



**Technical Report**  
NREL/TP-5600-56782  
October 2012

# **ARRA Material Handling Equipment Composite Data Products**

## **Data through Quarter 2 of 2012**

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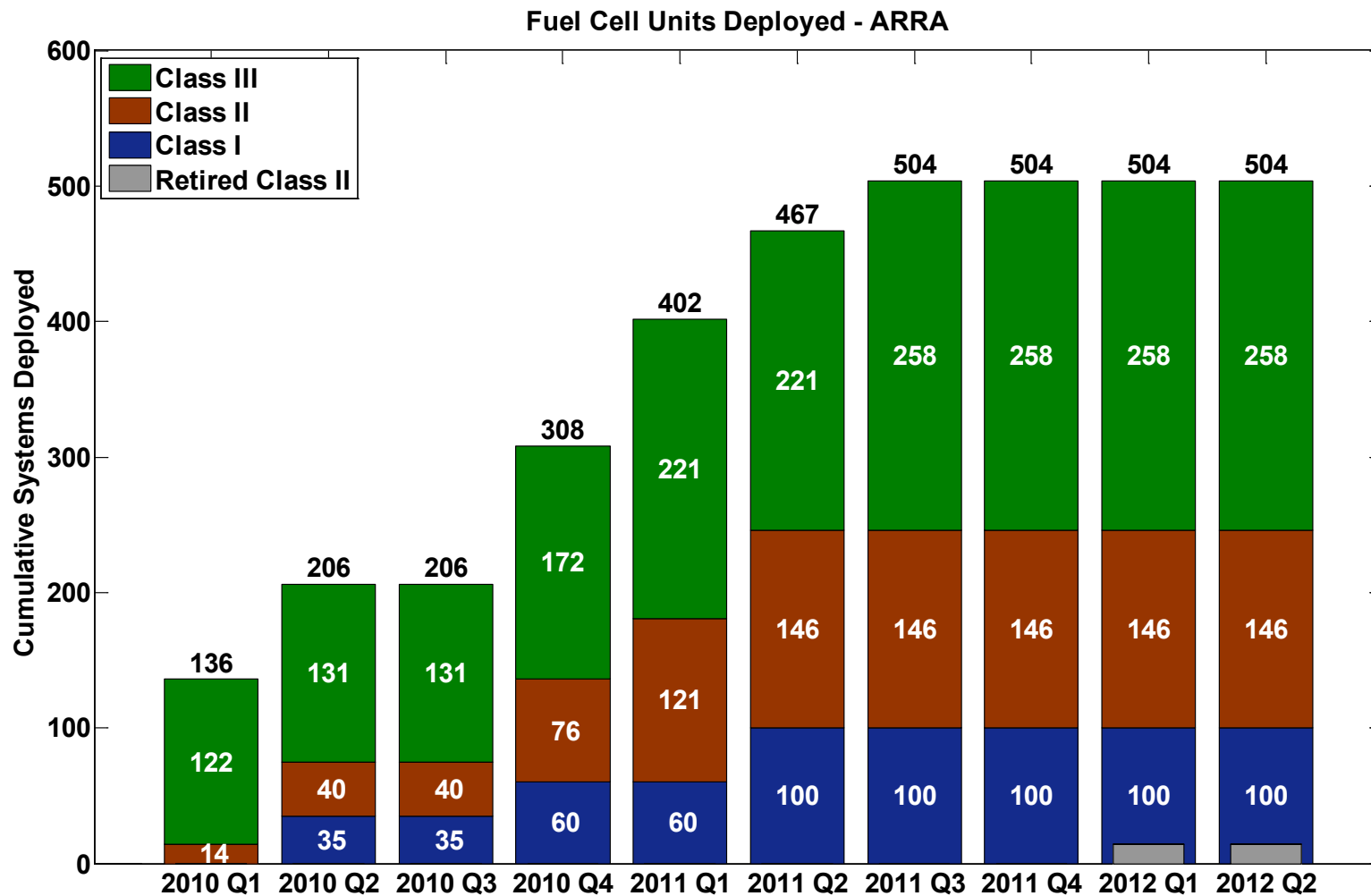
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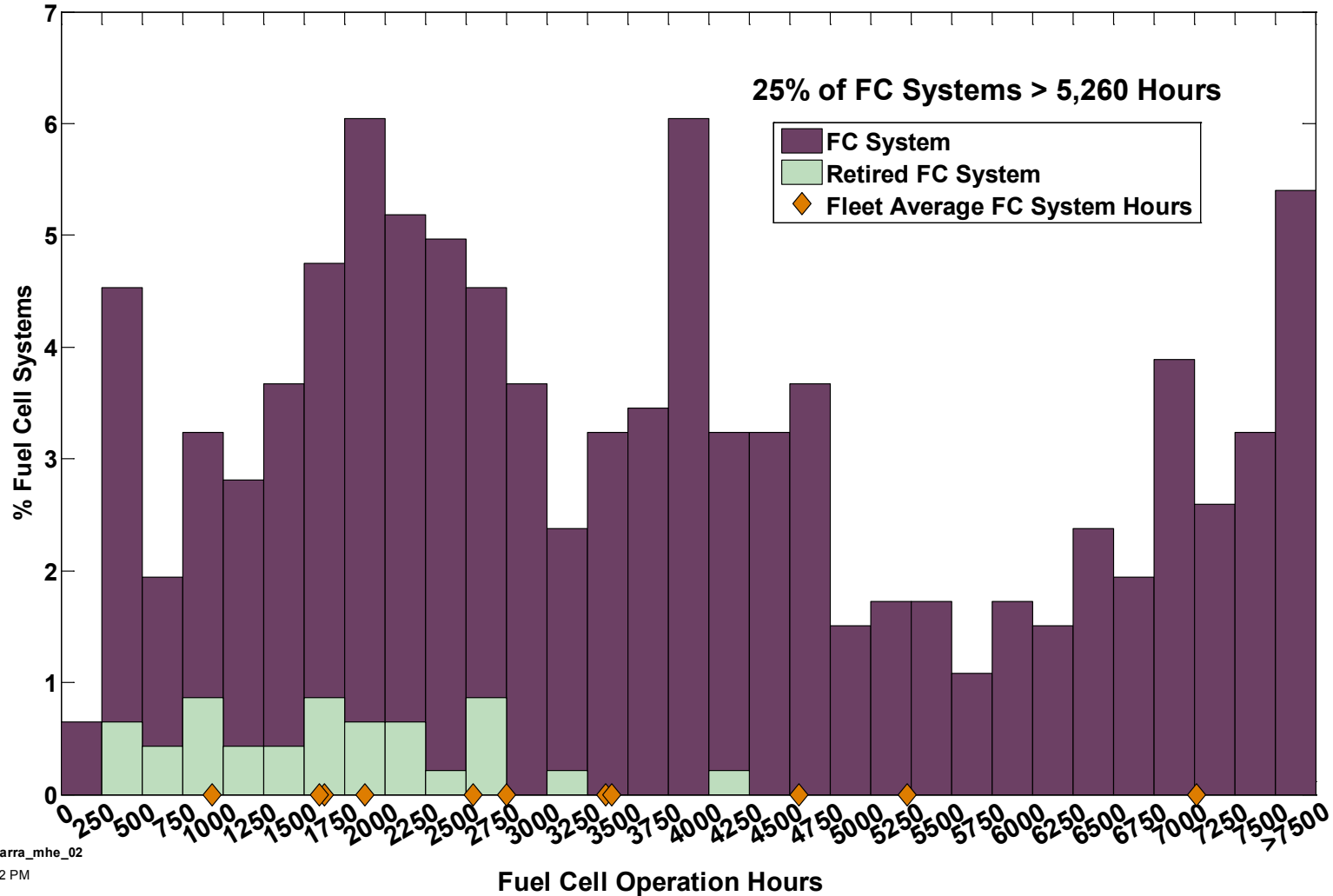
Printed on paper containing at least 50% wastepaper, including 10% post consumer waste.

## Fuel Cell MHE Systems Deployed

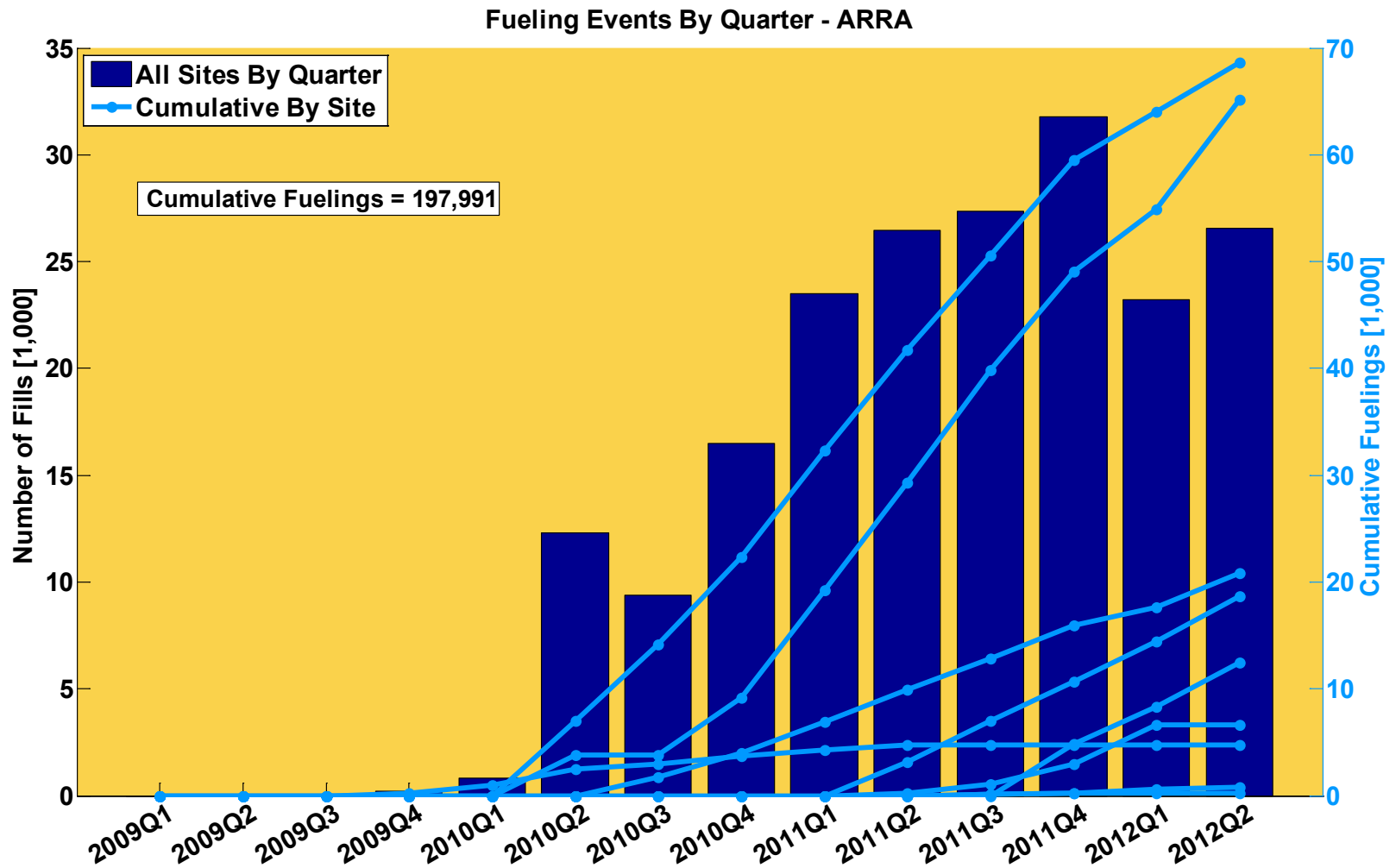


## Fuel Cell System Operation Hours

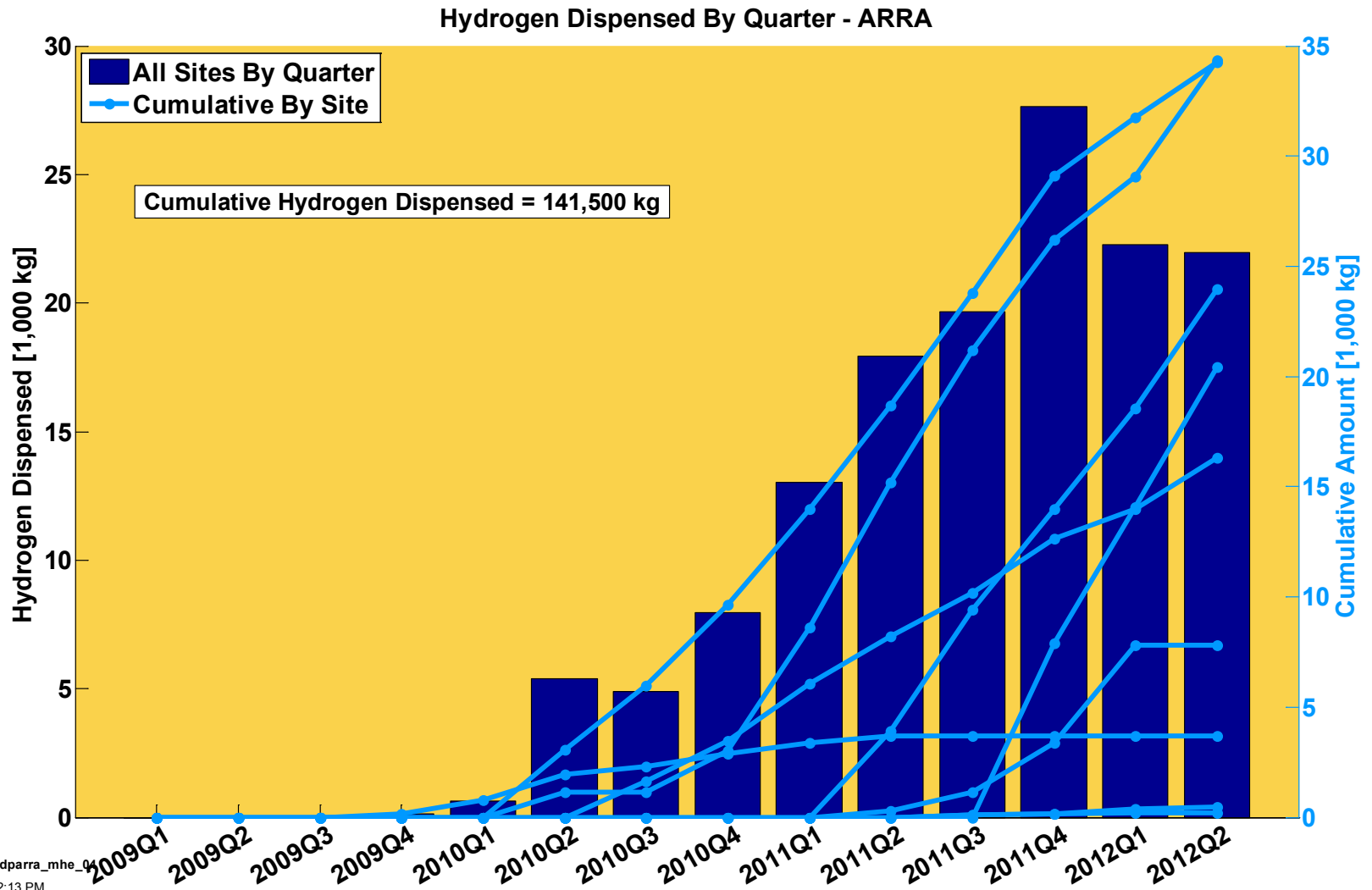
Cumulative Fuel Cell Operation Hours - ARRA  
Combined Fleet Through 2012Q2



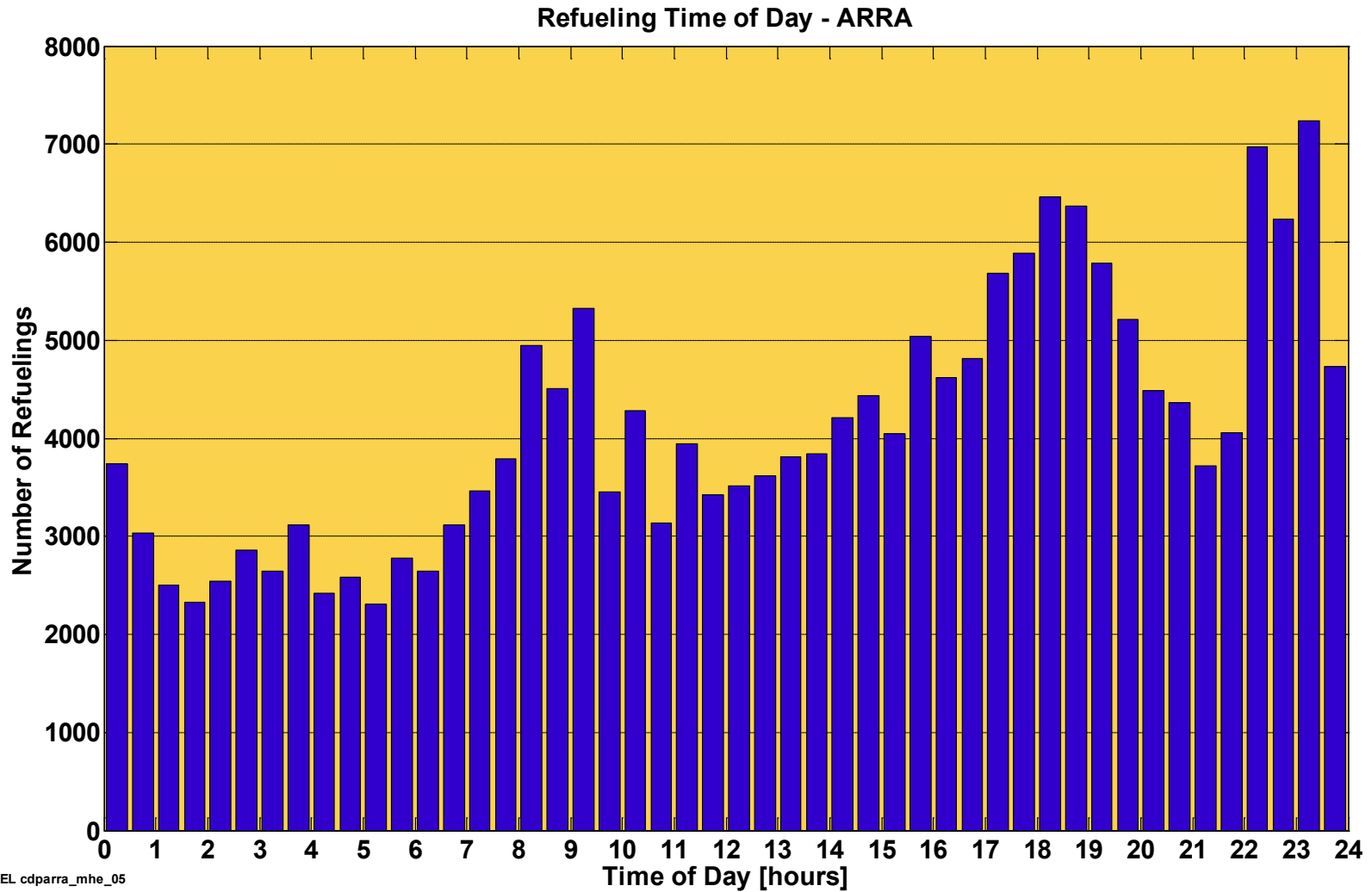
## Fueling Events by Quarter



## Hydrogen Dispensed by Quarter



## Refueling Time of Day

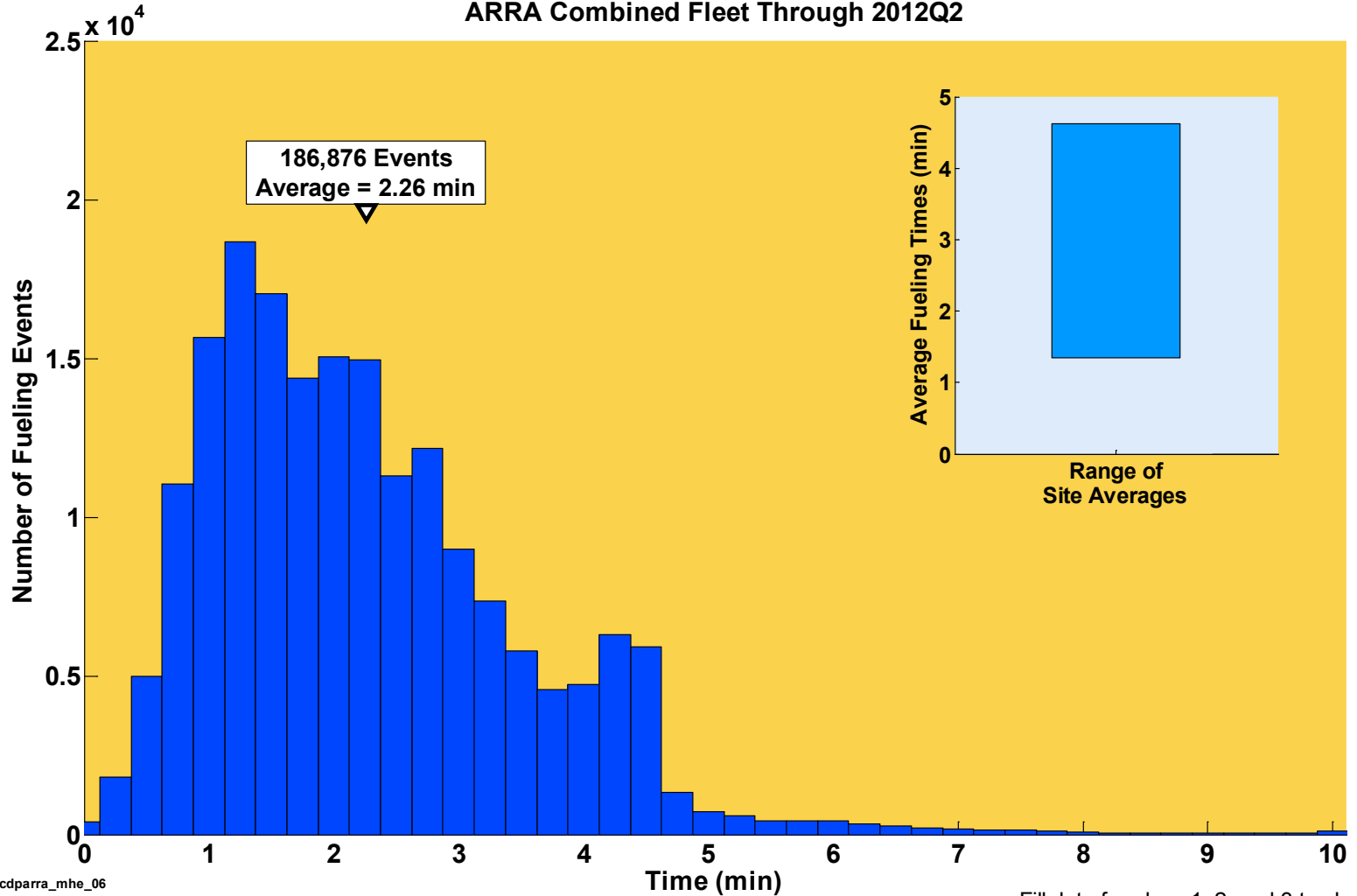


NREL cdparramhe\_05

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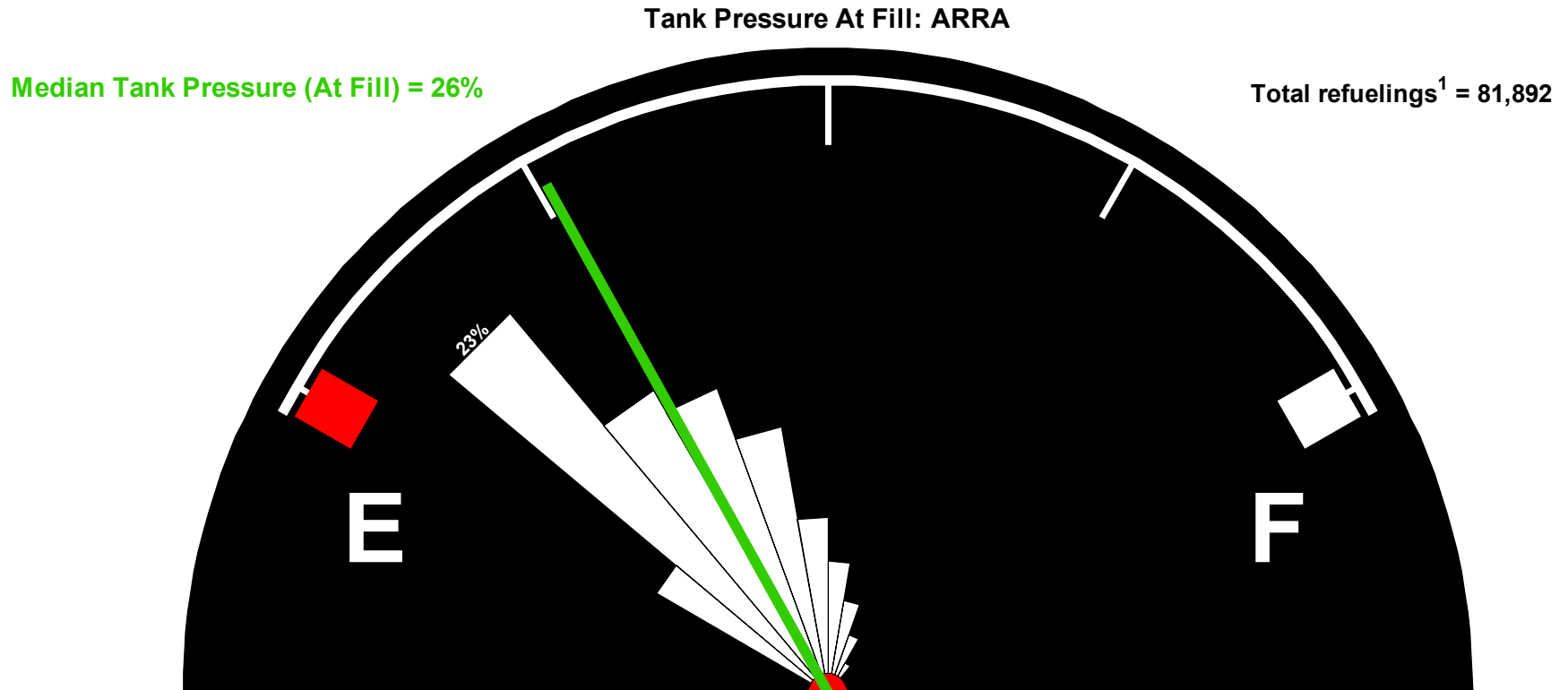
## Histogram of Fueling Times

Histogram of Fueling Times  
ARRA Combined Fleet Through 2012Q2





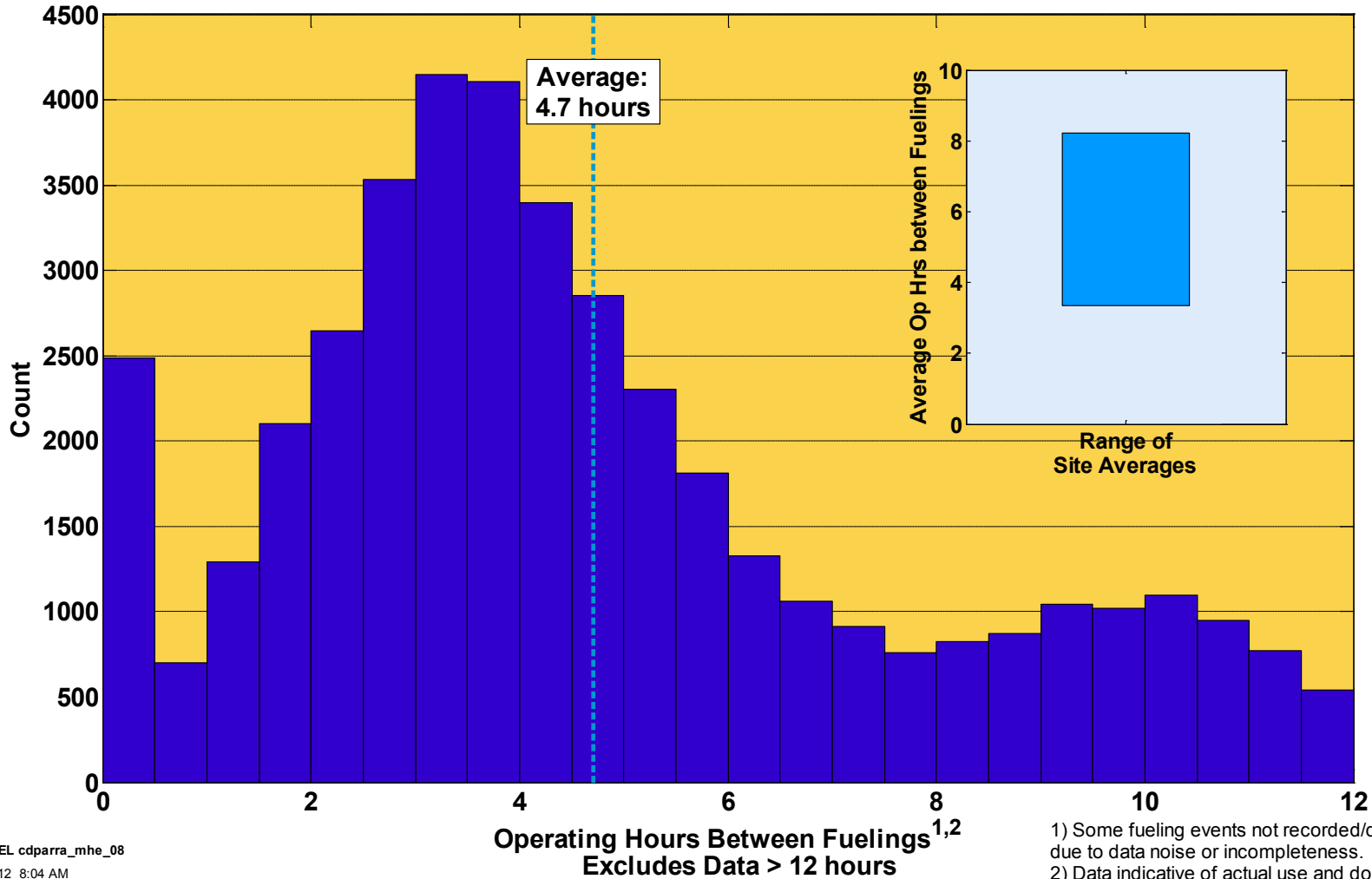
## Tank Pressure Level at Fueling



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.

## Operation Time between Fueling

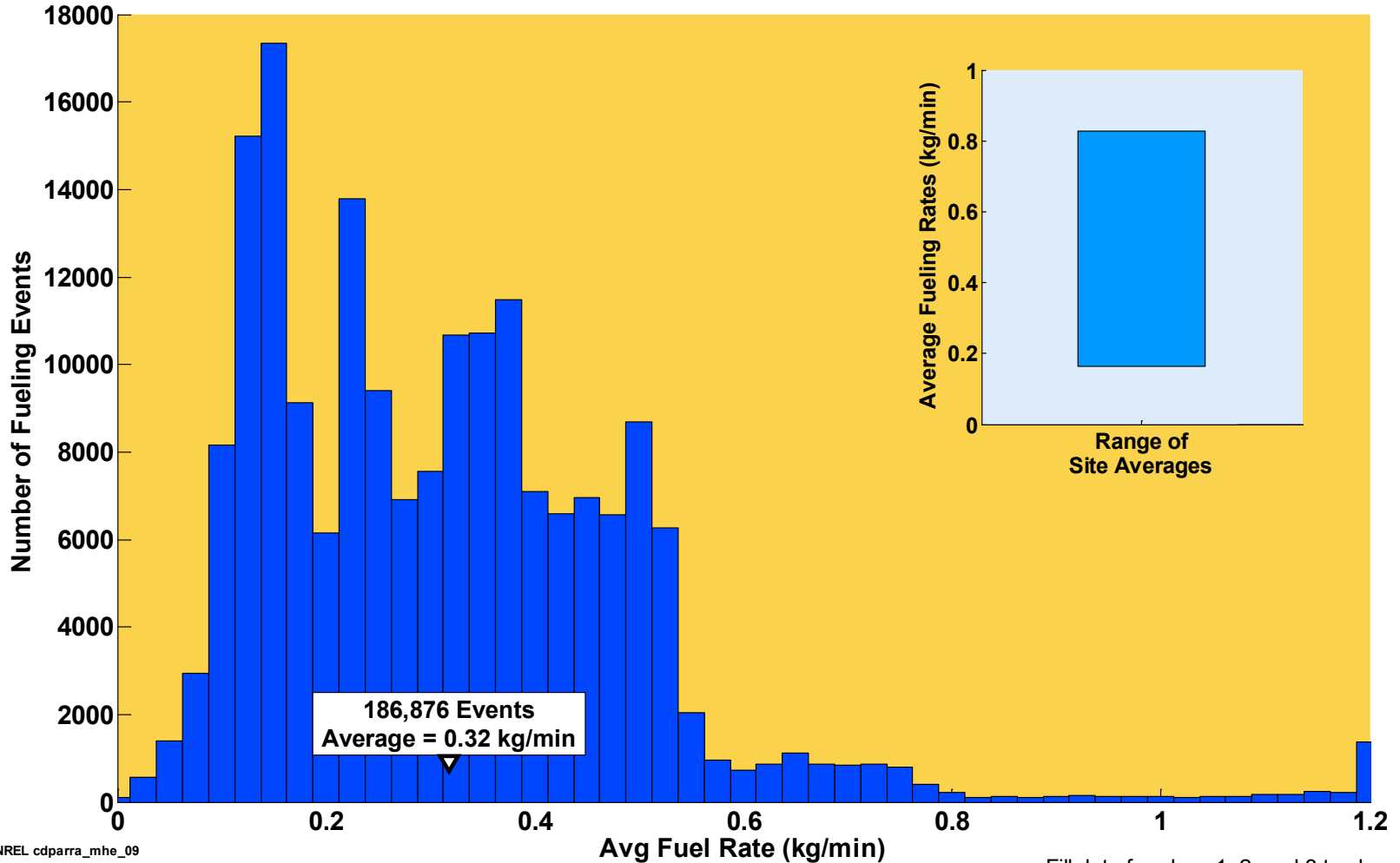
Operating Time Between Fuelings - ARRA  
Combined Fleet



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.

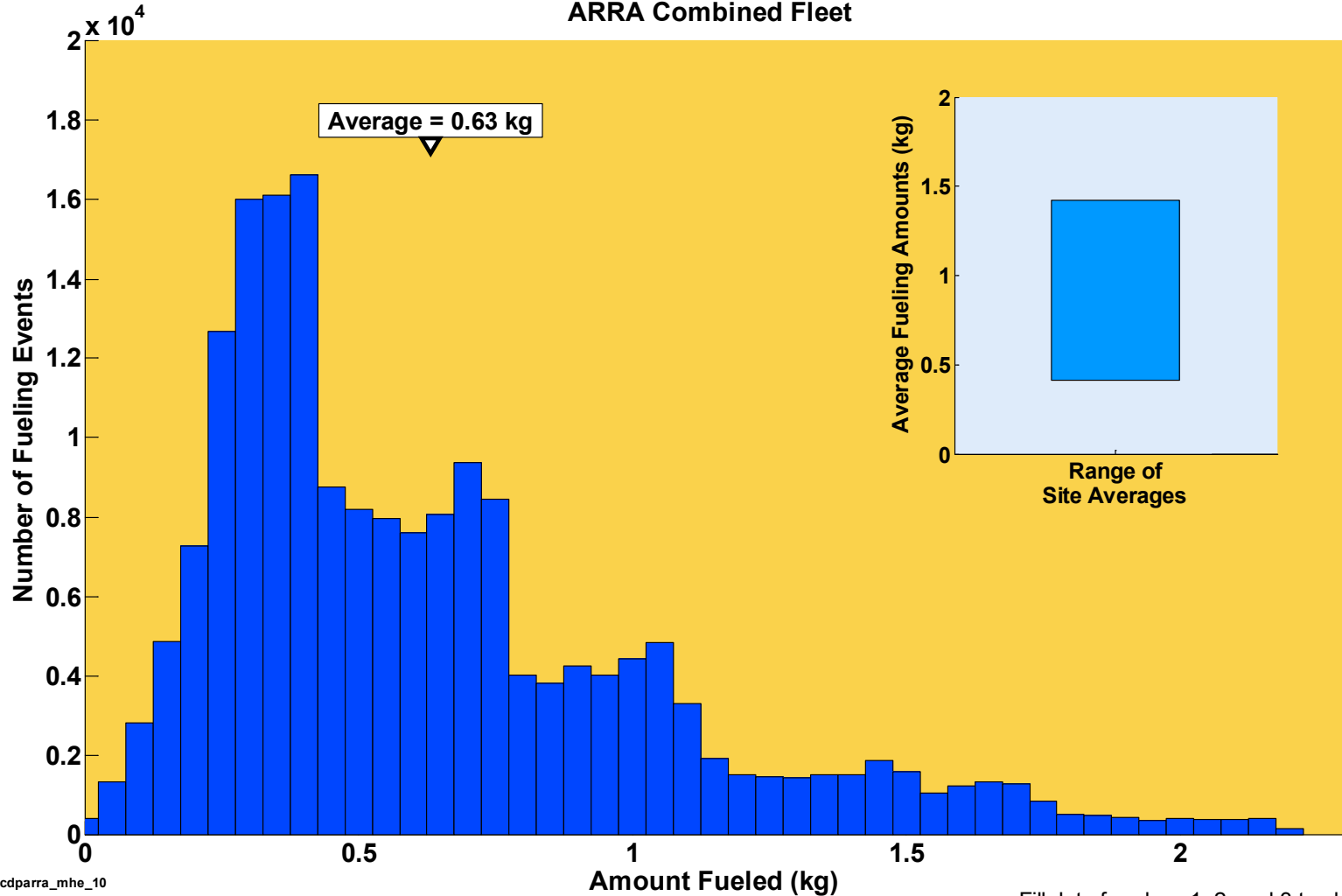
## Histogram of Fueling Rates

Histogram of Fueling Rates  
ARRA Combined Fleet



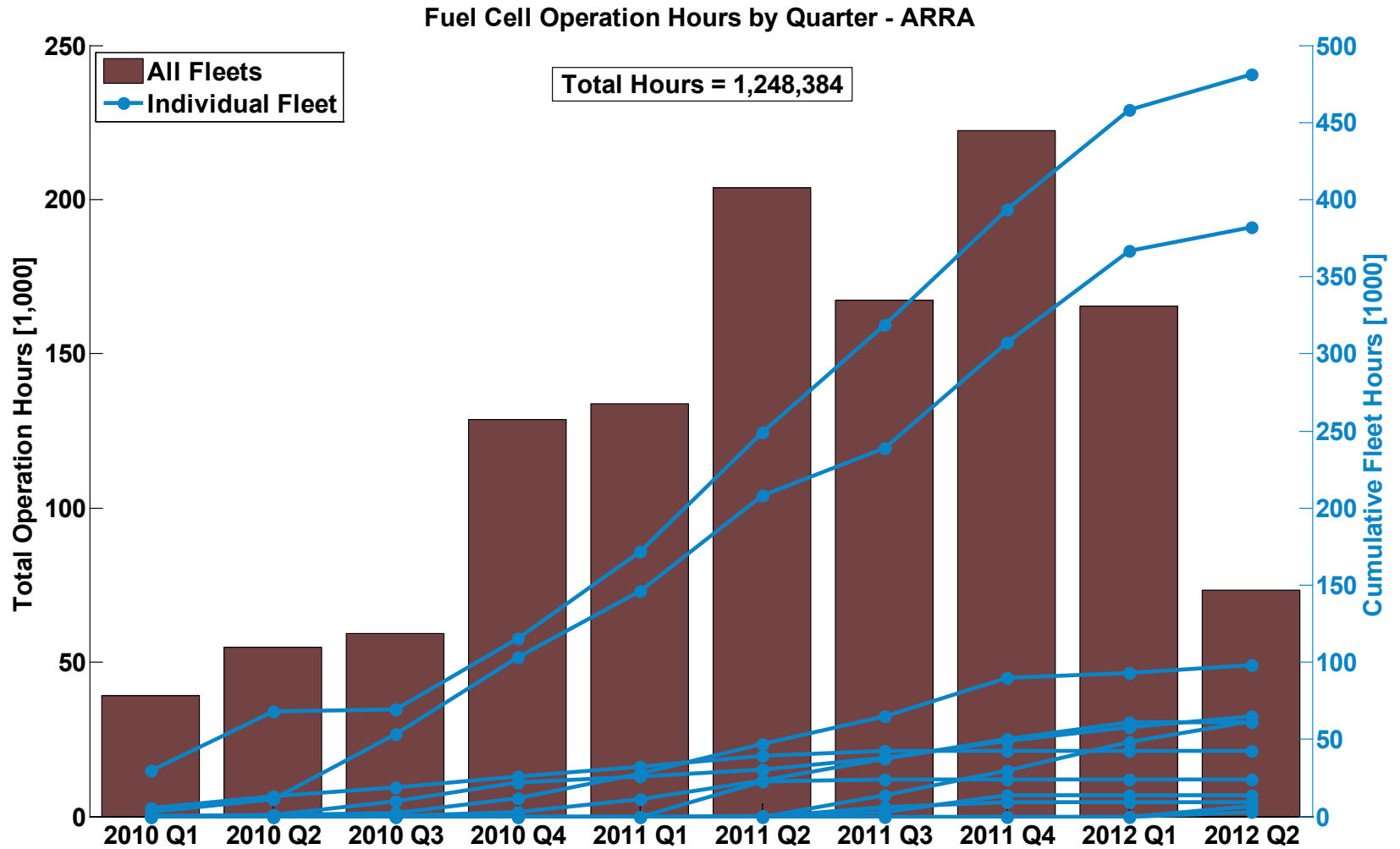
## Histogram of Fueling Amounts

Histogram of Fueling Amounts  
ARRA Combined Fleet

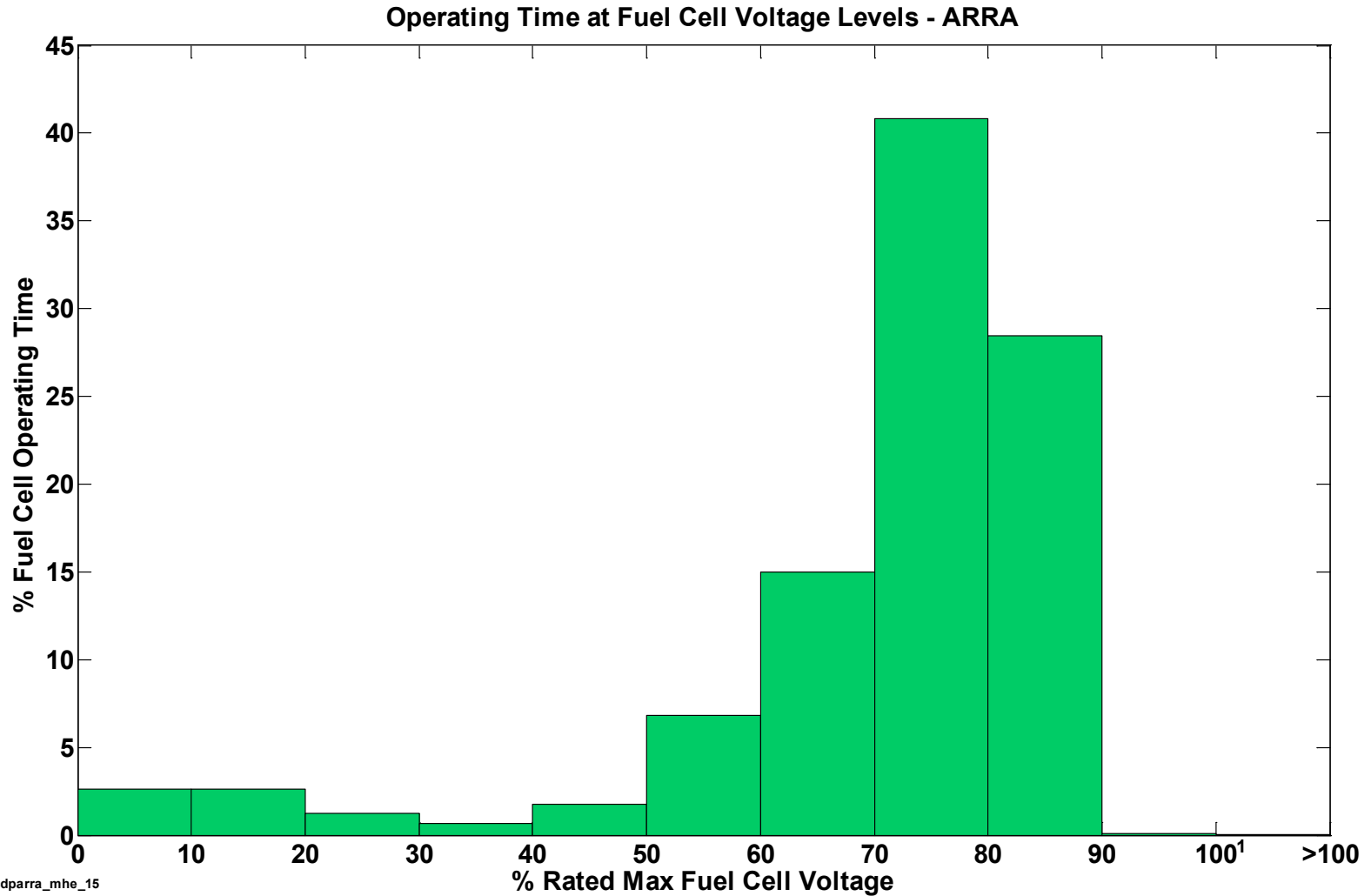


Fill data for class 1, 2, and 3 trucks

## Fuel Cell Operation Hours by Quarter



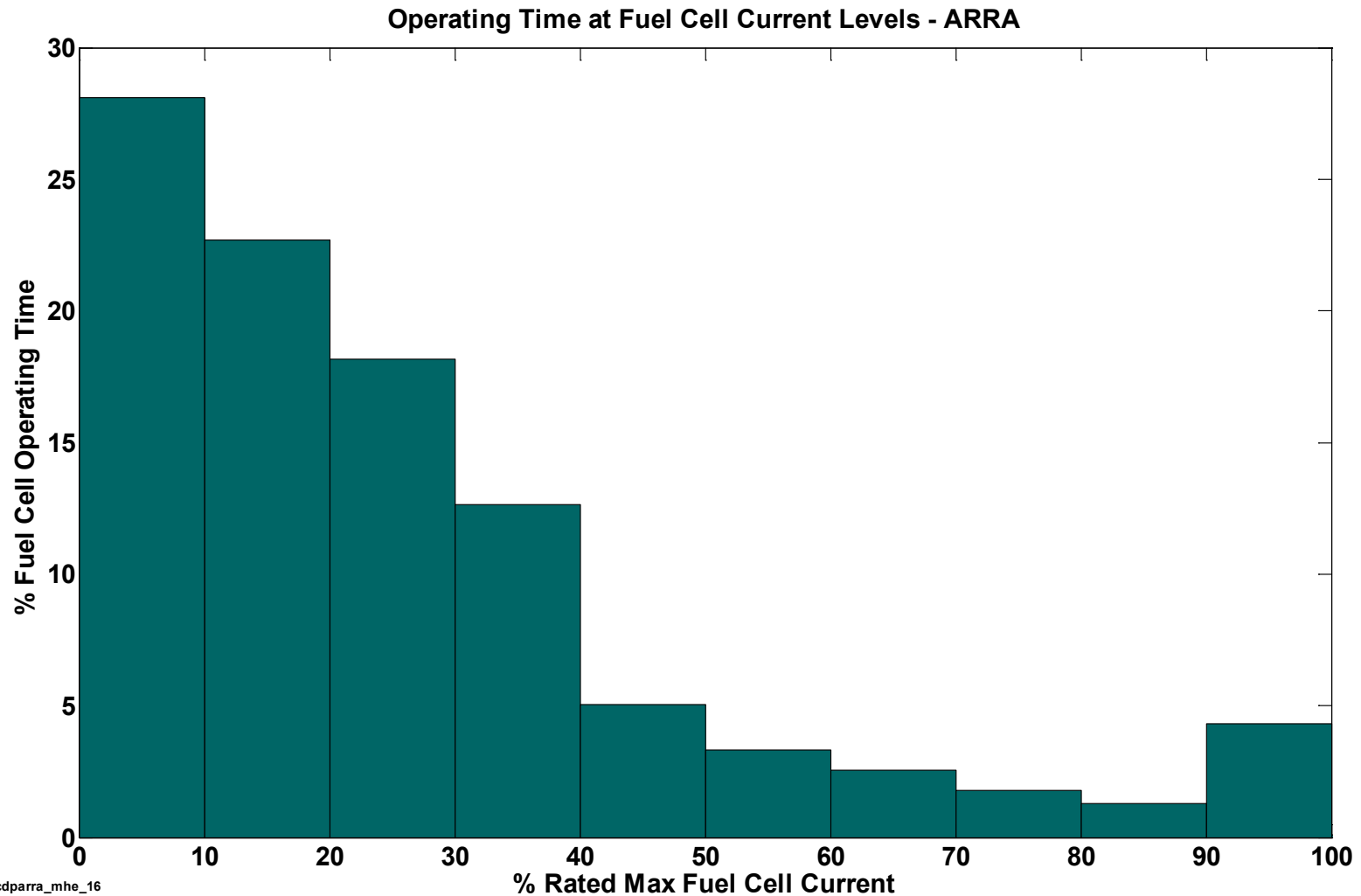
## Operating Time at Fuel Cell Voltage Levels



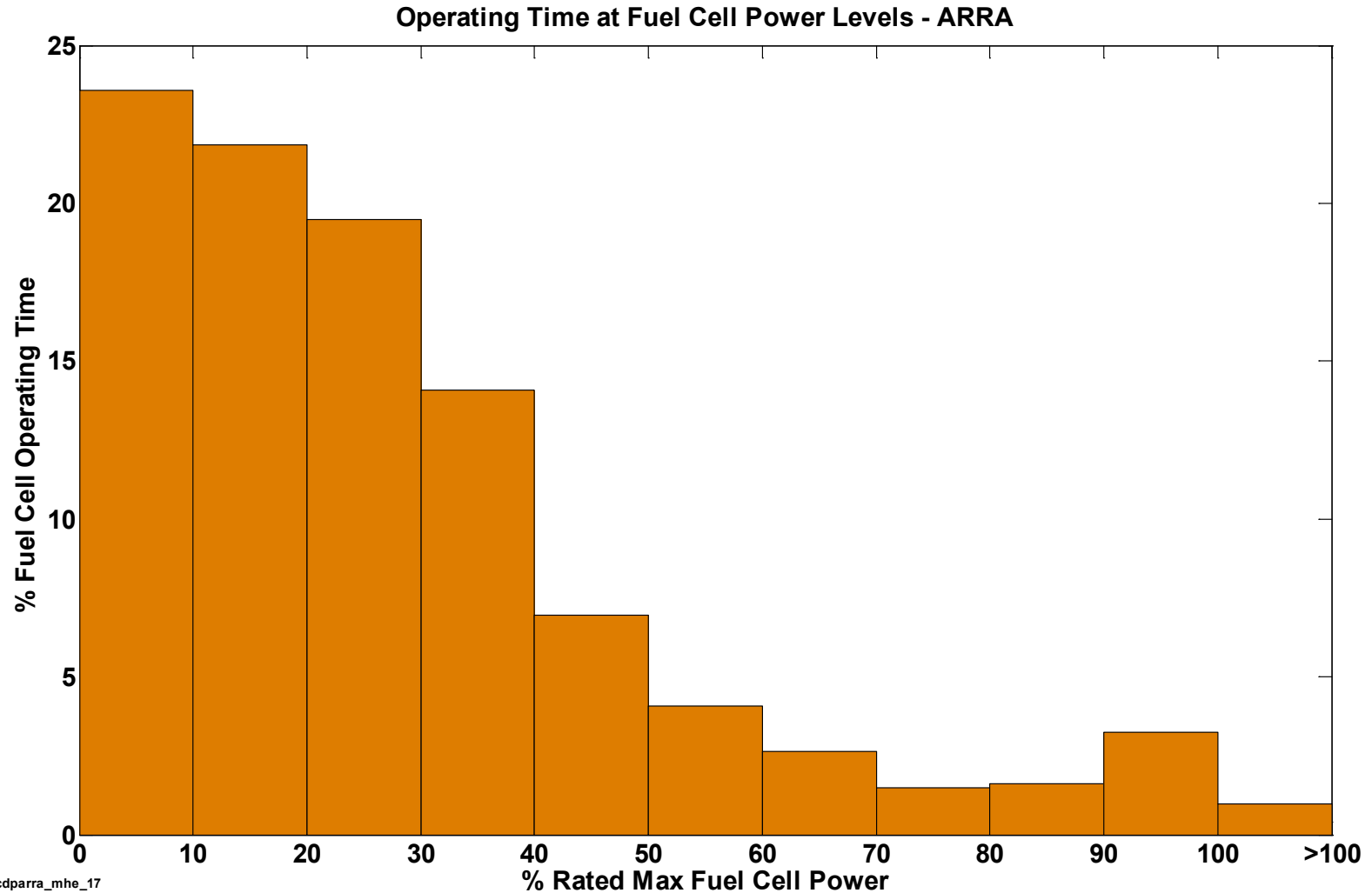
NREL cdparra\_mhe\_15

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

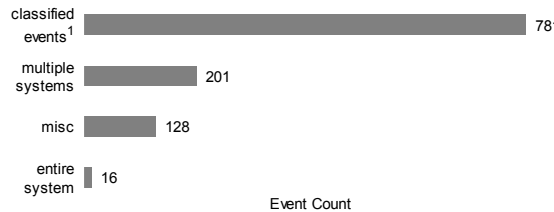
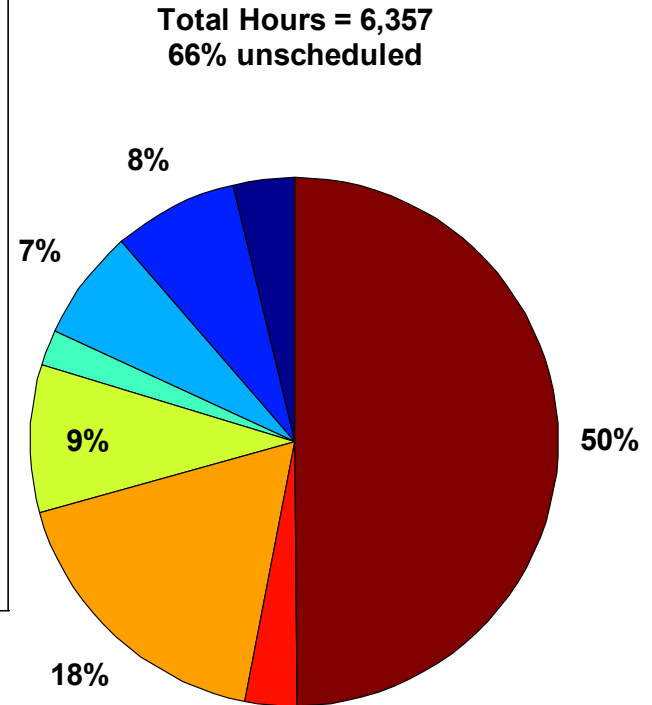
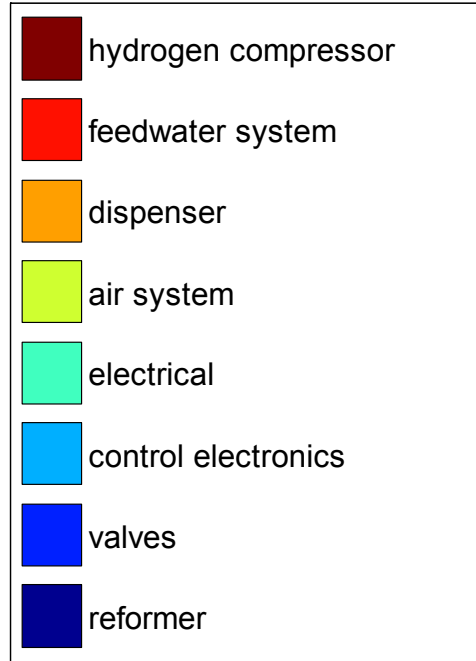
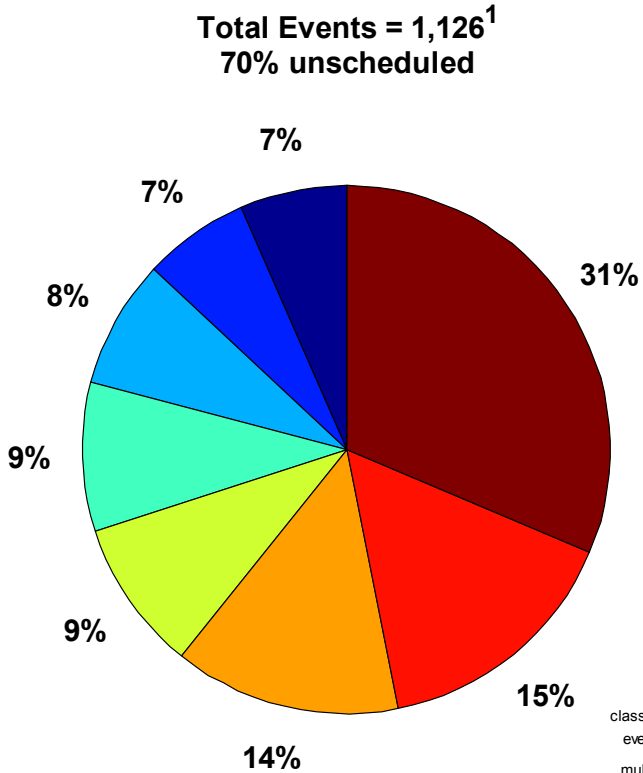


## Operating Time at Fuel Cell Power Levels





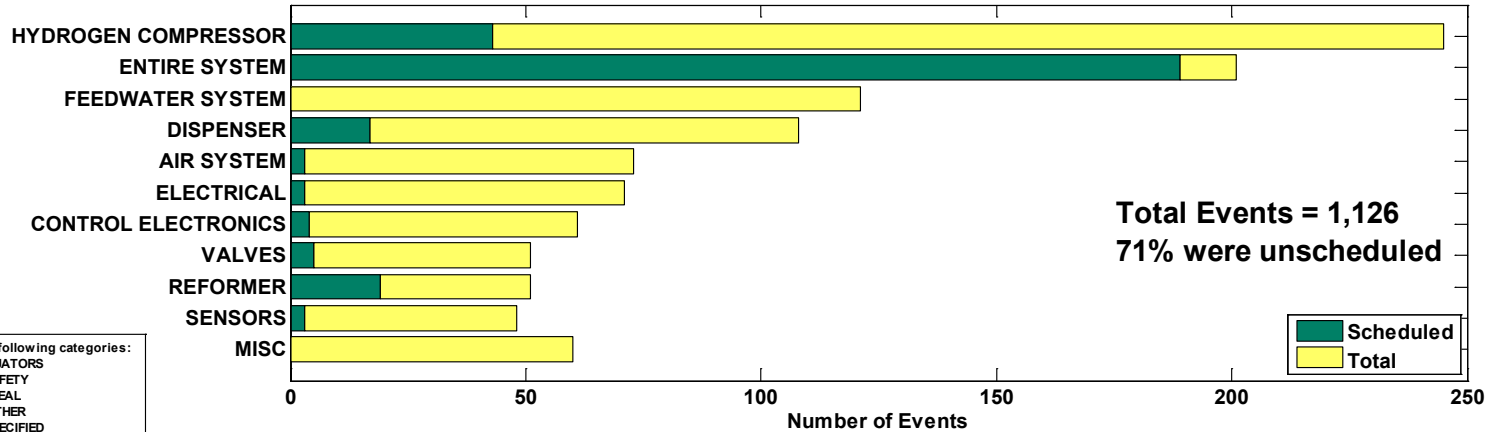
### Infrastructure Maintenance By Equipment Type



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

## Infrastructure Scheduled & Unscheduled Maintenance by Category

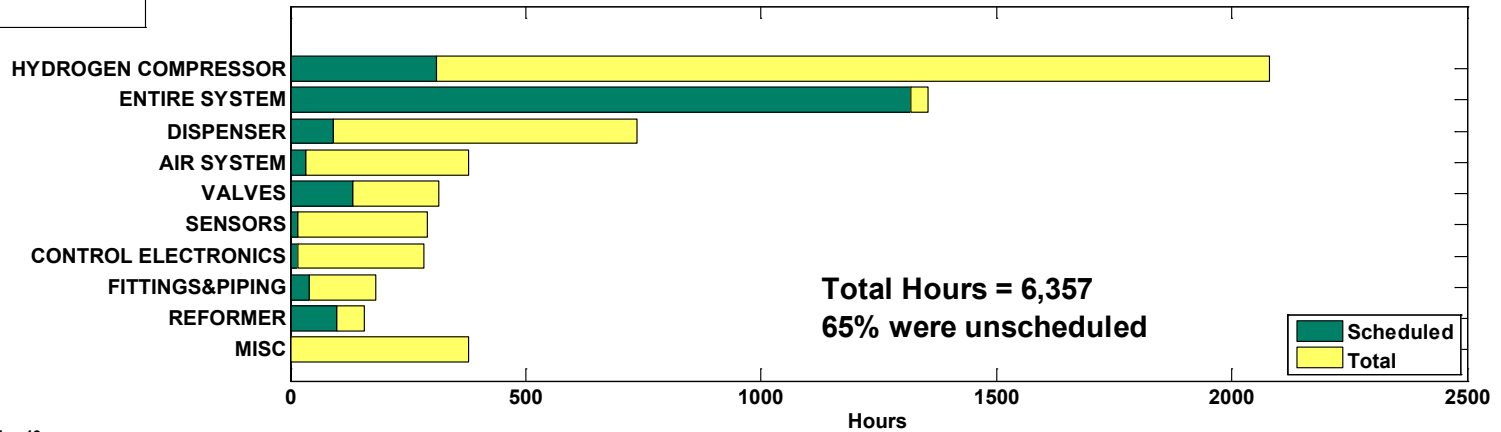
Infrastructure Maintenance Scheduled vs. Unscheduled  
Number of Maintenance Events by Category



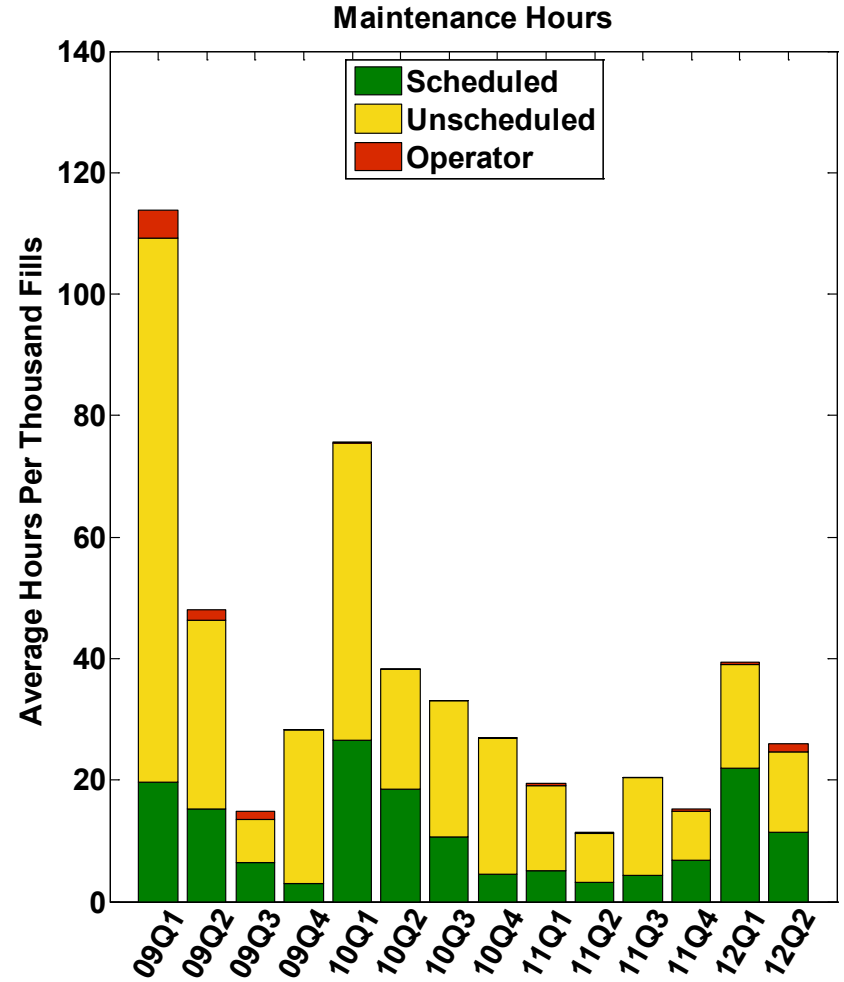
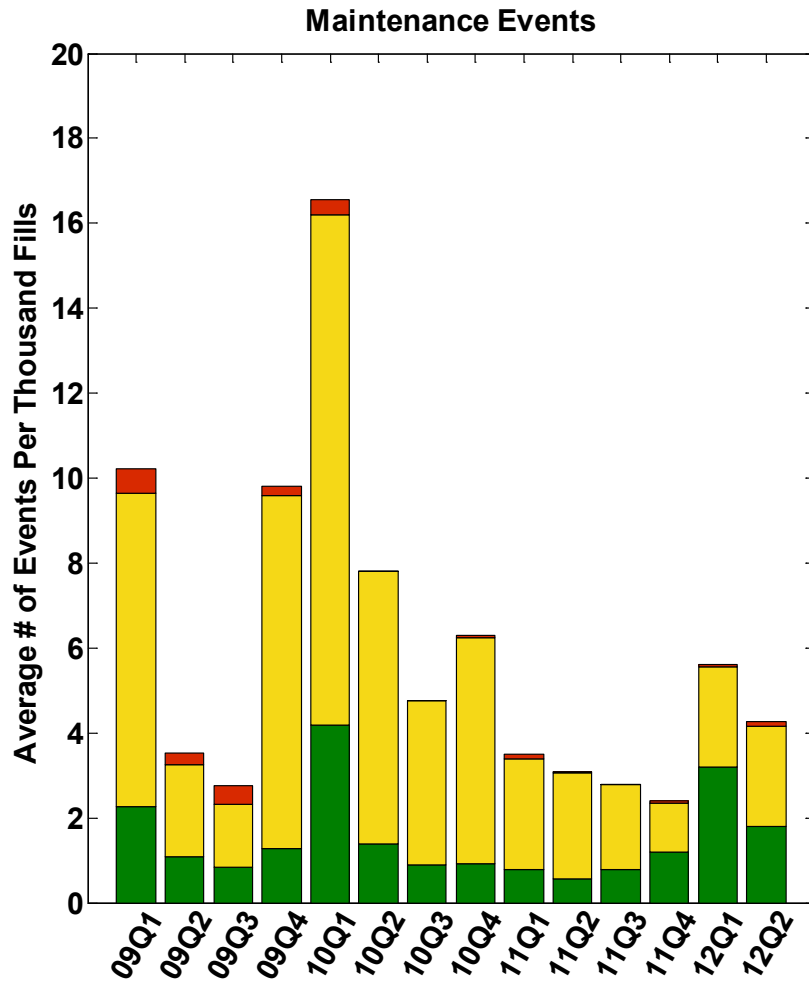
MISC includes the following categories:

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

Number of Labor Hours by Category



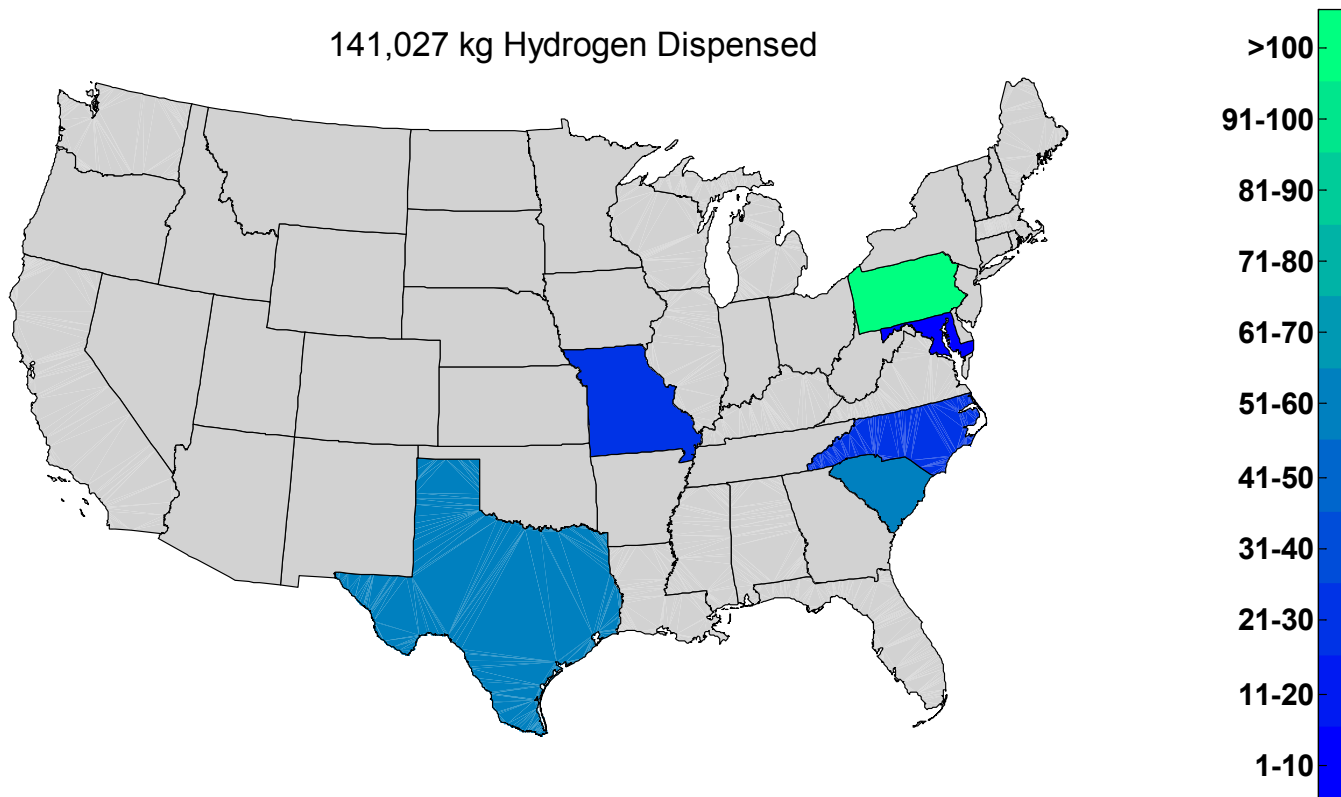
### Average Infrastructure Site Quarterly Maintenance



## Average Daily Hydrogen Dispensed by Location

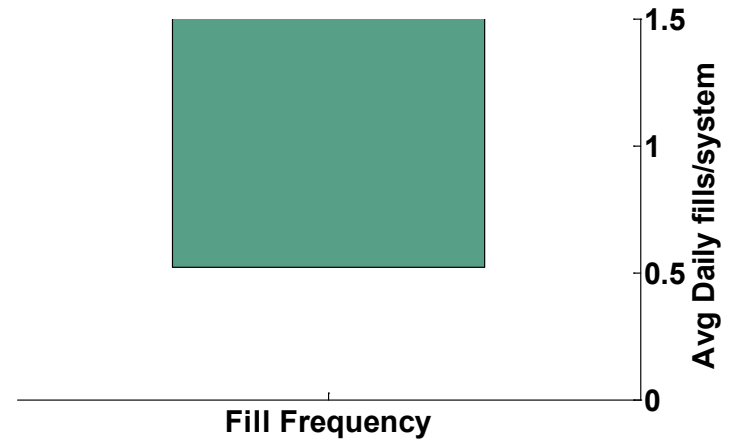
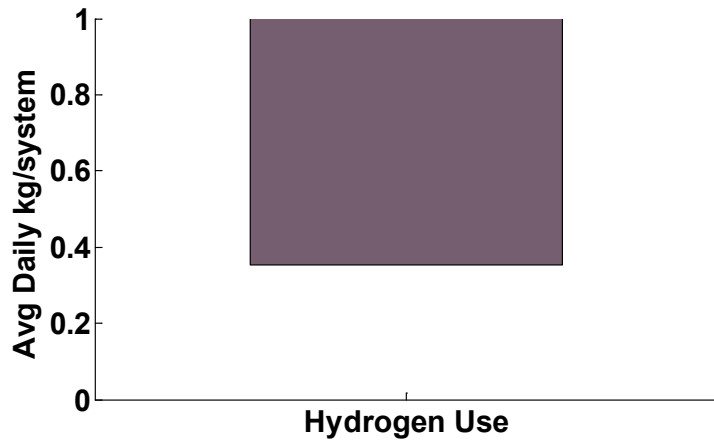
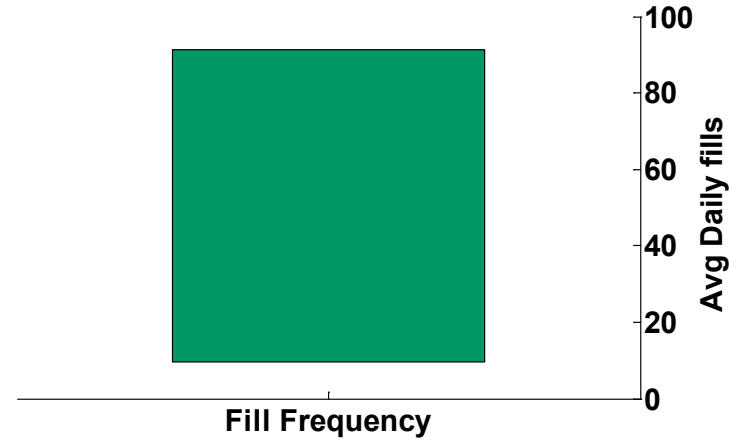
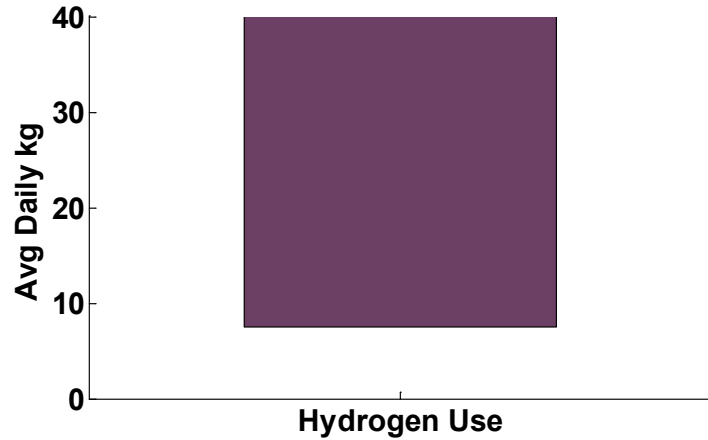
Average Daily Hydrogen Dispensed by Location - ARRA

141,027 kg Hydrogen Dispensed



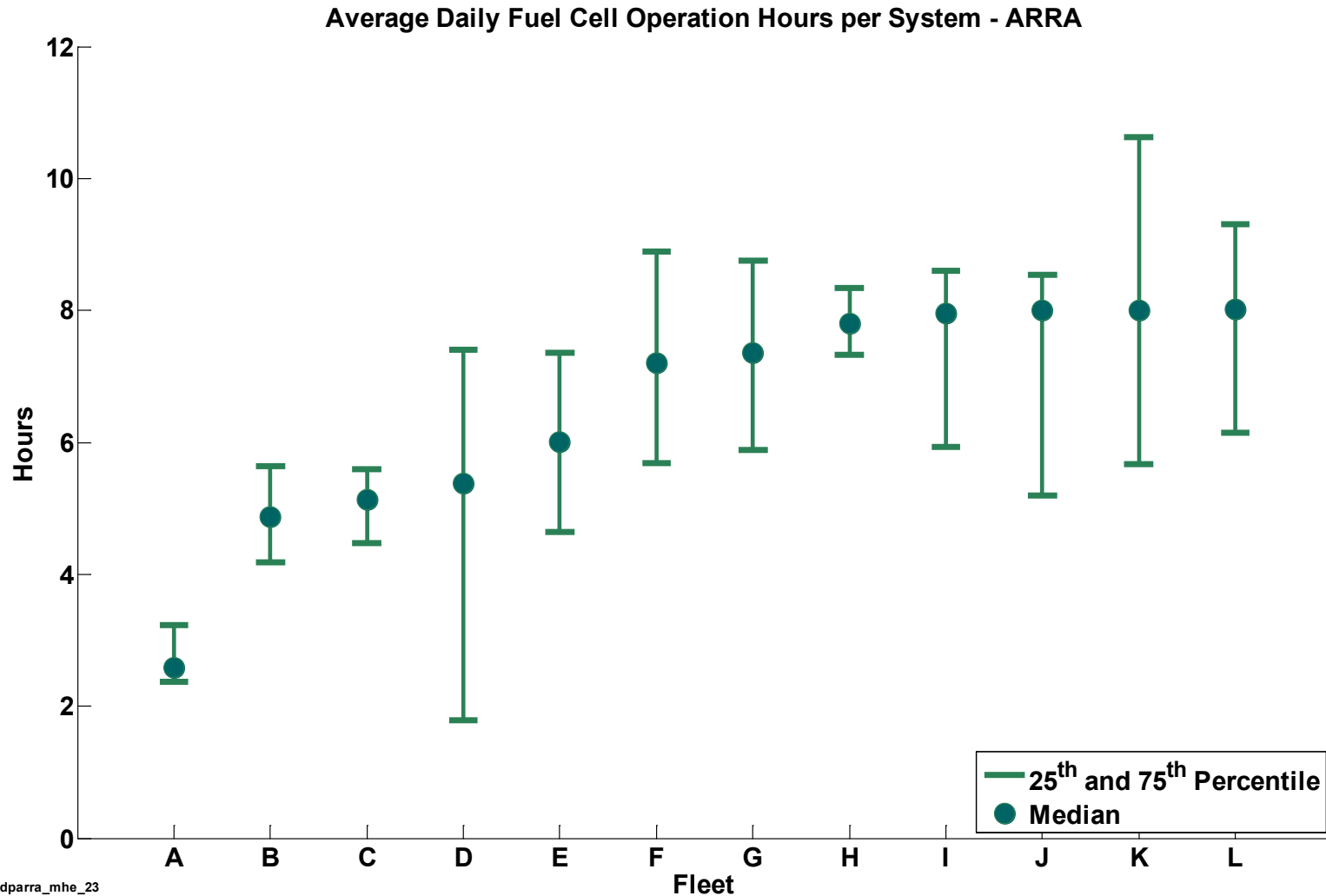
## Average Daily Dispensing Operations by Site

### Average Daily Dispensing Operations by Site - ARRA

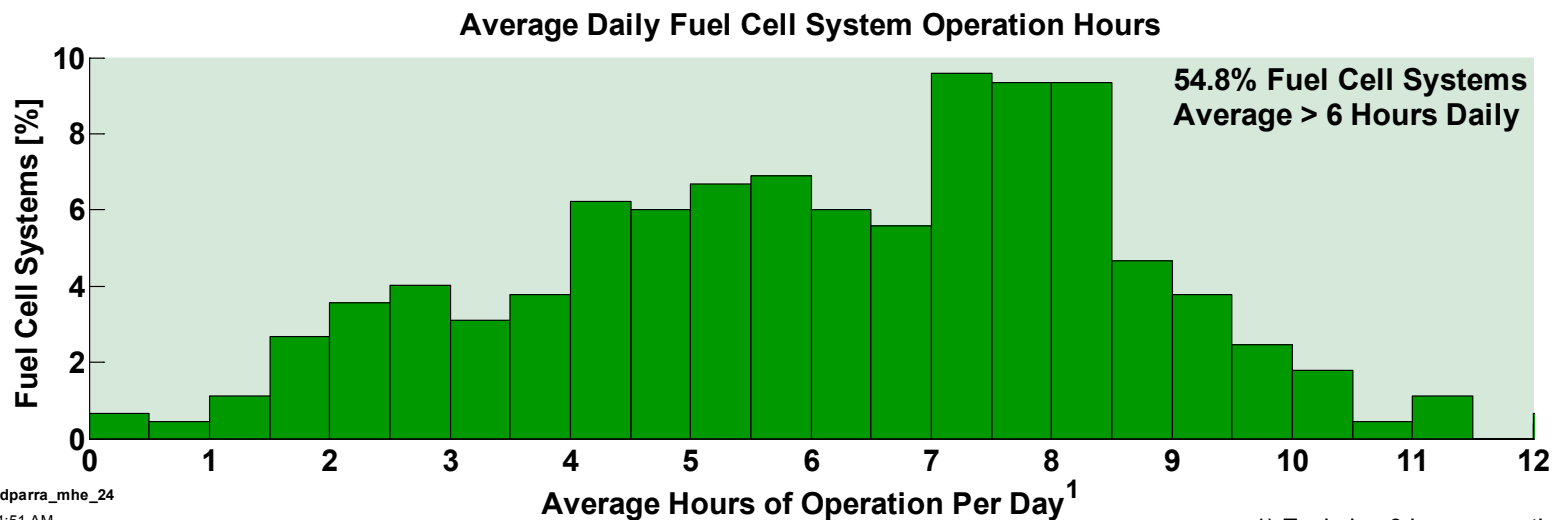
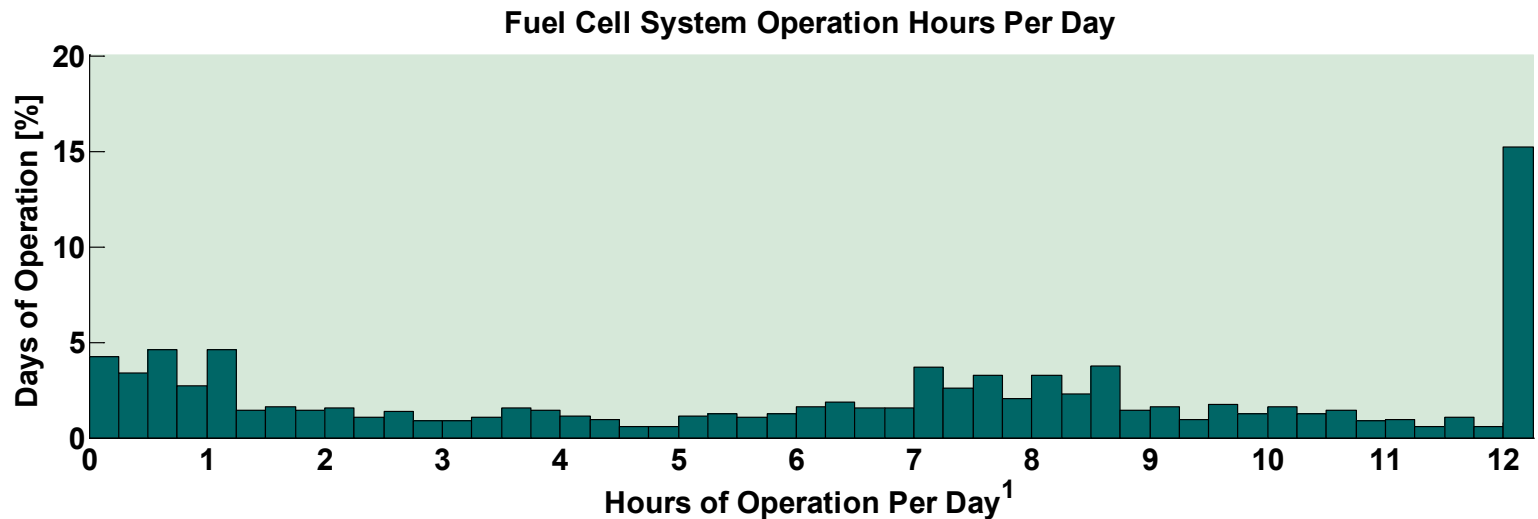


Shaded areas represent the min and max site average hydrogen use and fill frequency

## Average Daily Fuel Cell Operation Hours per Fleet

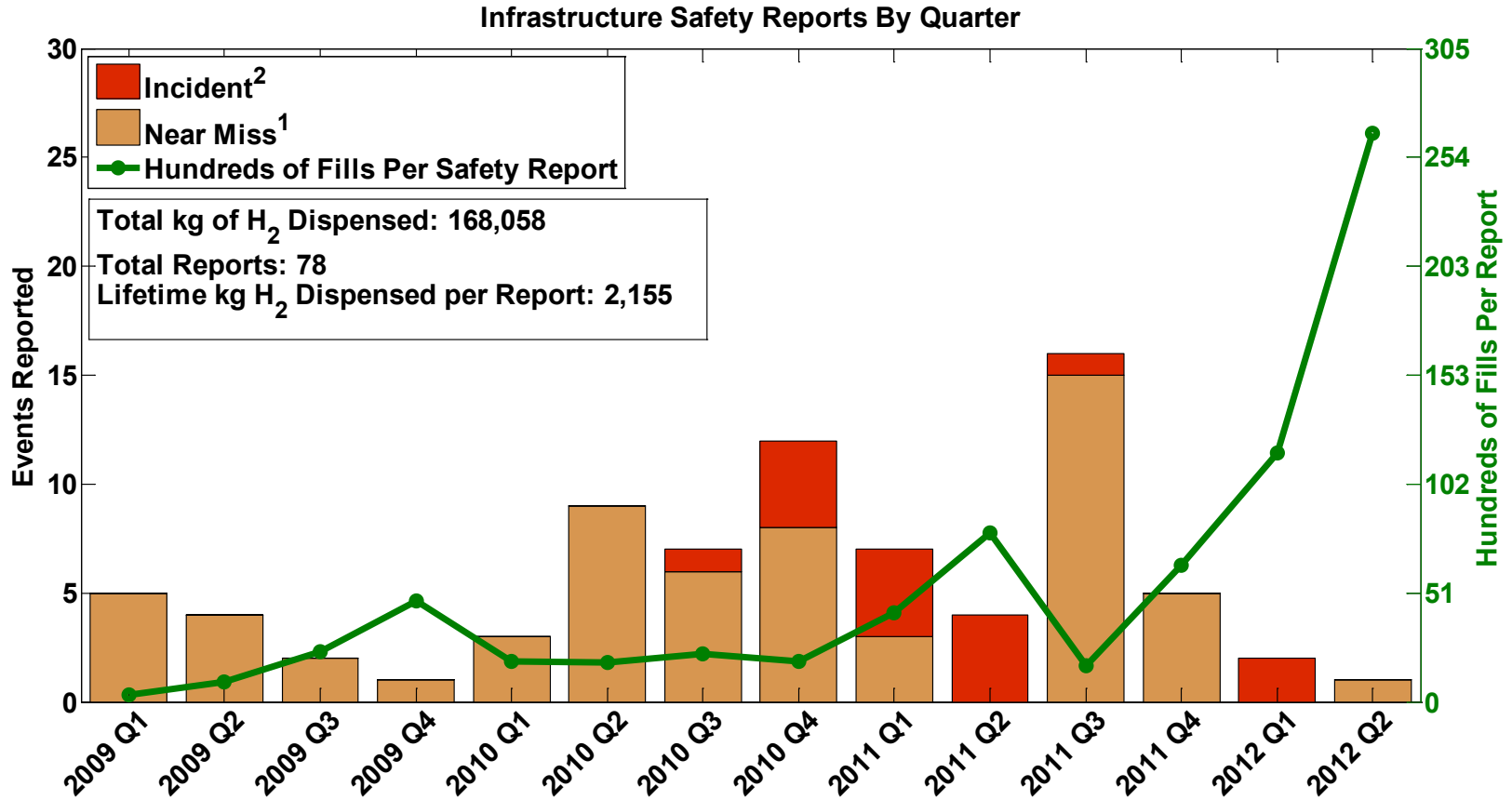


## Average Daily Fuel Cell Operation Hours per System



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)

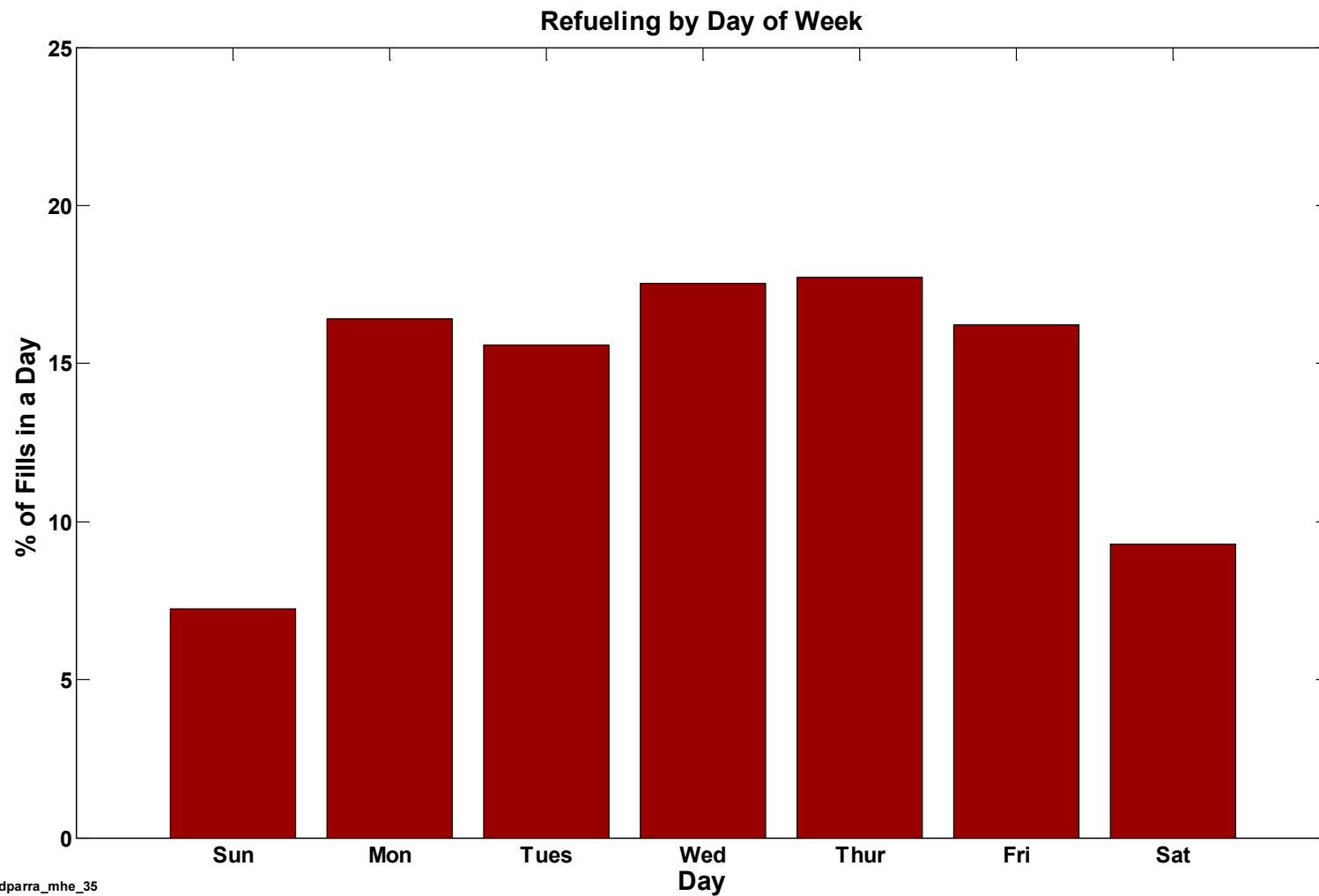


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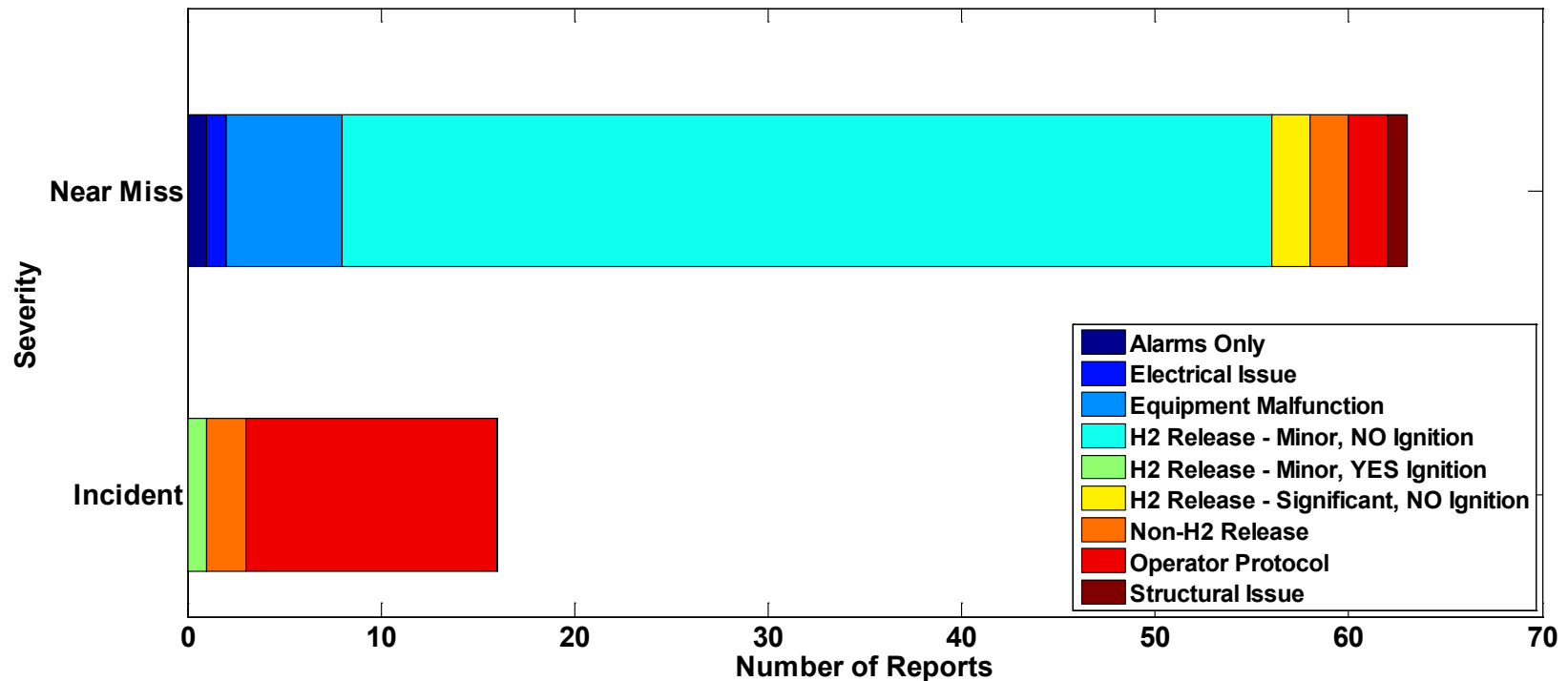


## Refuel Events by Day of Week



## Infrastructure Safety Categories

Infrastructure Safety Reports by Severity - All Sites and Report Type



An INCIDENT is an event that results in:

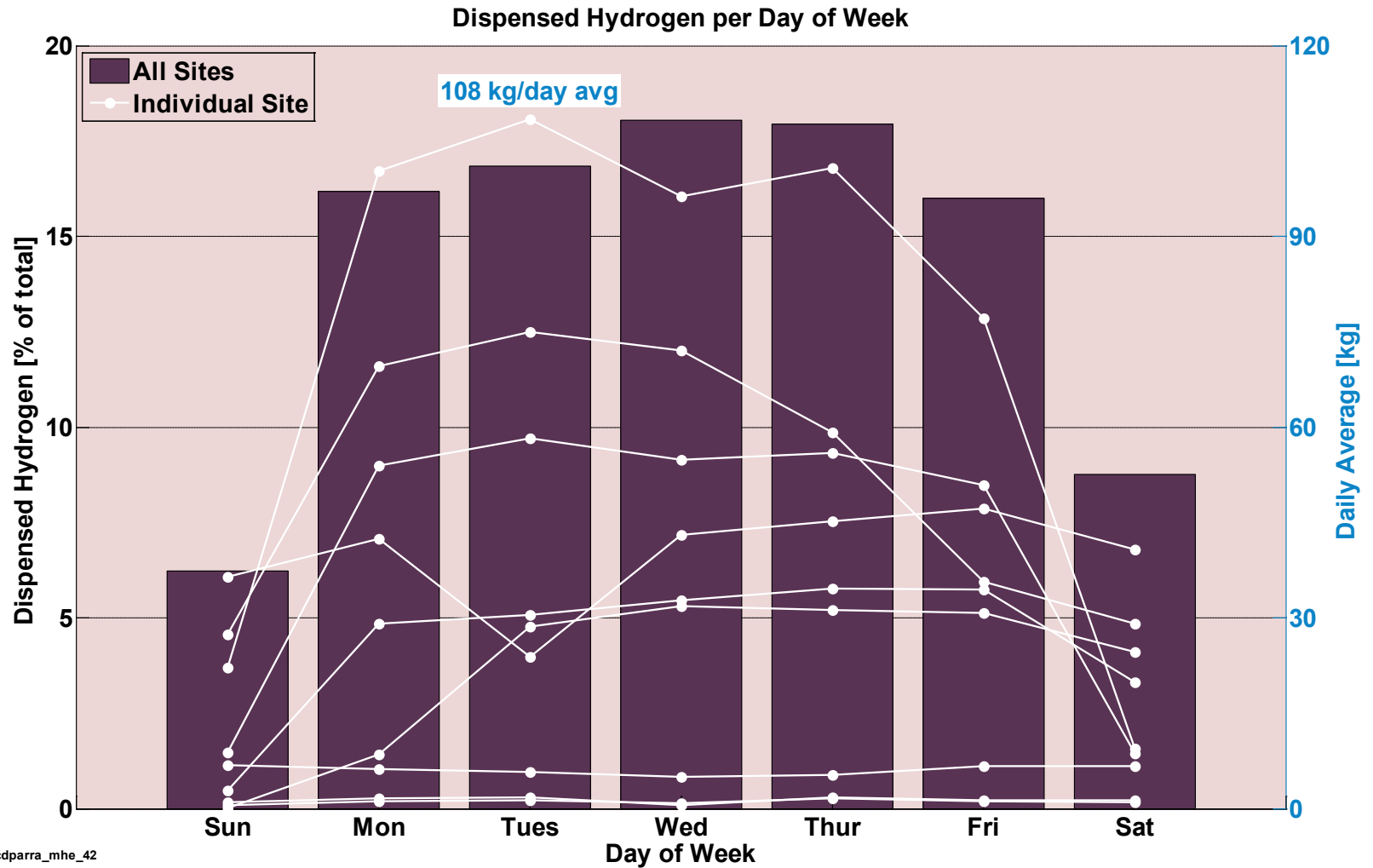
- a lost time accident and/or injury to personnel
- damage/unplanned downtime for project equipment, facilities or property
- impact to the public or environment
- any hydrogen release that unintentionally ignites or is sufficient to sustain a flame if ignited
- release of any volatile, hydrogen containing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

A NEAR-MISS is:

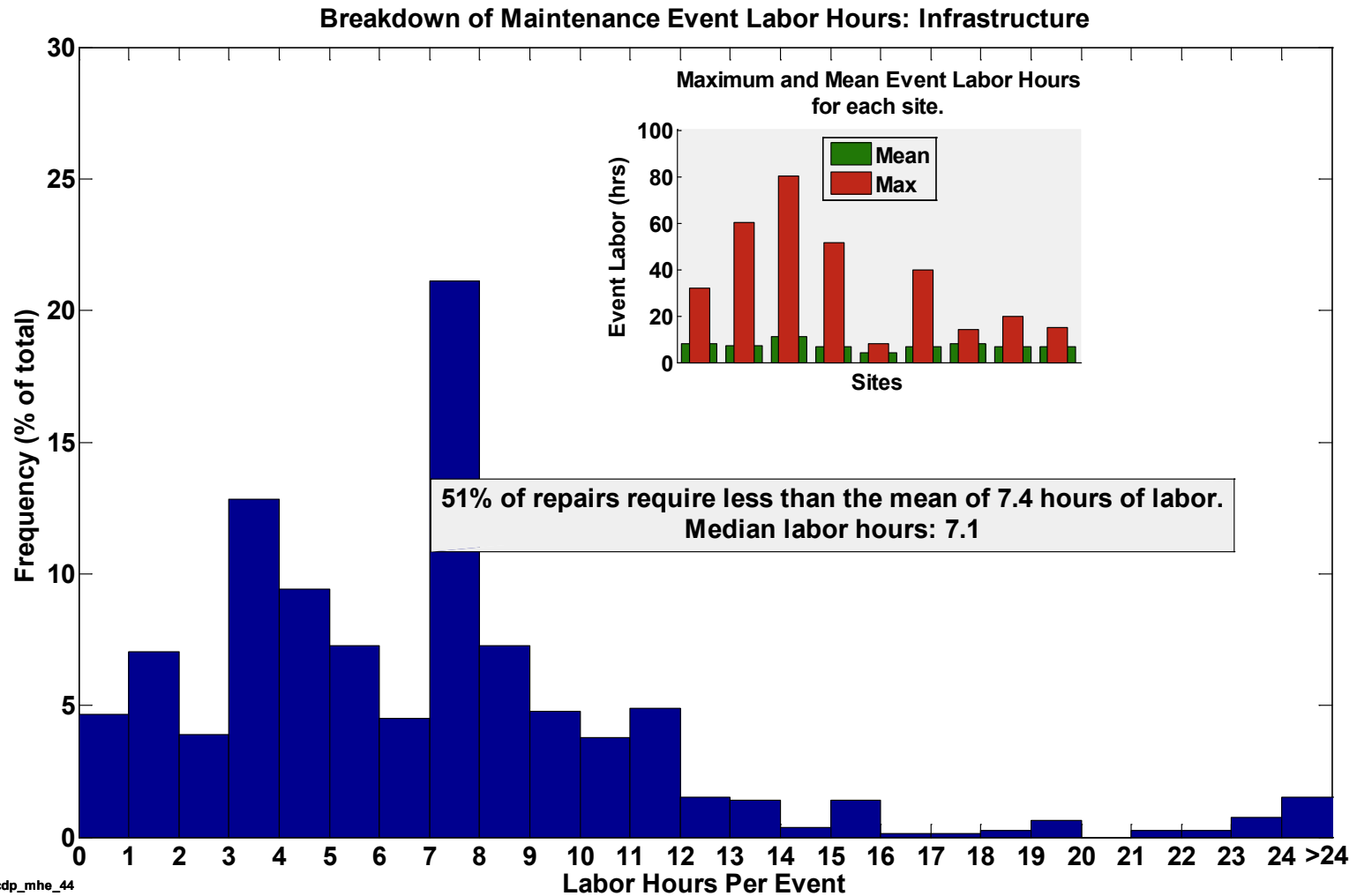
- an event that under slightly different circumstances could have become an incident
- unplanned H2 release insufficient to sustain a flame

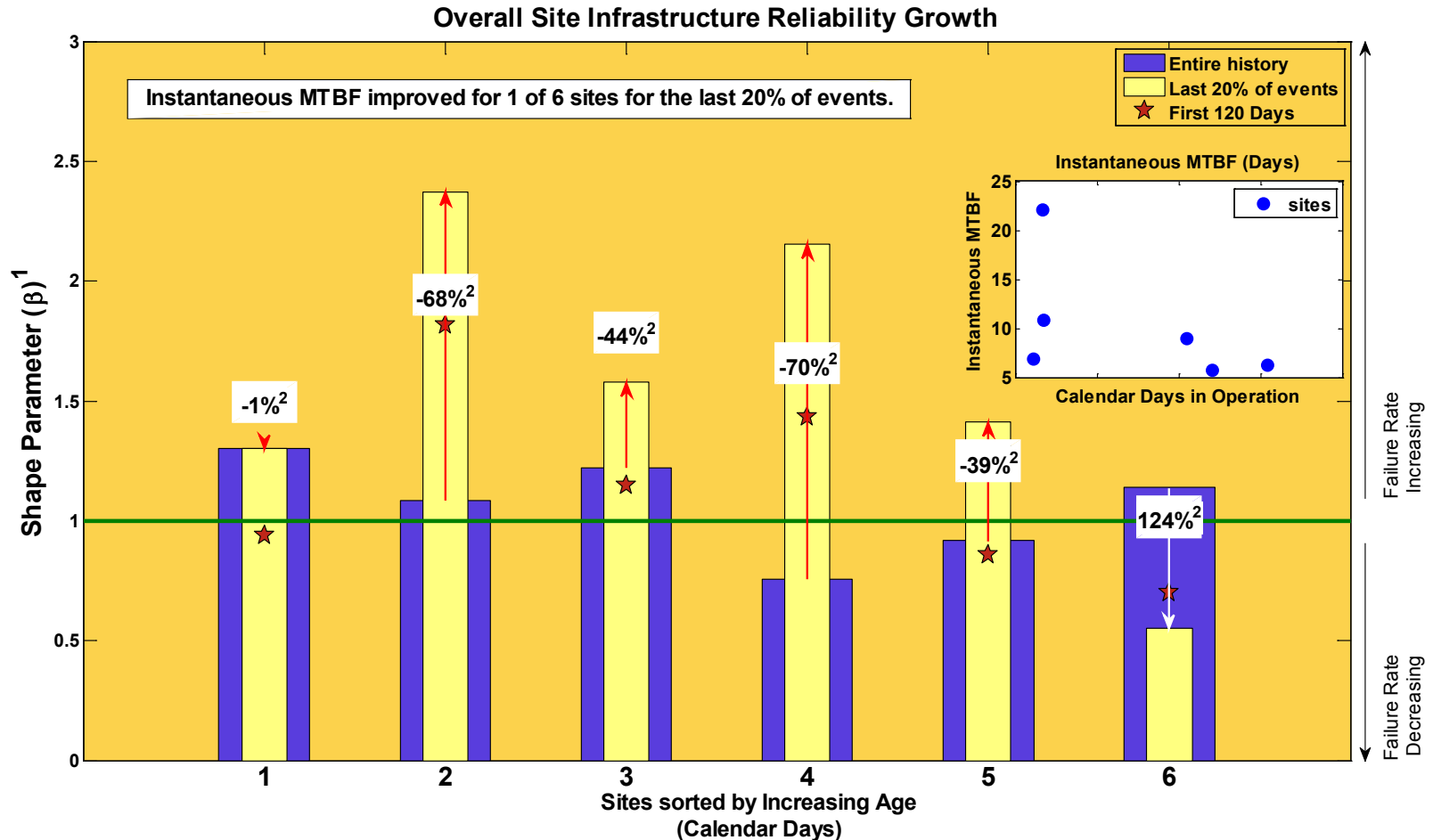


## Amount of Hydrogen Dispensed by Day of Week



## Infrastructure Maintenance Labor Hours





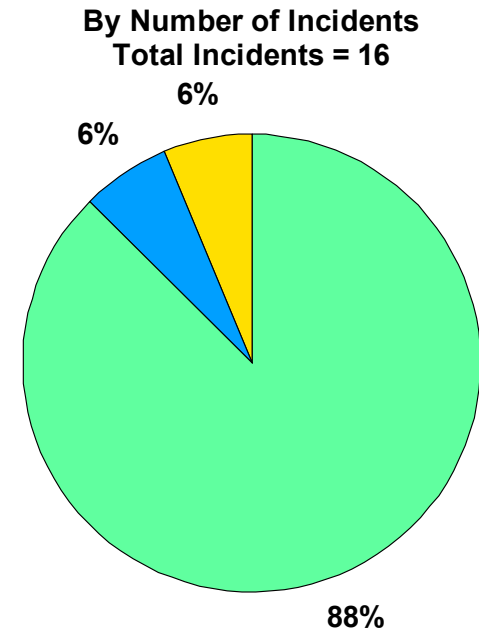
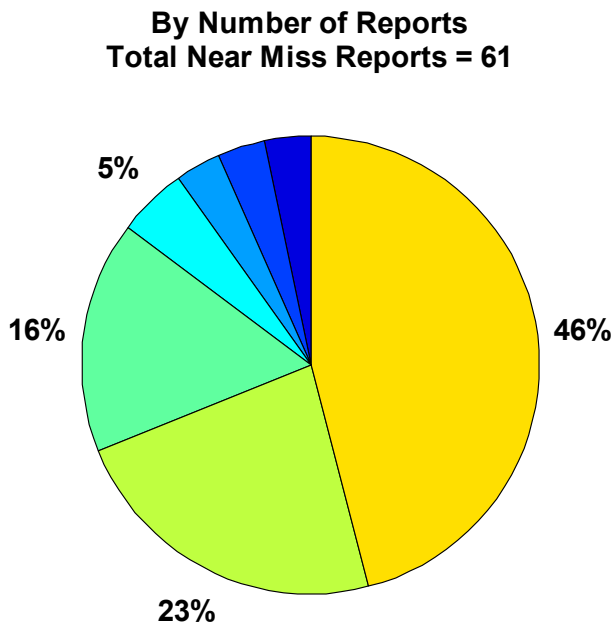
1. IEC 61164:2004(E), Reliability Growth - Statistical Test and Evaluation Methods, IEC. 2004.

2. % change in instantaneous MTBF



## 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)

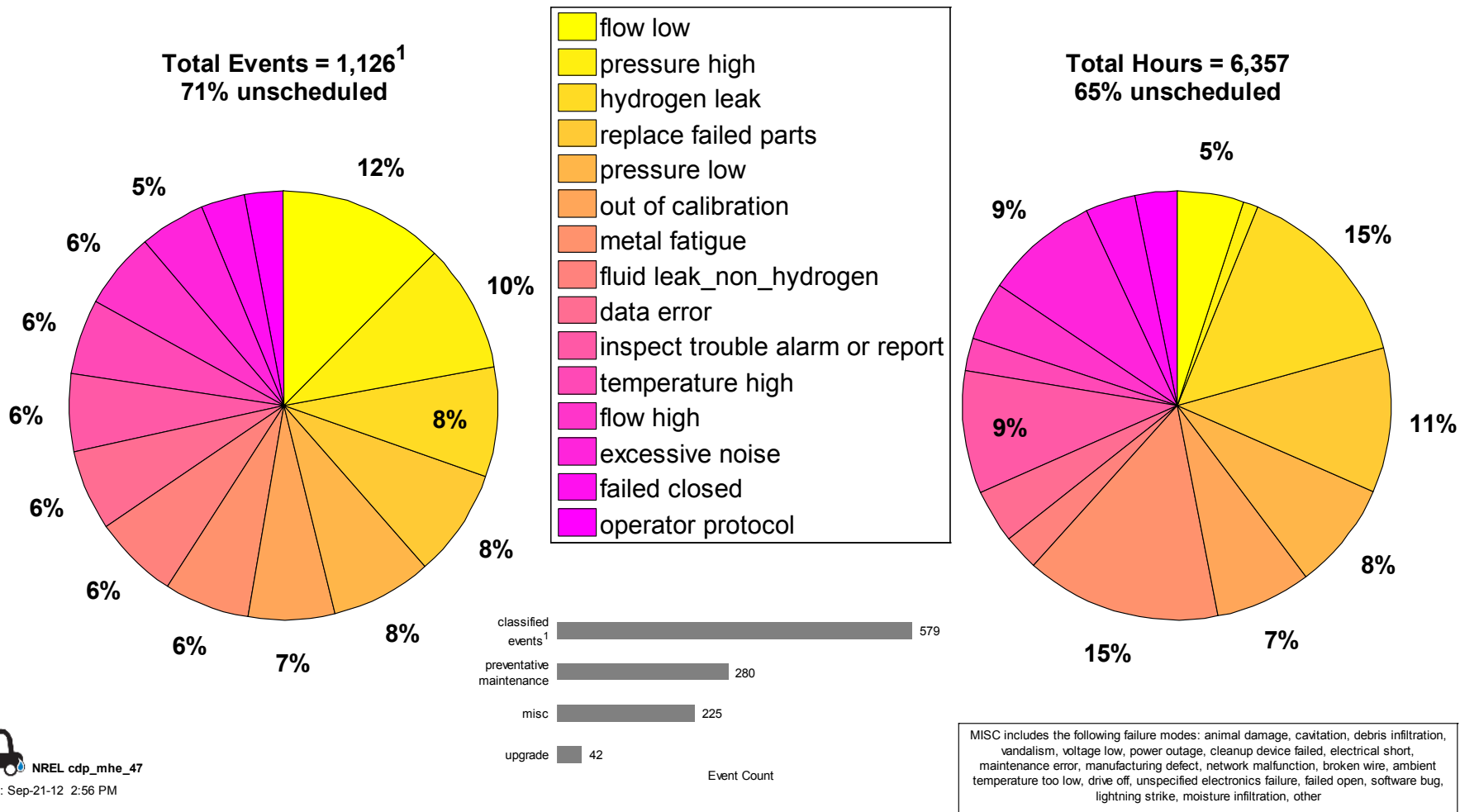
A NEAR-MISS is:

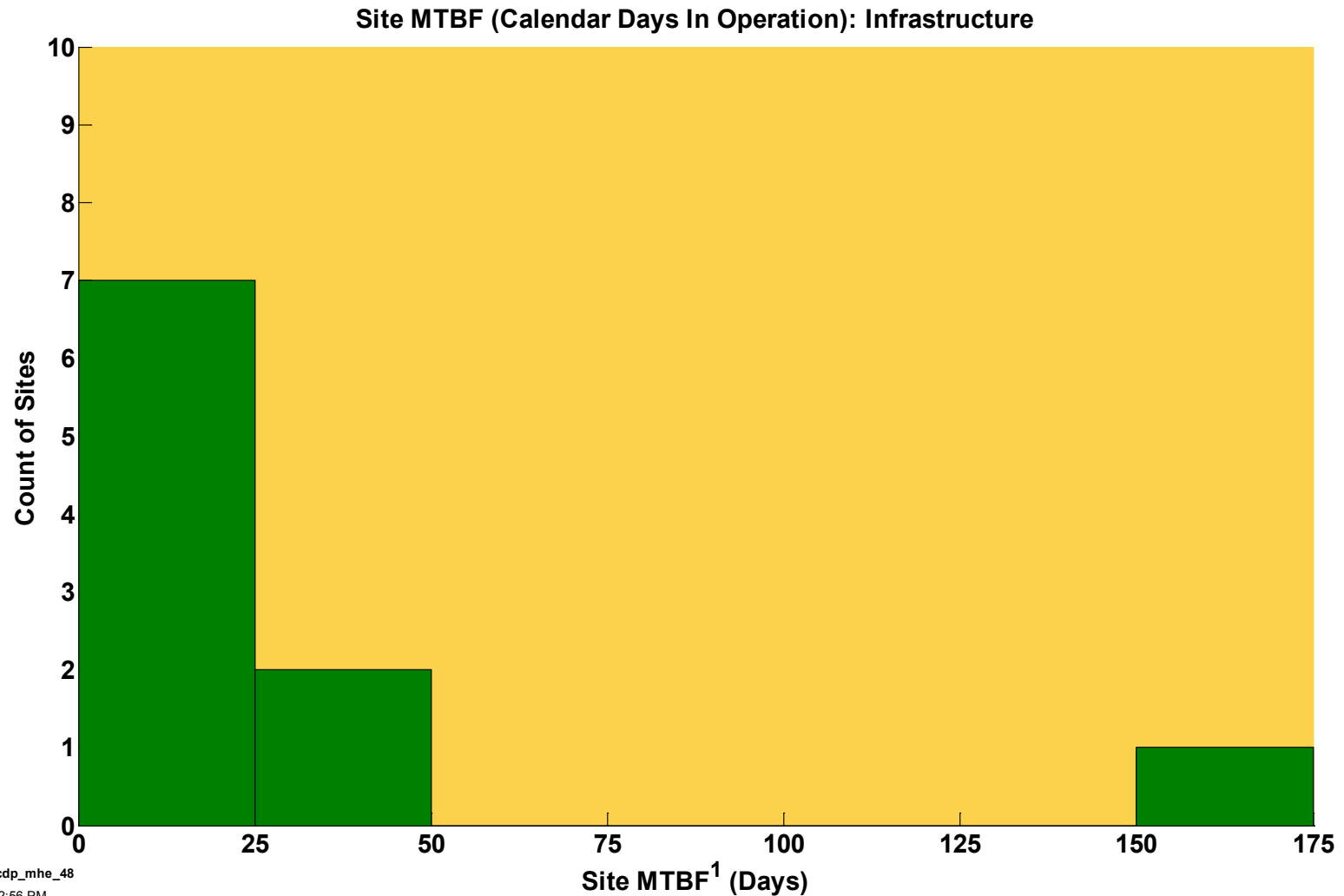
- an event that under slightly different circumstances could have become an incident
- unplanned H2 release insufficient to sustain a flame



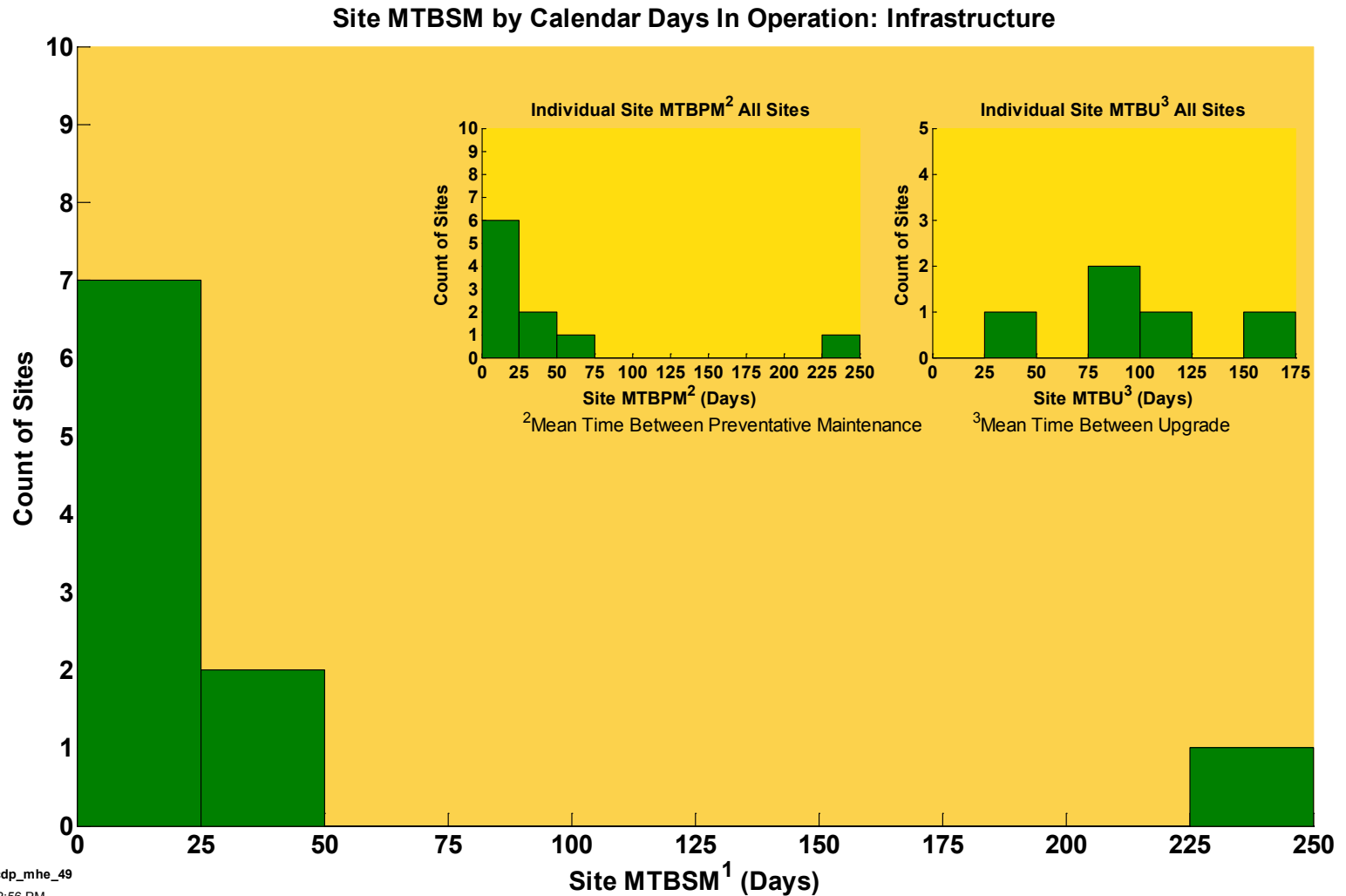
## Infrastructure Maintenance by Mode

Infrastructure Maintenance By Mode



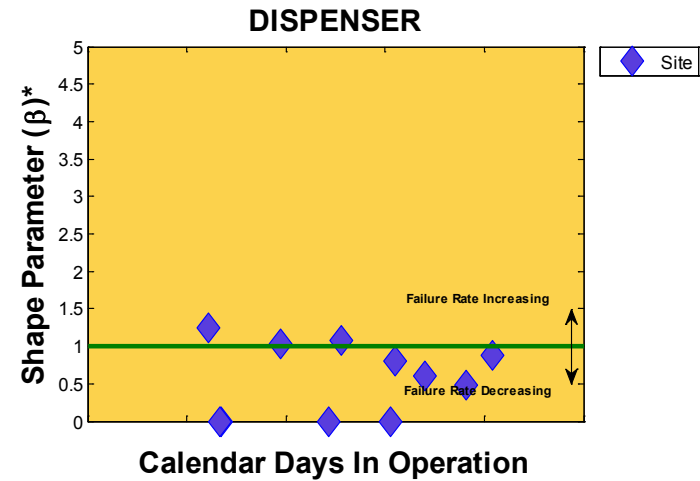
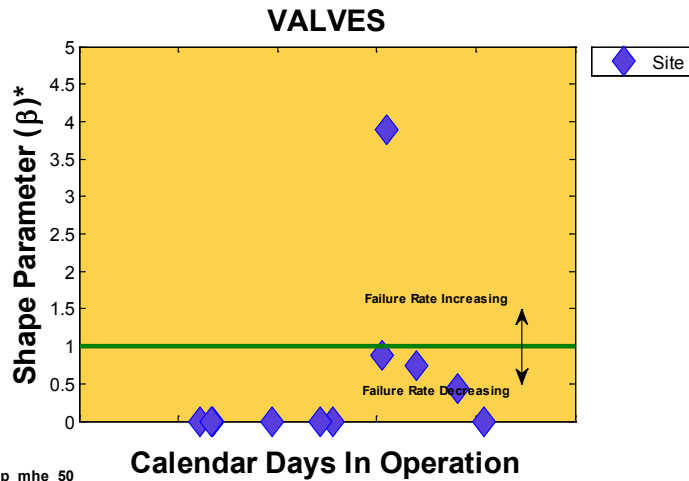
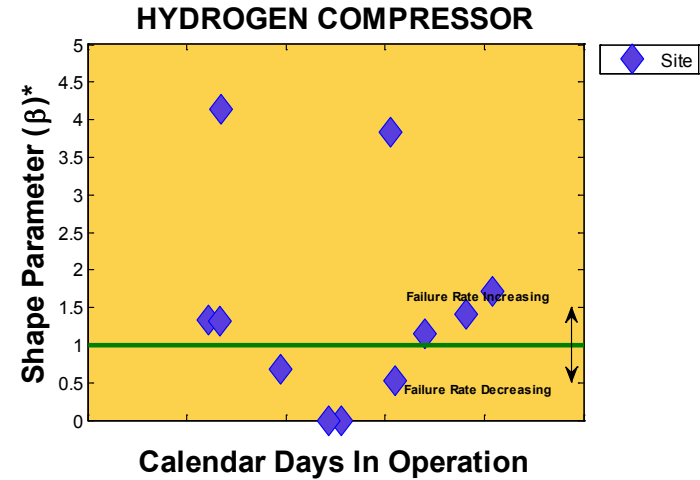
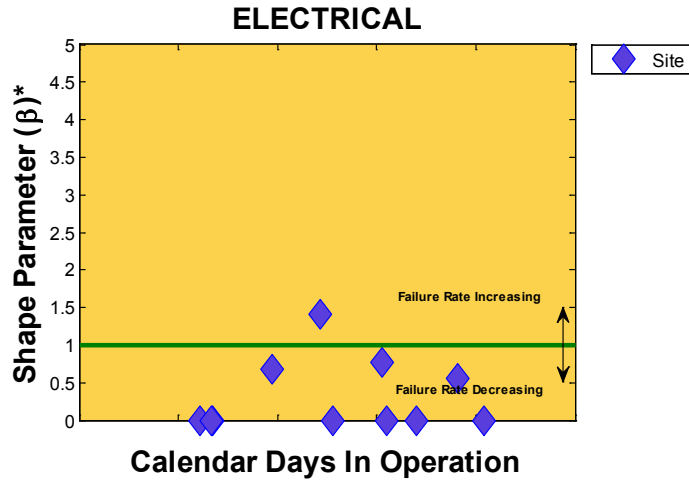






1. Cumulative Mean Time Between Scheduled Maintenance. Includes Preventative and Upgrades

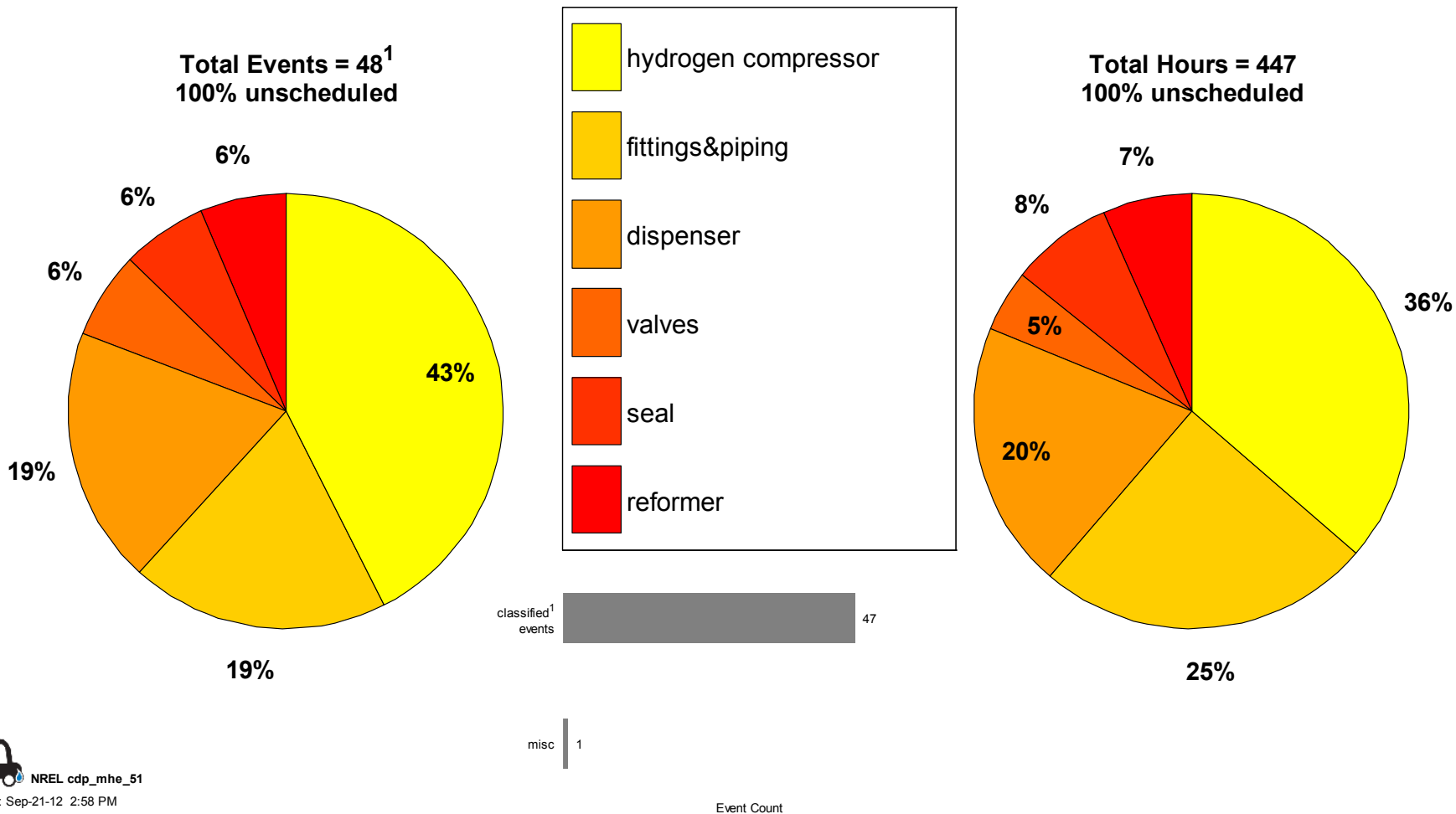
## Infrastructure Reliability Growth by Category



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

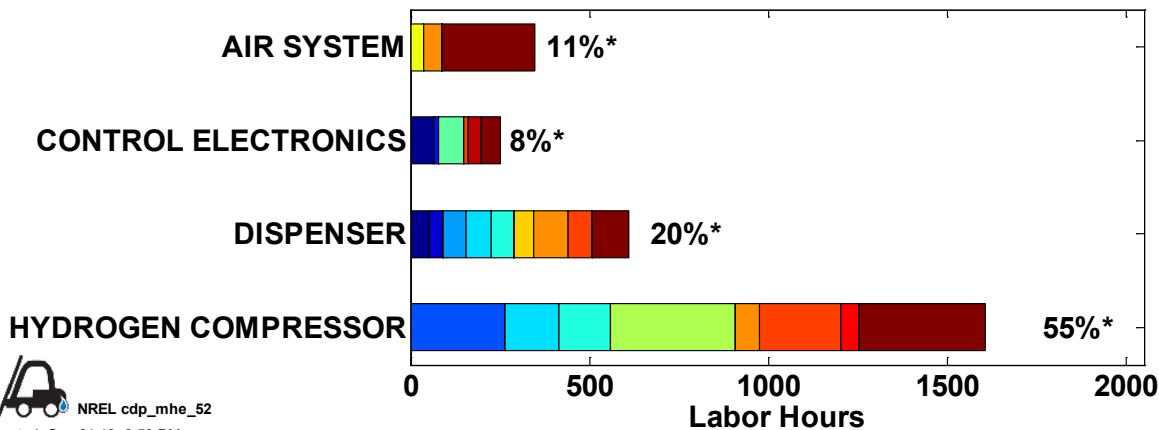
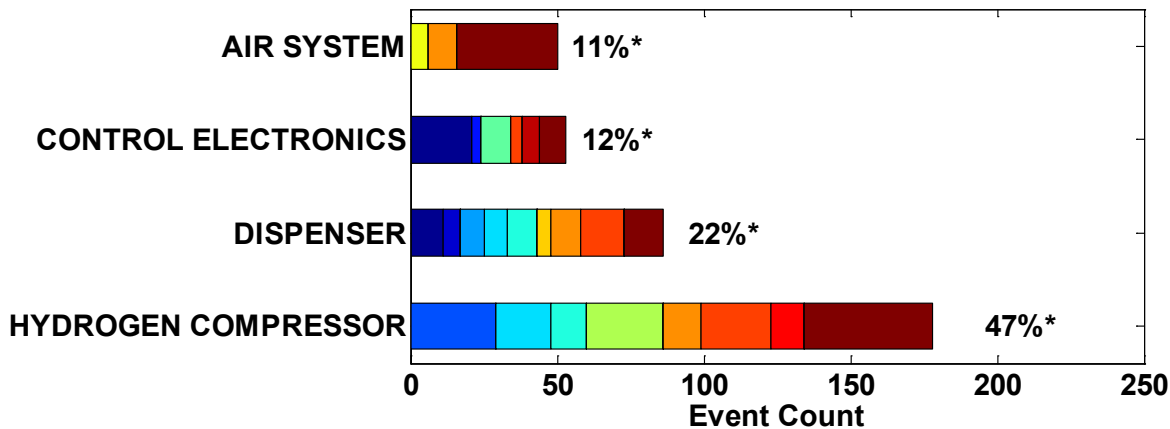
## Infrastructure Hydrogen Leaks by Equipment Type

Hydrogen Leaks By Equipment Category: Infrastructure



## Infrastructure Failures by Mode

Failure Modes for Top Four Infrastructure Equipment Categories

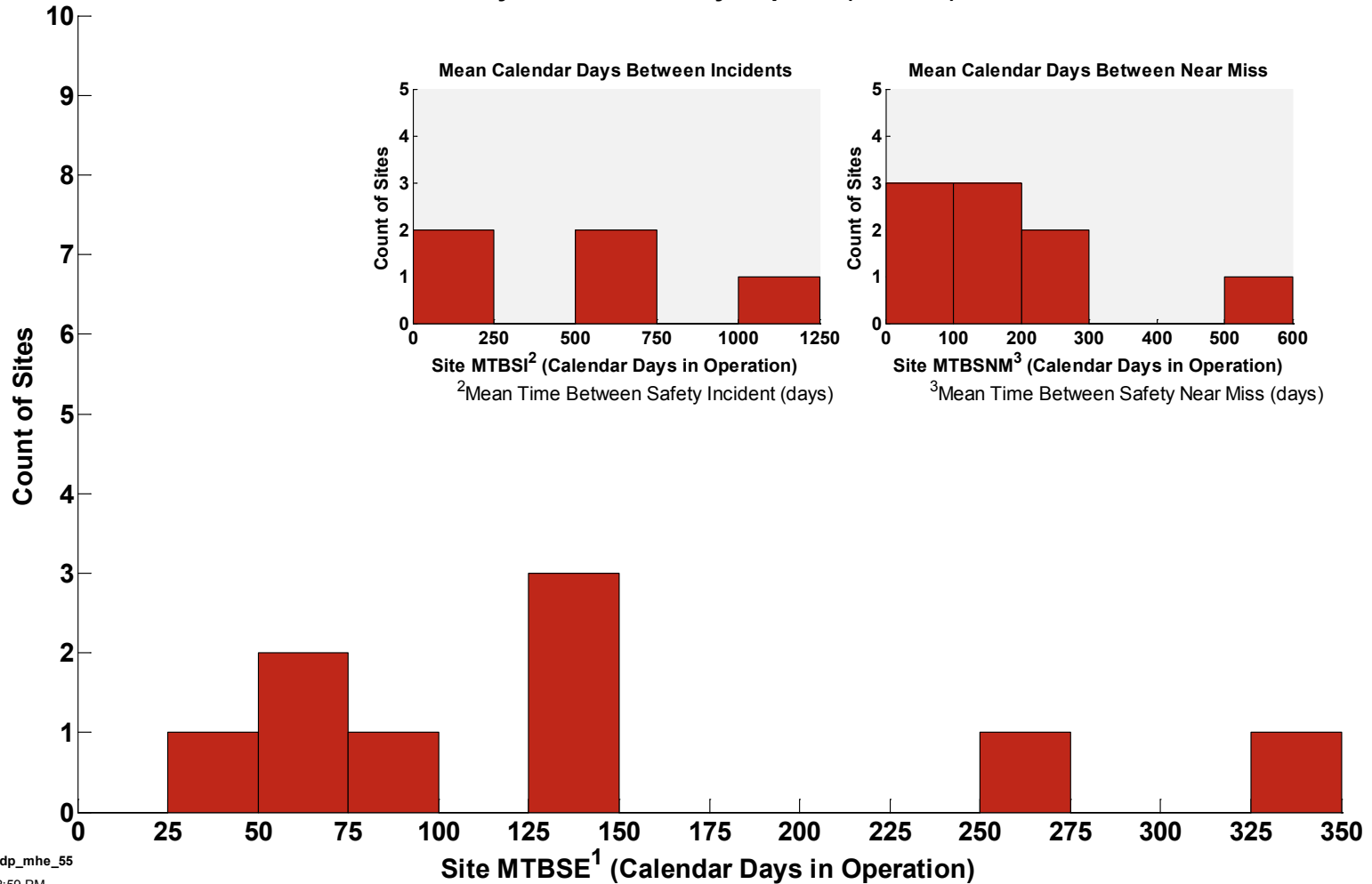


MISC includes the following failure modes: ambient temperature too low, broken wire, cavitation, debris infiltration, failed closed, flow high, flow low, fluid leak\_non\_hydrogen, inspect trouble alarm or report, maintenance error, manufacturing defect, metal fatigue, moisture infiltration, network malfunction, operator protocol, other, pressure high, software bug, vandalism, voltage low, other

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

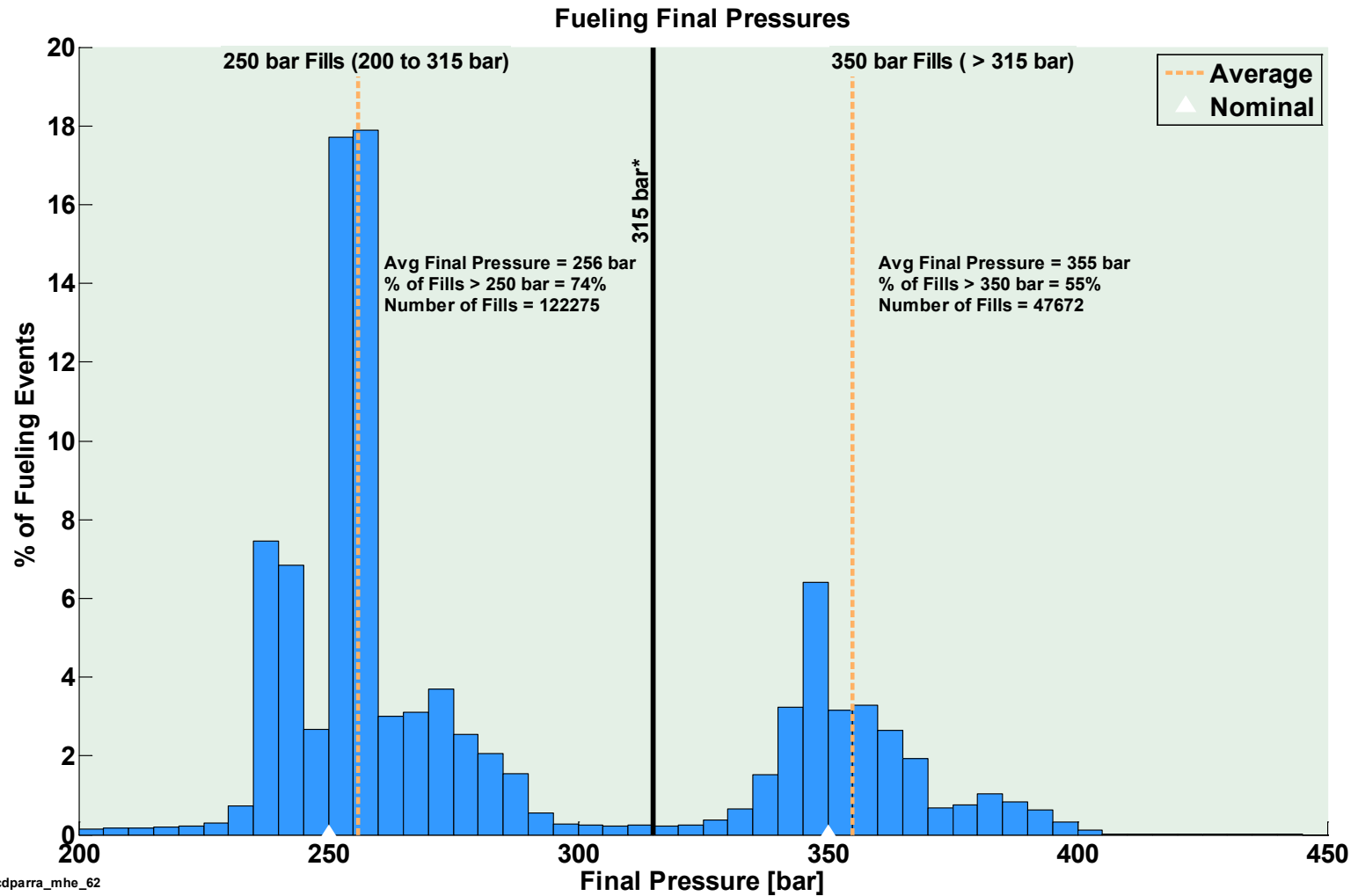


Mean Calendar Days Between Safety Reports (MTBSR): Infrastructure



1. Cumulative Mean Time Between Safety Report (days)

## Final Pressure of Hydrogen Fills

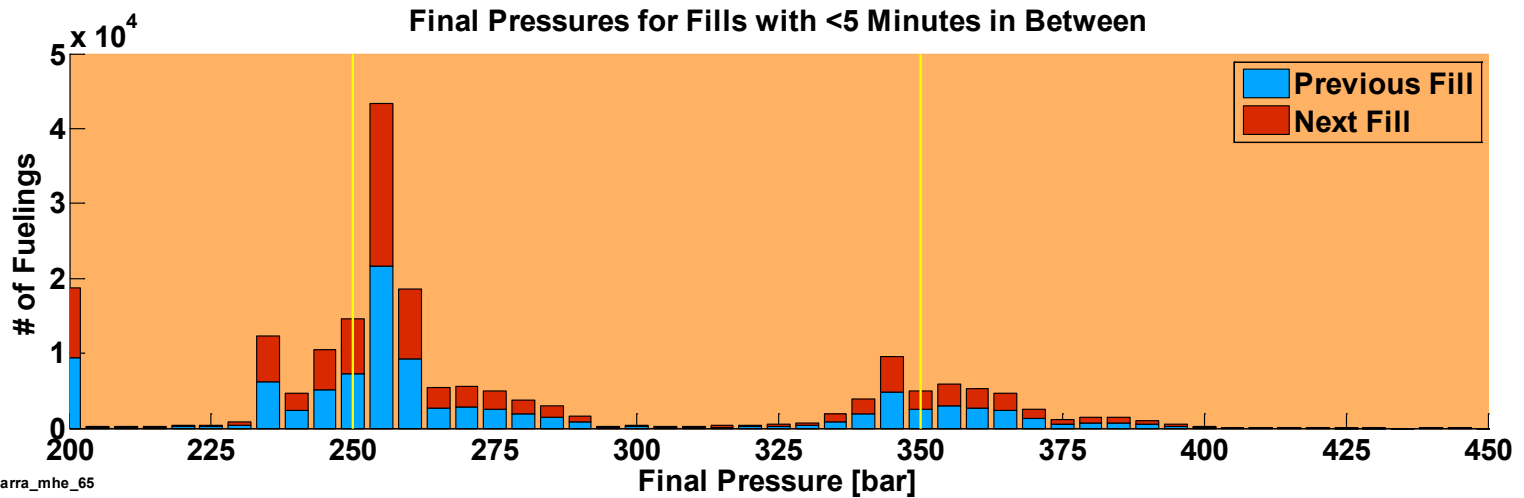
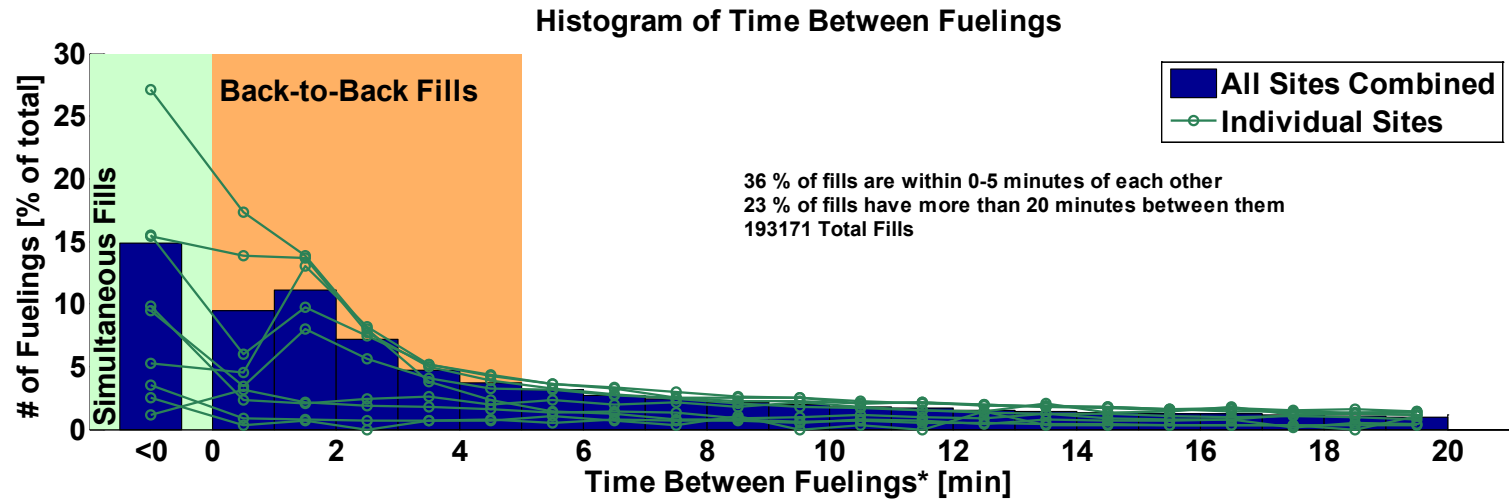


NREL cdparramhe\_62

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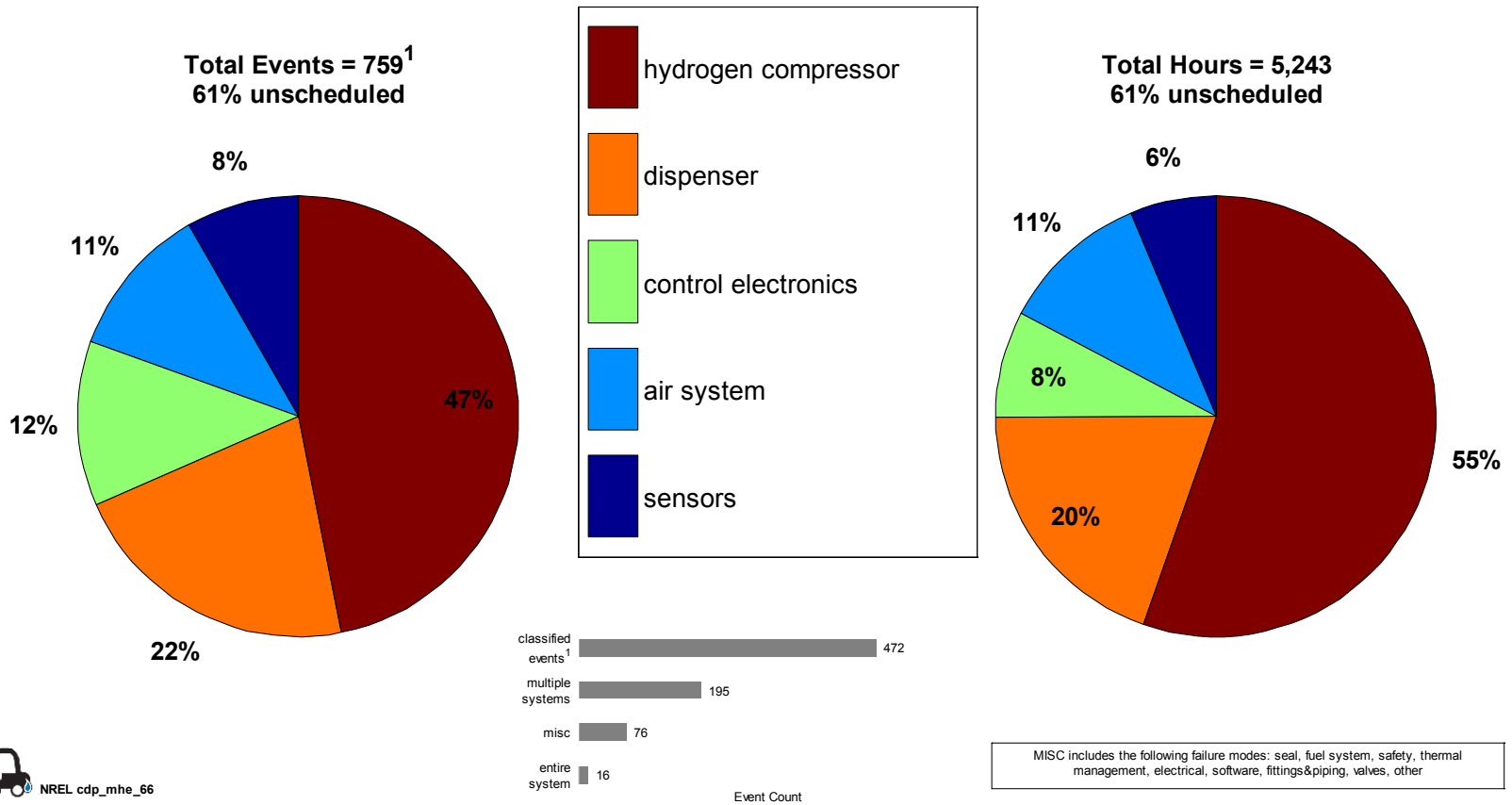
\*The line at 315 bar separates 250 bar fills from 350 bar fills. It is slightly over the allowable 125% of nominal pressure (312.5 bar) from SAE J2601.

## Details of Back-to-Back Fills



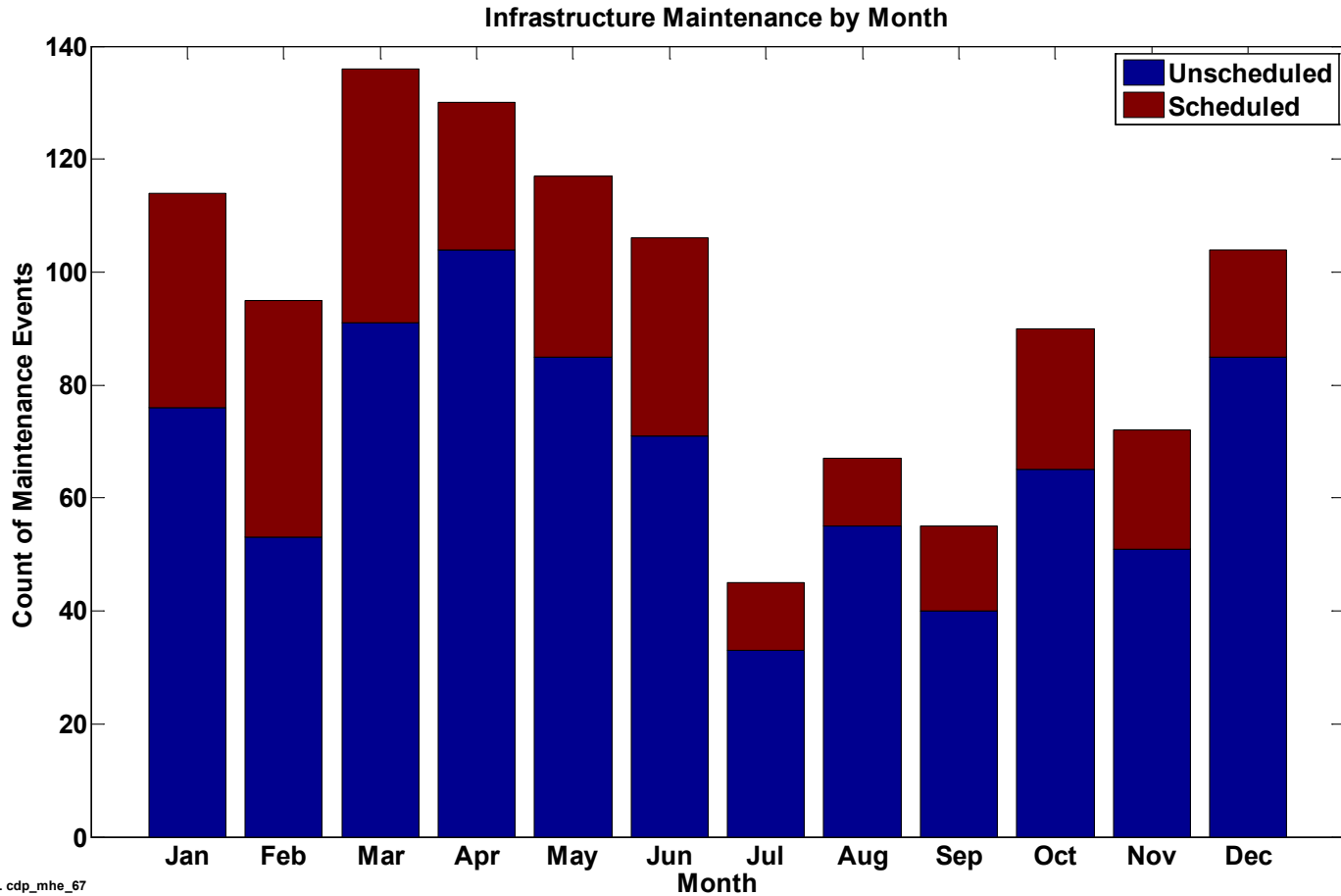
## Infrastructure Maintenance for Delivered Hydrogen

Delivered Hydrogen Infrastructure Maintenance By Equipment Type



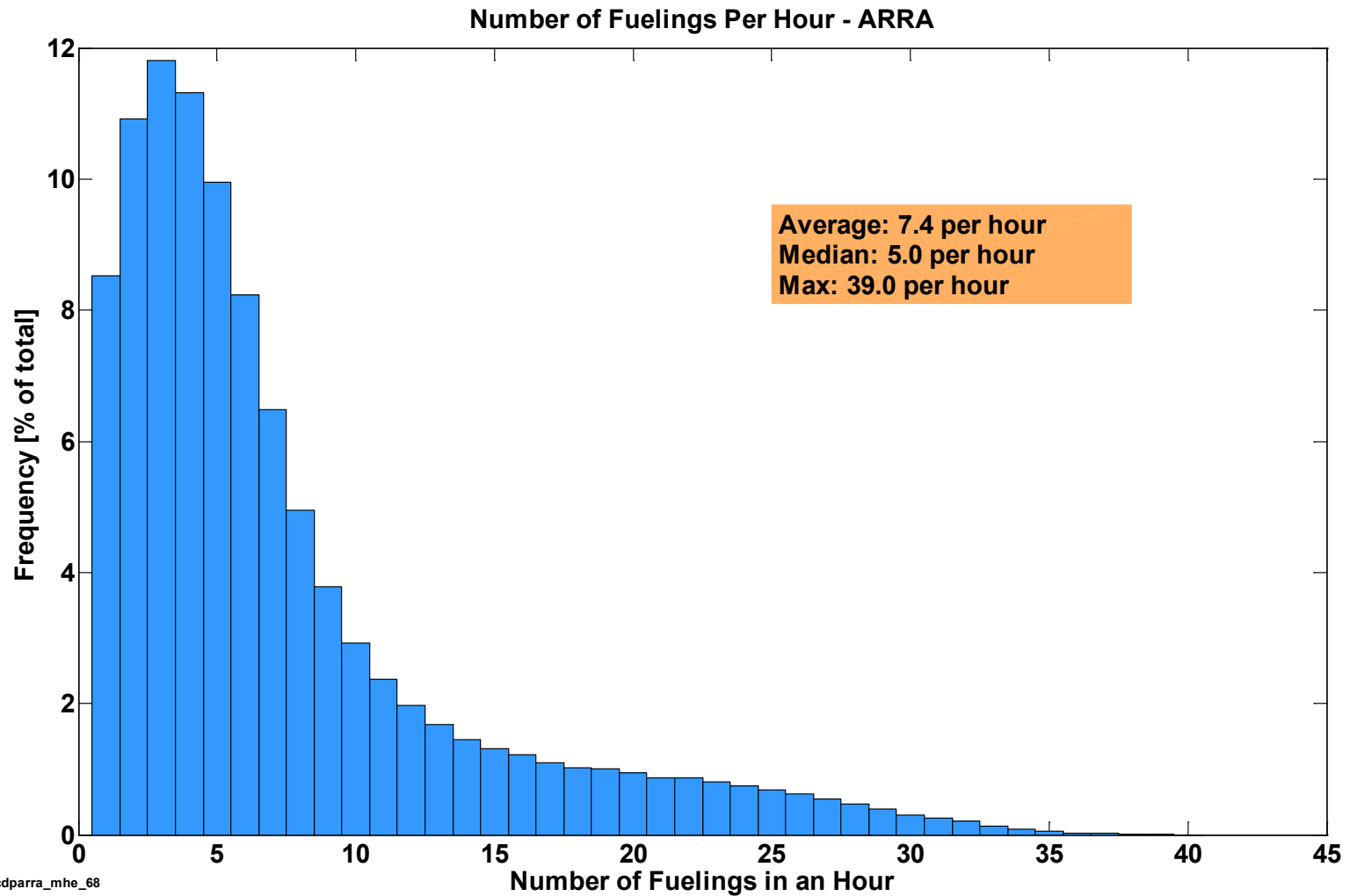


## Infrastructure Maintenance by Month



# CDPARRA-MHE-68

## Fill Counts per Hours



NREL cdparrar\_mhe\_68

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# CDPARRA-MHE-69

## Fill Amount per Hour

