



Next Generation Hydrogen Station Composite Data Products: All Stations (Retail and Non-Retail Combined)

Data through Quarter 3 of 2016

Sam Sprik, Jennifer Kurtz, Chris Ainscough, Genevieve Saur, Michael Peters, and Matthew Jeffers

January 20, 2017

NREL/PR-5400-68012

H2 Station Project Partners



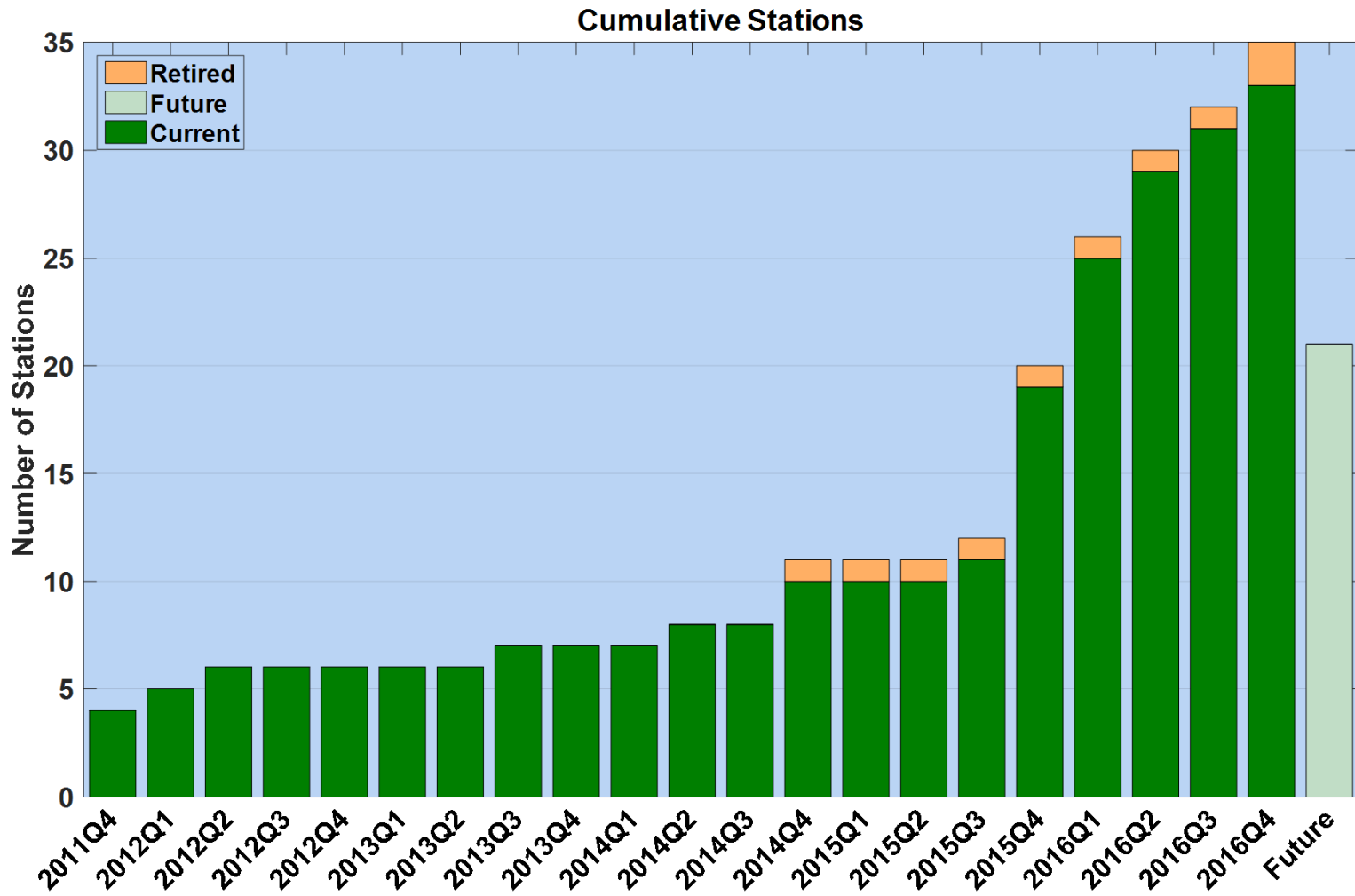
- Air Liquide
- Air Products
- California Air Resources Board
- California Energy Commission
- California State University Los Angeles
- First Element
- Gas Technology Institute
- Linde
- H2 Frontier
- Proton OnSite
- Shell
- IPHE and HySUT



Analysis Categories



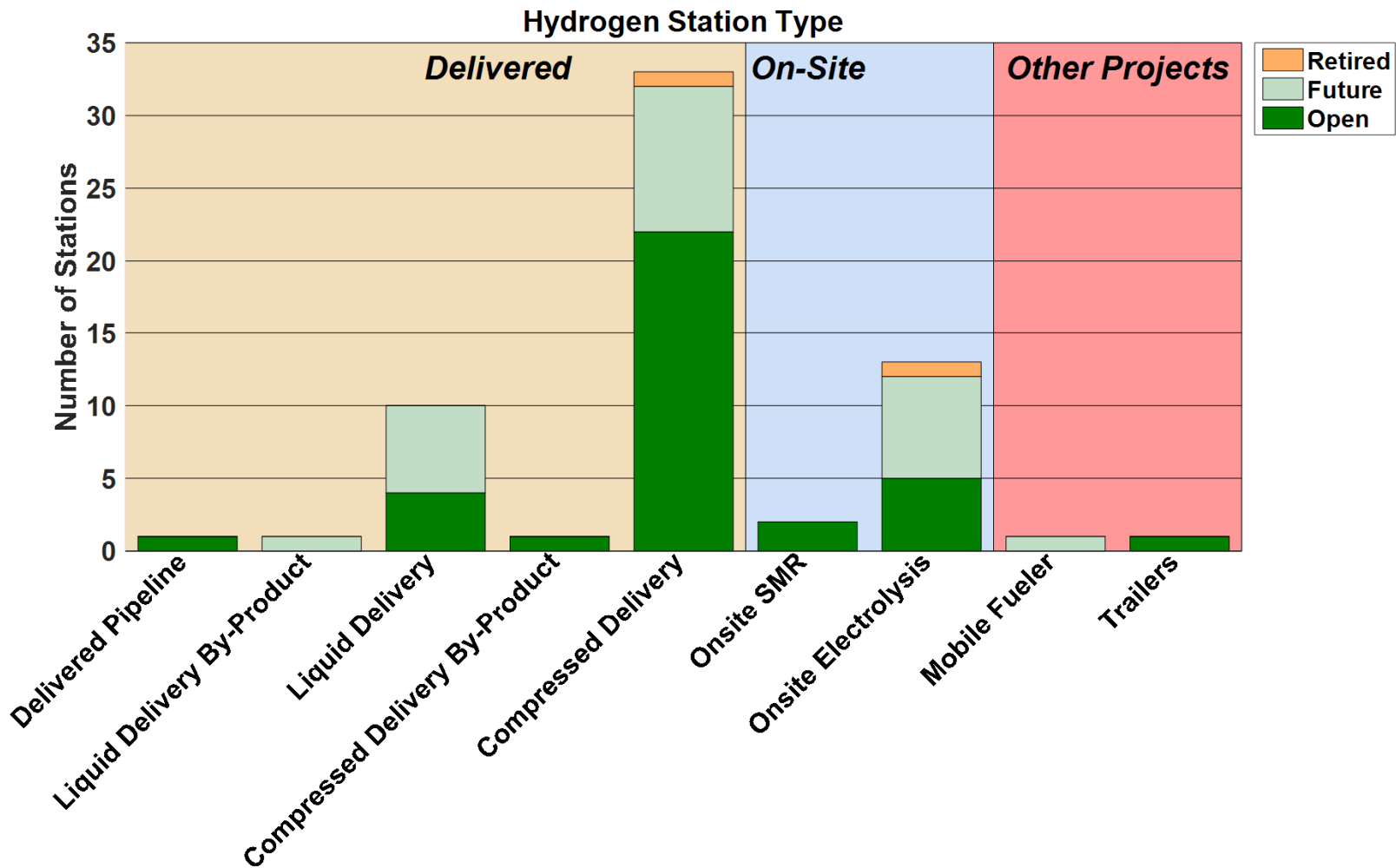
Deployment

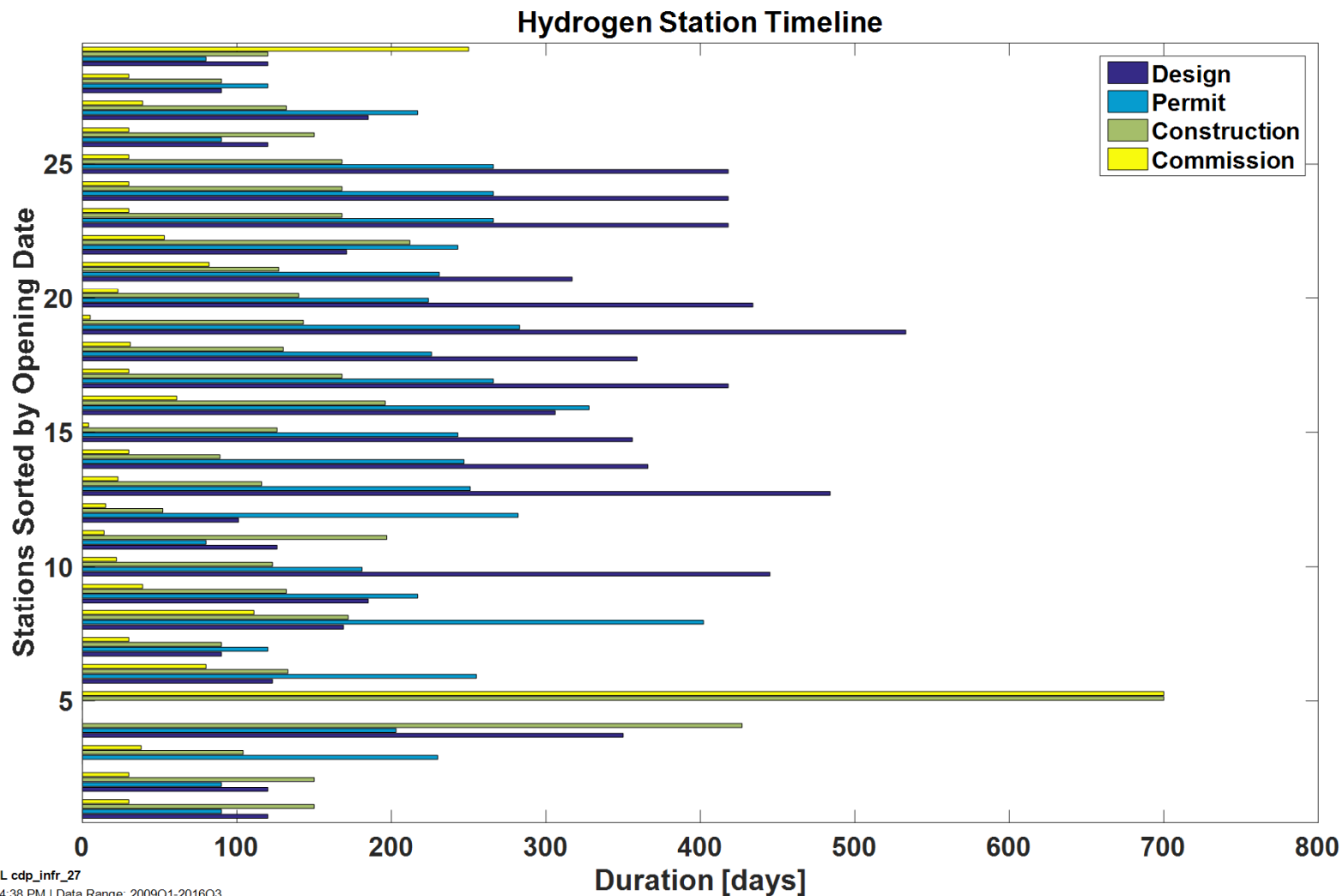


NREL cdp_infr_10

Created: Dec-21-16 9:10 AM | Data Range: 2009Q1-2016Q3

Hydrogen Stations by Type





NREL cdp_infr_27

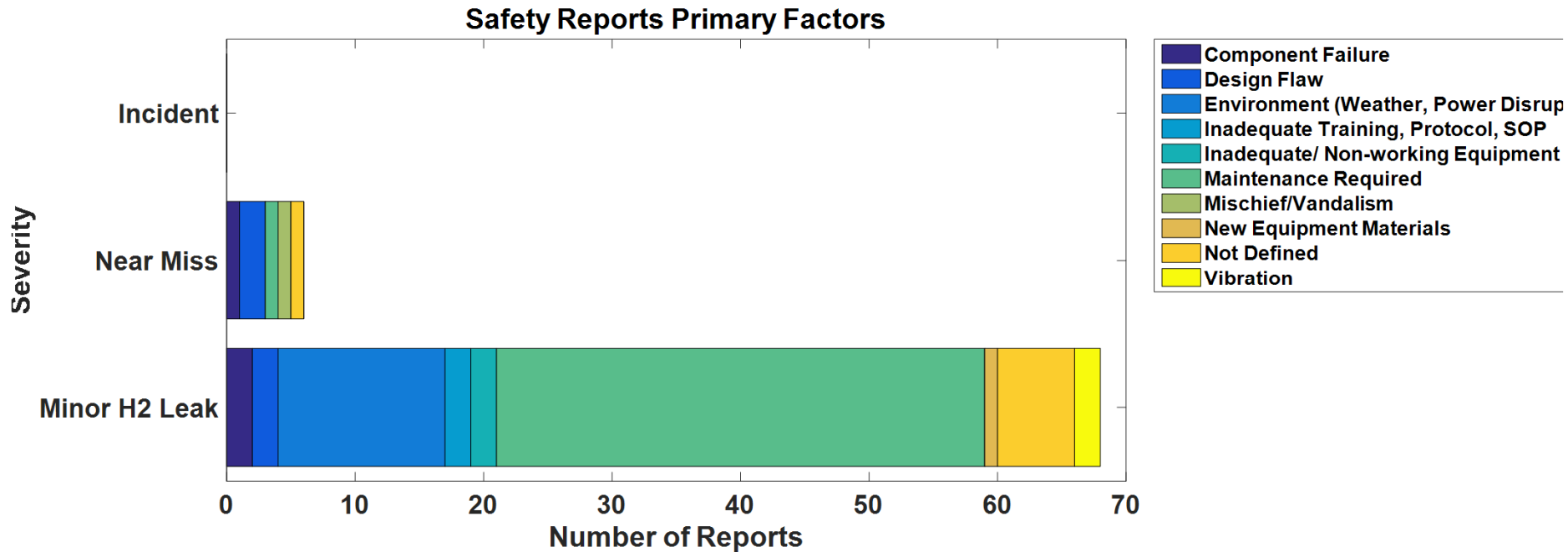
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Safety

Safety (and Maintenance) Learnings

From Safety Reports Template

- Alarms not communicated
- Breakaway leak
- Check compressor oil filter
- Check integrity of delivered equipment
- Compressor leaking at startup normal?
- Does isolated leak need to shut down station?
- Electrical glitch
- Estop activated after hearing escaping gas-nitrogen
- Estop activated when nozzle stuck on car
- Estop activated without cause
- Estop flooded prevented restart
- False Alarm - No Fire
- Fill and leak check together caused shutdown - false leak alarm
- Filter to catch scrap from material processing
- Forgot to turn back on after maintenance
- Freezing and thawing caused moisture in communication connector
- Frozen cooling block - defrost
- HTO sensor fault
- Heat trace short caused false fire alarm
- Heavy rain triggered fire alarm
- Hose vent failure - nozzle stuck on car
- Loose wire intermittent problems
- Loud popping could be relief valve
- Mass balance alarm bug
- Mass balance alarm caused by high ambient temperature
- Power Issue - 3 Phase
- Predict service life better
- Proper installation prevents leaks
- Rain on sensor causing alarm
- Regular inspection of compressor valves
- Regular leak checks
- Regular station inspection
- Reset
- Spider web obscuring sensor
- Thermocouple failure shutdown station
- Vibration from normal activity shutdown dispenser
- Vibration isolation



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
- release of any volatile, hydrogen containing compound (including the hydrocarbons used as common fuels)

A Near Miss is:

- an event that under slightly different circumstances could have become an incident
- any hydrogen release sufficient to sustain a flame if ignited

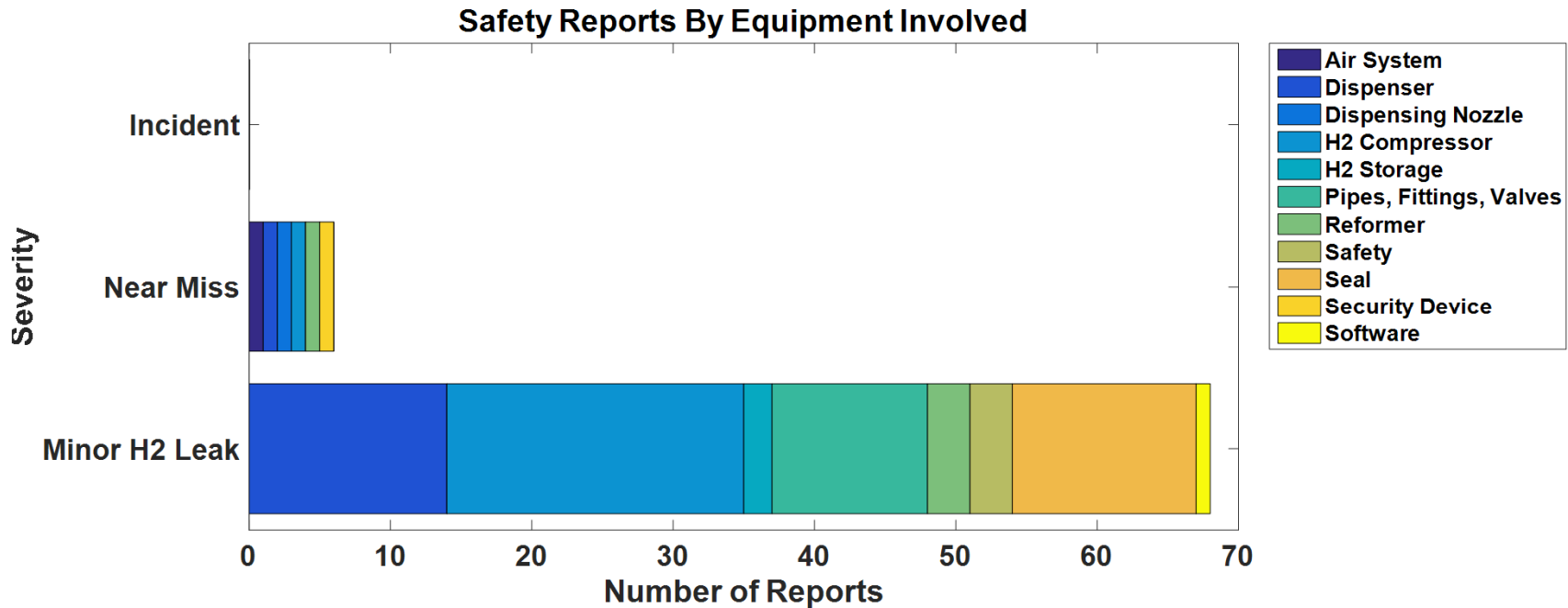
A Minor H2 Leak is:

- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdp_infr_31

Created: Dec-12-16 1:56 PM | Data Range: 2008Q3-2016Q3



An 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
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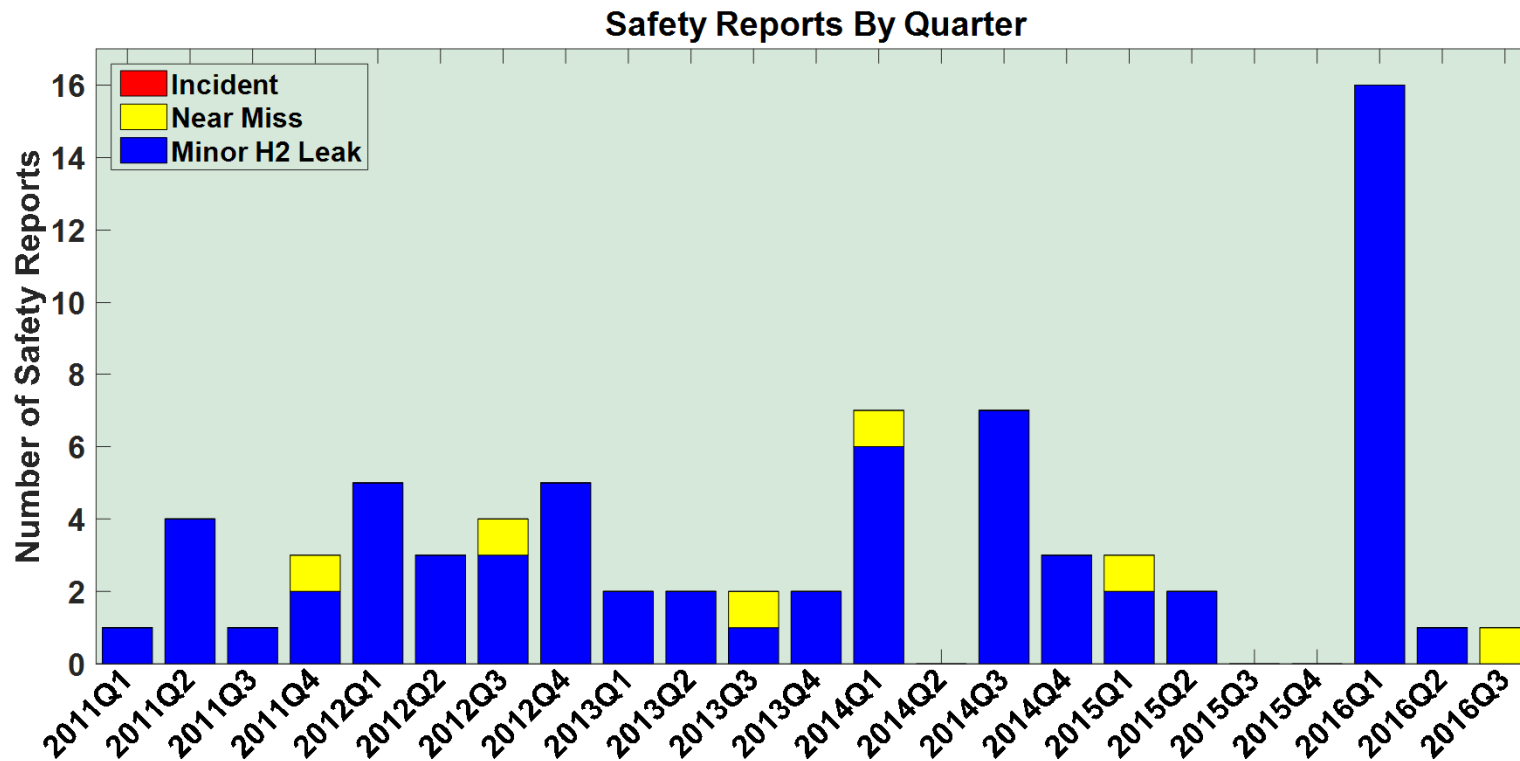
A Minor H2 Leak is:

- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdp_infr_32

Created: Dec-12-16 1:56 PM | Data Range: 2008Q3-2016Q3



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
- release of any volatile, hydrogen containing compound (including the hydrocarbons used as common fuels)

A Near Miss is:

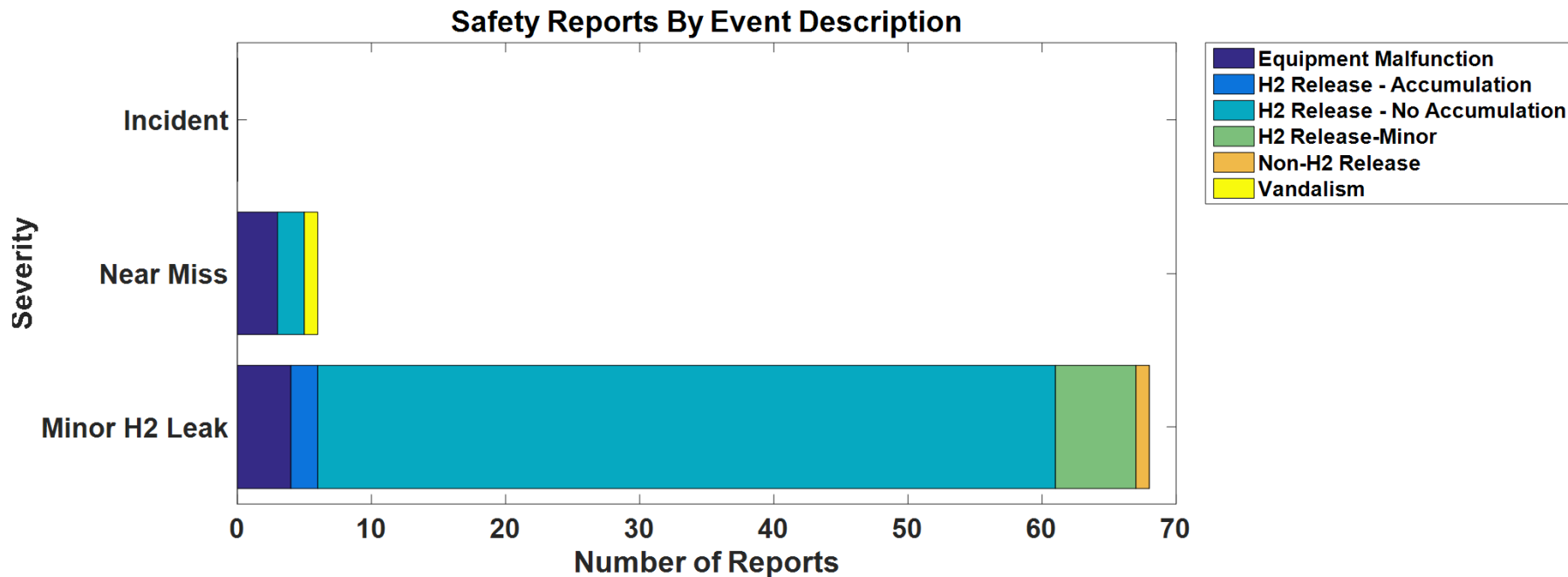
- an event that under slightly different circumstances could have become an incident
- any hydrogen release sufficient to sustain a flame if ignited

A Minor H2 Leak is:



NREL cdp_infr_33

Created: Dec-12-16 2:00 PM | Data Range: 2008Q3-2016Q3



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
- release of any volatile, hydrogen containing compound (including the hydrocarbons used as common fuels)

A Near Miss is:

- an event that under slightly different circumstances could have become an incident
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A Minor H2 Leak is:

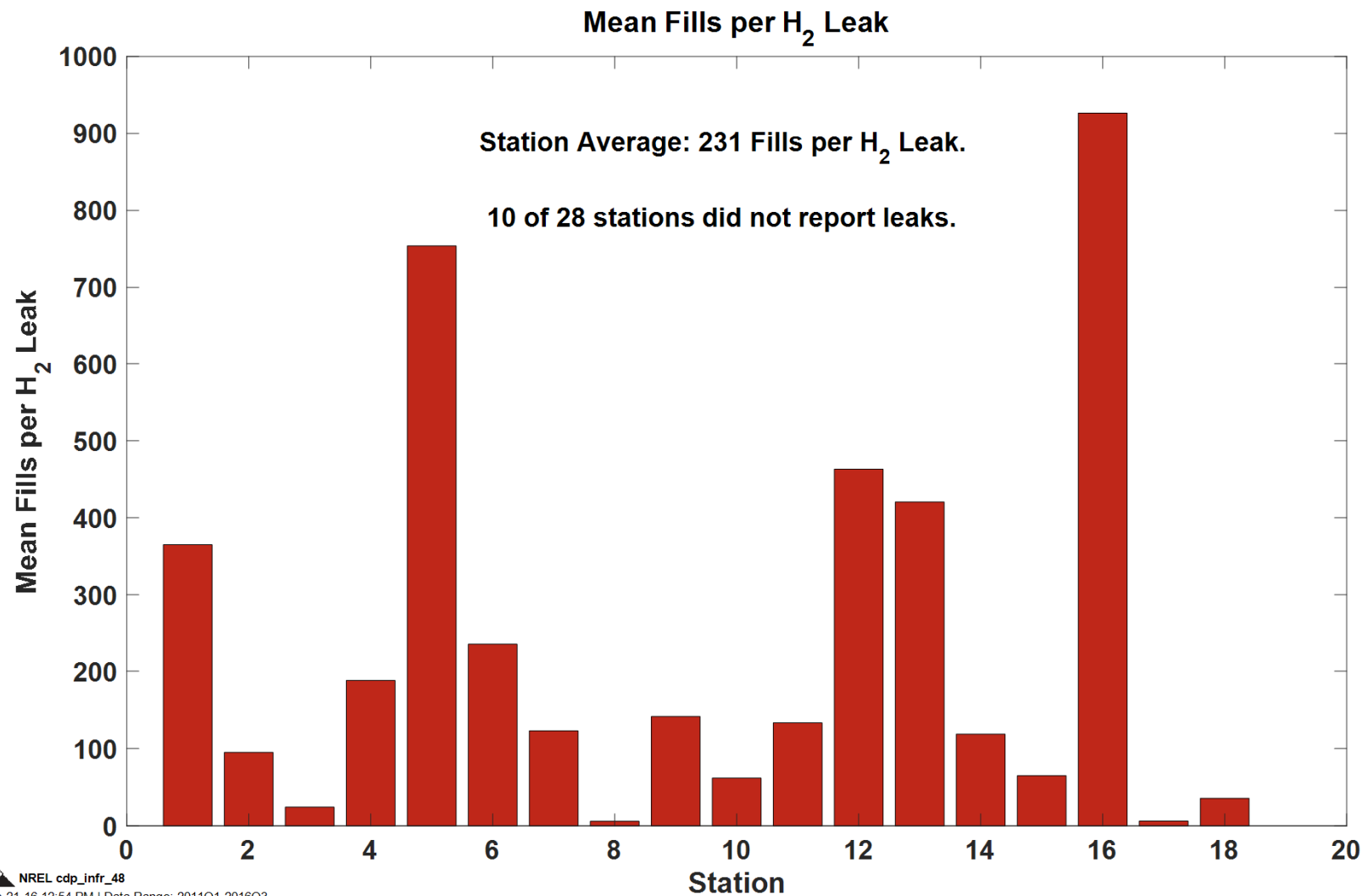
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



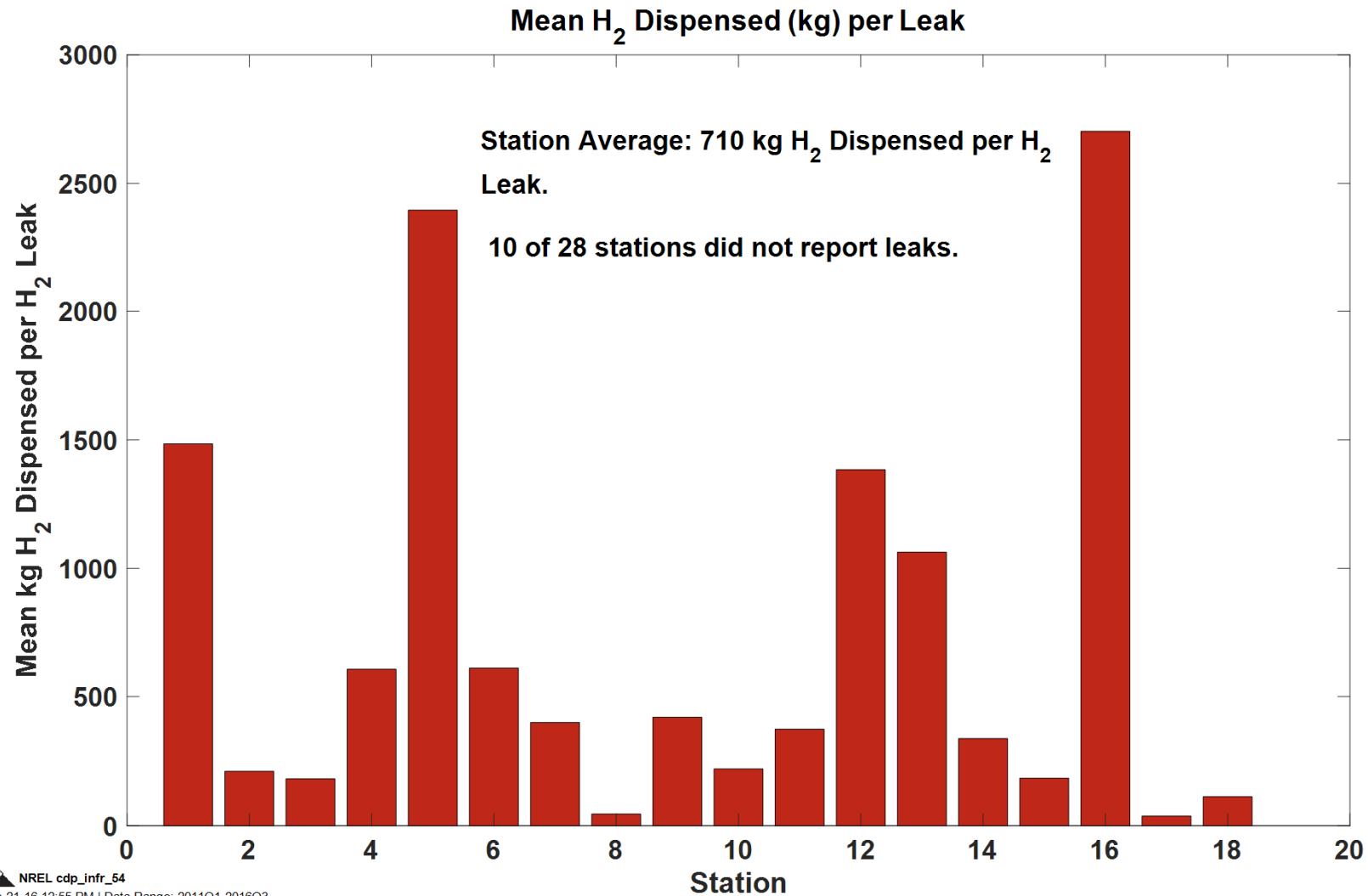
NREL cdp_infr_34

Created: Dec-12-16 1:58 PM | Data Range: 2008Q3-2016Q3

Mean Fills per Hydrogen Leak

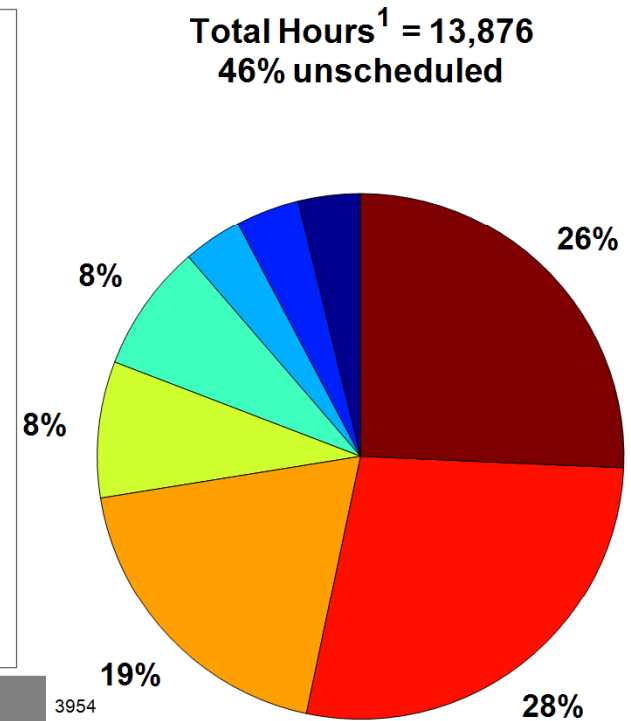
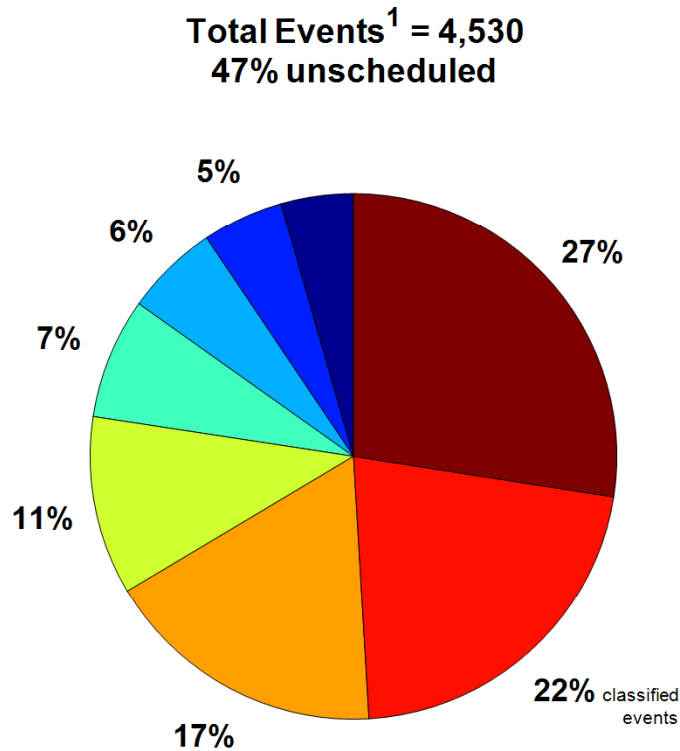


Mean Hydrogen Dispensed per Hydrogen Leak



Maintenance and Reliability

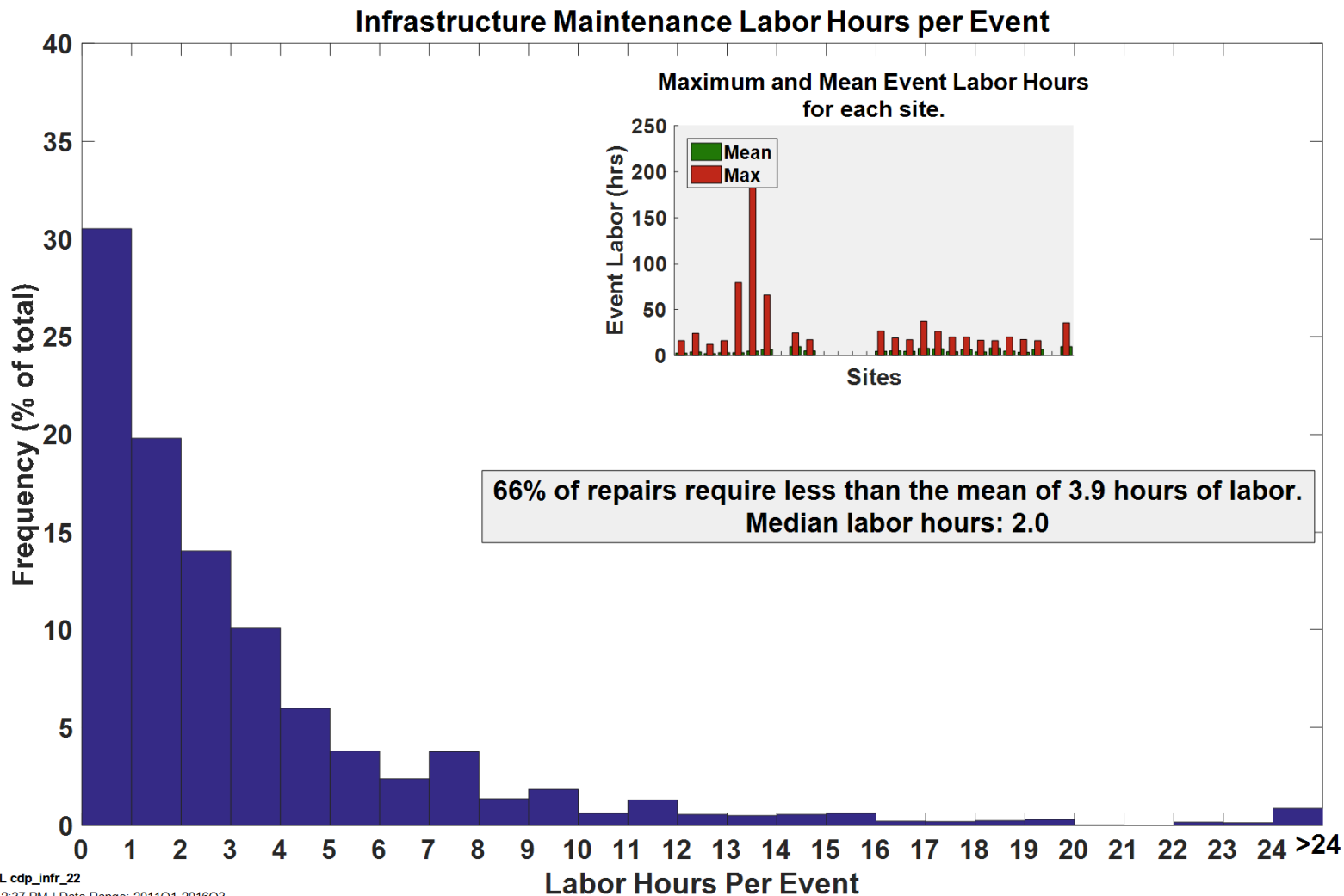
Maintenance by Equipment Type

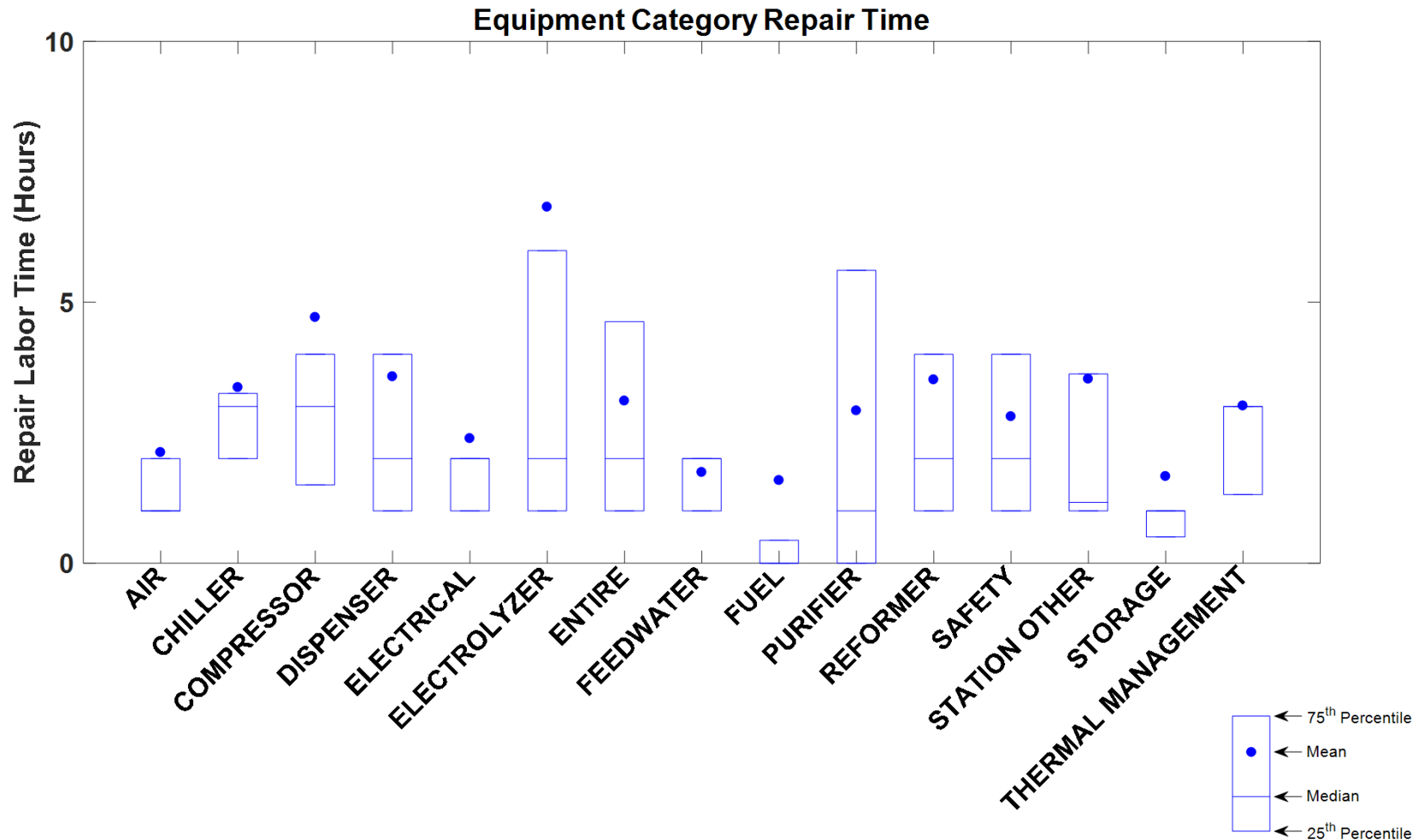


multiple systems 576 **Event Count**

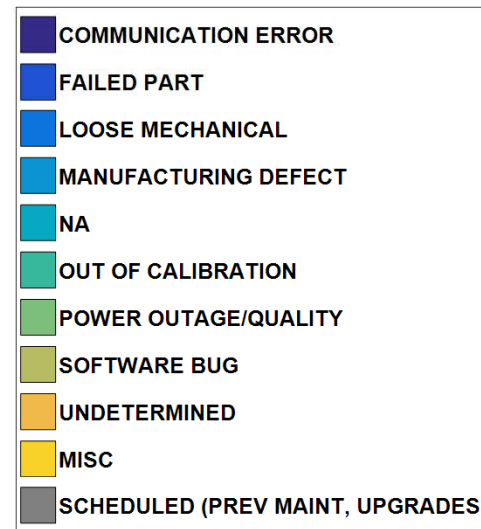
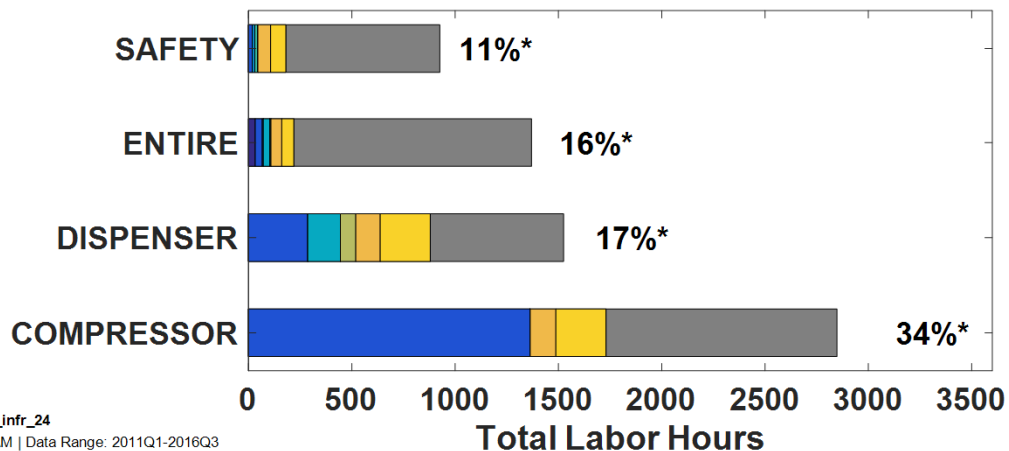
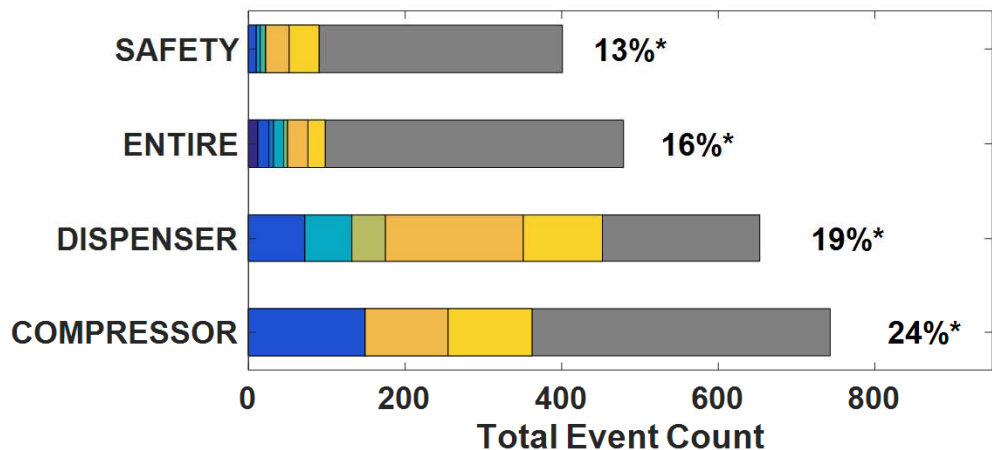
MISC includes the following failure modes: fuel, electrolyzer, station other, purifier, feedwater, air, electrical, other

1. Total includes classified events (plotted) and unclassified events.



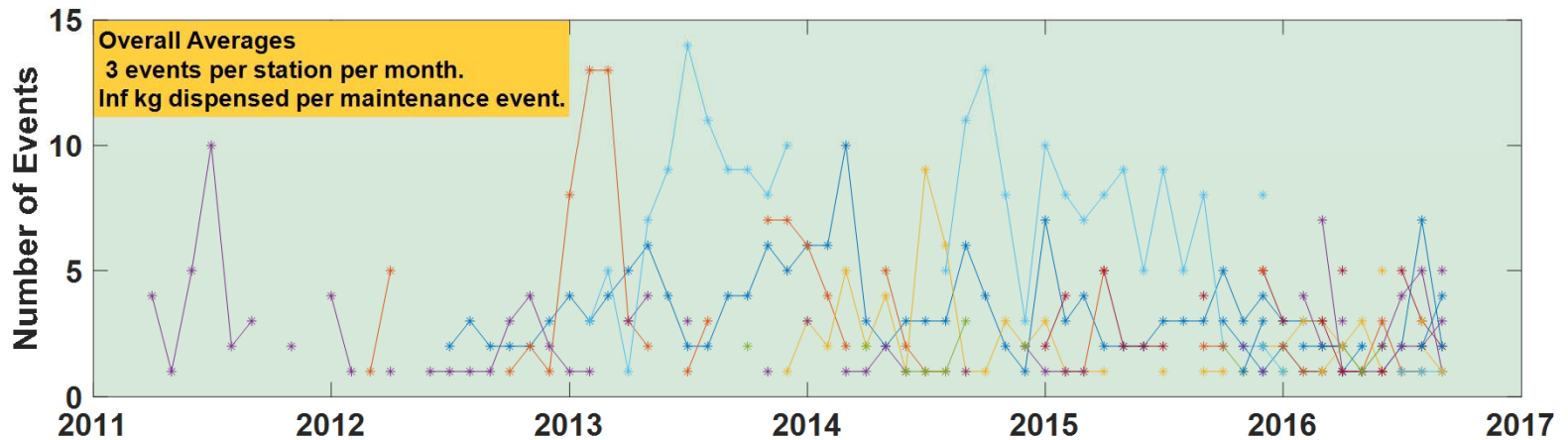
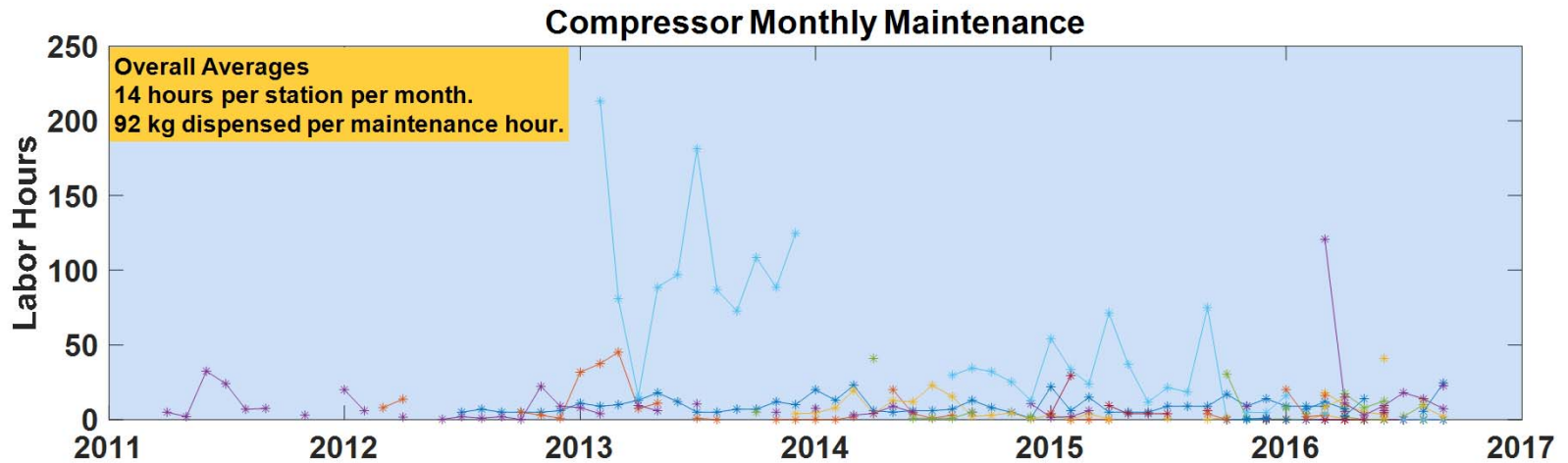


Failure Modes for Top Equipment Categories



MISC includes the following failure modes: animal damage, collision, communication error, contamination, corrective maintenance, debris, design flaw, electrical breaker, end of life, environmental factors, freezing, installation error, inspect trouble alarm or report, level low, loose electrical, loose mechanical, maintenance error, manufacturing defect, material deform/degrade/fatigue, moisture, na, operator error, out of calibration, overtemperature, power outage/quality, pressure loss, software bug, stress outside design limit, vibration, other

* Percentage of total events or hours.

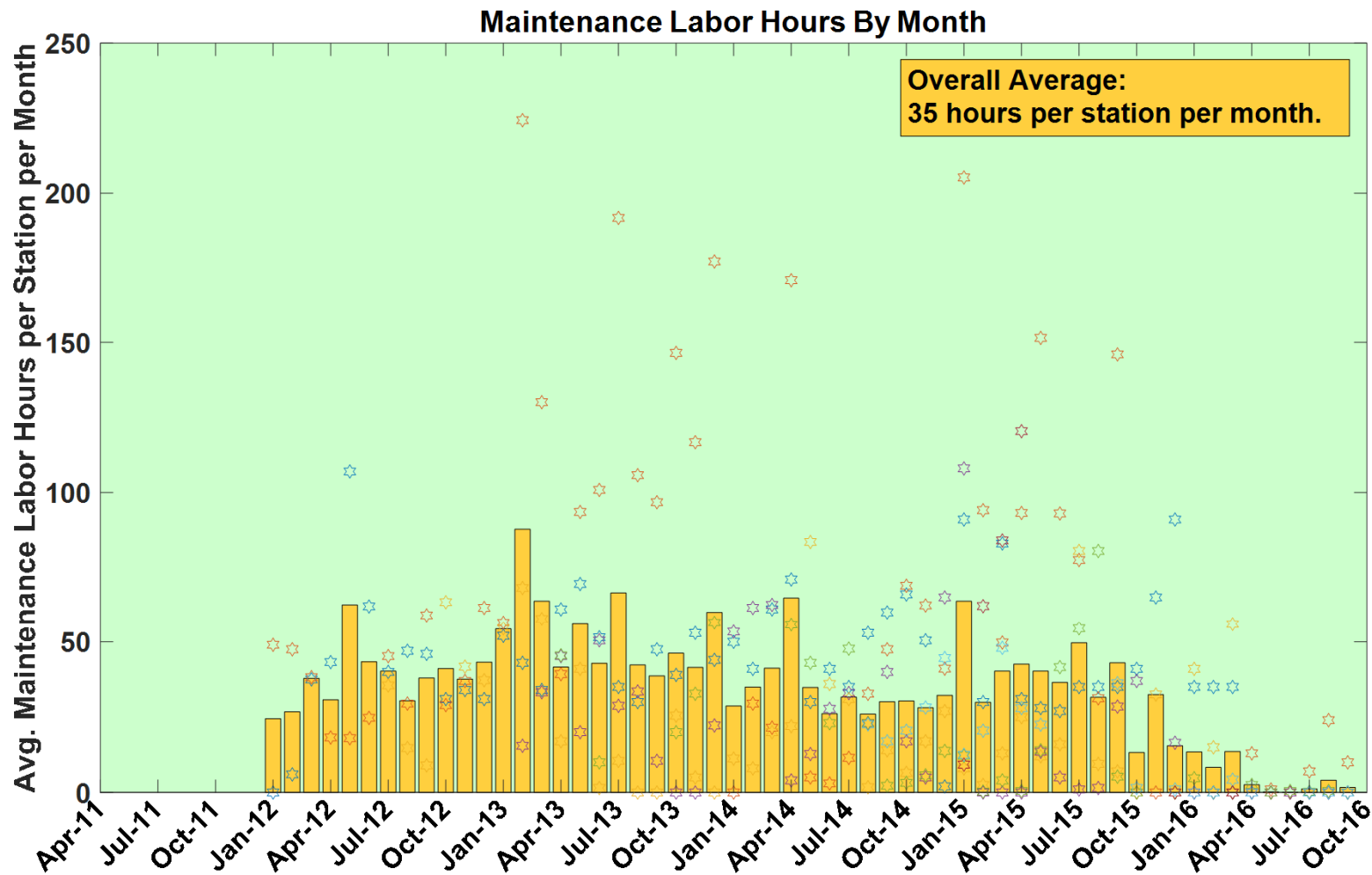


NREL cdp_infr_26

Created: Dec-19-16 10:36 AM | Data Range: 2011Q1-2016Q3

* Trendlines connect continuous months of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

Maintenance Labor Hours by Month

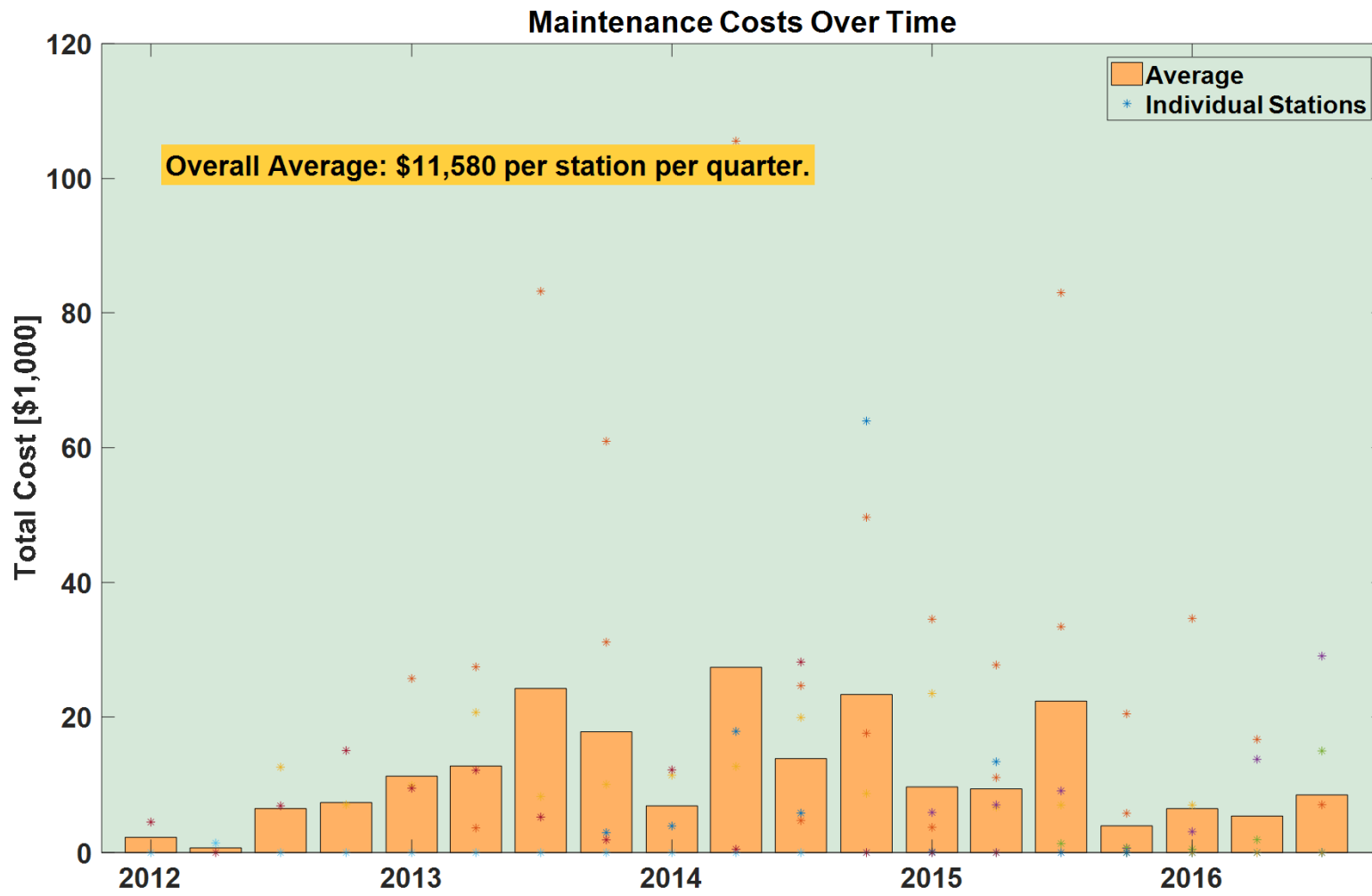


**Overall Average:
35 hours per station per month.**



NREL cdp_infr_28
Created: Dec-21-16 12:37 PM | Data Range: 2011Q1-2016Q3

Stars represent individual station maintenance hours in a given month.

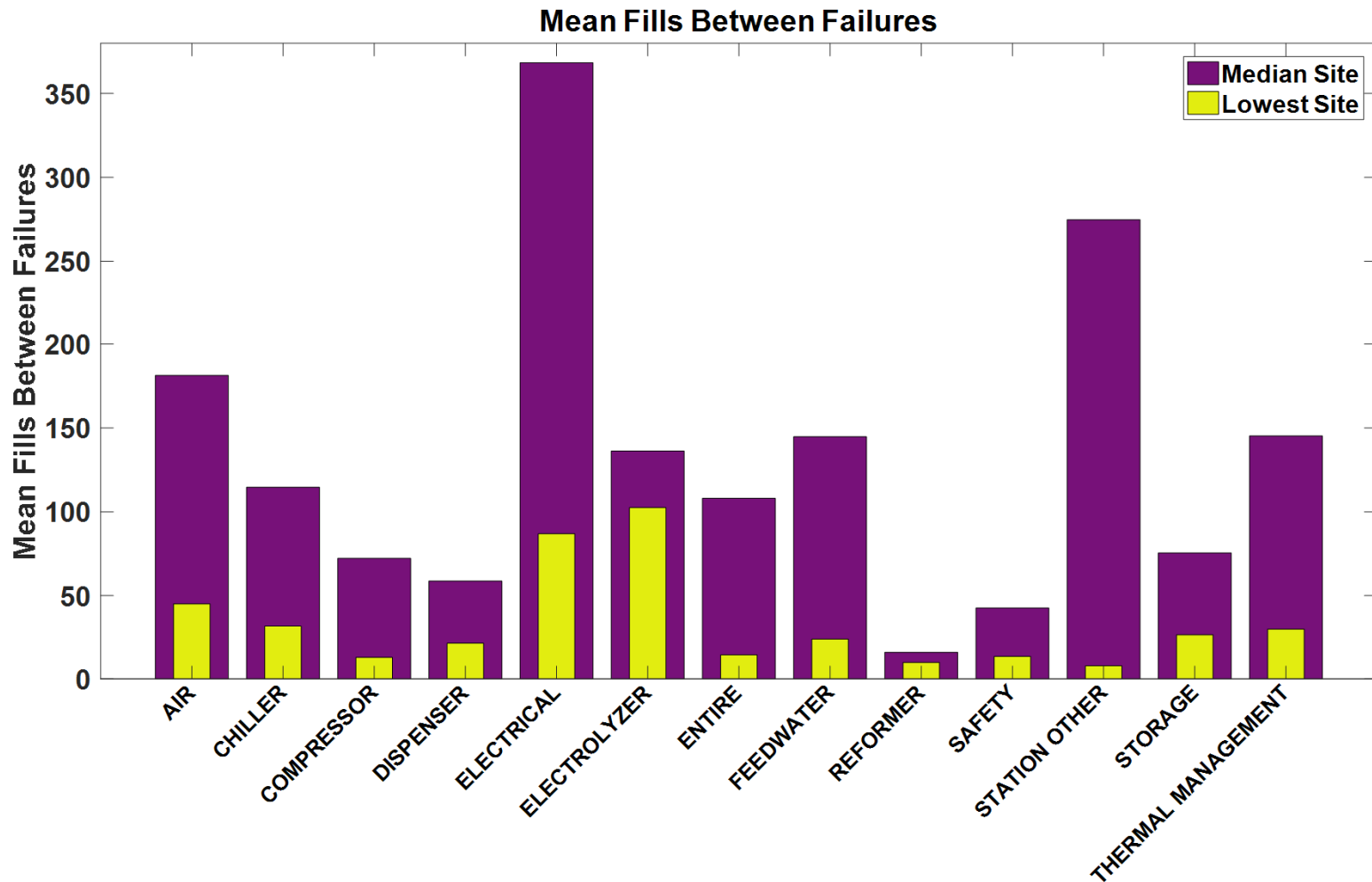


*Each color represents a unique station.

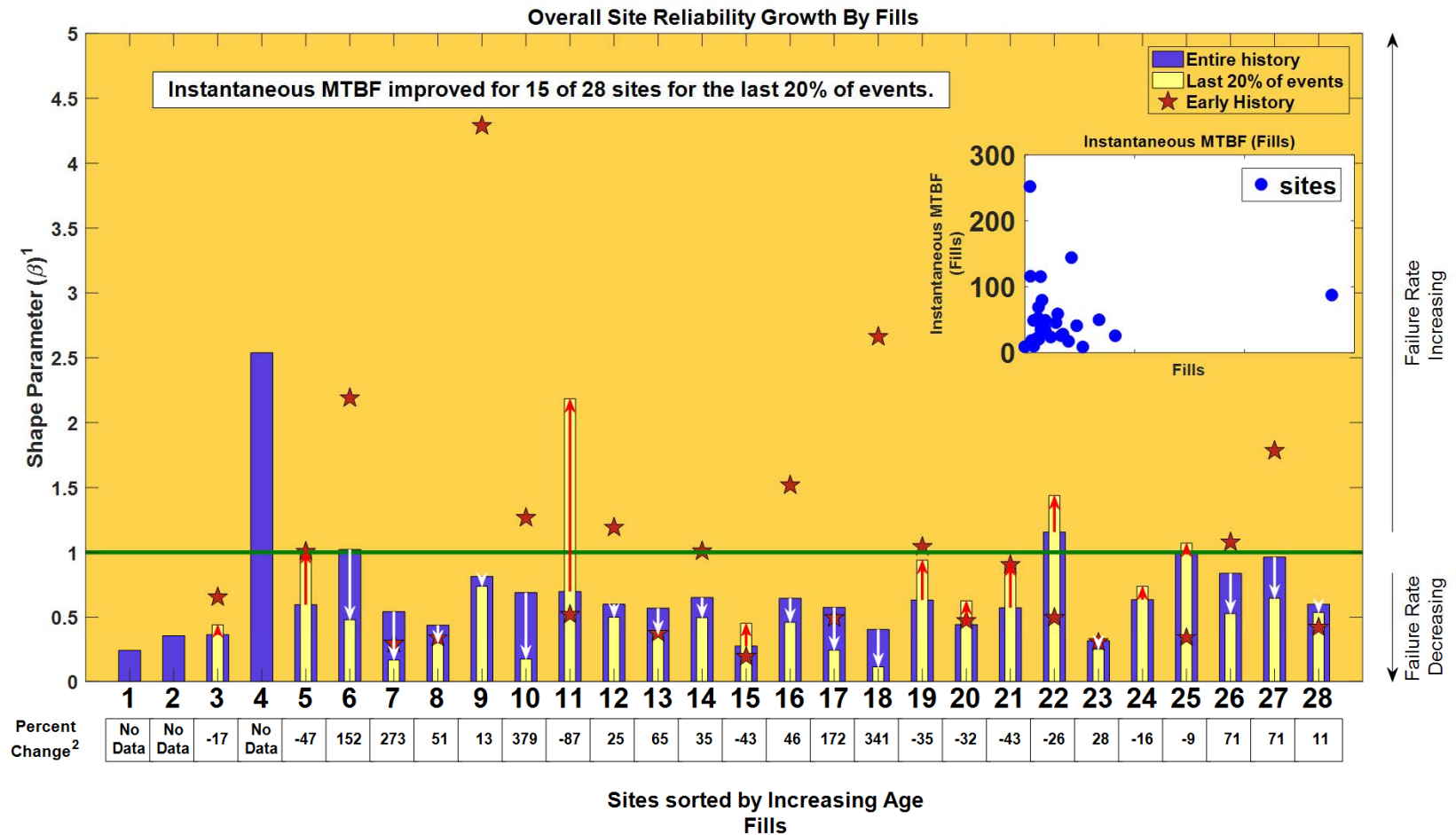


NREL cdp_infr_30

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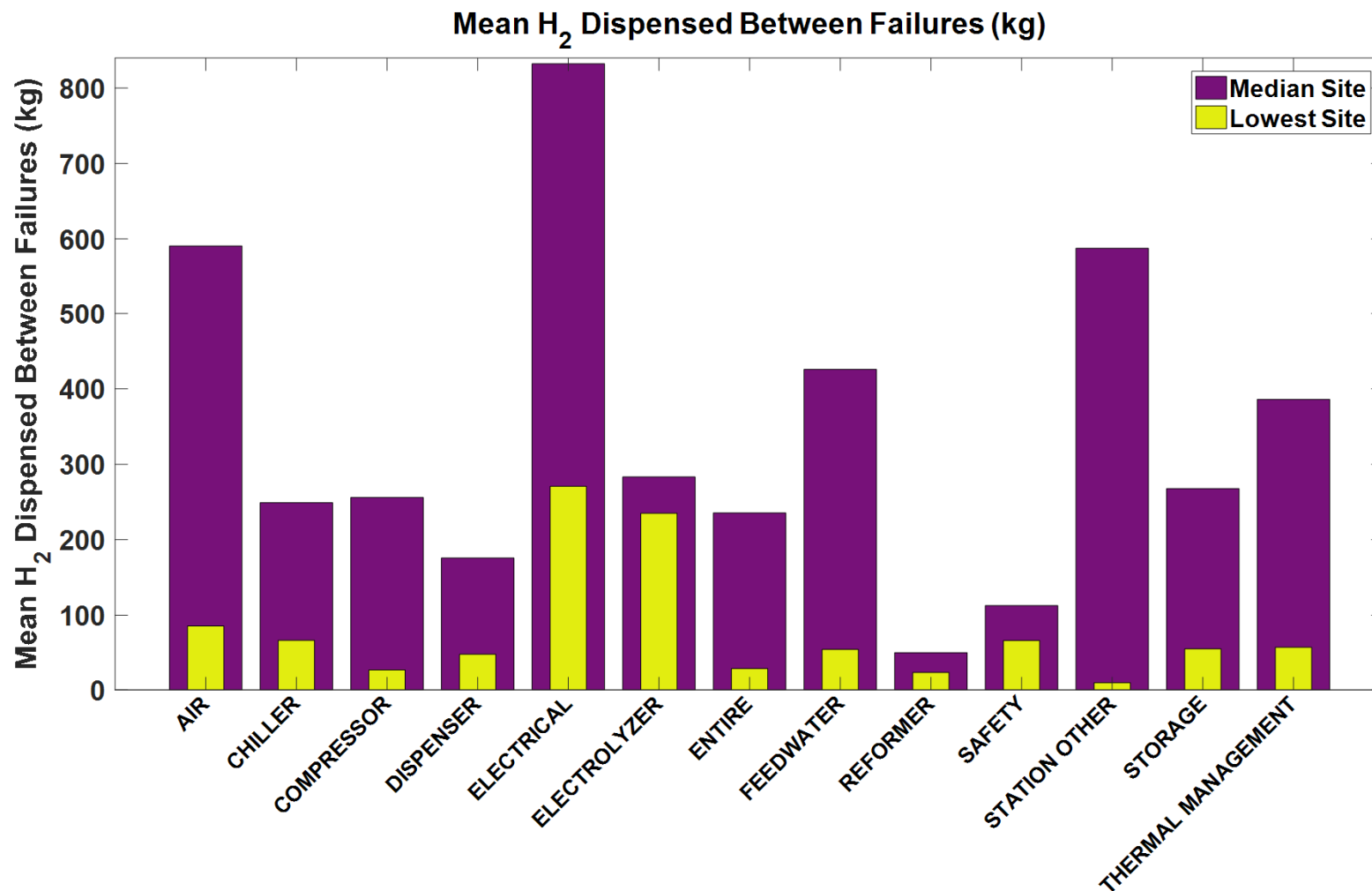


NREL cdp_infr_49
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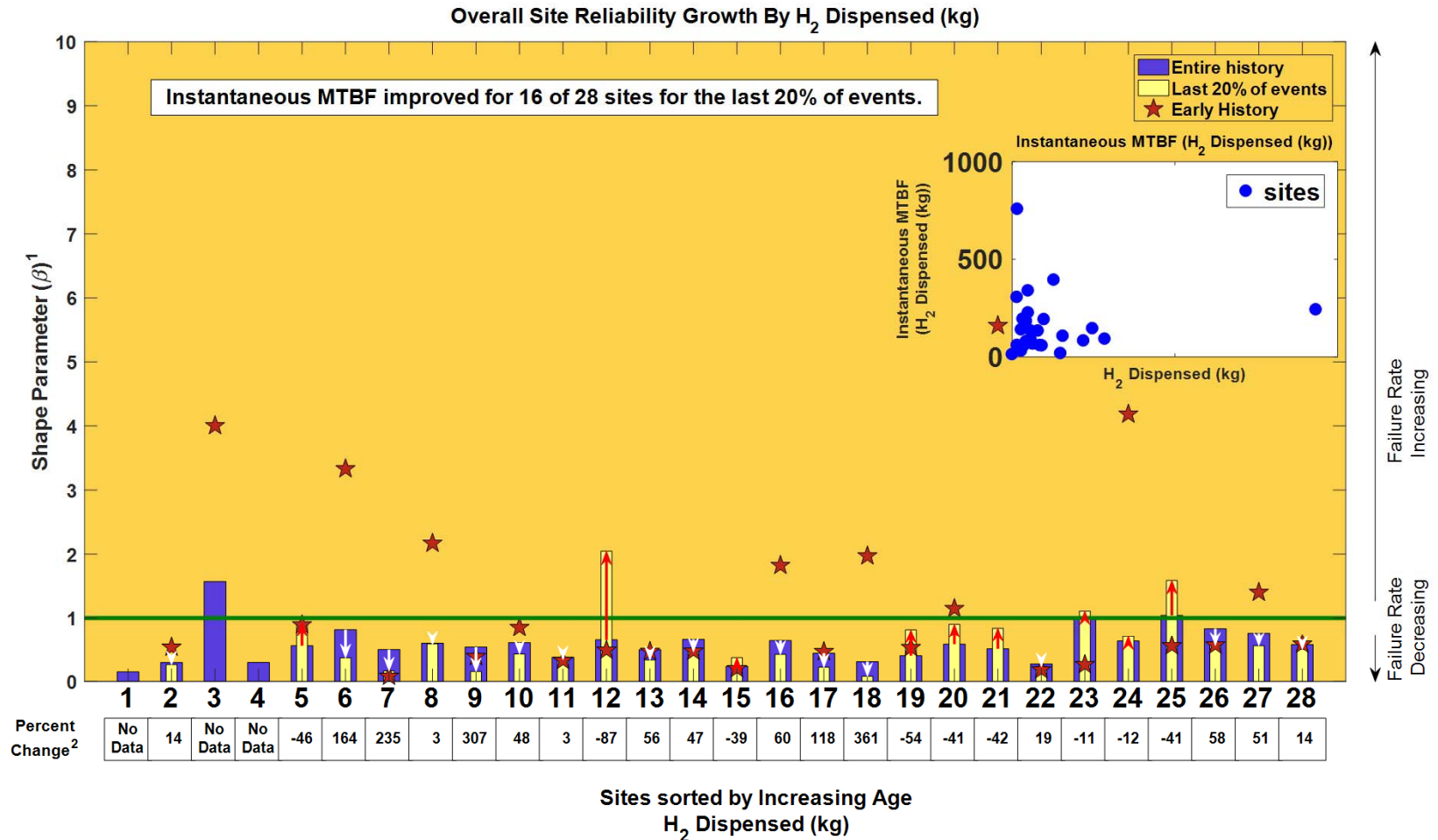


1. IEC 61164:2004(E), Reliability Growth - Statistical Test and Evaluation Methods, IEC. 2004.
2. % change in instantaneous mean Fills between failures

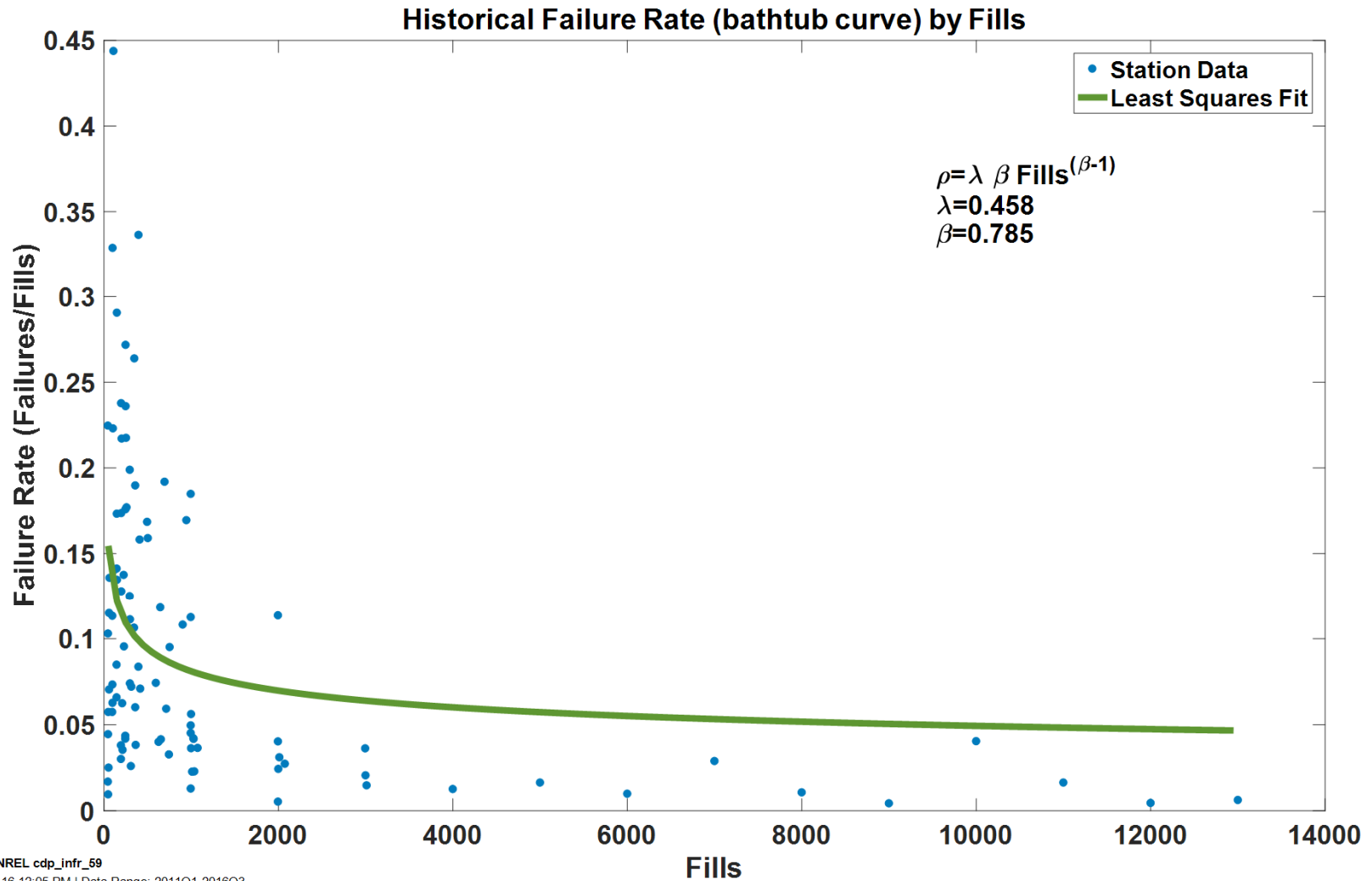
Mean Amount Dispensed Between Failures



NREL cdp_infr_51
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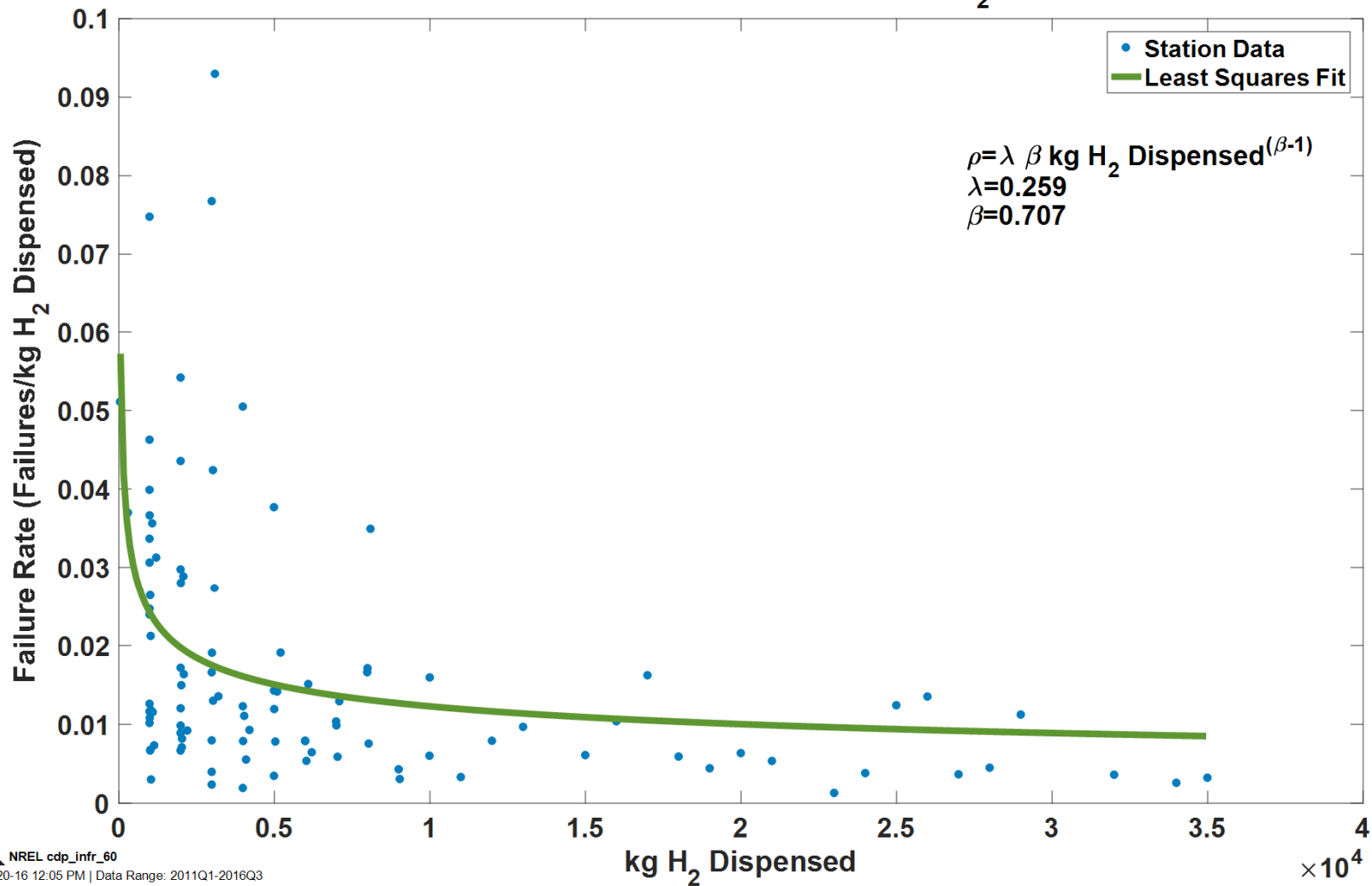


1. IEC 61164:2004(E), Reliability Growth - Statistical Test and Evaluation Methods, IEC. 2004.
2. % change in instantaneous mean H₂ Dispensed (kg) between failures



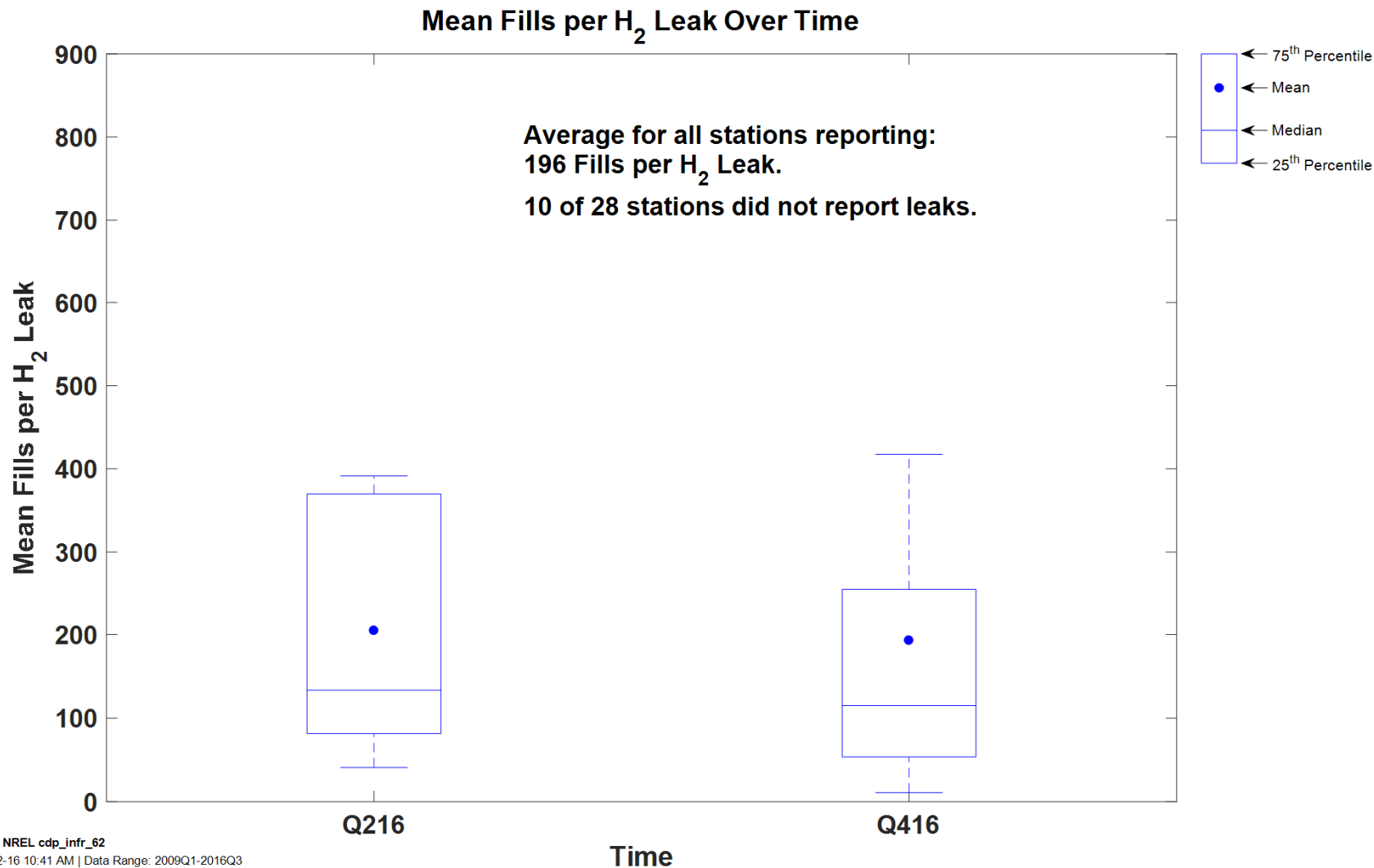
Historical Failure Rate by Amount Dispensed

Historical Failure Rate (bathtub curve) by kg H₂ Dispensed



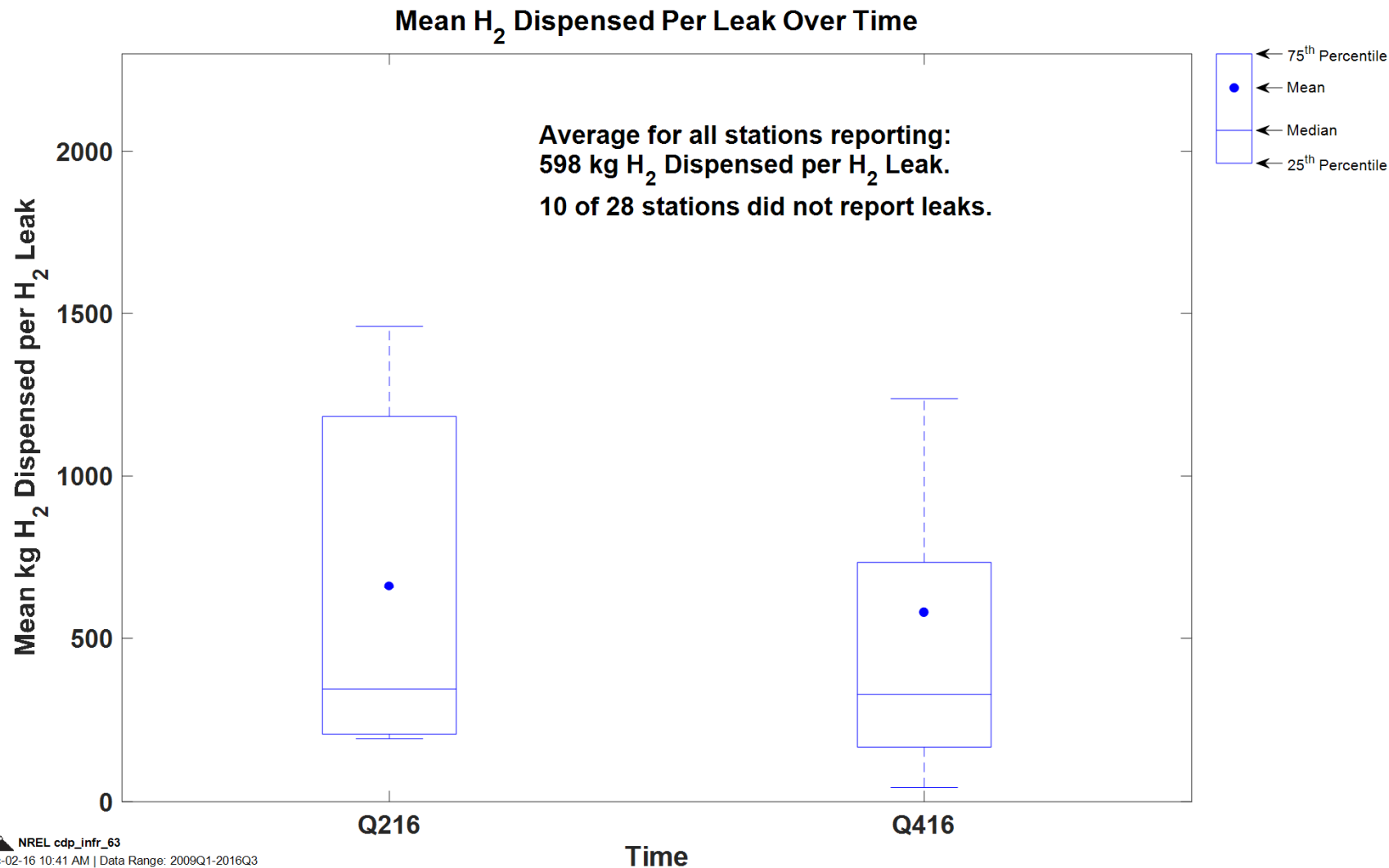
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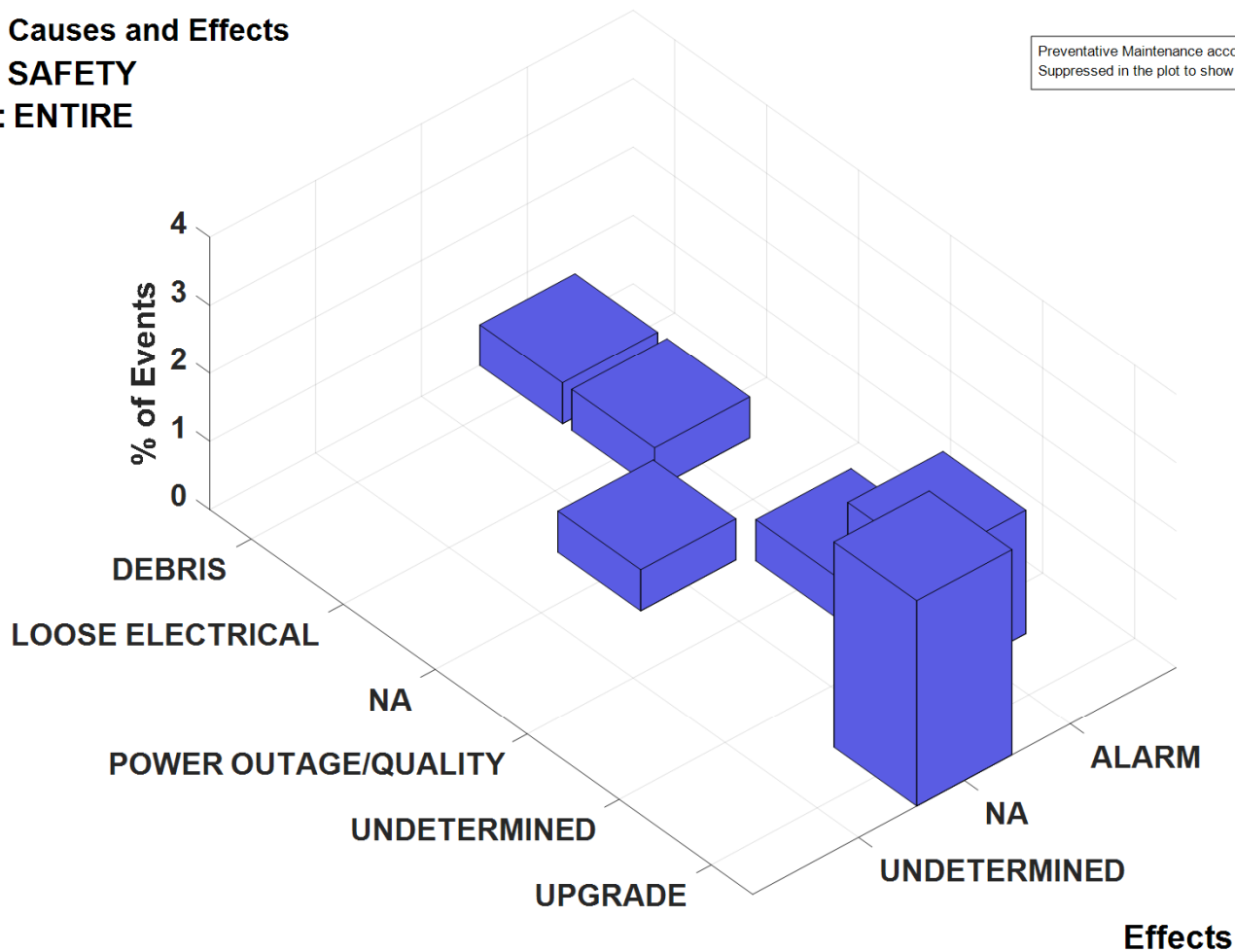


Maintenance Causes and Effects

Subsystem: SAFETY

Component: ENTIRE

Preventative Maintenance accounted for 93% of all events.
Suppressed in the plot to show detail for other causes.



Causes

Effects



NREL cdp_infr_64

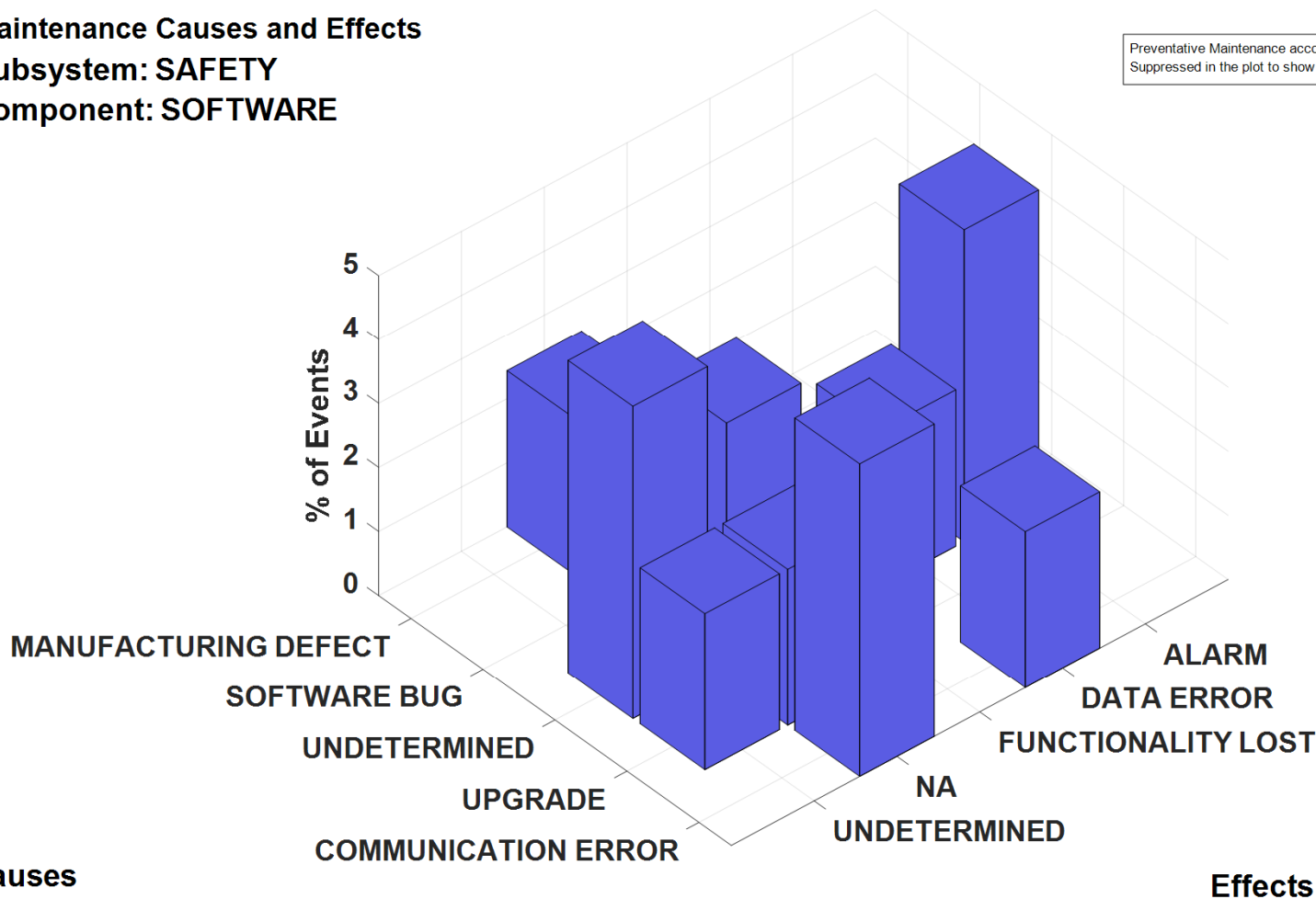
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Maintenance Causes and Effects

Subsystem: SAFETY

Component: SOFTWARE

Preventative Maintenance accounted for 71% of all events.
Suppressed in the plot to show detail for other causes.



Causes

Effects



NREL cdp_infr_66

Created: Dec-02-16 3:15 PM | Data Range: 2011Q1-2016Q3

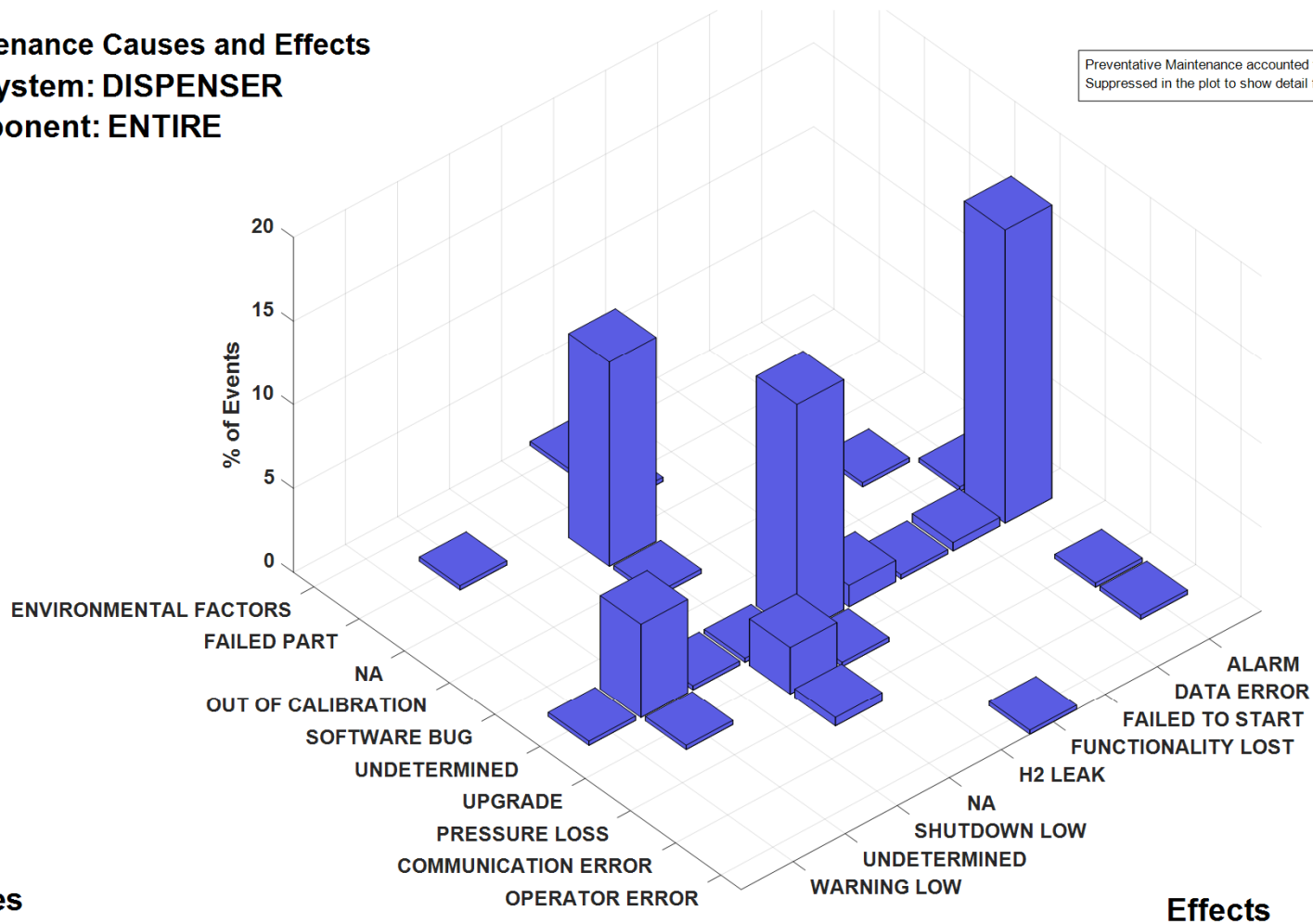
Maintenance Causes and Effects: Dispenser (Entire)

Maintenance Causes and Effects

Subsystem: DISPENSER

Component: ENTIRE

Preventative Maintenance accounted for 42% of all events.
Suppressed in the plot to show detail for other causes.



Causes

Effects



NREL cdp_infr_67

Created: Dec-02-16 3:15 PM | Data Range: 2011Q1-2016Q3

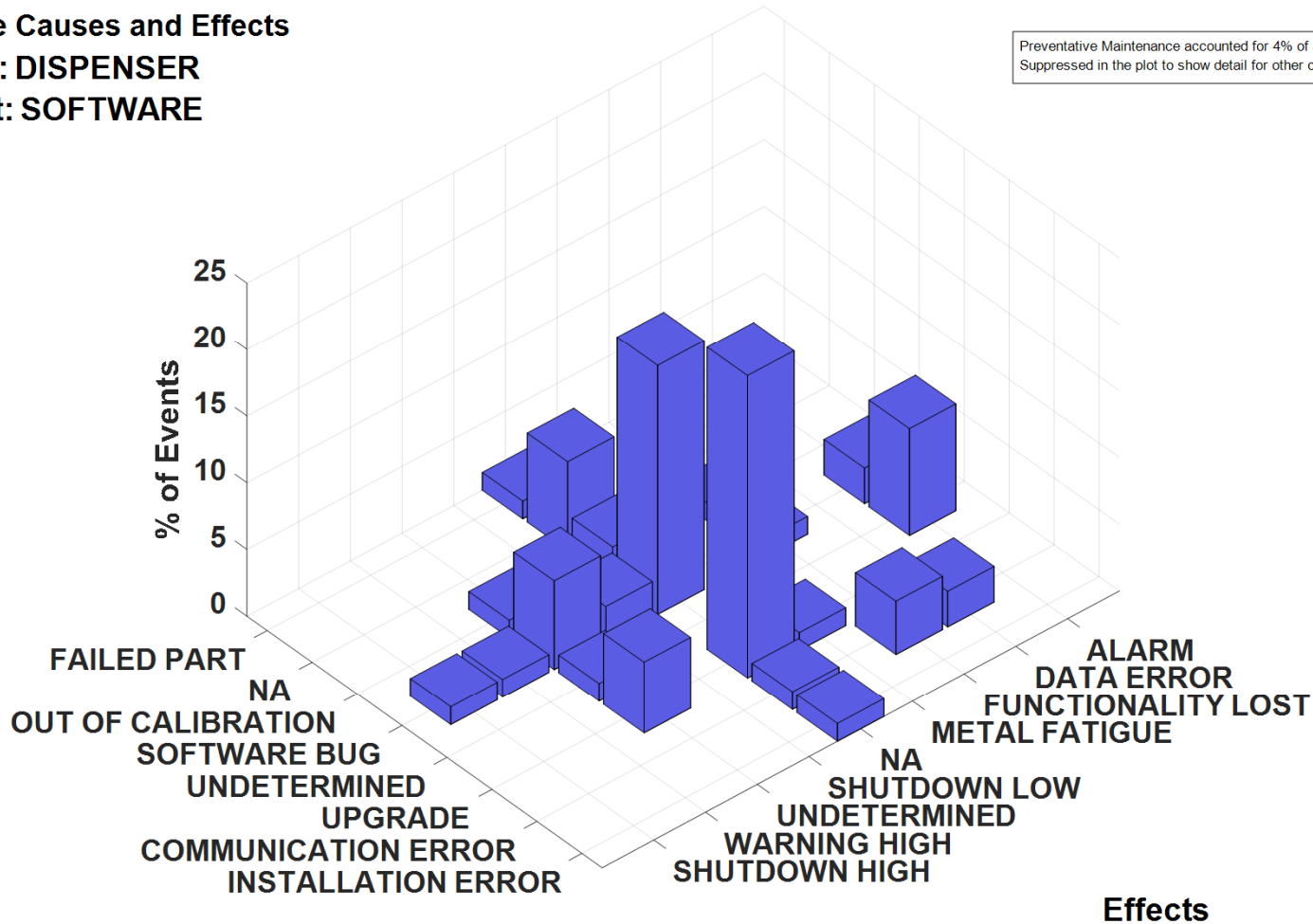
Maintenance Causes and Effects: Dispenser (Software)

Maintenance Causes and Effects

Subsystem: DISPENSER

Component: SOFTWARE

Preventative Maintenance accounted for 4% of all events.
Suppressed in the plot to show detail for other causes.



Causes

Effects

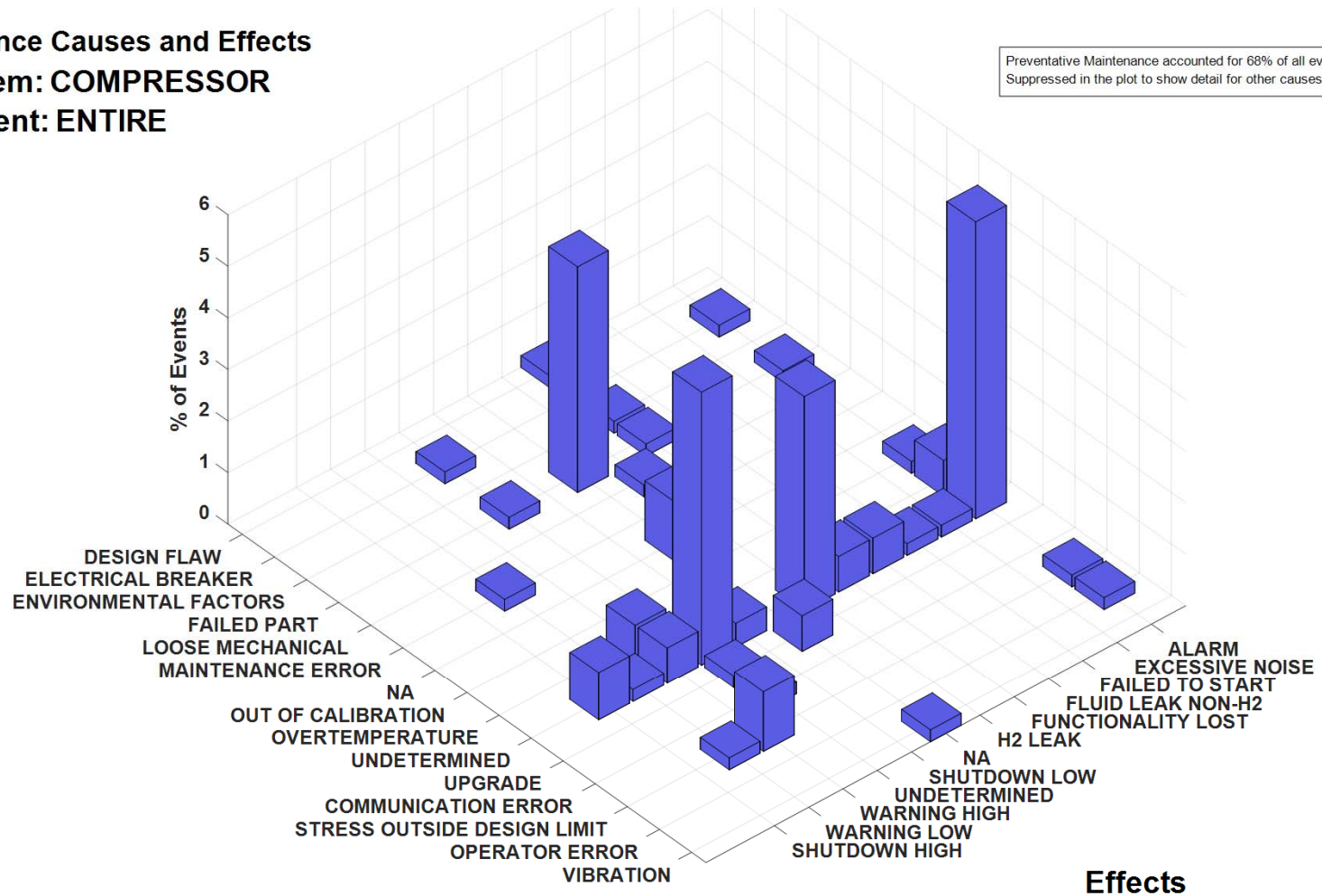


NREL cdp_infr_69

Created: Dec-02-16 3:15 PM | Data Range: 2011Q1-2016Q3

Maintenance Causes and Effects
Subsystem: COMPRESSOR
Component: ENTIRE

Preventative Maintenance accounted for 68% of all events.
 Suppressed in the plot to show detail for other causes.



Causes

Effects



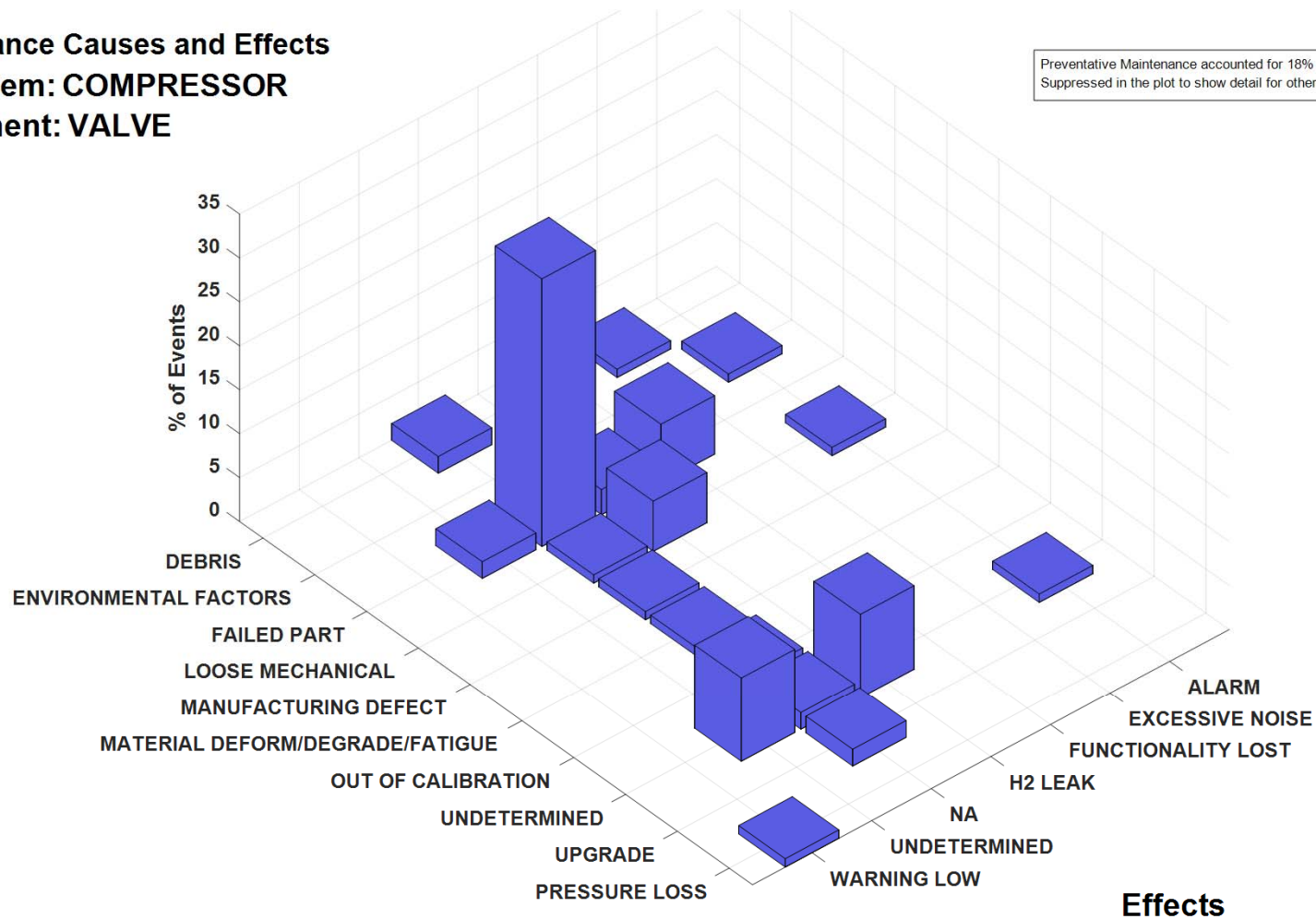
NREL cdp_infr_70

Created: Dec-02-16 3:15 PM | Data Range: 2011Q1-2016Q3

Maintenance Causes and Effects: Compressor (Valve)

Maintenance Causes and Effects
Subsystem: COMPRESSOR
Component: VALVE

Preventative Maintenance accounted for 18% of all events.
 Suppressed in the plot to show detail for other causes.



Causes

Effects



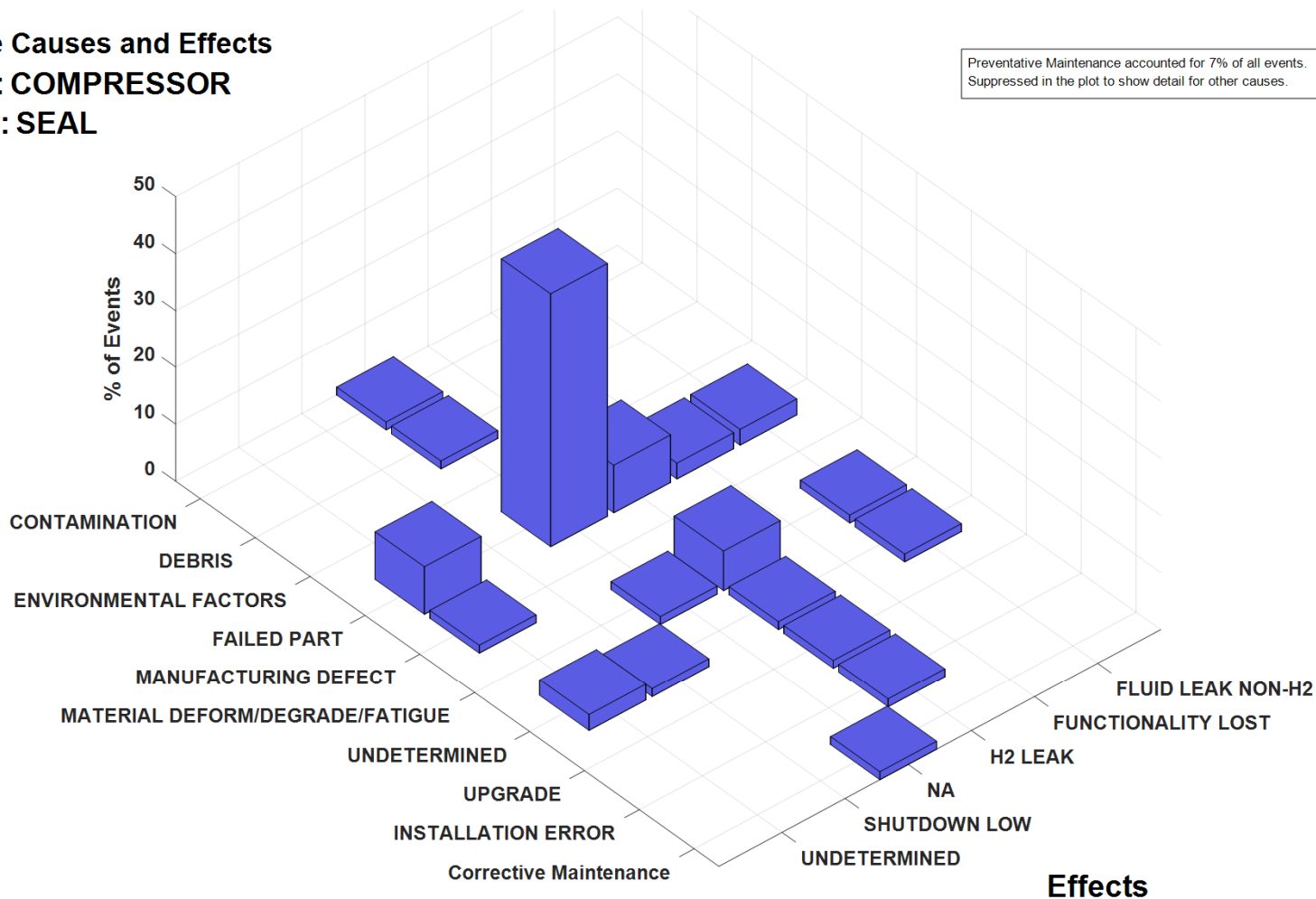
NREL cdp_infr_71

Created: Dec-02-16 3:15 PM | Data Range: 2011Q1-2016Q3

Maintenance Causes and Effects: Compressor (Seal)

Maintenance Causes and Effects
Subsystem: COMPRESSOR
Component: SEAL

Preventative Maintenance accounted for 7% of all events.
 Suppressed in the plot to show detail for other causes.



Causes

Effects

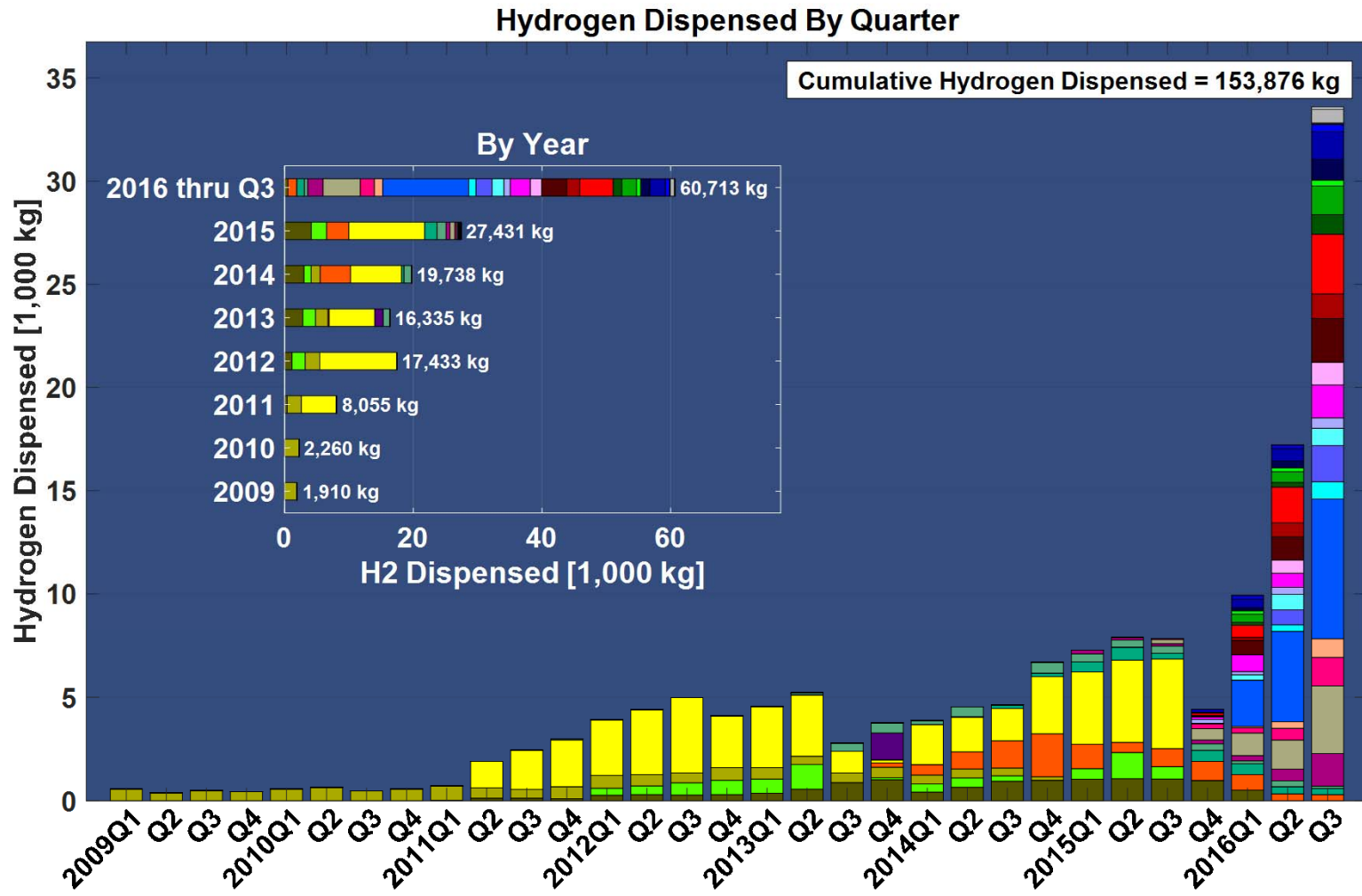


NREL cdp_infr_72

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Performance

Hydrogen Dispensed by Quarter

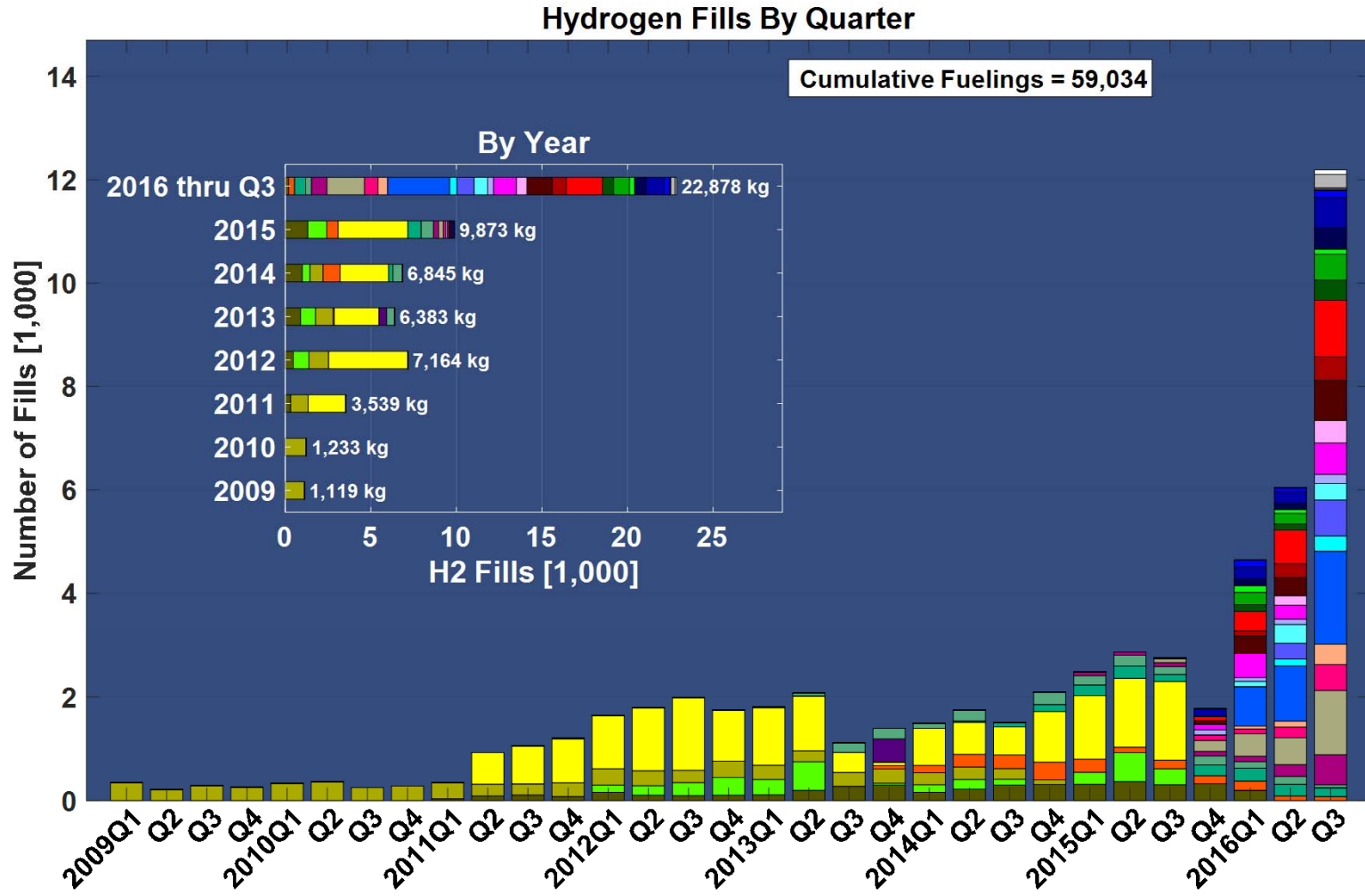


NREL cdp_infr_01

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Note: Colors represent individual stations

Hydrogen Fills by Quarter

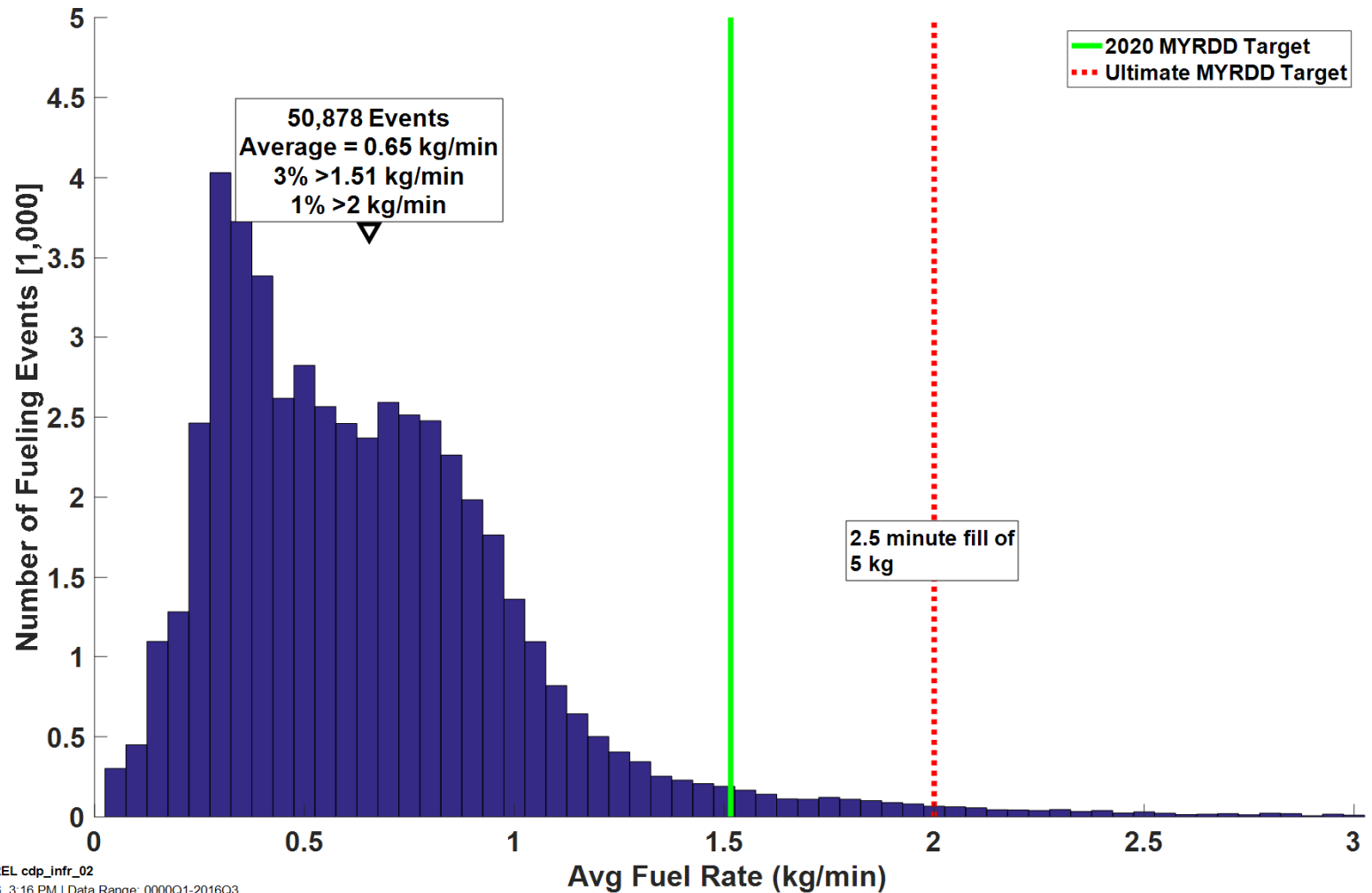


NREL cdp_infr_58

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Note: Colors represent individual stations

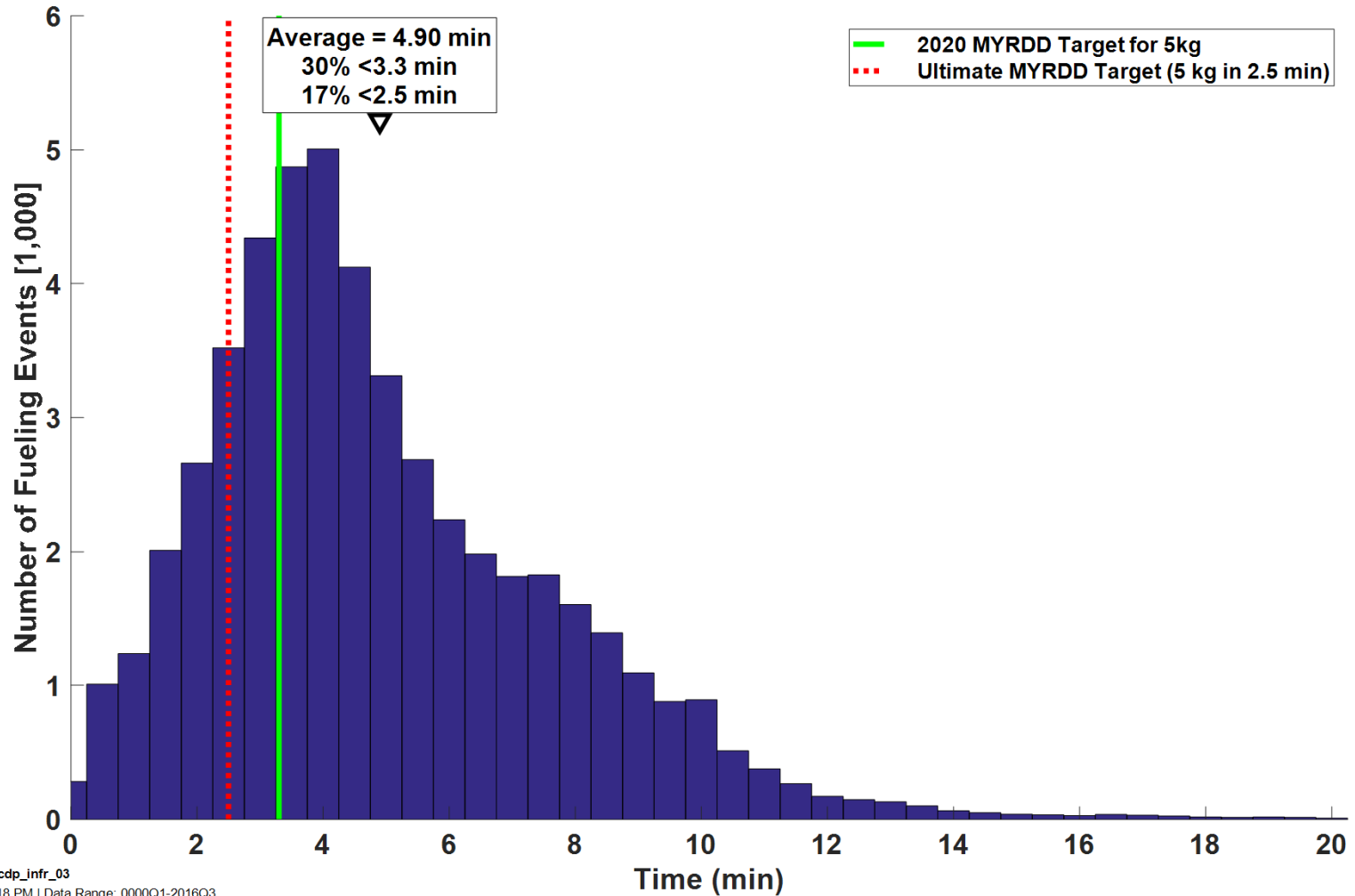
Histogram of Fueling Rates



NREL cdp_infr_02

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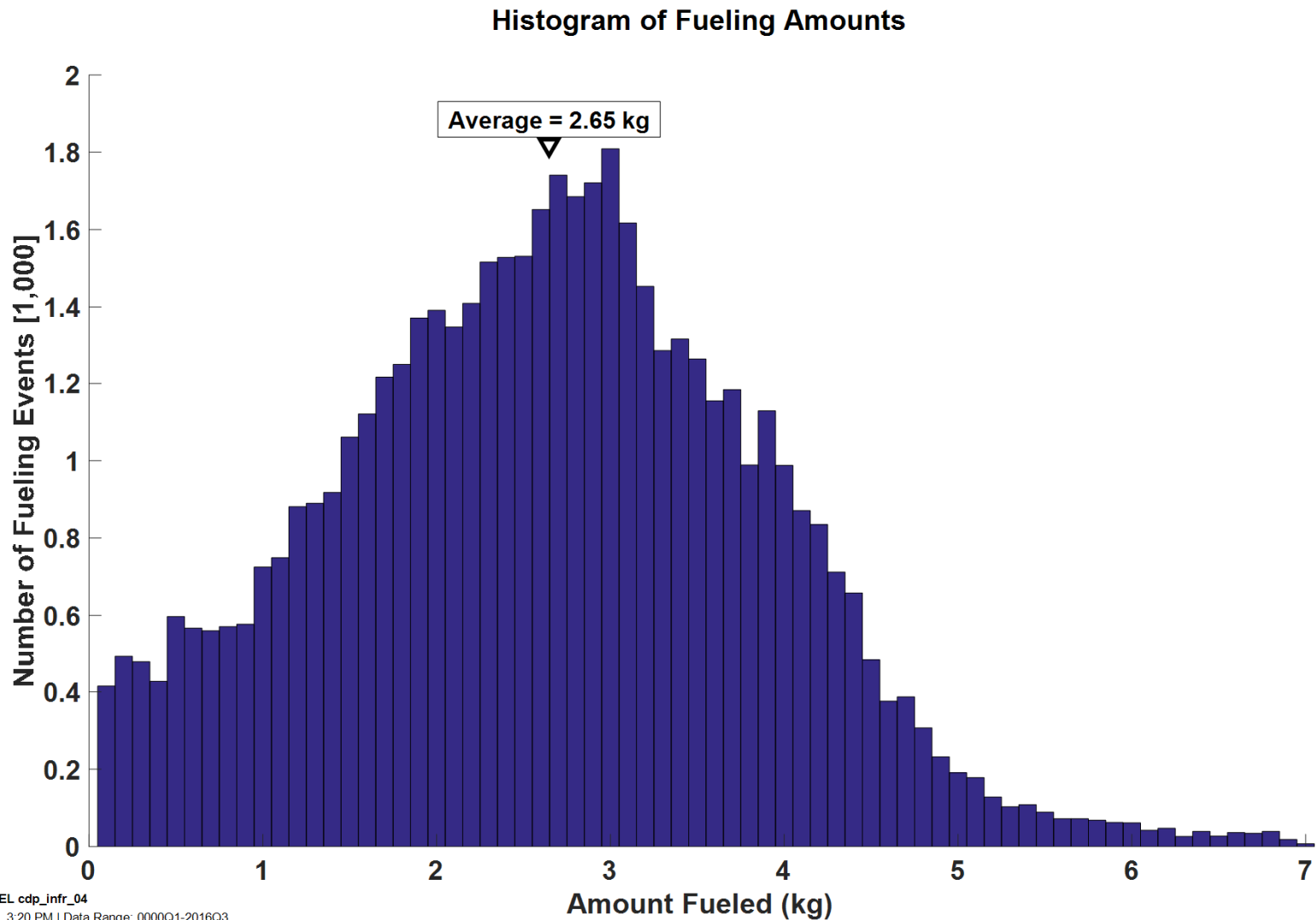
Histogram of Fueling Times



NREL cdp_infr_03

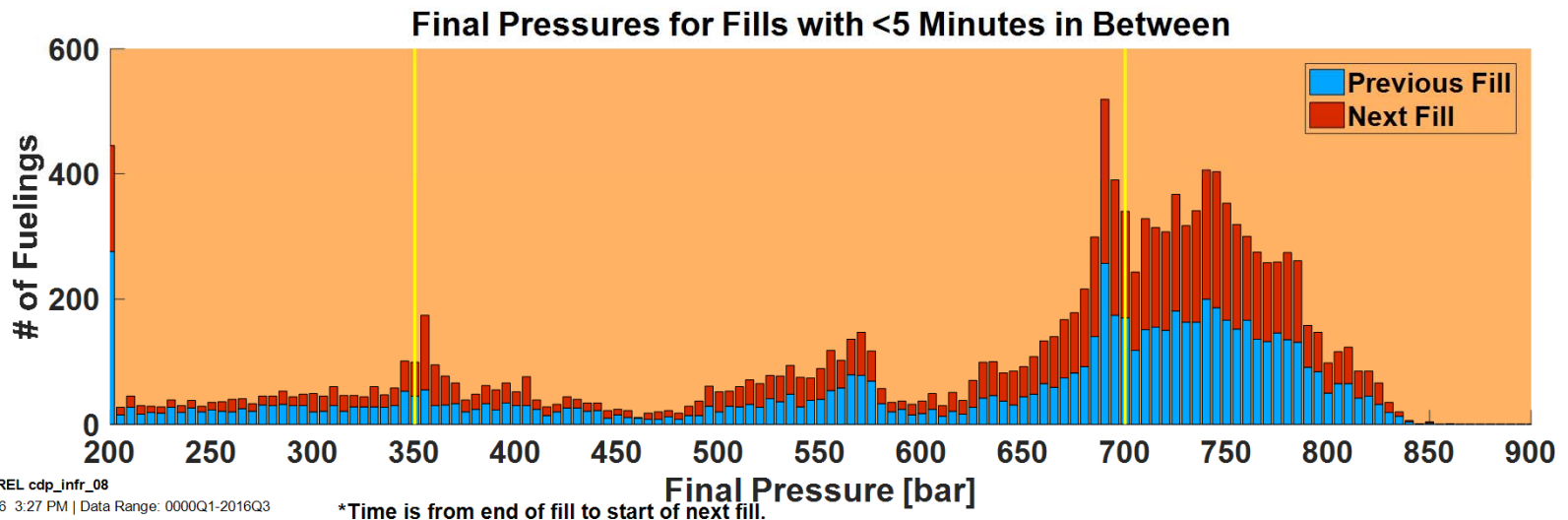
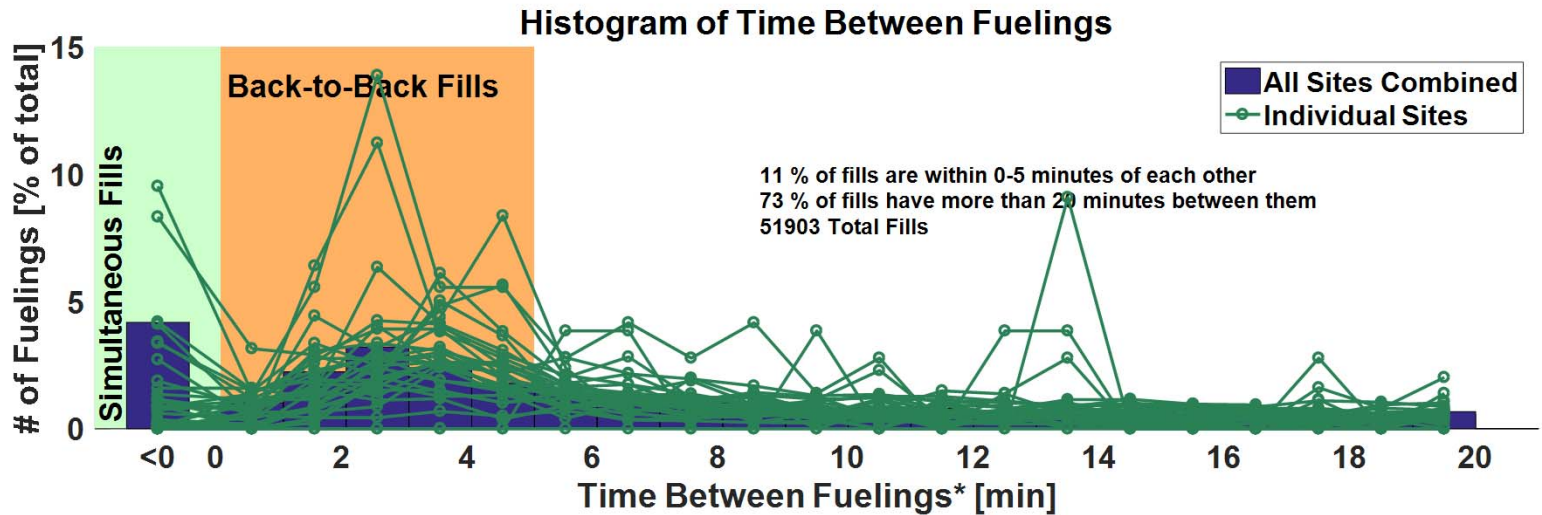
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Histogram of Fueling Amounts



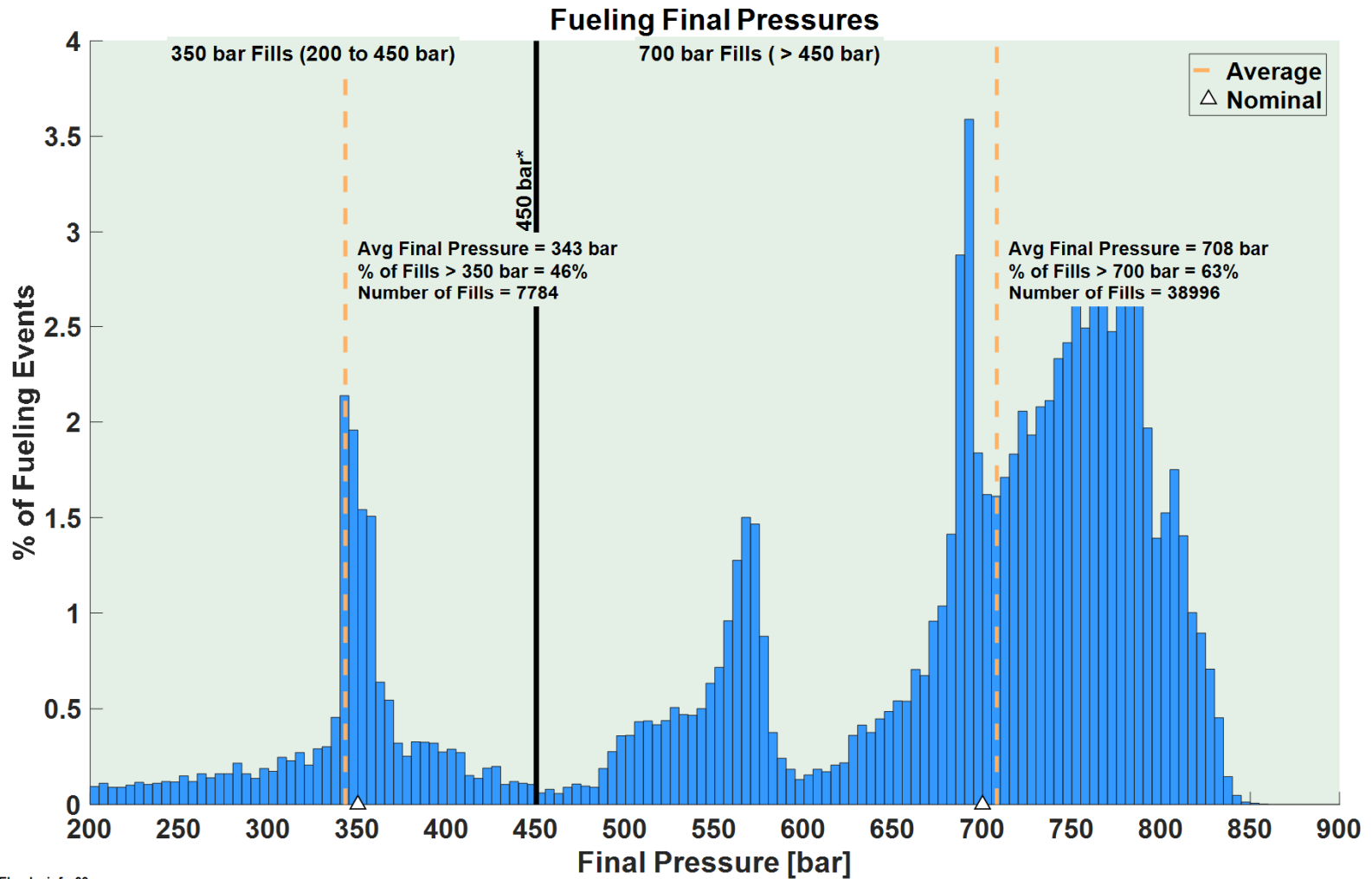
NREL cdp_infr_04

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NREL cdp_infr_08

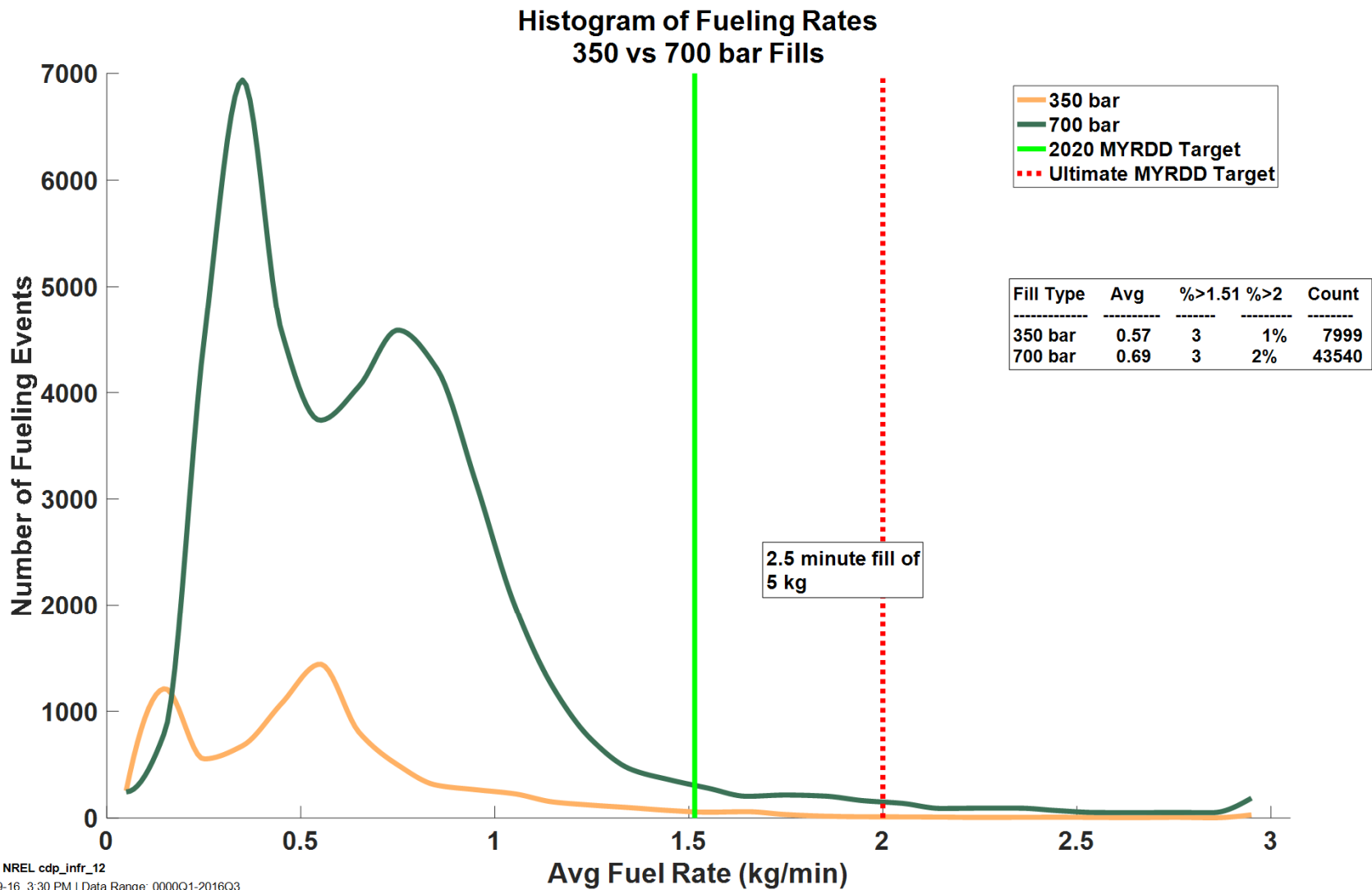
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NREL cdp_infr_09

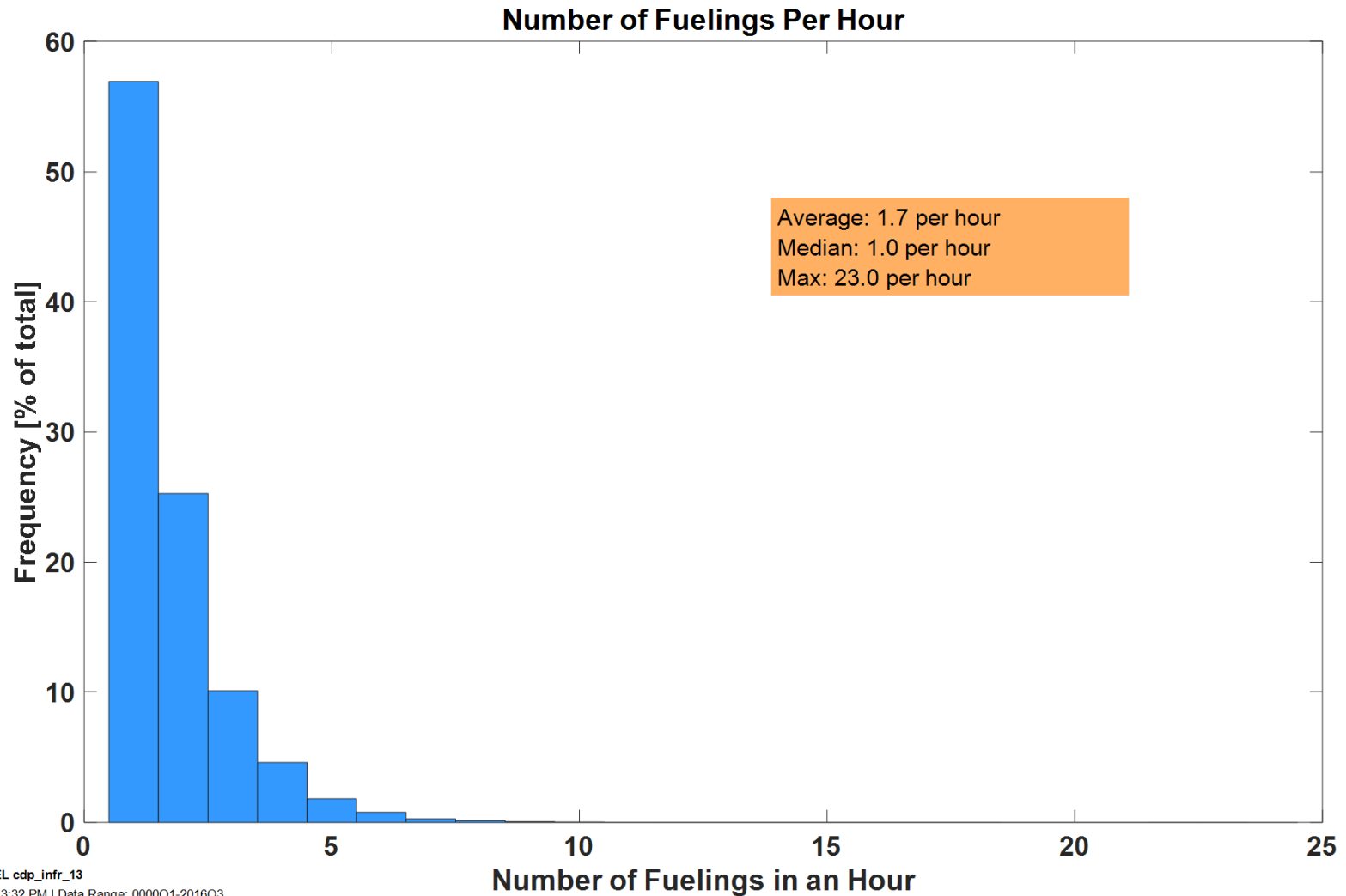
Created: Dec-09-16 3:29 PM | Data Range: 0000Q1-2016Q3

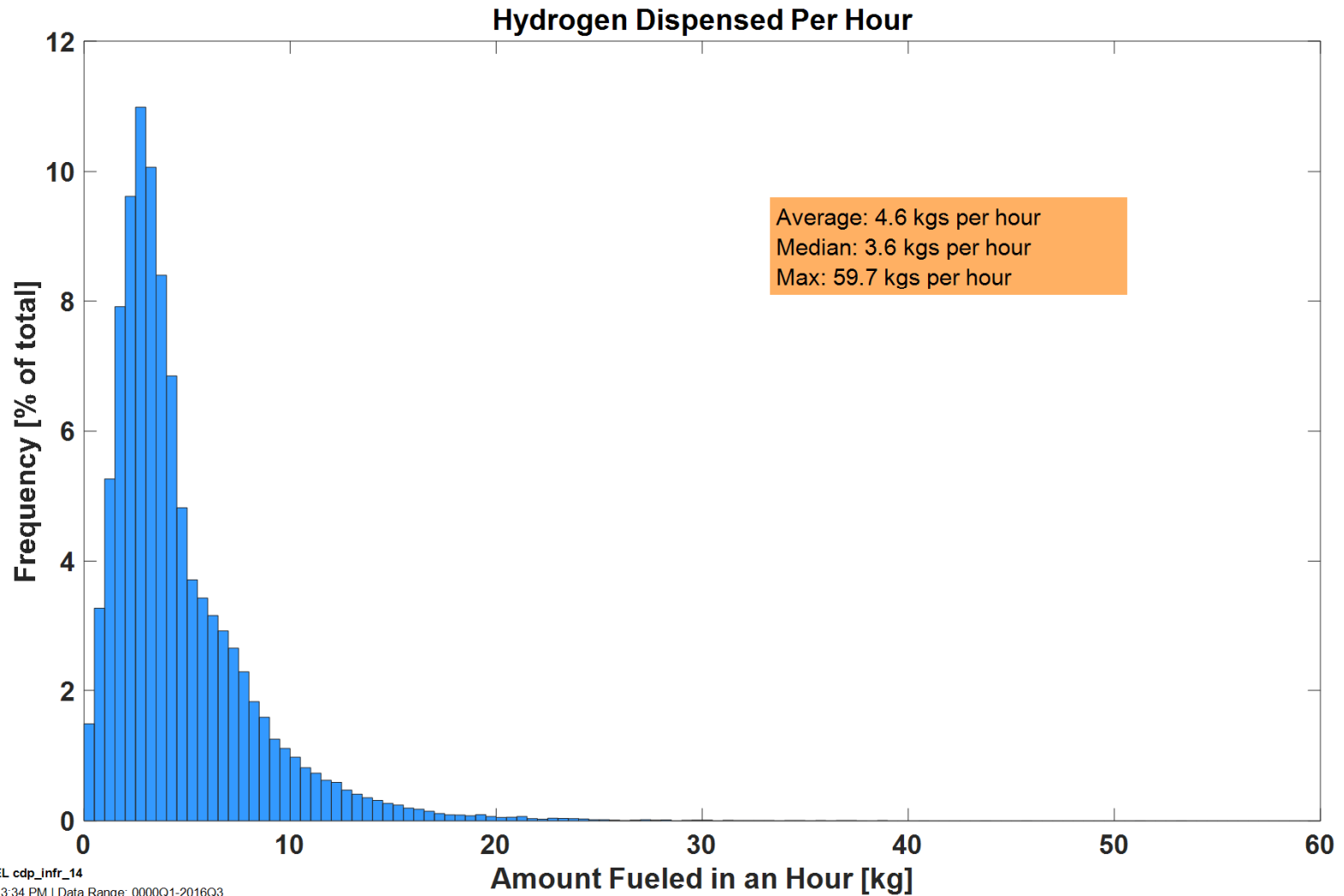
*The line at 450 bar separates 350 bar fills from 700 bar fills. It is slightly over the allowable 125% of nominal pressure (437.5 bar) from SAE J2601.



NREL cdp_infr_12

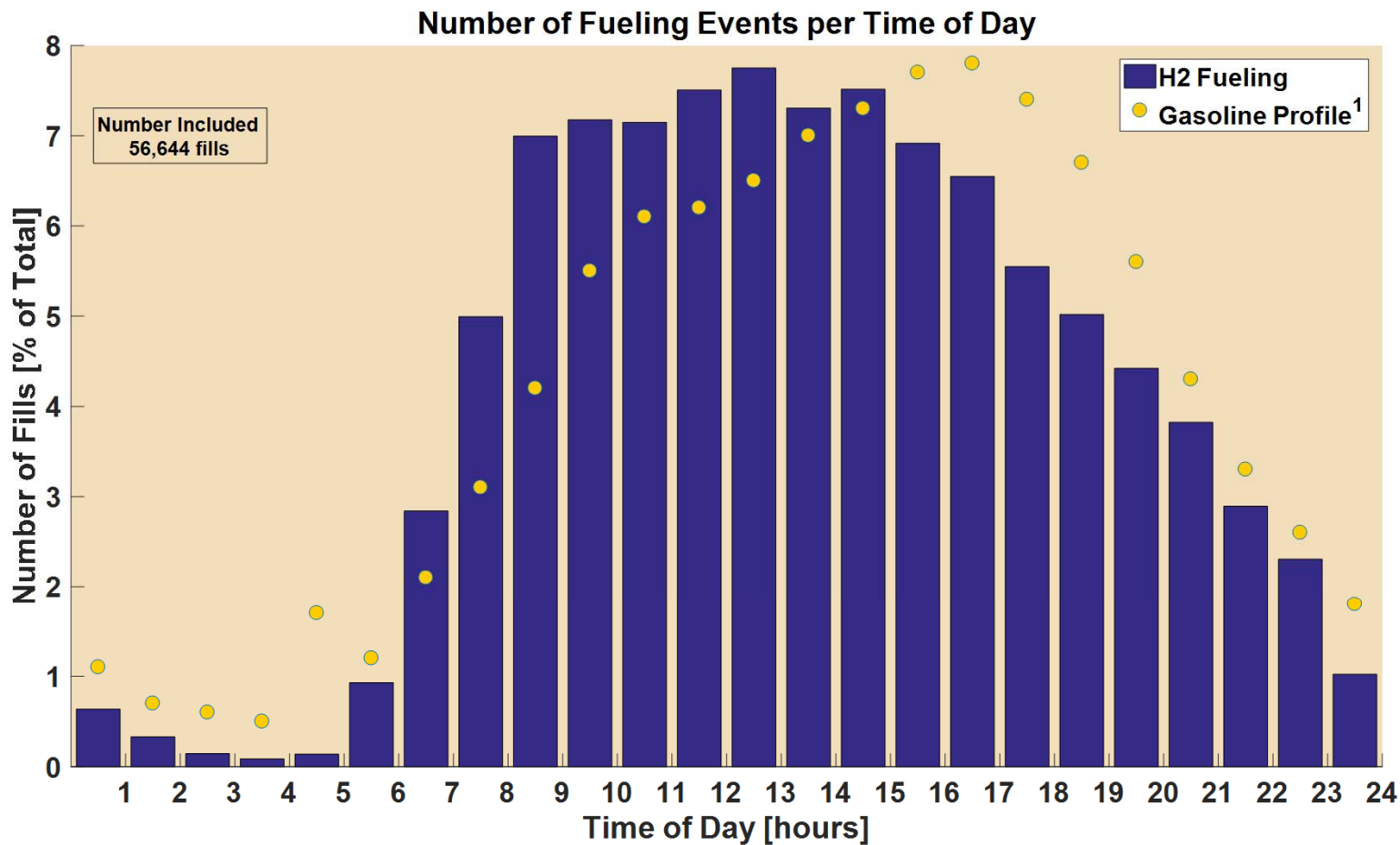
Created: Dec-09-16 3:30 PM | Data Range: 0000Q1-2016Q3



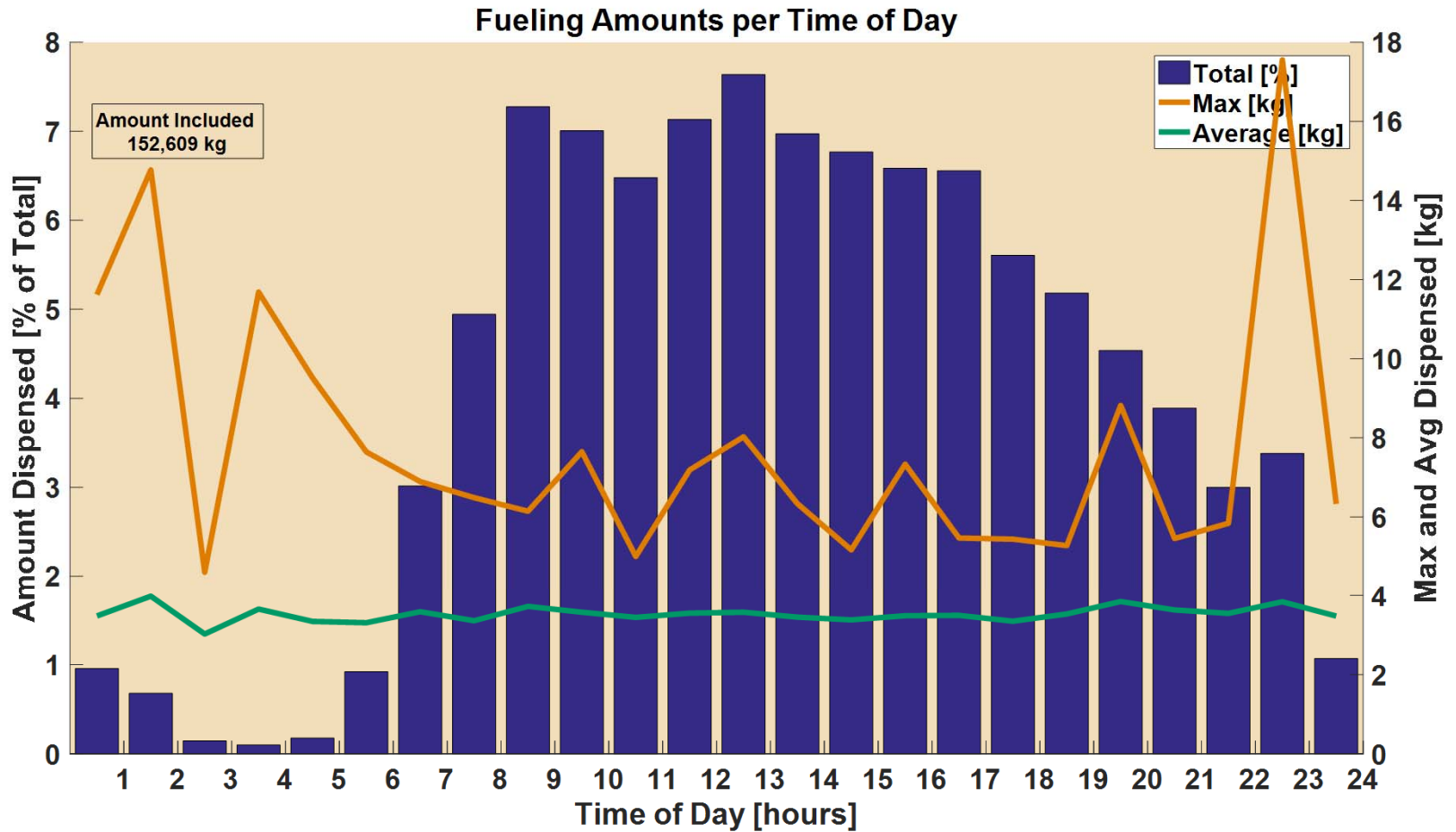


NREL cdp_infr_14

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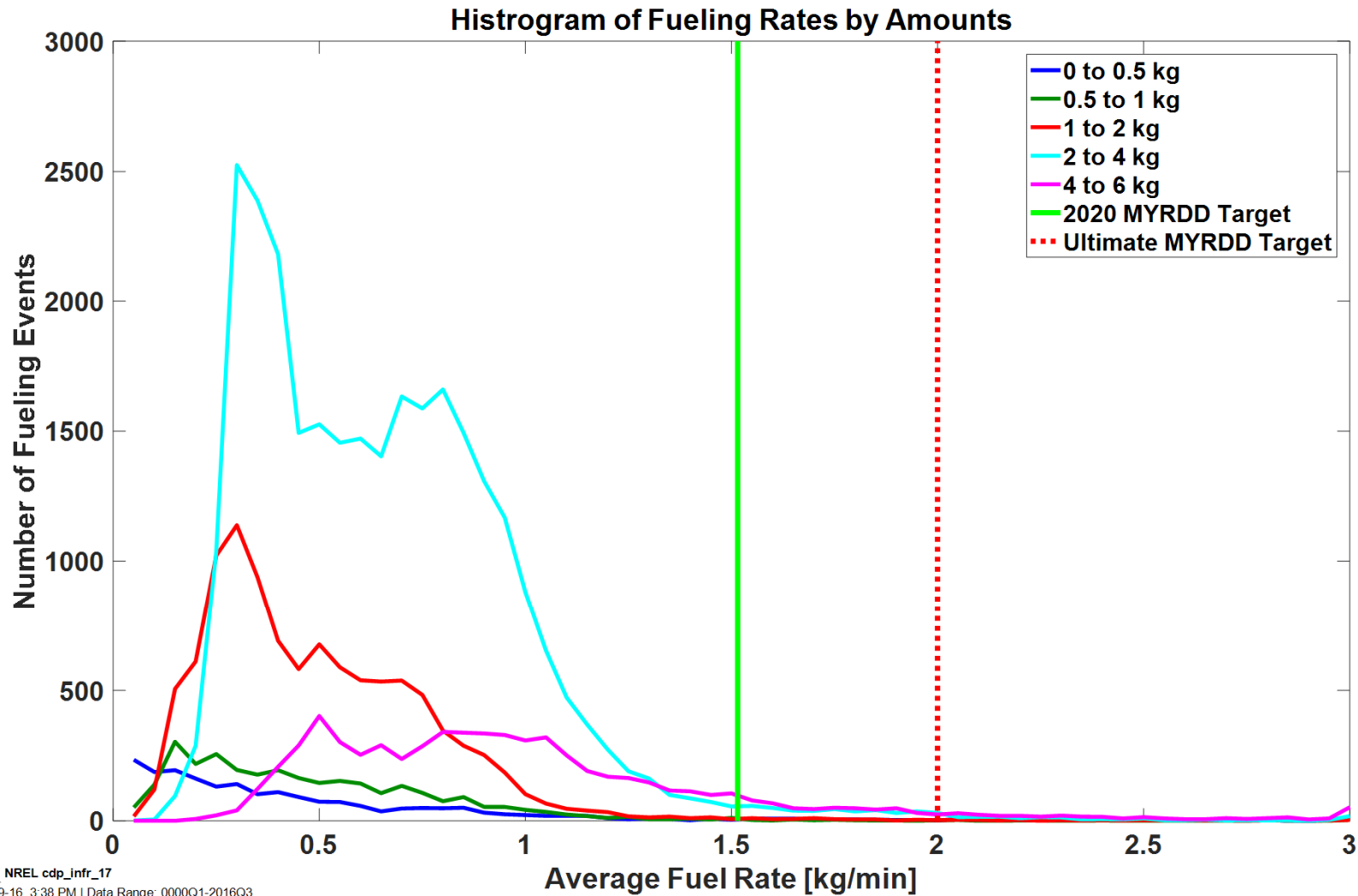


1. Friday Chevron profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.

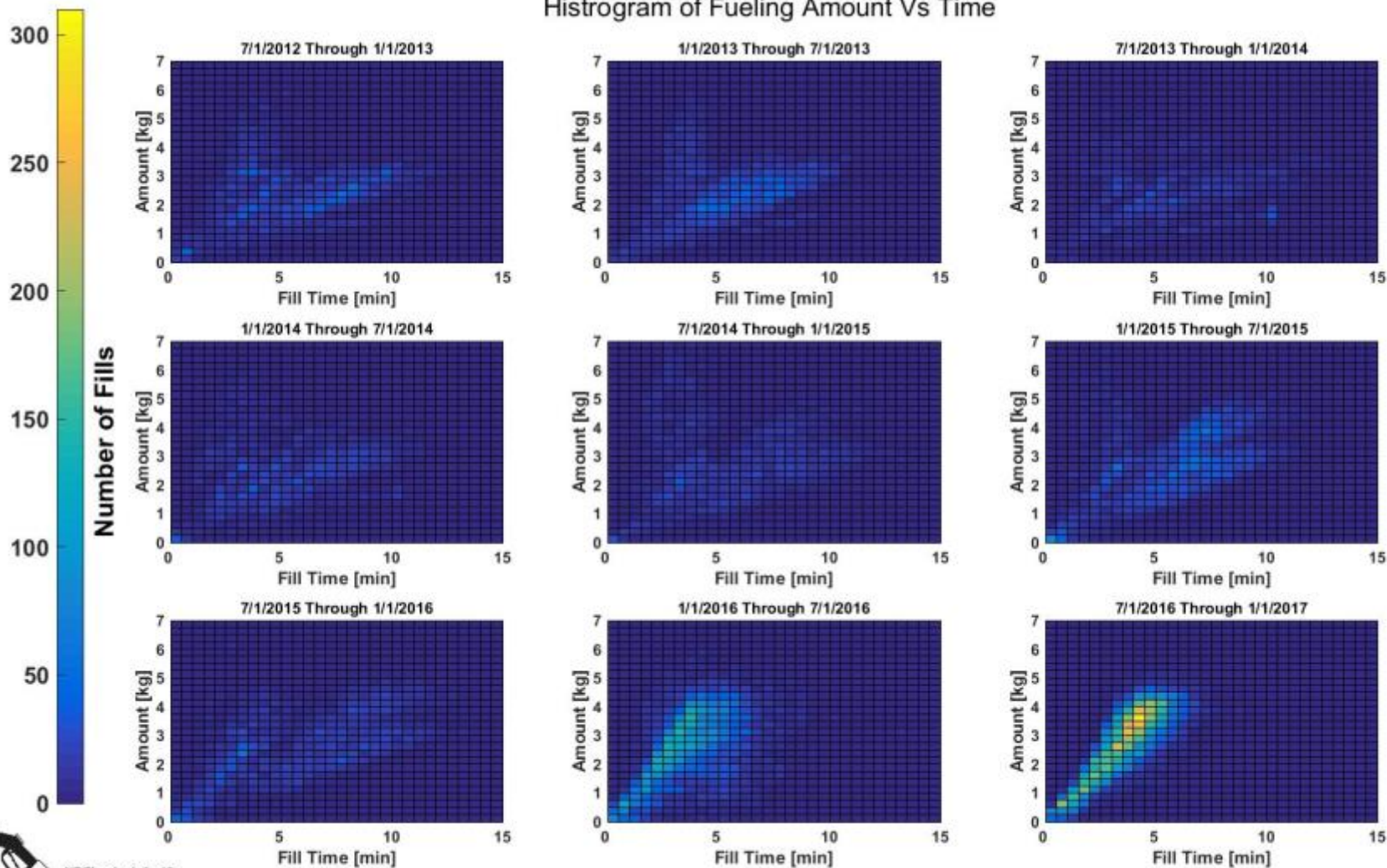


NREL cdp_infr_16

Created: Dec-09-16 3:37 PM | Data Range: 0000Q1-2016Q3



Histogram of Fueling Amount Vs Time



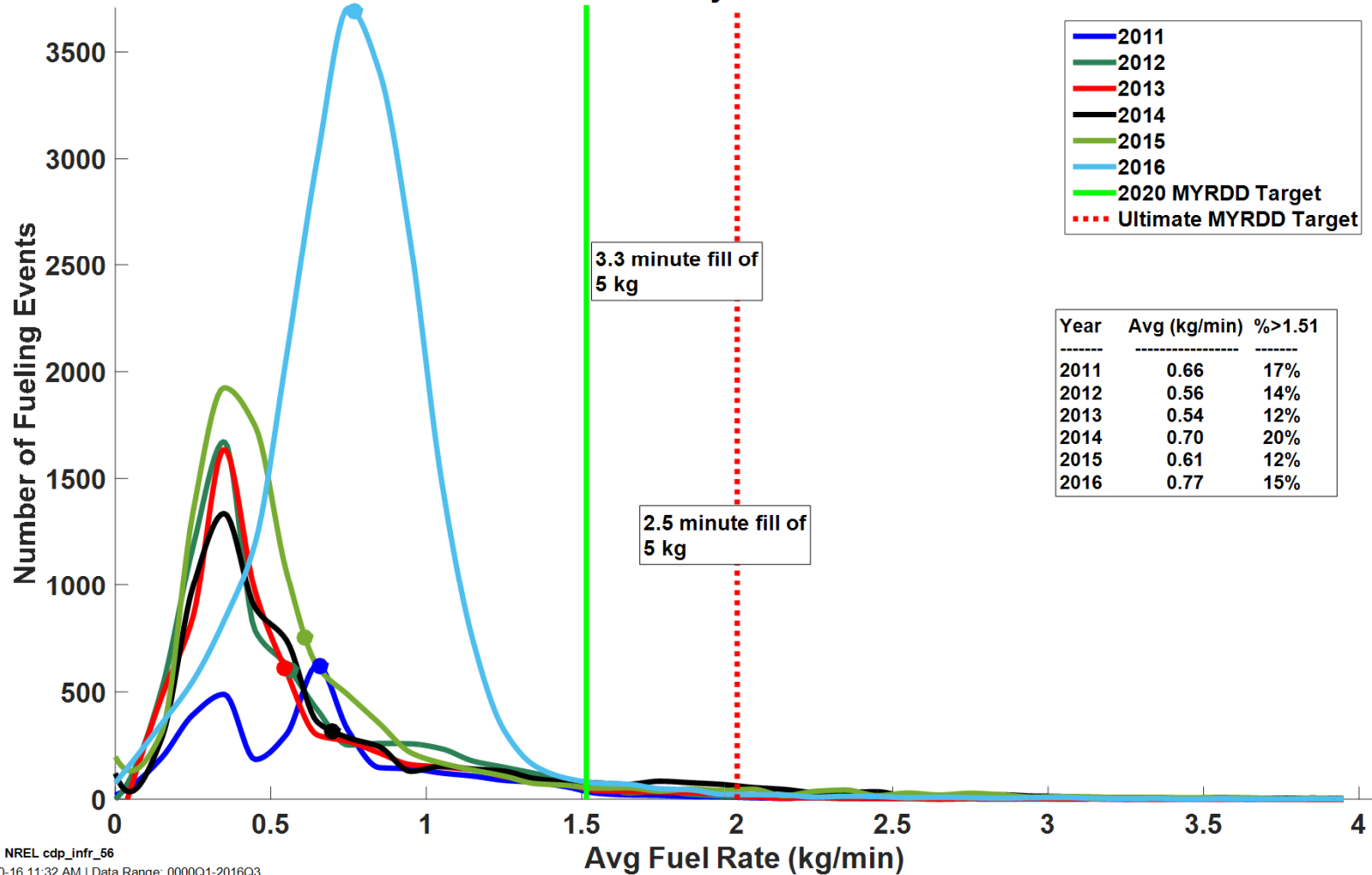
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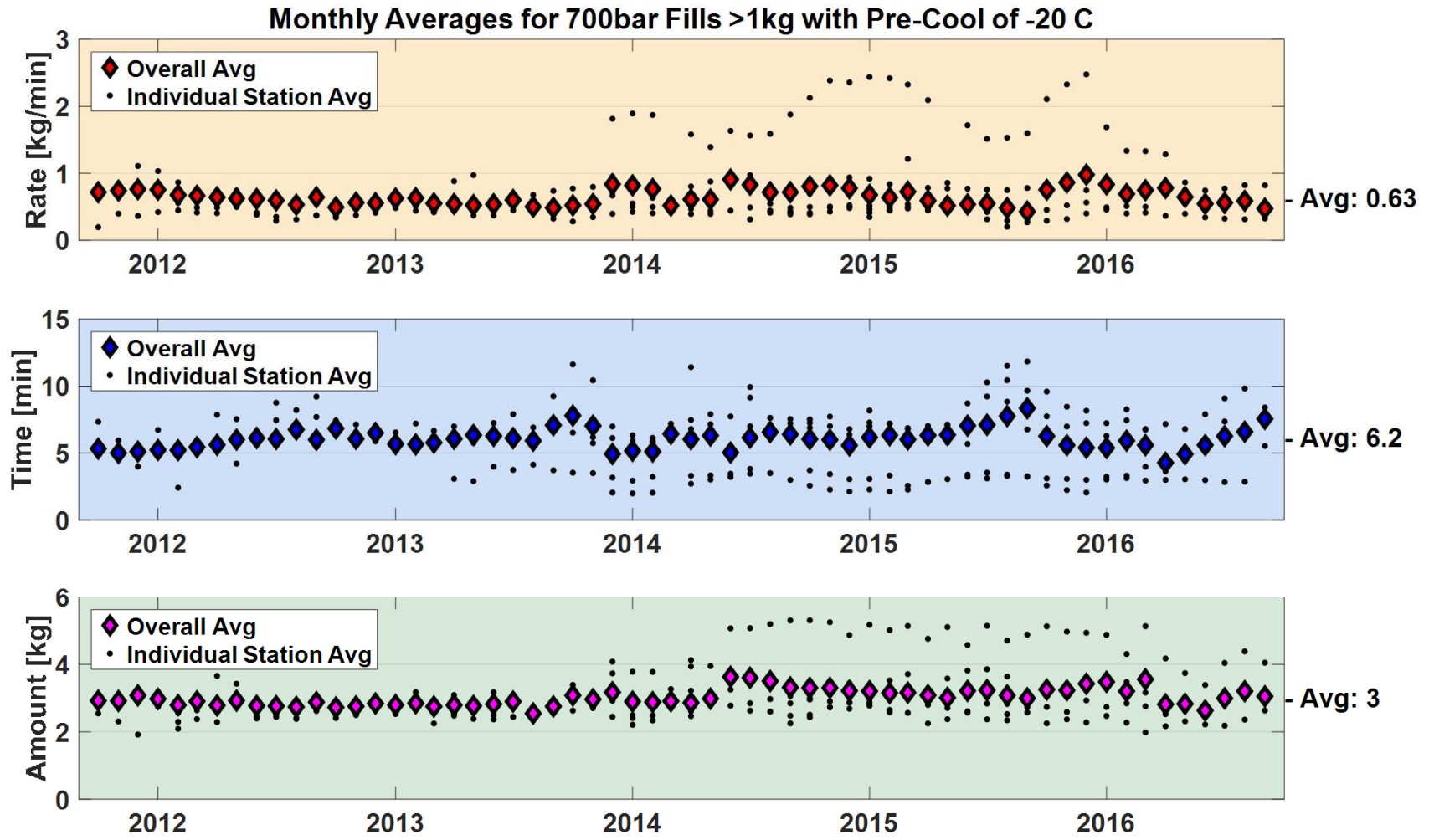
CDP-INFR-56

Fueling Rates by Year

Histogram of Fueling Rates By Year



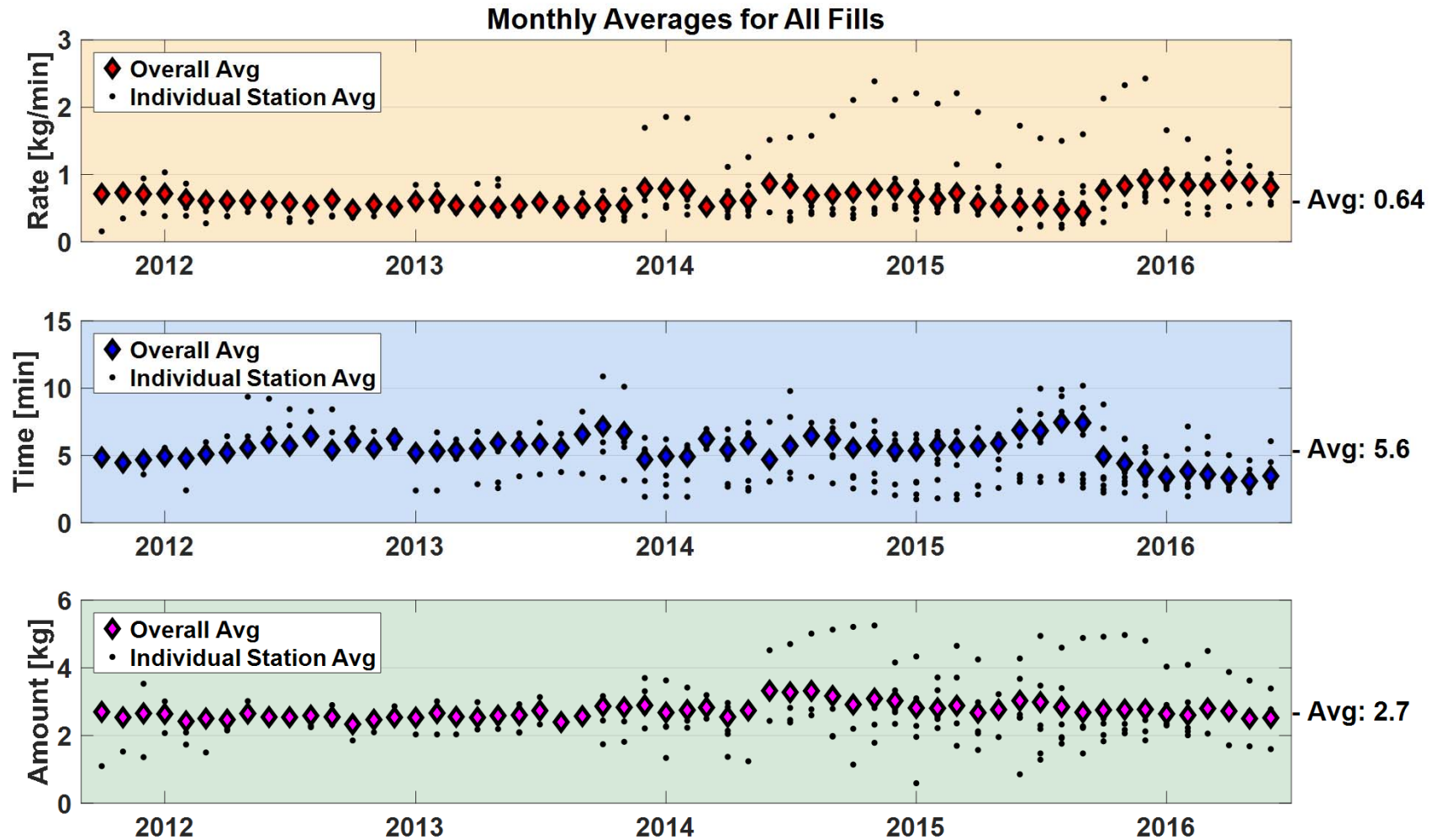
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NREL cdp_infr_29

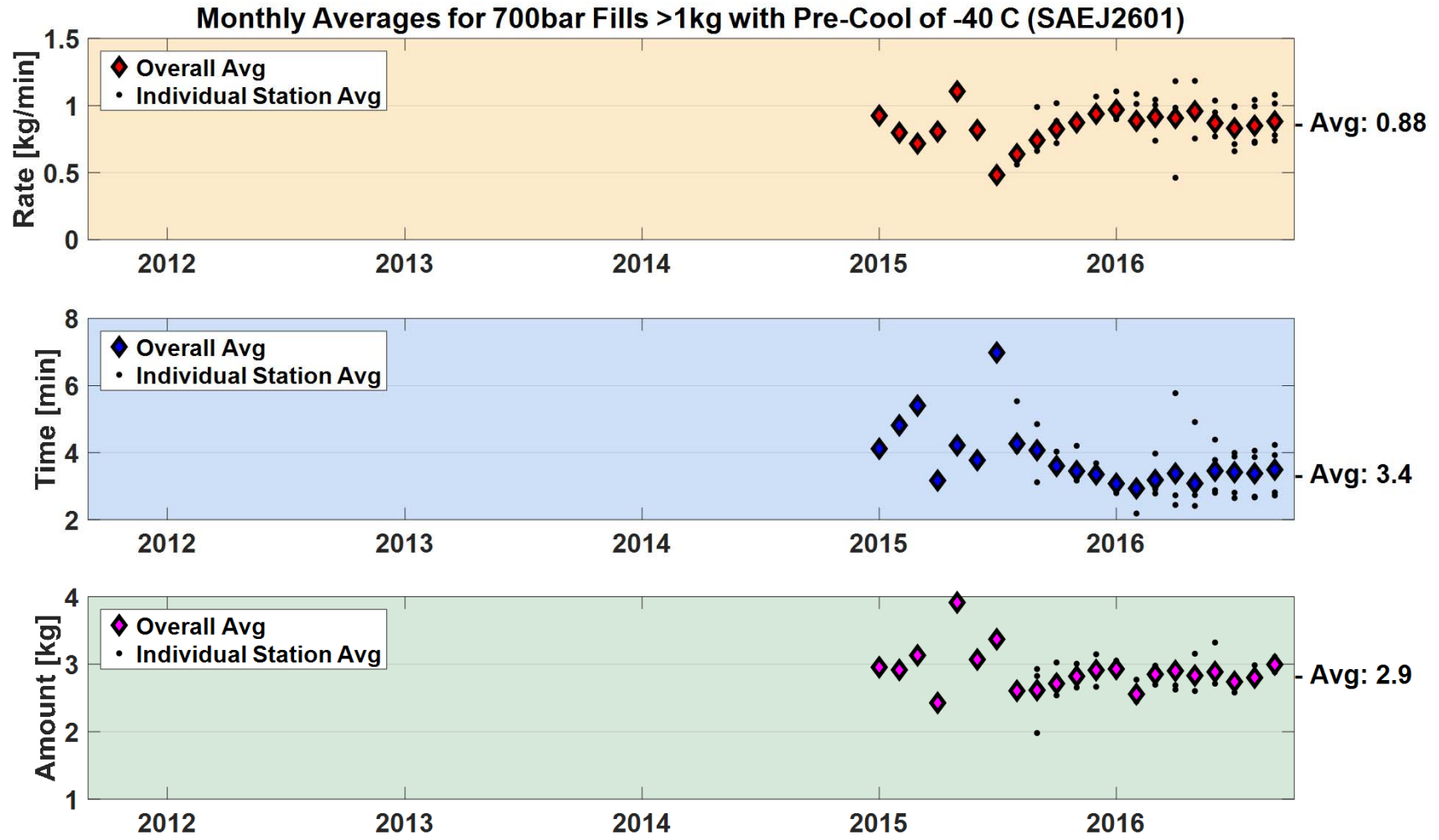
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Monthly Averages: All Fills



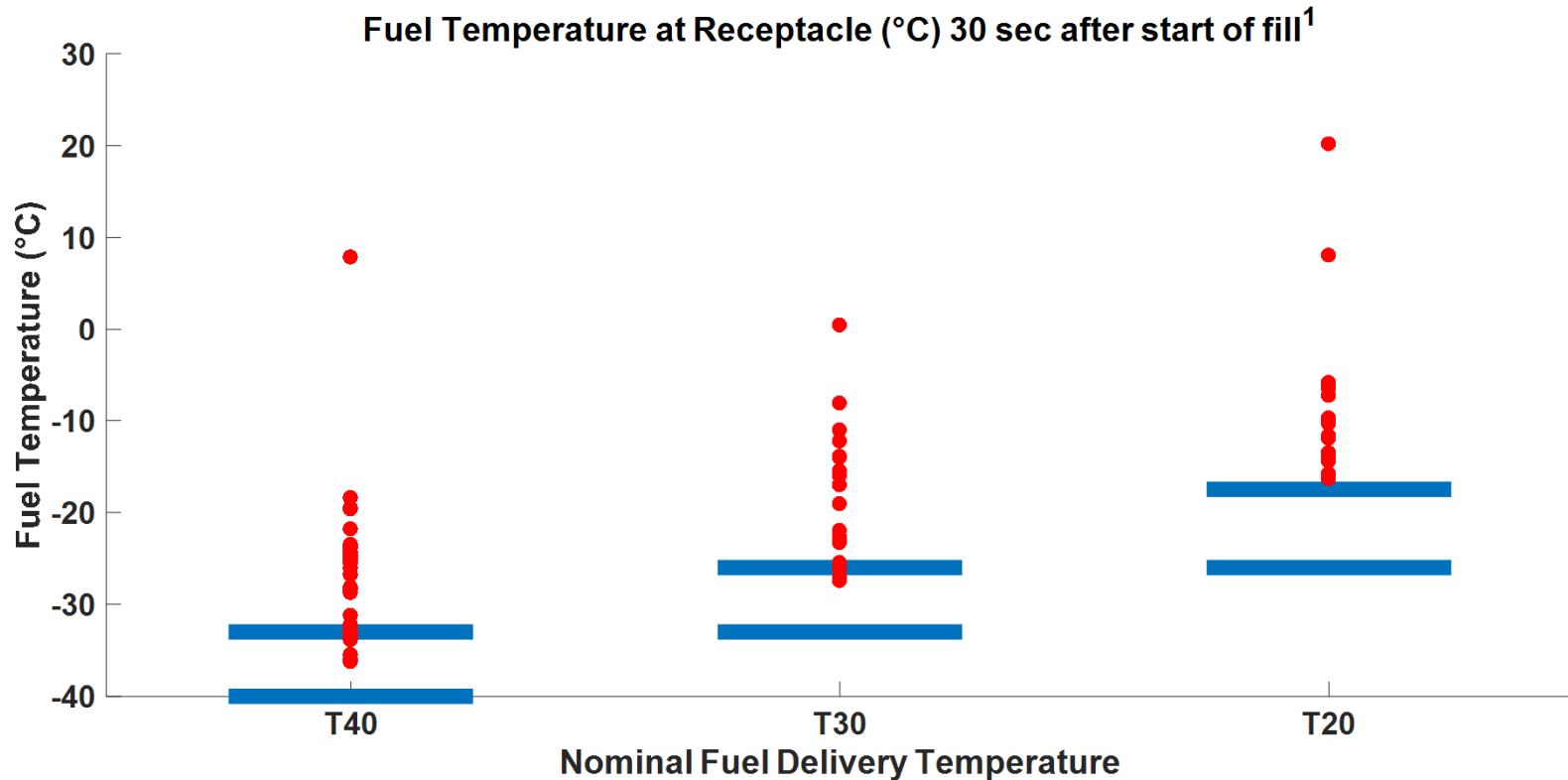
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NREL cdp_infr_57

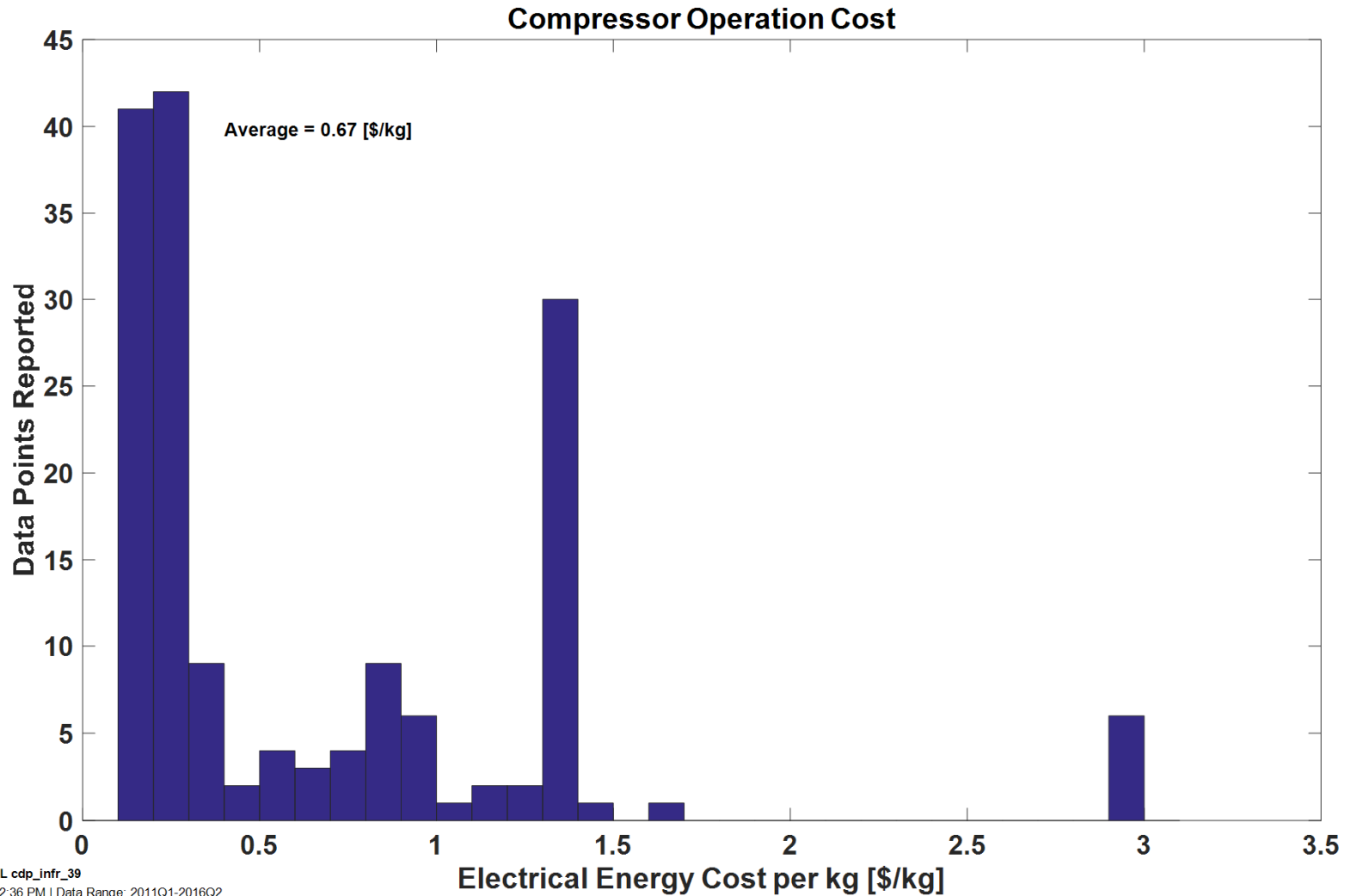
Created: Dec-09-16 3:51 PM | Data Range: 2014Q3-2016Q3



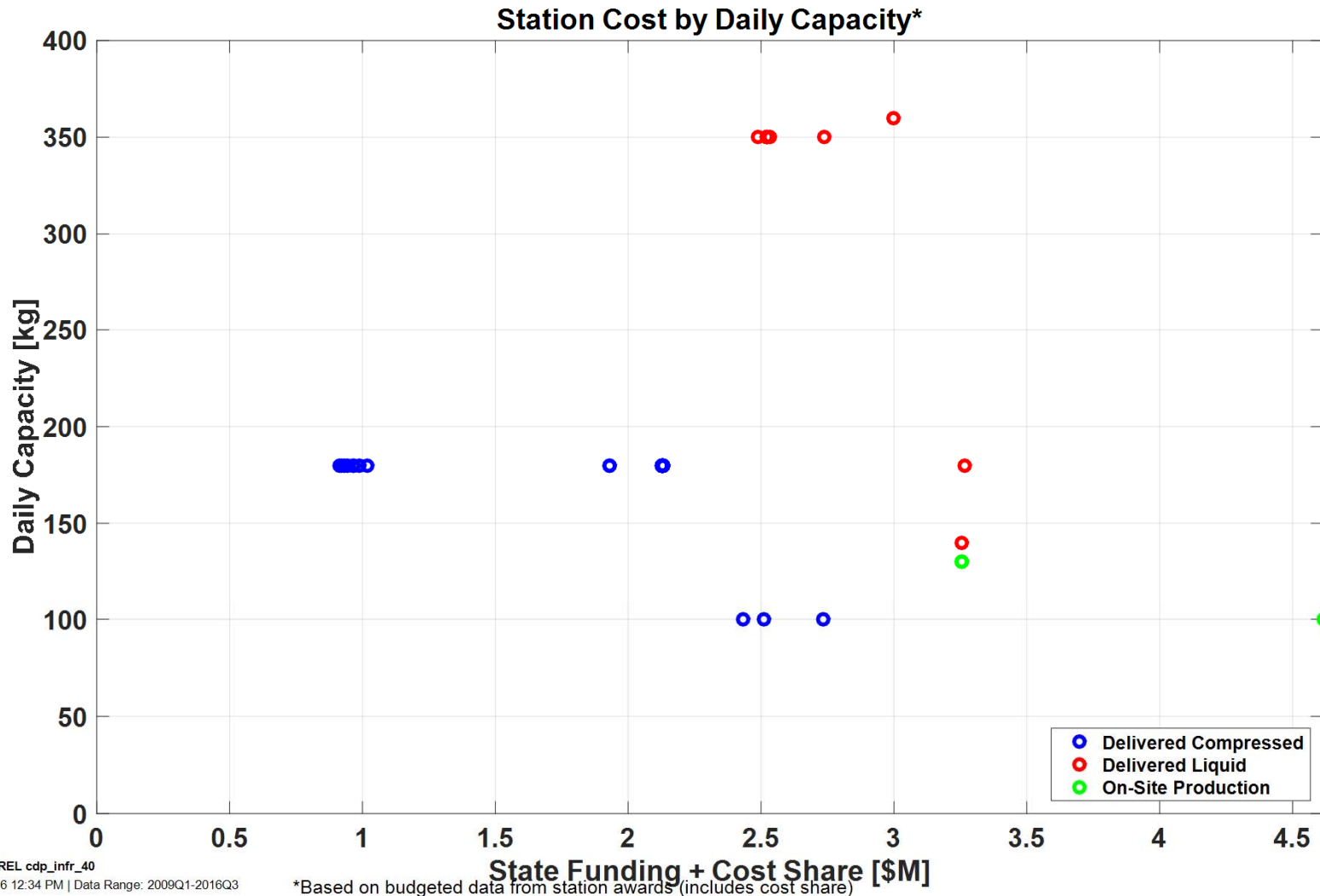
1. SAE J2601 (2014) defines fuel delivery temperature as measured near the dispenser breakaway. See paragraph 4.21. Temperature data here are from HyStEP tests measuring fuel temperature just downstream of the receptacle. SAE J2601 requires that fuel delivery temperature reach the limits shown in blue above within 30 seconds of the start of fueling.



Cost



Station Costs by Daily Capacity

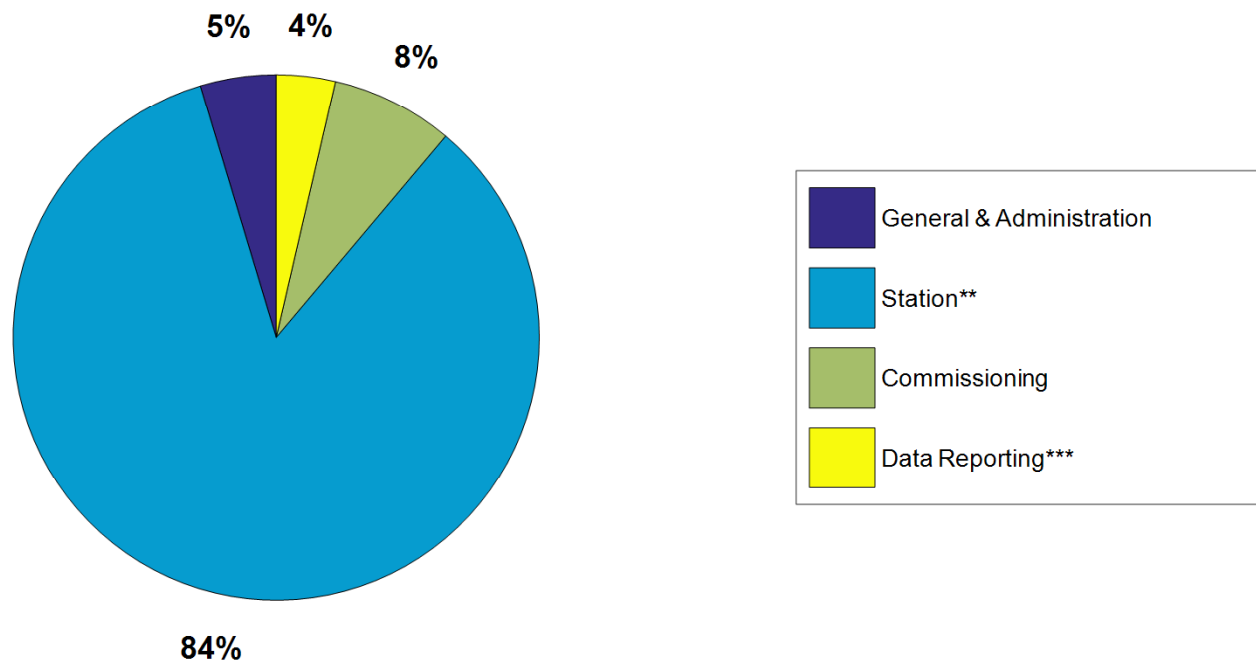


NREL cdp_infr_40

Created: Dec-16-16 12:34 PM | Data Range: 2009Q1-2016Q3

Average Station Cost by Category

Budget Amounts* (Avg Total = \$2.2M), 46 Stations



*Based on budgeted data from station awards (includes cost share)

**Station includes: Hydrogen Equipment and Station Engineering, Design, Fabrication, Procurement, Site Preparation, Installation, and Construction

***Data Reporting includes quarterly reporting on performance, operation and maintenance

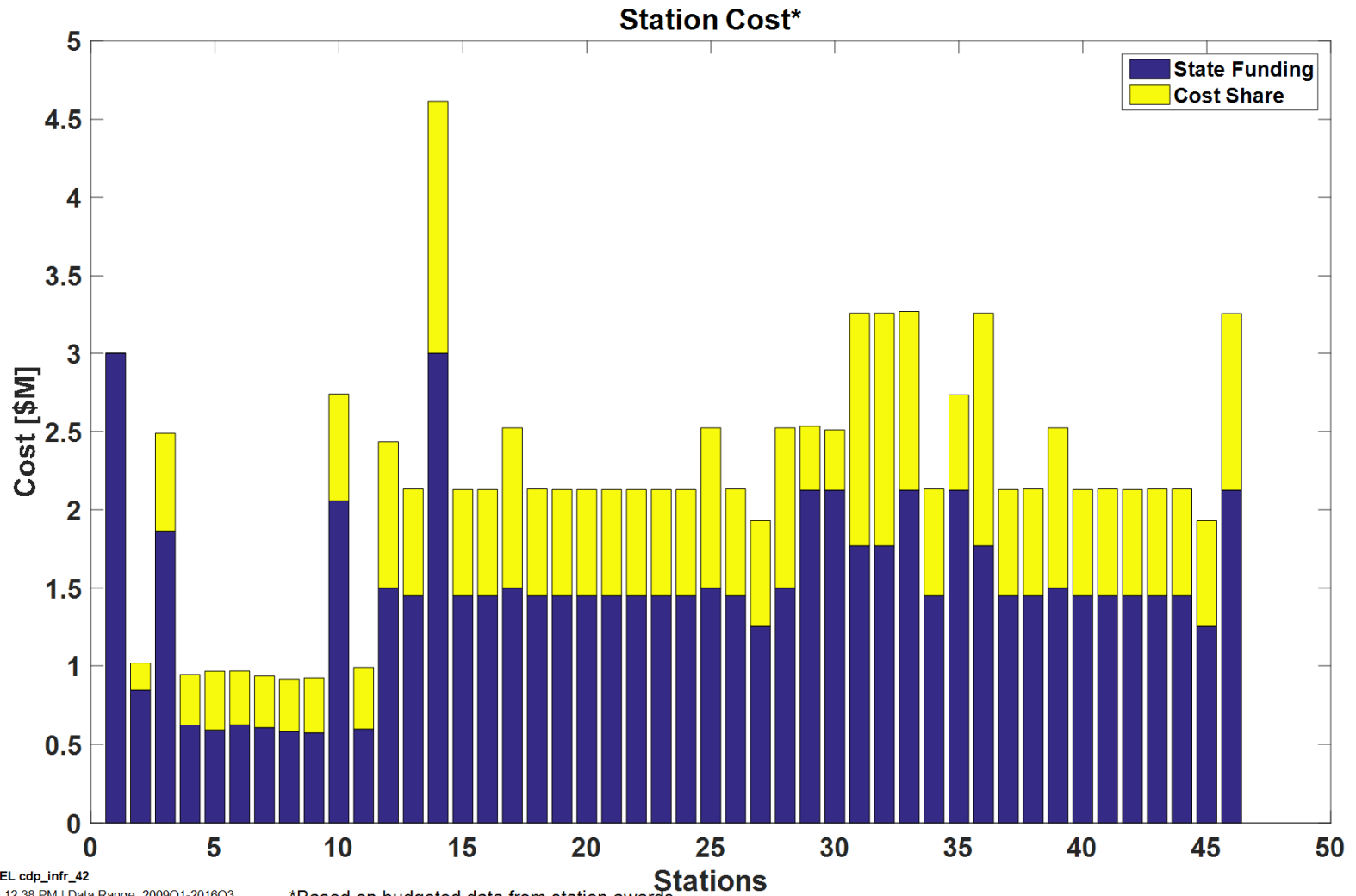


NREL cdp_infr_41

Created: Dec-16-16 12:36 PM | Data Range: 2009Q1-2016Q3

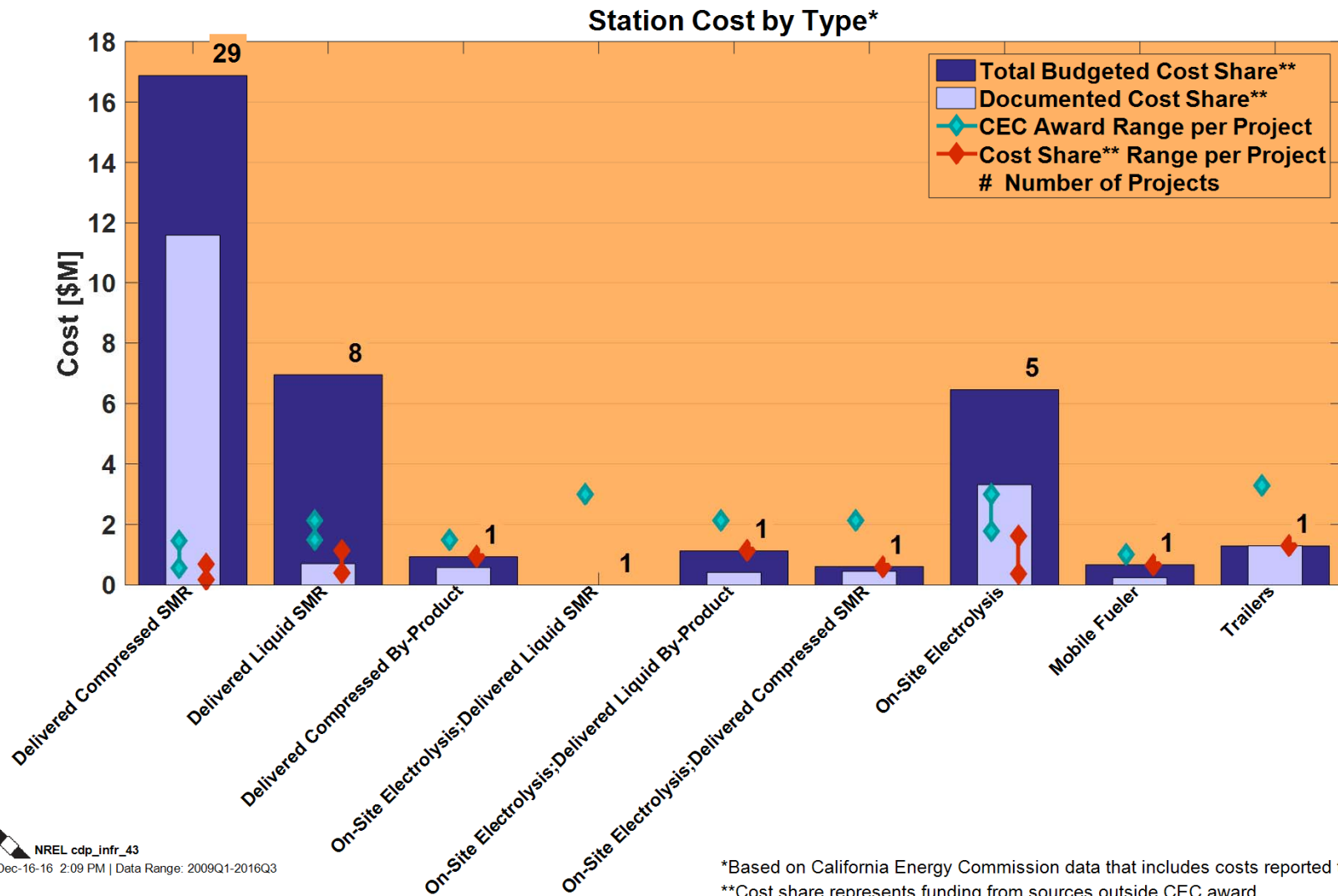
CDP-INFR-42

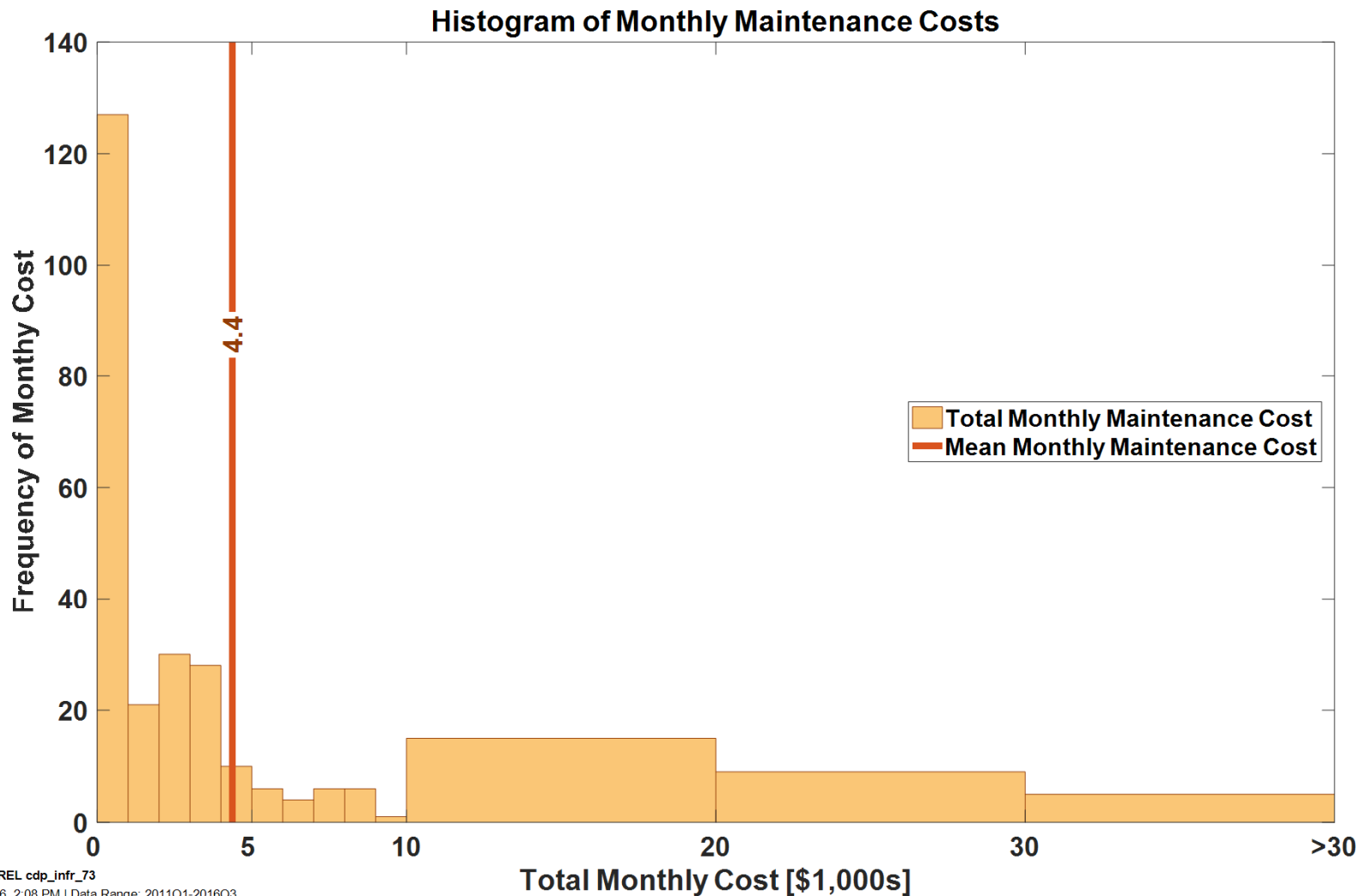
Station Cost



*Based on budgeted data from station awards.

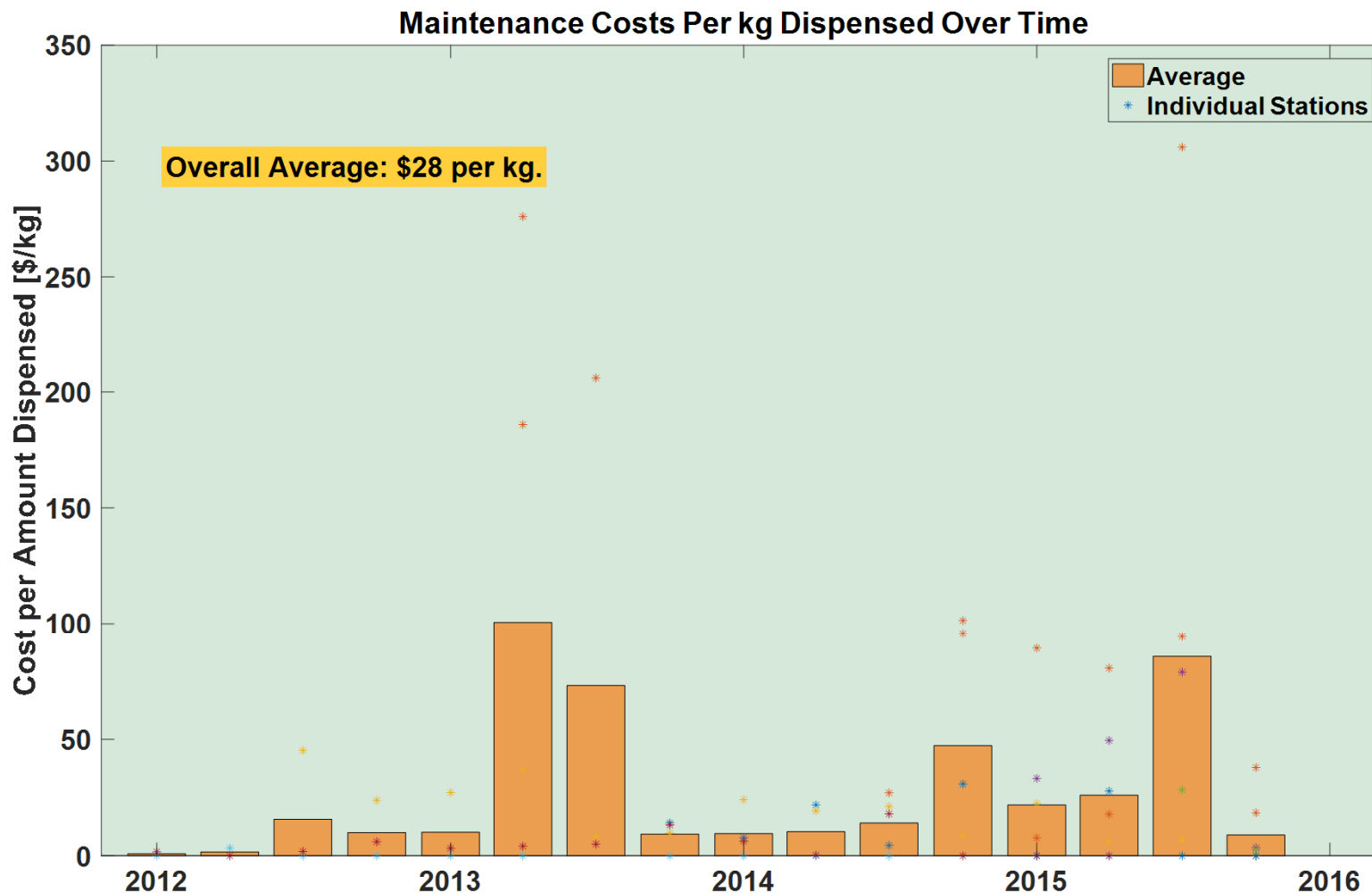
Station Cost by Type






NREL cdp_infr_73

Created: Dec-05-16 2:08 PM | Data Range: 2011Q1-2016Q3

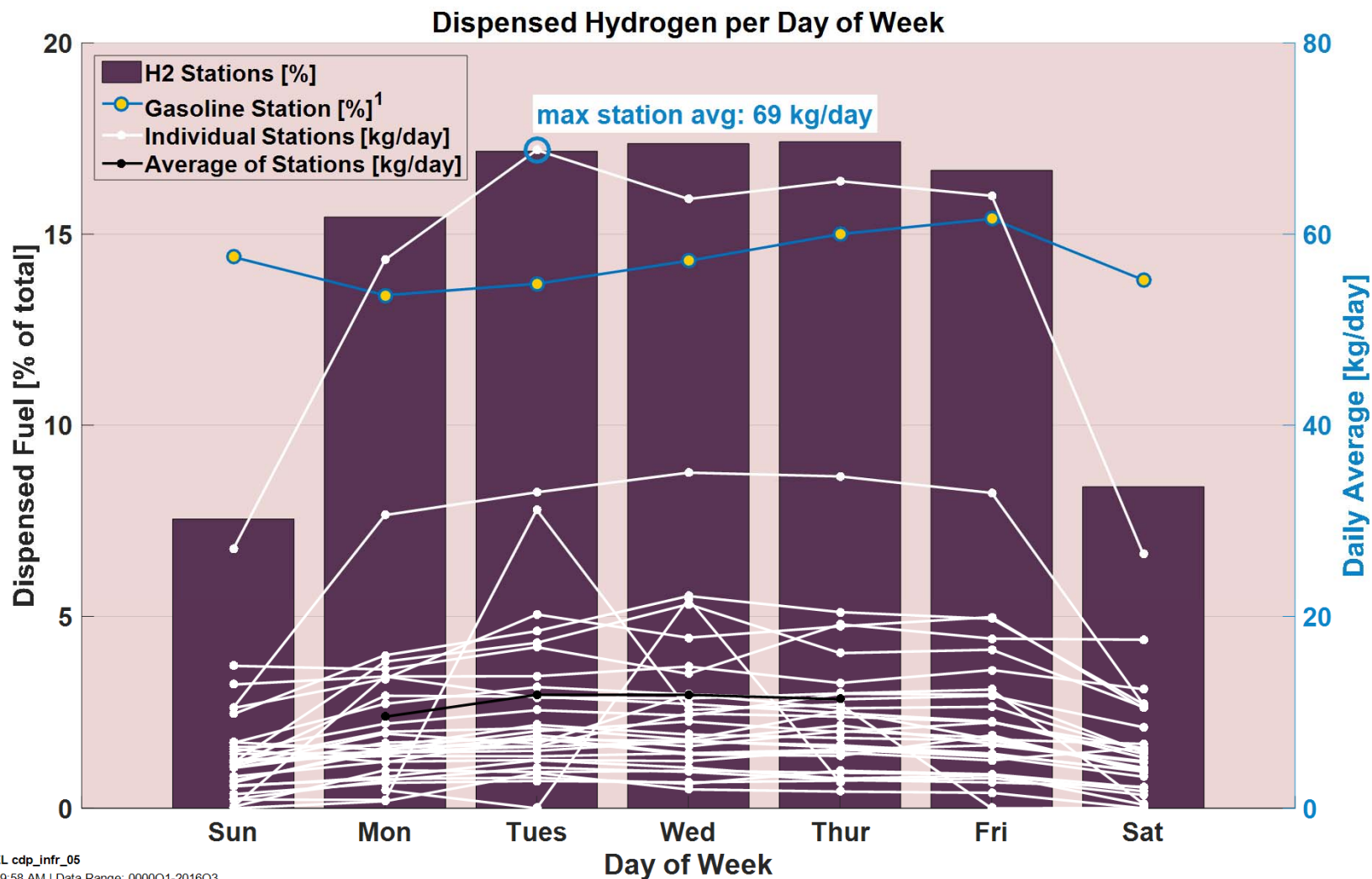


 NREL cdp_infr_53
 Created: Dec-02-16 10:41 AM | Data Range: 2011Q1-2016Q3

*Each color represents a unique station. 3 data points excluded that were over \$1000/kg

Utilization

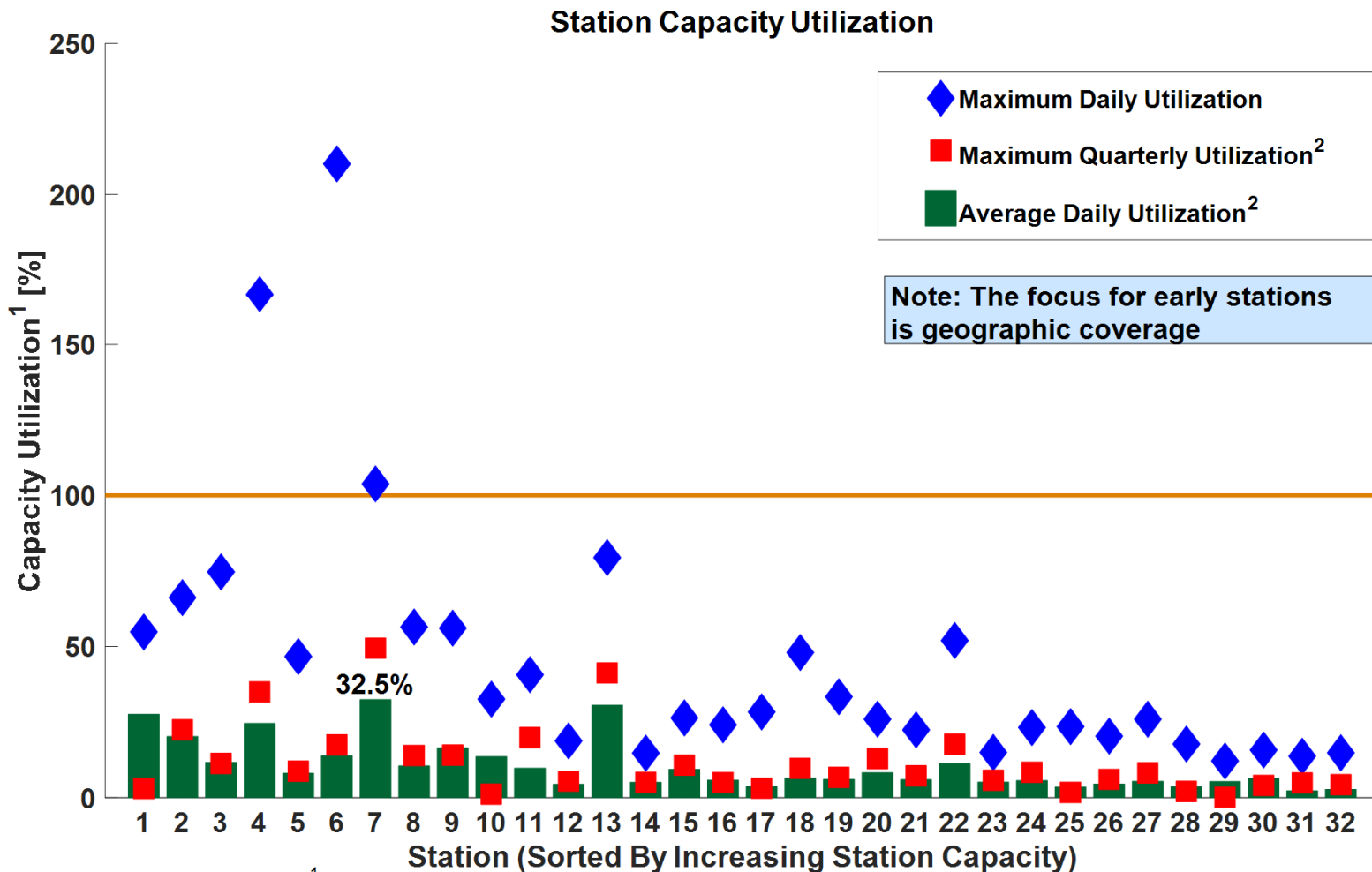
Dispensed Hydrogen per Day of Week



NREL cdp_infr_05

Created: Dec-21-16 9:58 AM | Data Range: 0000Q1-2016Q3

1. Chevron weekly demand profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen.



NREL cdp_infr_06

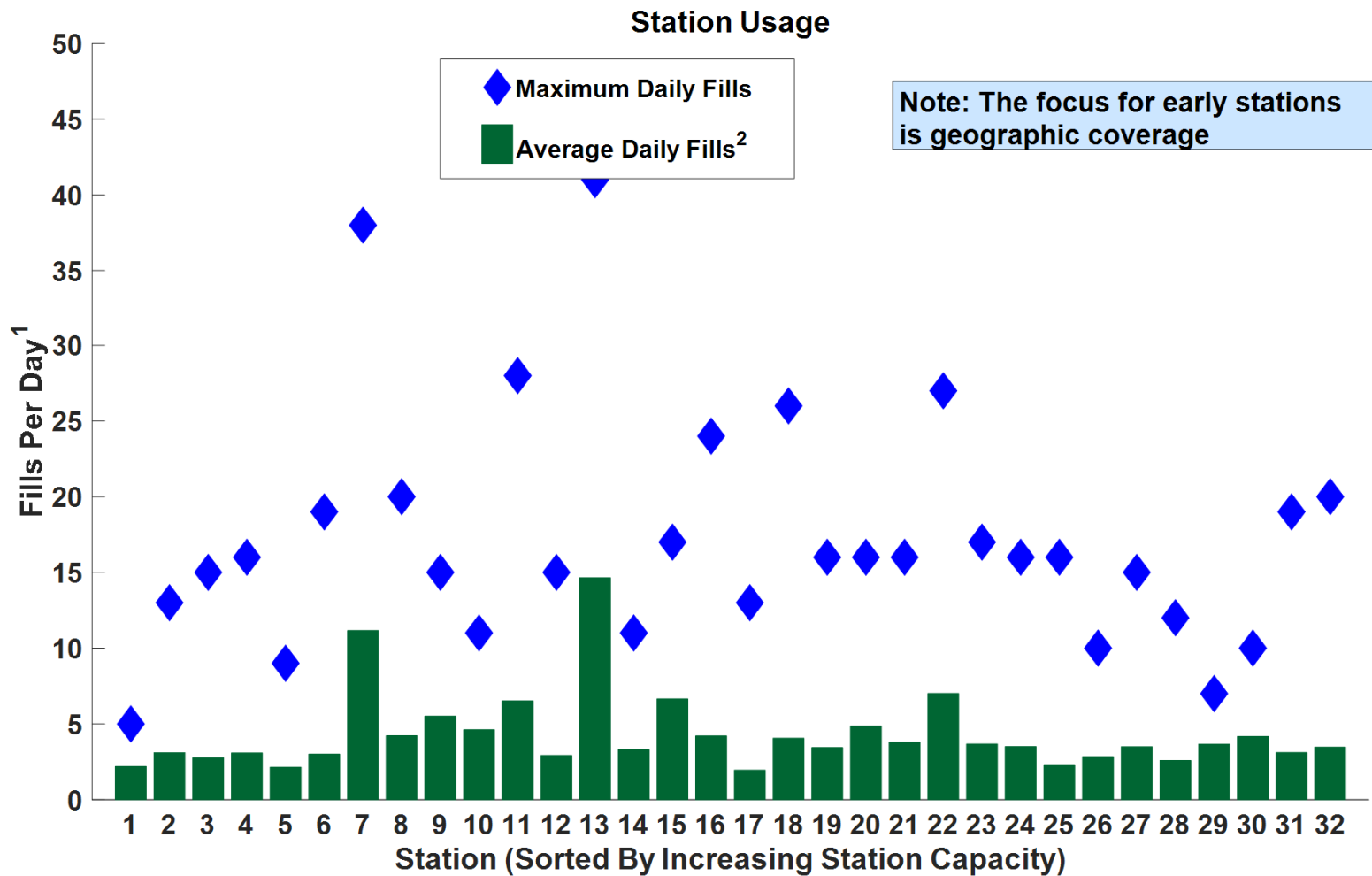
Created: Dec-09-16 3:23 PM | Data Range: 0000Q1-2016Q3


¹Station nameplate capacity reflects a variety of system design considerations including system capacity, throughput, system reliability and durability, and maintenance. Actual daily usage may exceed nameplate capacity.

²Maximum quarterly utilization considers all days; average daily utilization considers only days when at least one filling occurred

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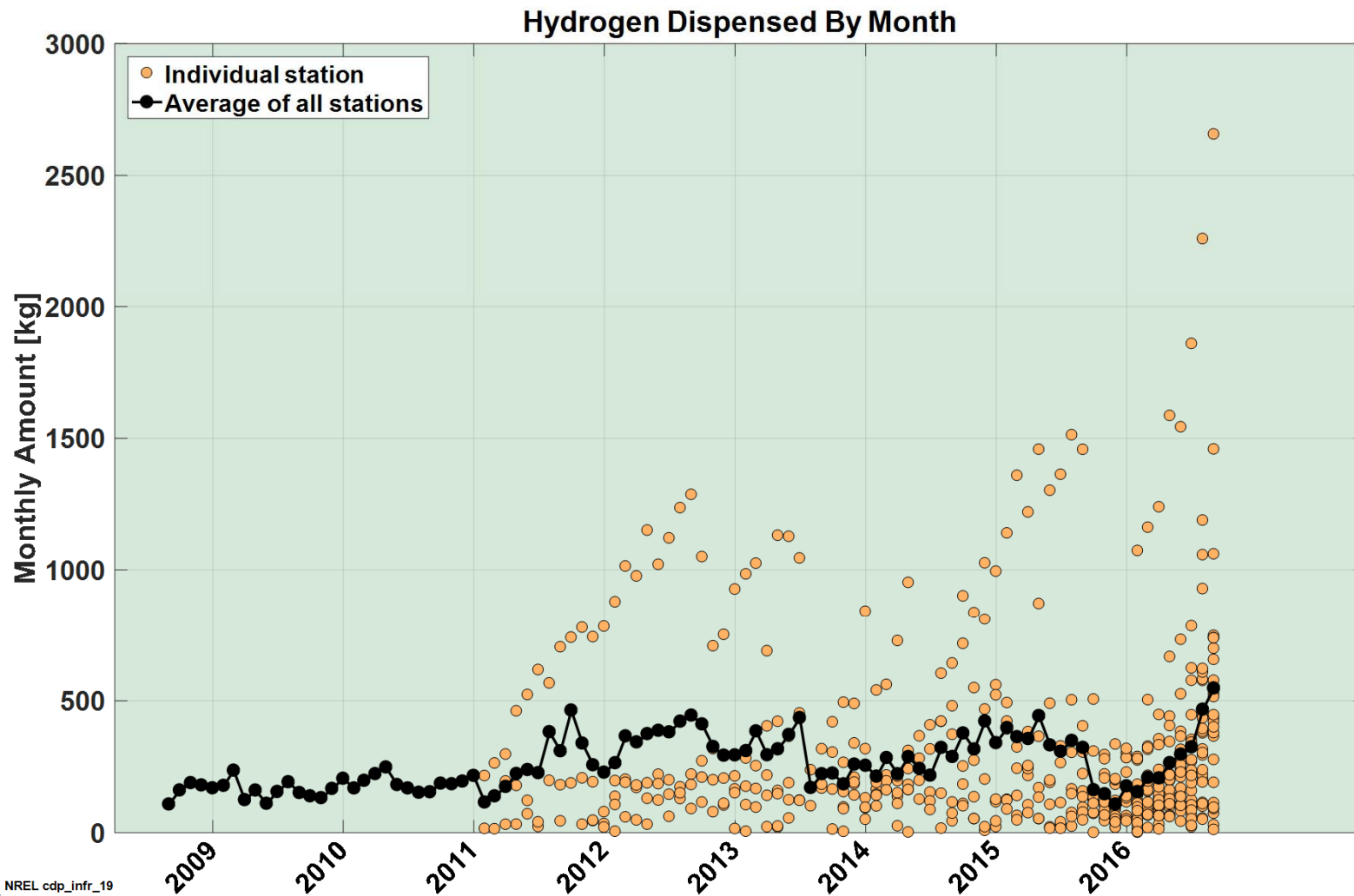
Station Usage



 NREL cdp_infr_07
 Created: Dec-09-16 3:25 PM | Data Range: 0000Q1-2016Q3

¹Excludes hydrogen fills of < 0.5 kg
²Average daily fills considers only days when at least one fill occurred

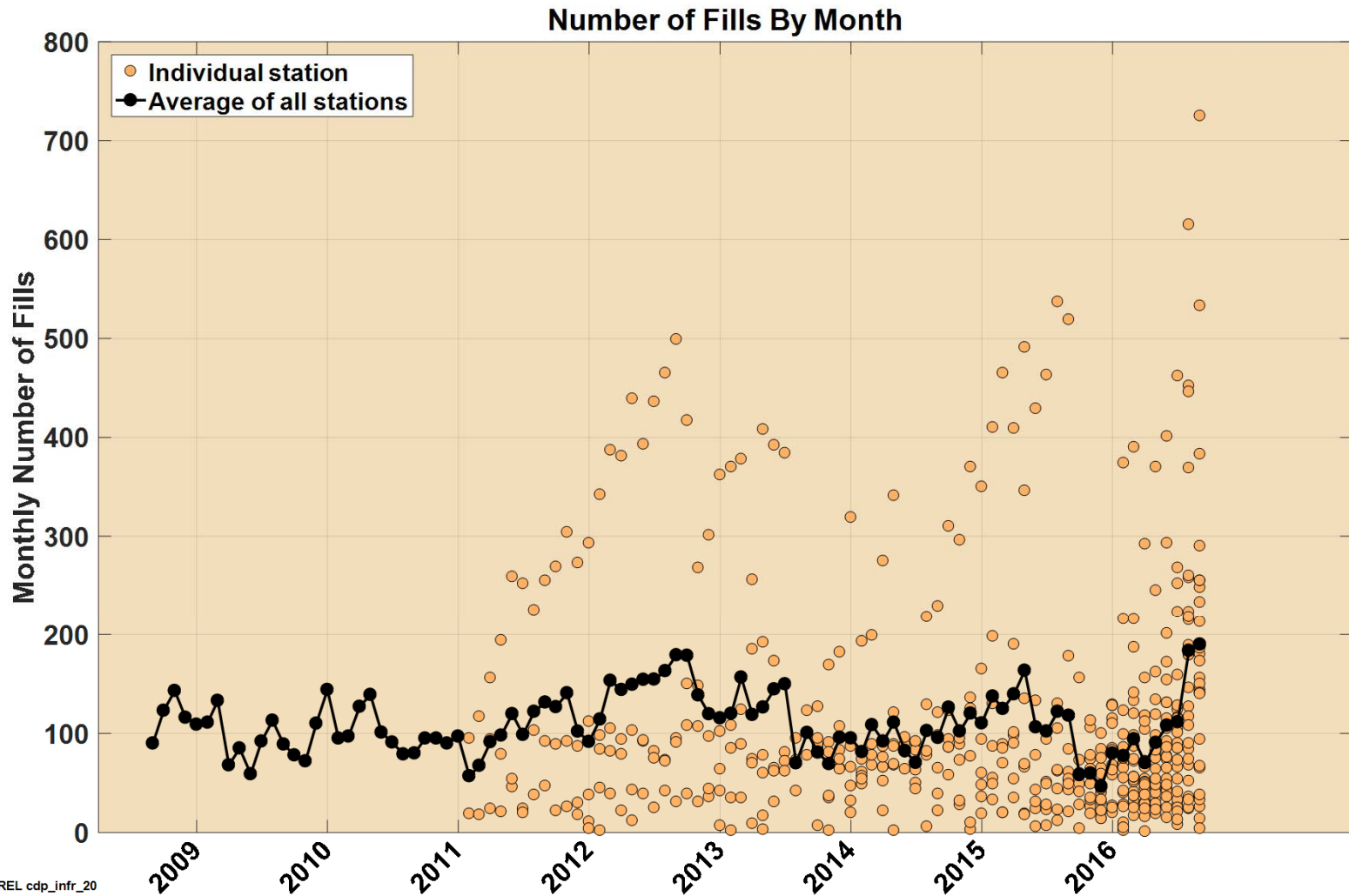
Hydrogen Dispensed by Month



NREL cdp_infr_19

Created: Dec-09-16 3:40 PM | Data Range: 0000Q1-2016Q3

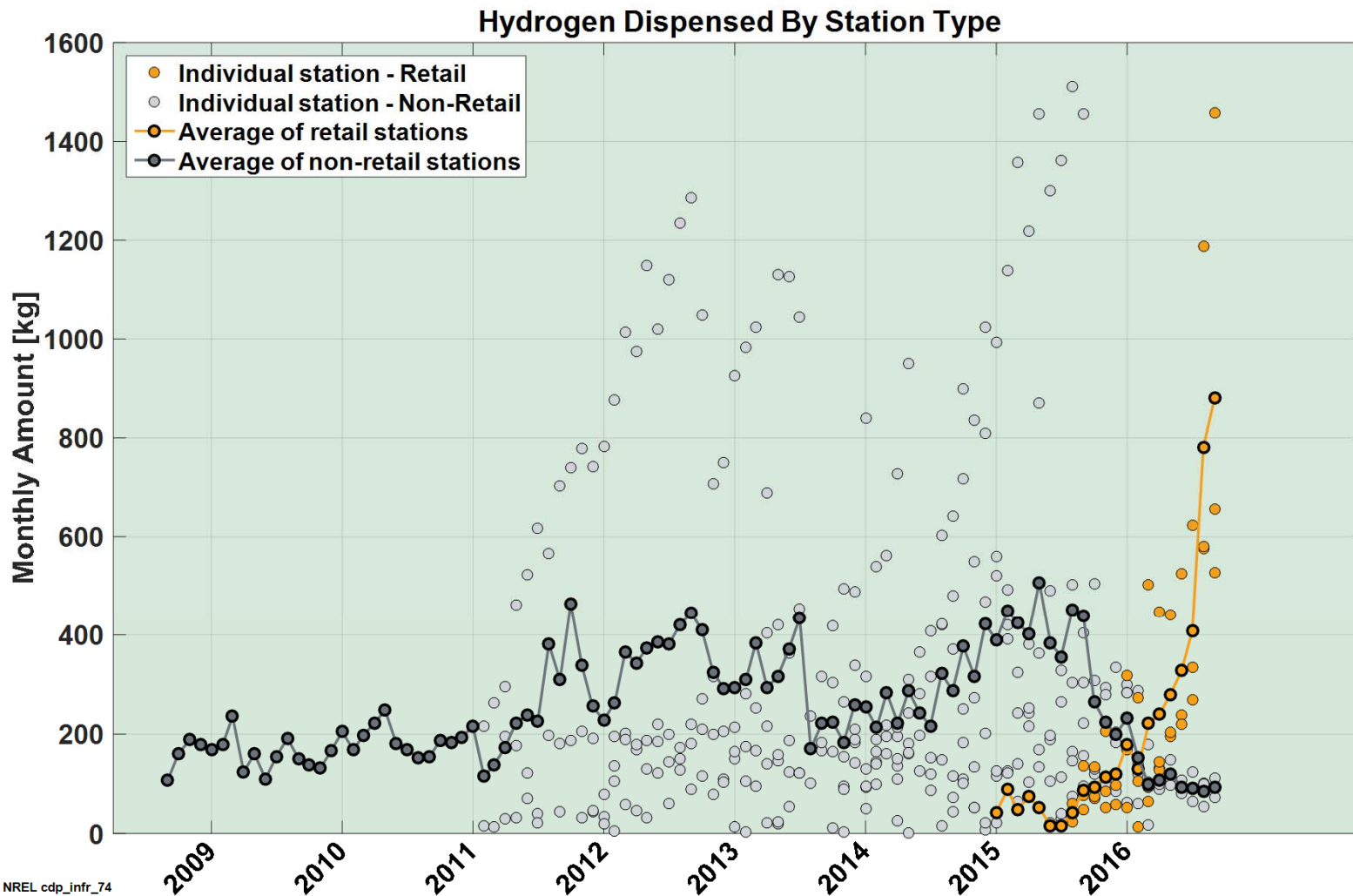
Number of Fills by Month



NREL cdp_infr_20

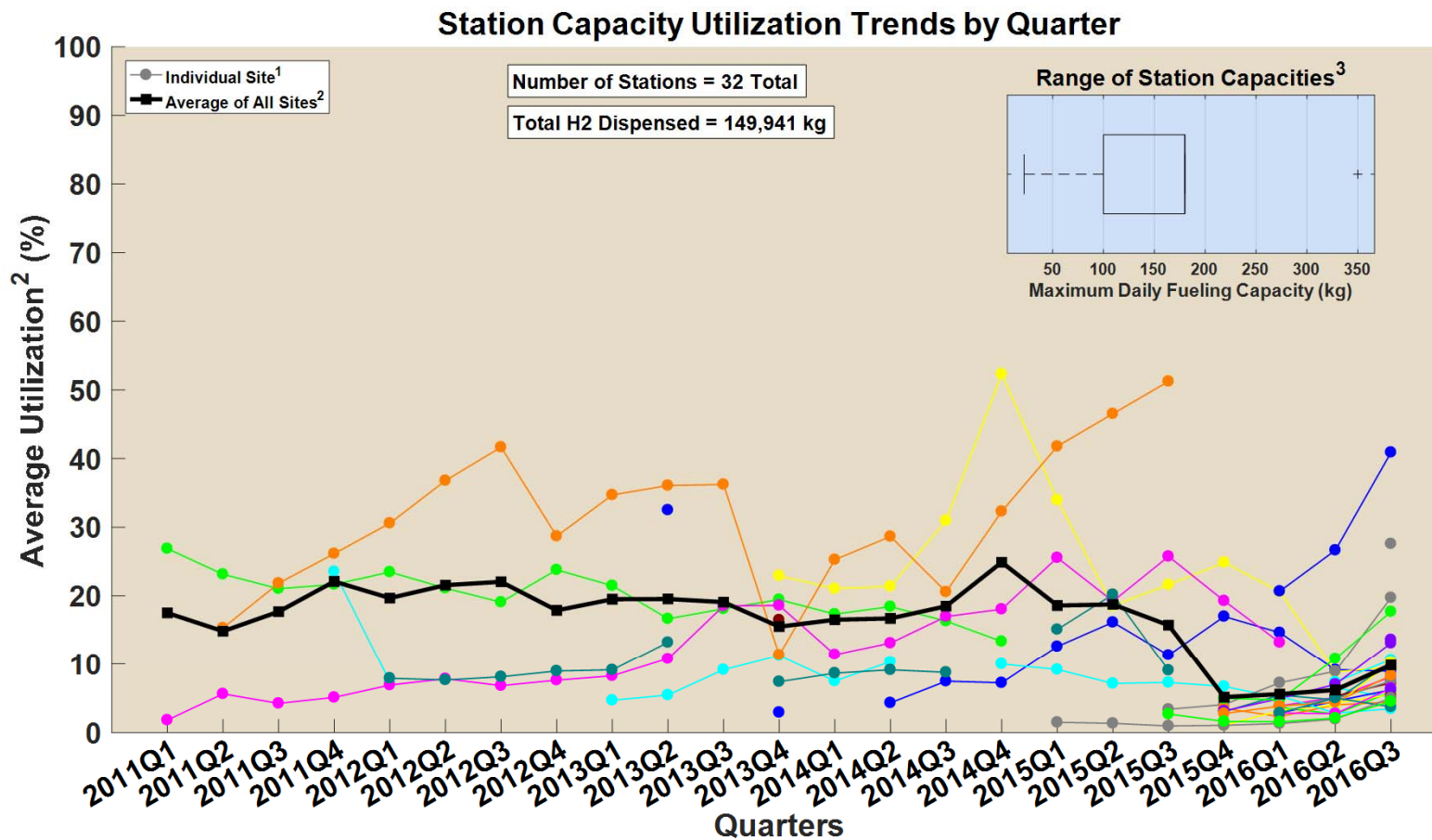
Created: Dec-09-16 3:41 PM | Data Range: 0000Q1-2016Q3

Hydrogen Dispensed by Station Type



NREL cdp_infr_74

Created: Dec-12-16 2:09 PM | Data Range: 2008Q3-2016Q3



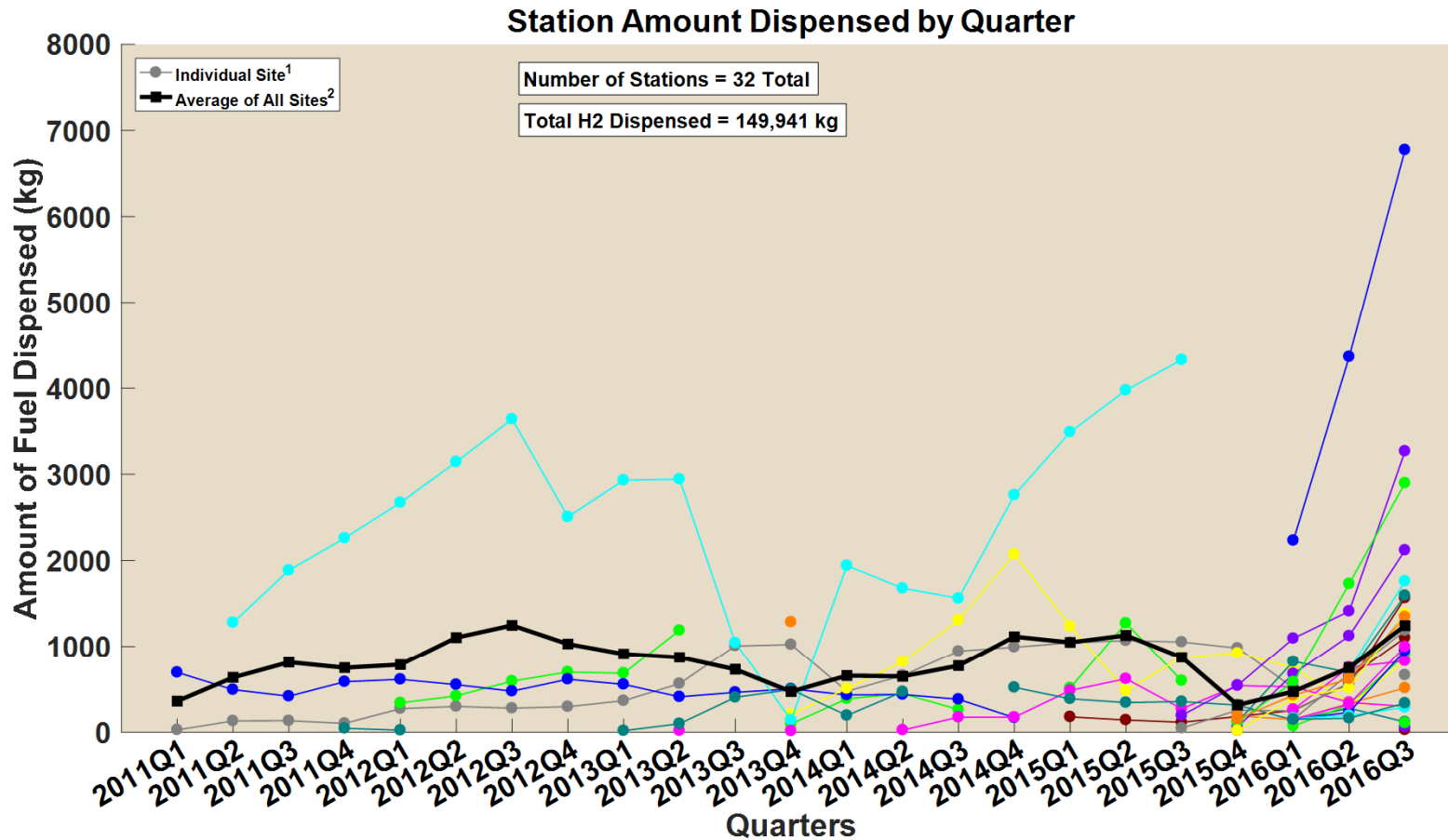
¹ Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

² Average quarterly utilization only considers quarters when at least one fill occurred.

³ Station nameplate capacity is as reported to NREL and reflects a variety of system design considerations including: system capacity, throughput, system reliability, and maintenance. Actual daily usage may exceed nameplate capacity.



Station Amount Dispensed by Quarter



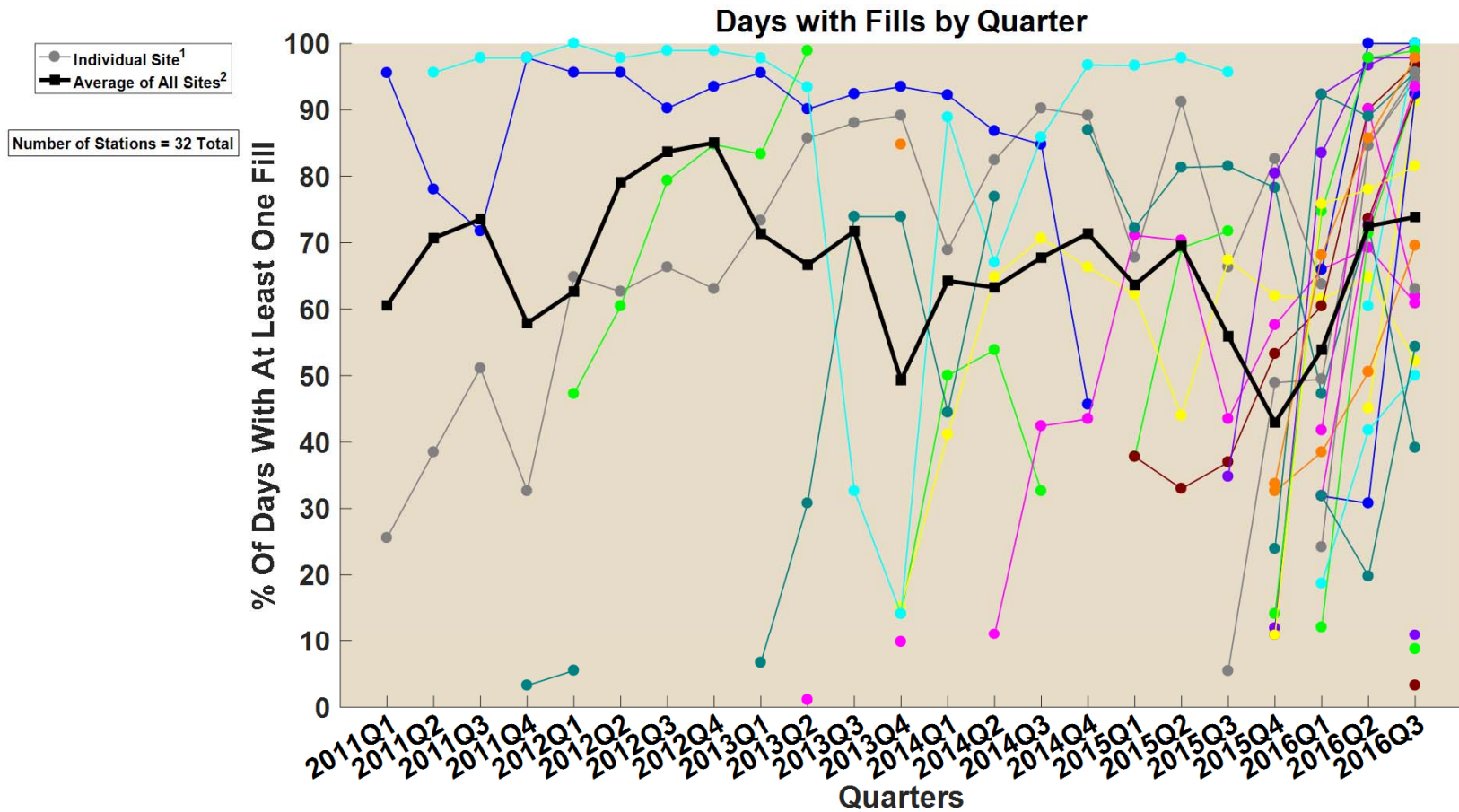
¹ Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

² Average quarterly amount only considers quarters when at least one fill occurred.



NREL cdp_infr_45

Created: Dec-09-16 3:45 PM | Data Range: 0000Q1-2016Q3

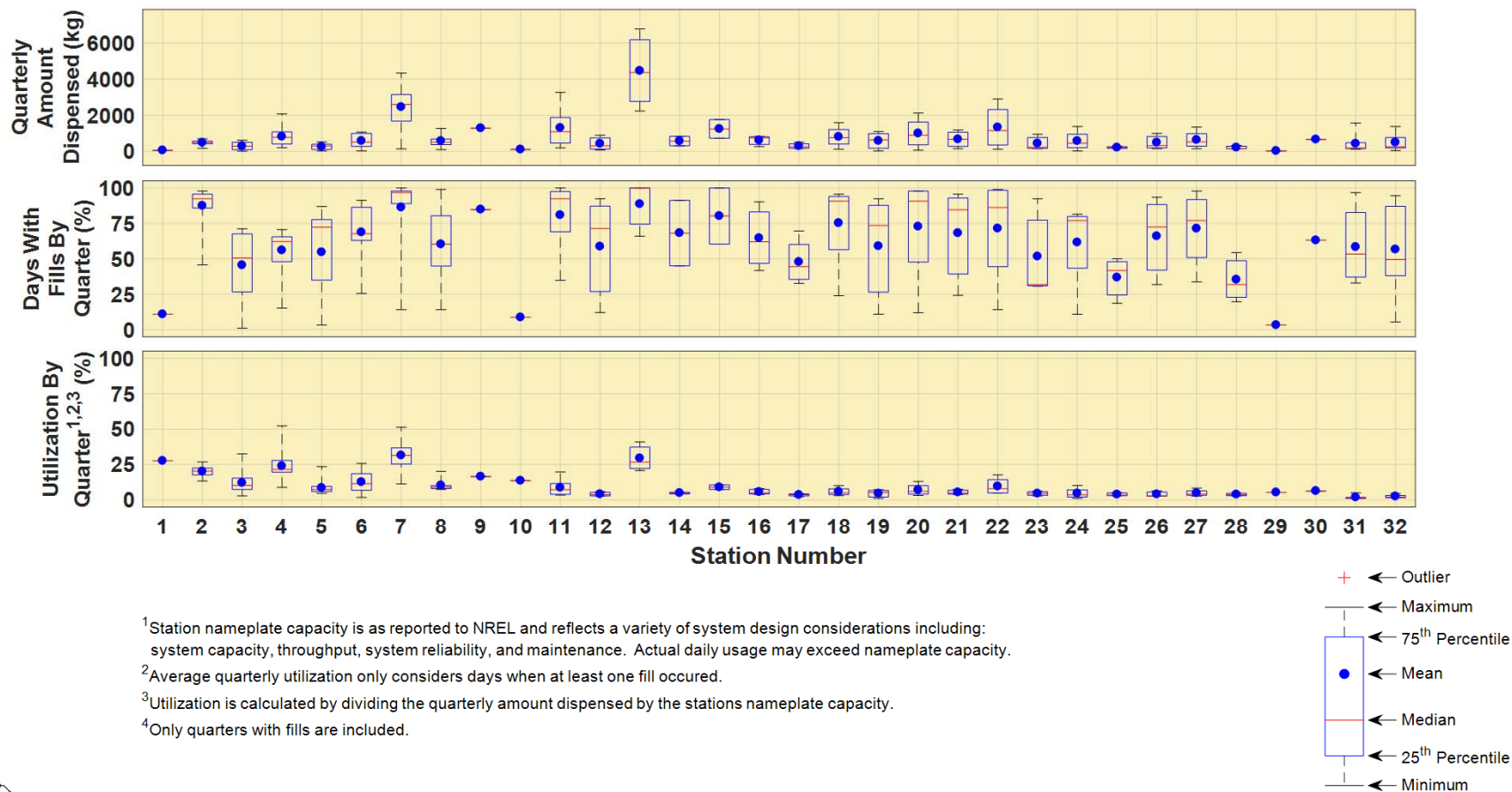


¹ Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station had no fills or was missing data. Each station is represented by a unique color.

² The average percent of days with fills only considers quarters in which at least one fill occurred. Stations with no filling days in a quarter are excluded from the average for that quarter. All stations with at least one fill in a quarter are given equal weight when calculating the average for the quarter.



Summary of Station Usage Statistics⁴



¹Station nameplate capacity is as reported to NREL and reflects a variety of system design considerations including: system capacity, throughput, system reliability, and maintenance. Actual daily usage may exceed nameplate capacity.

²Average quarterly utilization only considers days when at least one fill occurred.

³Utilization is calculated by dividing the quarterly amount dispensed by the stations nameplate capacity.

⁴Only quarters with fills are included.



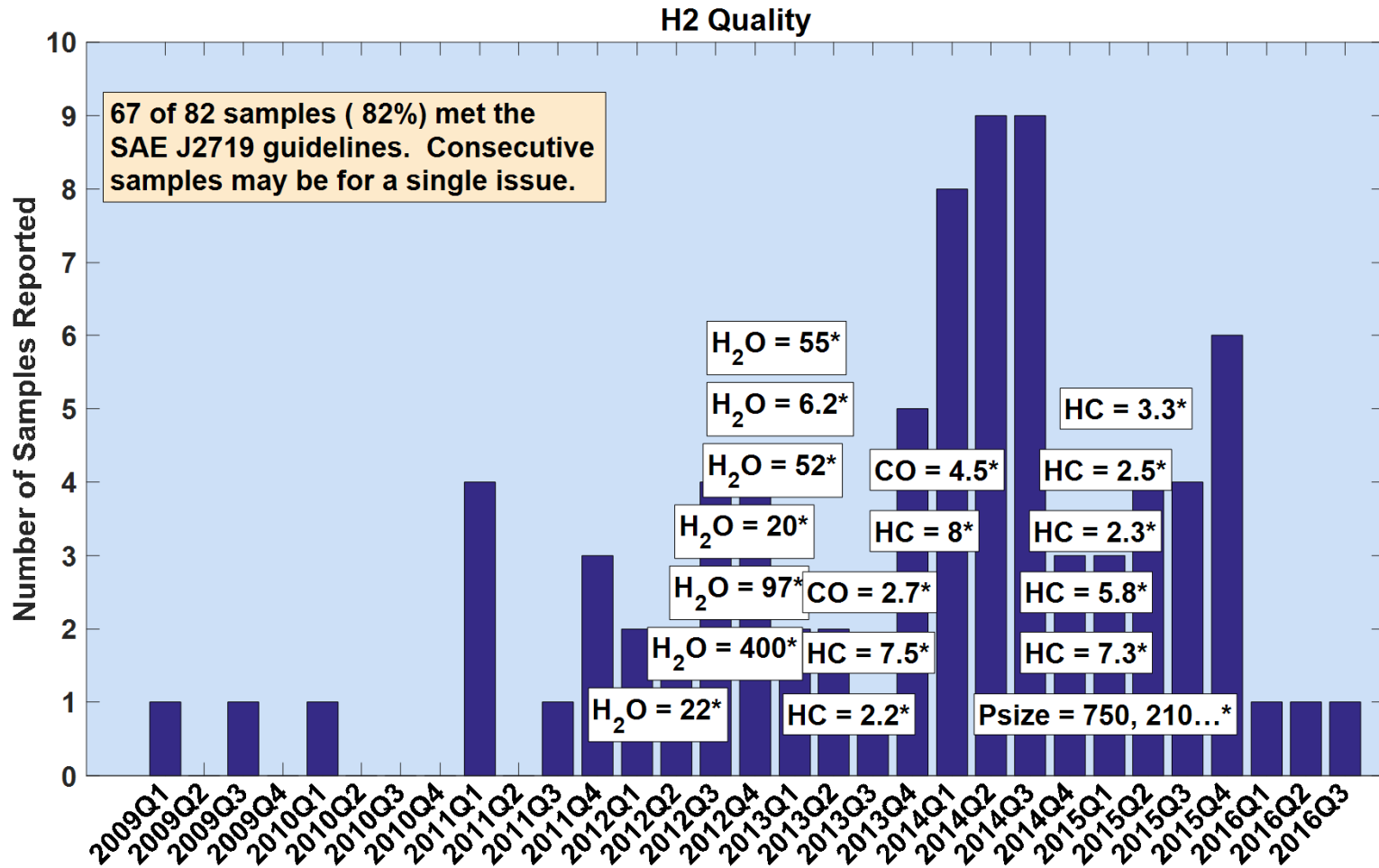
NREL cdp_infr_47

Created: Dec-09-16 3:47 PM | Data Range: 0000Q1-2016Q3

Hydrogen Quality

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Hydrogen Quality

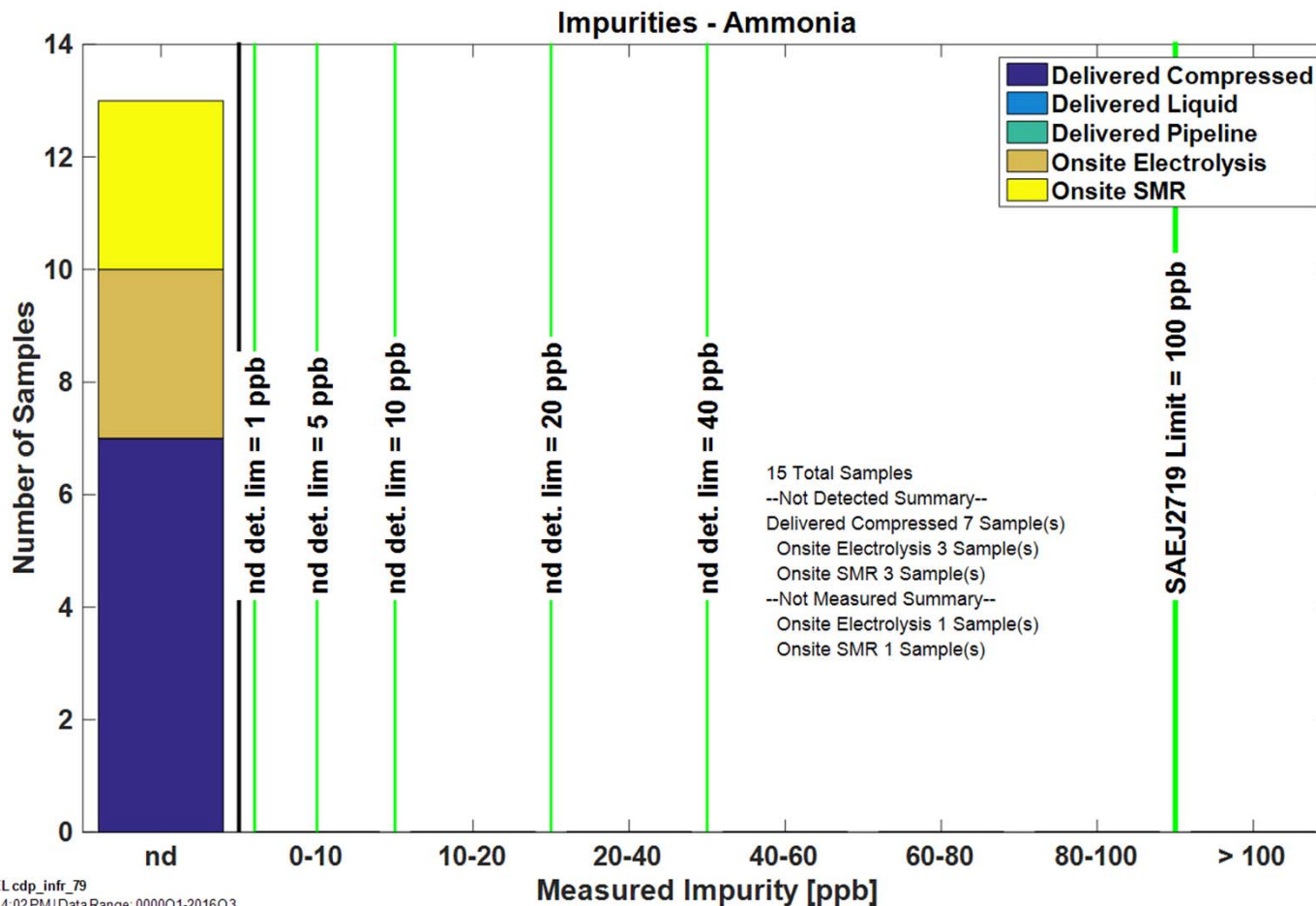


* Values are in micromole/mole, except for particulate size (Psize) in micrometer. Only values that exceed SAE J2719 guideline are shown in text. Left edge of text box aligns with date



NREL cdp_infr_25

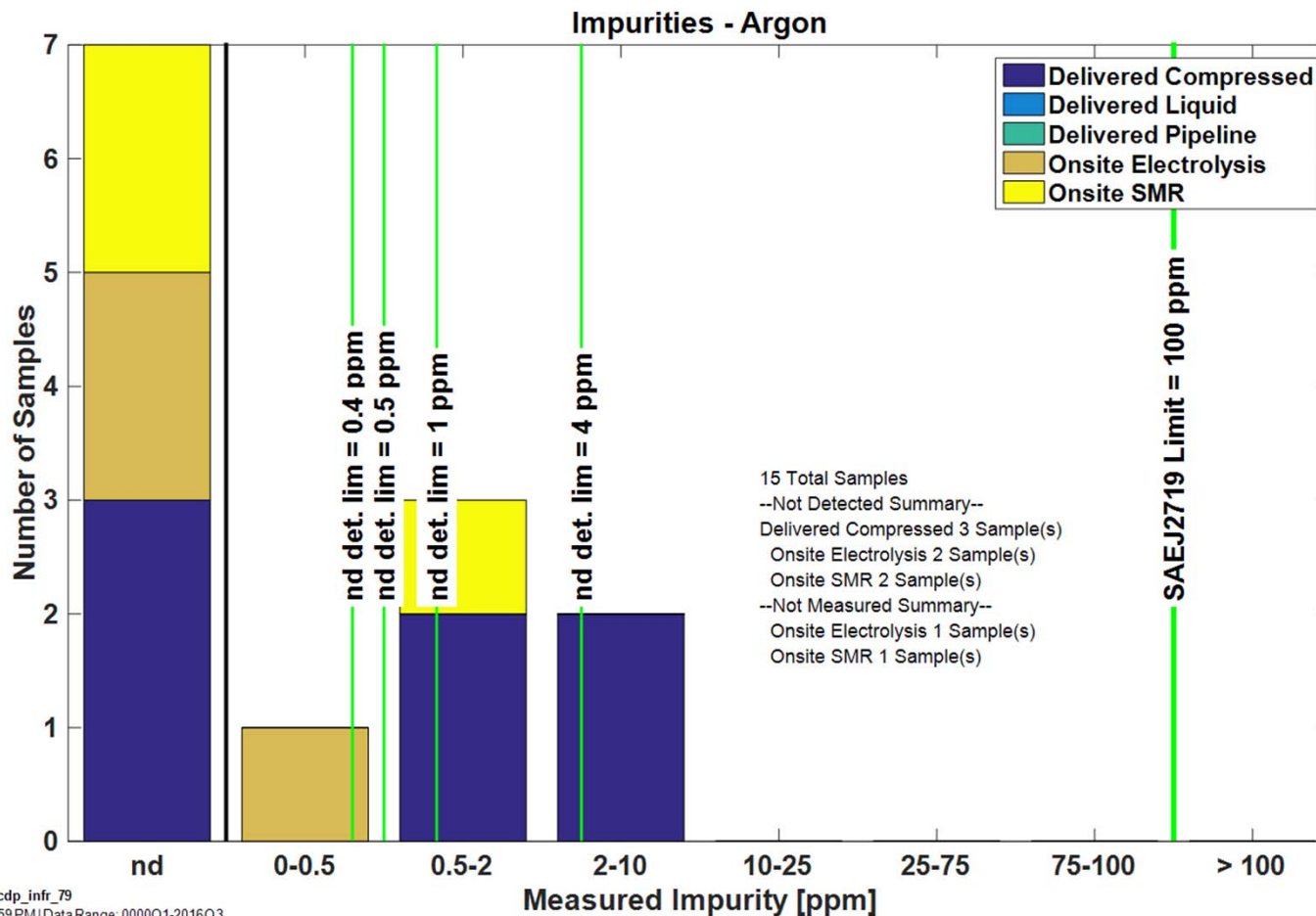
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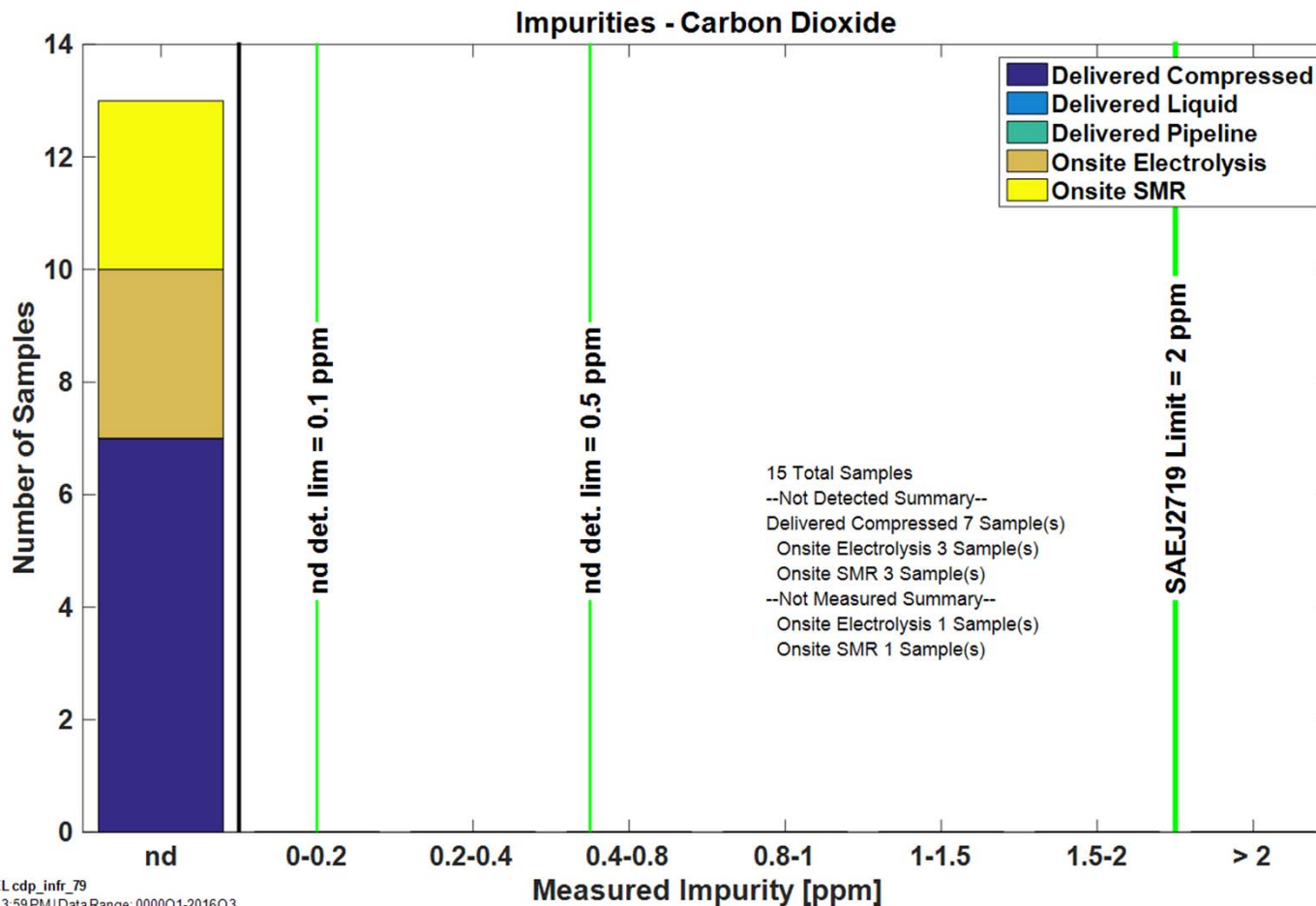
NREL cdp_infr_79
 Created: Dec-15-16 4:02 PM | Data Range: 0000Q1-2016Q3

CDP-INFR-79

Impurities—Argon

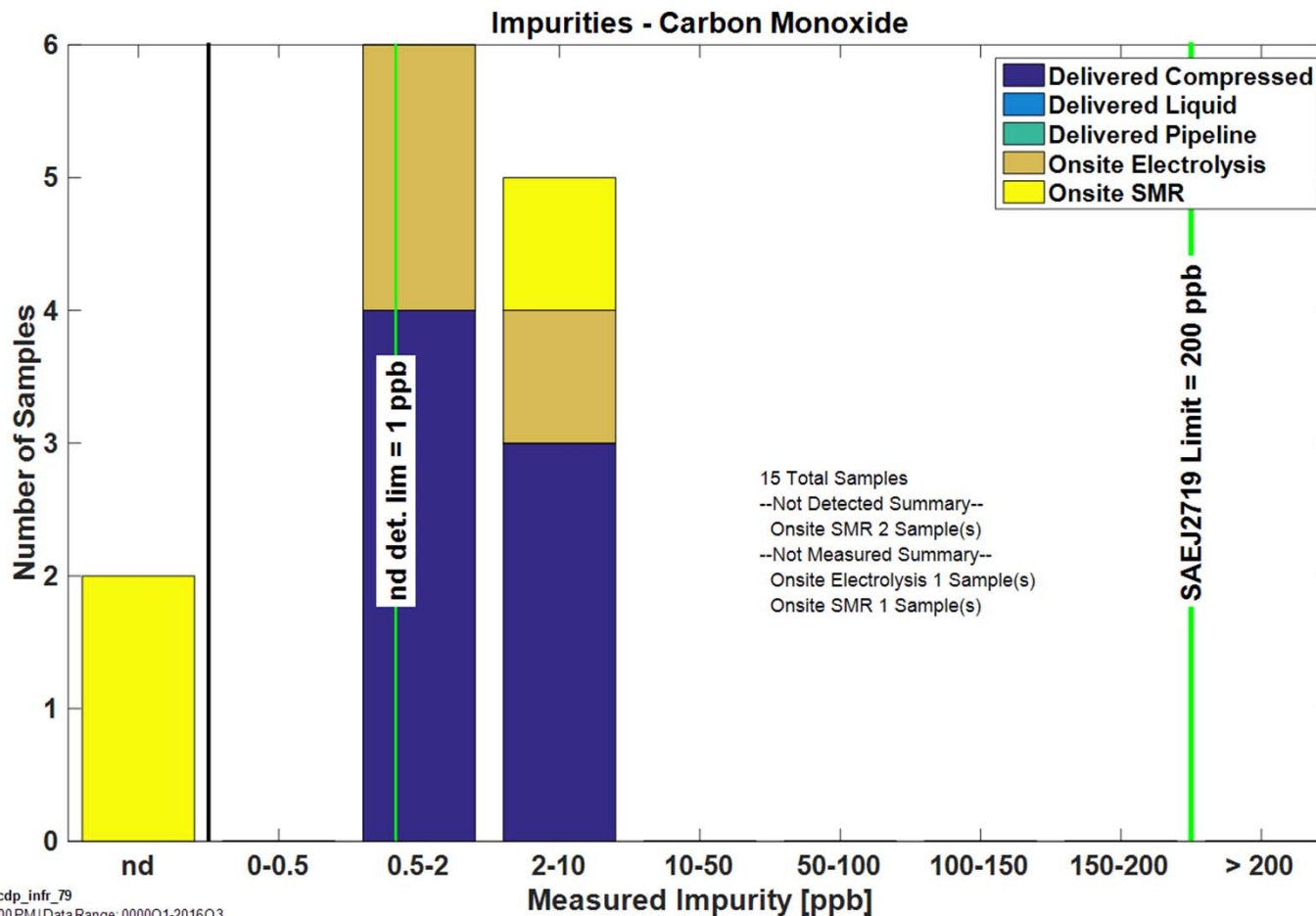


NREL cdp_infr_79
Created: Dec-15-16 3:59 PM | Data Range: 0000Q1-2016Q3



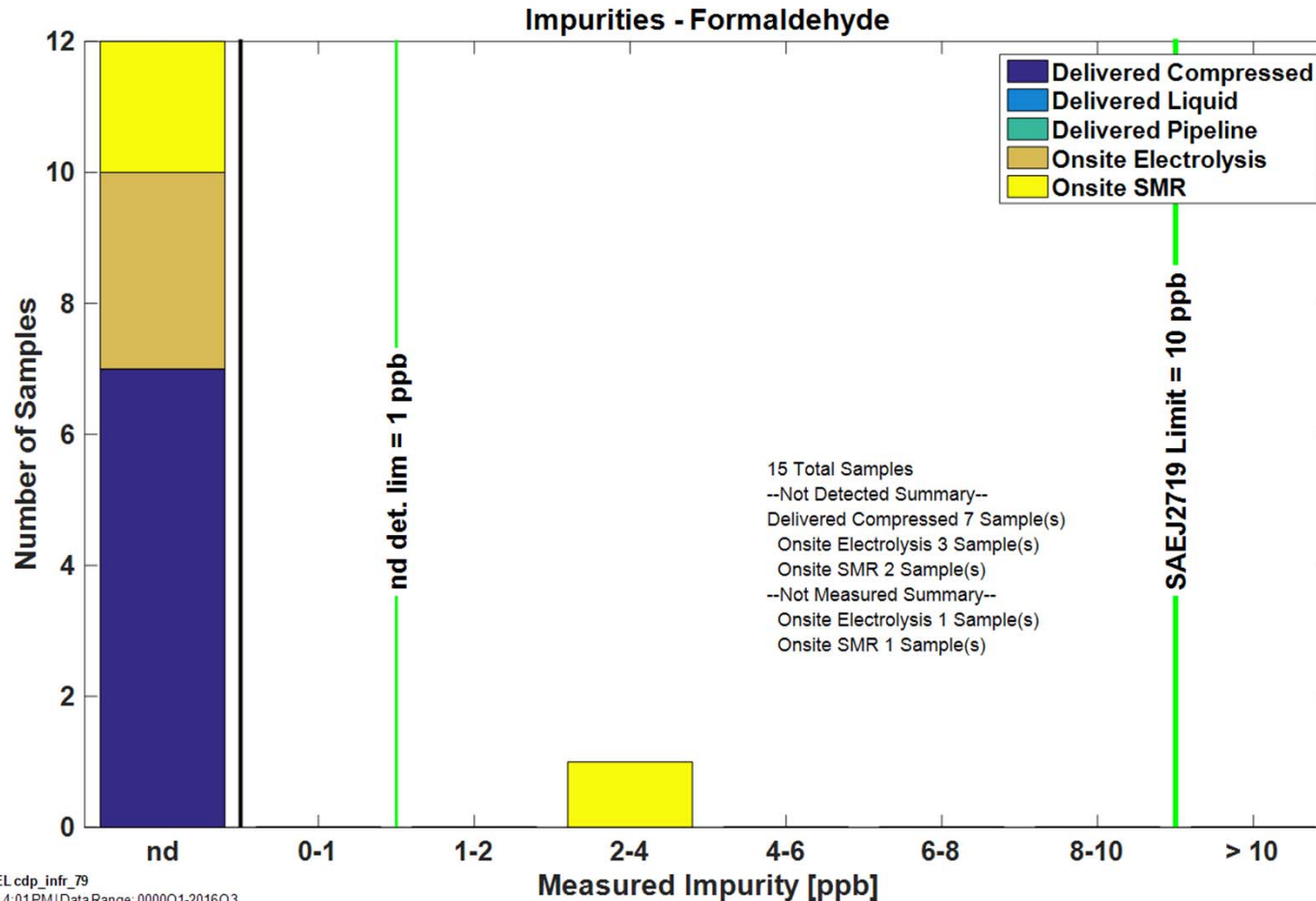
NREL cdp_infr_79

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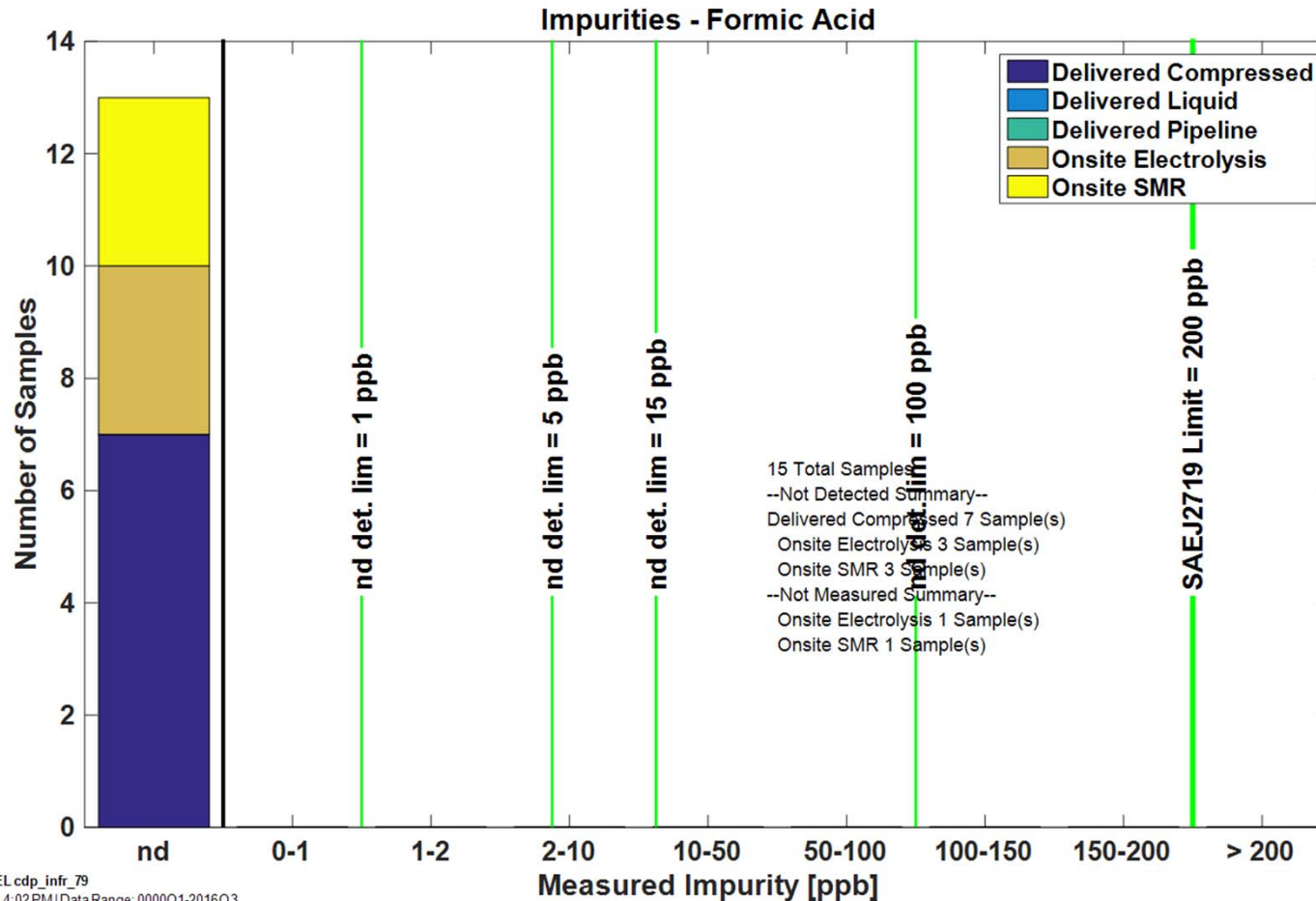
NREL cdp_infr_79

Created: Dec-15-16 4:00 PM | Data Range: 0000Q1-2016Q3



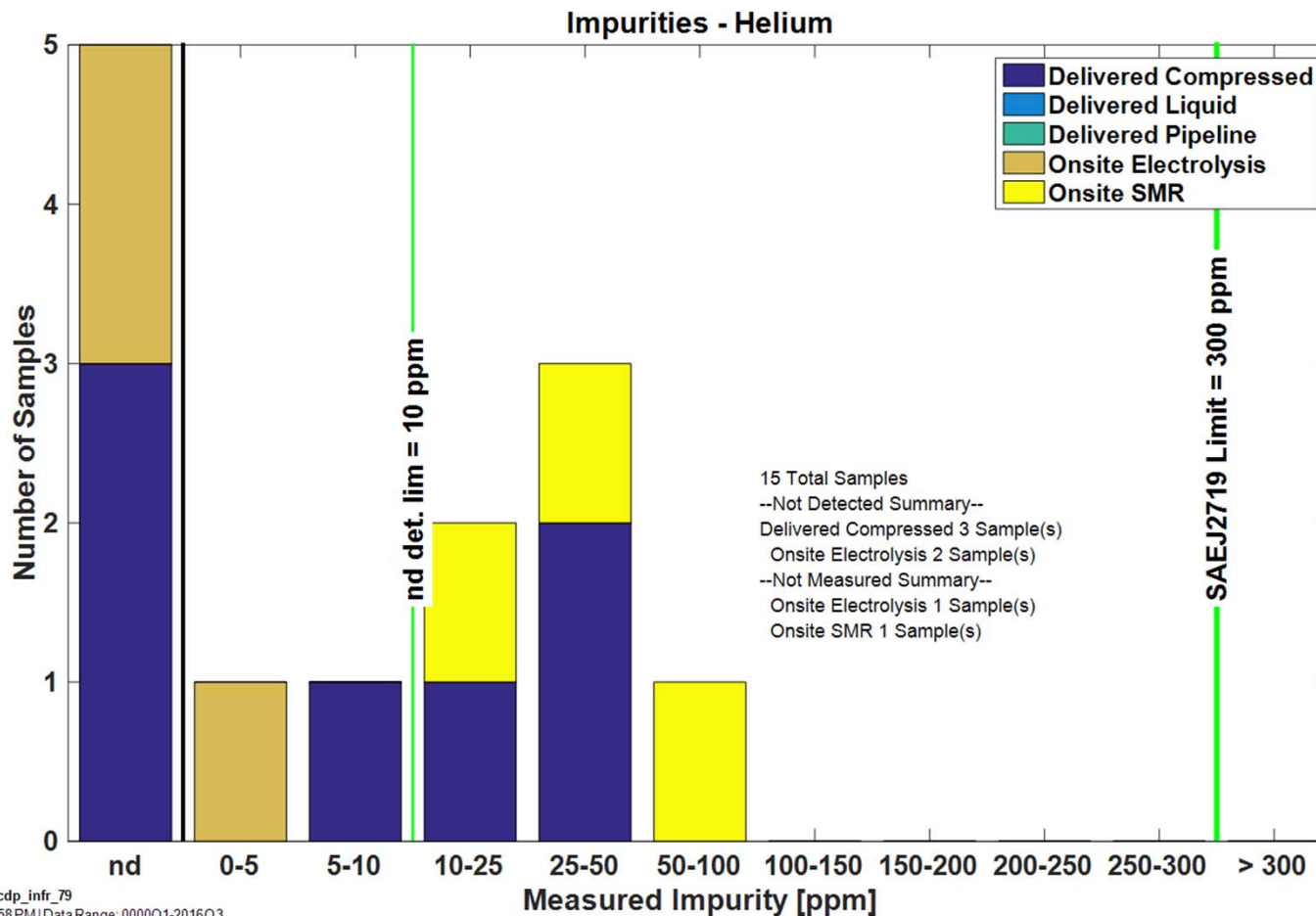
NREL cdp_infr_79

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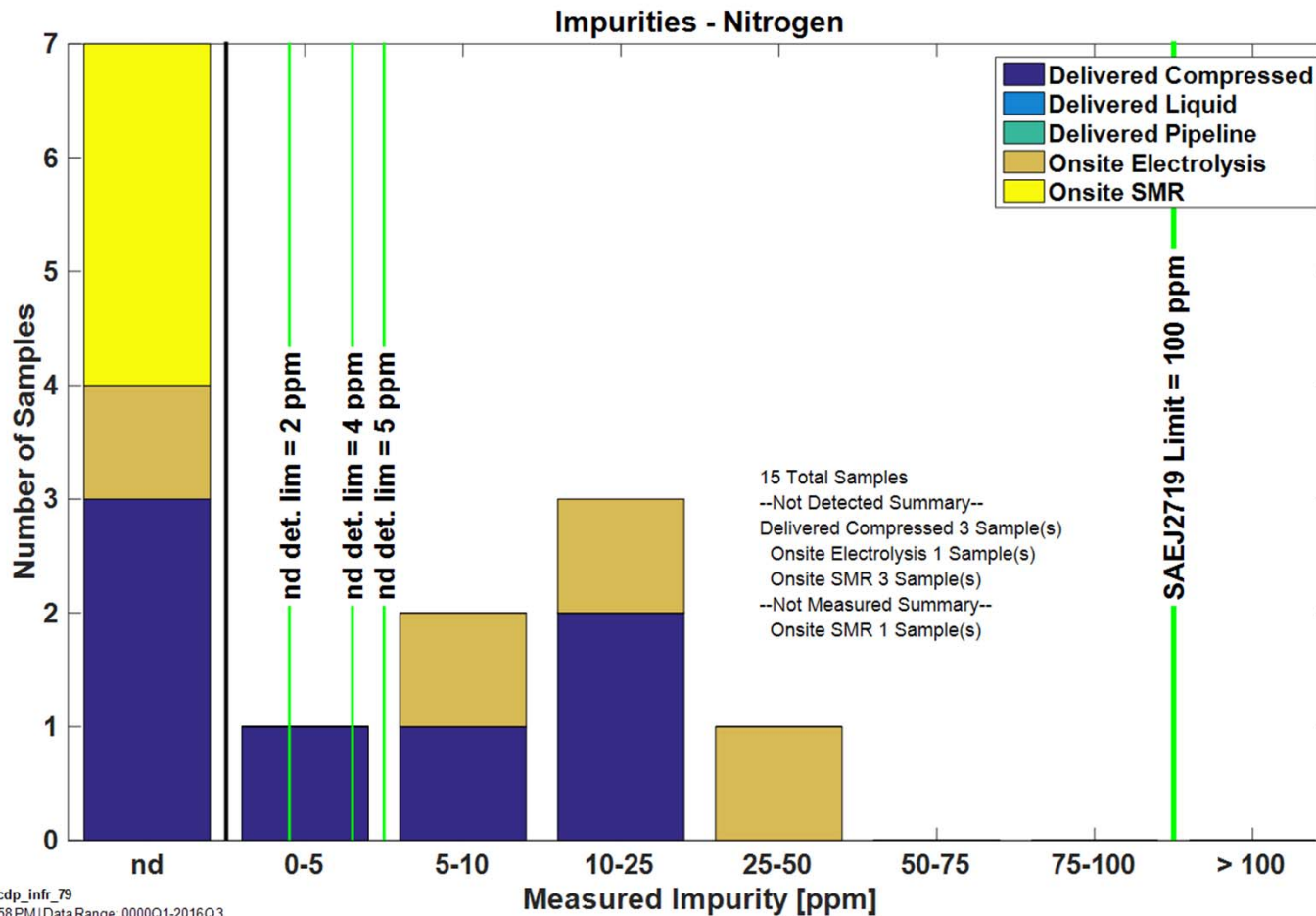
NREL cdp_infr_79

Created: Dec-15-16 4:02 PM | Data Range: 0000Q1-2016Q3



NREL cdp_infr_79

Created: Dec-15-16 3:58 PM | Data Range: 0000Q1-2016Q3

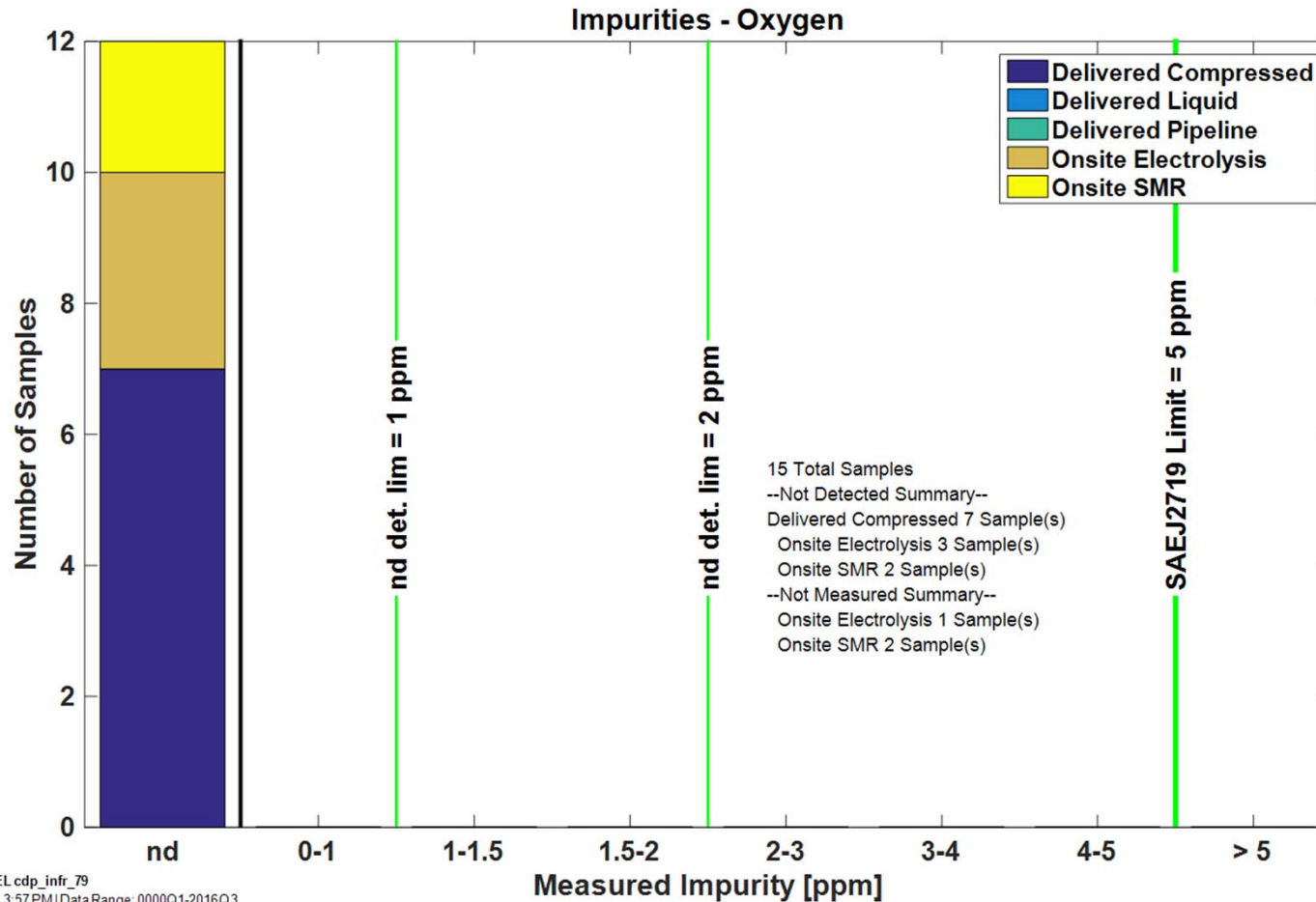


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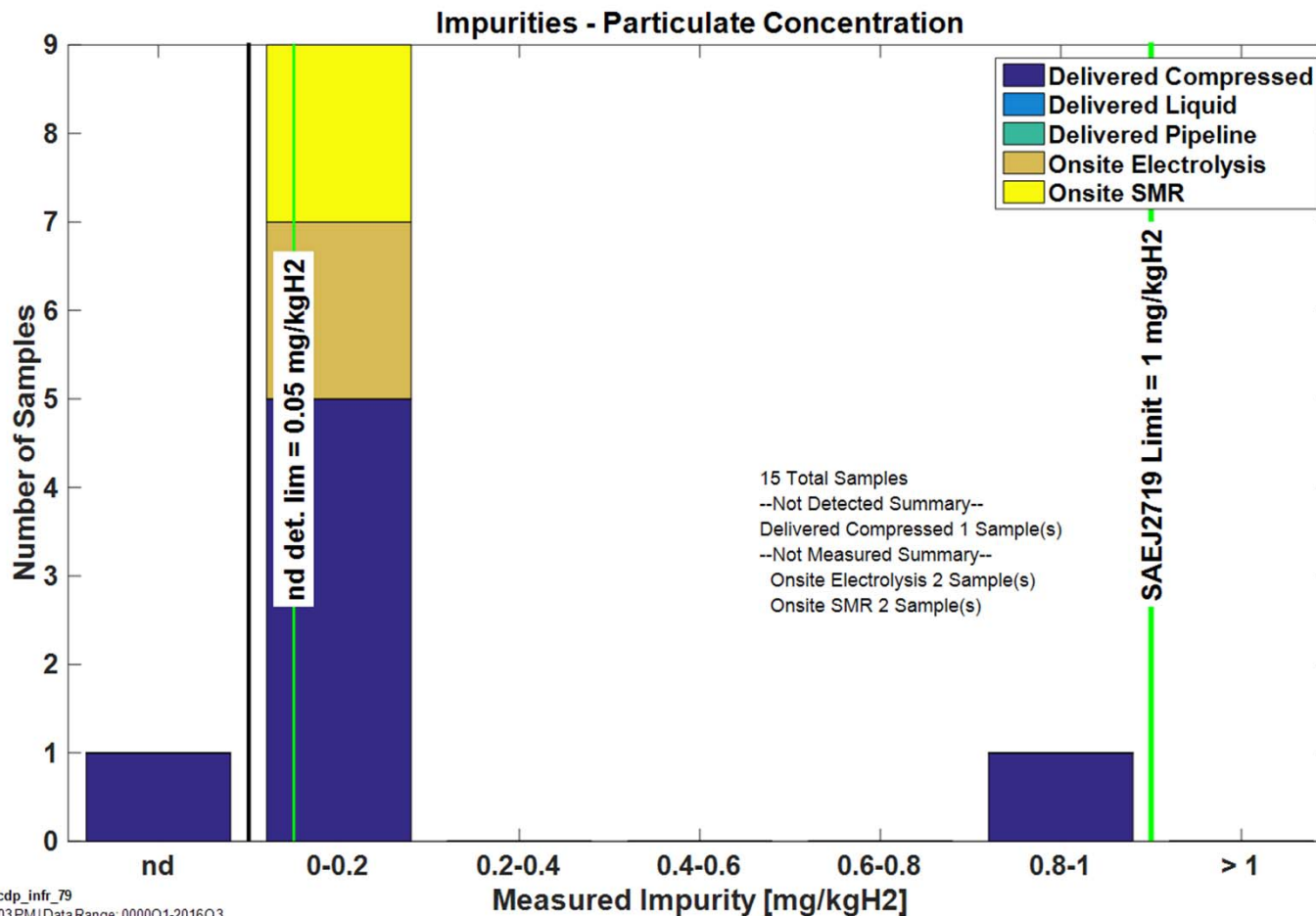
CDP-INFR-79

Impurities—Oxygen



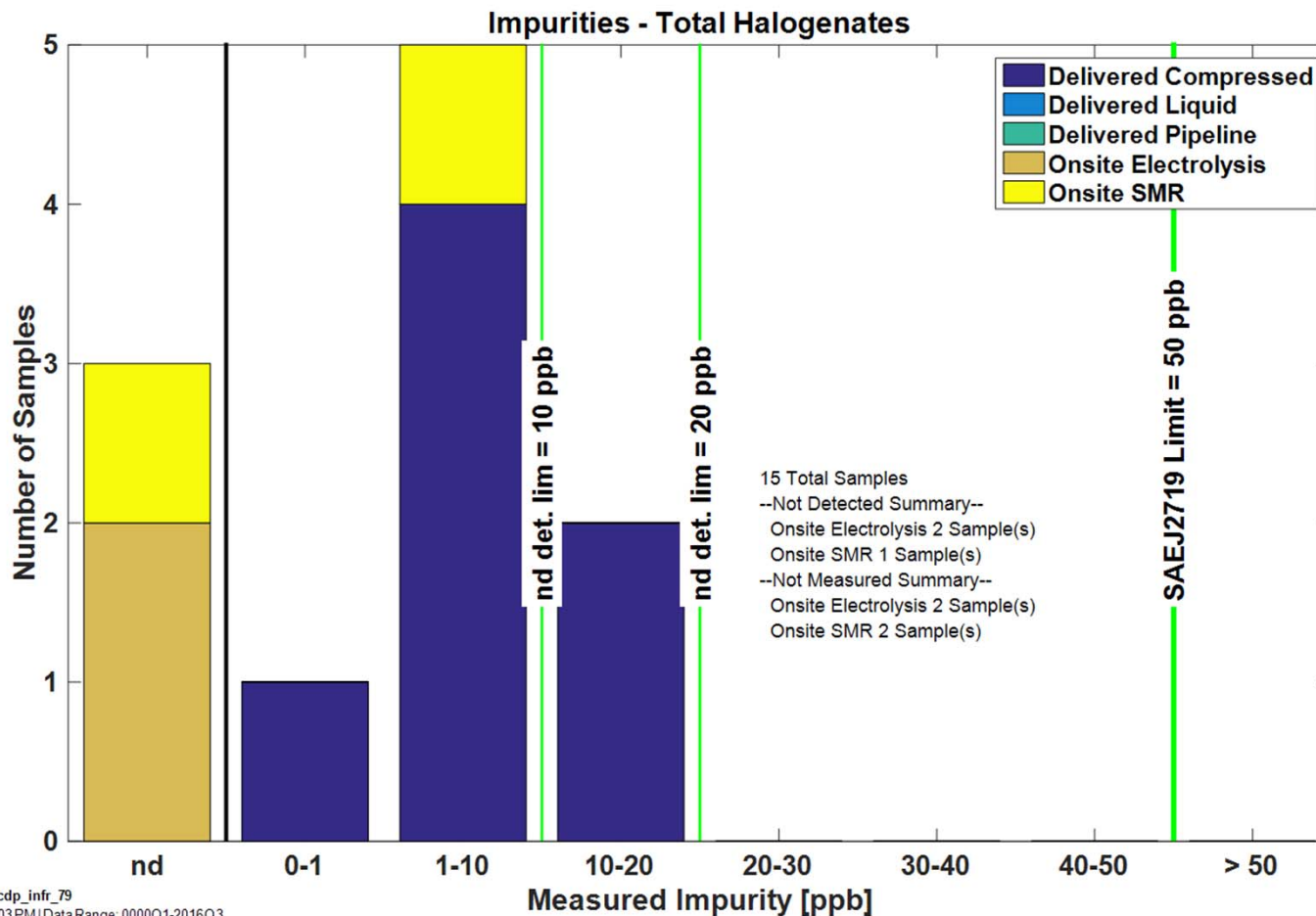
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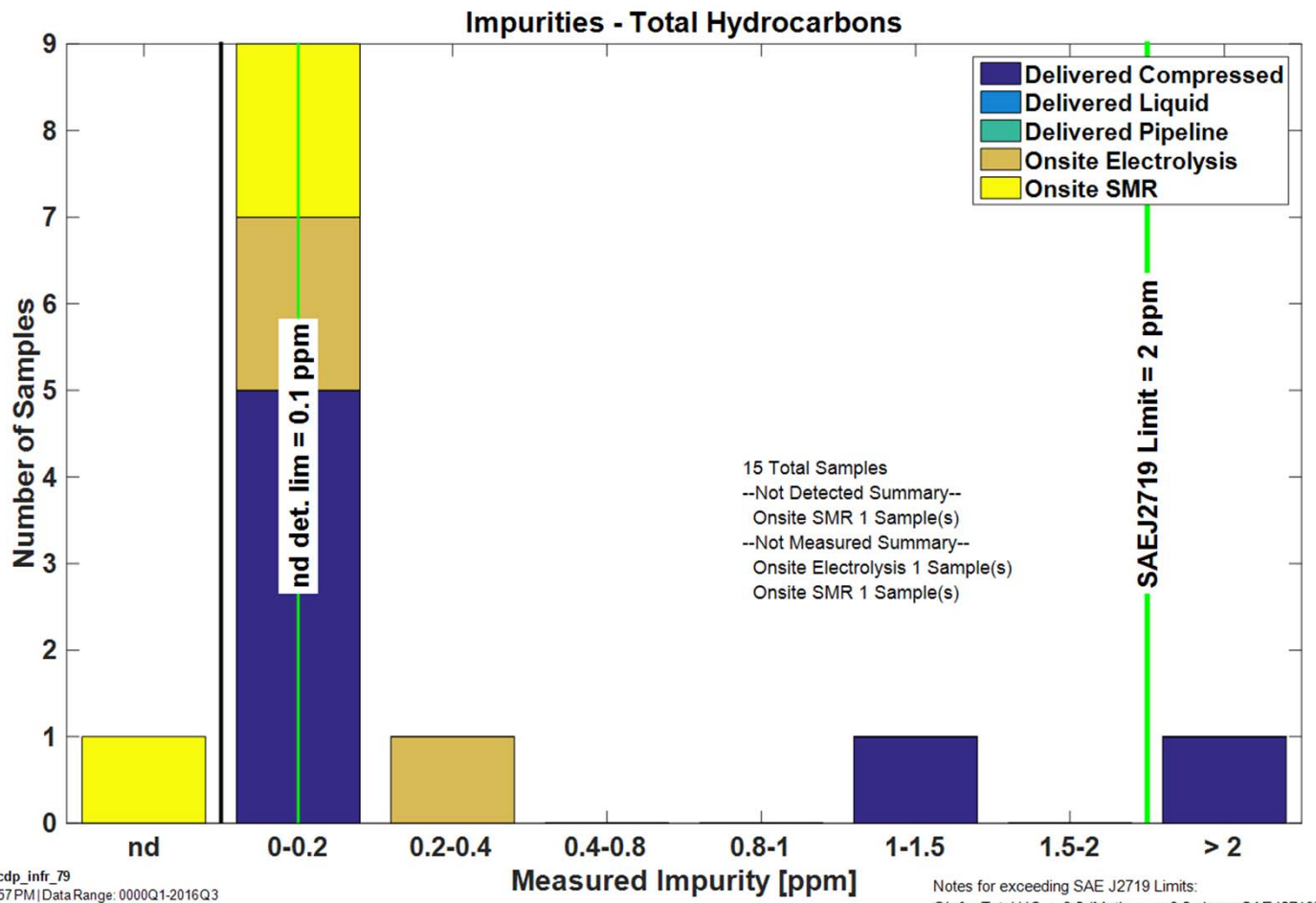
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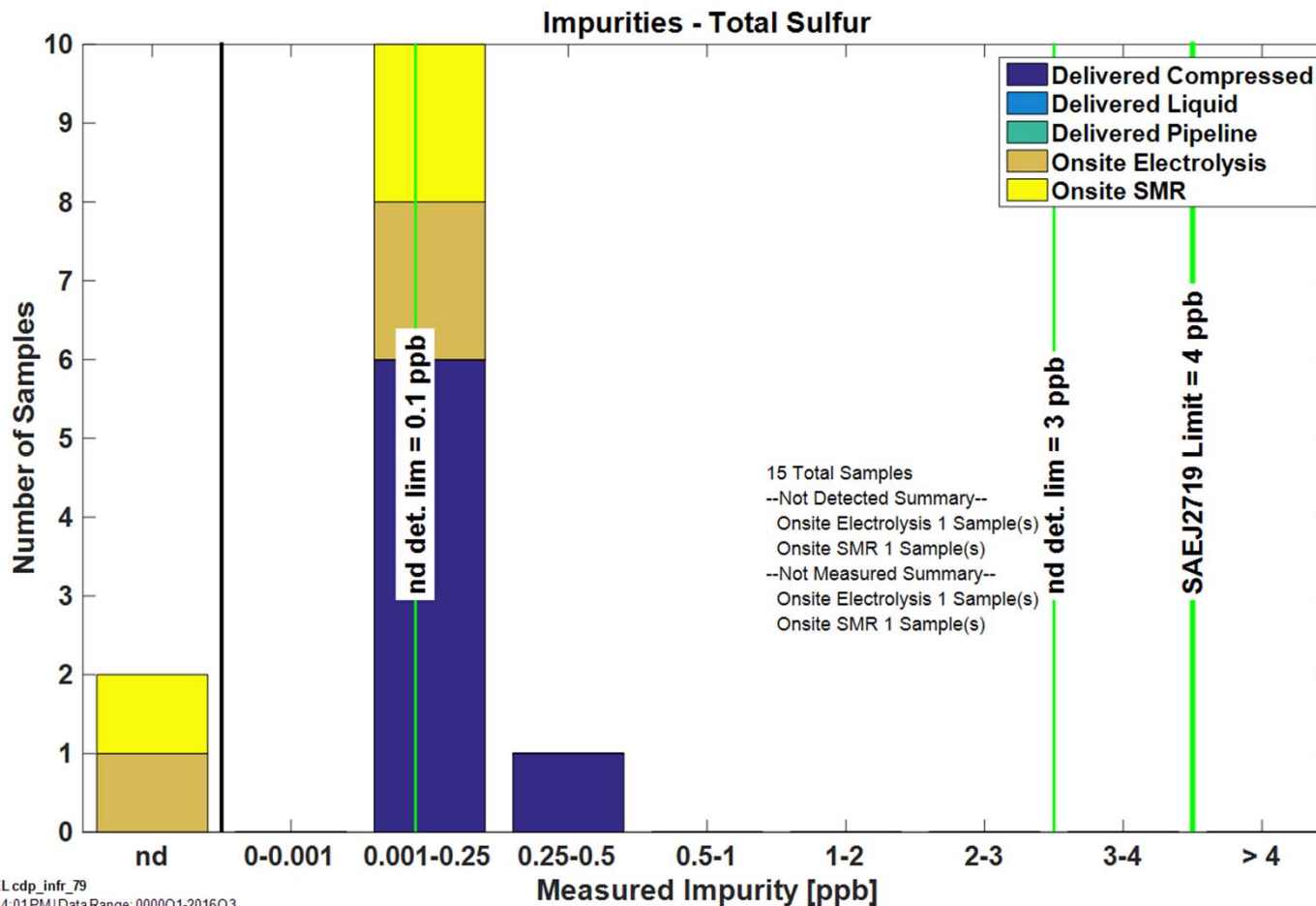
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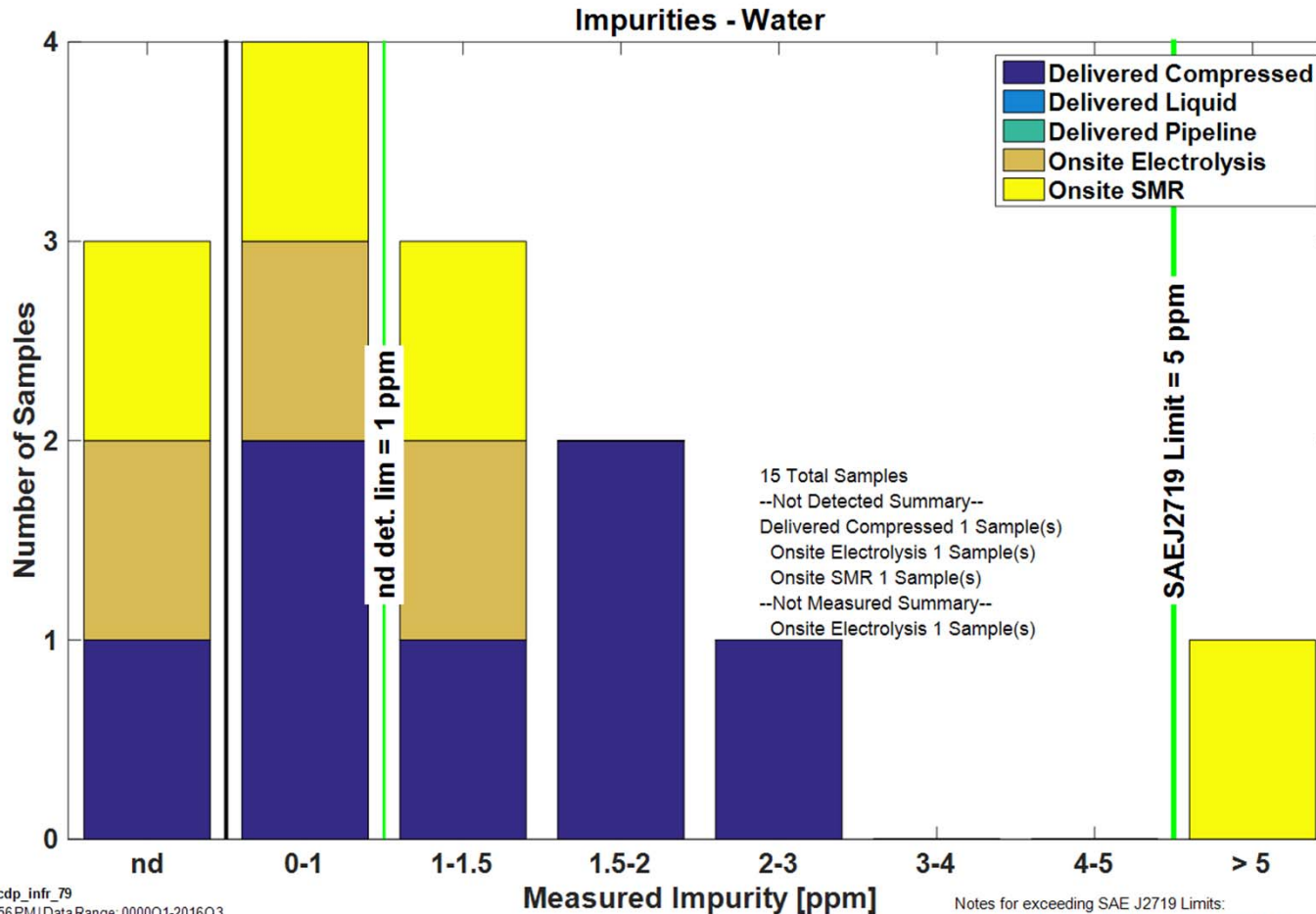


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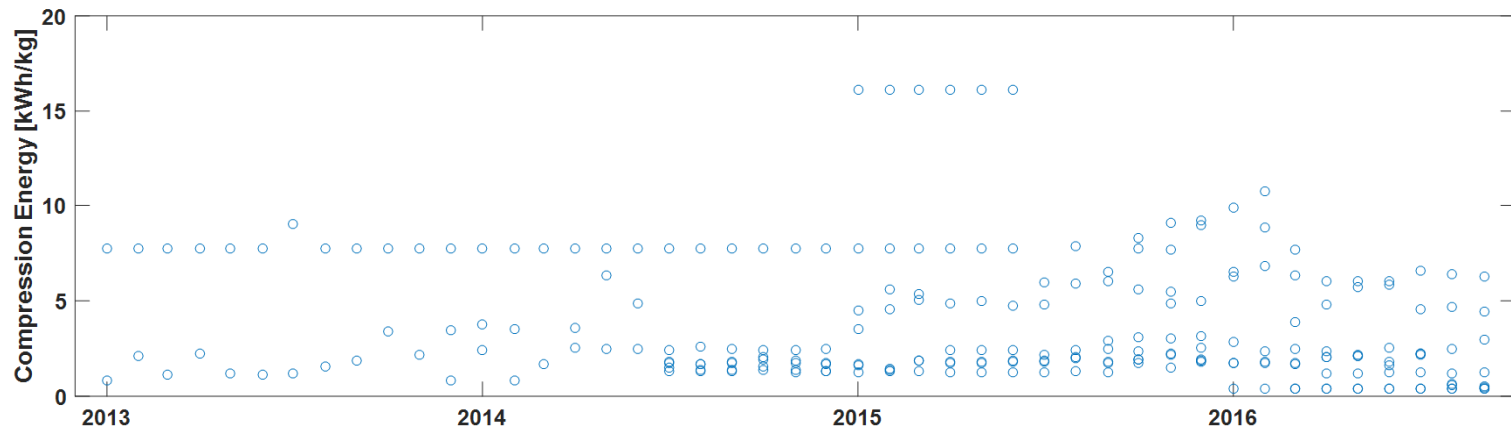
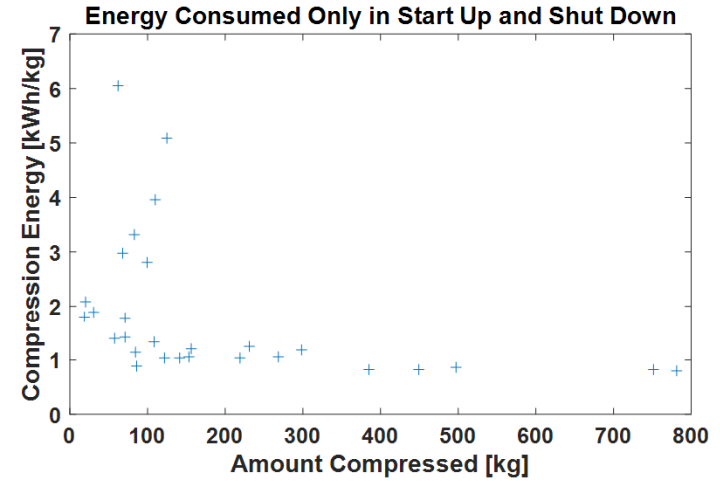
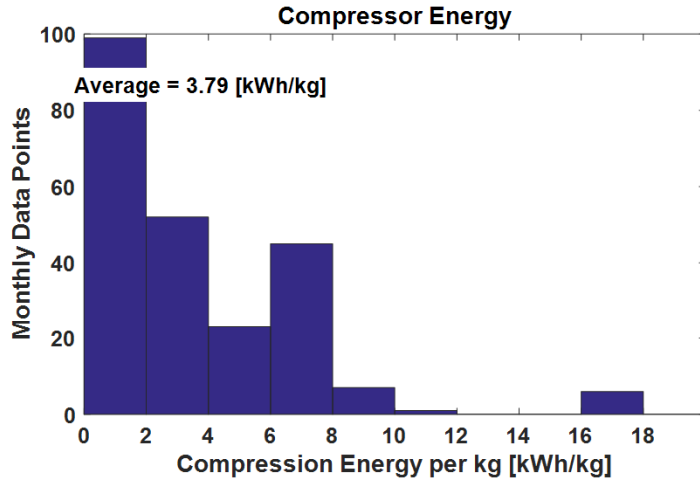
NREL cdp_infr_79

Created: Dec-15-16 3:56 PM | Data Range: 0000Q1-2016Q3

Component Energy

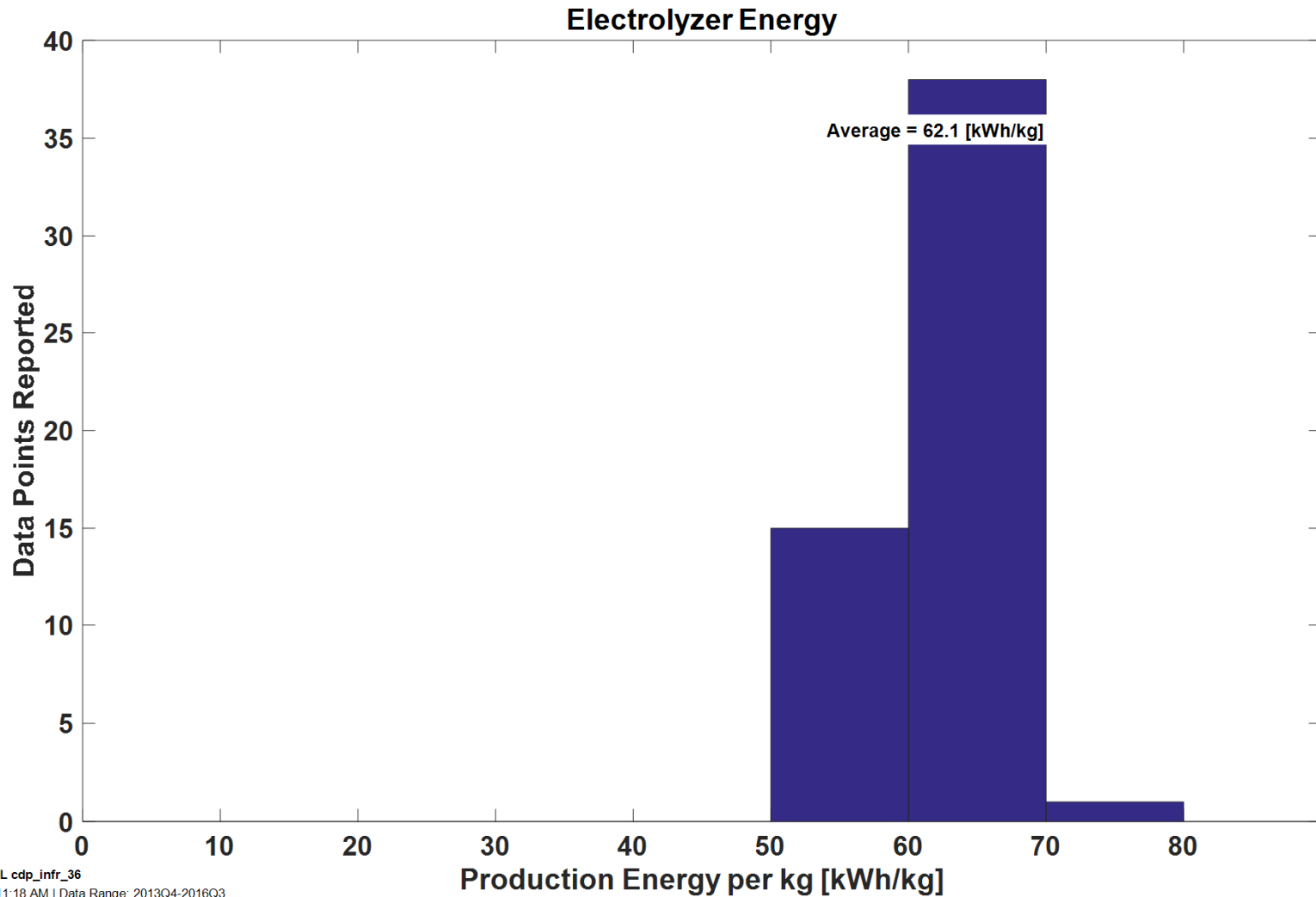
CDP-INFR-35

Compressor Energy



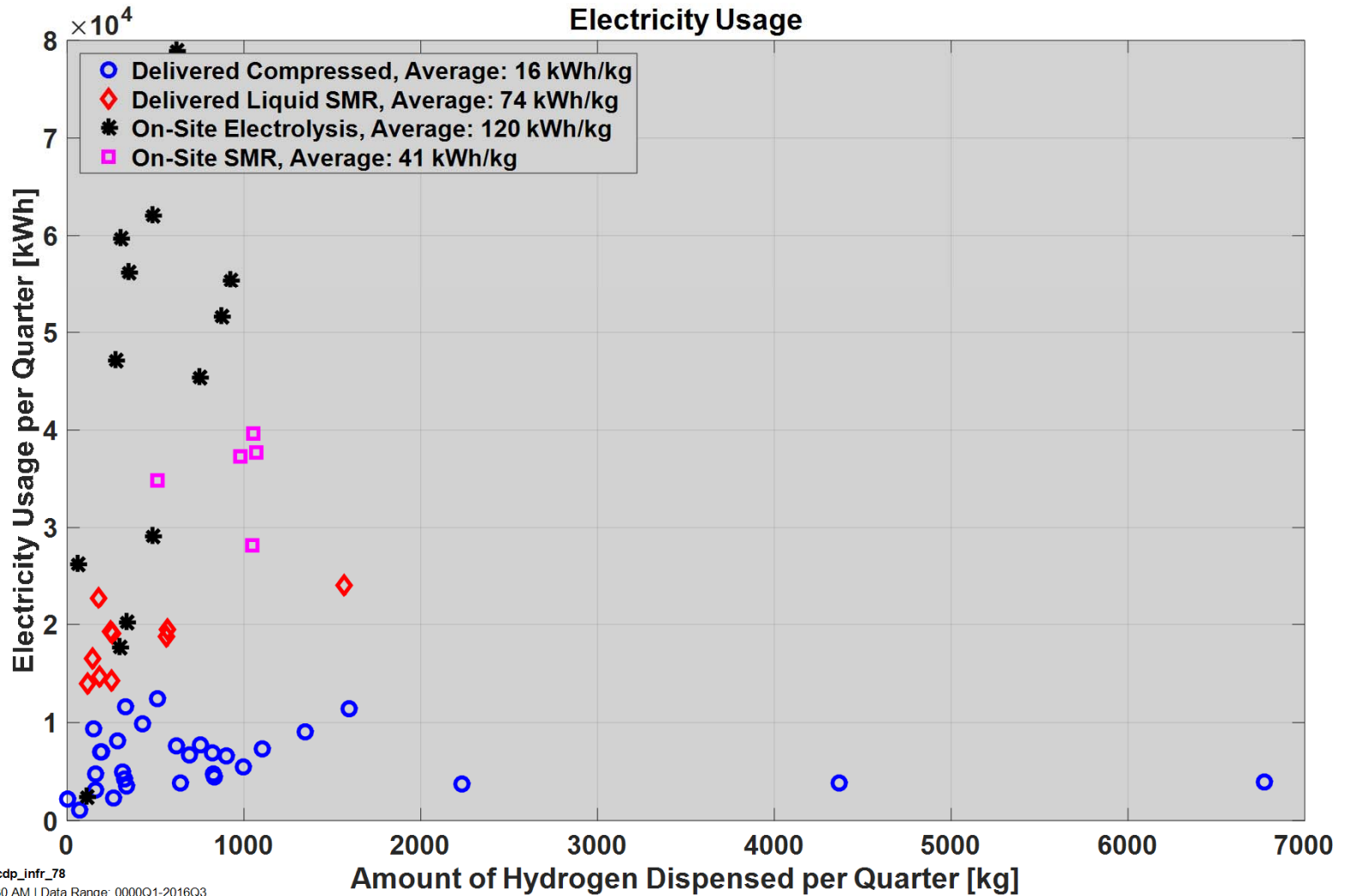
NREL cdp_infr_35

Created: Dec-21-16 11:15 AM | Data Range: 2011Q1-2016Q3



NREL cdp_infr_36

Created: Dec-21-16 11:18 AM | Data Range: 2013Q4-2016Q3



NREL cdp_infr_78

Created: Dec-15-16 8:30 AM | Data Range: 0000Q1-2016Q3