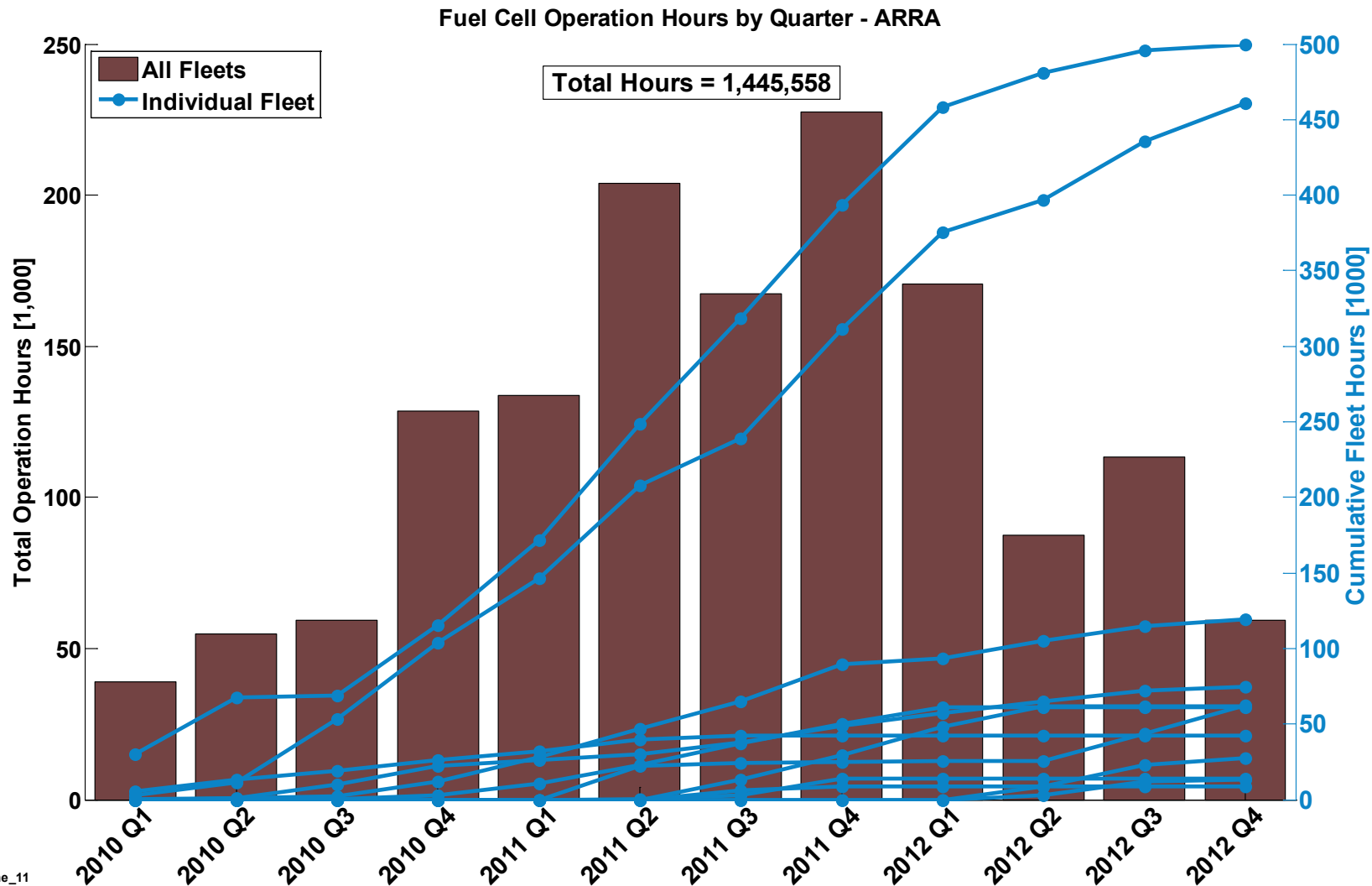
NREL cdparramhe\_10

Created: Apr-01-13 3:56 PM | Data Range: 2010Q1-2012Q4

Fill data for class 1, 2, and 3 trucks

# CDPARRA-MHE-11

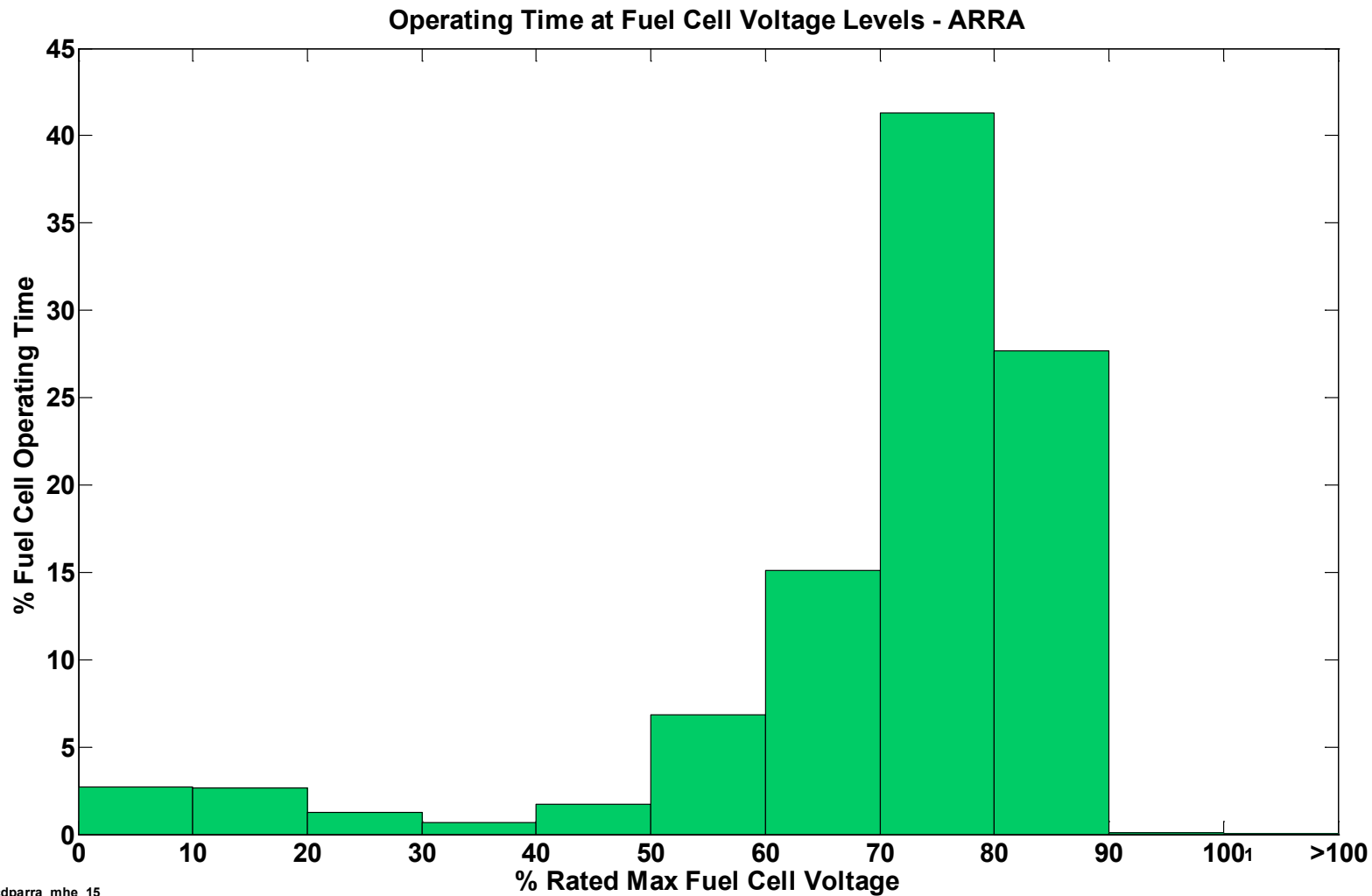
## Fuel Cell Operation Hours by Quarter



NREL cdparra\_mhe\_11

Created: Apr-02-13 10:22 AM | Data Range: 2009Q4-2012Q4

## Operating Time at Fuel Cell Voltage Levels

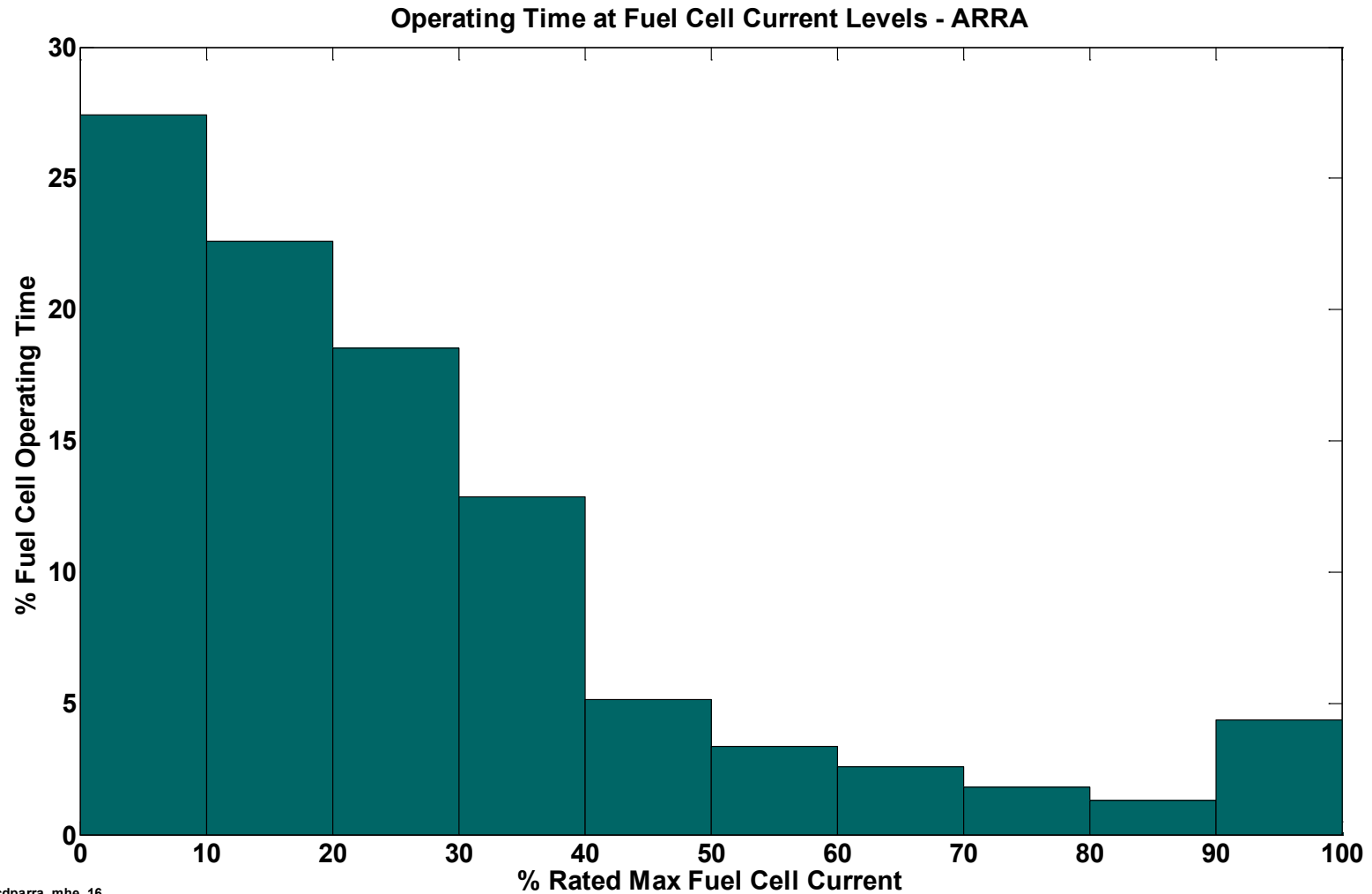


NREL cdparra\_mhe\_15

Created: Apr-01-13 4:01 PM | Data Range: 2010Q1-2012Q4

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

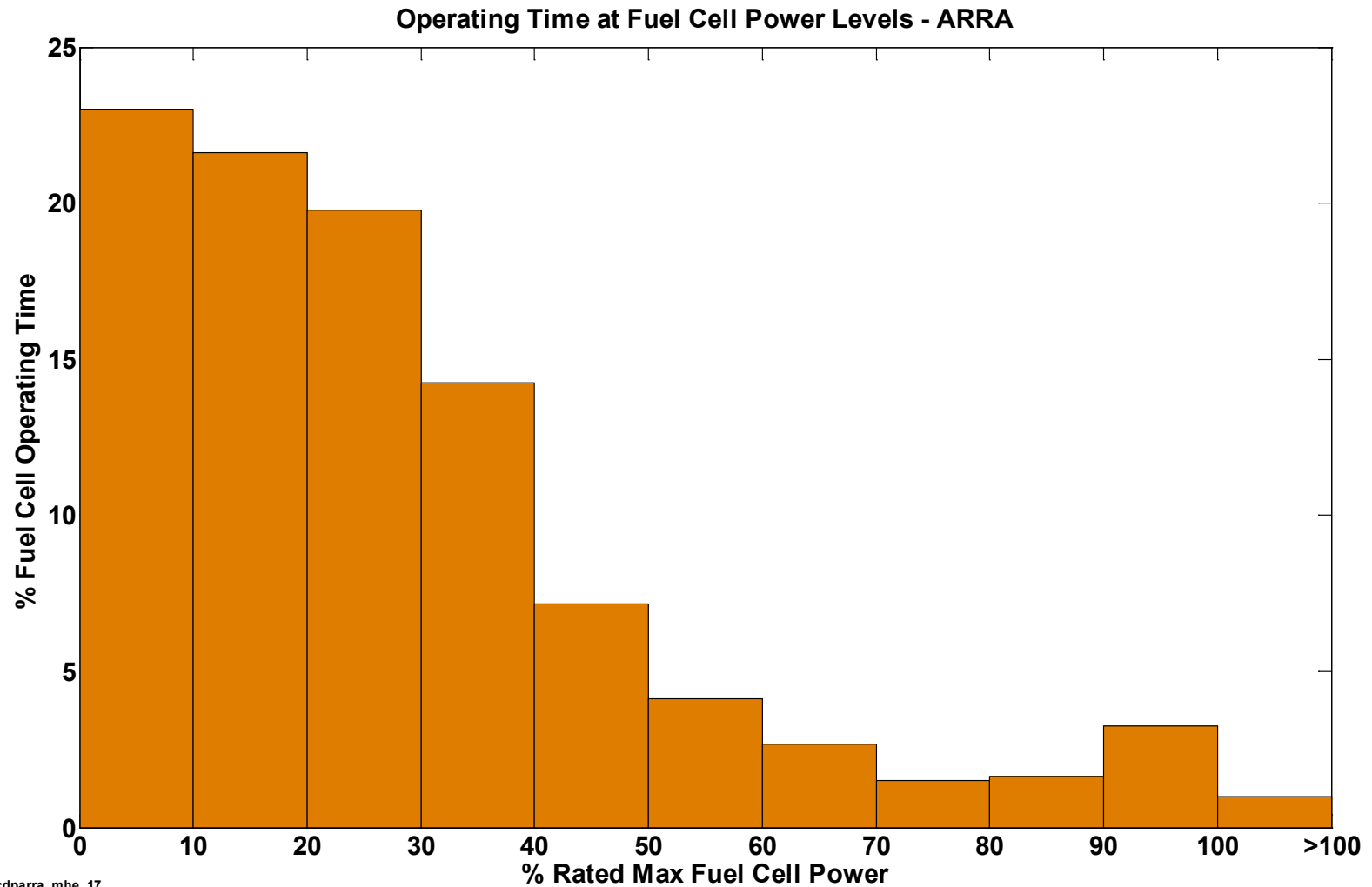
## Operating Time at Fuel Cell Current Levels



NREL cdparramhe\_16

Created: Apr-01-13 4:01 PM | Data Range: 2010Q1-2012Q4

## Operating Time at Fuel Cell Power Levels



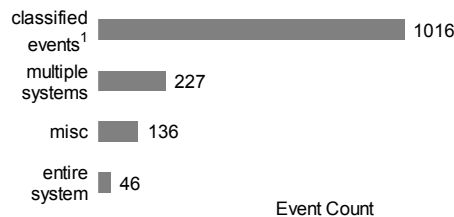
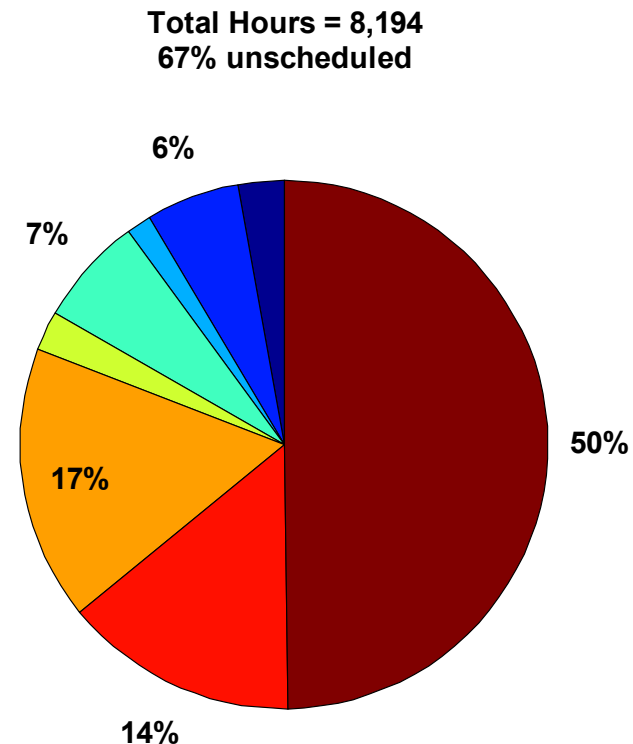
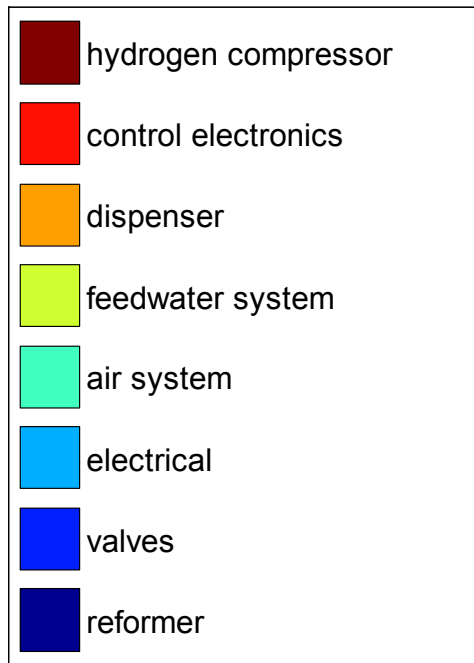
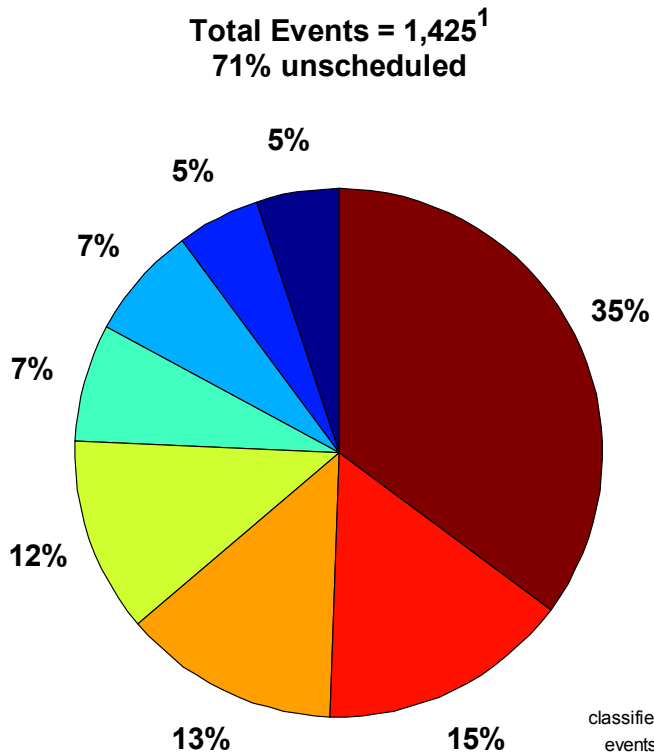
NREL cdparramhe\_17

Created: Apr-01-13 4:02 PM | Data Range: 2010Q1-2012Q4



## Infrastructure Maintenance by Category

### Infrastructure Maintenance By Equipment Type

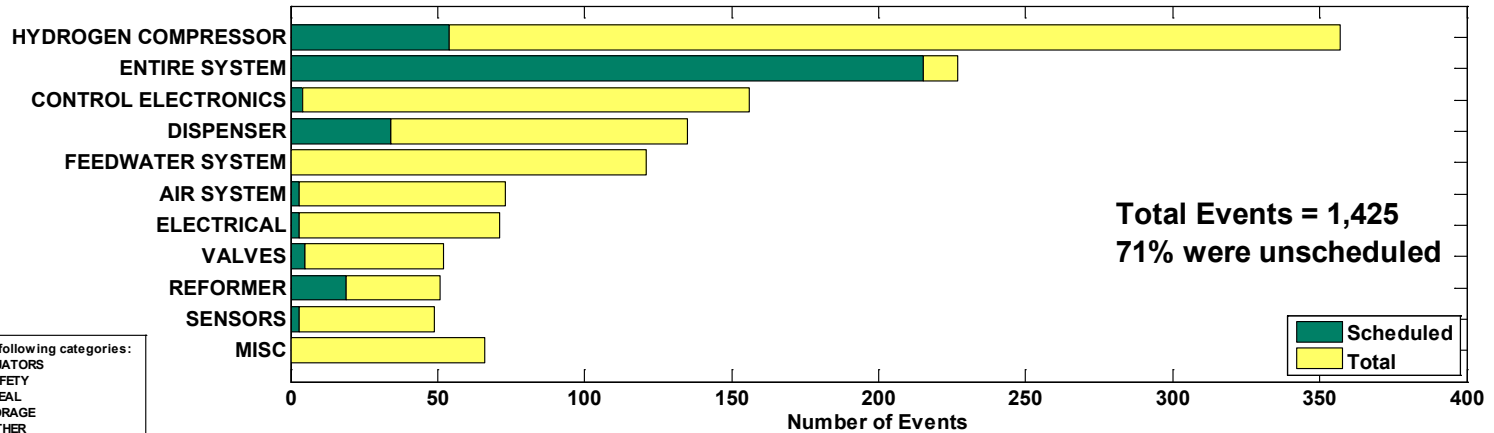


MISC includes the following failure modes: actuators, safety, seal, storage, unspecified, software, thermal management, fuel system, fittings&pipng, sensors, other



## Infrastructure Scheduled & Unscheduled Maintenance by Category

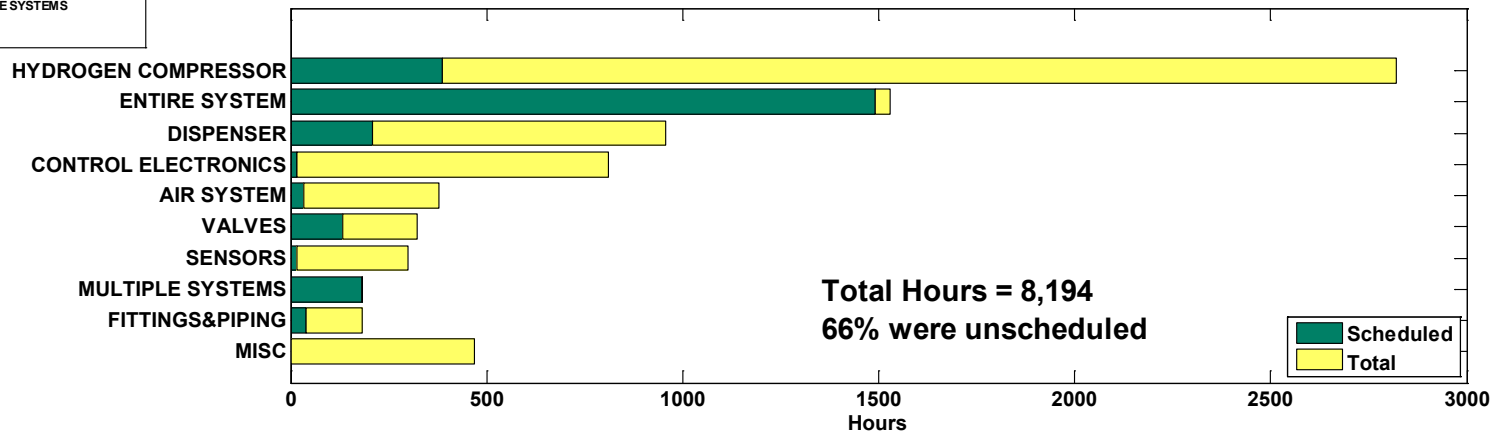
Infrastructure Maintenance Scheduled vs. Unscheduled  
Number of Maintenance Events by Category



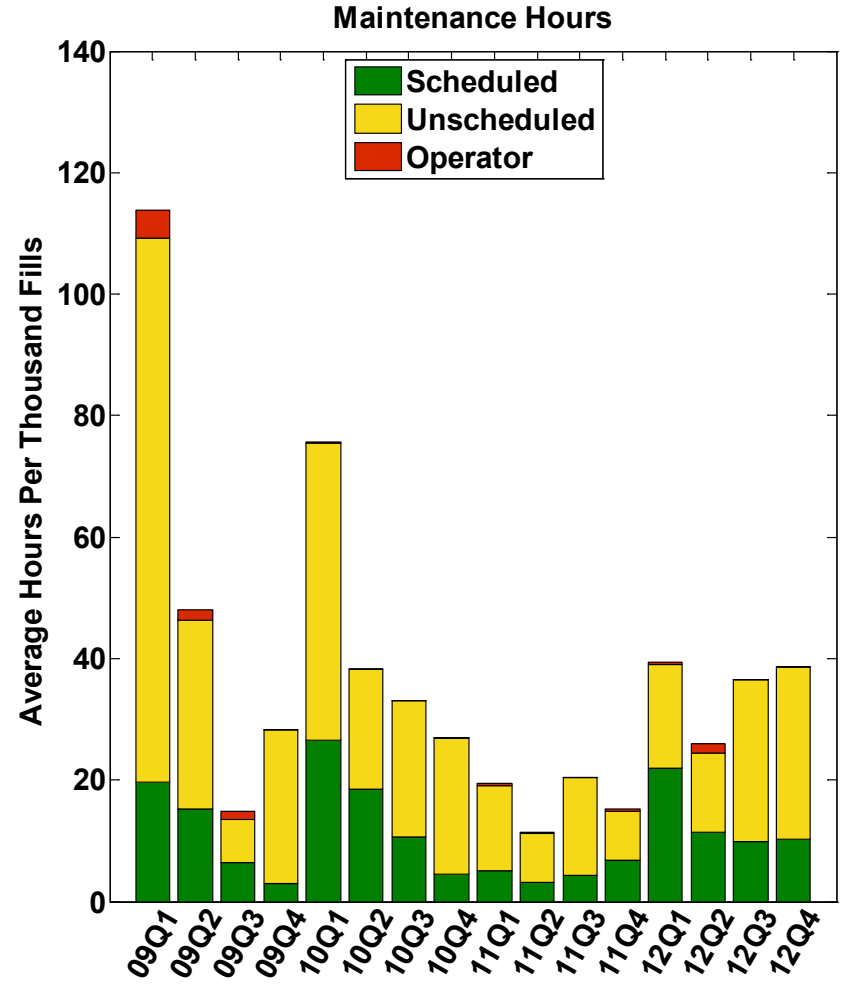
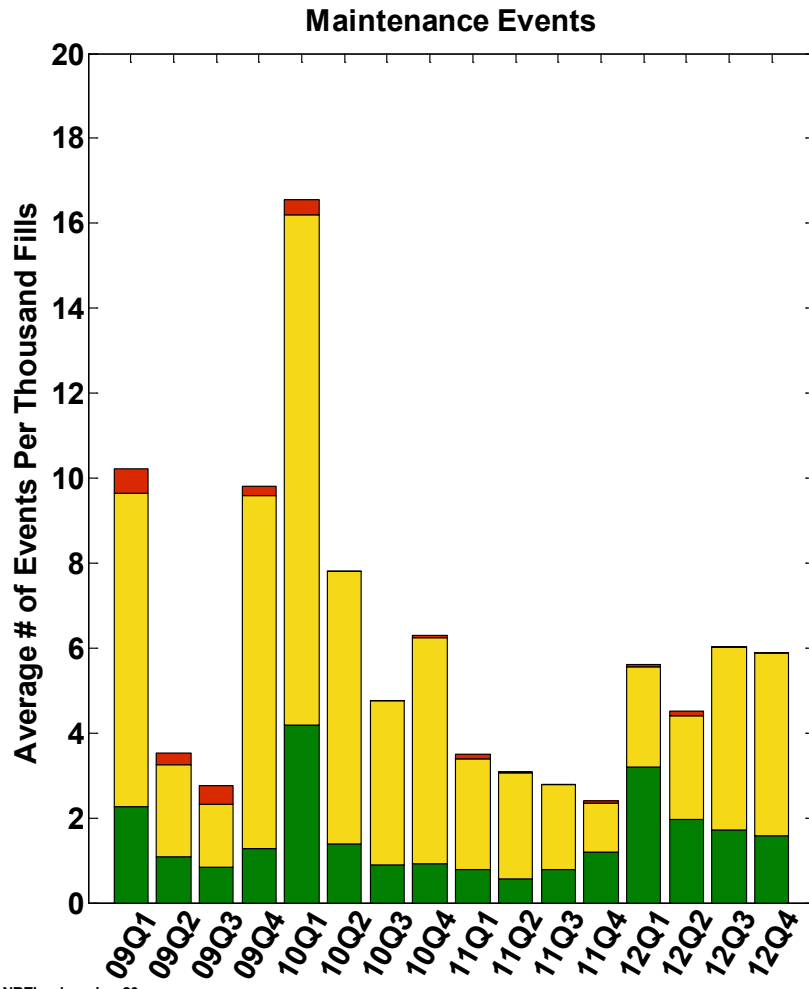
MISC includes the following categories:

- ACTUATORS
- SAFETY
- SEAL
- STORAGE
- OTHER
- UNSPECIFIED
- SOFTWARE
- THERMAL MANAGEMENT
- FUEL SYSTEM
- FITTINGS&PIPING
- MULTIPLE SYSTEMS

Number of Labor Hours by Category



### Average Infrastructure Site Quarterly Maintenance



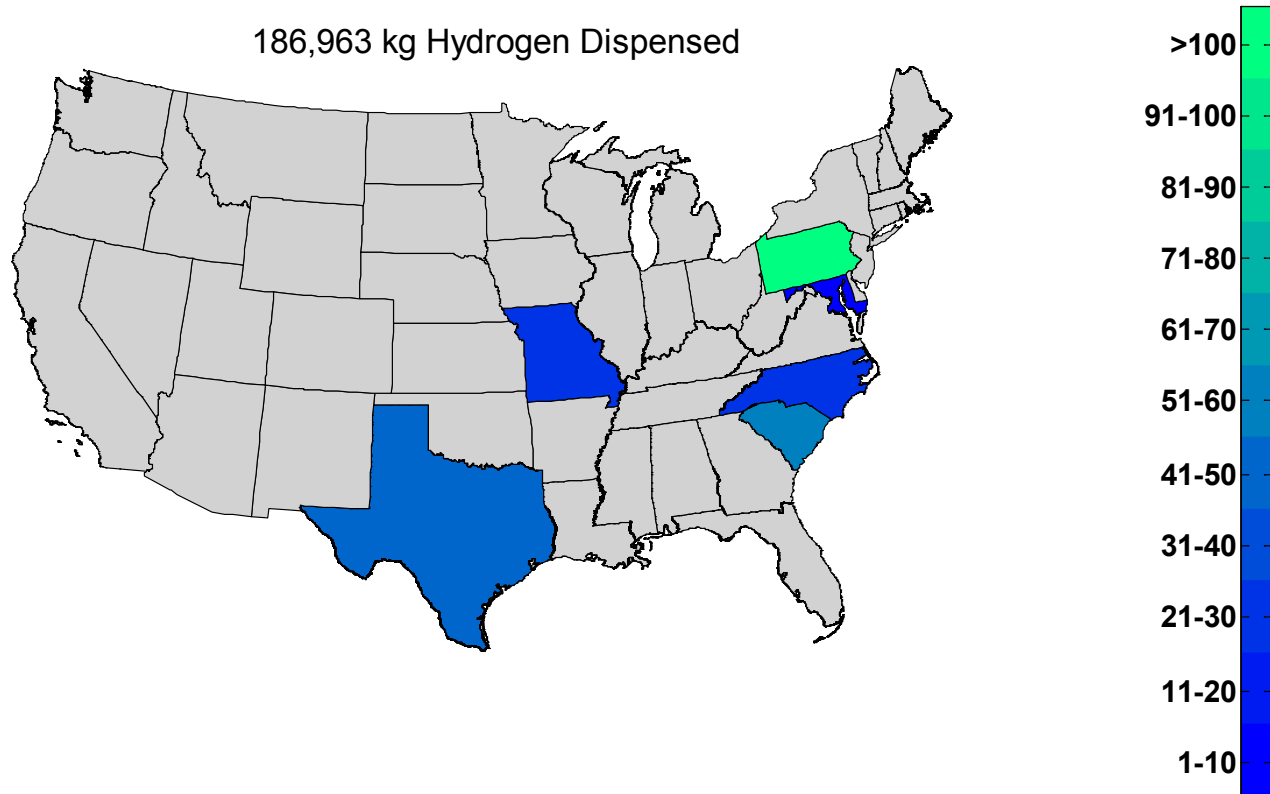
NREL cdp\_mhe\_20

Created: Apr-02-13 9:32 AM | Data Range: 2009Q1-2012Q4

## Average Daily Hydrogen Dispensed by Location

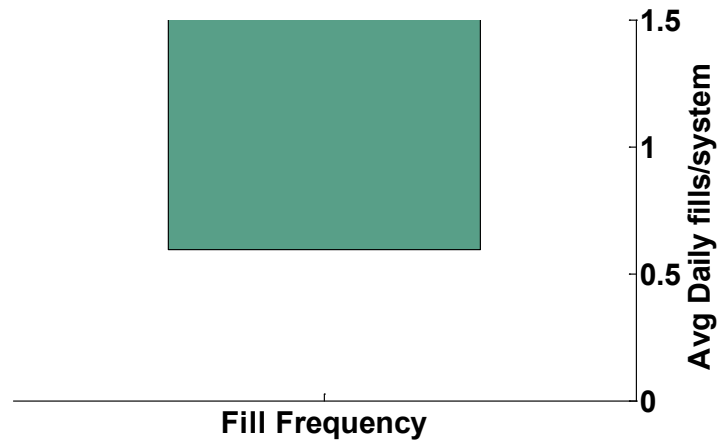
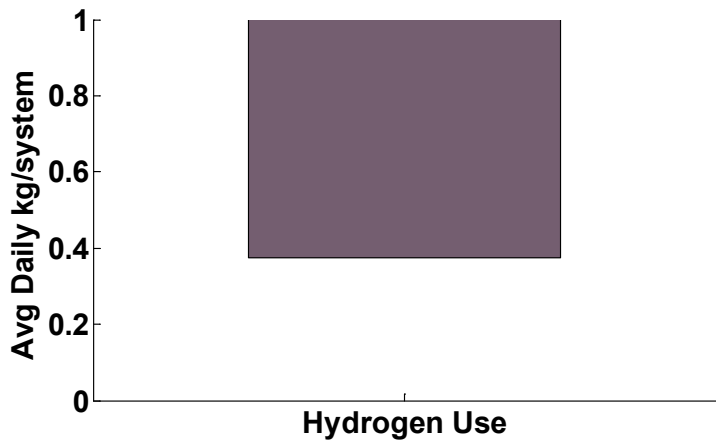
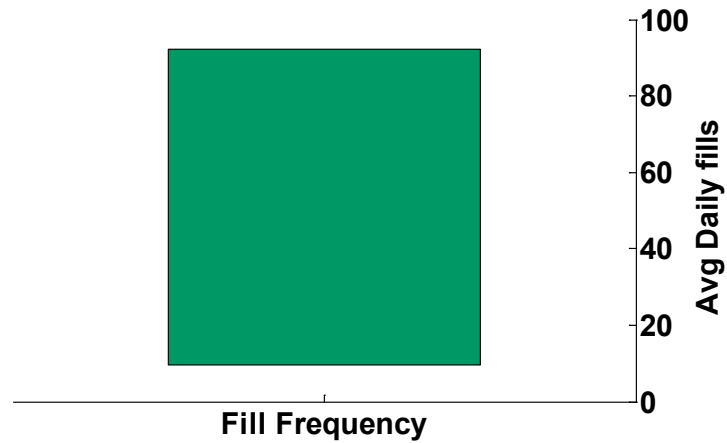
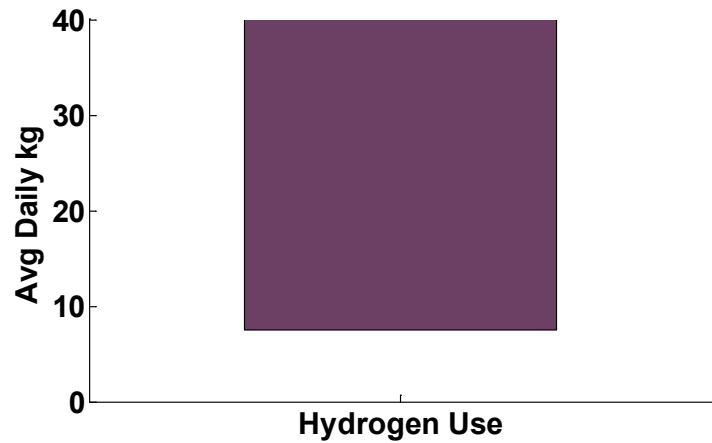
Average Daily Hydrogen Dispensed by Location - ARRA

186,963 kg Hydrogen Dispensed



## Average Daily Dispensing Operations by Site

### Average Daily Dispensing Operations by Site - ARRA

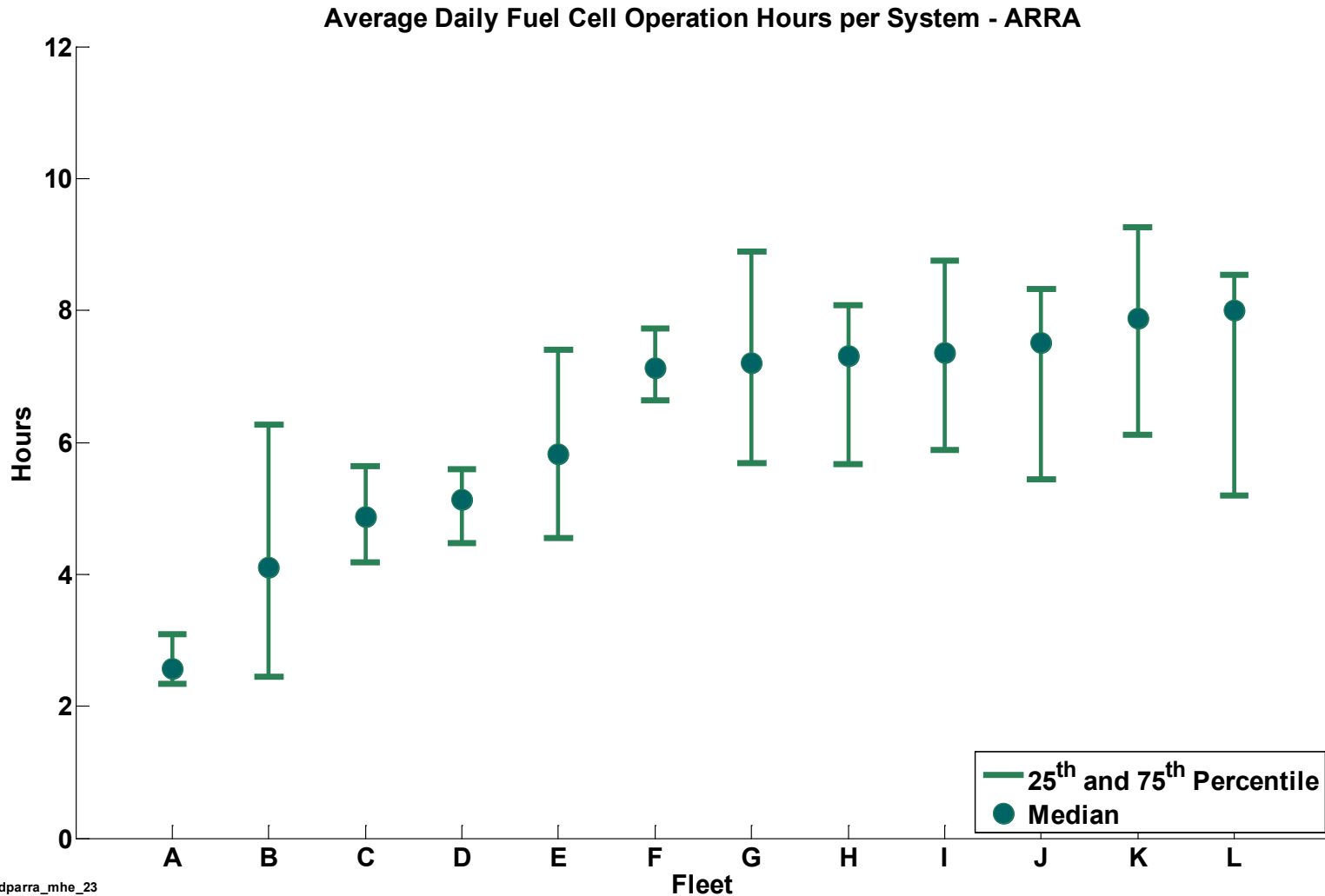


NREL cdparrar\_mhe\_22

Created: Apr-01-13 4:03 PM | Data Range: 2010Q1-2012Q4

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

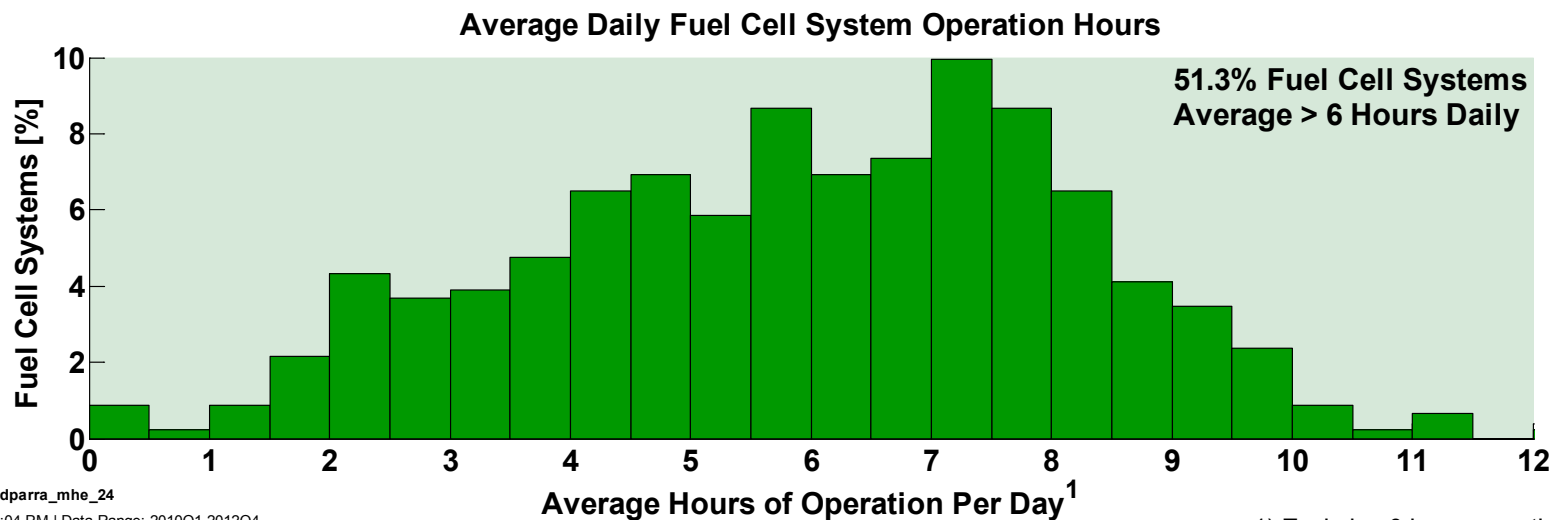
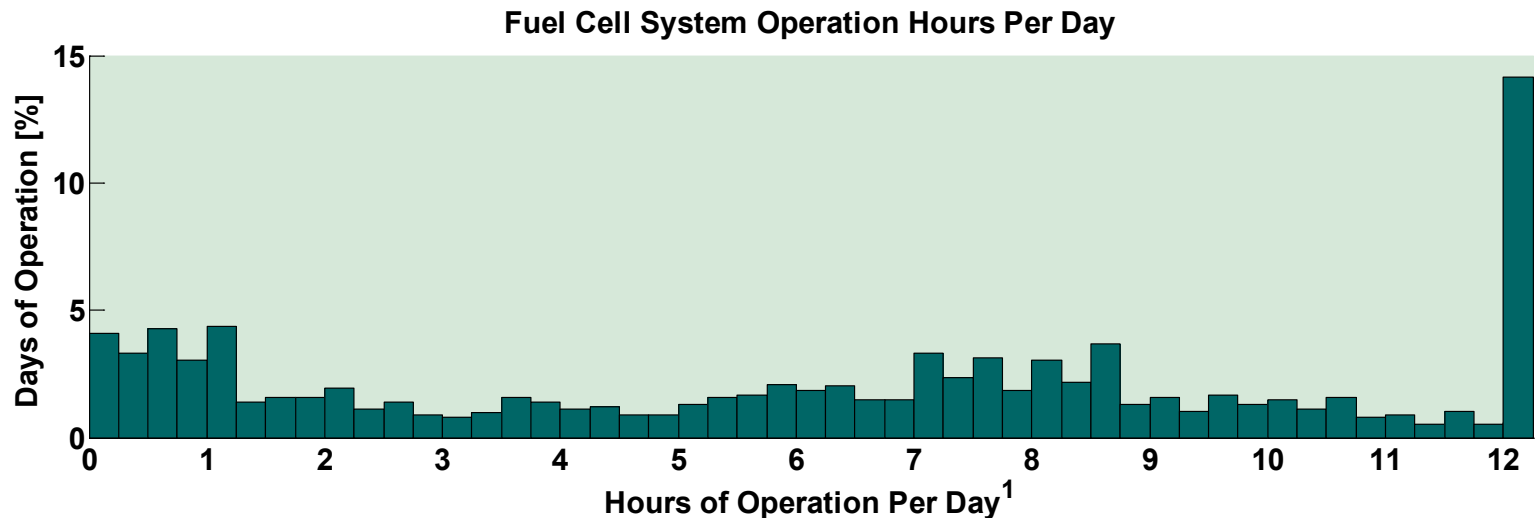
## Average Daily Fuel Cell Operation Hours per Fleet



NREL cdparramhe\_23

Created: Apr-01-13 4:03 PM | Data Range: 2010Q1-2012Q4

## Average Daily Fuel Cell Operation Hours per System

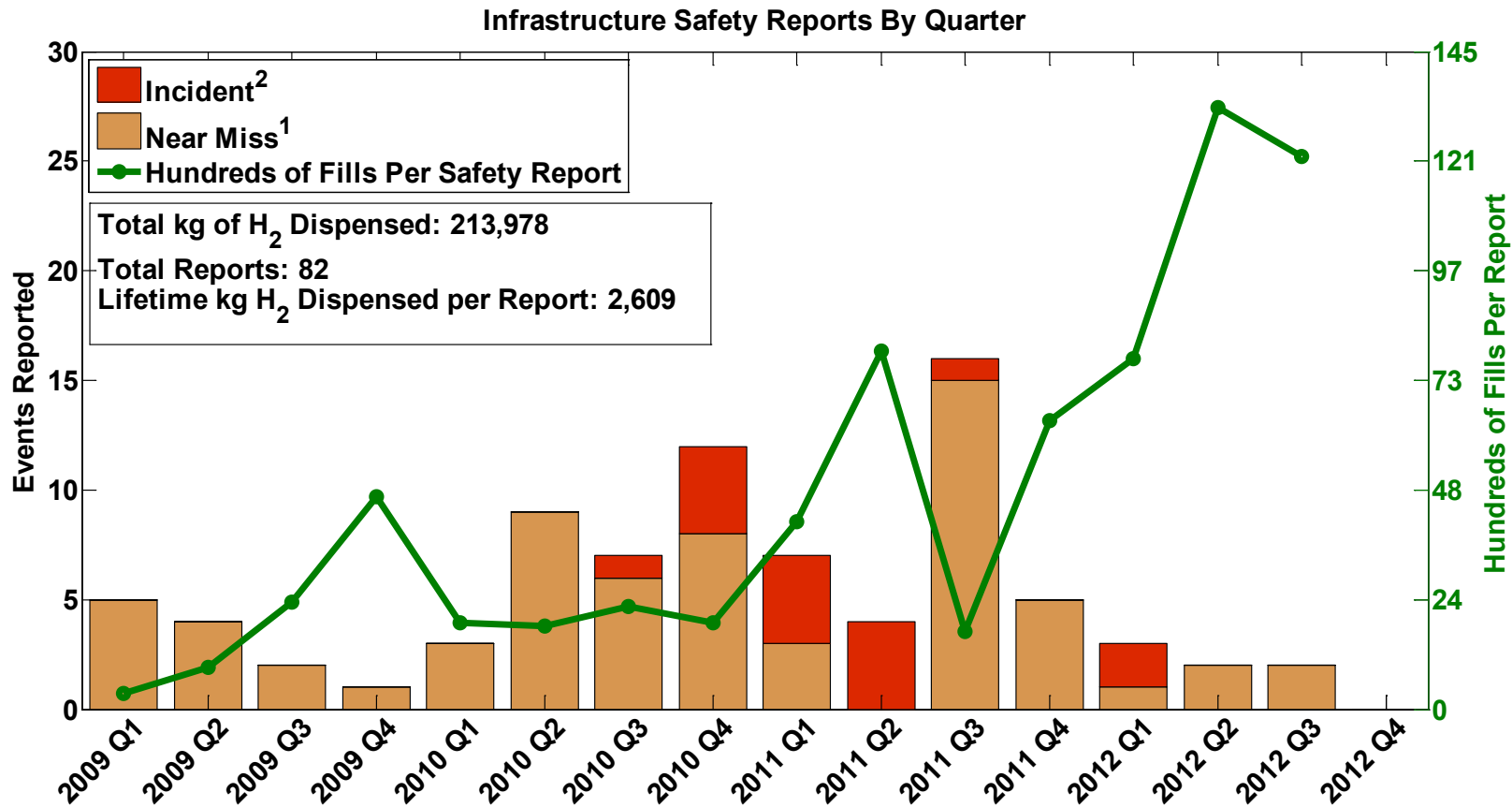


NREL cdparra\_mhe\_24

Created: Apr-01-13 4:04 PM | Data Range: 2010Q1-2012Q4

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 H2 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 uses as common fuels)



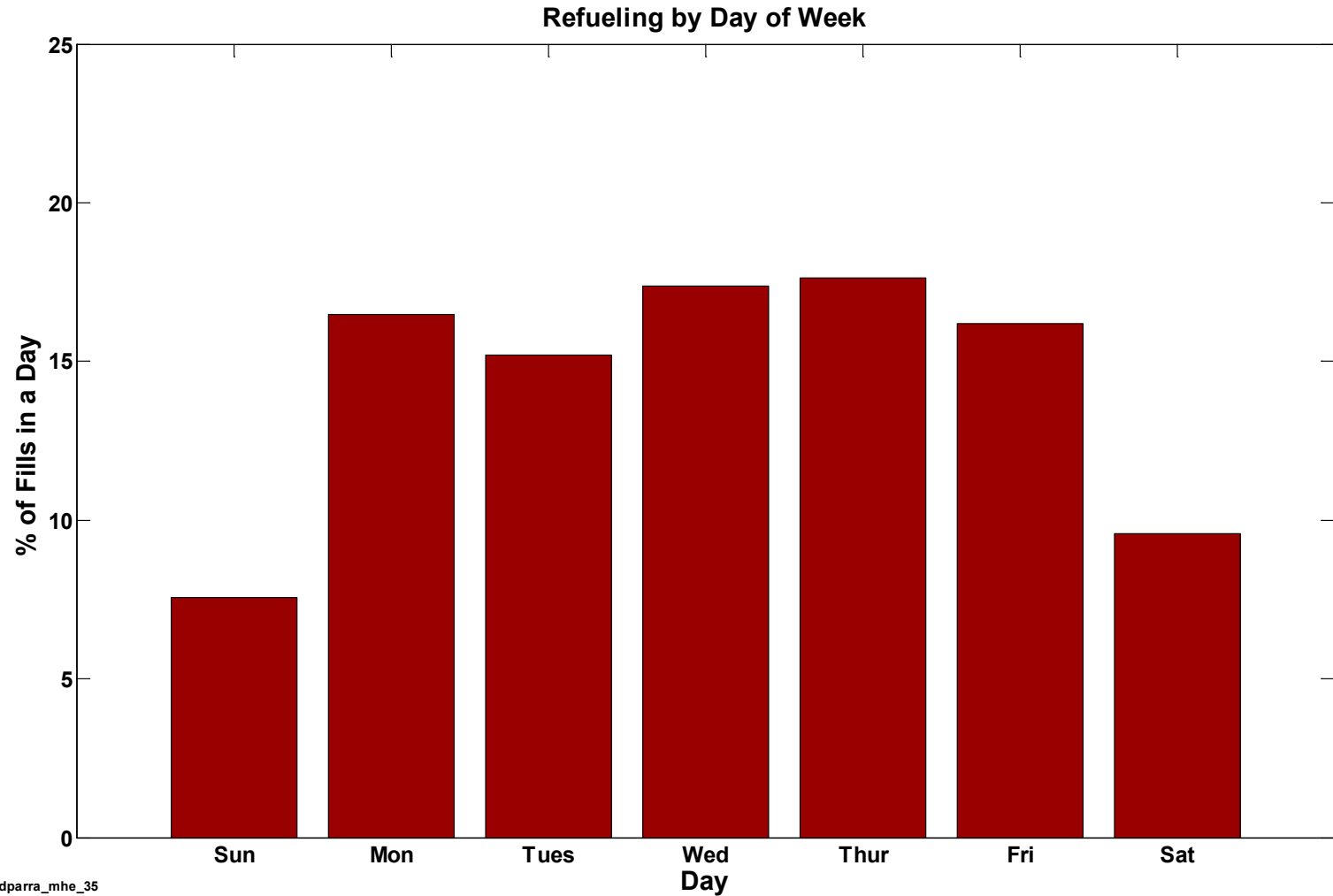
NREL cdp\_mhe\_25

Created: Apr-02-13 9:33 AM | Data Range: 2009Q1-2012Q4



# CDPARRA-MHE-35

## Refuel Events by Day of Week

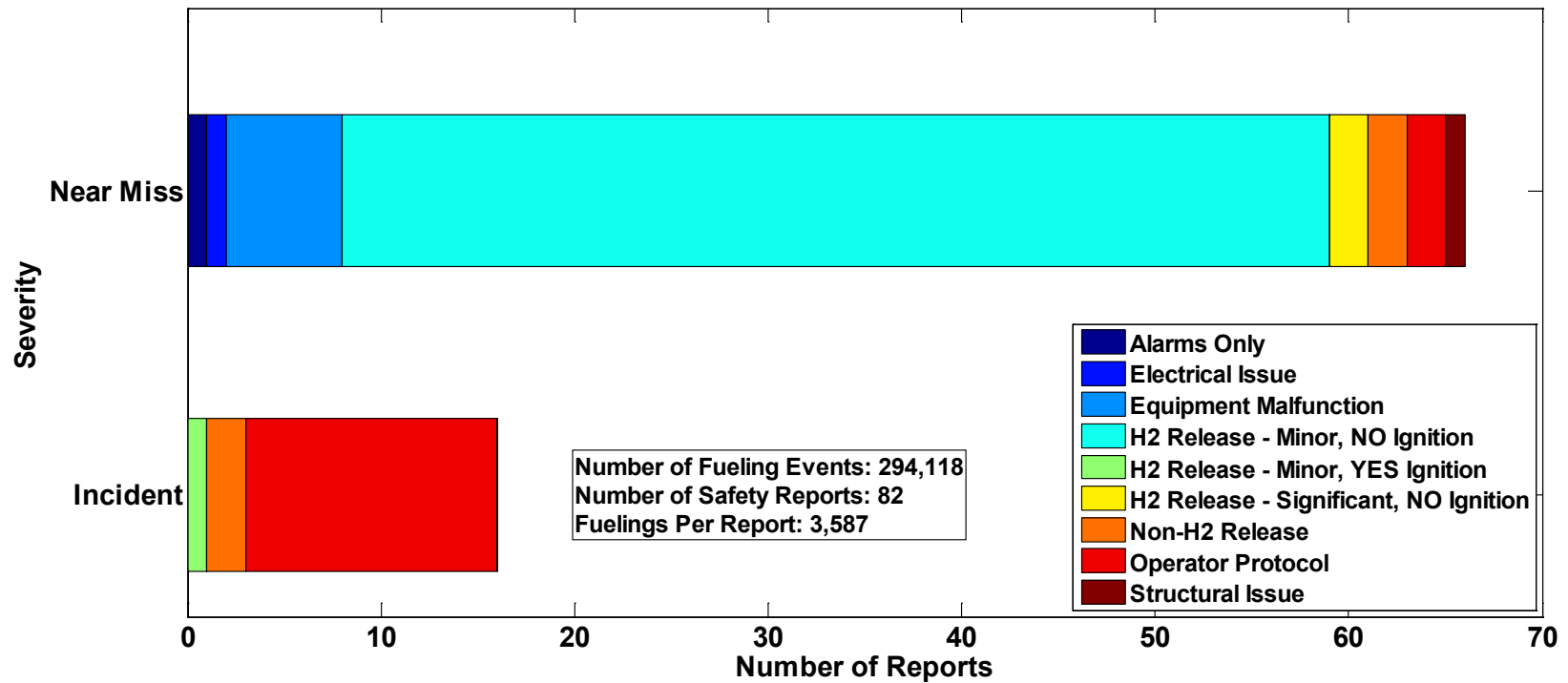


NREL cdparra\_mhe\_35

Created: Apr-01-13 4:09 PM | Data Range: 2010Q1-2012Q4

## Infrastructure Safety Categories

Infrastructure Safety Reports by Severity - All Sites and Report Type



An INCIDENT is an event that results in:

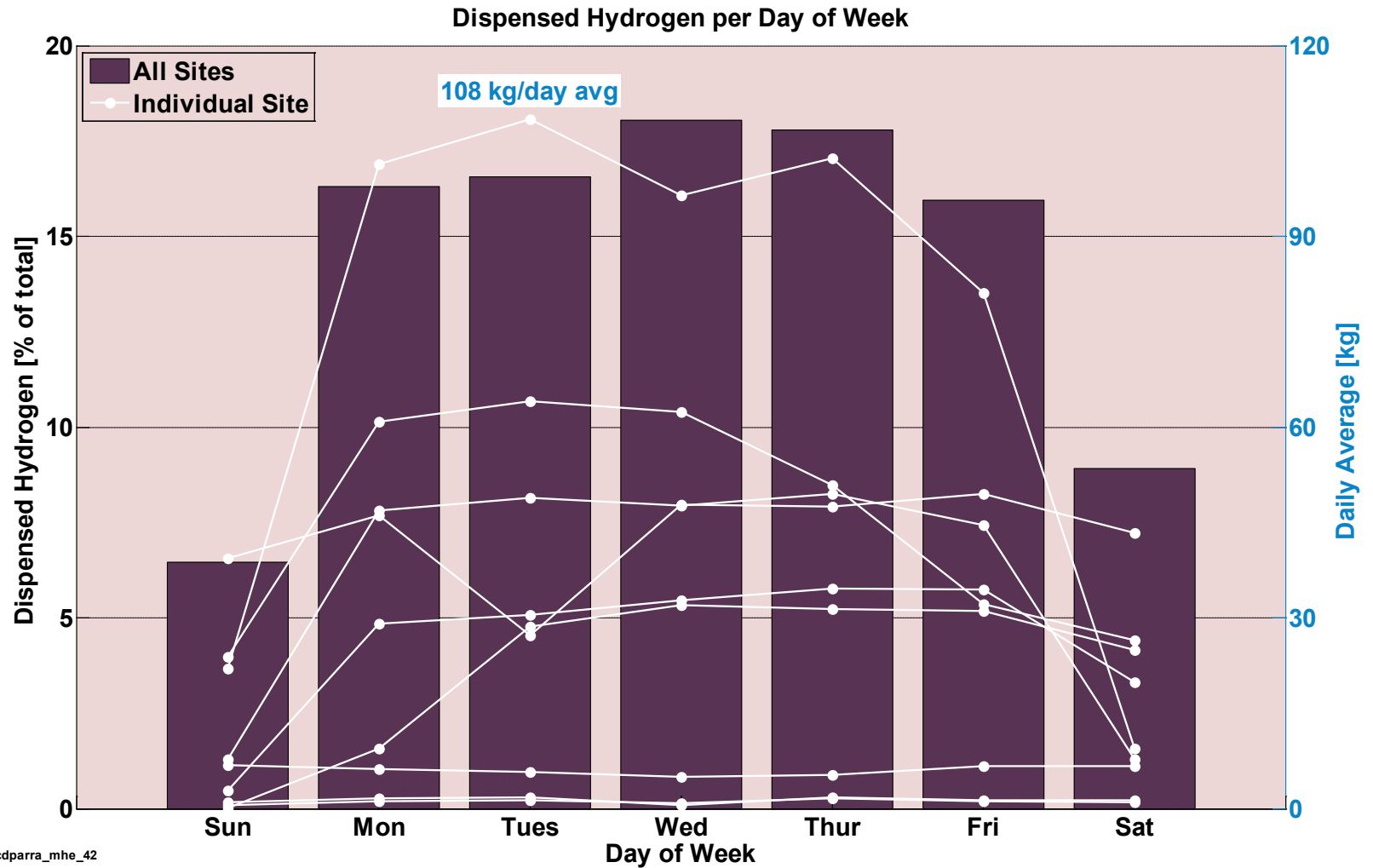
- a lost time accident and/or injury to personnel
- damage/unplanned downtime for project equipment, facilities or property
- impact to the public or environment
- any hydrogen release that unintentionally ignites or is sufficient to sustain a flame if ignited
- release of any volatile, hydrogen containing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

A NEAR-MISS is:

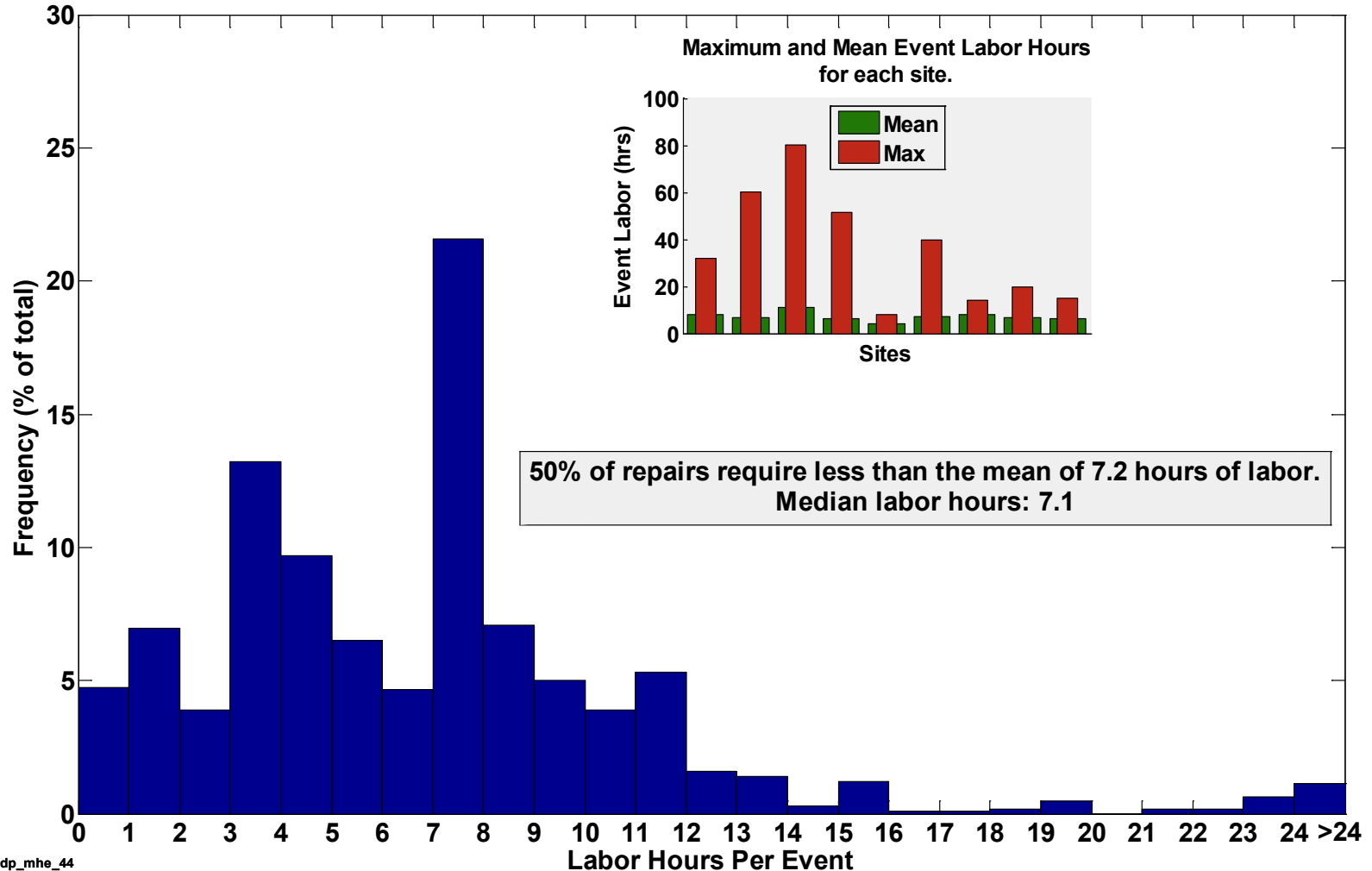
- an event that under slightly different circumstances could have become an incident
- unplanned H2 release insufficient to sustain a flame



## Amount of Hydrogen Dispensed by Day of Week

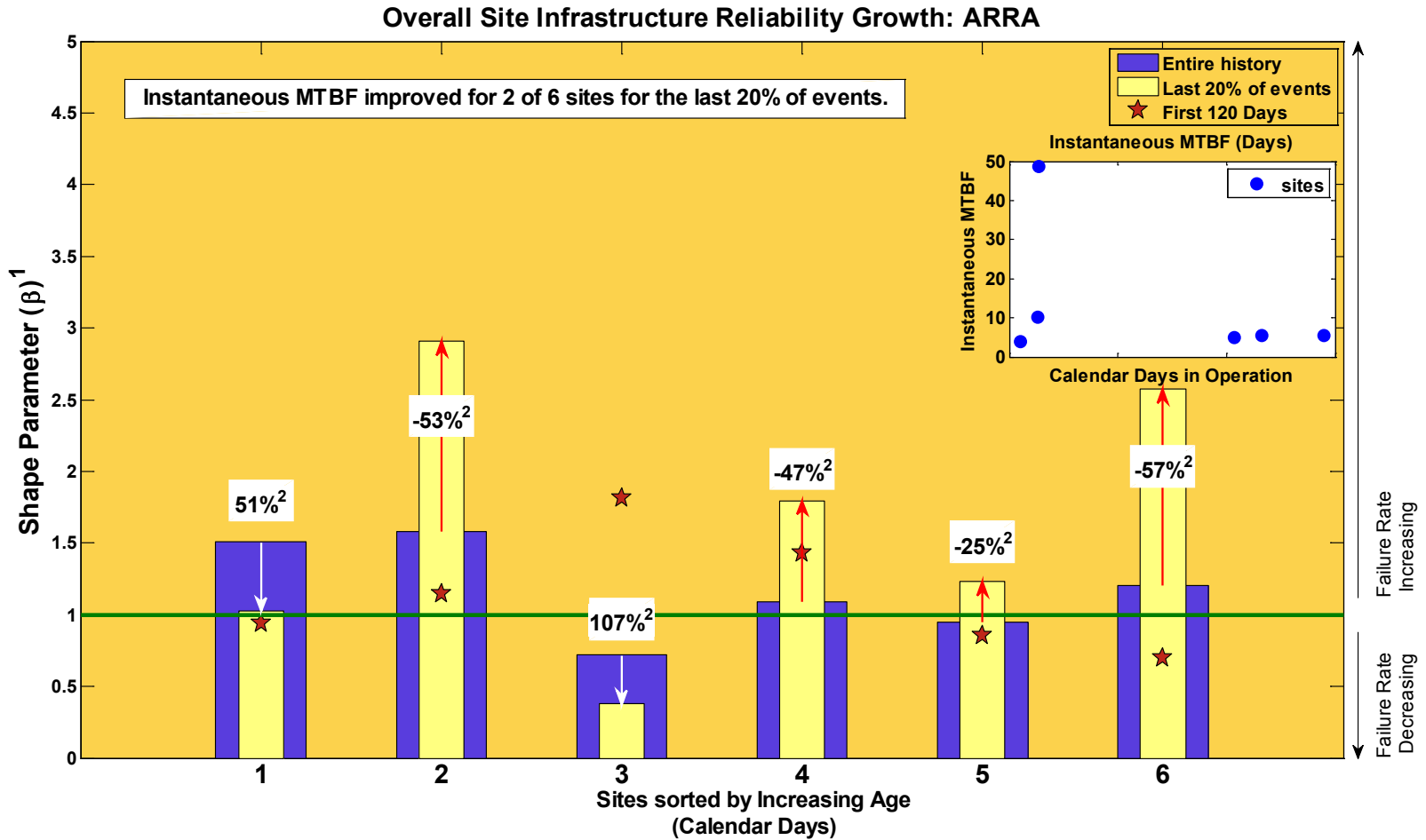


### Breakdown of Maintenance Event Labor Hours: Infrastructure



# 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

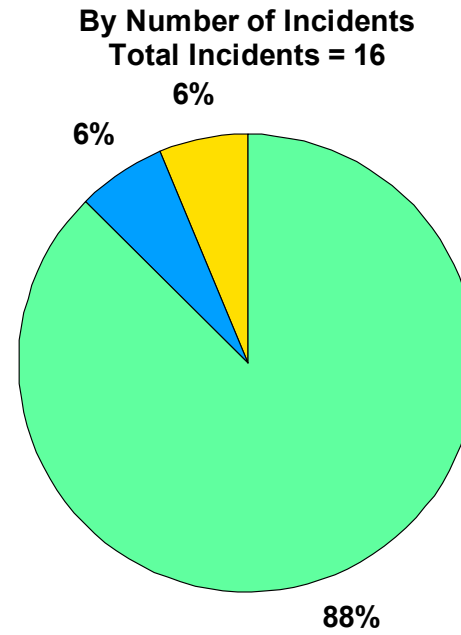
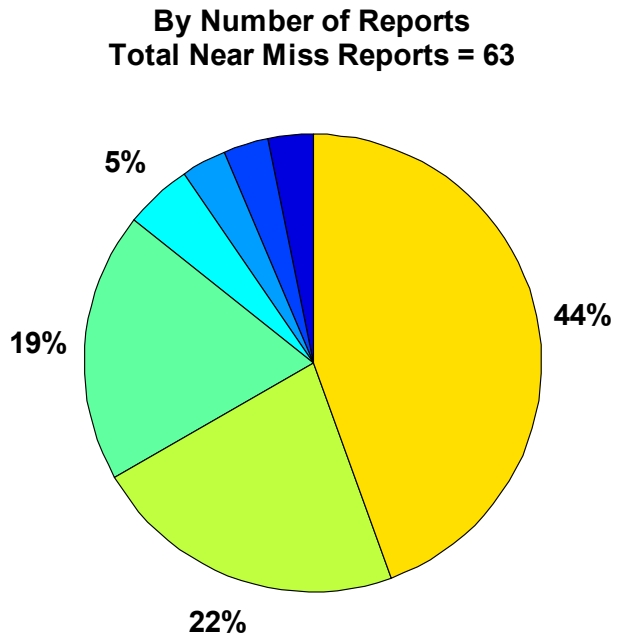


NREL cdparrar\_mhe\_45

Created: Apr-02-13 11:05 AM | Data Range: 2010Q1-2012Q4

## Infrastructure Equipment Category of Safety Events

Safety Reports By Equipment Category: Infrastructure



MISC includes the following categories:  
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:

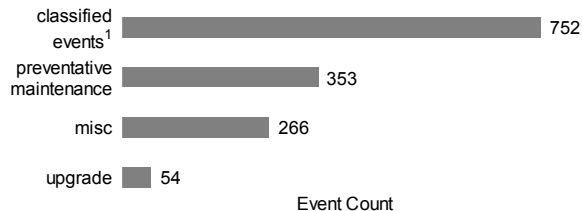
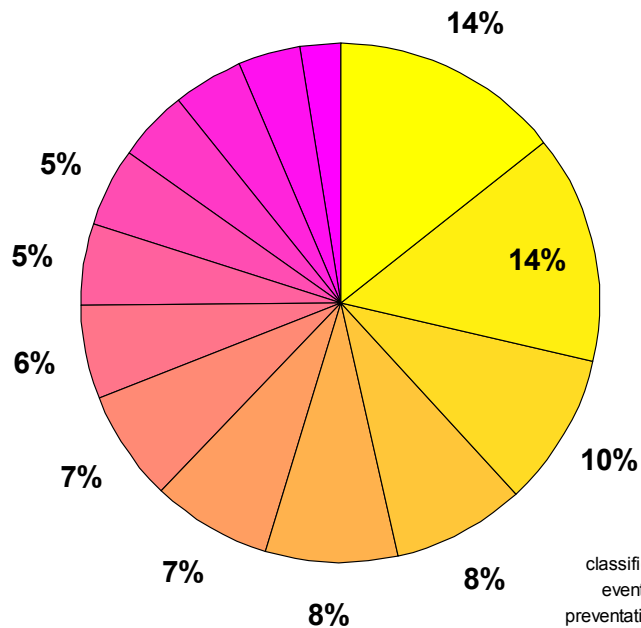
- an event that under slightly different circumstances could have become an incident
- unplanned H2 release insufficient to sustain a flame



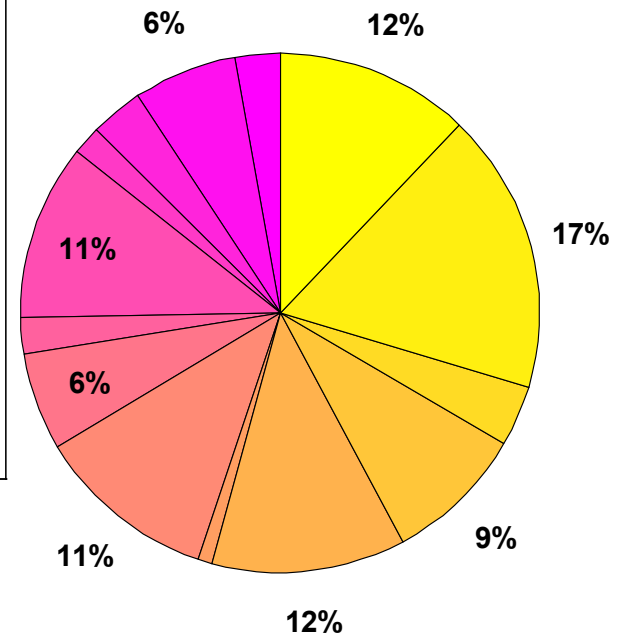
## Infrastructure Maintenance by Mode

Infrastructure Maintenance By Mode

Total Events = 1,425<sup>1</sup>  
71% unscheduled

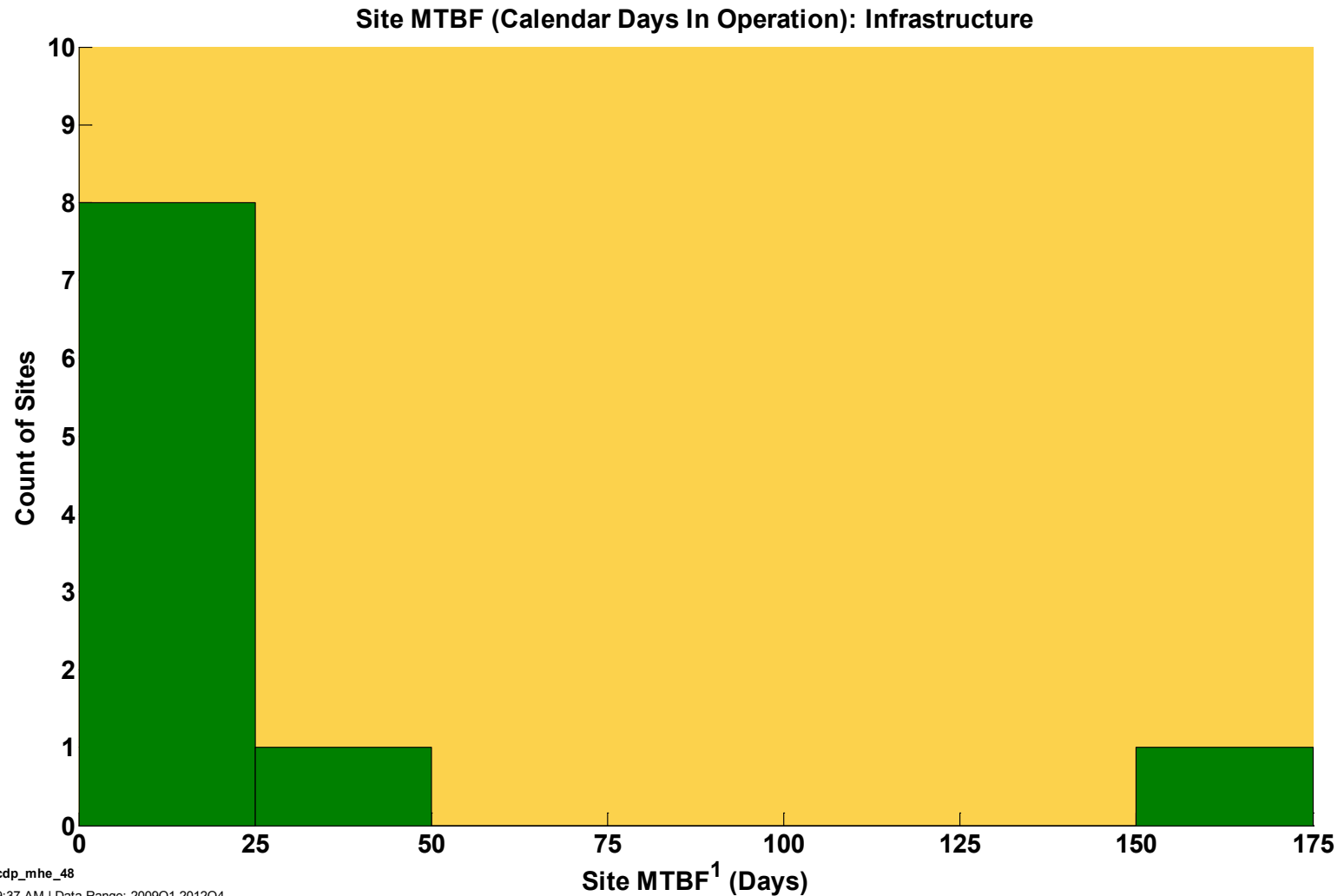


Total Hours = 8,194  
66% unscheduled



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, drive off, power outage, unspecified electronics failure, failed open, software bug, lightning strike, moisture





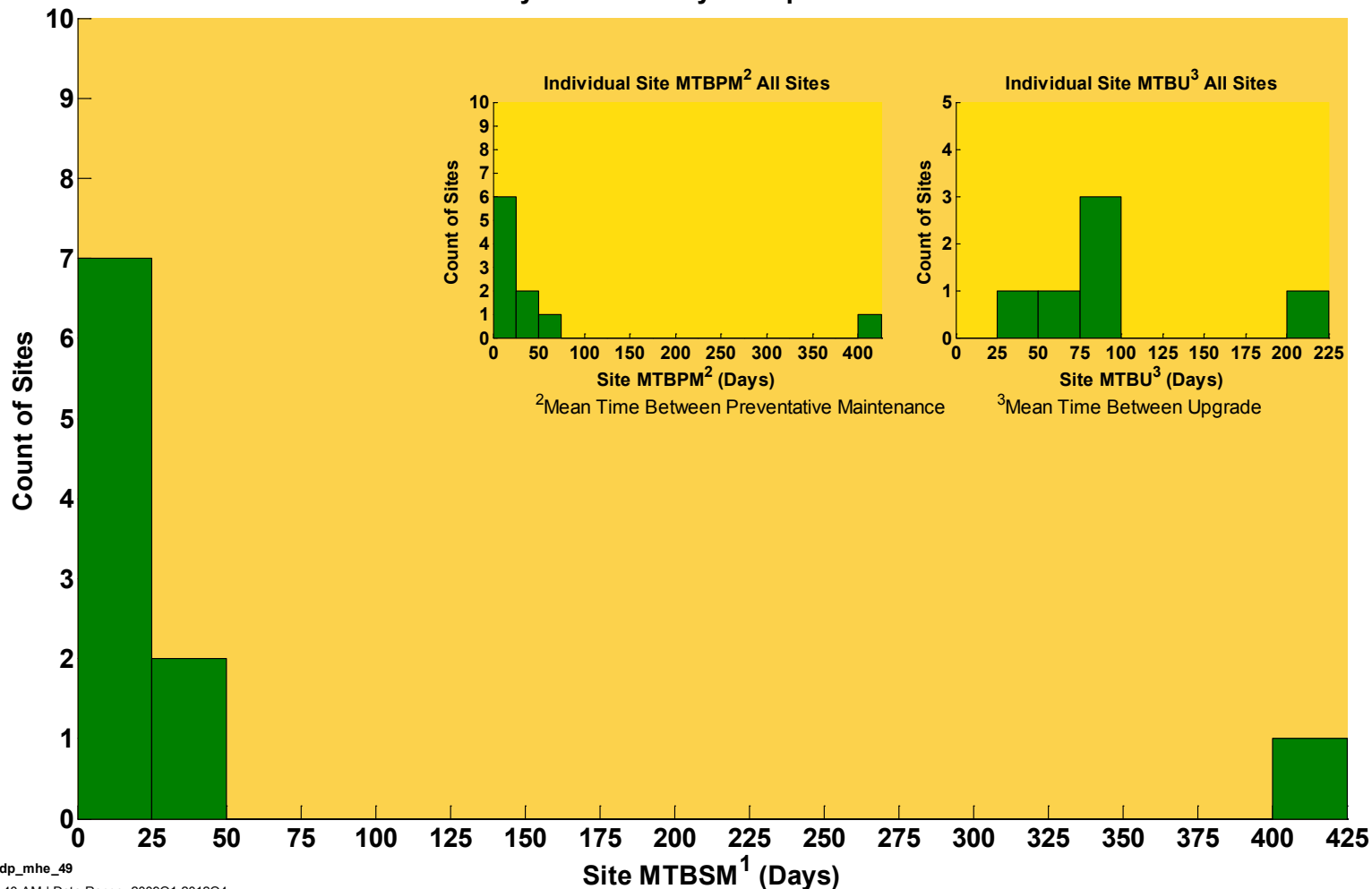
NREL cdp\_mhe\_48

Created: Apr-02-13 9:37 AM | Data Range: 2009Q1-2012Q4

1. Cumulative Mean Time Between Failure



Site MTBSM by Calendar Days In Operation: Infrastructure

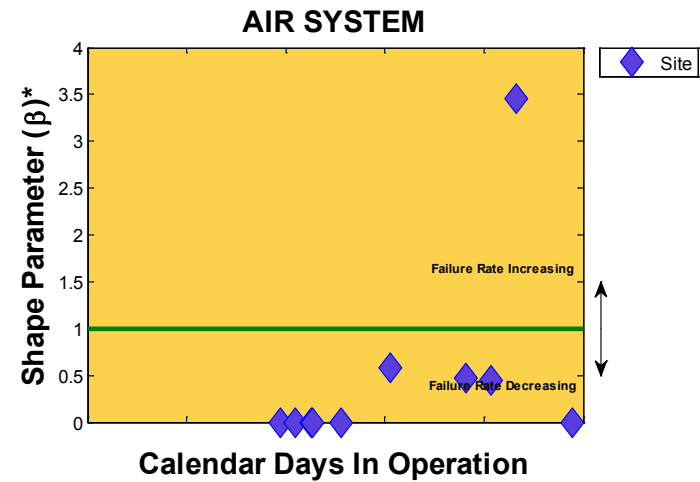
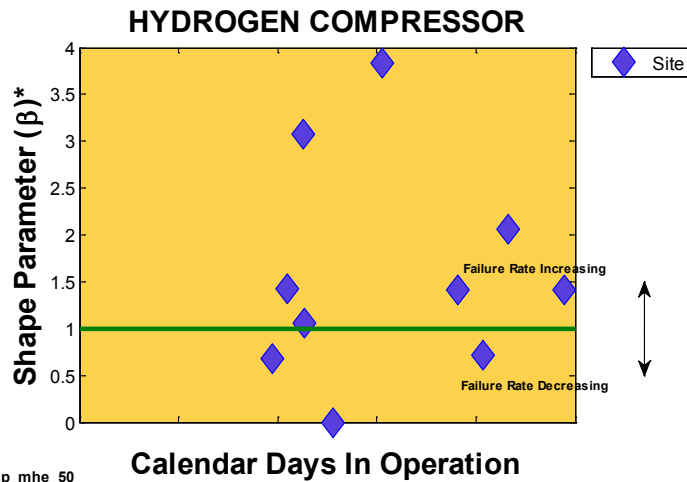
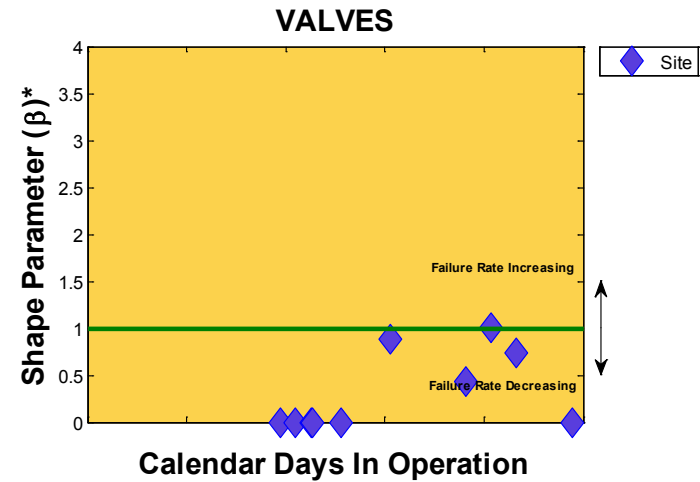
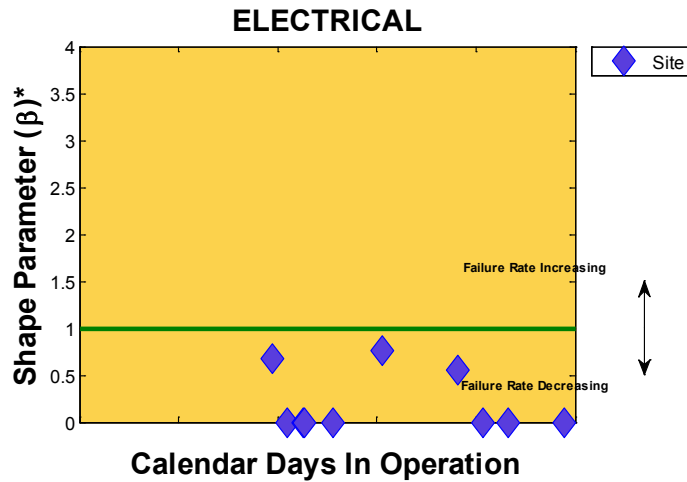


NREL cdp\_mhe\_49

Created: Apr-02-13 9:40 AM | Data Range: 2009Q1-2012Q4

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

## Infrastructure Reliability Growth by Category



NREL cdp\_mhe\_50

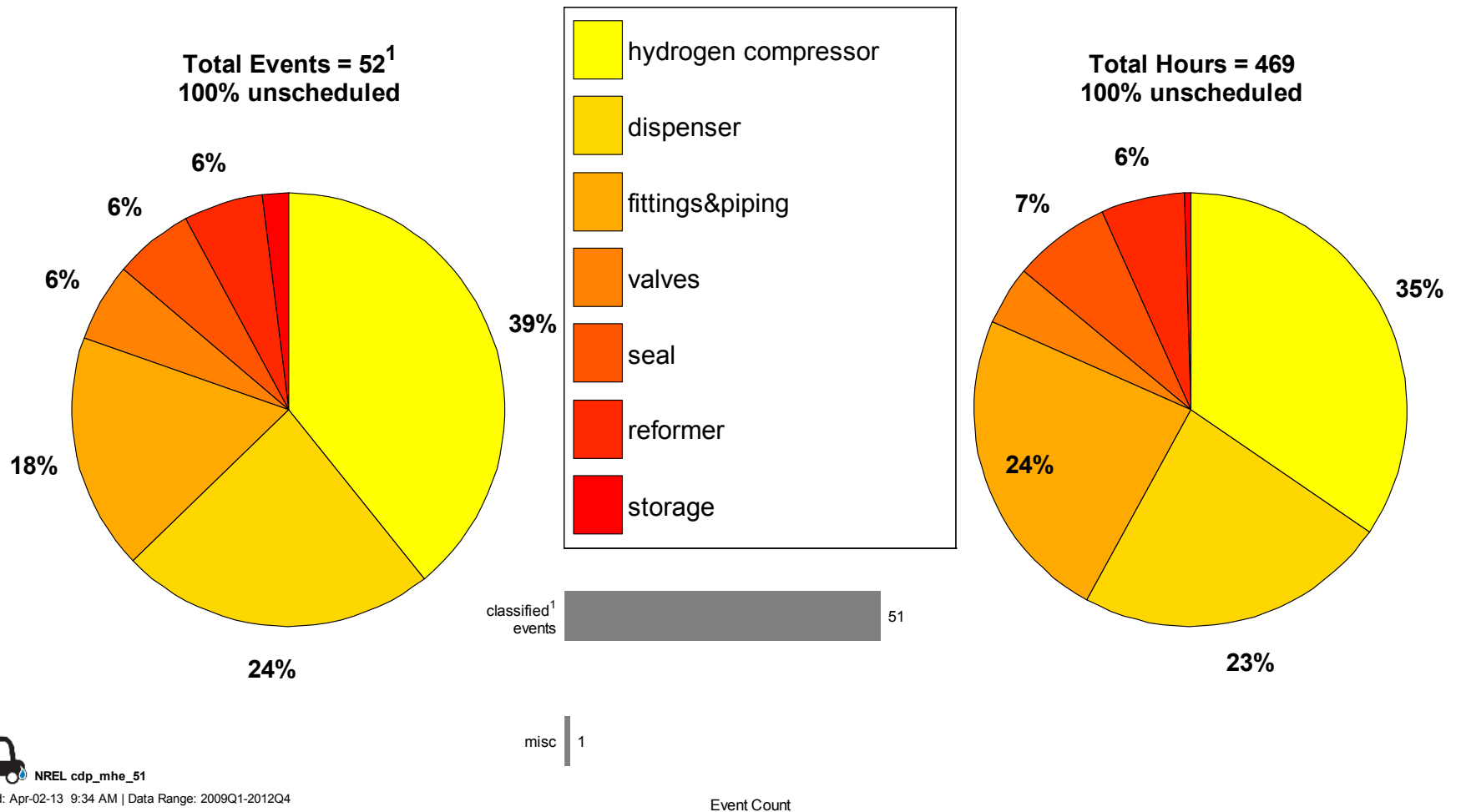
Created: Apr-02-13 9:48 AM | Data Range: 2009Q1-2012Q4

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

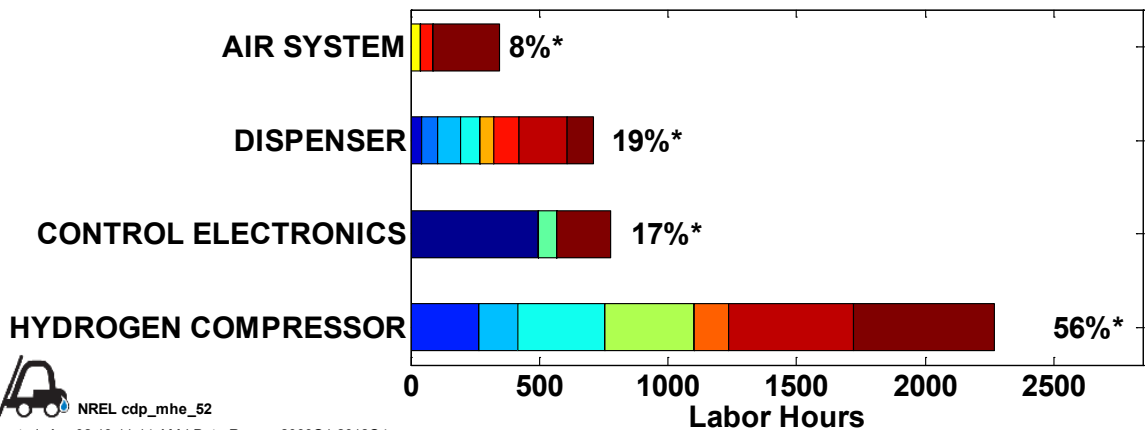
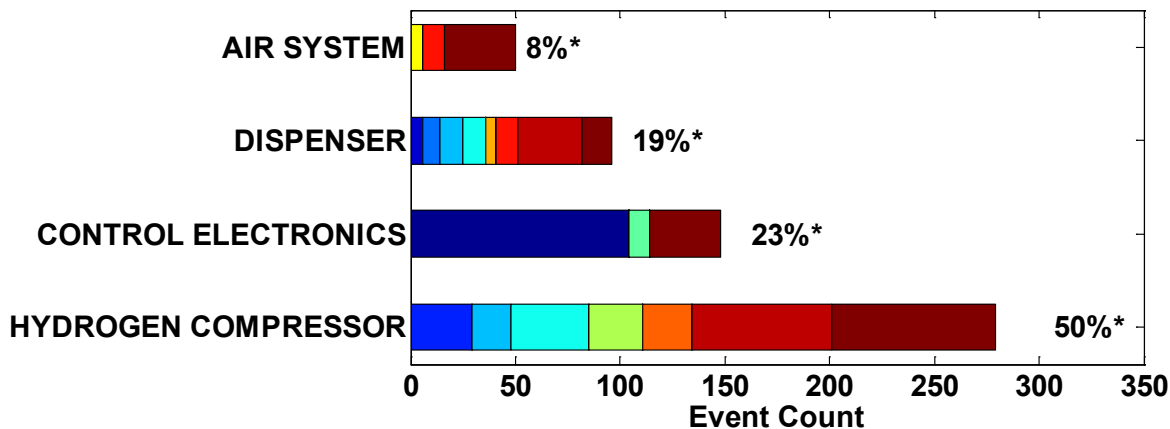
\*IEC 61164  $\beta$

## Infrastructure Hydrogen Leaks by Equipment Type

Hydrogen Leaks By Equipment Category: Infrastructure



Failure Modes for Top Four Infrastructure Equipment Categories



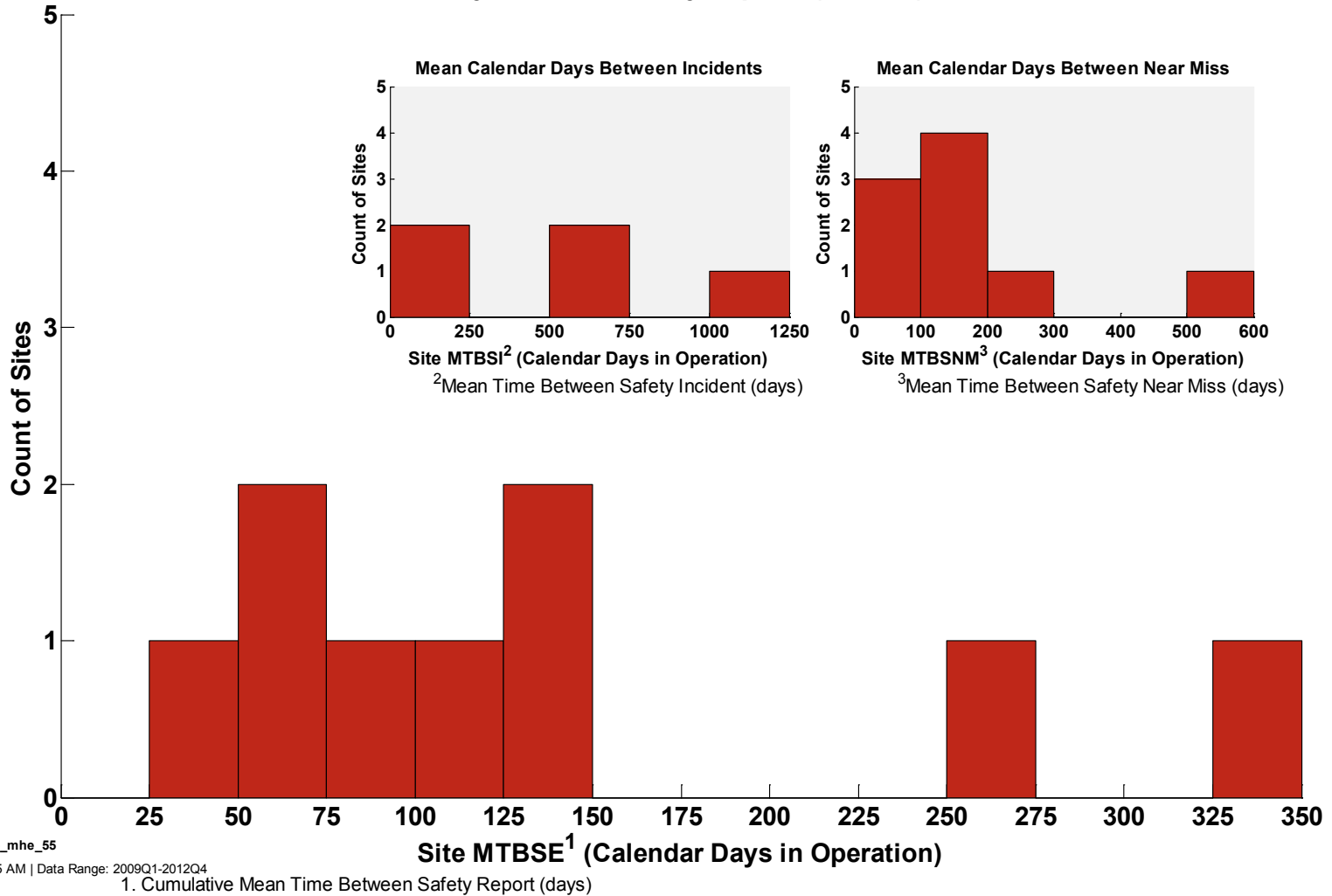
MISC includes the following failure modes: ambient temperature too low, broken wire, cavitation, data error, debris infiltration, electrical short, failed closed, false alarm, flow high, flow low, fluid leak non-hydrogen, fluid leak non\_hydrogen, fluid leak\_non\_hydrogen, inspect trouble alarm or report,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

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

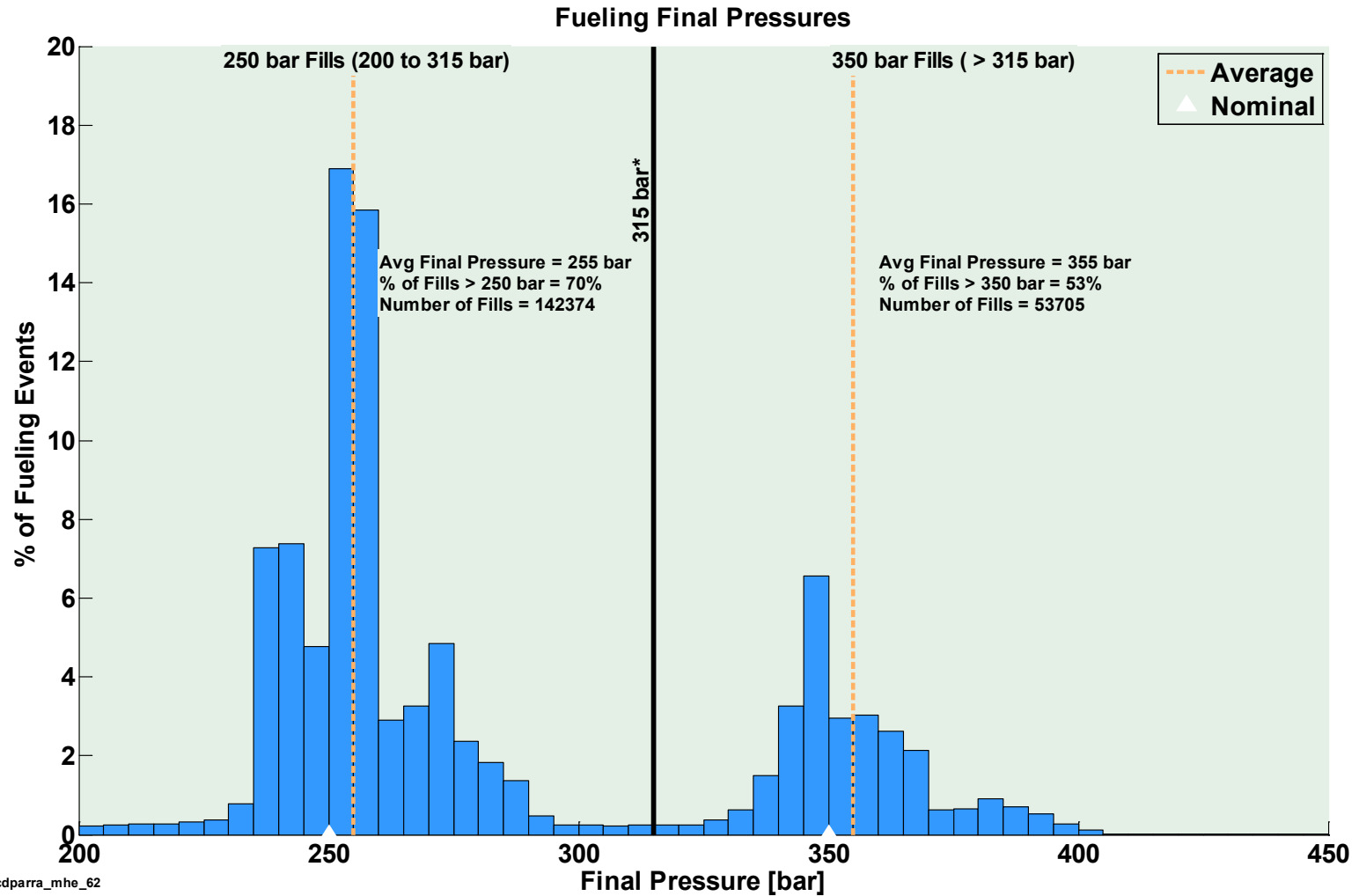


## Infrastructure Mean Time Between Safety Events

Mean Calendar Days Between Safety Reports (MTBSR): Infrastructure



## Final Pressure of Hydrogen Fills

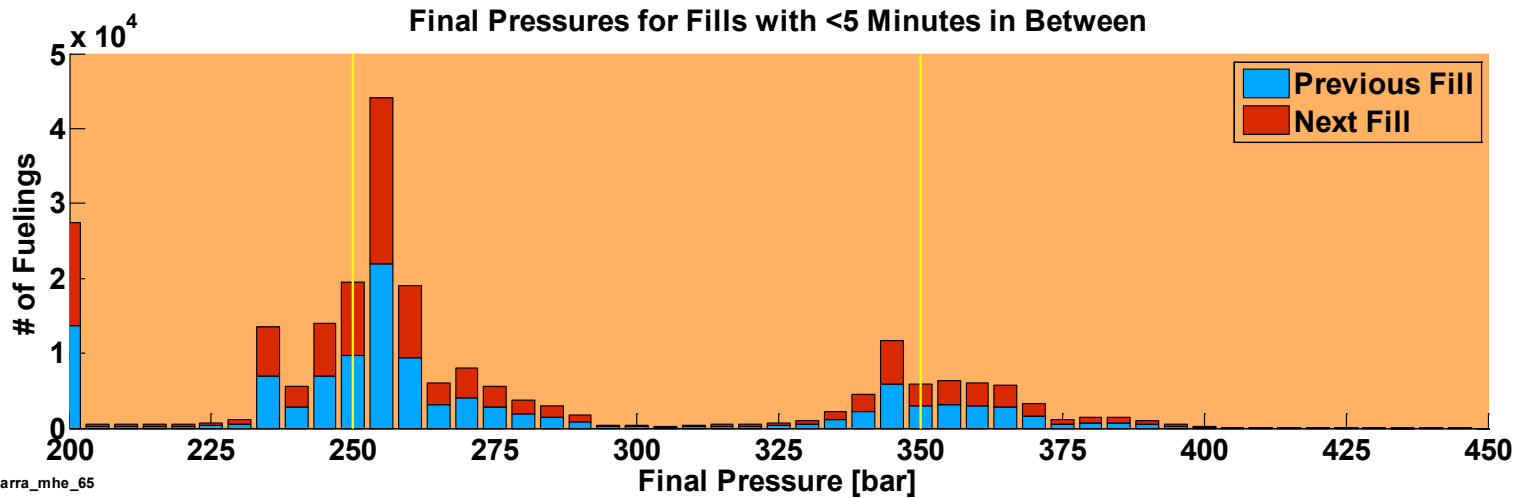
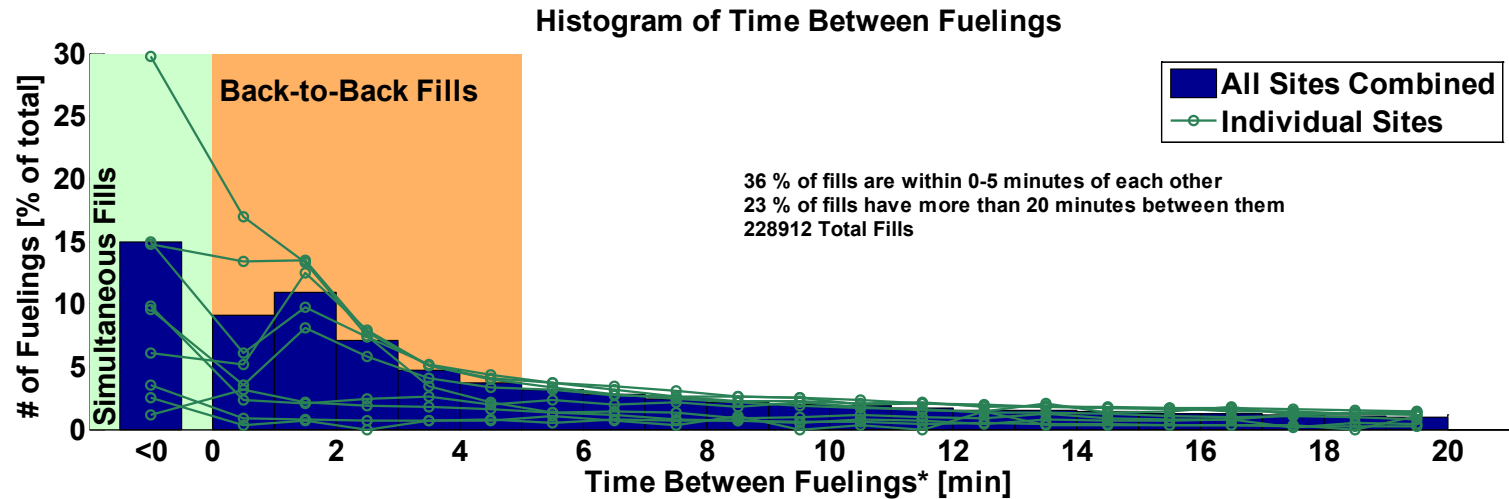


NREL cdparra\_mhe\_62

Created: Apr-02-13 8:03 AM | Data Range: 2010Q1-2012Q4

\*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



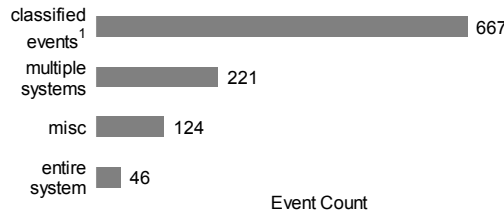
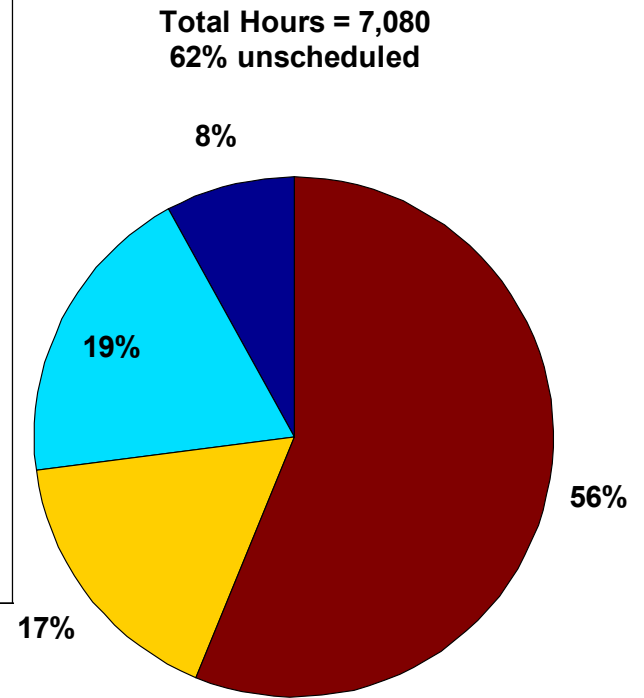
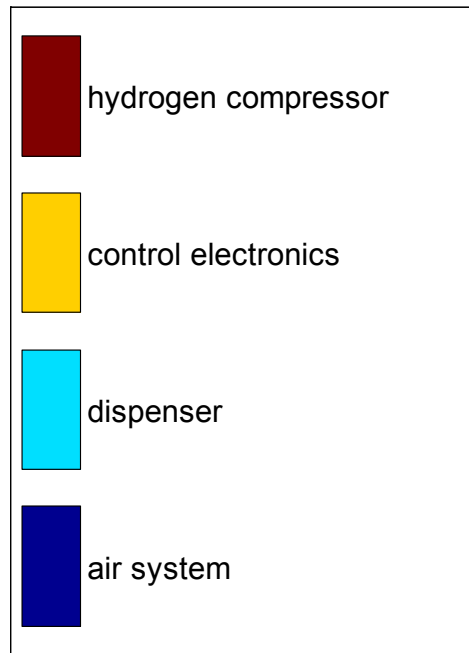
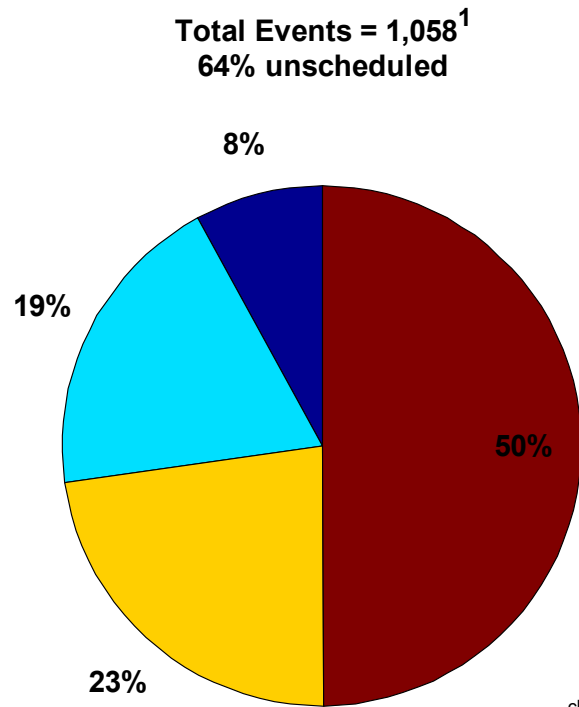
NREL cdparra\_mhe\_65

Created: Apr-02-13 8:12 AM | Data Range: 2010Q1-2012Q4

\*Time is from end of fill to start of next fill.

## Infrastructure Maintenance for Delivered Hydrogen

Delivered Hydrogen Infrastructure Maintenance By Equipment Type

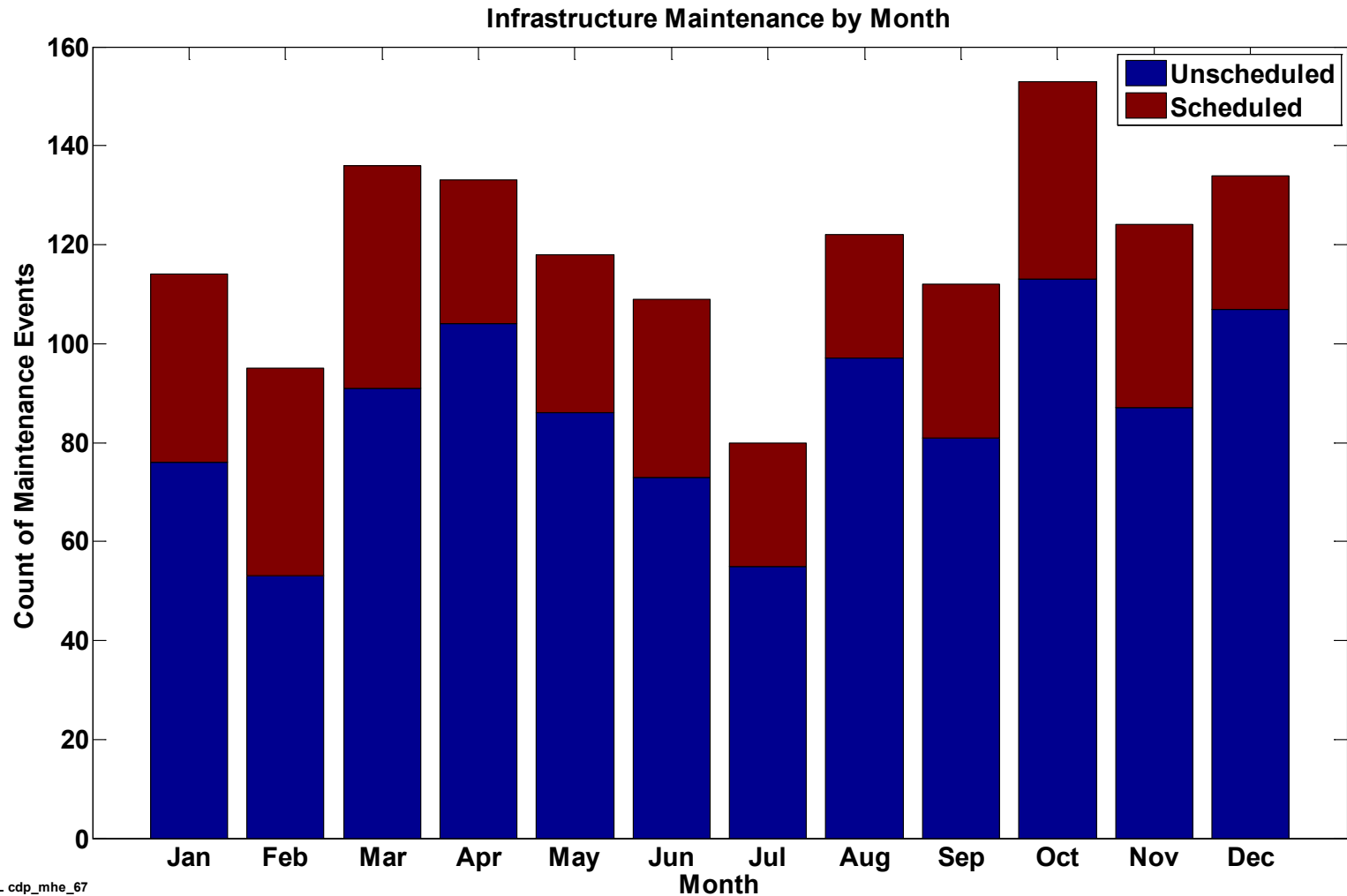


MISC includes the following failure modes: seal, fuel system, safety, thermal management, storage, electrical, software, fittings&pipng, valves, sensors, other





## Infrastructure Maintenance by Month

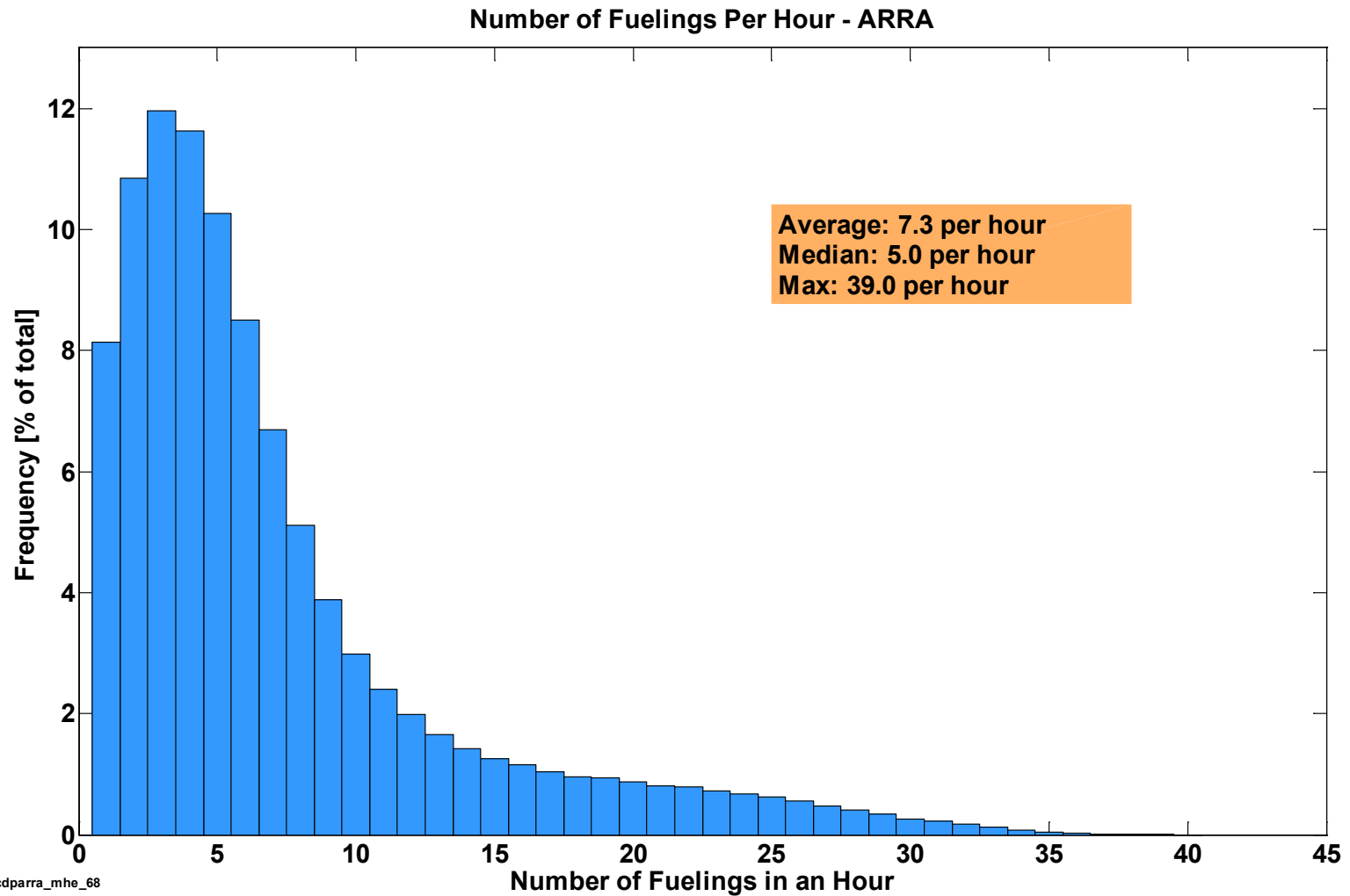


NREL cdp\_mhe\_67

Created: Apr-02-13 9:36 AM | Data Range: 2009Q1-2012Q4

# CDPARRA-MHE-68

## Fill Counts per Hours

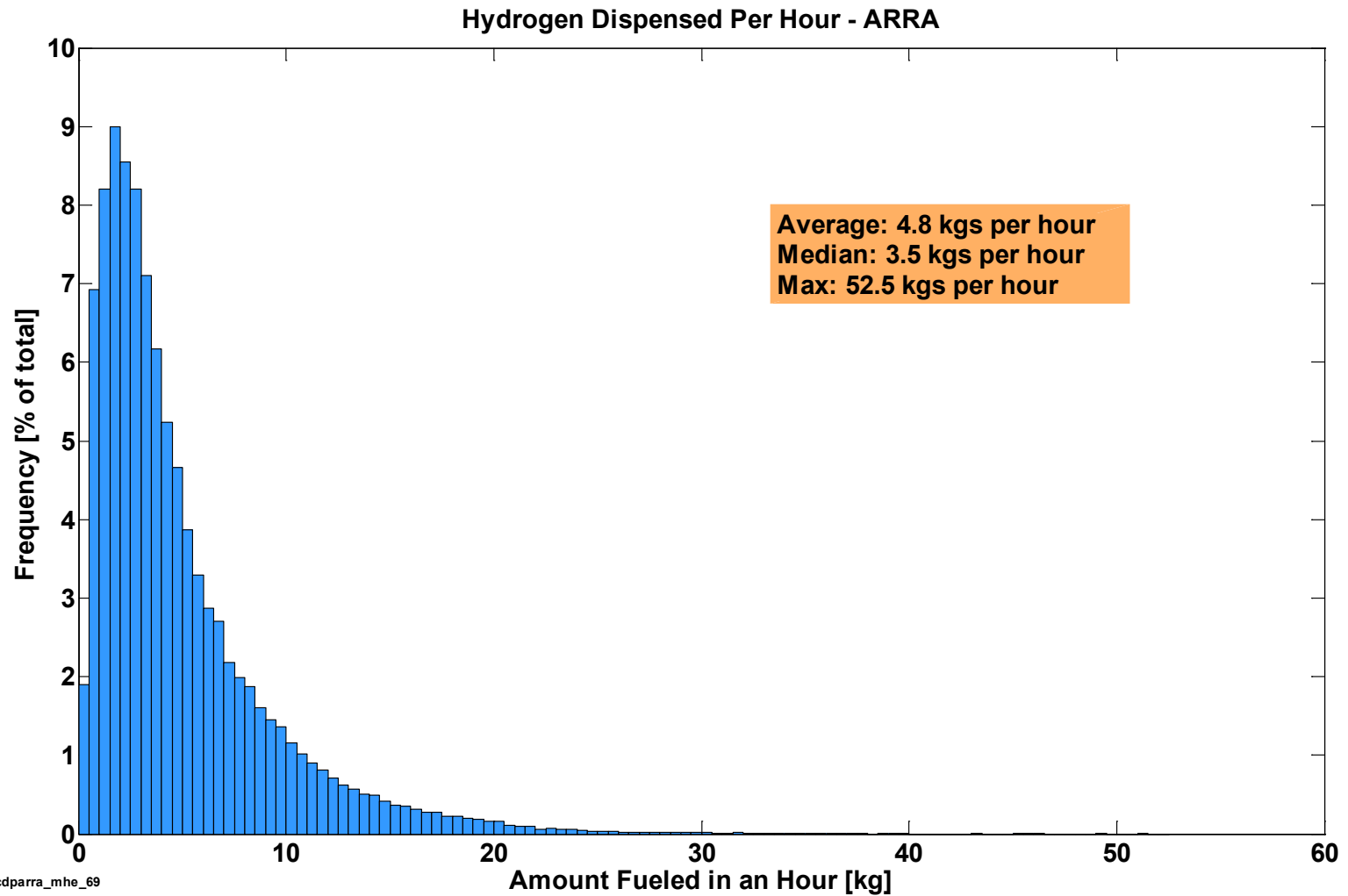


NREL cdparra\_mhe\_68

Created: Apr-02-13 8:25 AM | Data Range: 2010Q1-2012Q4

# CDPARRA-MHE-69

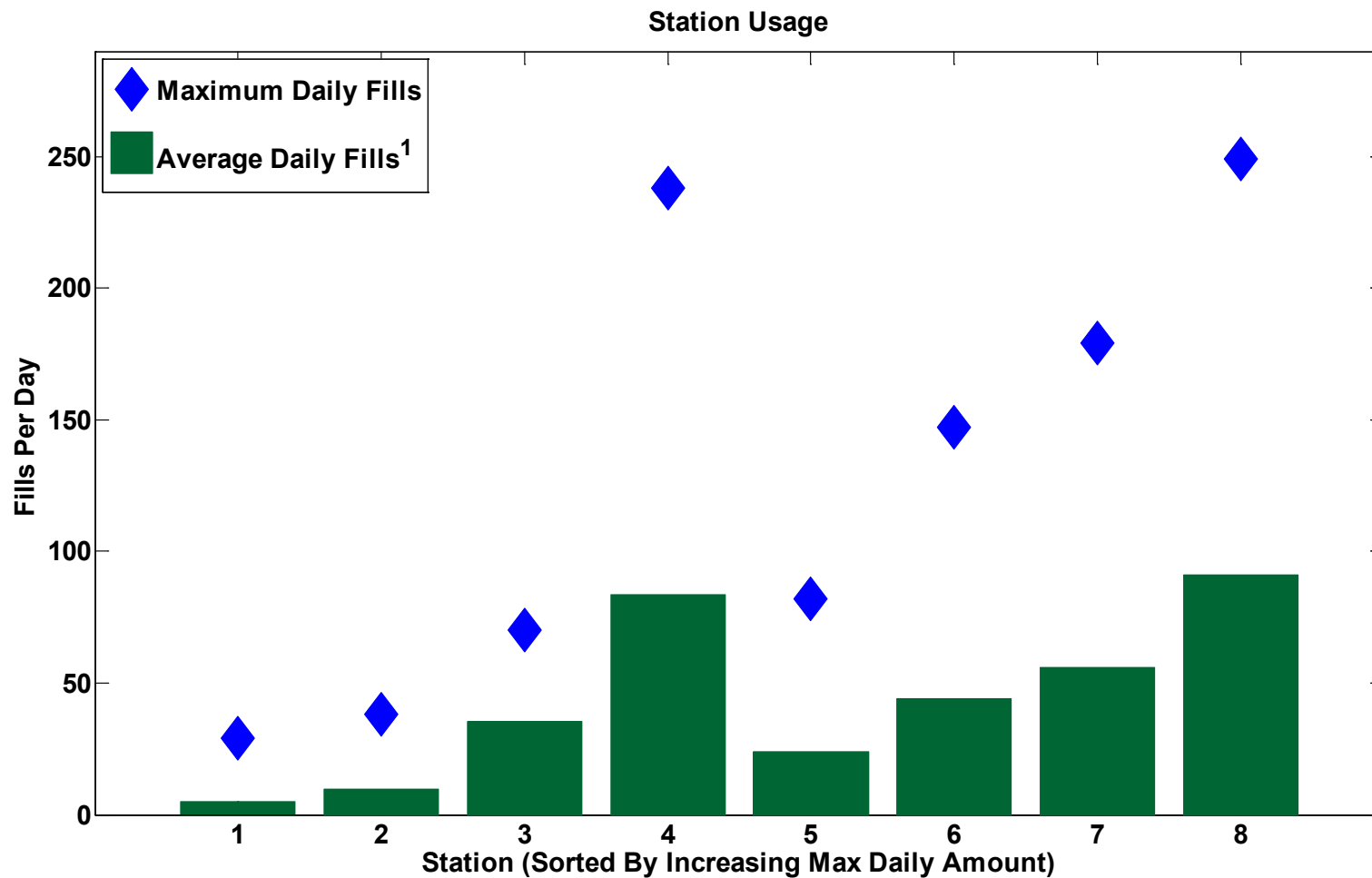
## Fill Amount per Hour



NREL cdparra\_mhe\_69

Created: Apr-02-13 8:41 AM | Data Range: 2010Q1-2012Q4

## Station Usage



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

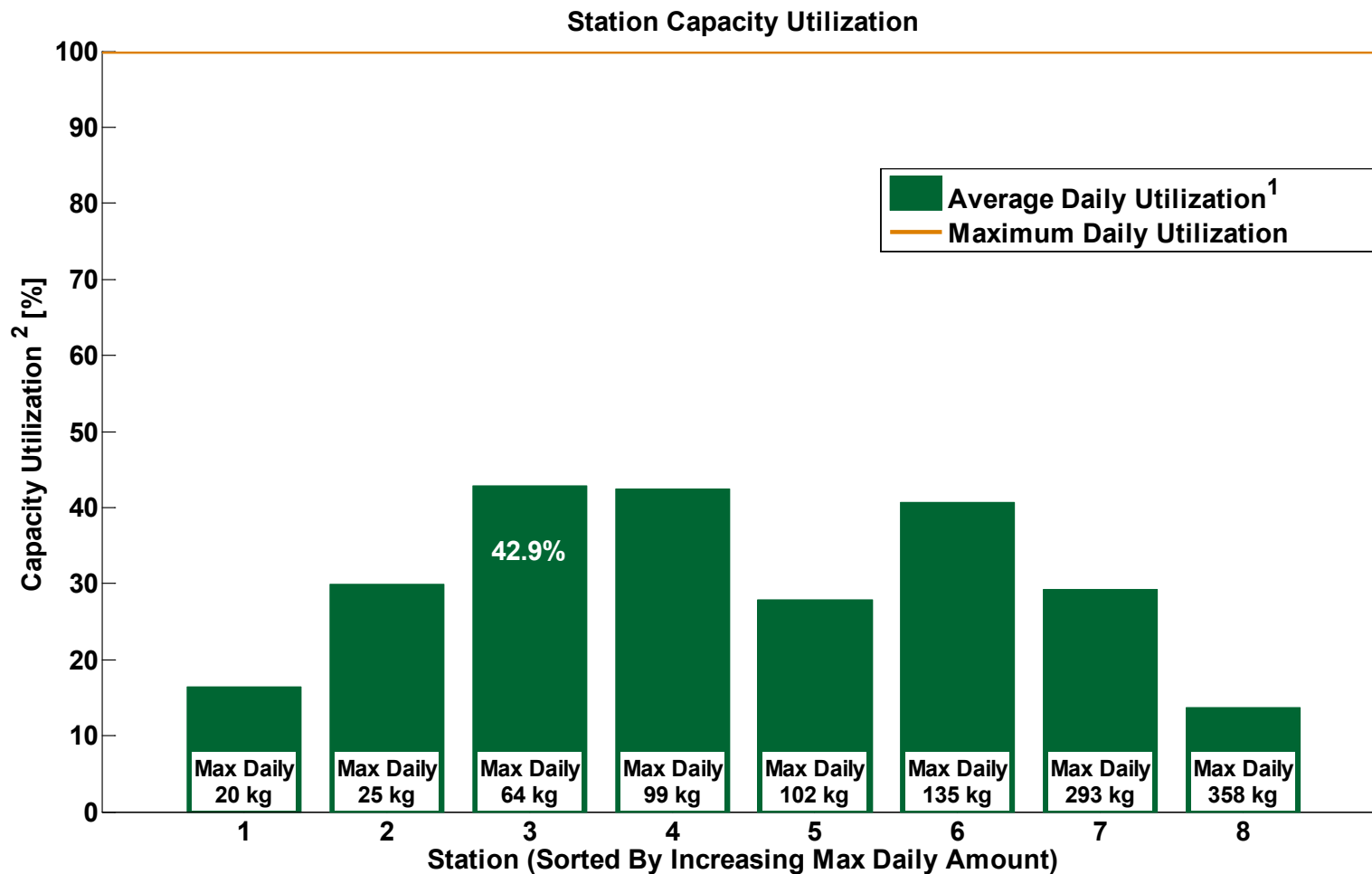


NREL cdparra\_mhe\_70

Created: Apr-02-13 8:52 AM | Data Range: 2010Q1-2012Q4

# CDPARRA-MHE-71

## Station Capacity Utilization



NREL cdparra\_mhe\_71

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

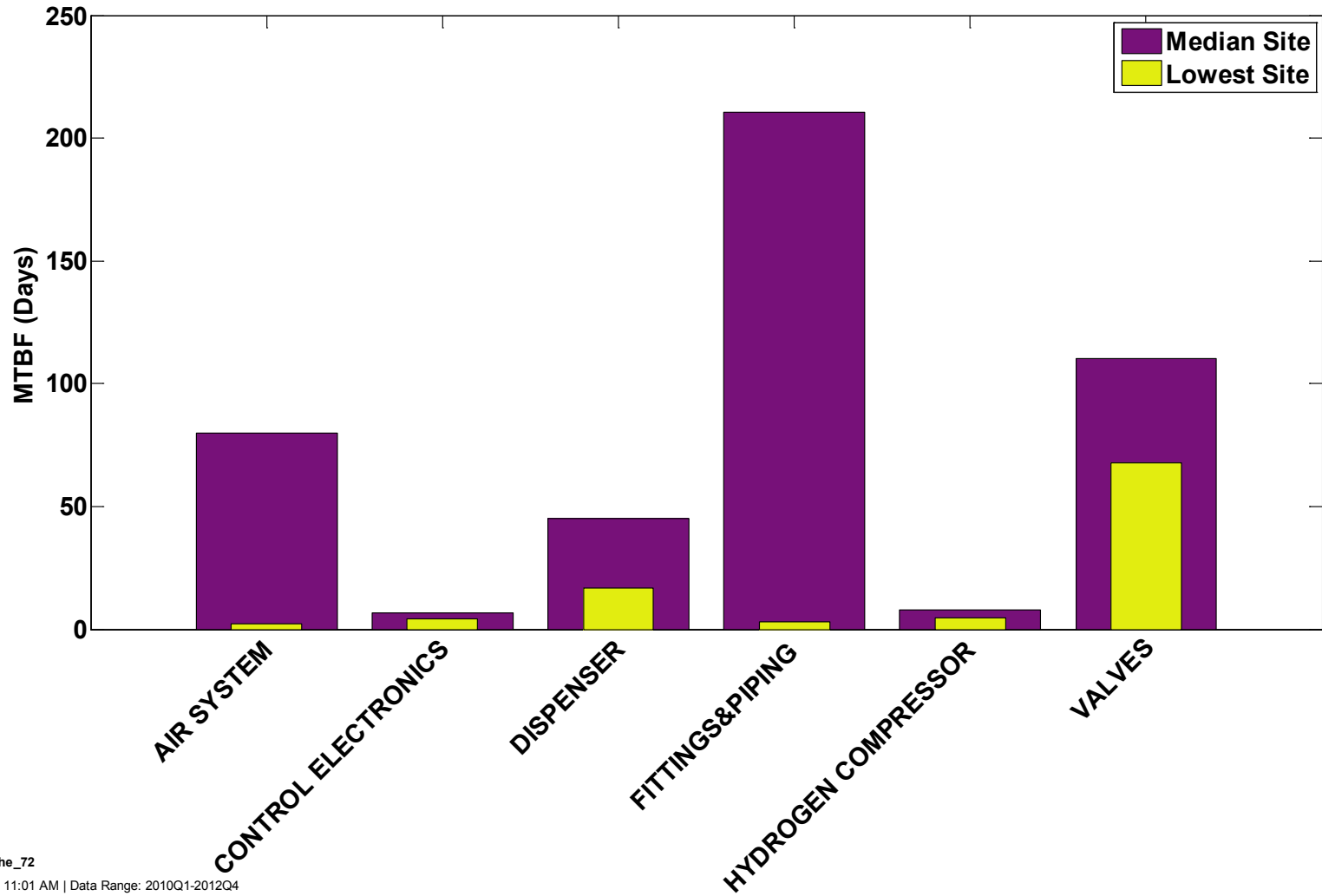
<sup>2</sup>100% represents maximum daily amount dispensed for each individual site

Created: Apr-02-13 10:48 AM | Data Range: 2009Q4-2012Q4

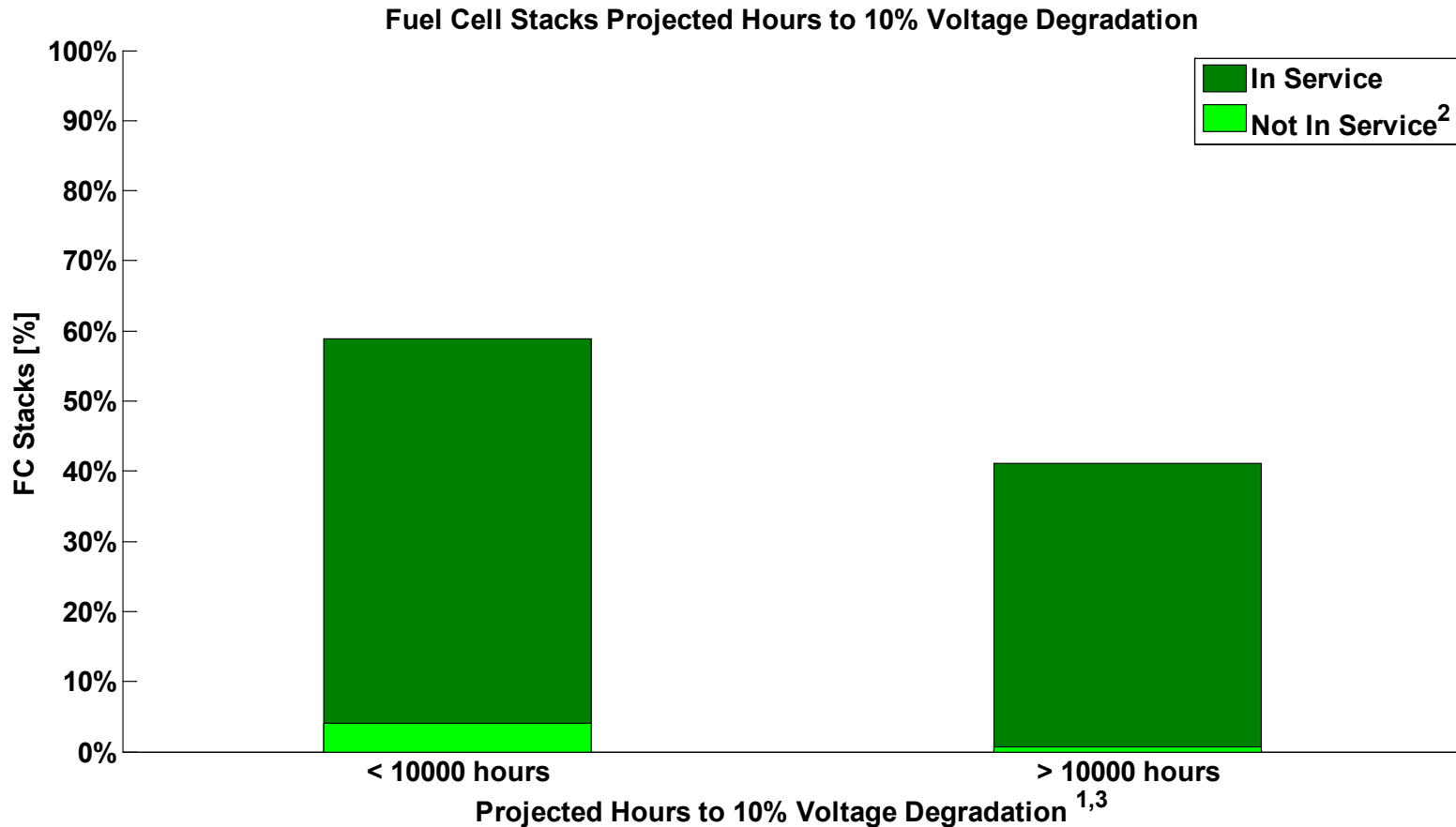
# CDPARRA-MHE-72

## Component MTBF

MTBF by Equipment Category: Infrastructure (Delivered H<sub>2</sub> Only)



## 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: Apr-02-13 9:36 AM | Data Range: 2009Q1-2012Q4