



Technical Report
NREL/TP-5600-51577
April 2011

Spring 2011 Composite Data Products ARRA Material Handling Equipment

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Spring 2011 Composite Data Products ARRA Material Handling Equipment



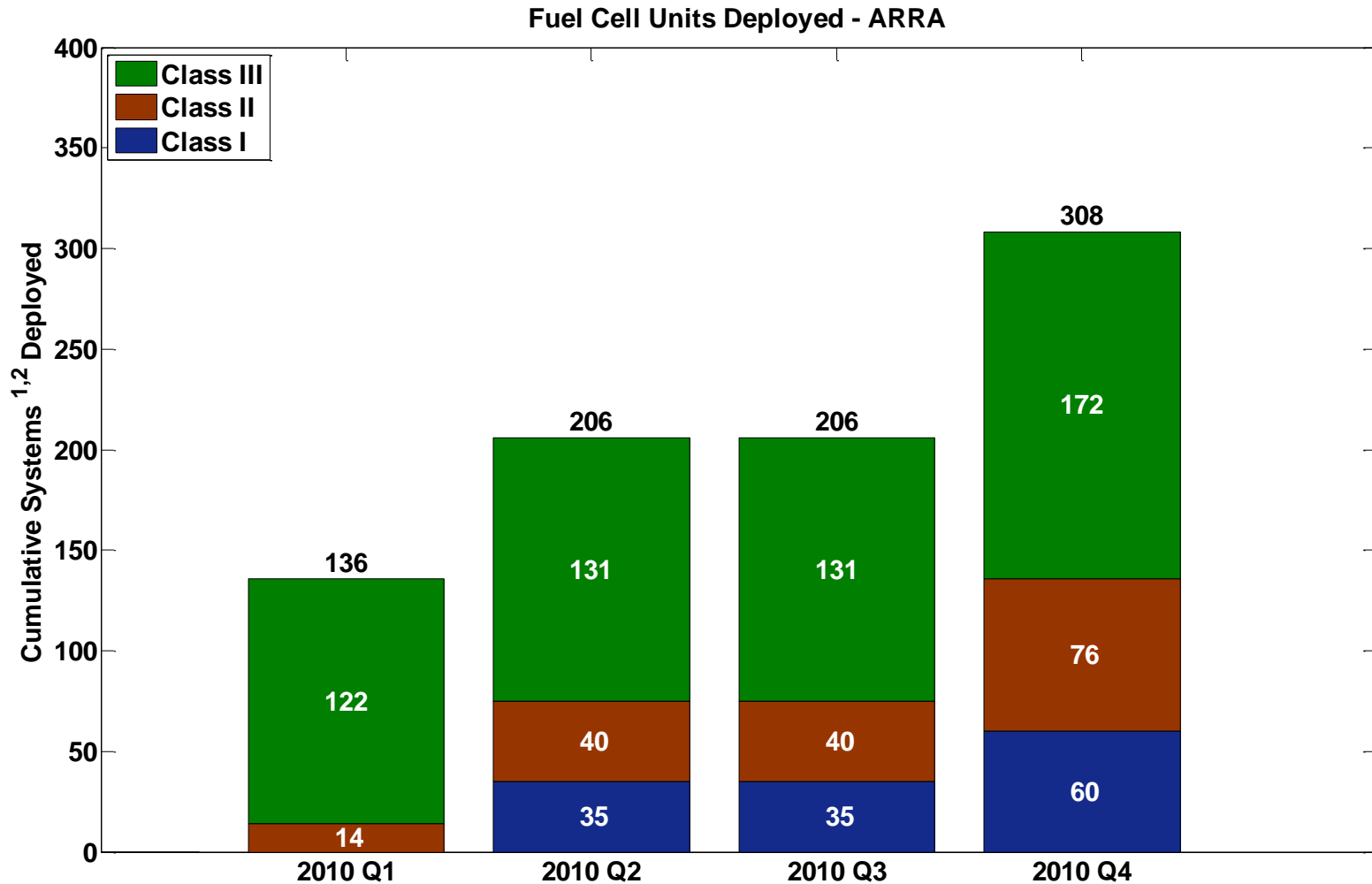
Jennifer Kurtz, Keith
Wipke, Sam Sprik, Todd
Ramsden, Chris
Ainscough, Genevieve
Saur

April 6th, 2011

TP-5600-51577

CDPARRA-MHE-01

Fuel Cell MHE Systems Deployed

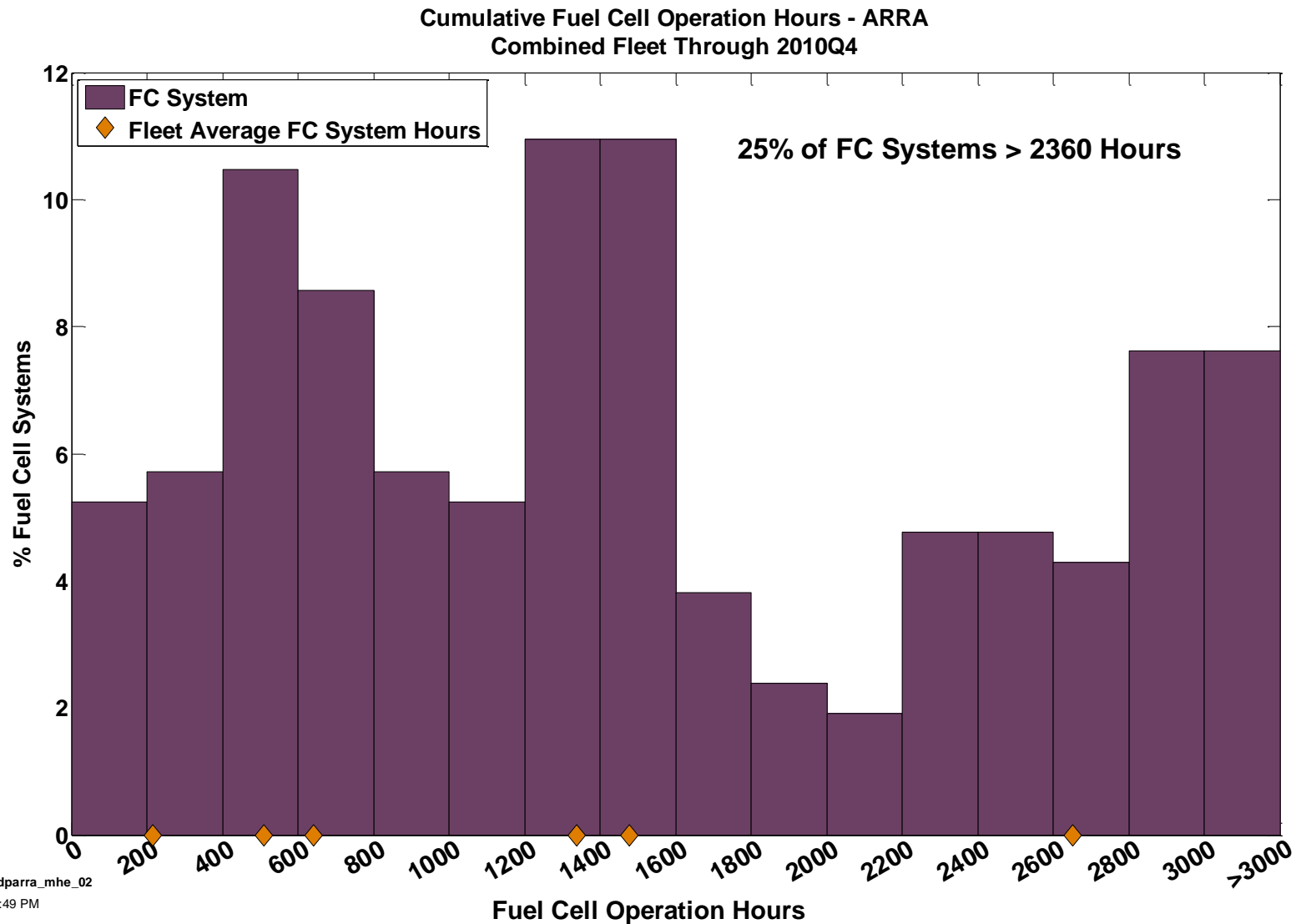


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CDPARRA-MHE-02

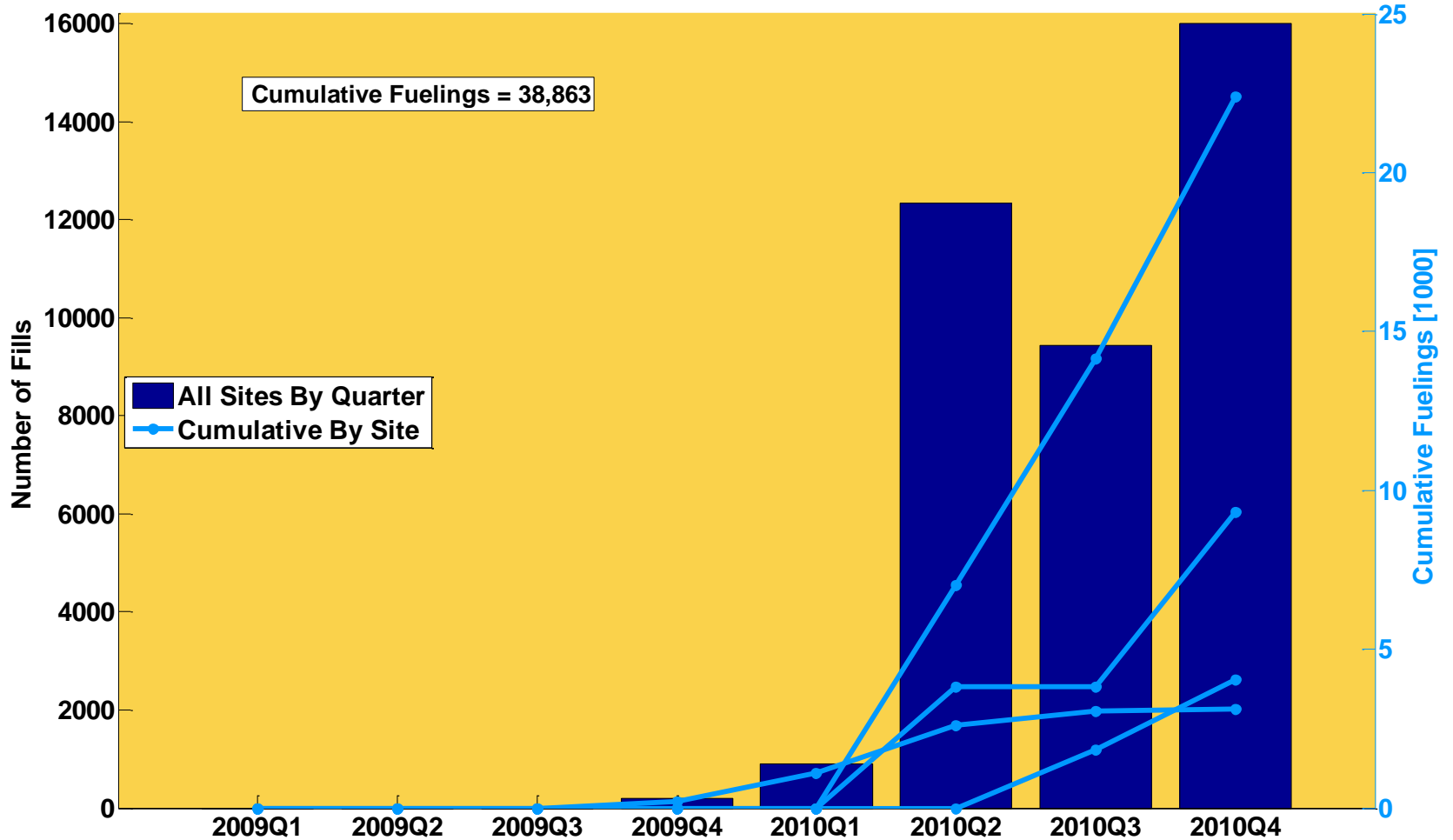
Fuel Cell System Operation Hours



CDPARRA-MHE-03

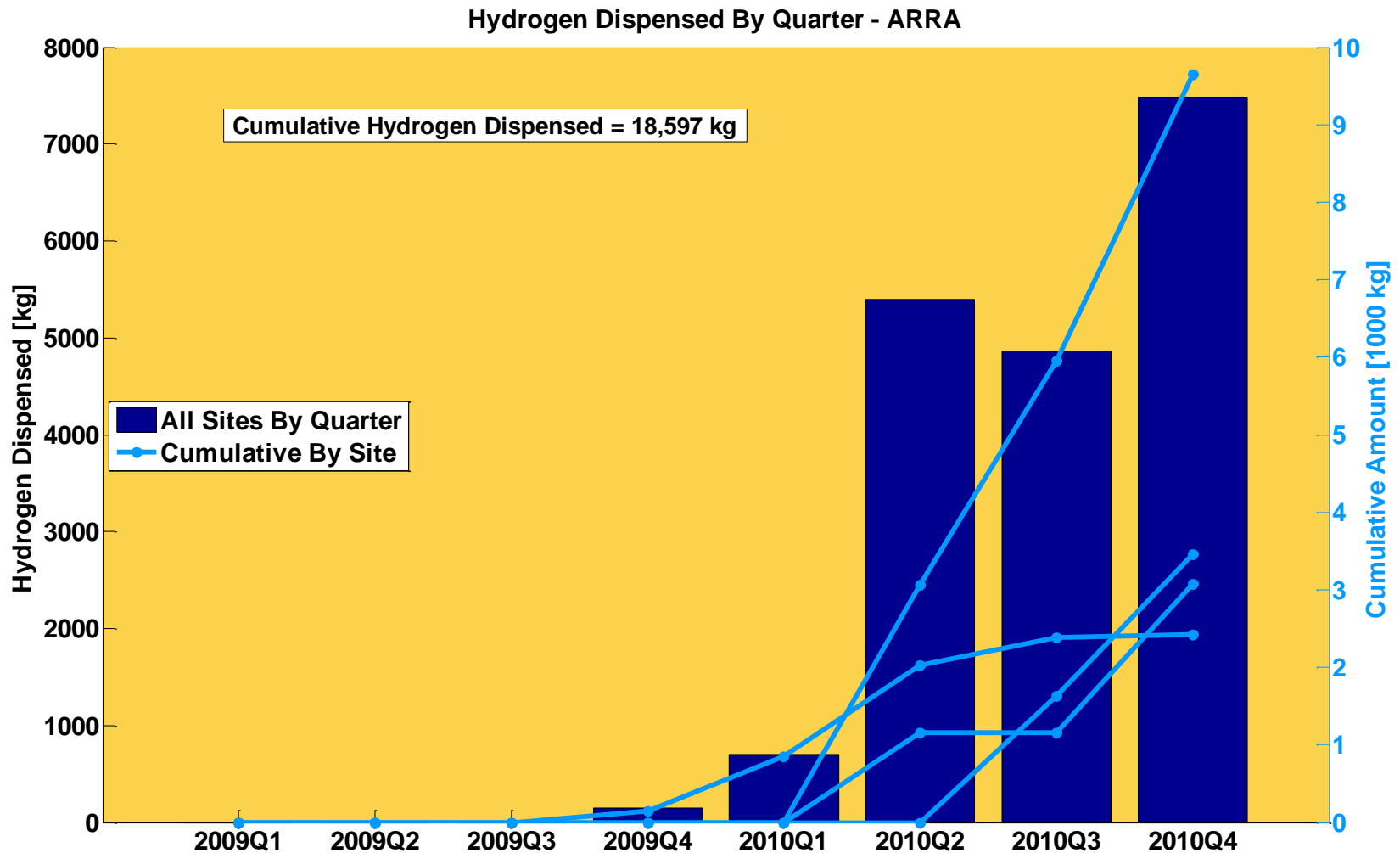
Fueling Events by Quarter

Fueling Events By Quarter - ARRA



CDPARRA-MHE-04

Hydrogen Dispensed by Quarter

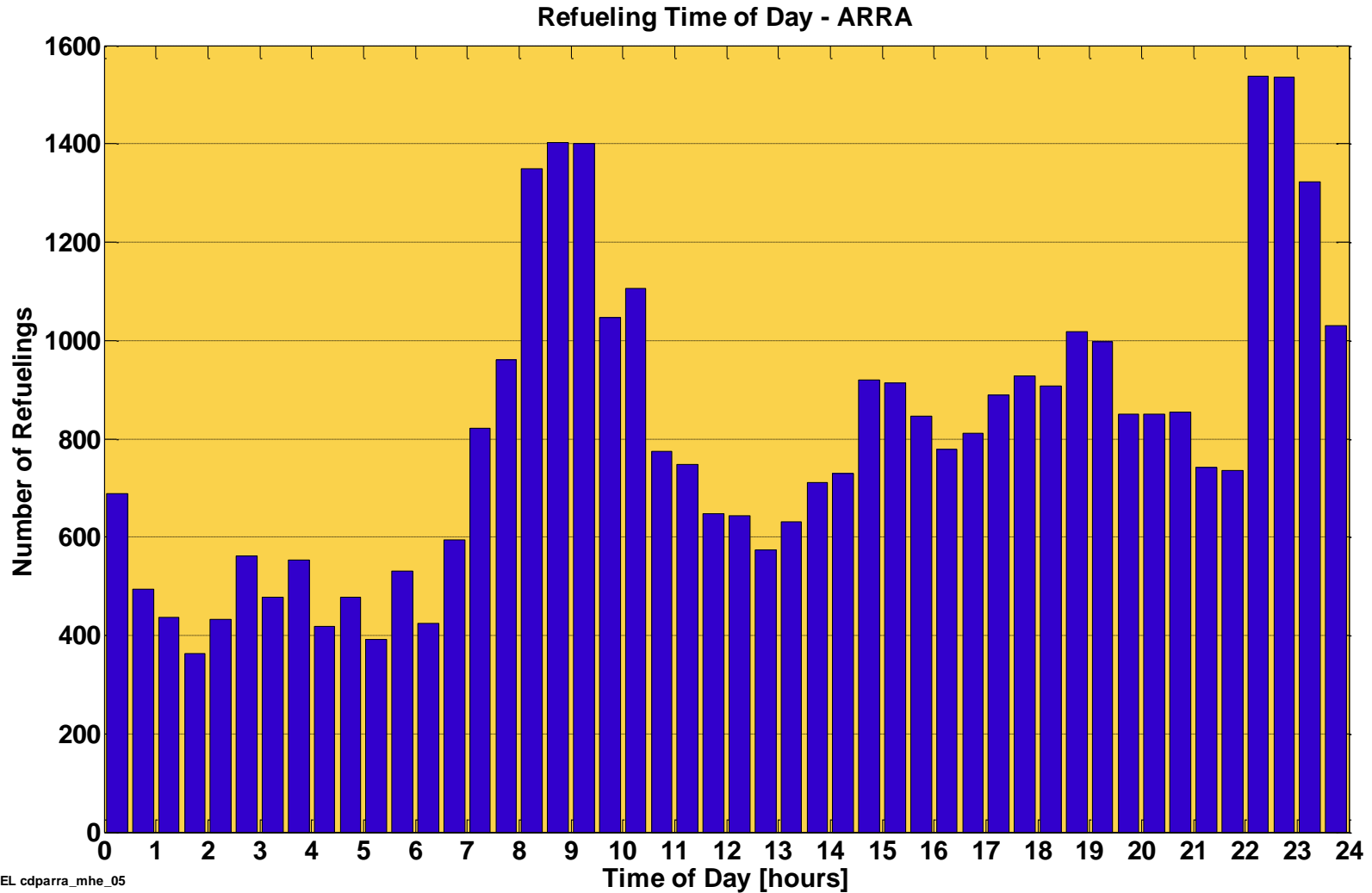


NREL cdparra_mhe_04

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CDPARRA-MHE-05

Refueling Time of Day



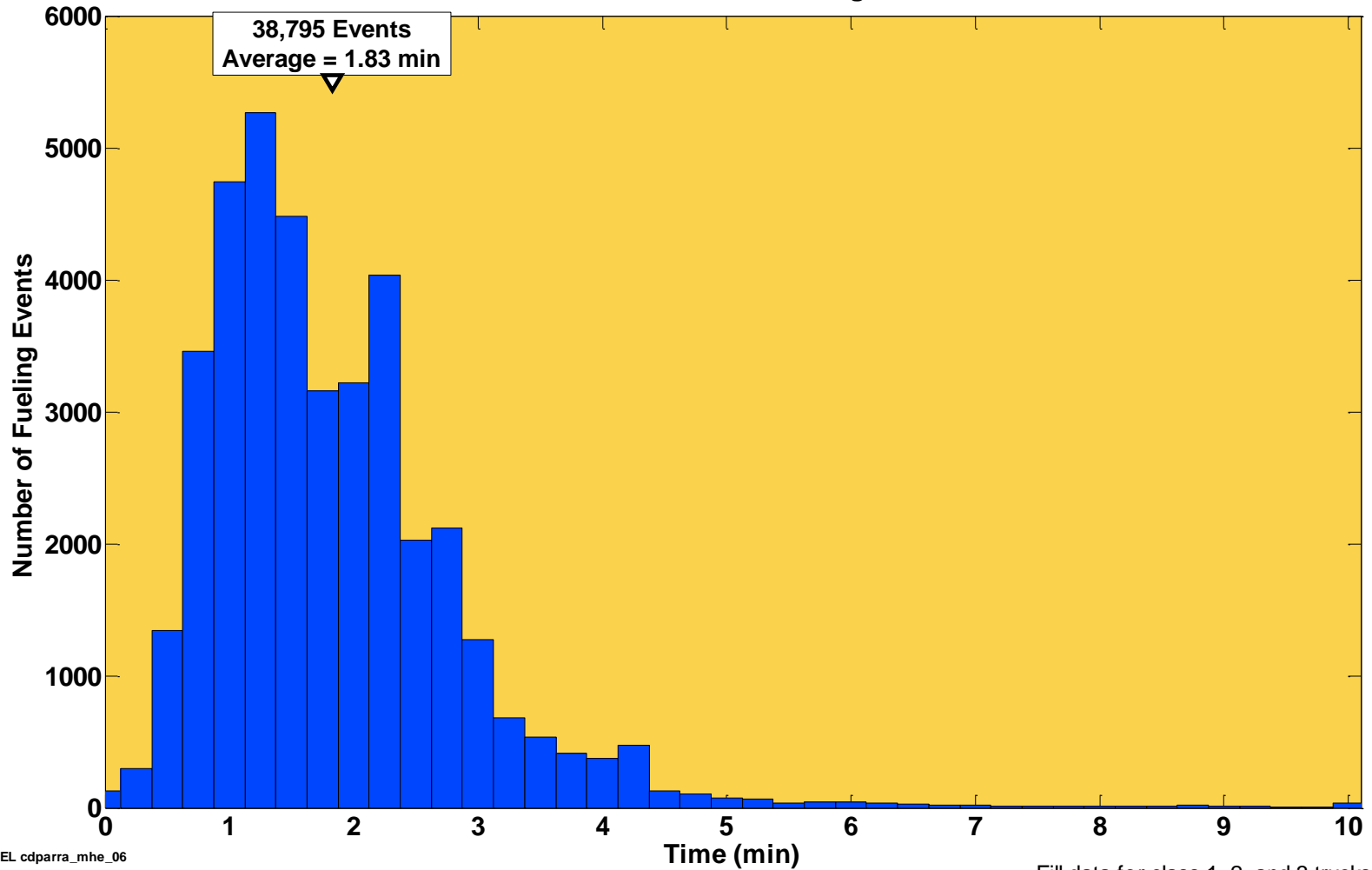
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CDPARRA-MHE-06

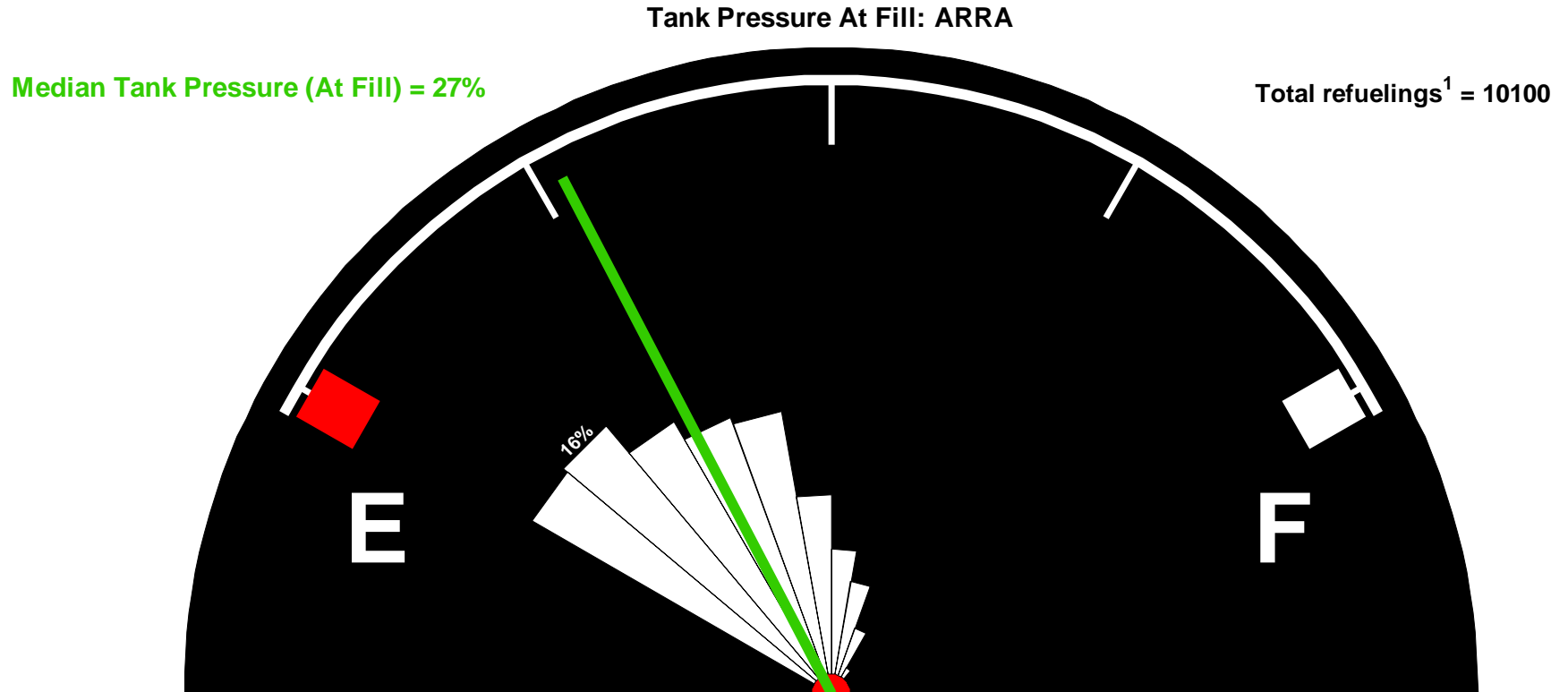
Histogram of Fueling Times

Histogram of Fueling Times
ARRA Combined Fleet Through 2010Q4



CDPARRA-MHE-07

Tank Pressure Level at Fueling

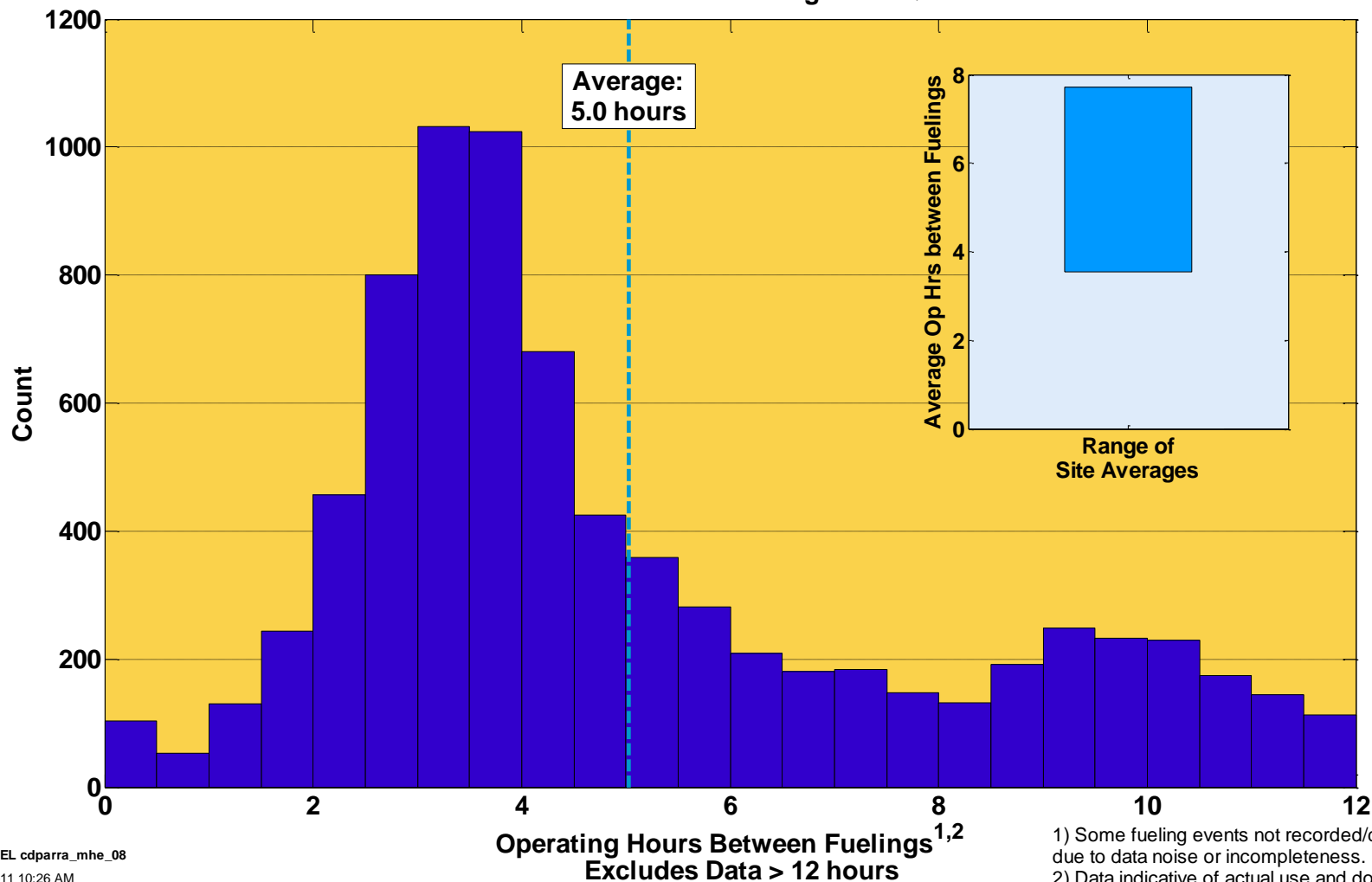


1. Some refueling events not recorded/detected due to data noise or incompleteness.
2. The outer arc is set at 30% total refuelings.
3. Full Pressure is either 3600 psi or 5000 psi.

CDPARRA-MHE-08

Operation Time between Fueling

Operating Time Between Fuelings - ARRA
Combined Fleet Through 2010Q4

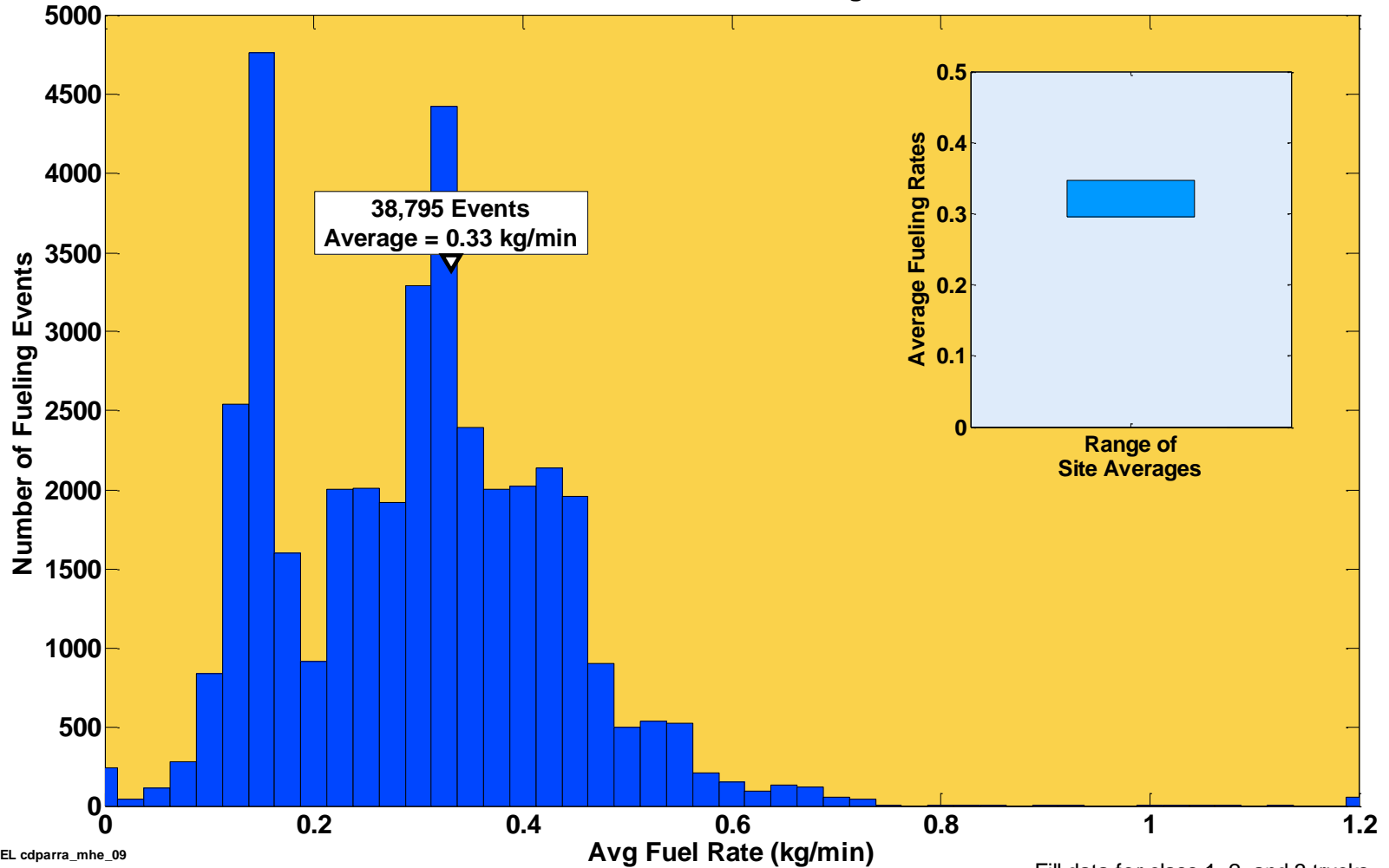


1) Some fueling events not recorded/detected due to data noise or incompleteness.
2) Data indicative of actual use and does not represent the max capability of the systems.

CDPARRA-MHE-09

Histogram of Fueling Rates

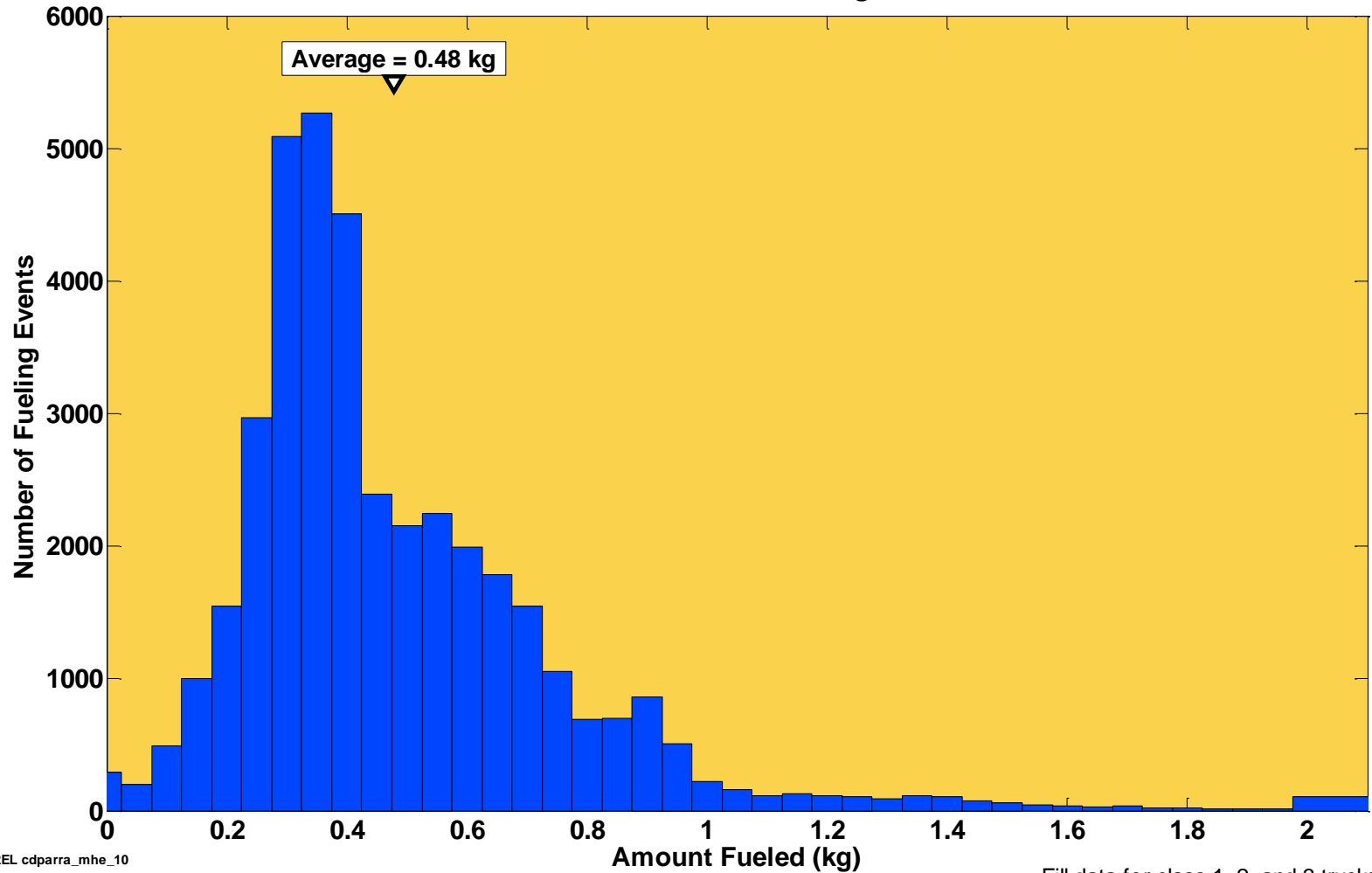
Histogram of Fueling Rates
ARRA Combined Fleet Through 2010Q4



CDPARRA-MHE-10

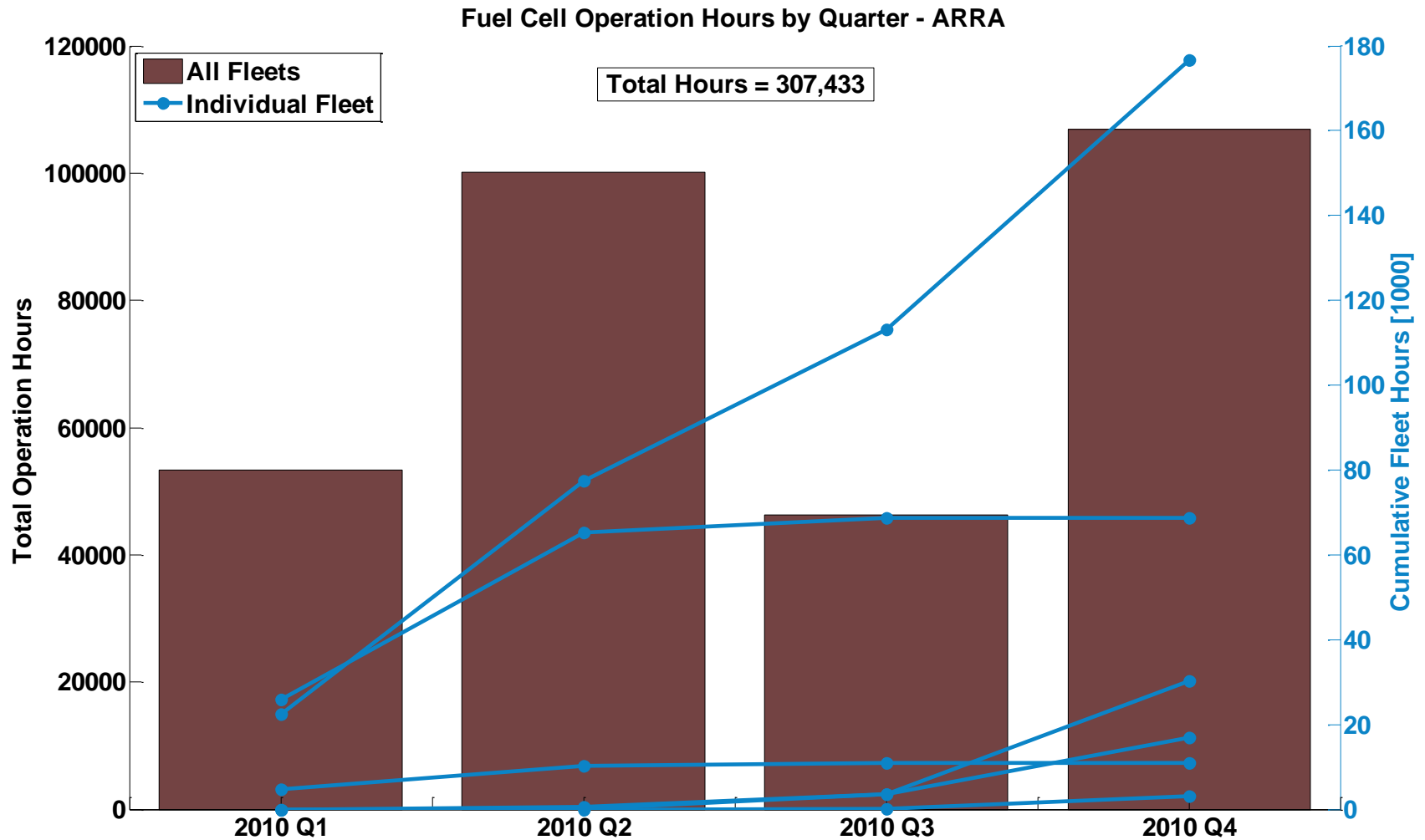
Histogram of Fueling Amounts

Histogram of Fueling Amounts
ARRA Combined Fleet Through 2010Q4



CDPARRA-MHE-11

Fuel Cell Operation Hours by Quarter



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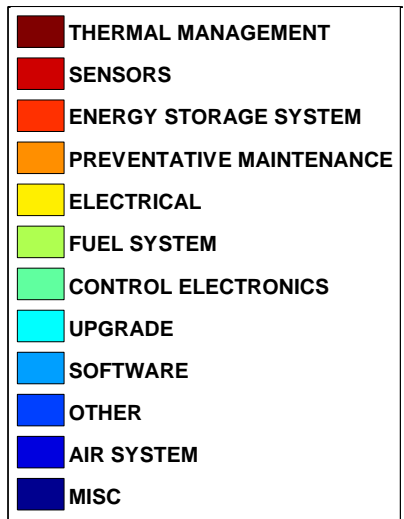
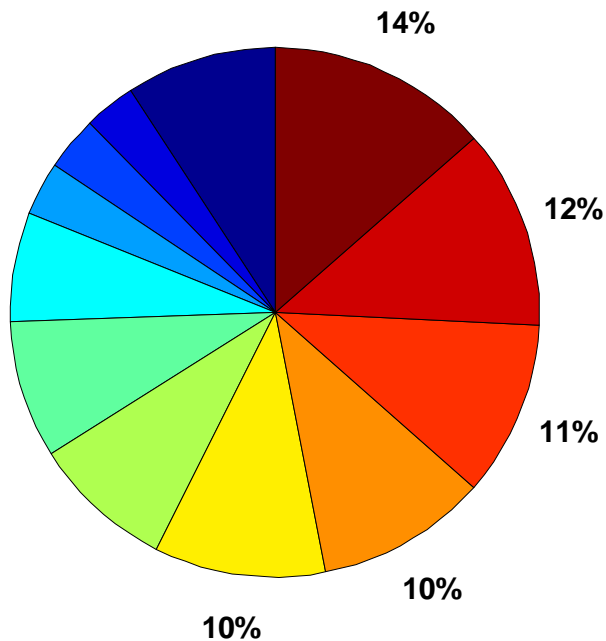
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CDPARRA-MHE-12

Fuel Cell System Maintenance by Category

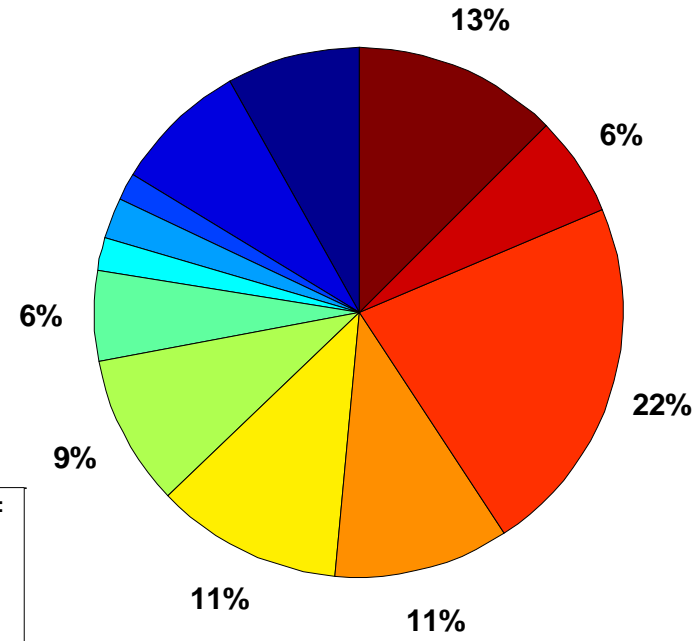
Fuel Cell System Maintenance By Category - ARRA
All ARRA Sites Thru 2010Q4

Number of Events
Total Events = 1149
83% were unscheduled



MISC includes the following categories:
FC STACK
MANUFACTURING DEFECT
VALVES
ACTUATORS
SERVICE
OPERATOR PROTOCOL

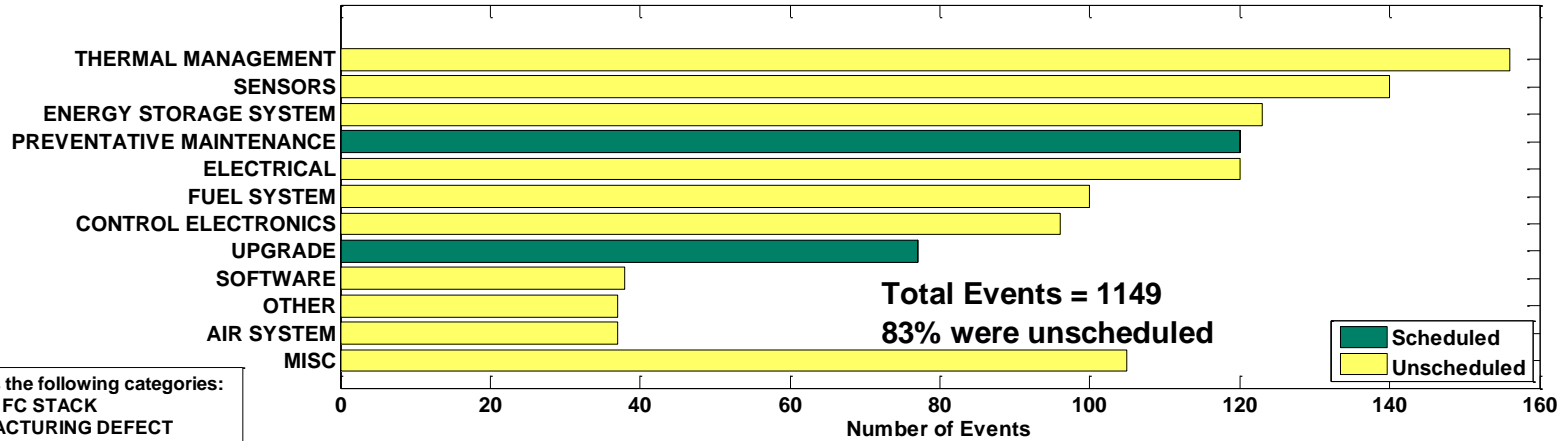
Labor Hours
Total Hours = 1676
87% were unscheduled



CDPARRA-MHE-13

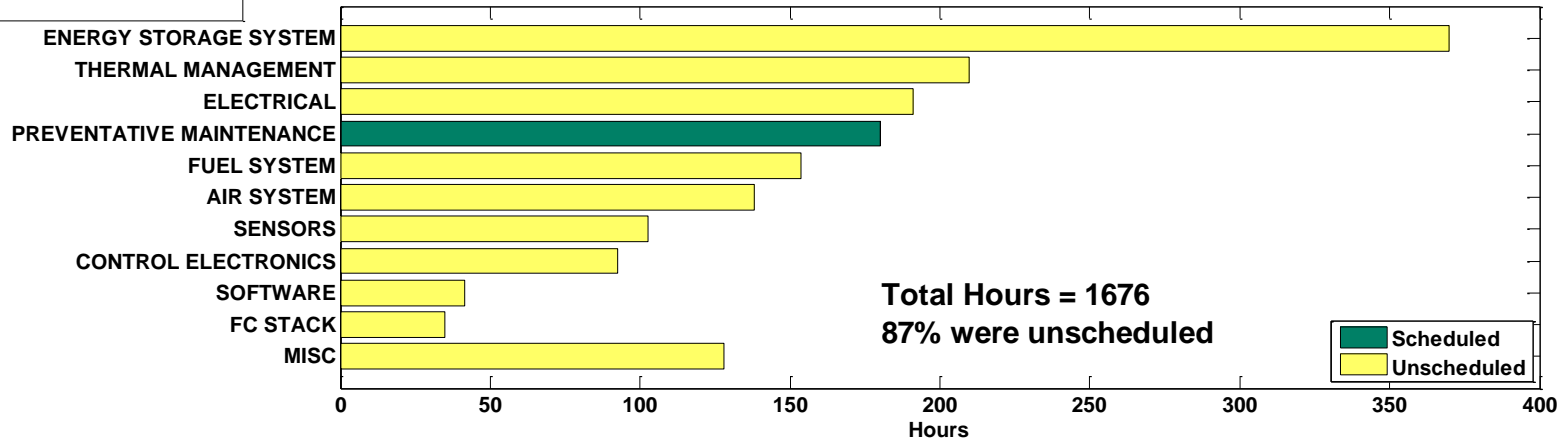
Fuel Cell System Scheduled and Unscheduled Maintenance by Category

Fuel Cell System Maintenance Scheduled vs. Unscheduled - ARRA
Number of Maintenance Events by Category



MISC includes the following categories:
FC STACK
MANUFACTURING DEFECT
VALVES
ACTUATORS
SERVICE
OPERATOR PROTOCOL

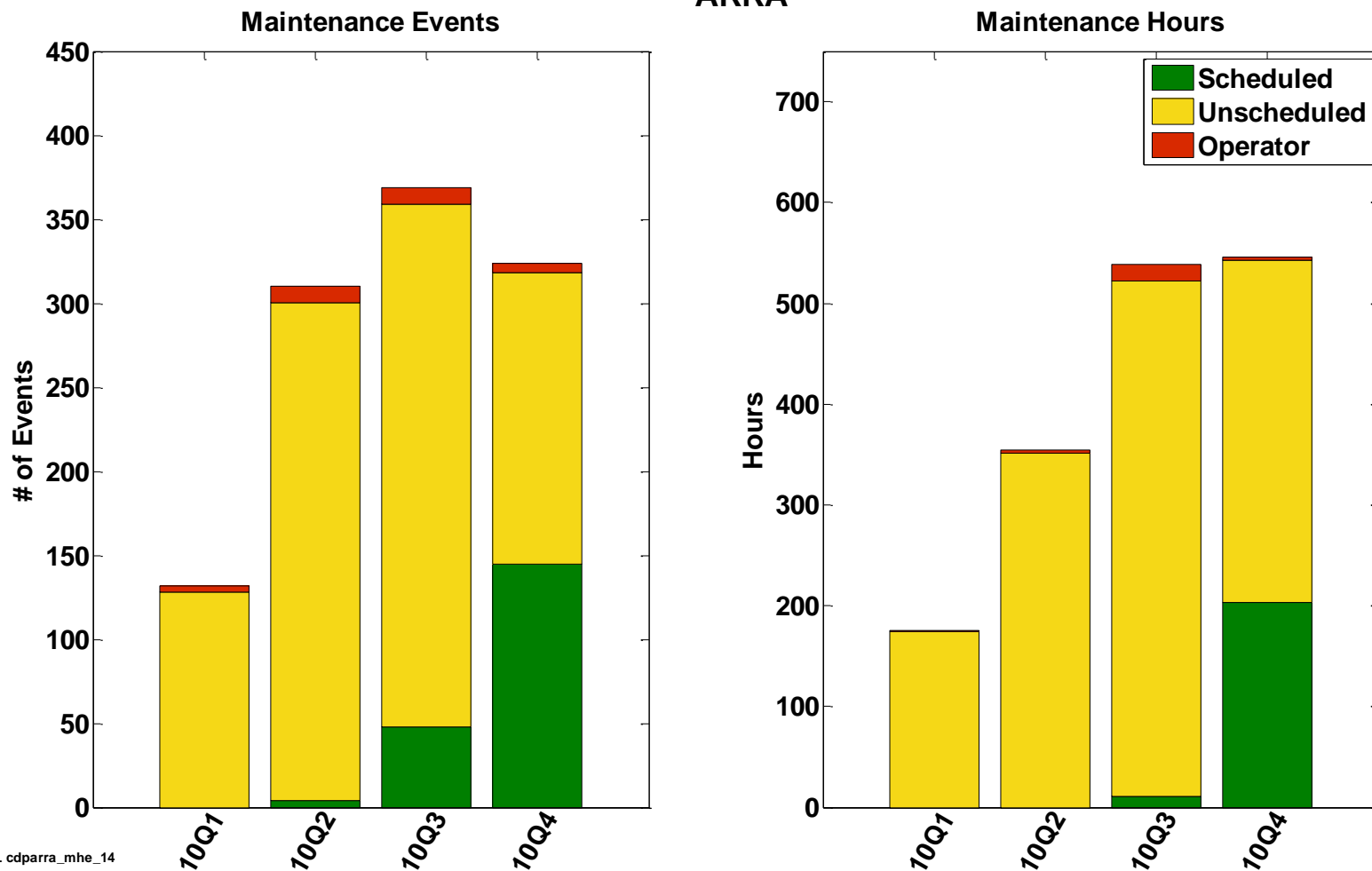
Number of Labor Hours by Category



CDPARRA-MHE-14

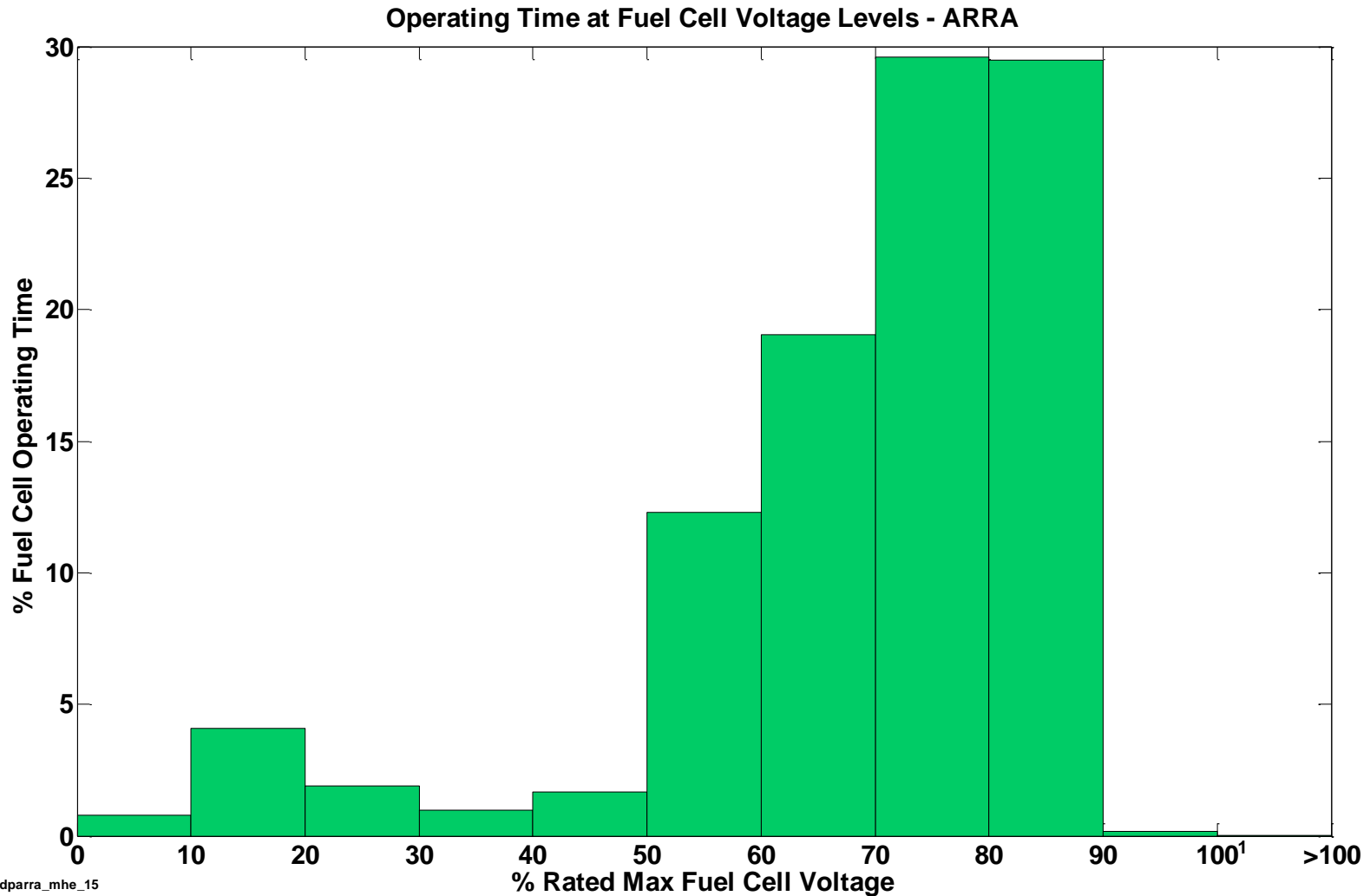
Average Fuel Cell System Maintenance by Quarter

Average Fuel Cell System Quarterly Maintenance - ARRA



CDPARRA-MHE-15

Operating Time at Fuel Cell Voltage Levels



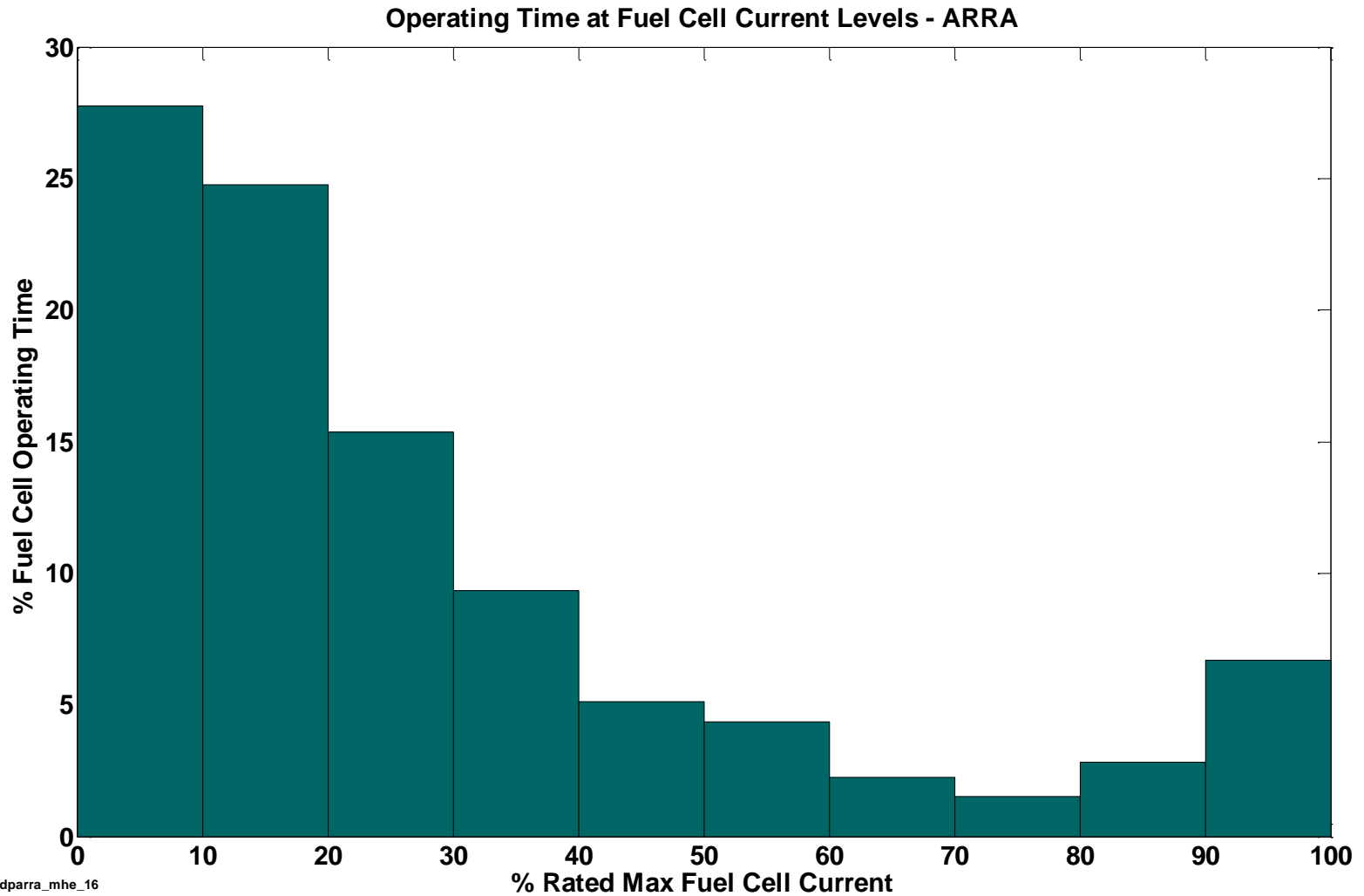
NREL cdparr_mhe_15

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

CDPARRA-MHE-16

Operating Time at Fuel Cell Current Levels

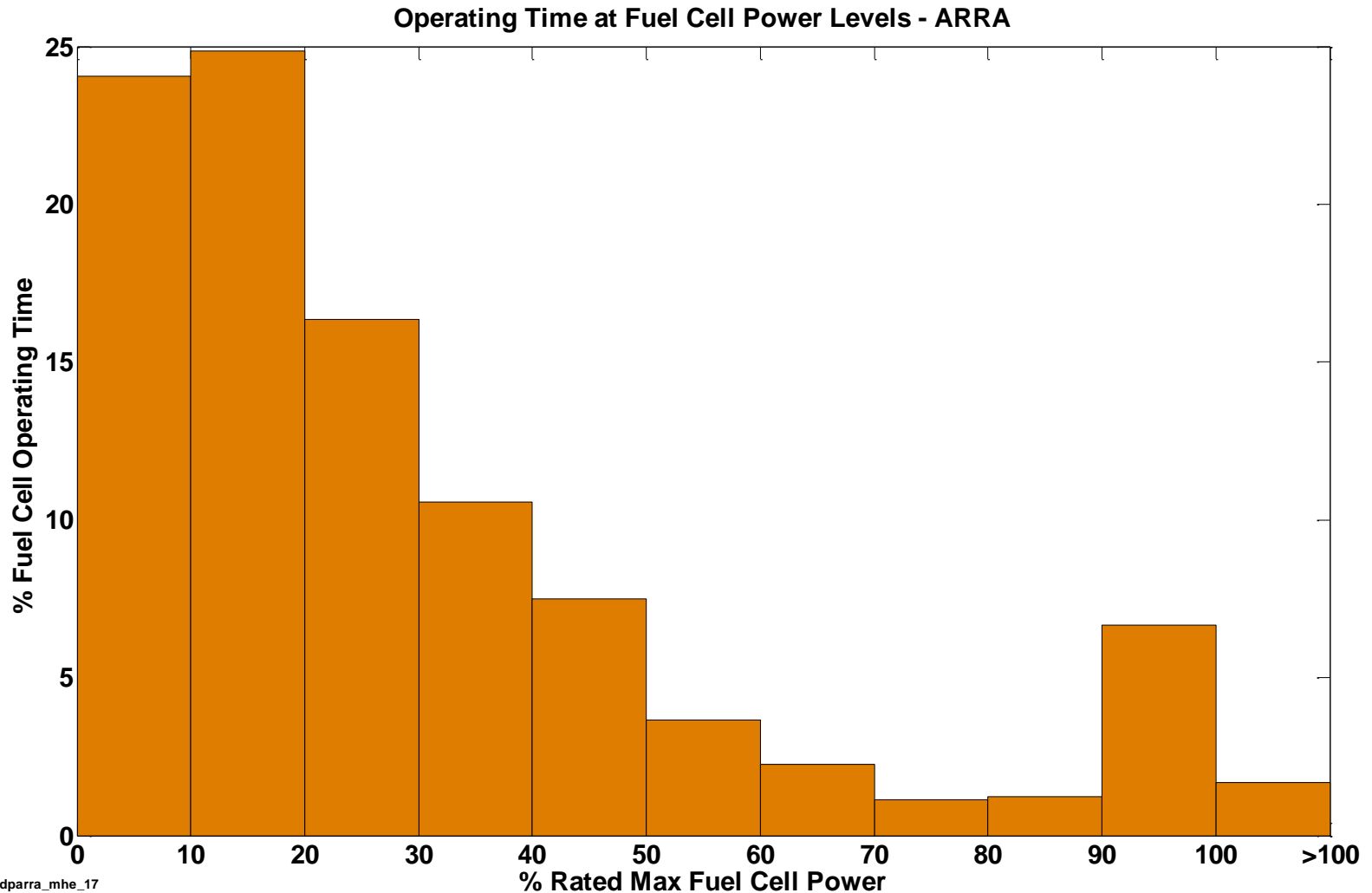


NREL cdparramhe_16

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CDPARRA-MHE-17

Operating Time at Fuel Cell Power Levels



NREL cdparra_mhe_17

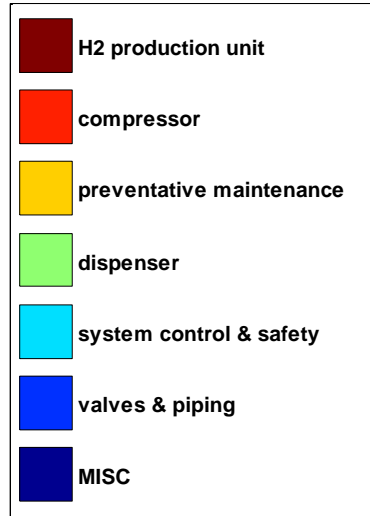
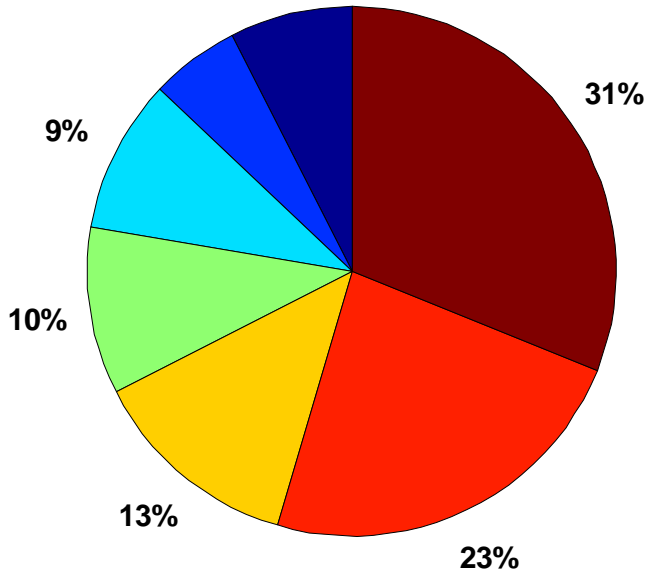
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CDP-MHE-18

Infrastructure Maintenance by Category

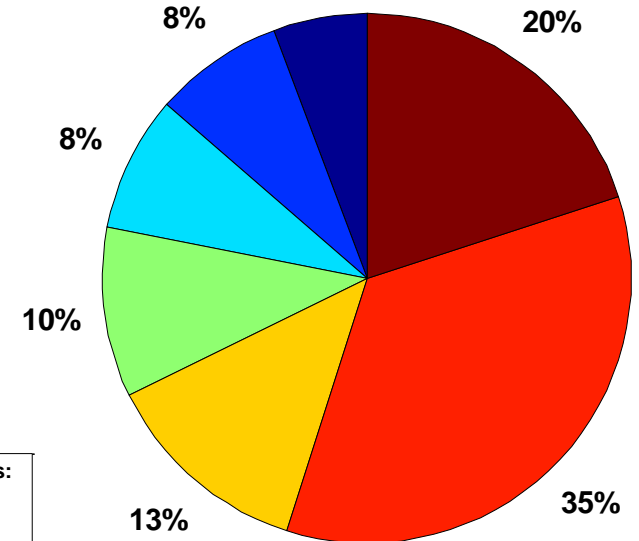
Infrastructure Maintenance By Category
All Sites Thru 2010Q4

Number of Events
Total Events = 363
87% were unscheduled



MISC includes the following categories:
Data collection
electrical
other
storage

Labor Hours
Total Hours = 2427
87% were unscheduled



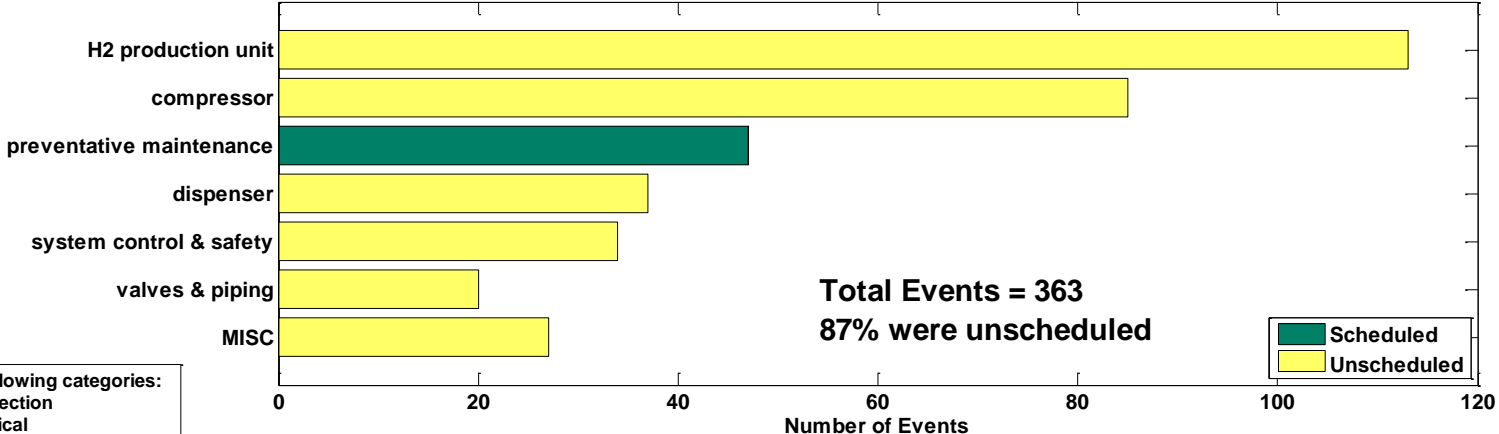
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CDP-MHE-19

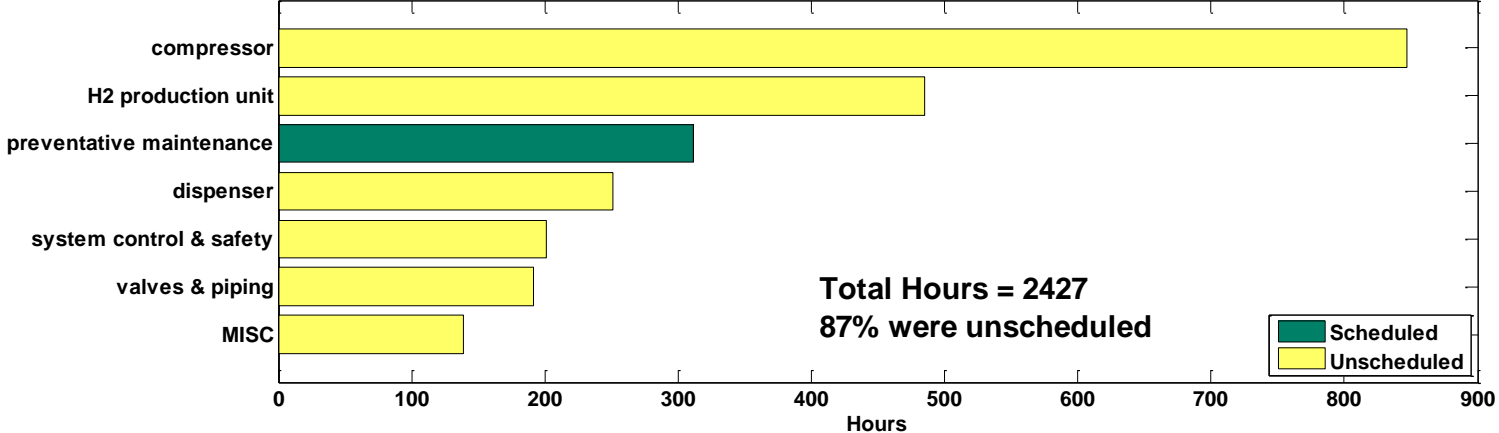
Infrastructure Scheduled & Unscheduled Maintenance by Category

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



MISC includes the following categories:
Data collection
electrical
other
storage

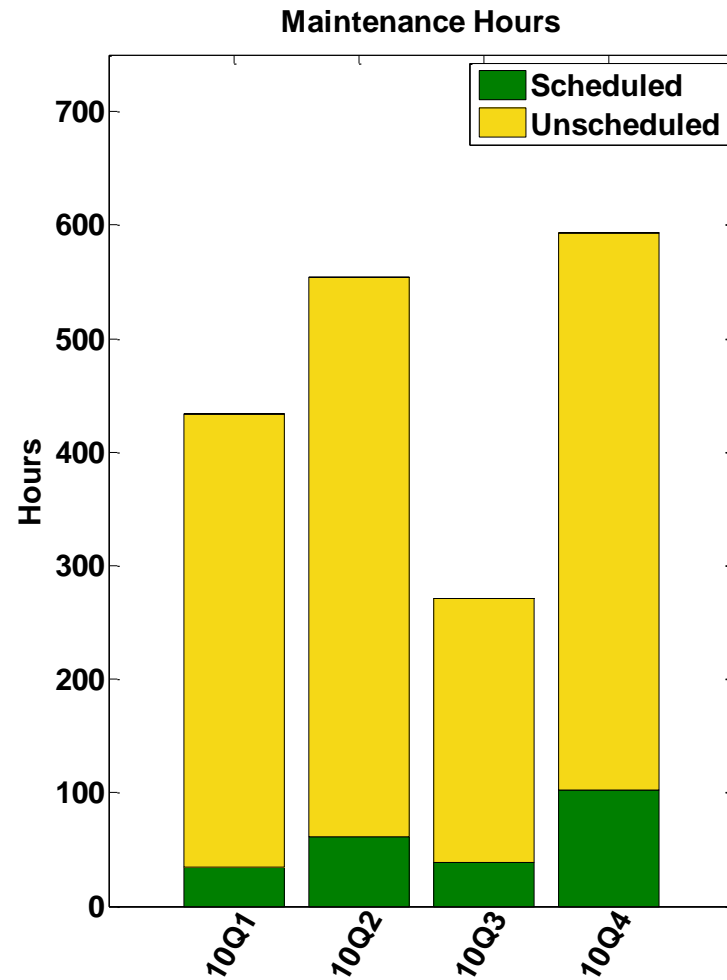
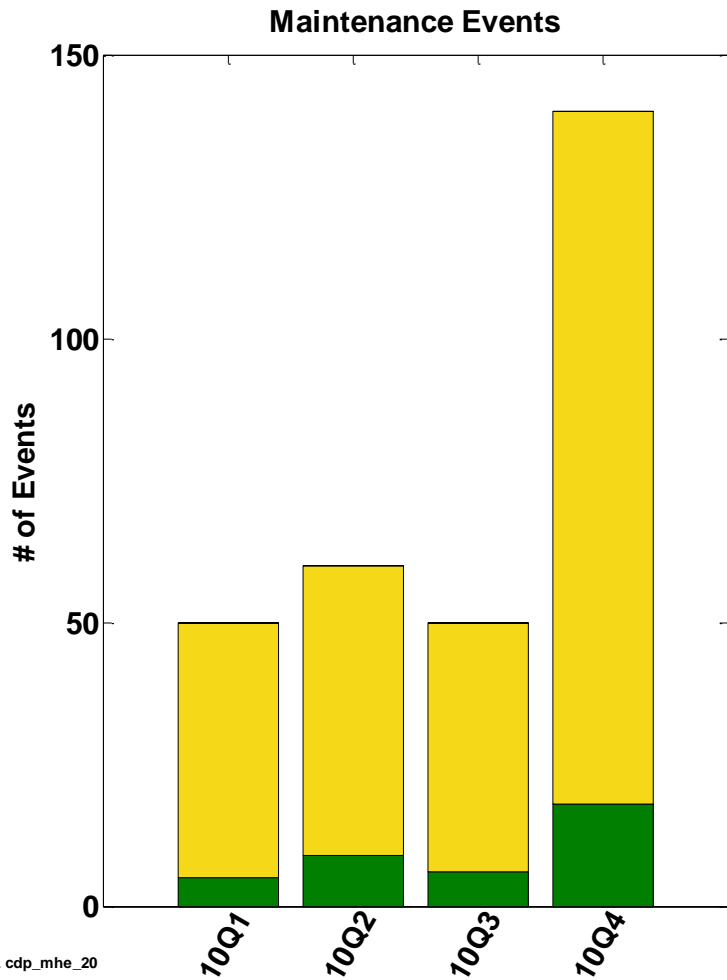
Number of Labor Hours by Category



CDP-MHE-20

Infrastructure Maintenance by Quarter

Average Infrastructure Site Quarterly Maintenance

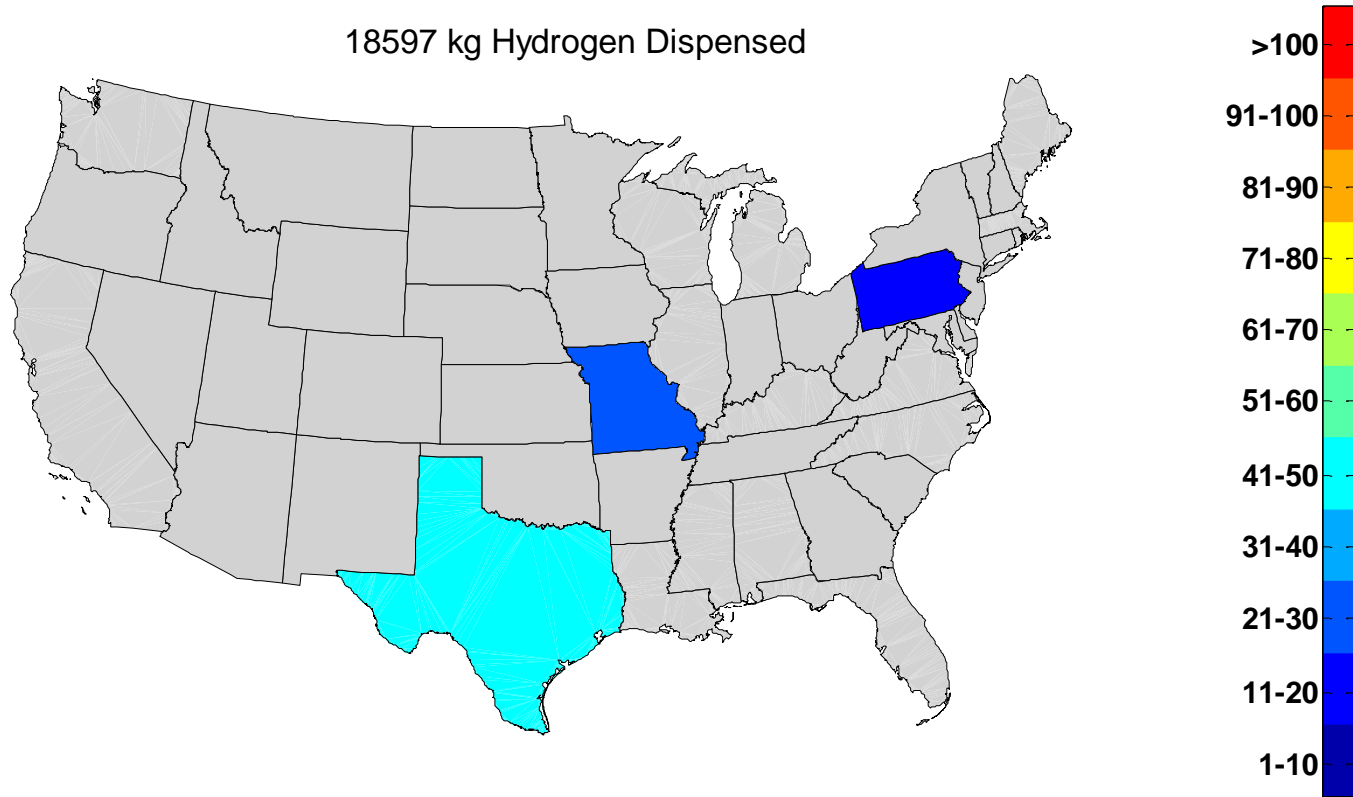


CDPARRA-MHE-21

Average Daily Hydrogen Dispensed by Location

Average Daily Hydrogen Dispensed by Location - ARRA

18597 kg Hydrogen Dispensed



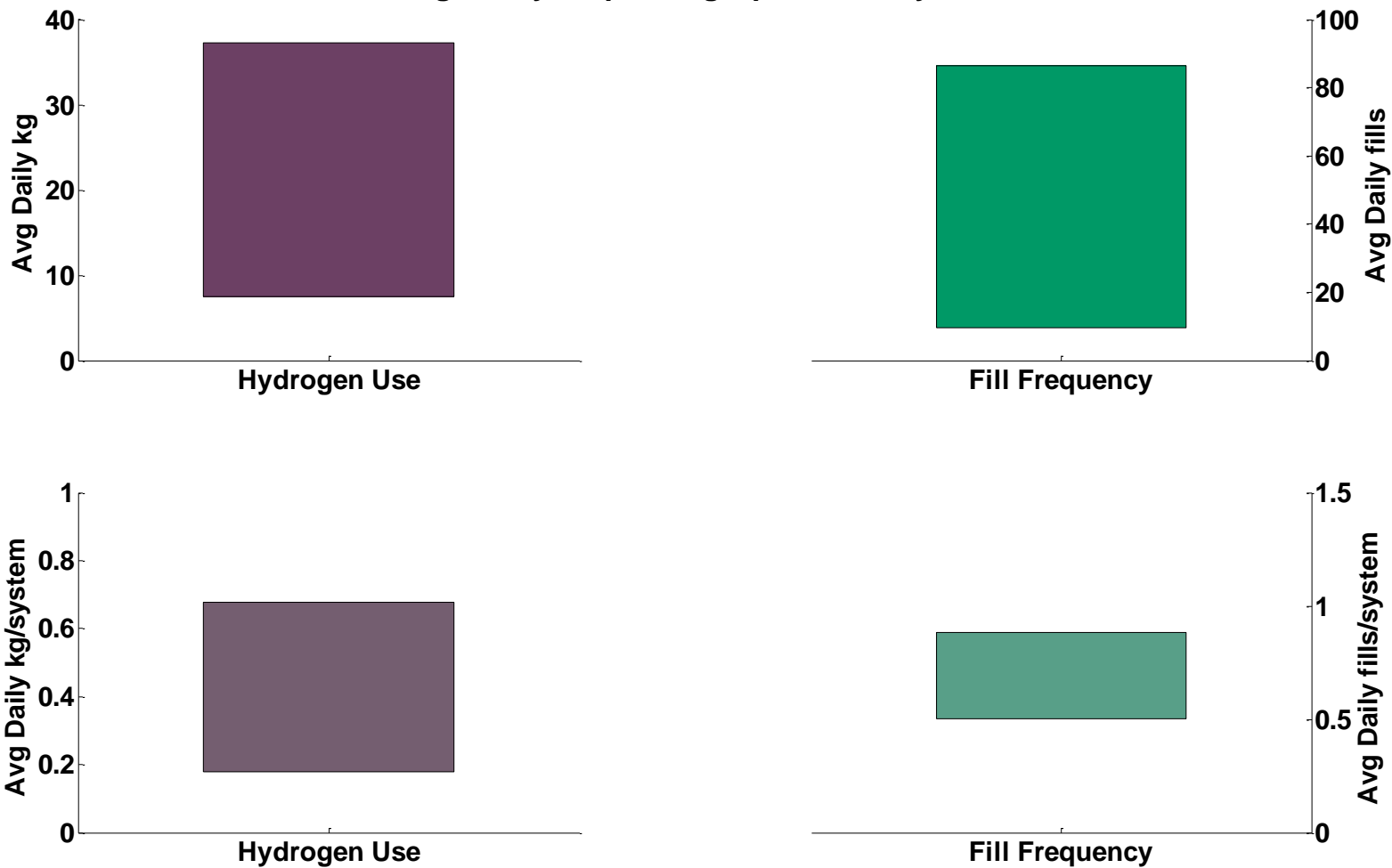
NREL cdparramhe_21

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CDPARRA-MHE-22

Average Daily Dispensing Operations by Site

Average Daily Dispensing Operations by Site - ARRA



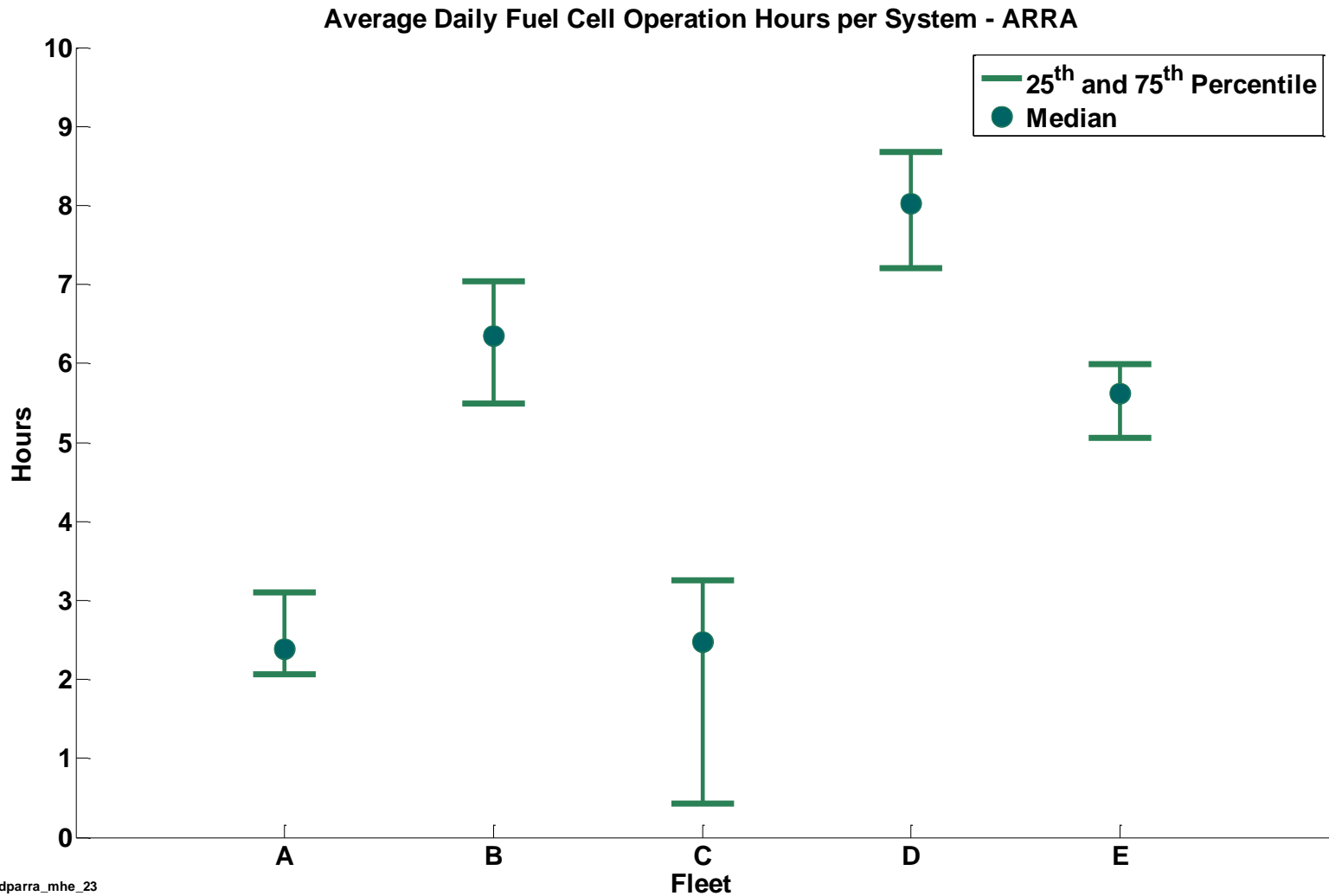
NREL cdparrar_mhe_22

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

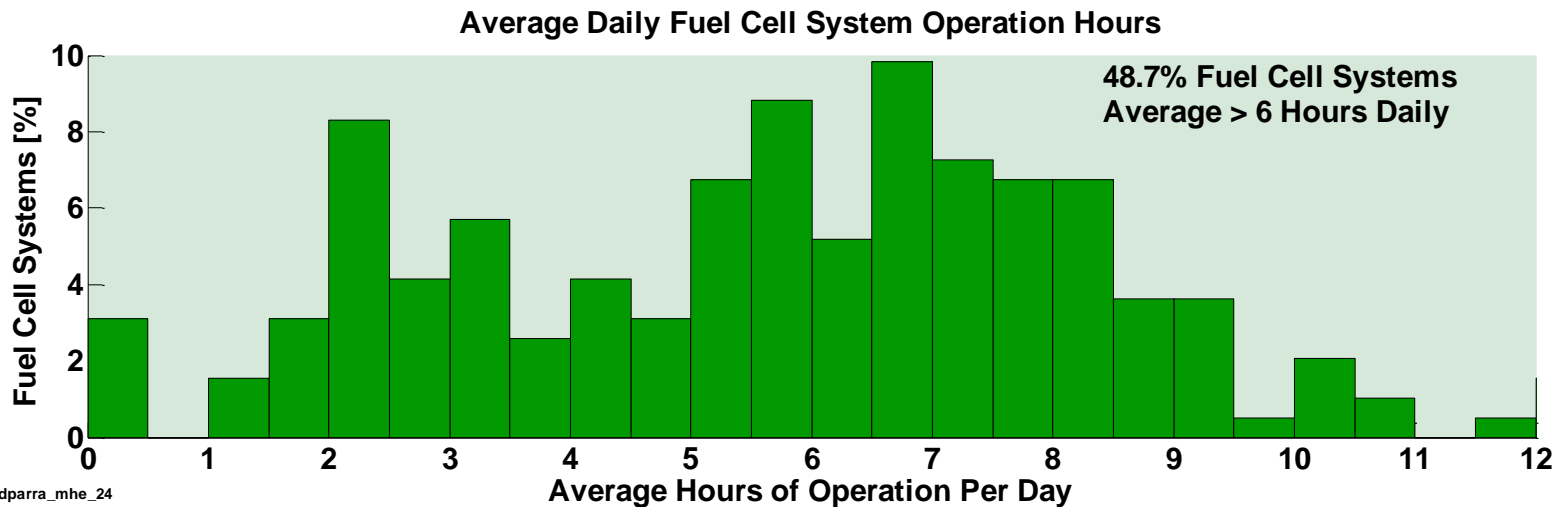
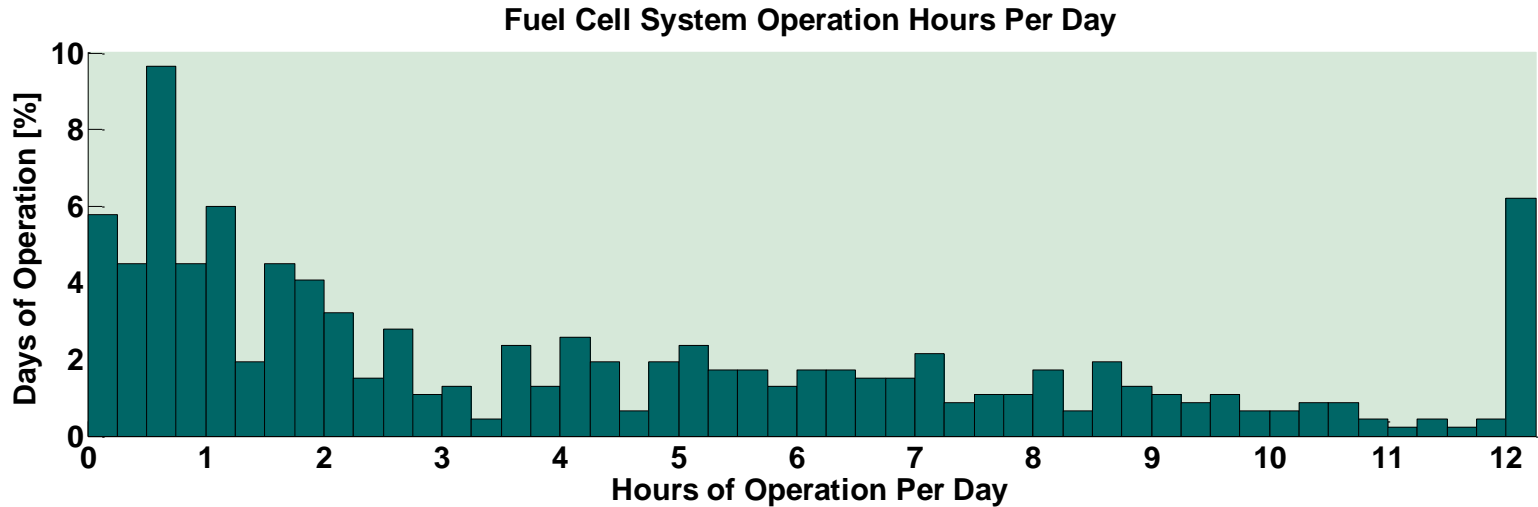
CDPARRA-MHE-23

Average Daily Fuel Cell Operation Hours per Fleet



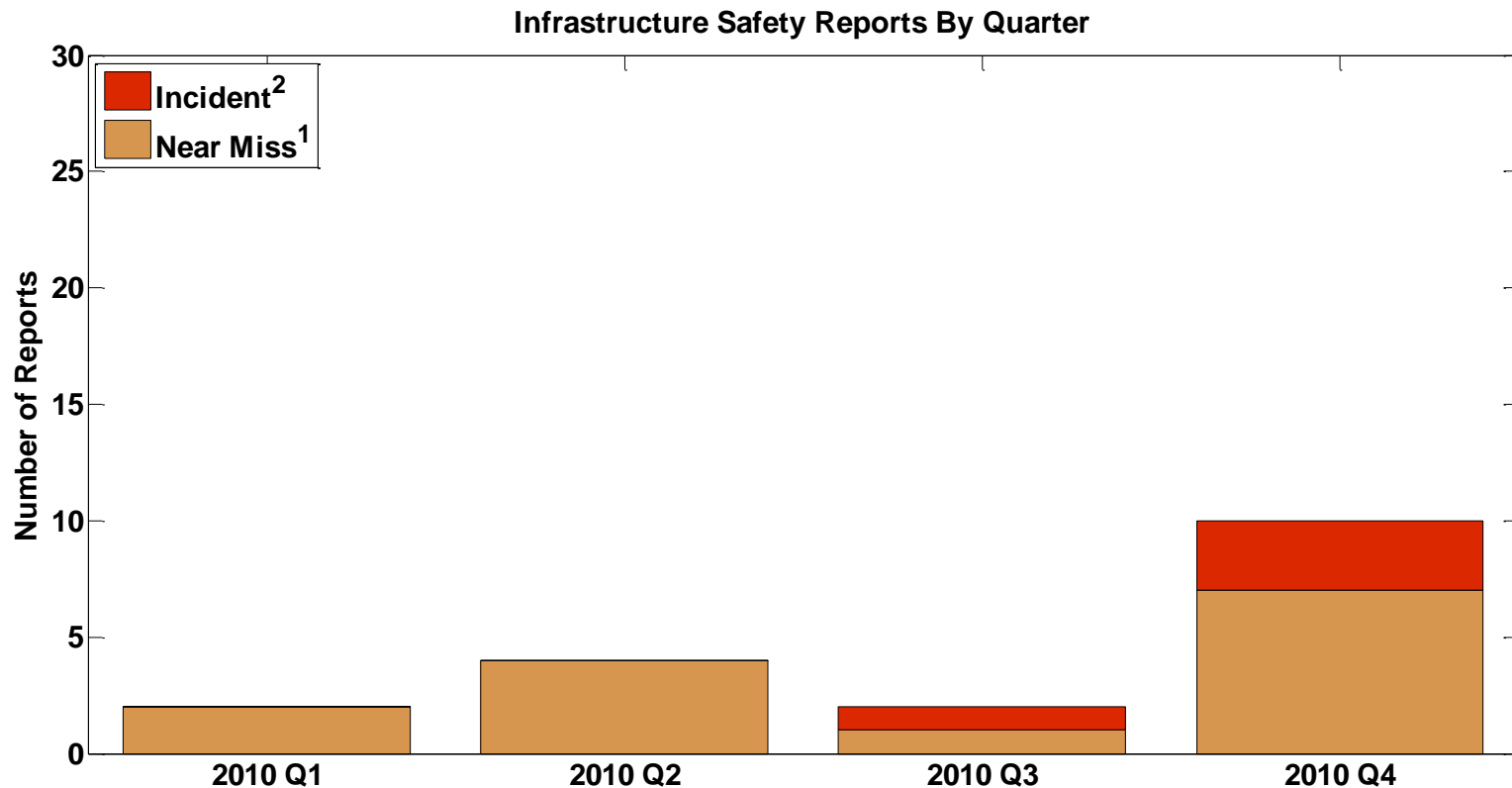
CDPARRA-MHE-24

Average Daily Fuel Cell Operation Hours per System



CDP-MHE-25

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)

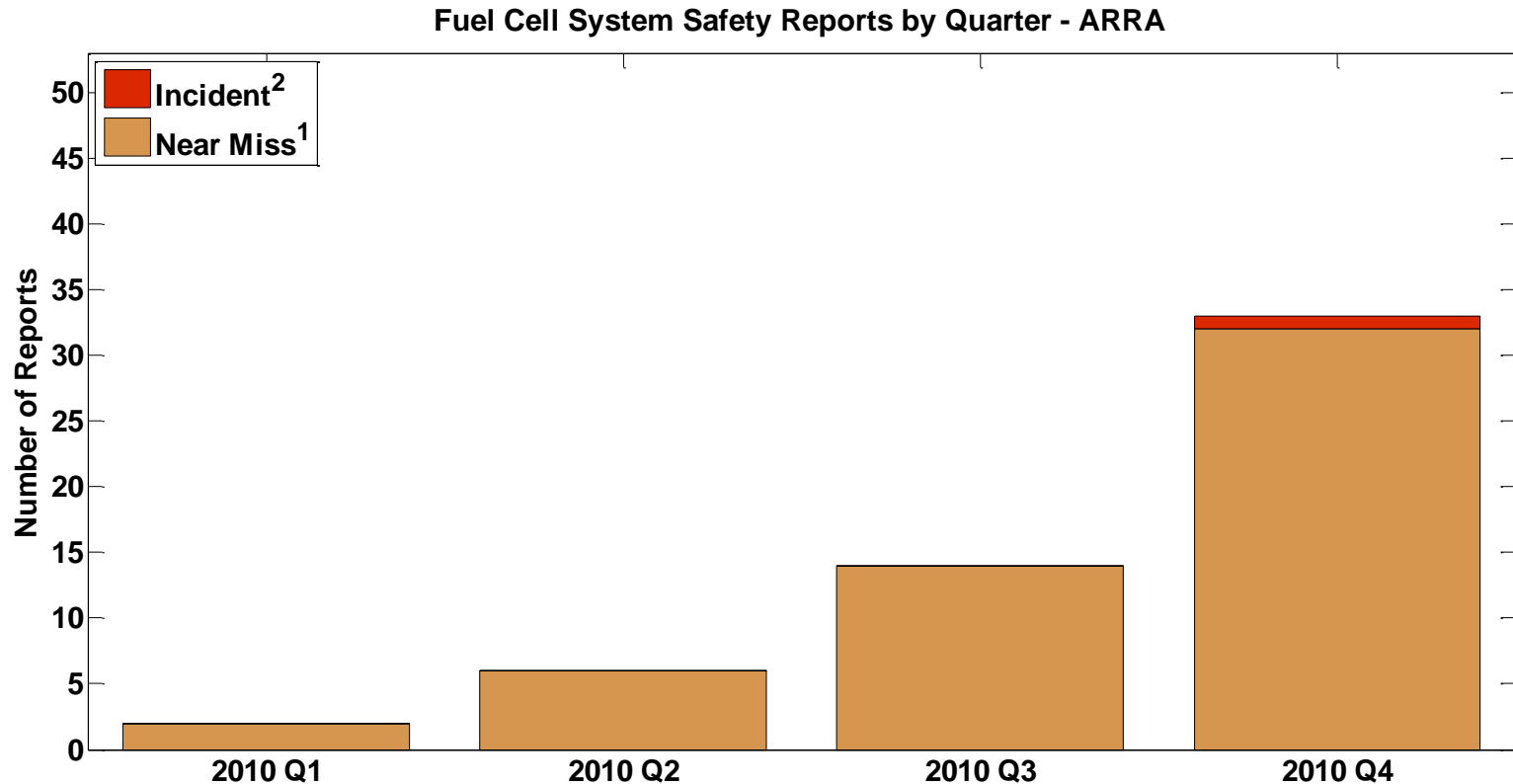


NREL cdp_mhe_25

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CDPARRA-MHE-26

Fuel Cell System Safety Reports by Quarter



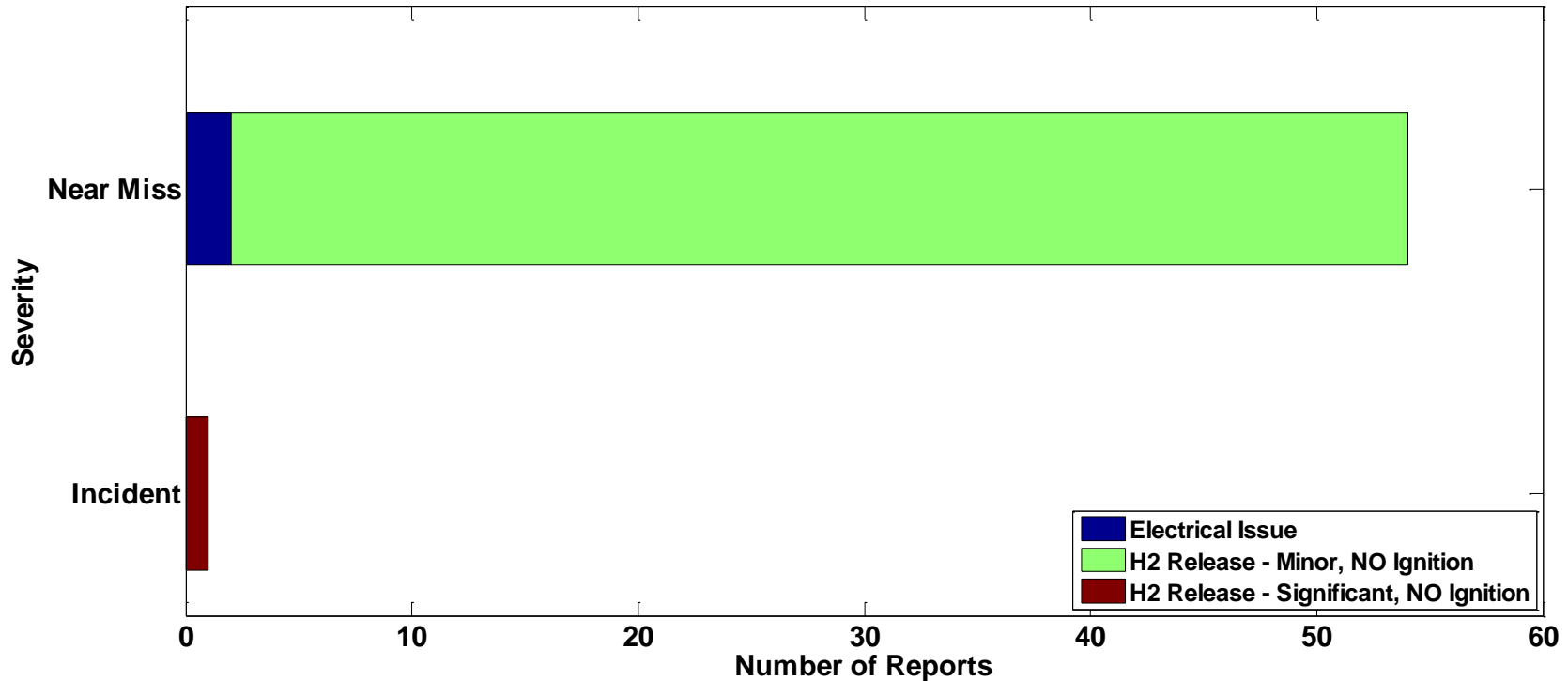
1) Near Miss is an event that under slightly different circumstances could have become an incident
-unplanned H₂ release insufficient to sustain a flame

2) Incident is an event that results in:

- a lost time accident and/or injury to personnel
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- 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)



Fuel Cell System Safety Reports by Severity - ARRA and Report Type 2010Q4



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)

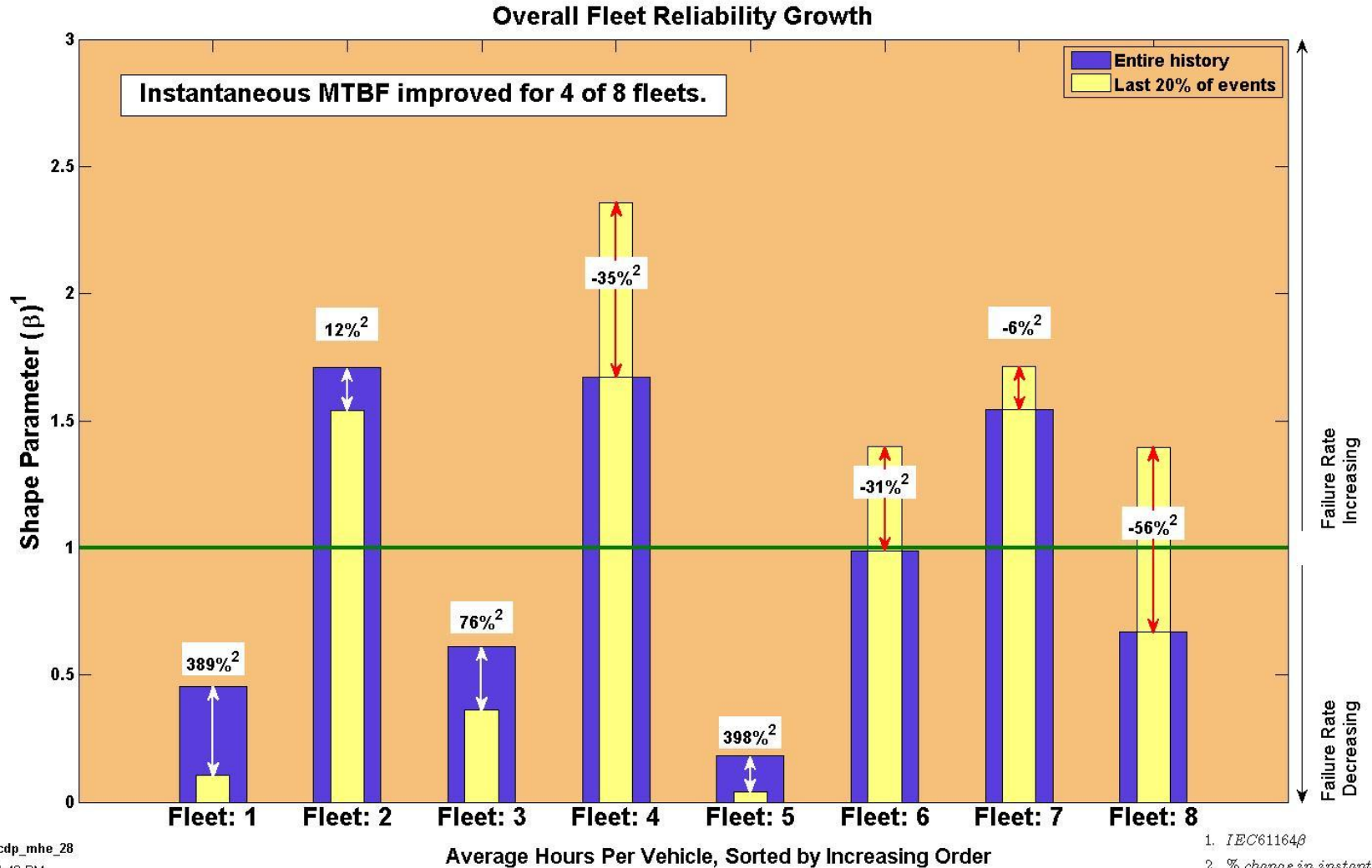
A NEAR-MISS is:

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



CDP-MHE-28

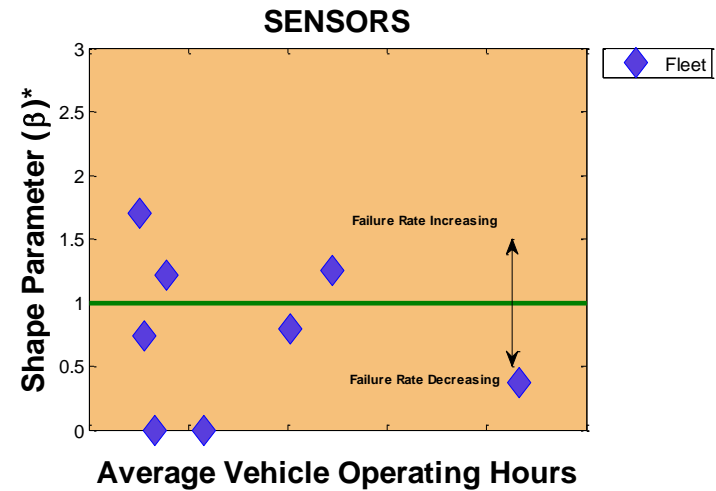
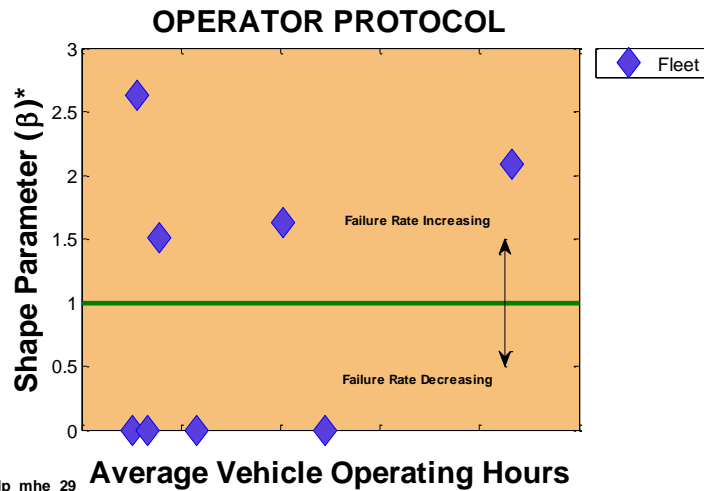
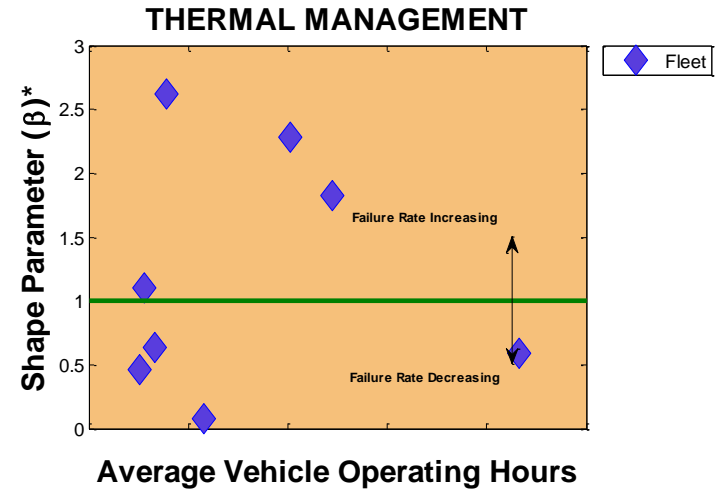
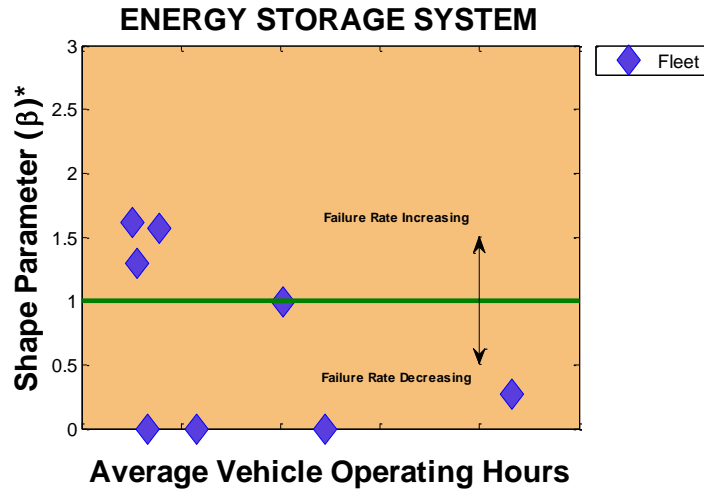
Fuel Cell System Reliability Growth by Site for Quarter



1. IEC61164β
2. % change in instantaneous MTBF = $[\lambda\beta_i^{(\beta-1)}]^{-1}$

CDP-MHE-29

Fuel Cell System Reliability Growth by Top 4 Categories



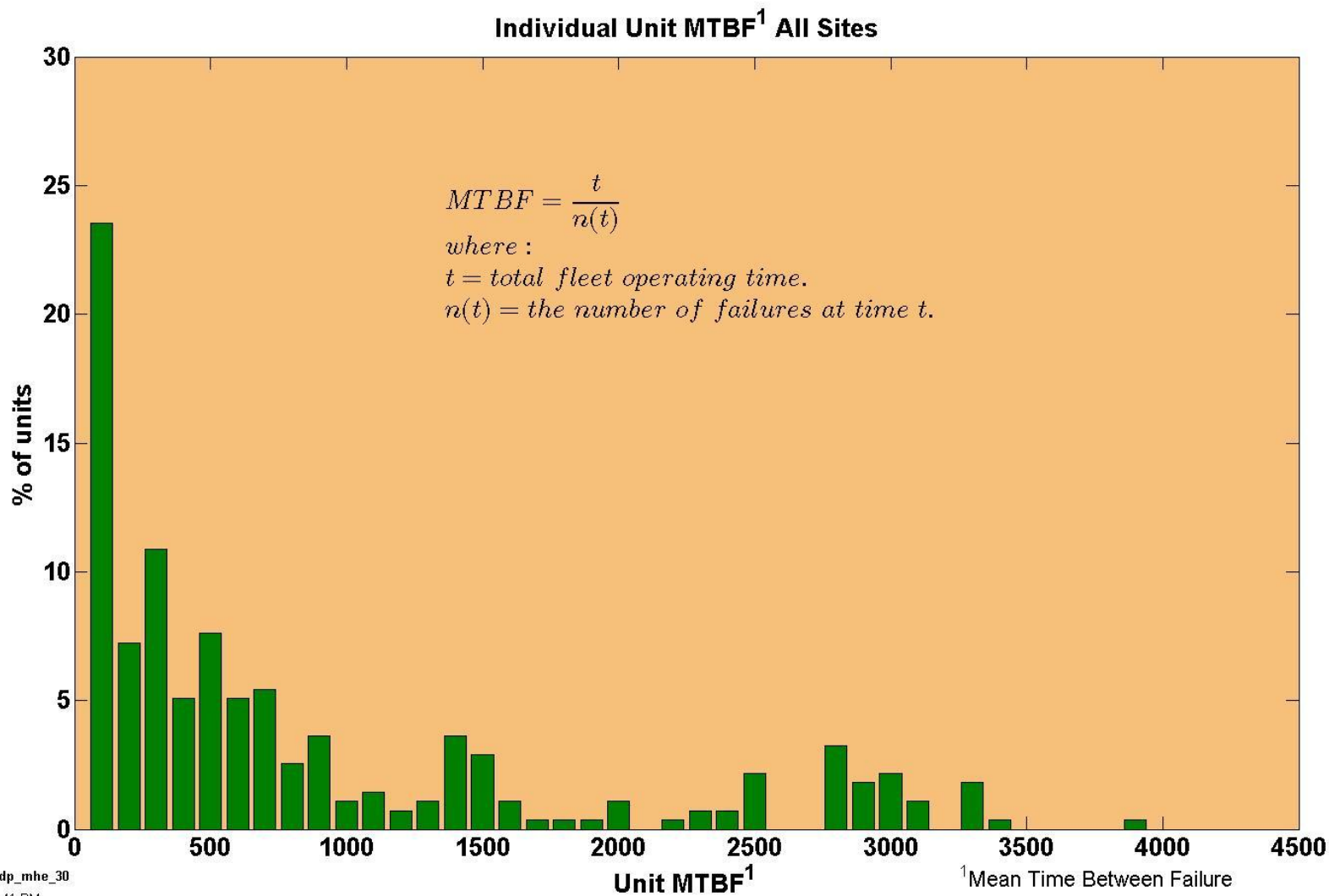
NREL cdp_mhe_29

Created: Apr-05-11 4:40 PM

*IEC 61164 β

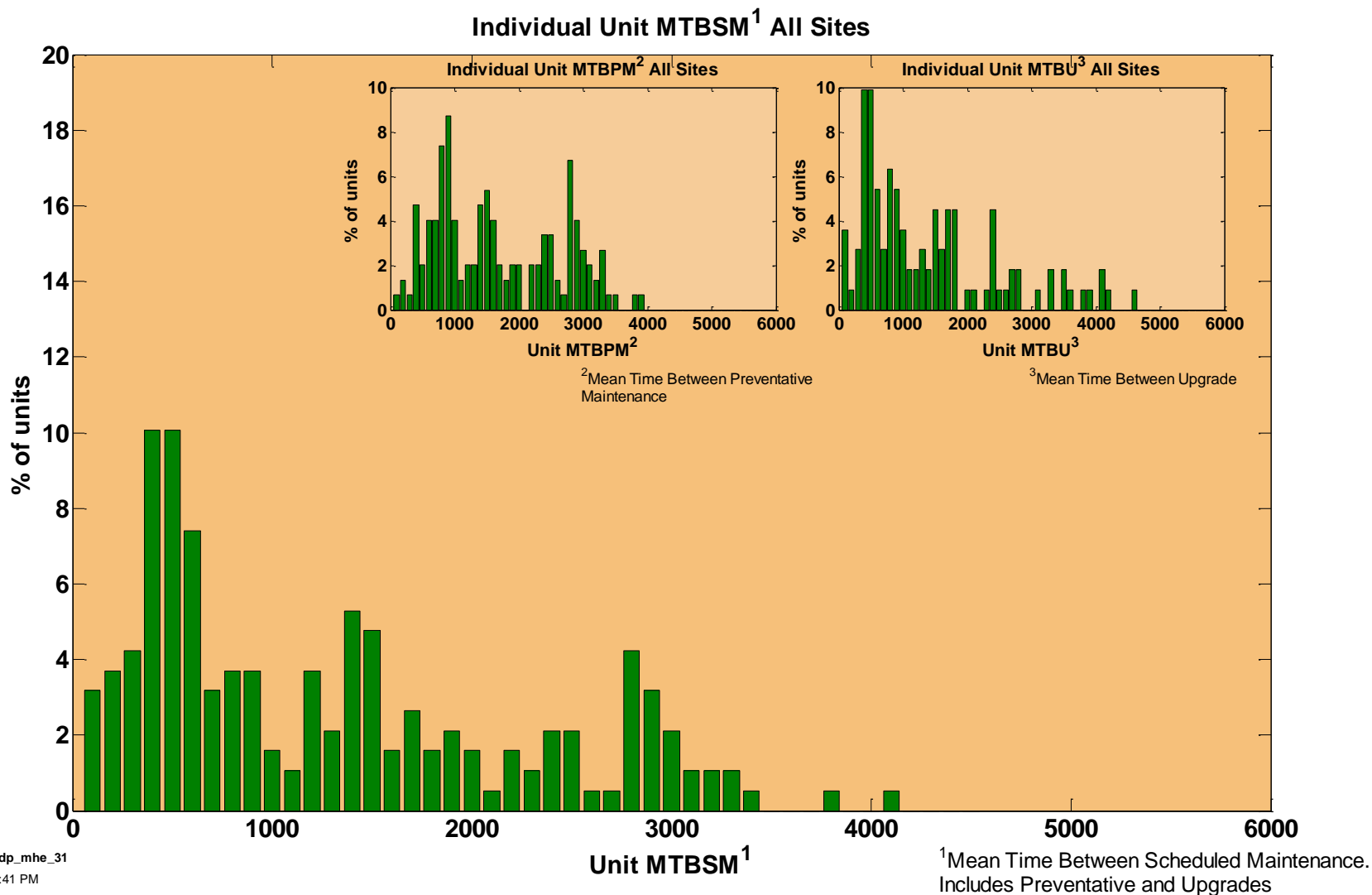
CDP-MHE-30

Fuel Cell System Mean Time Between Failure



CDP-MHE-31

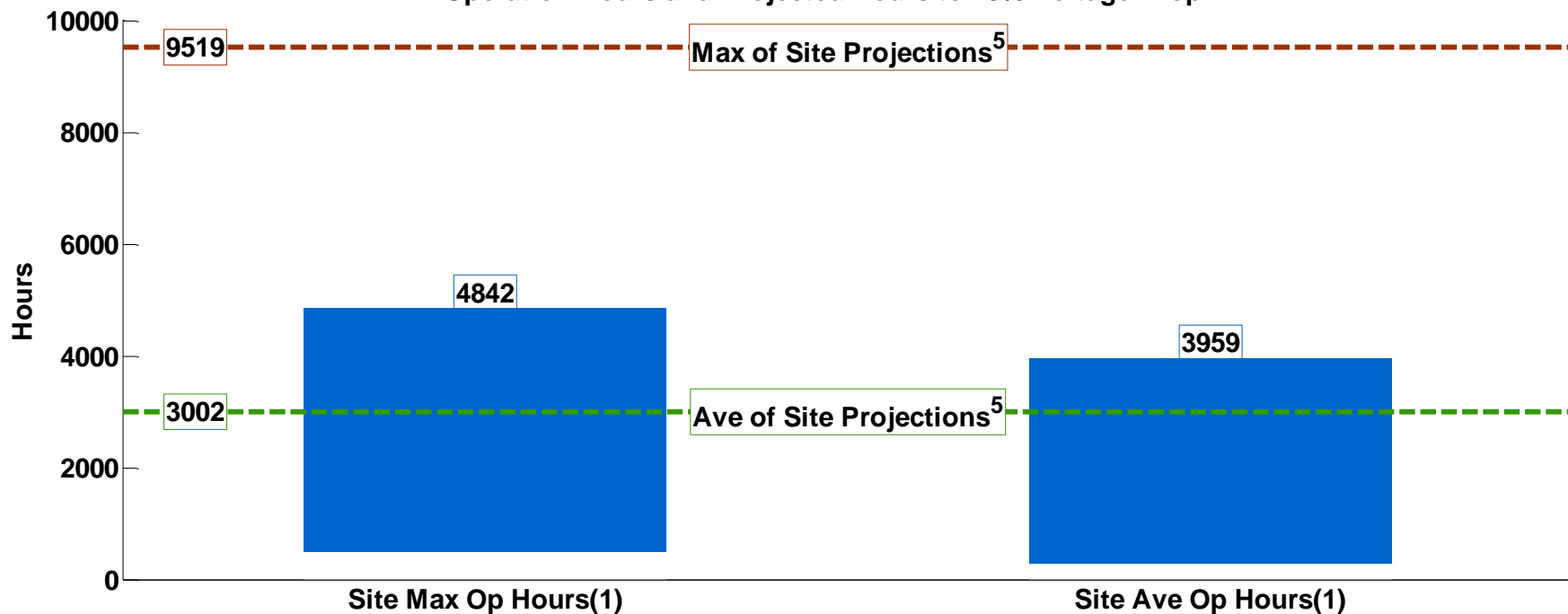
Fuel Cell System Mean Time Between Scheduled Maintenance



NREL cdp_mhe_31

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Operation Hours and Projected Hours to 10% Voltage Drop⁽²⁻⁴⁾

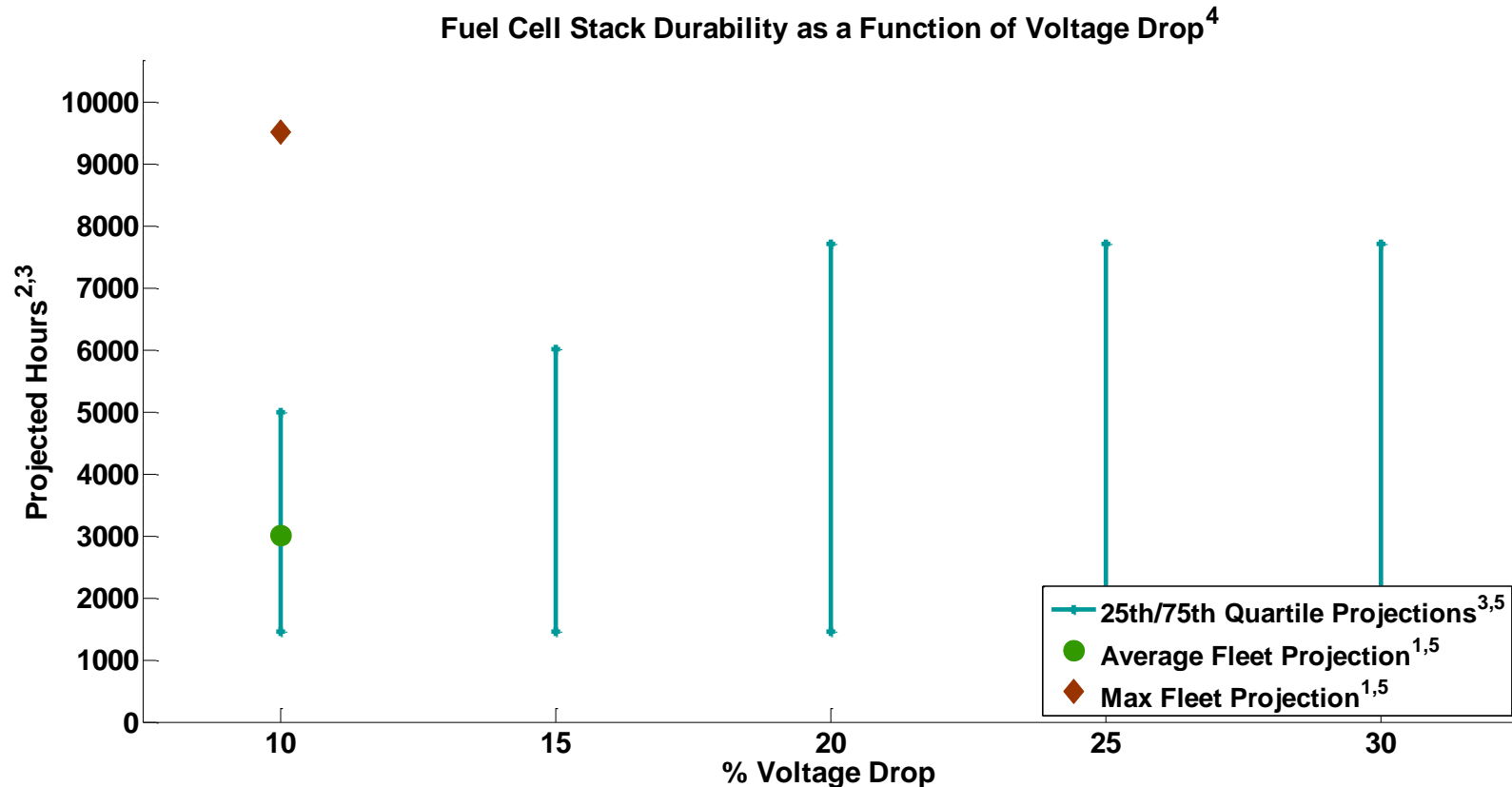


- (1) Range bars created using one data point for each fleet. Some stacks have accumulated hours beyond 10% voltage degradation.
- (2) 10% voltage drop level is a DOE metric for assessing fuel cell performance.
- (3) Projections using field data and calculated at a high stack current.
- (4) 10% voltage drop is NOT an indication of an OEM's end-of-life criteria and projections do not address catastrophic stack failure.
- (5) Each site has one voltage projection value that is the weighted average of the site's fuel cell stack projections.



CDP-MHE-33

Fuel Cell Stack Voltage Durability as a Function of Voltage Drop Levels



(1) 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.

(3) 25th and 75th percentiles spans the range of stack projection. The included stacks satisfy a minimum number of operation hours and weighting factor.

(4) The projection curves display the sensitivity to percentage of voltage degradation, but the projections do not imply that all stacks will (or do) operate at these voltage degradation levels.

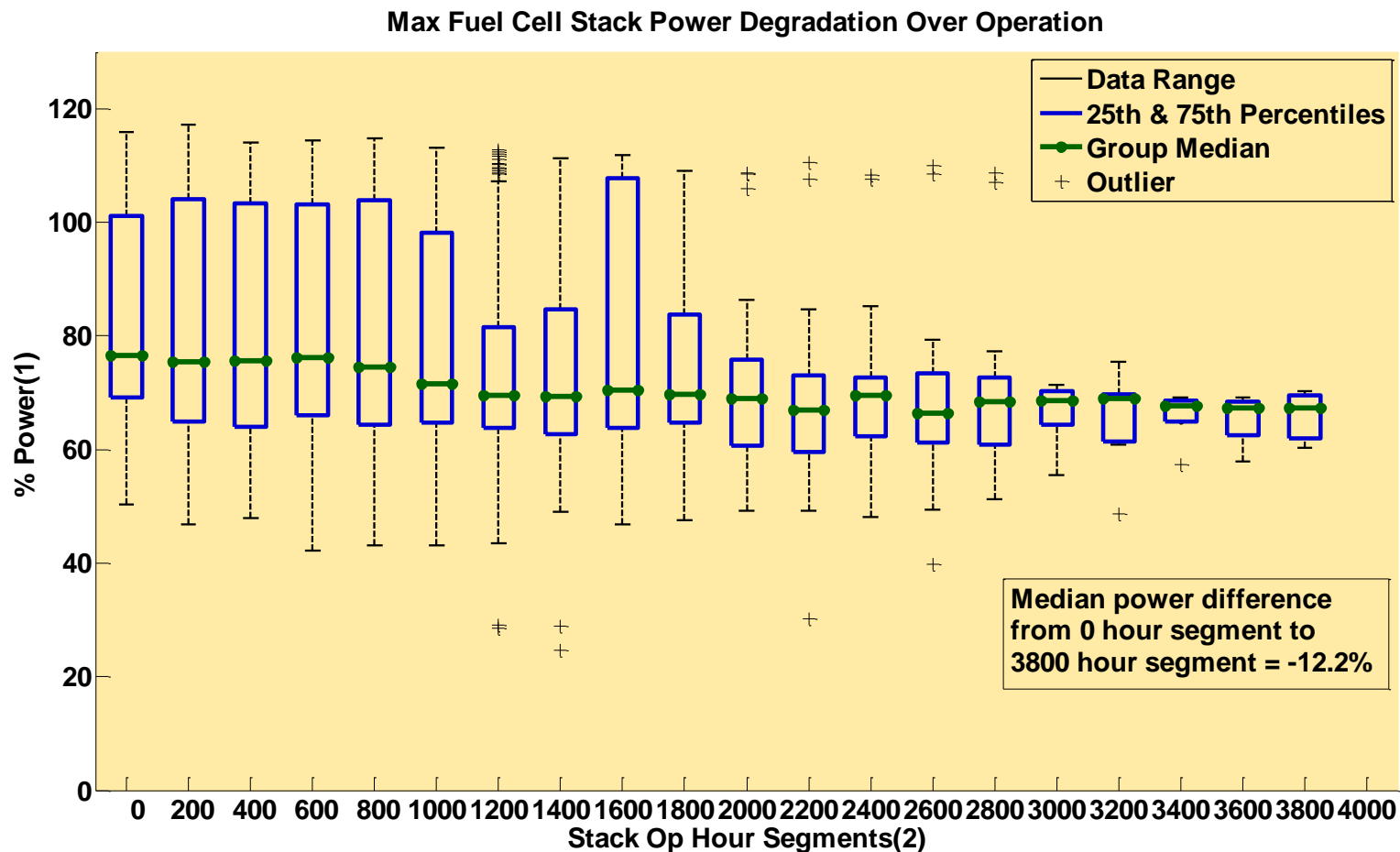
(5) Each site has one voltage projection value that is the weighted average of the sites's fuel cell stack projections.



NREL cdp_mhe_33

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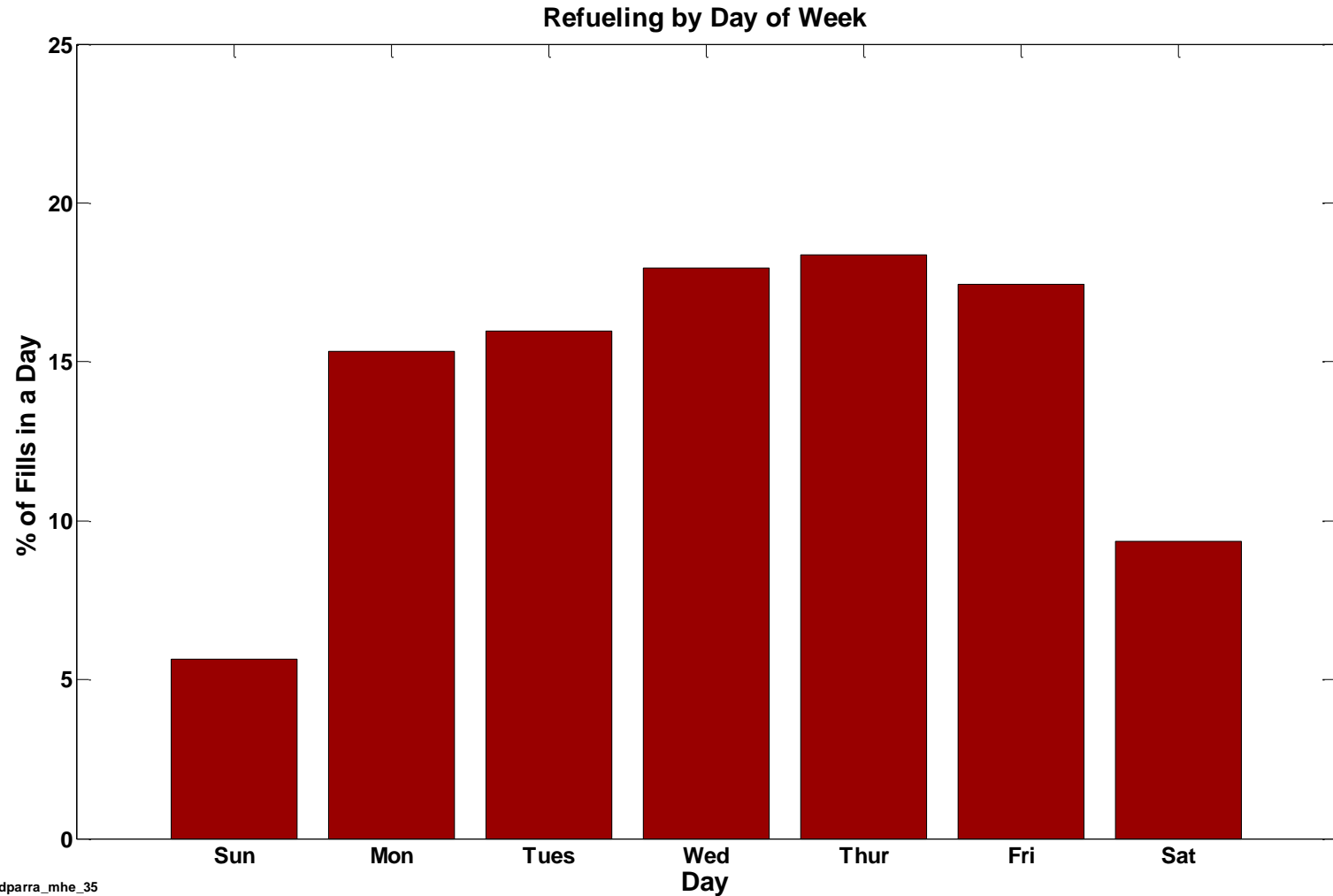
Fuel Cell Stack Power Degradation over Time



- 1) Normalized by fleet maximum power.
- 2) Each segment point is median FC power (+-100 hrs).
Box not drawn if fewer than 3 points in segment.

CDPARRA-MHE-35

Dispensed Hydrogen by Day of Week

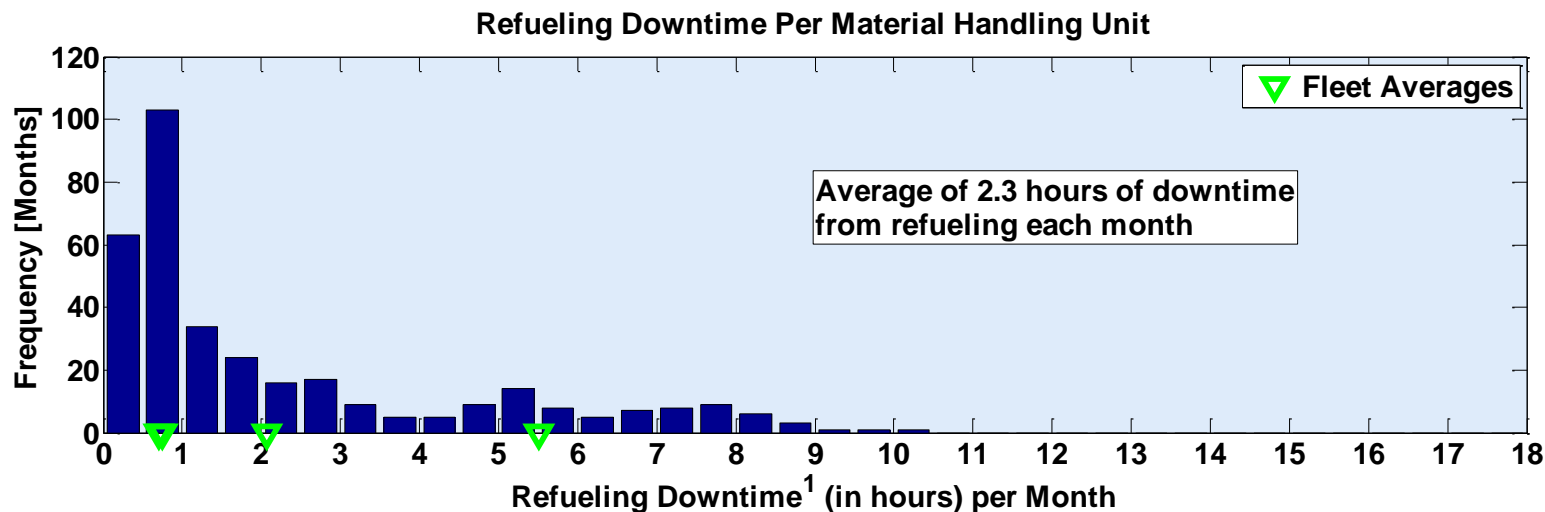


NREL cdparra_mhe_35

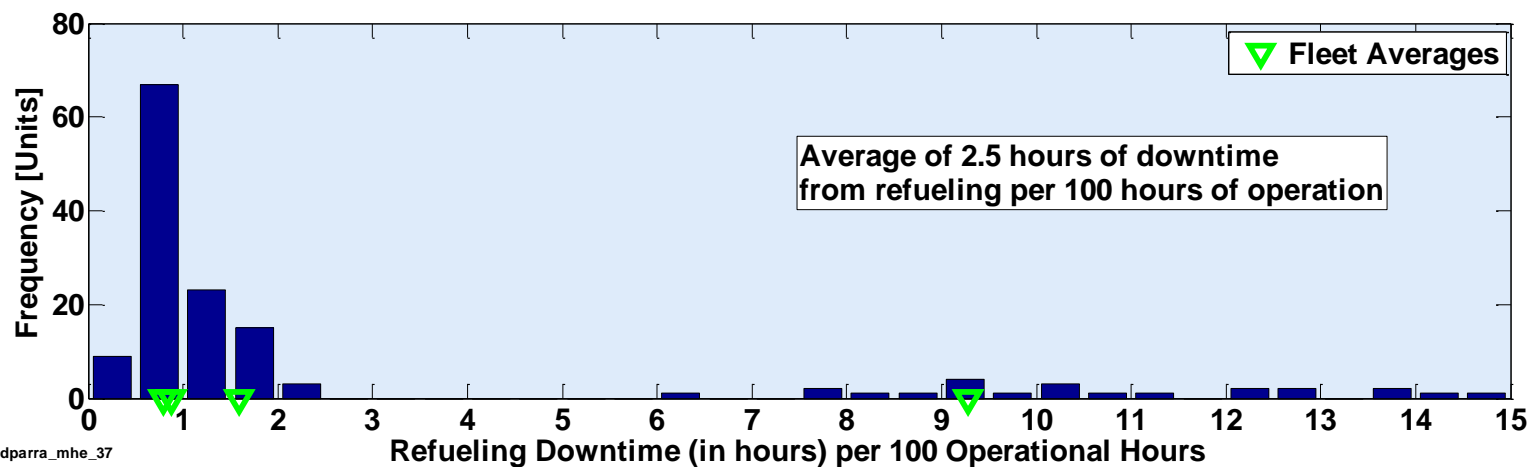
Created: Mar-10-11 9:35 AM

CDPARRA-MHE-37

Fuel Cell System Downtime



¹ Refueling downtime represents total refueling time from "drive-up" to "drive-away" not only hydrogen gas dispensing time



Note: Some refueling events not recorded/included due to data noise or incompleteness



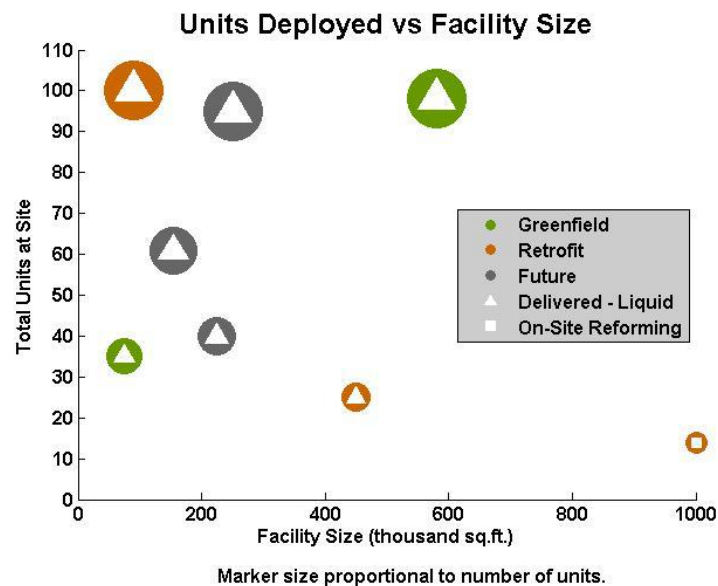
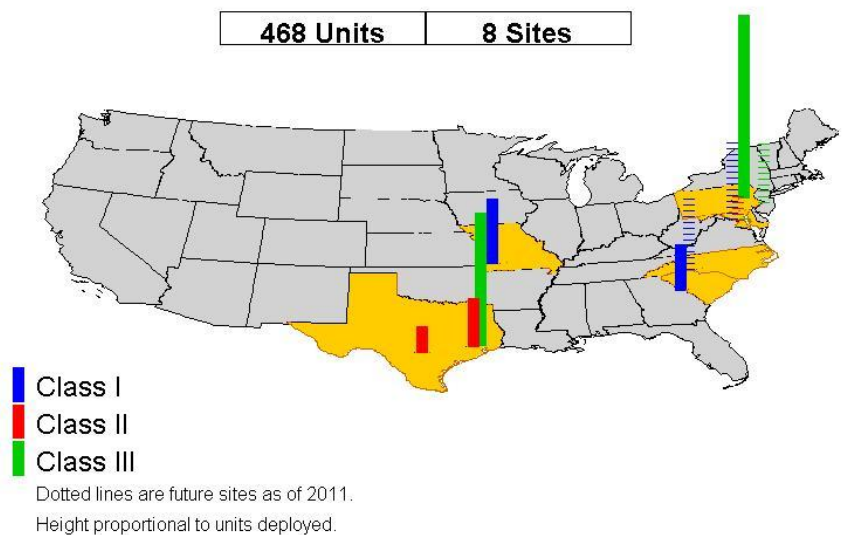
NREL cdparramhe_37

Created: Mar-10-11 10:21 AM

CDPARRA-MHE-40

Site Summary

MHE Deployment - ARRA



Forklift Units (I,II,III)	0,26,72	0,14,0	35,0,0	25,0,0	45,14,2	0,36,100	40,0,0	0,25,70
Operation								
<i>Shifts per Day</i>	2	2	3	1-2	3	2	2	3
<i>Hours per Shift</i>	8-10	9.5	8	10	8	8-10	8	8
<i>Days per Week</i>	6	N/A	N/A	7	7	6	6	6



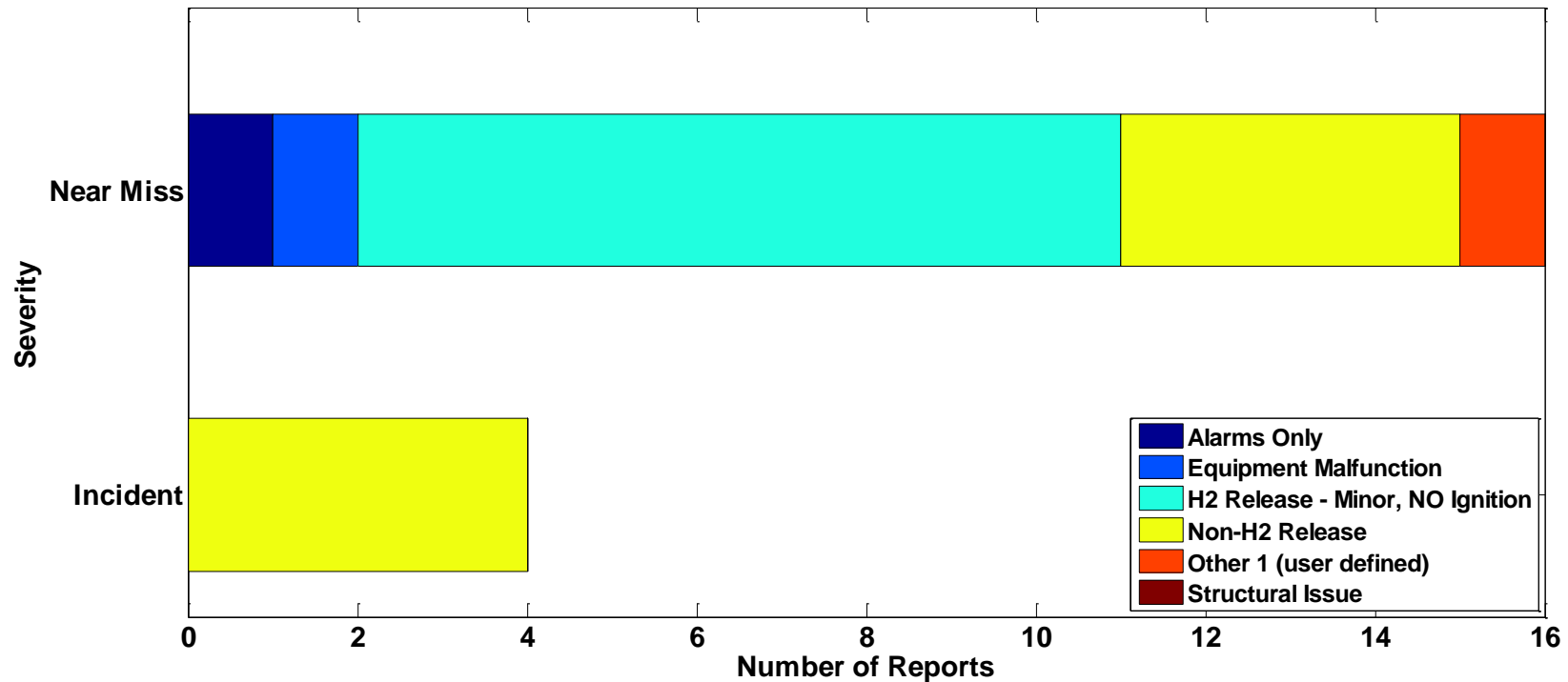
NREL cdparrar_mhe_40

Created: Mar-30-11 9:27 AM

CDP-MHE-41

Infrastructure Safety Categories

Infrastructure Safety Reports by Severity - All Sites and Report Type 2010Q4



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

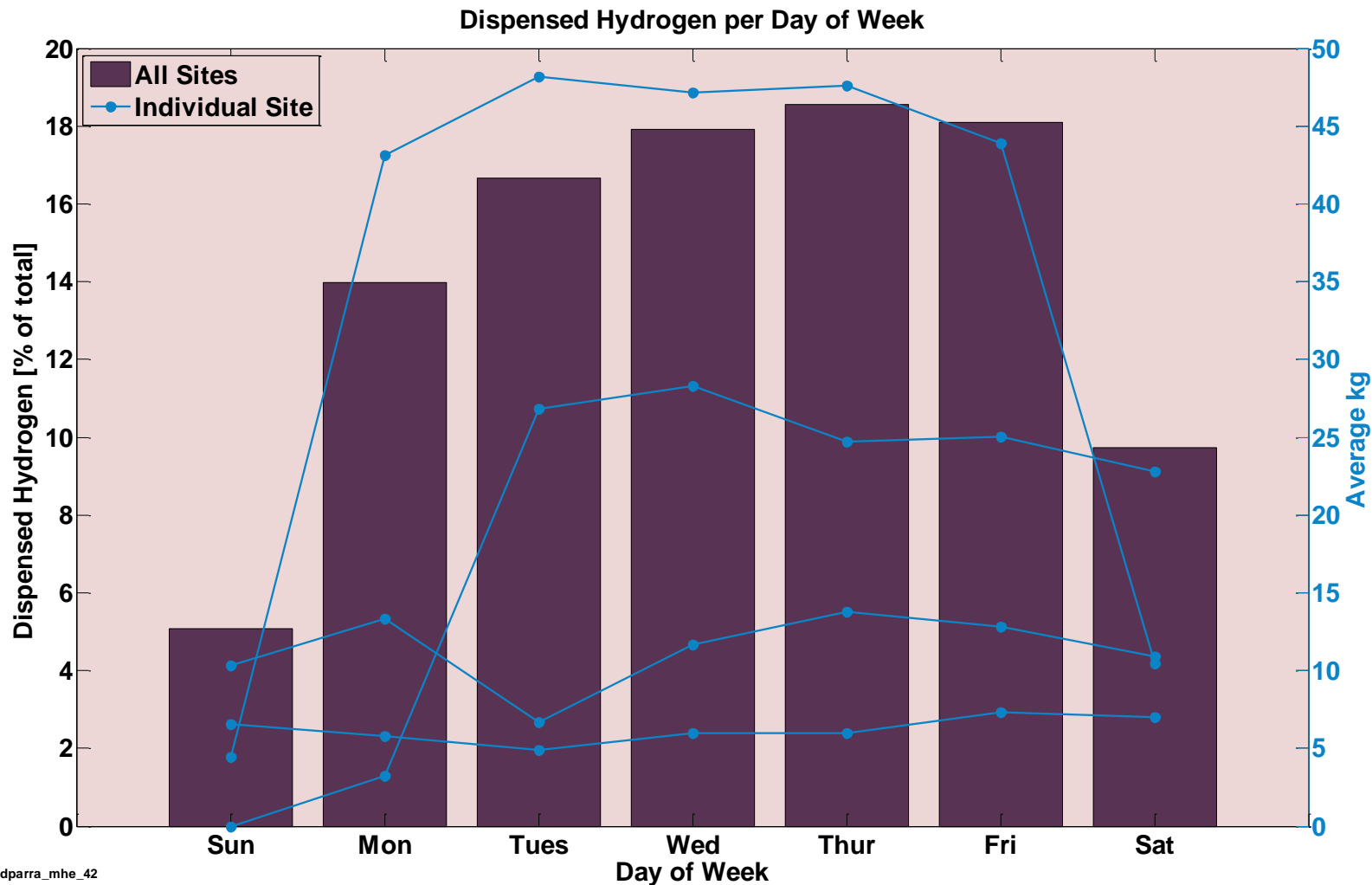


NREL cdp_mhe_41

Created: Mar-09-11 2:26 PM

CDP-MHE-42

Amount of Hydrogen Dispensed by Day of Week



NREL cdparra_mhe_42

Created: Mar-29-11 4:19 PM