



Next Generation Hydrogen Station Composite Data Products: Retail Stations

Data through Quarter 4 of 2016

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Genevieve Saur, and Michael Peters

May 10, 2017

NREL/PR-5400-68555

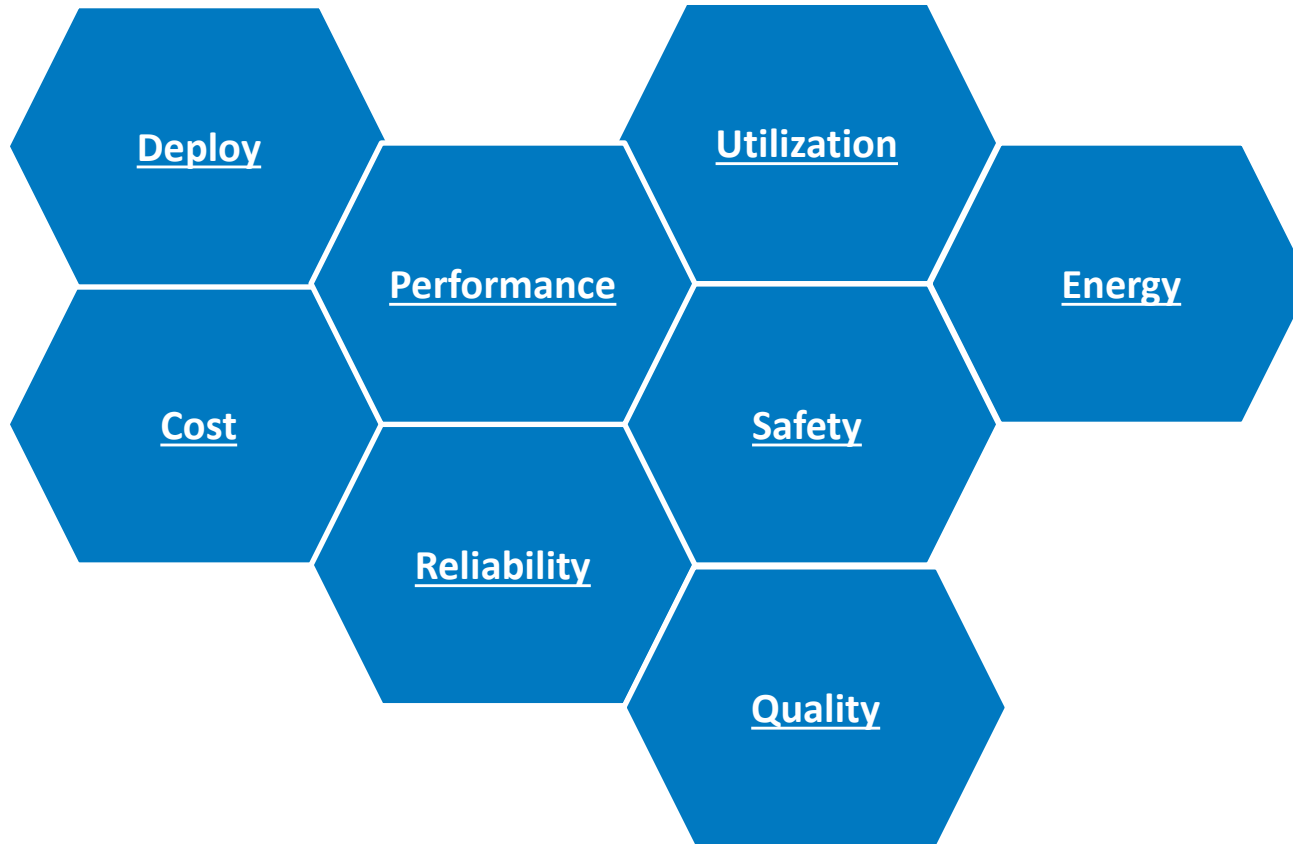
Hydrogen Station Project Partners



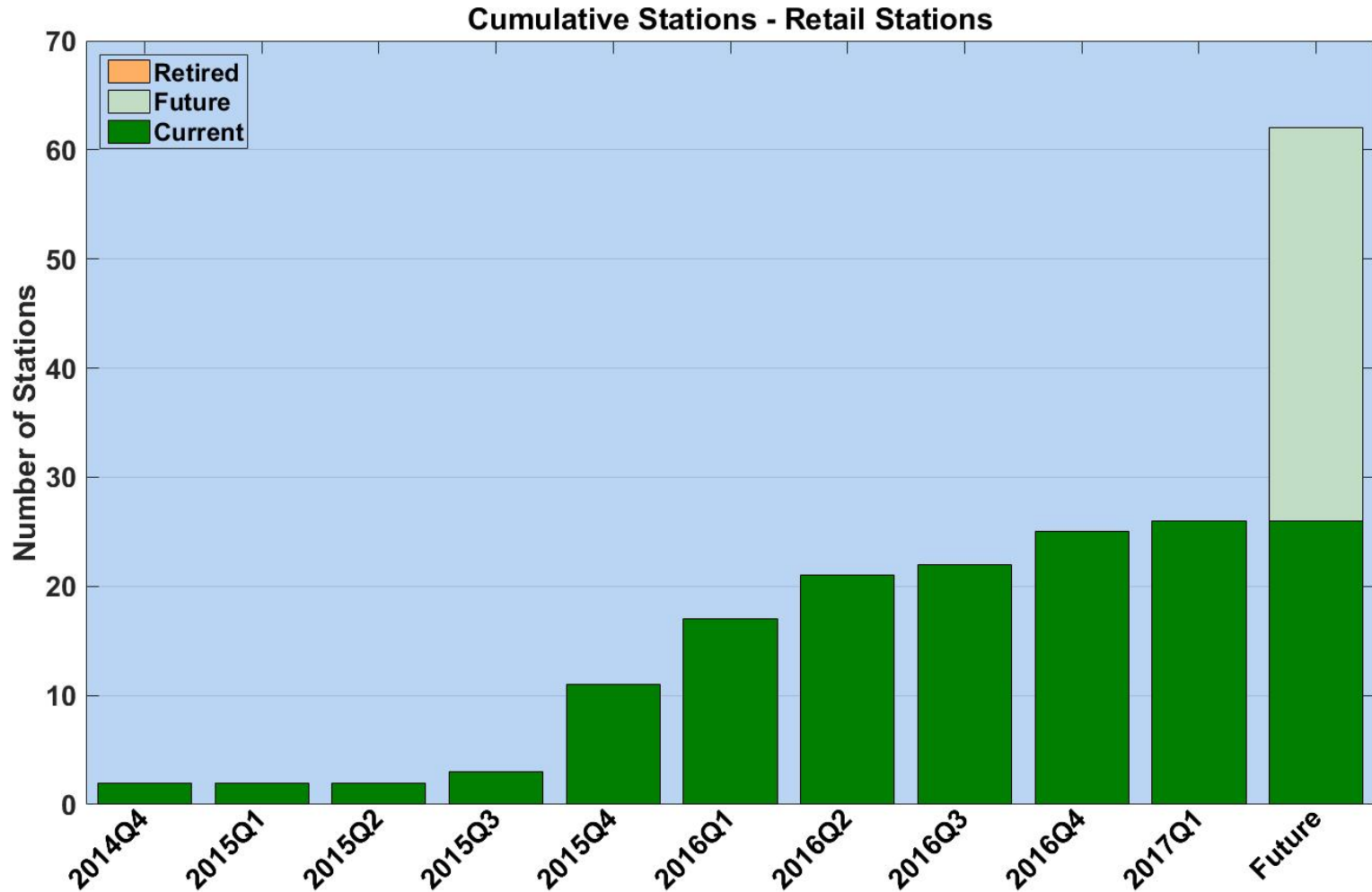
- Air Liquide
- Air Products
- California Air Resources Board
- California Energy Commission
- California State University Los Angeles
- First Element
- Gas Technology Institute
- Linde
- H2 Frontier
- Proton OnSite
- Shell
- IPHE and HySUT



Analysis Categories



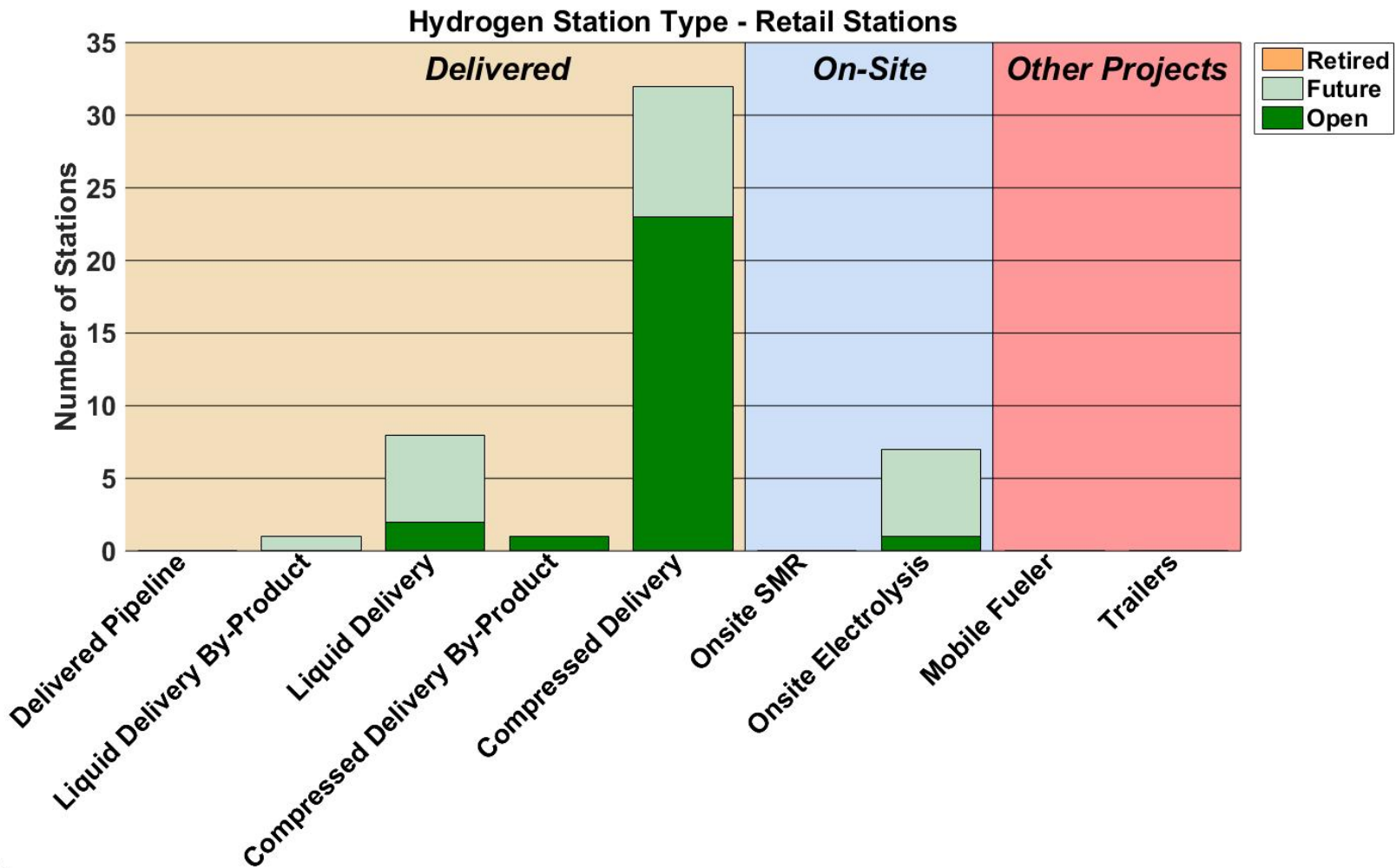
Deployment



NREL cdpRETAIL_infr_10

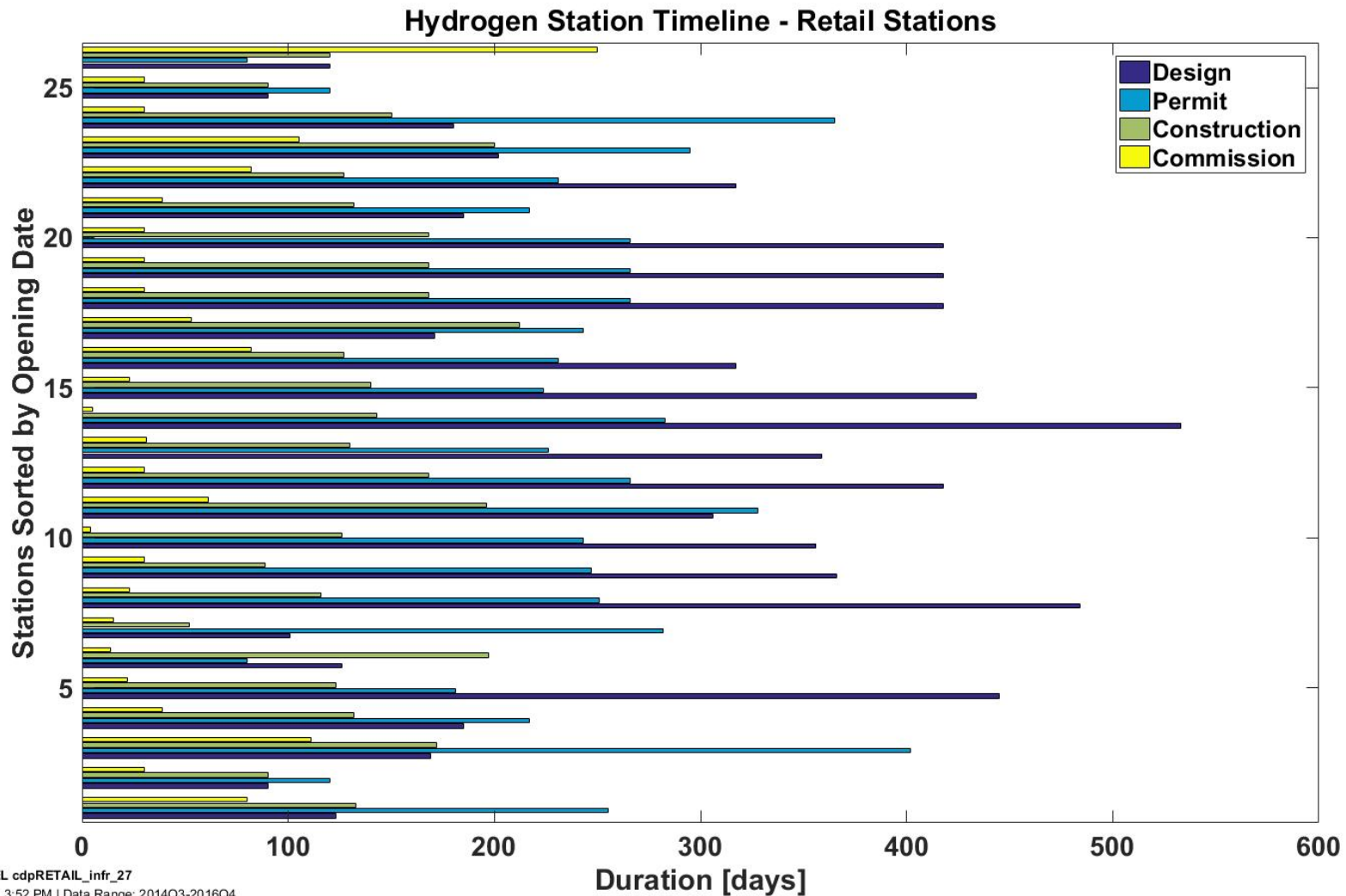
Created: May-08-17 12:36 PM | Data Range: 2014Q3-2016Q4

Hydrogen Stations by Type

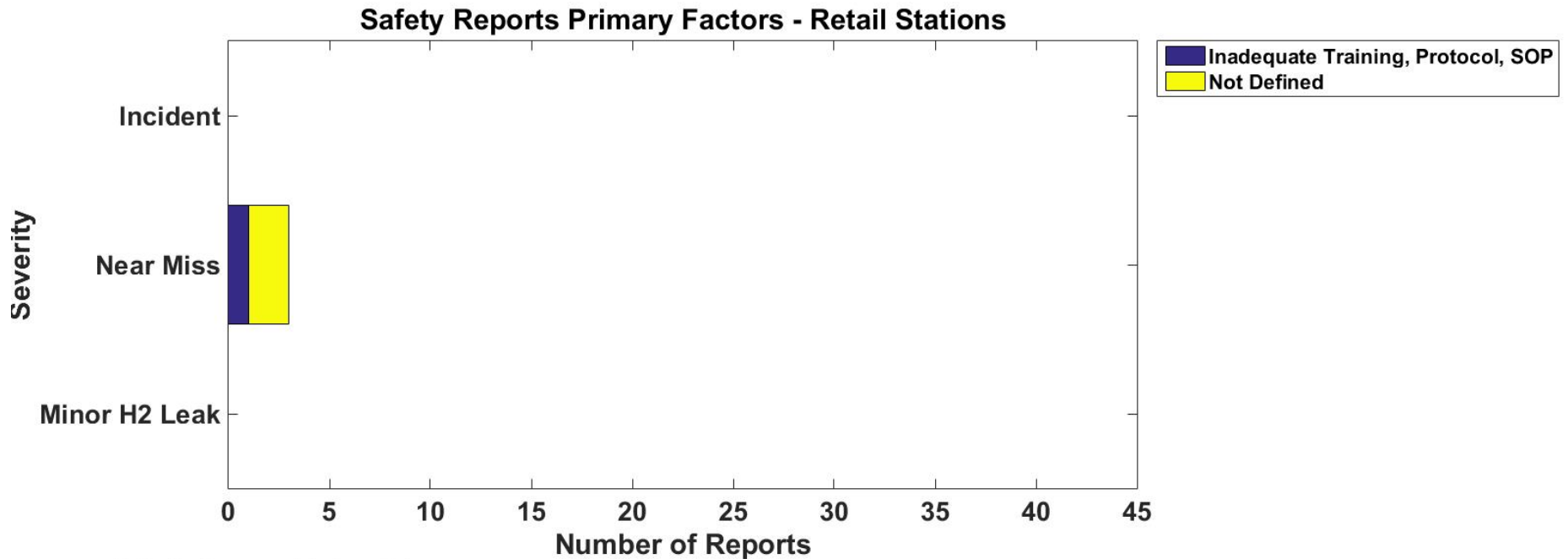


NREL cdpRETAIL_infr_11

Created: May-05-17 3:35 PM | Data Range: 2014Q3-2016Q4



Safety



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:

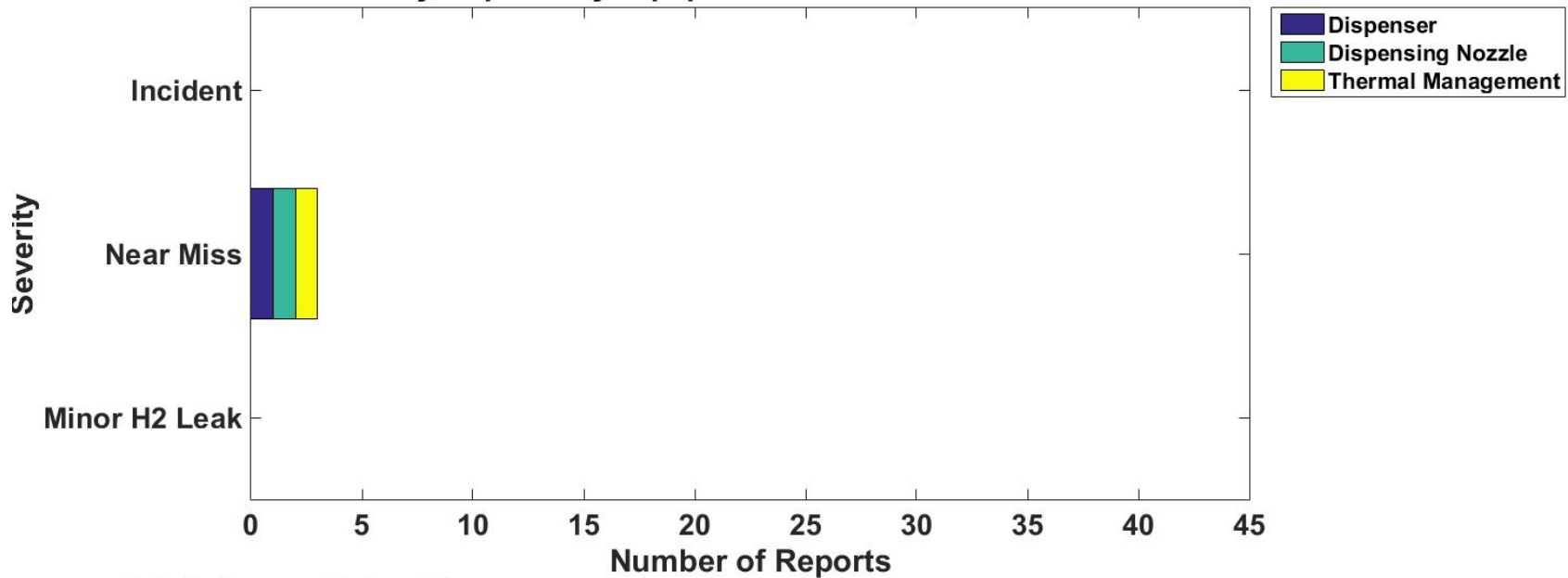
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdpRETAIL_infr_31

Created: Apr-19-17 4:28 PM | Data Range: 2015Q3-2016Q4

Safety Reports By Equipment Involved - Retail Stations



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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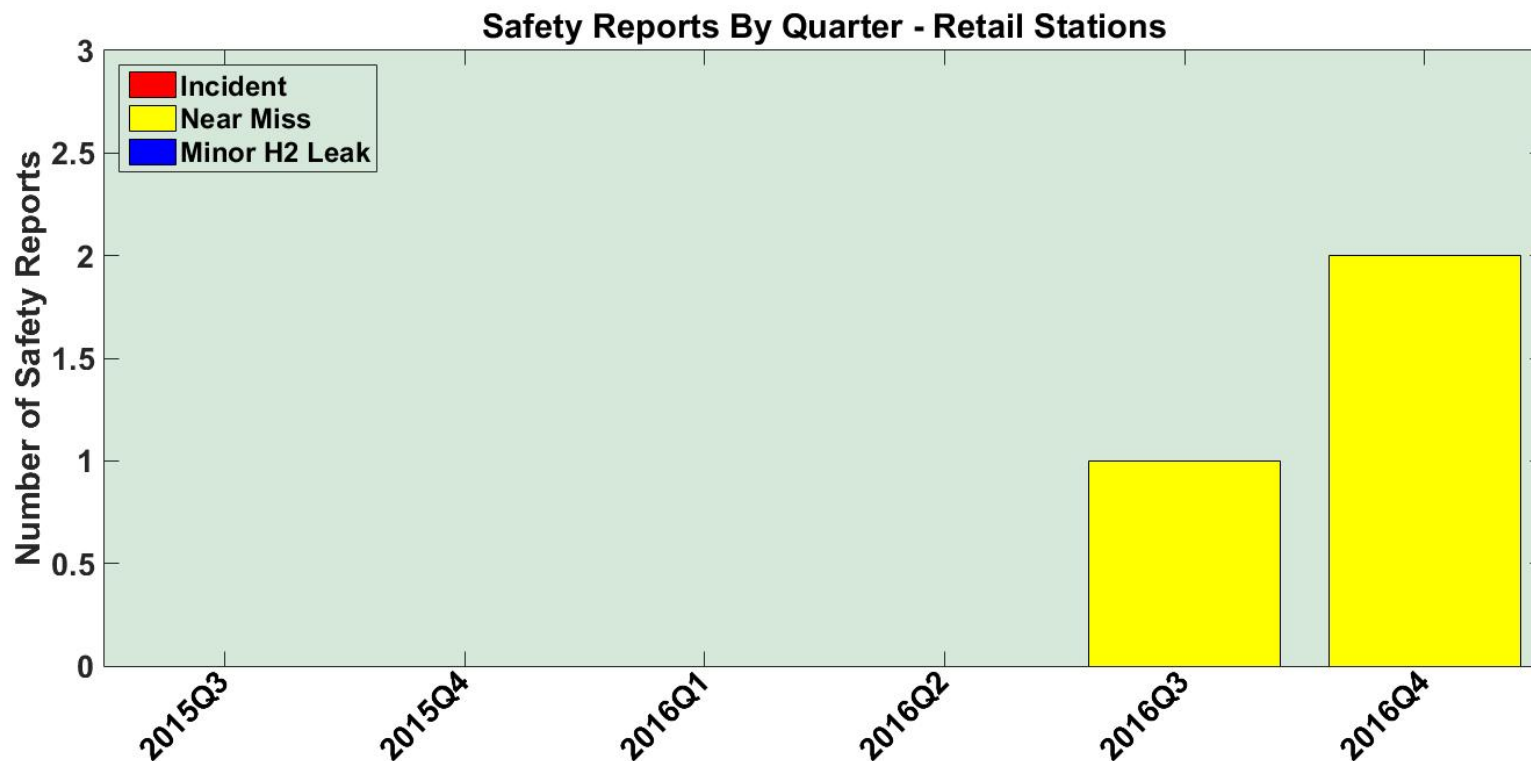
A Minor H2 Leak is:

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



NREL cdpRETAIL_infr_32

Created: Apr-19-17 4:28 PM | Data Range: 2015Q3-2016Q4



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:

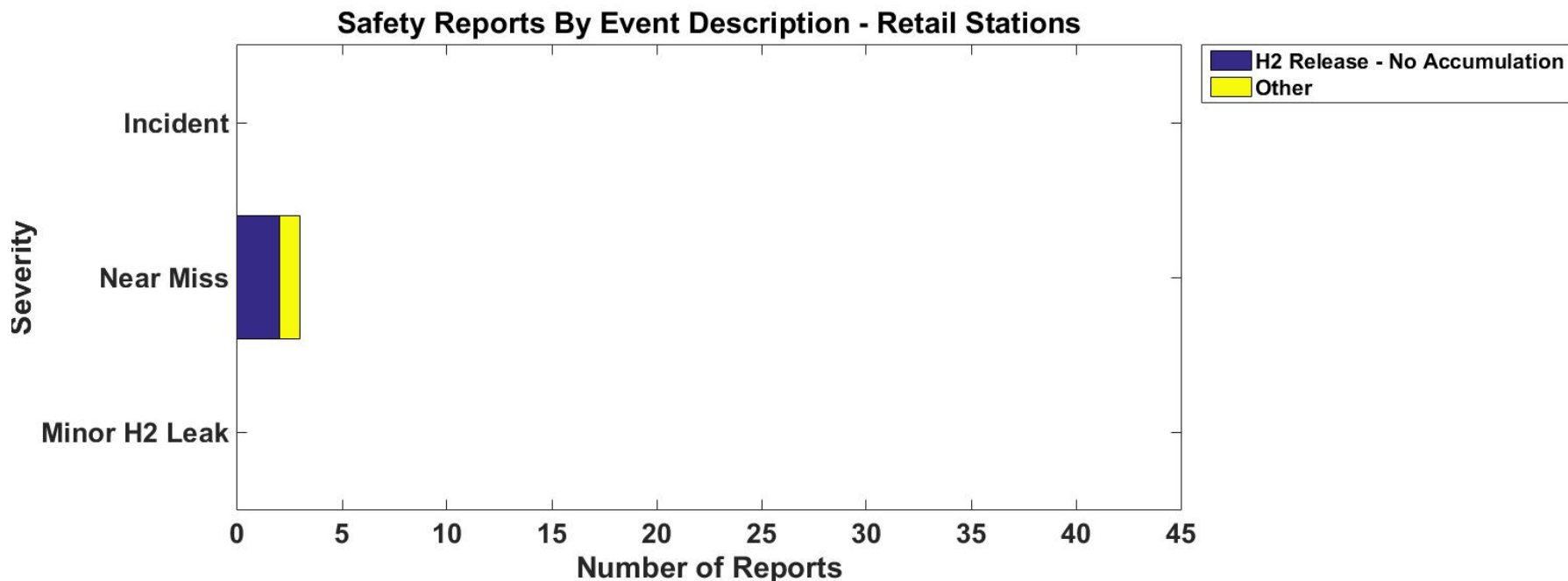
- an event that under slightly different circumstances could have become an incident
- any hydrogen release sufficient to sustain a flame if ignited

A Minor H2 Leak is:



NREL cdpRETAIL_infr_33

Created: Apr-20-17 10:05 AM | Data Range: 2015Q3-2016Q4



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:

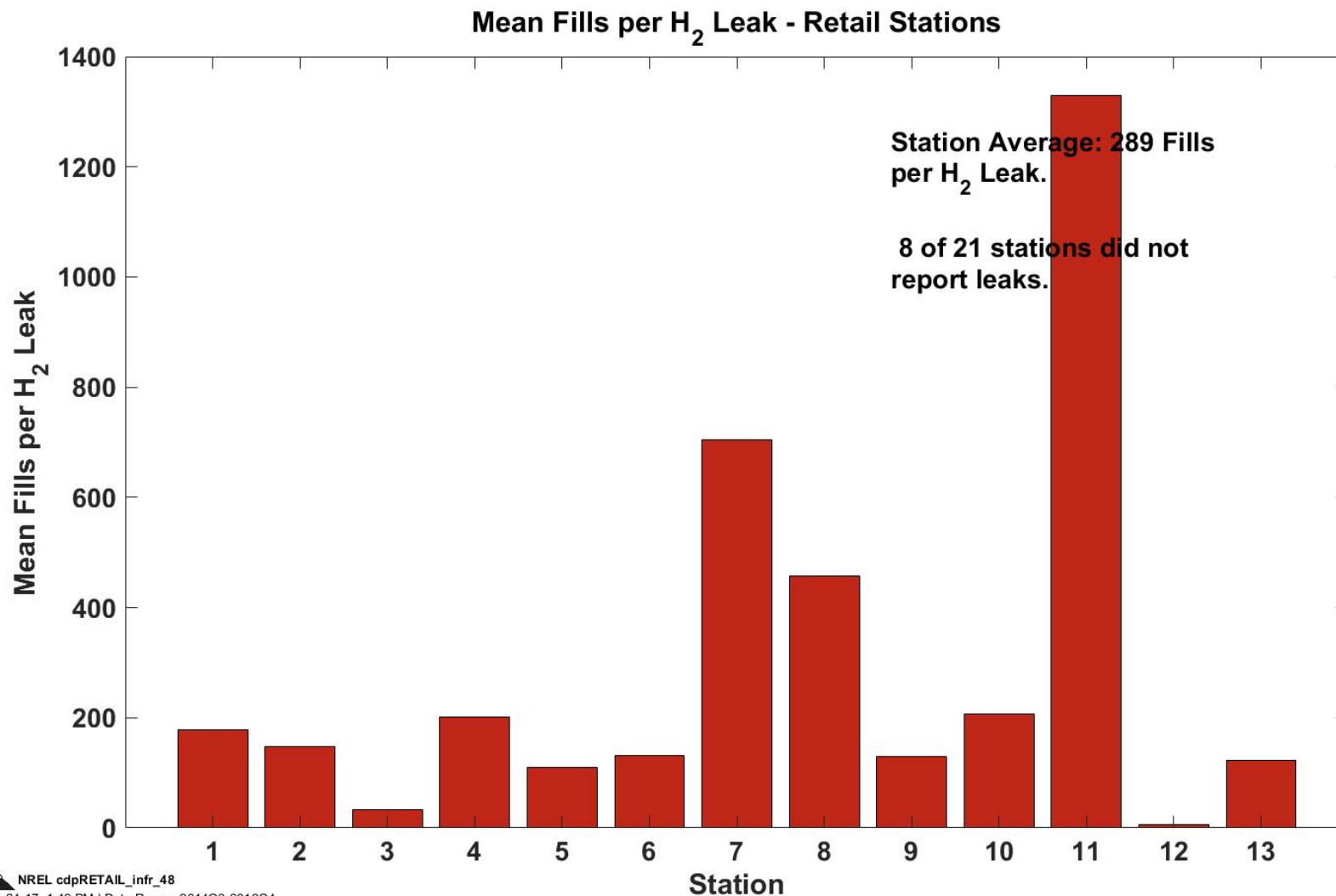
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdpRETAIL_infr_34

Created: Apr-19-17 4:29 PM | Data Range: 2015Q3-2016Q4

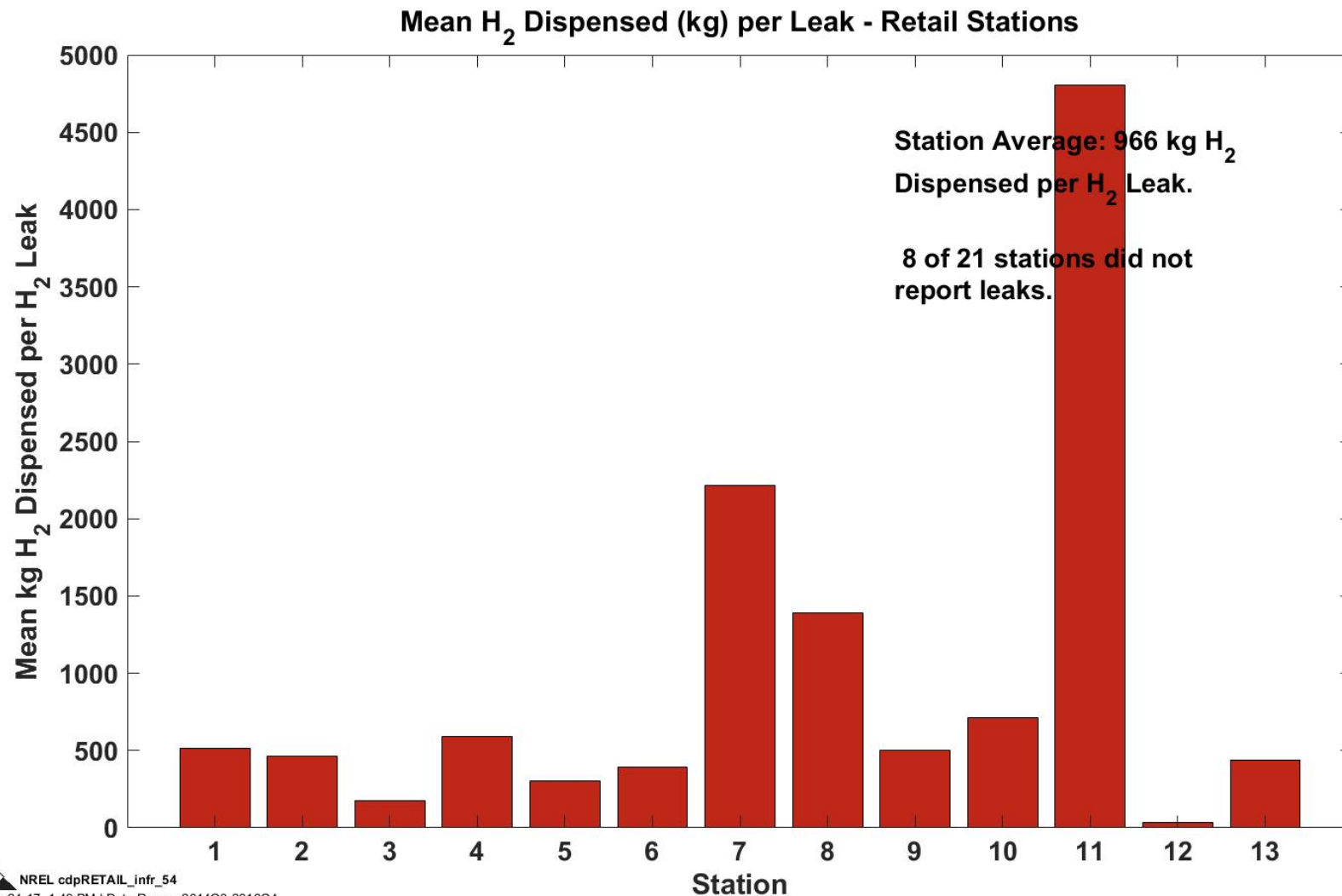
Mean Fills per Hydrogen Leak



NREL cdpRETAIL_infr_48

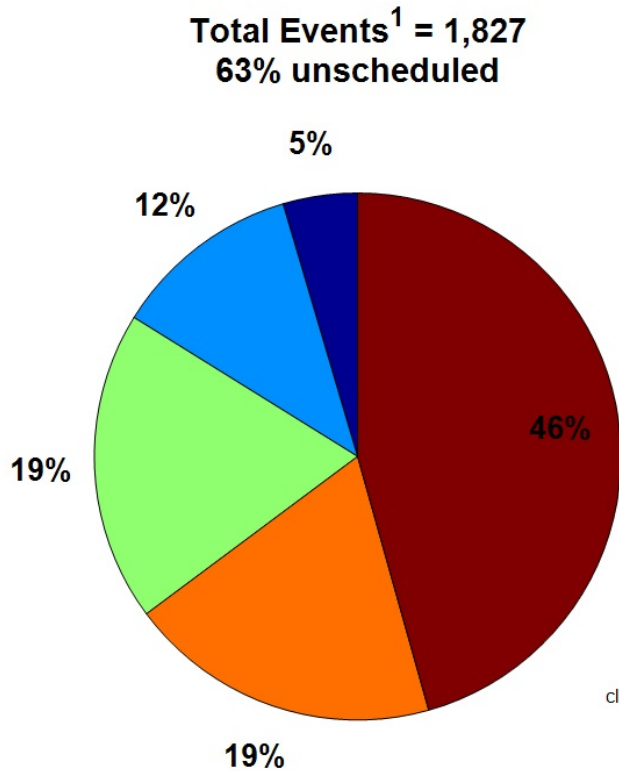
Created: Mar-24-17 1:49 PM | Data Range: 2014Q3-2016Q4

Mean Hydrogen Dispensed per Hydrogen Leak

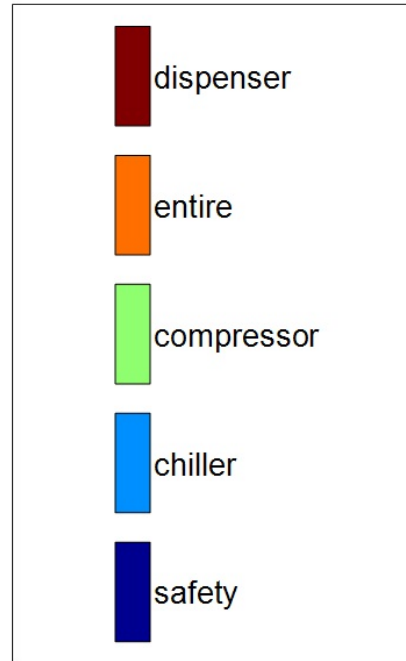


Maintenance and Reliability

Maintenance by Equipment Type - Retail Stations

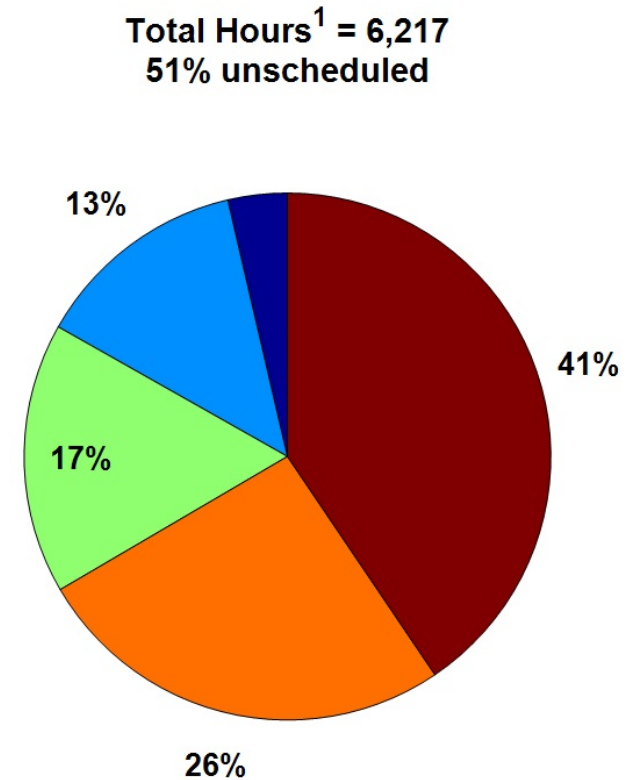


Classified Events



classified events 1597

multiple systems 230 **Event Count**

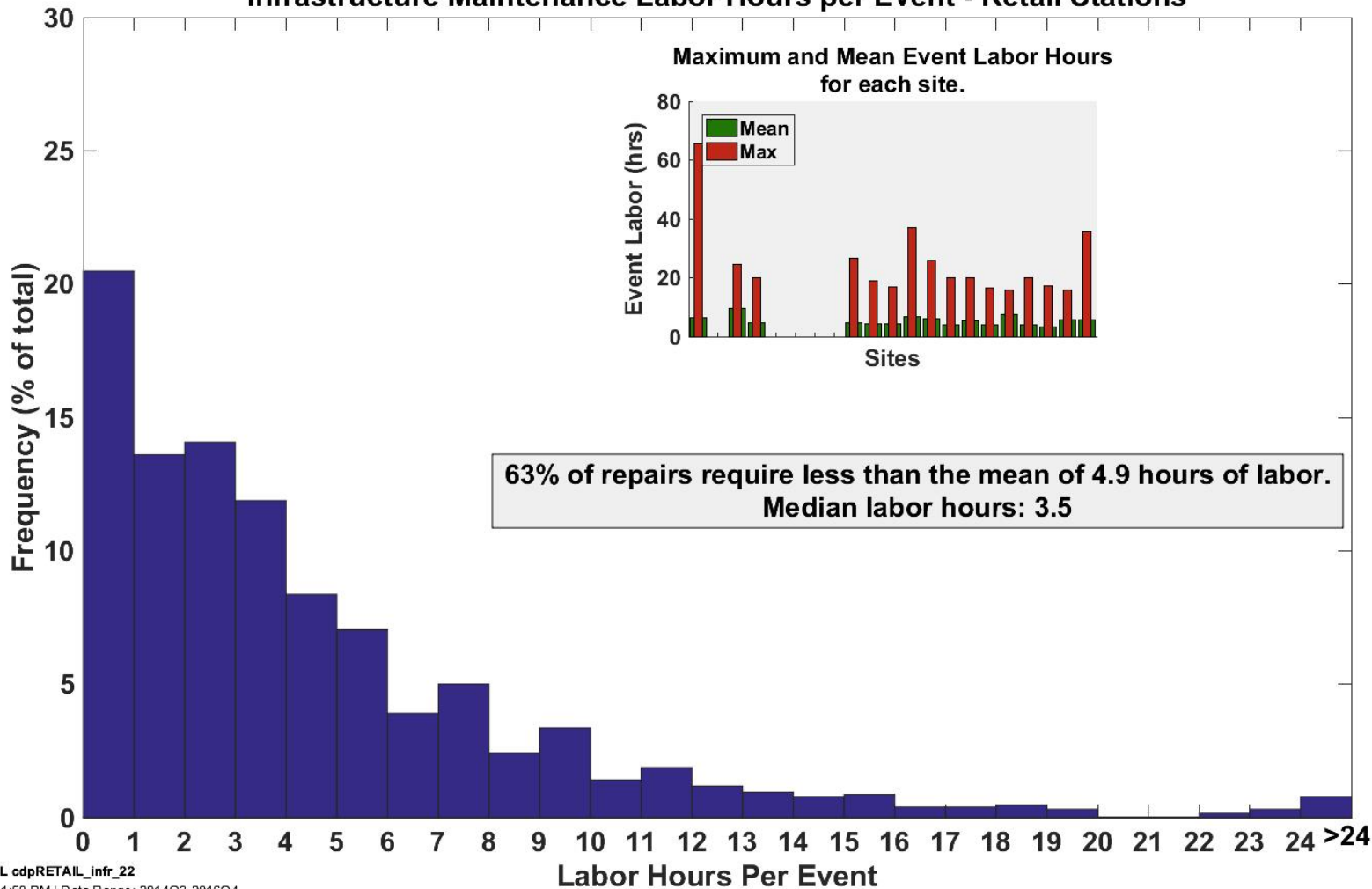


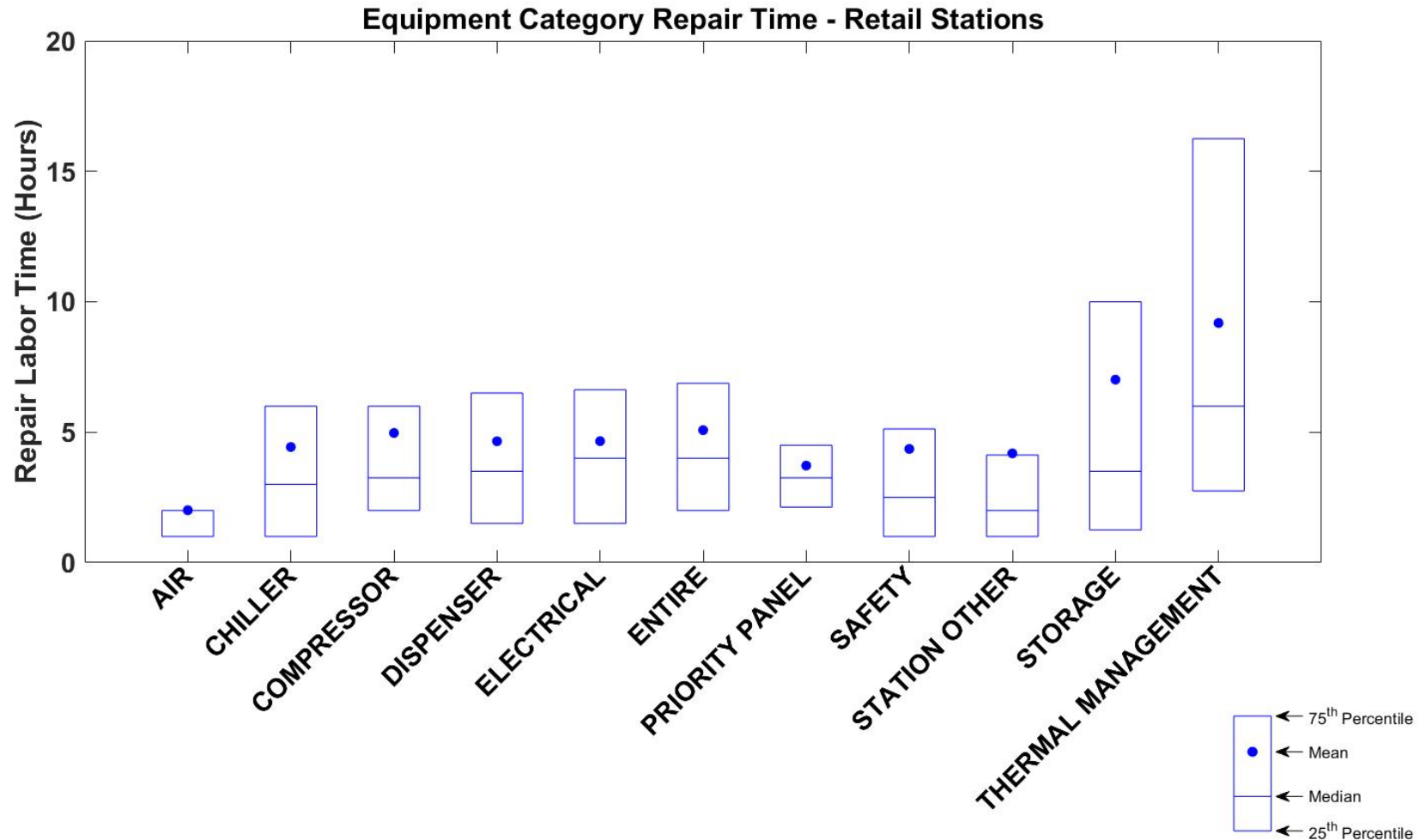
MISC includes the following failure modes: thermal management, priority panel, storage, station other, air, electrical, other

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

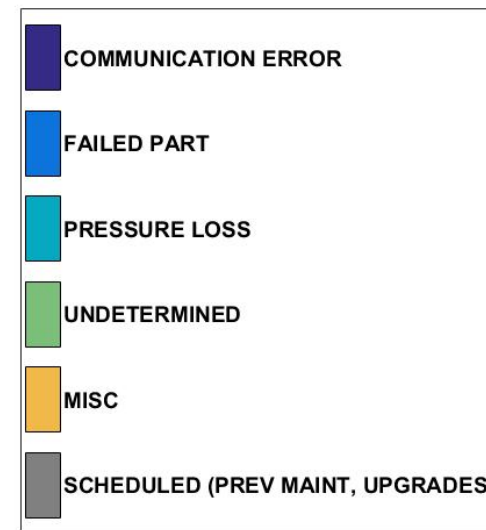
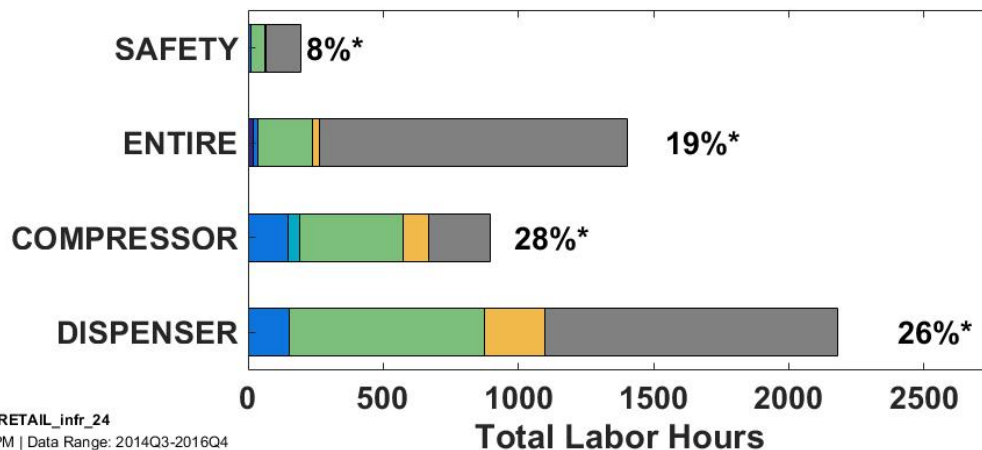
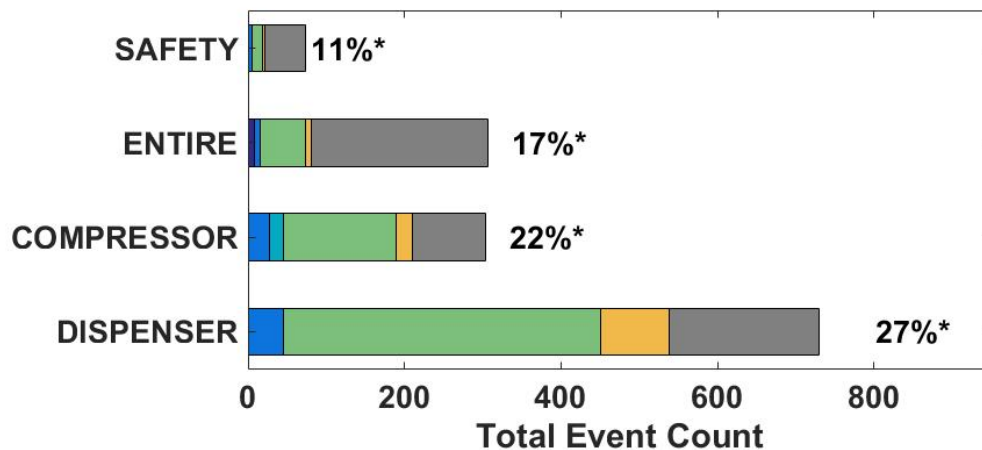


Infrastructure Maintenance Labor Hours per Event - Retail Stations





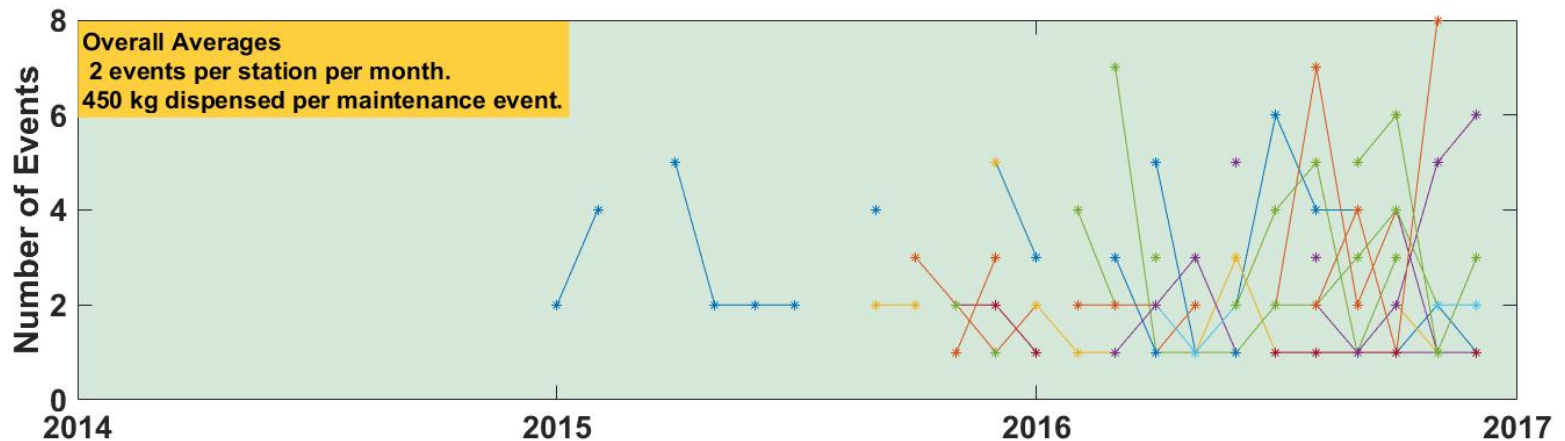
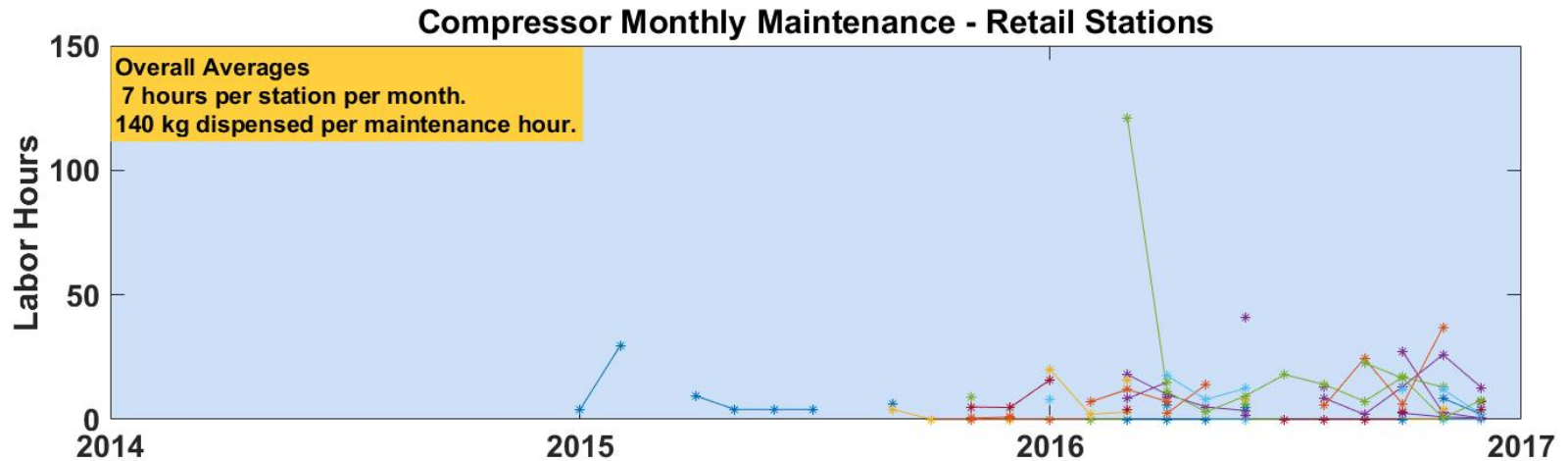
Failure Modes for Top Equipment Categories - Retail Stations



MISC includes the following failure modes: communication error, debris, design flaw, electrical breaker, end of life, environmental factors, fluid temp, freezing, installation error, level low, loose electrical, loose mechanical, maintenance error, manufacturing defect, na, operator error, out of calibration, overtemperature, power outage/quality, pressure loss, software bug, tight, vandalism, other

* Percentage of total events or hours.



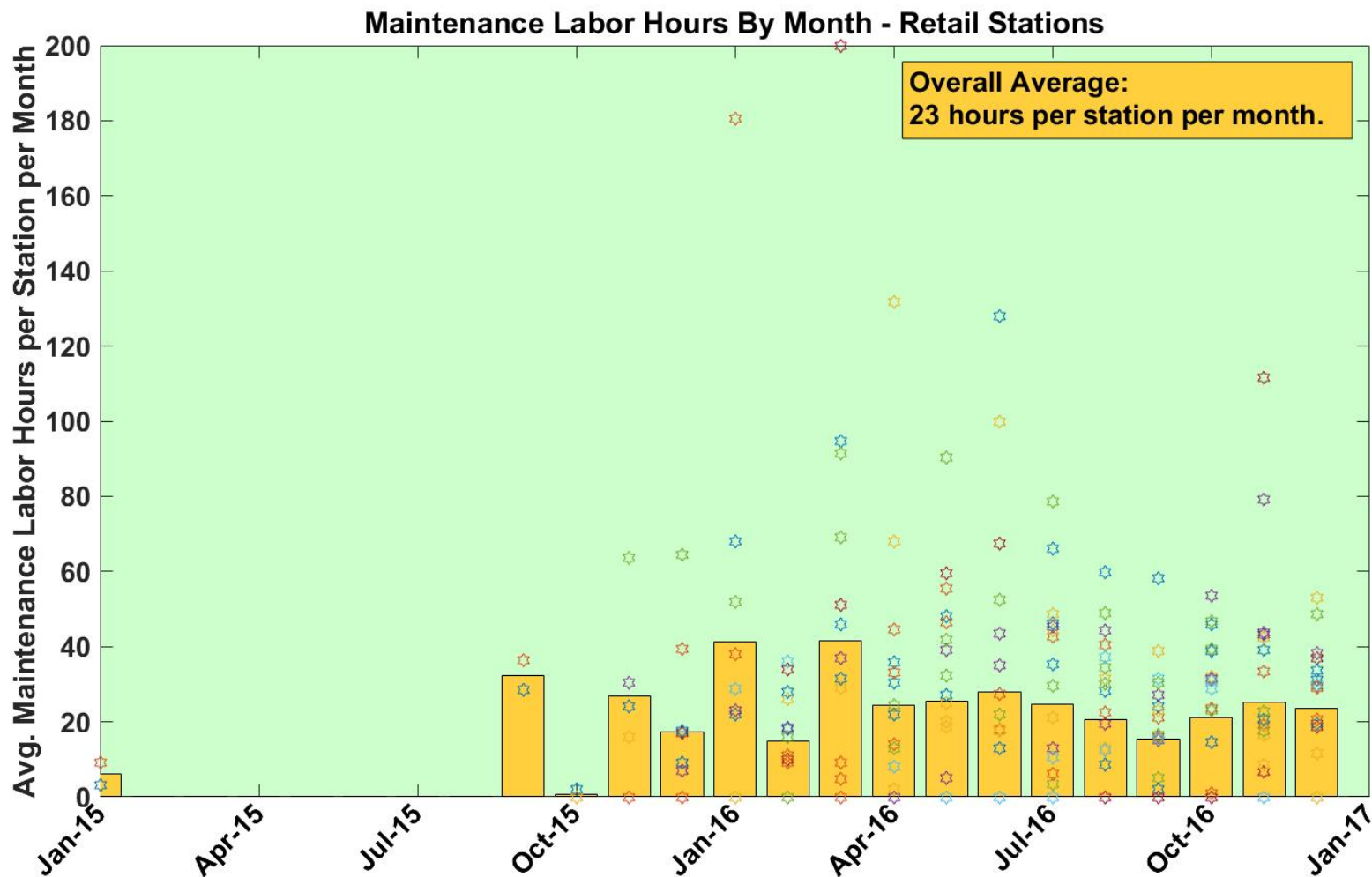


NREL cdpRETAIL_infr_26

Created: Mar-24-17 1:50 PM | Data Range: 2014Q3-2016Q4

* 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.

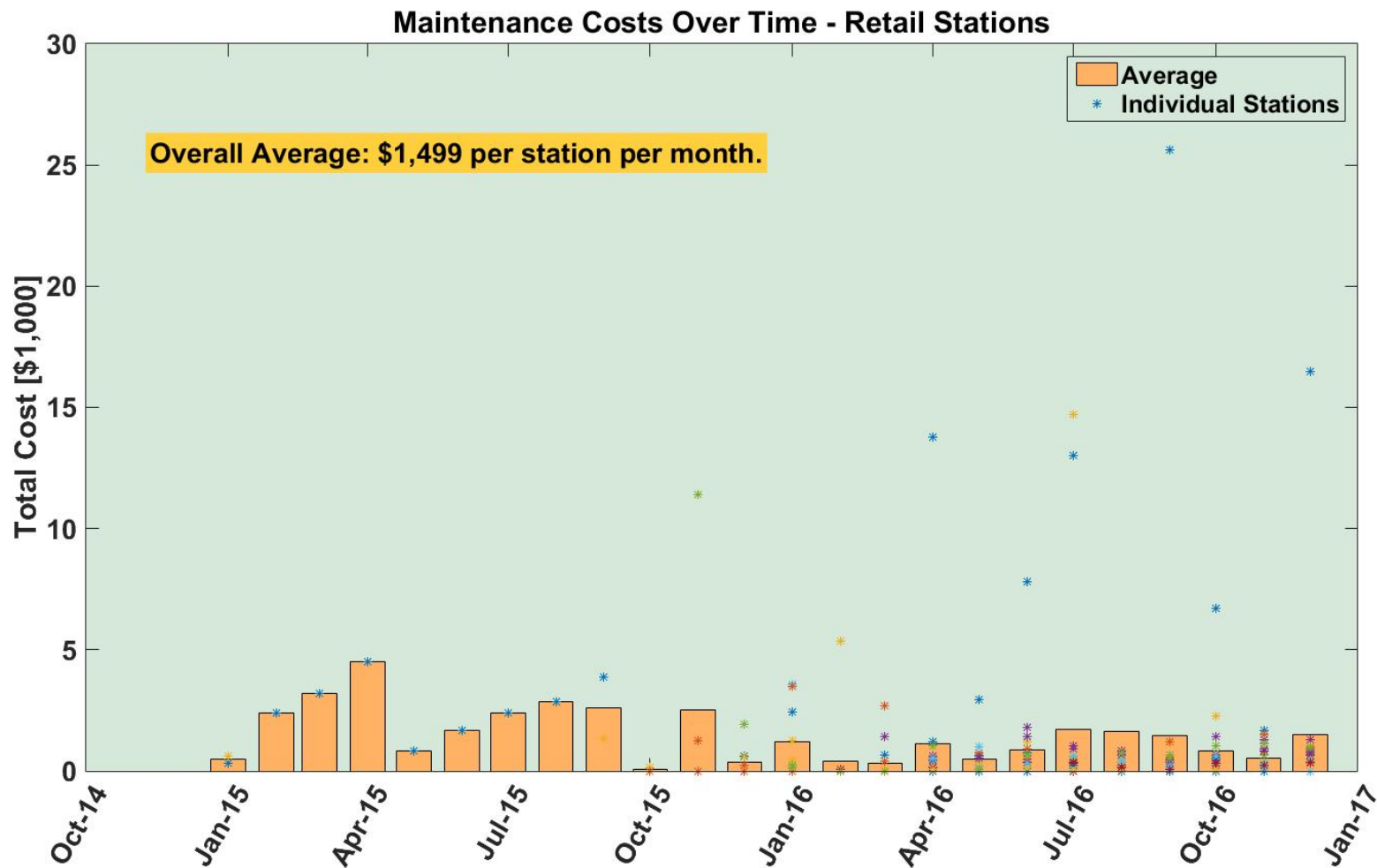
Maintenance Labor Hours by Month



NREL cdpRETAIL_infr_28

Created: May-08-17 9:04 AM | Data Range: 2014Q3-2016Q4

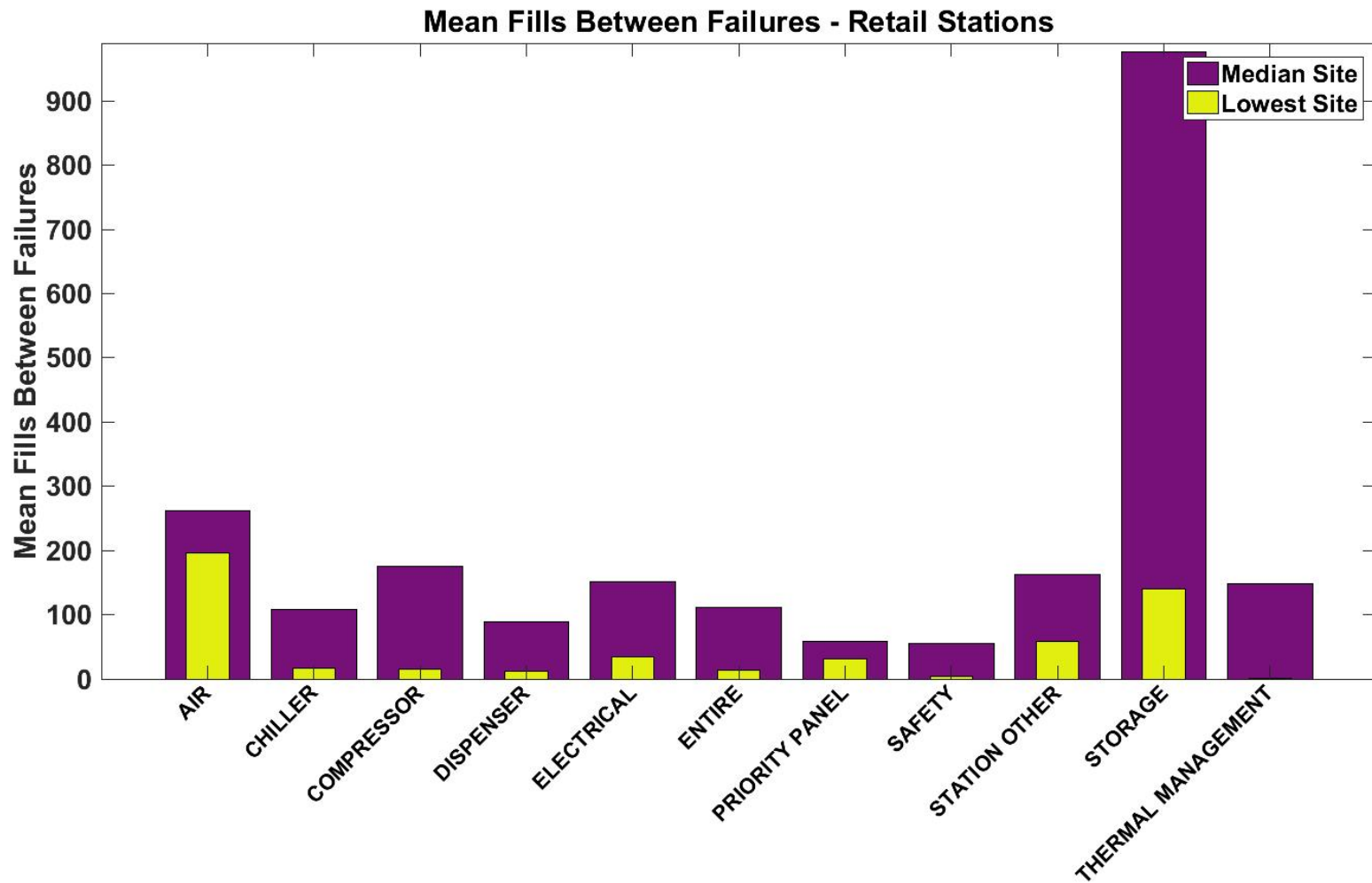
Stars represent individual station maintenance hours in a given month.



NREL cdpRETAIL_infr_30

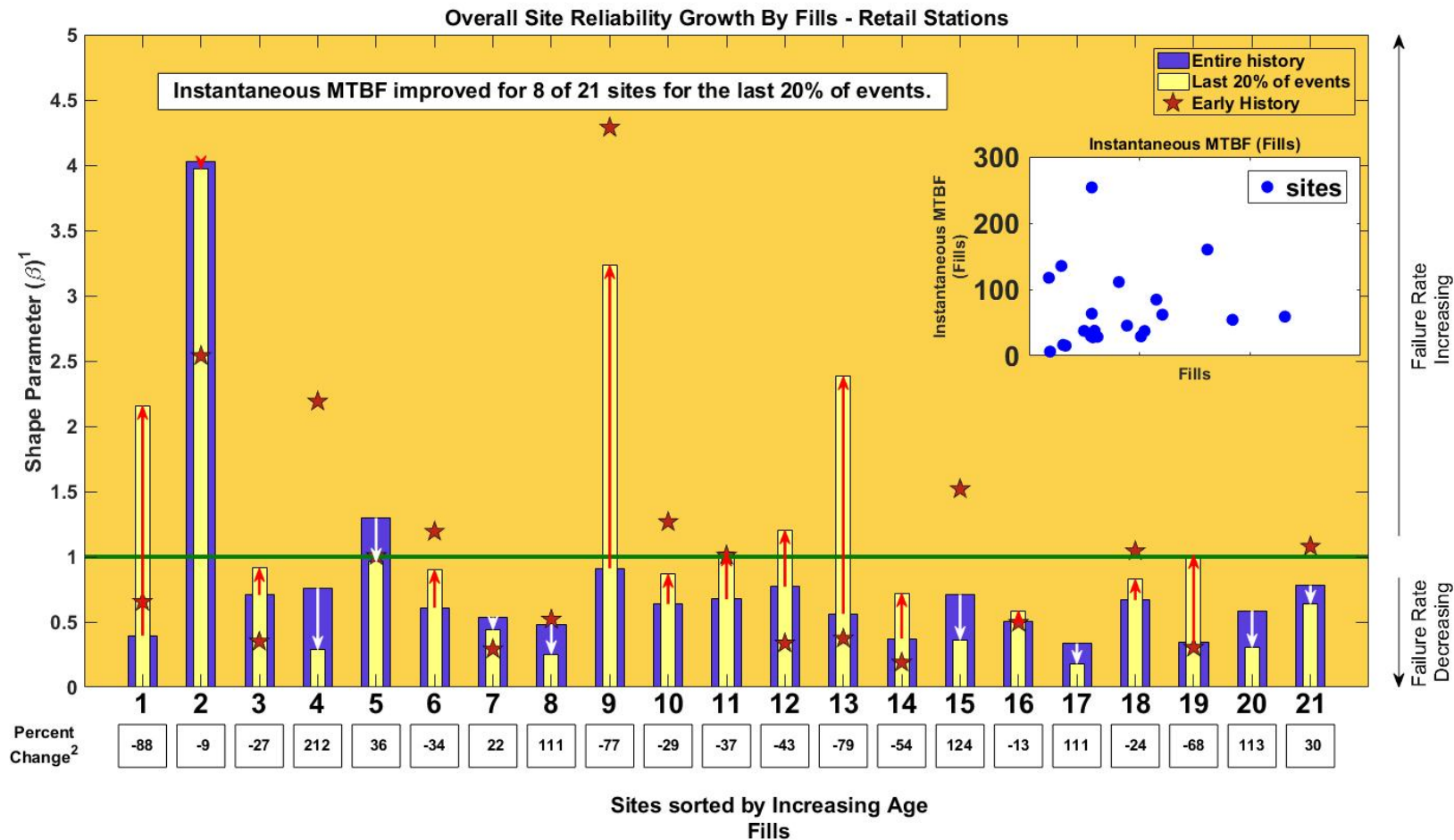
Created: Apr-24-17 10:23 AM | Data Range: 2014Q3-2016Q4

*Each color represents a unique station.



NREL cdpRETAIL_infr_49

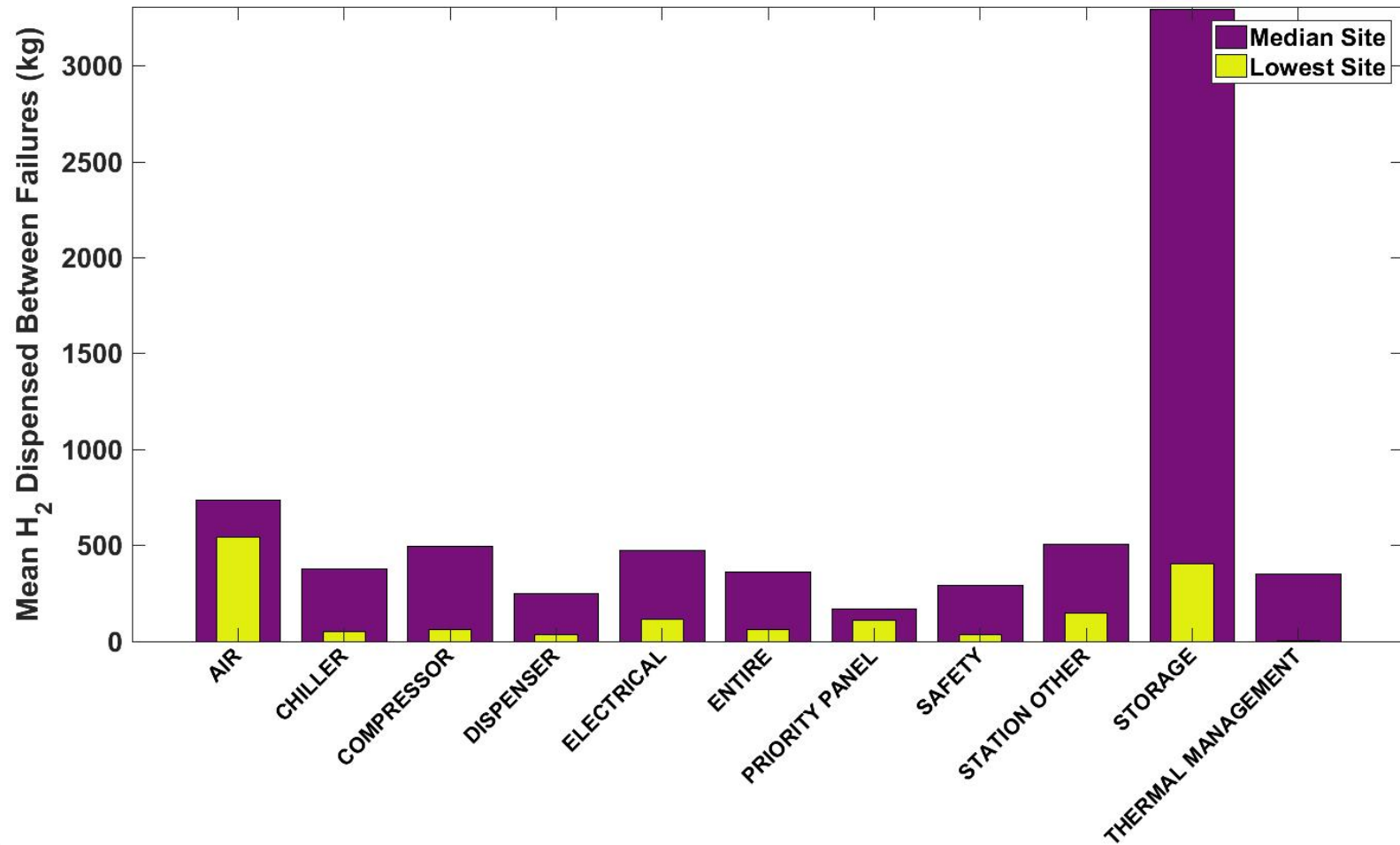
Created: Apr-24-17 2:13 PM | Data Range: 2014Q3-2016Q4



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

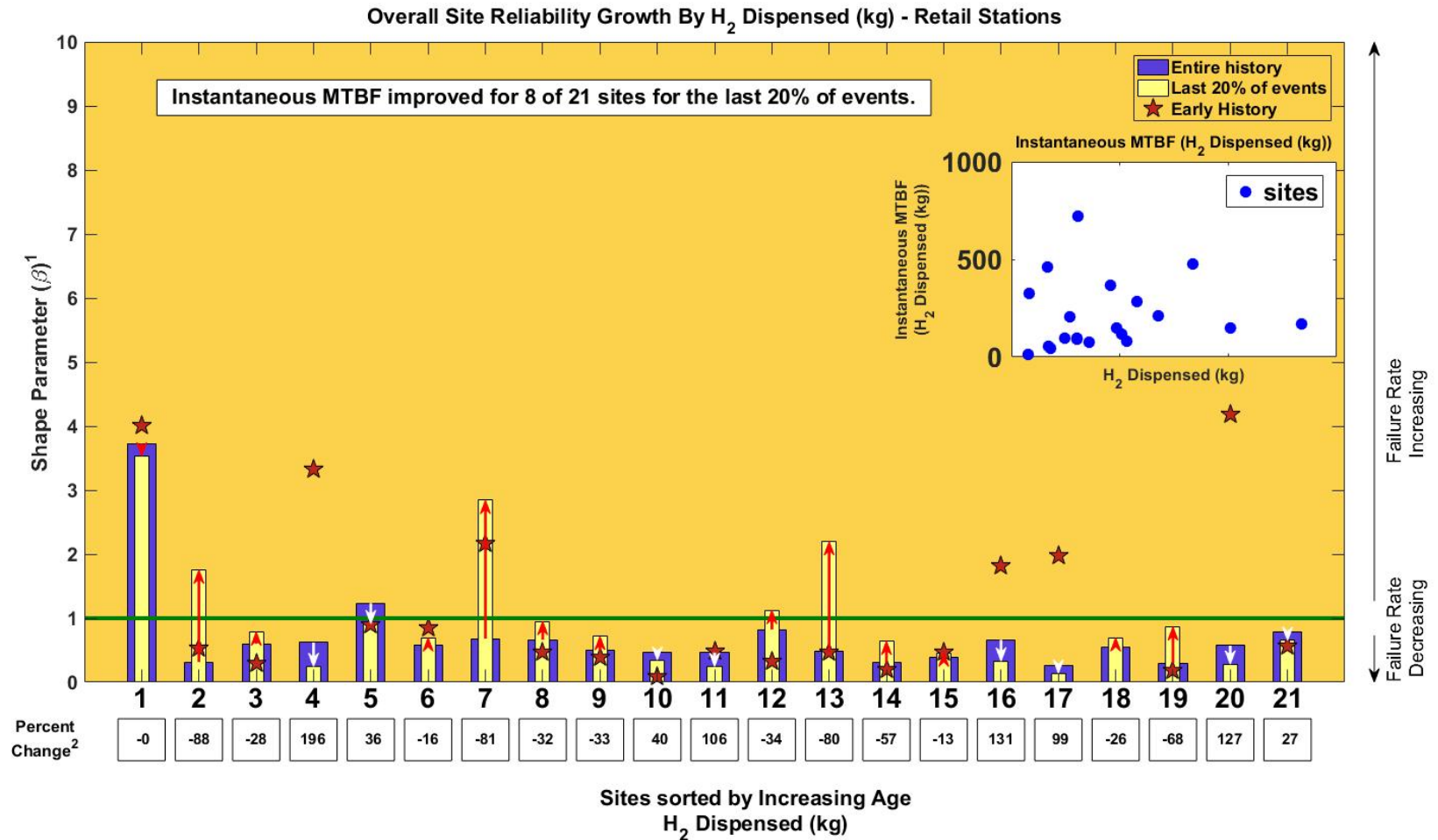
Mean H₂ Dispensed Between Failures (kg) - Retail Stations



NREL cdpRETAIL_infr_51

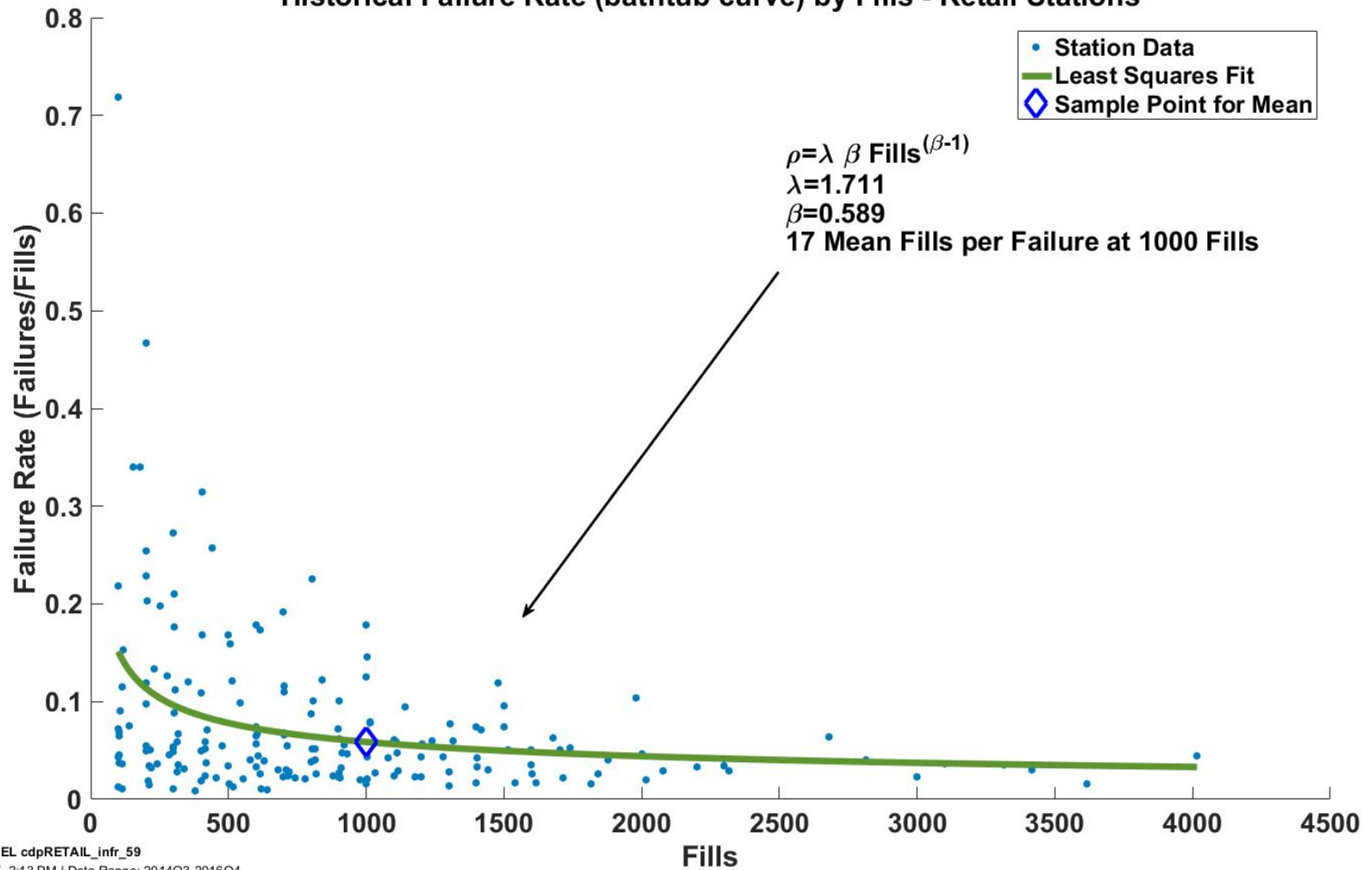
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Reliability Growth by Amount Dispensed



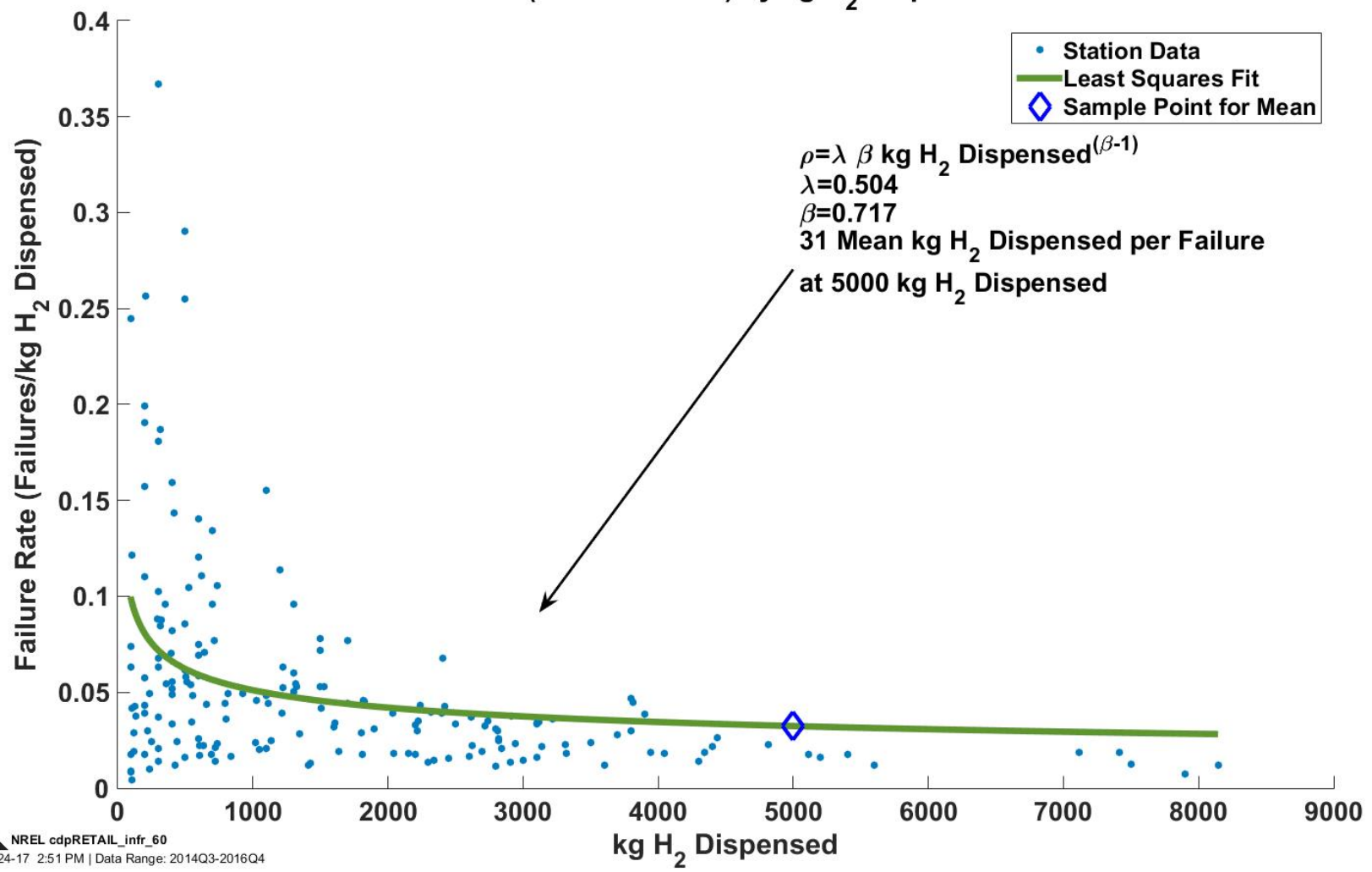
1. IEC 61164:2004(E)., Reliability Growth - Statistical Test and Evaluation Methods, IEC. 2004.
2. % change in instantaneous mean H₂ Dispensed (kg) between failures

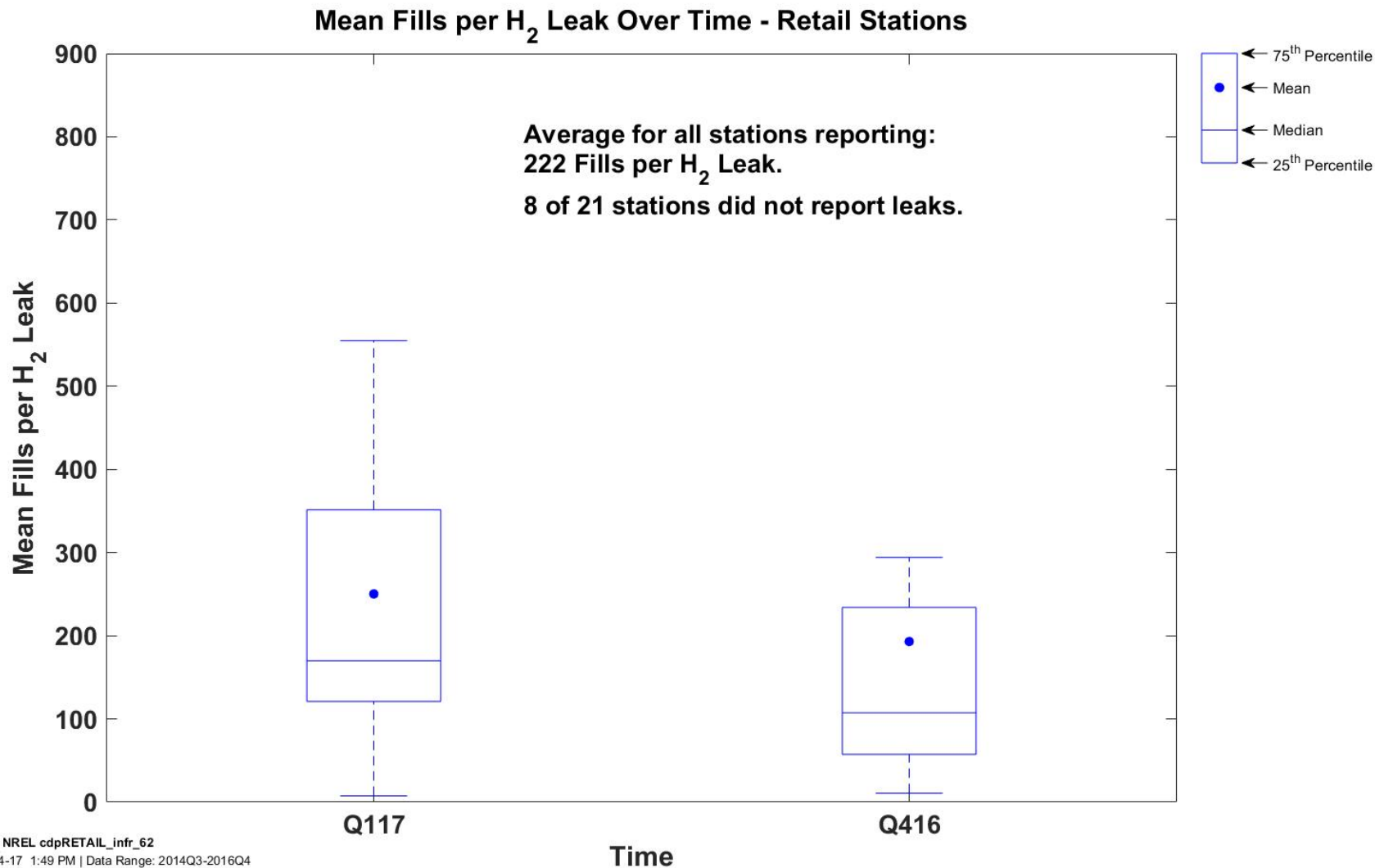
Historical Failure Rate (bathtub curve) by Fills - Retail Stations



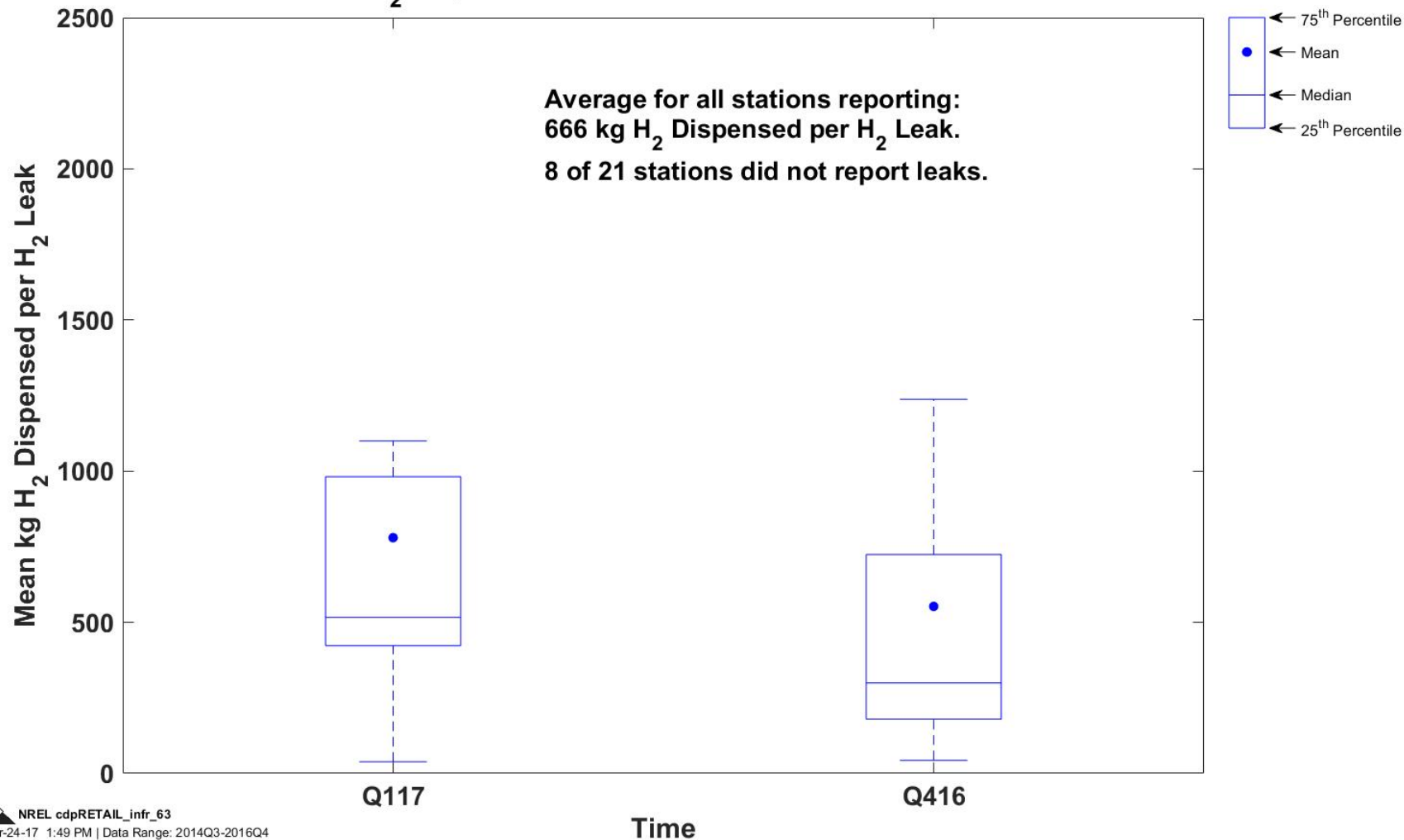
Historical Failure Rate by Amount Dispensed

Historical Failure Rate (bathtub curve) by kg H₂ Dispensed - Retail Stations





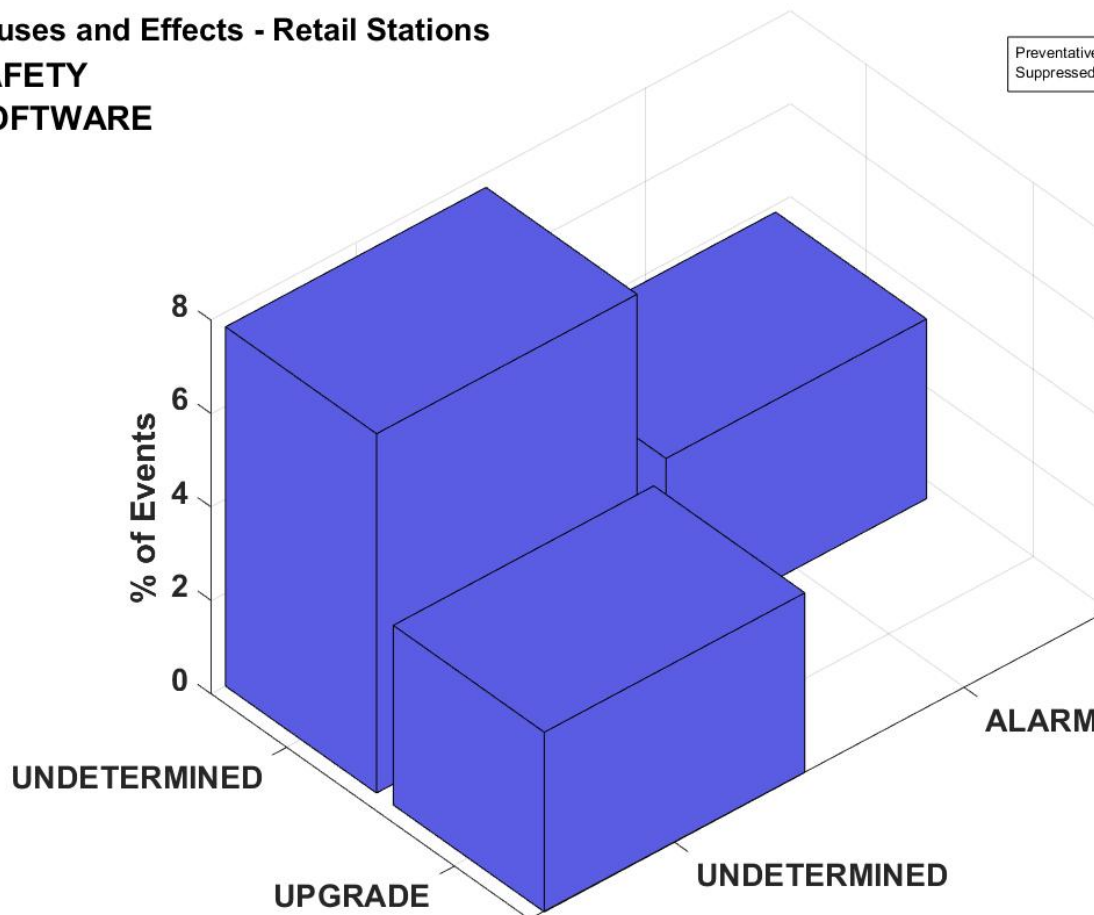
Mean H₂ Dispensed Per Leak Over Time - Retail Stations



Maintenance Causes and Effects - Retail Stations

Subsystem: SAFETY

Component: SOFTWARE



Causes

Effects



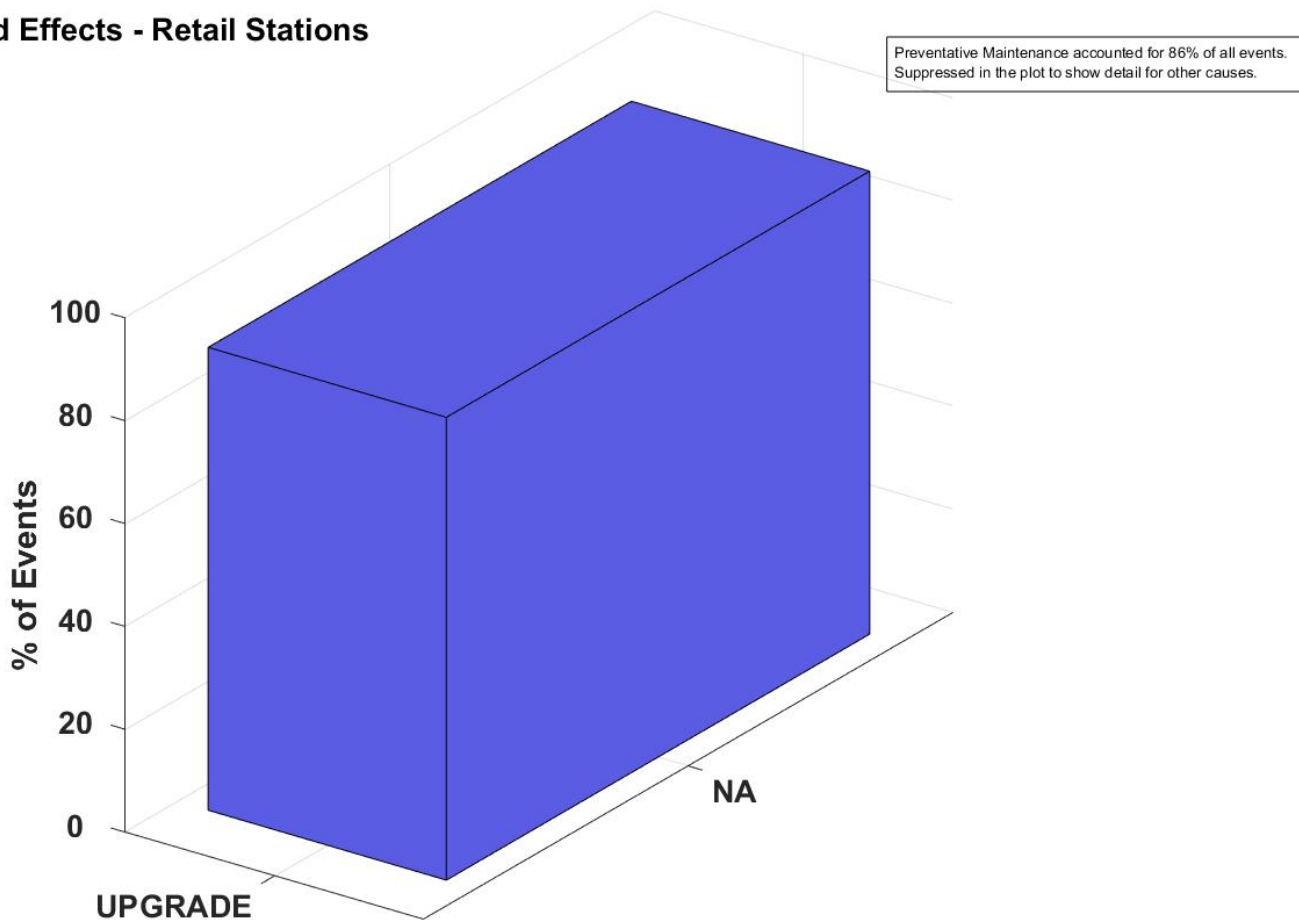
NREL cdpRETAIL_infr_64

Created: Mar-24-17 1:49 PM | Data Range: 2014Q3-2016Q4

Maintenance Causes and Effects - Retail Stations

Subsystem: SAFETY

Component: ENTIRE



Causes

Effects



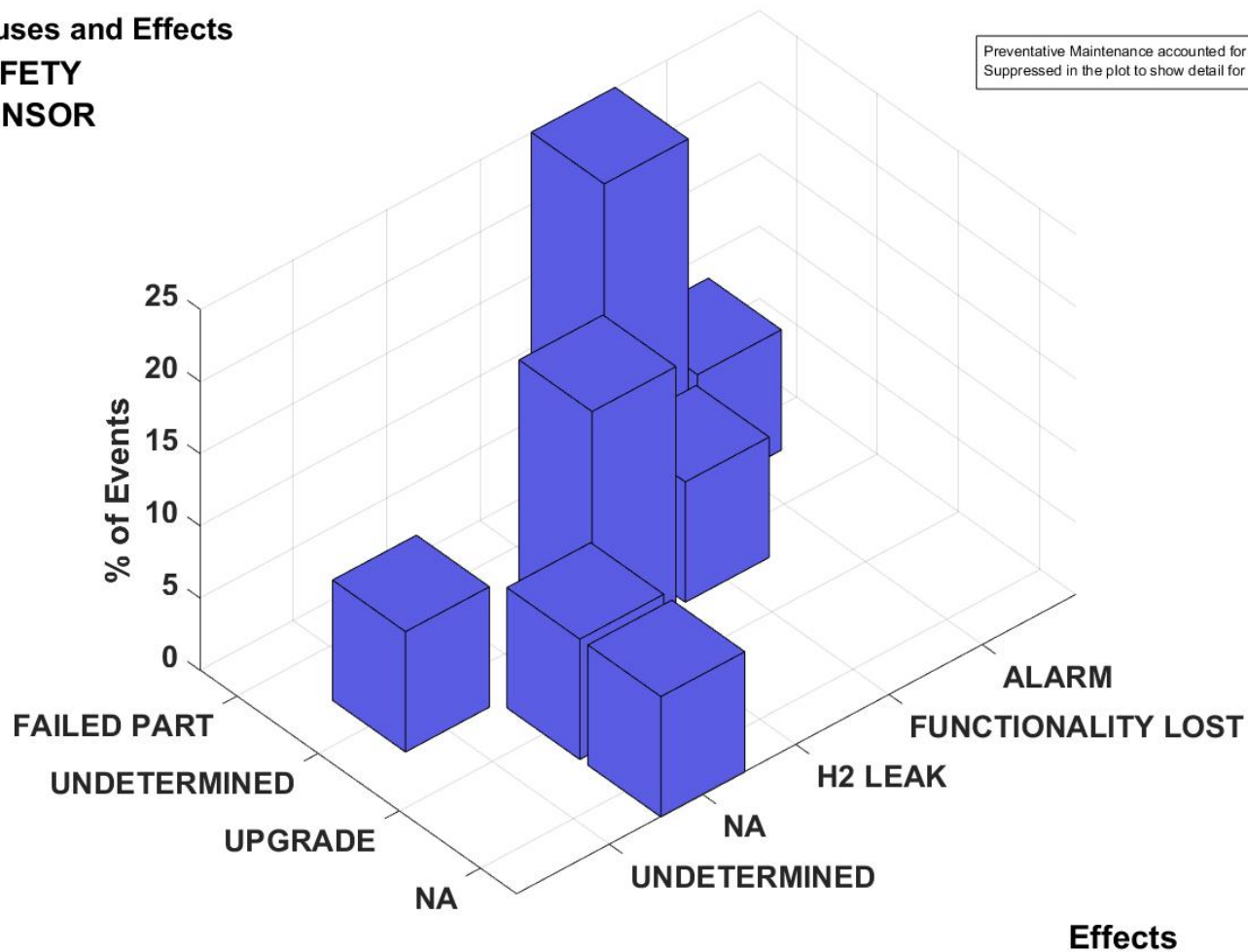
NREL cdpRETAIL_infr_65

Created: Mar-24-17 1:50 PM | Data Range: 2014Q3-2016Q4

Maintenance Causes and Effects

Subsystem: SAFETY

Component: SENSOR



Causes

Effects



NREL cdpRETAIL_infr_66

Created: Mar-24-17 1:49 PM | Data Range: 2014Q3-2016Q4

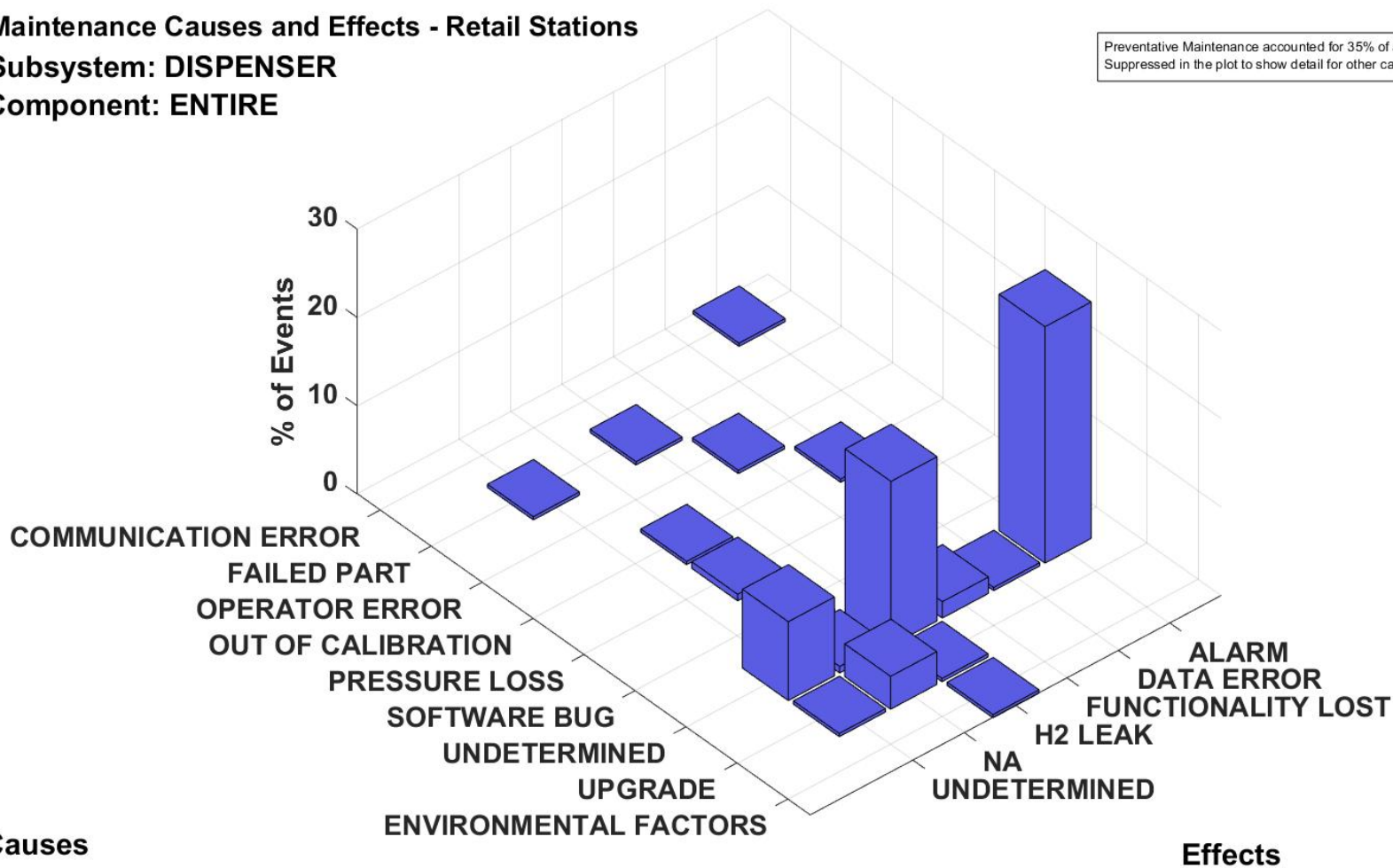
Maintenance Causes and Effects: Dispenser (Entire)

Maintenance Causes and Effects - Retail Stations

Subsystem: DISPENSER

Component: ENTIRE

Preventative Maintenance accounted for 35% of all events.
Suppressed in the plot to show detail for other causes.



Causes

Effects



NREL cdpRETAIL_infr_67

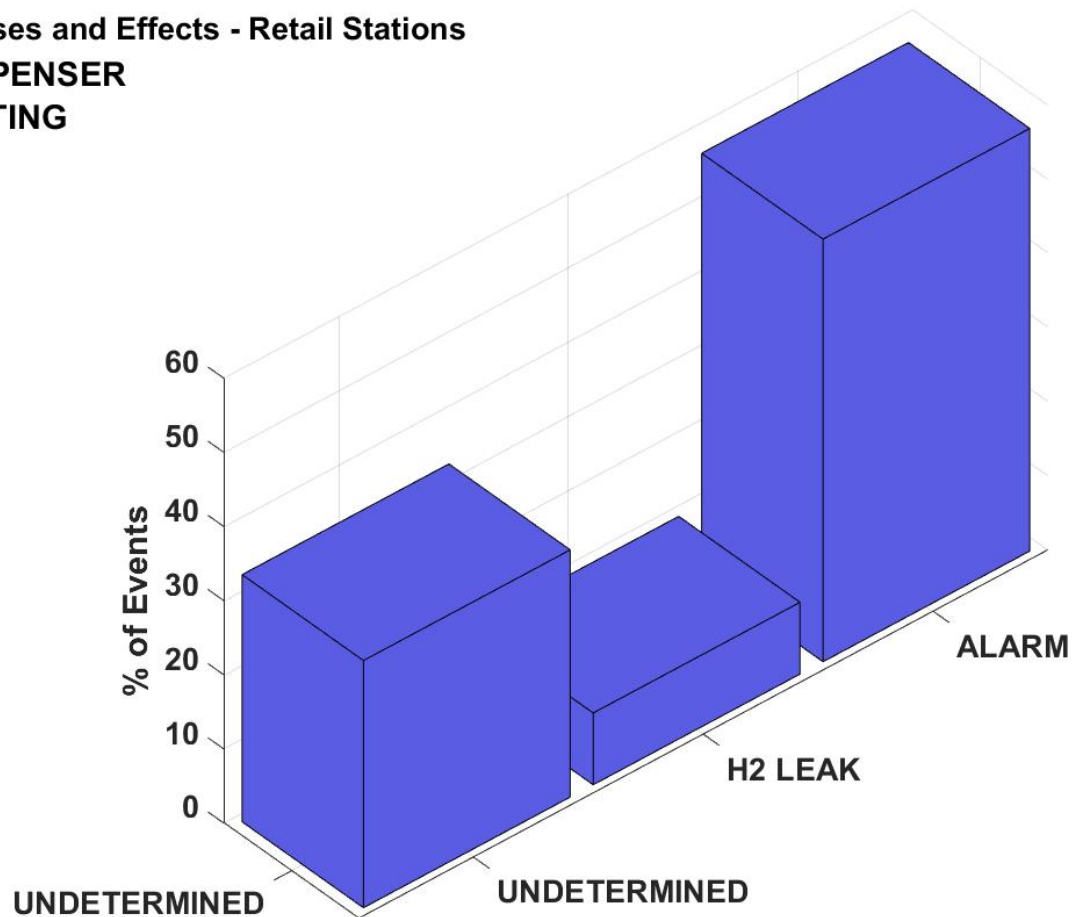
Created: May-08-17 9:05 AM | Data Range: 2014Q3-2016Q4

Maintenance Causes and Effects: Dispenser (Fitting)

Maintenance Causes and Effects - Retail Stations

Subsystem: DISPENSER

Component: FITTING



Causes

Effects



NREL cdpRETAIL_infr_68

Created: Mar-24-17 1:49 PM | Data Range: 2014Q3-2016Q4

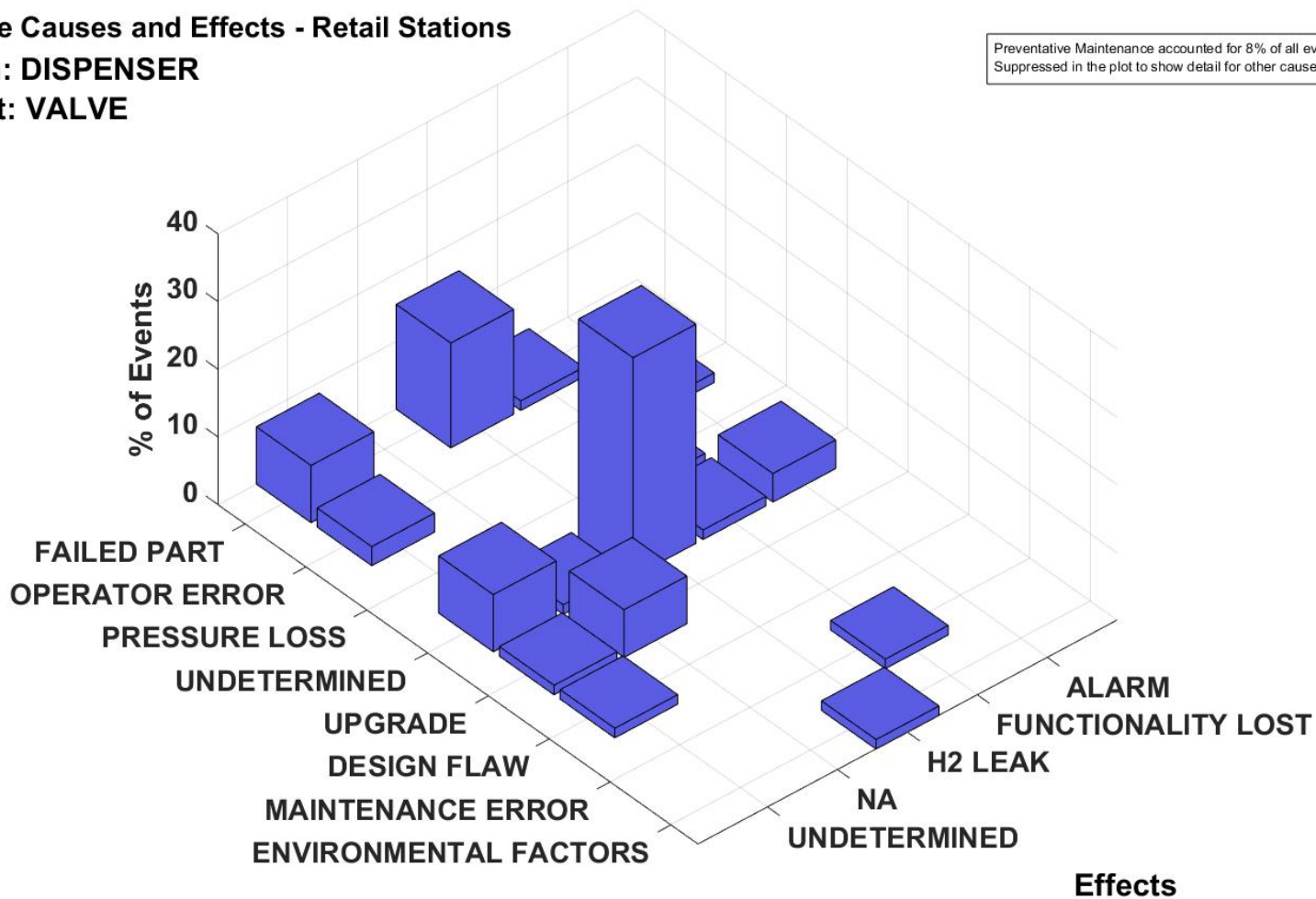
Maintenance Causes and Effects: Dispenser (Valve)

Maintenance Causes and Effects - Retail Stations

Subsystem: DISPENSER

Component: VALVE

Preventative Maintenance accounted for 8% of all events.
Suppressed in the plot to show detail for other causes.



Causes

Effects



NREL cdpRETAIL_infr_69

Created: Mar-24-17 1:49 PM | Data Range: 2014Q3-2016Q4

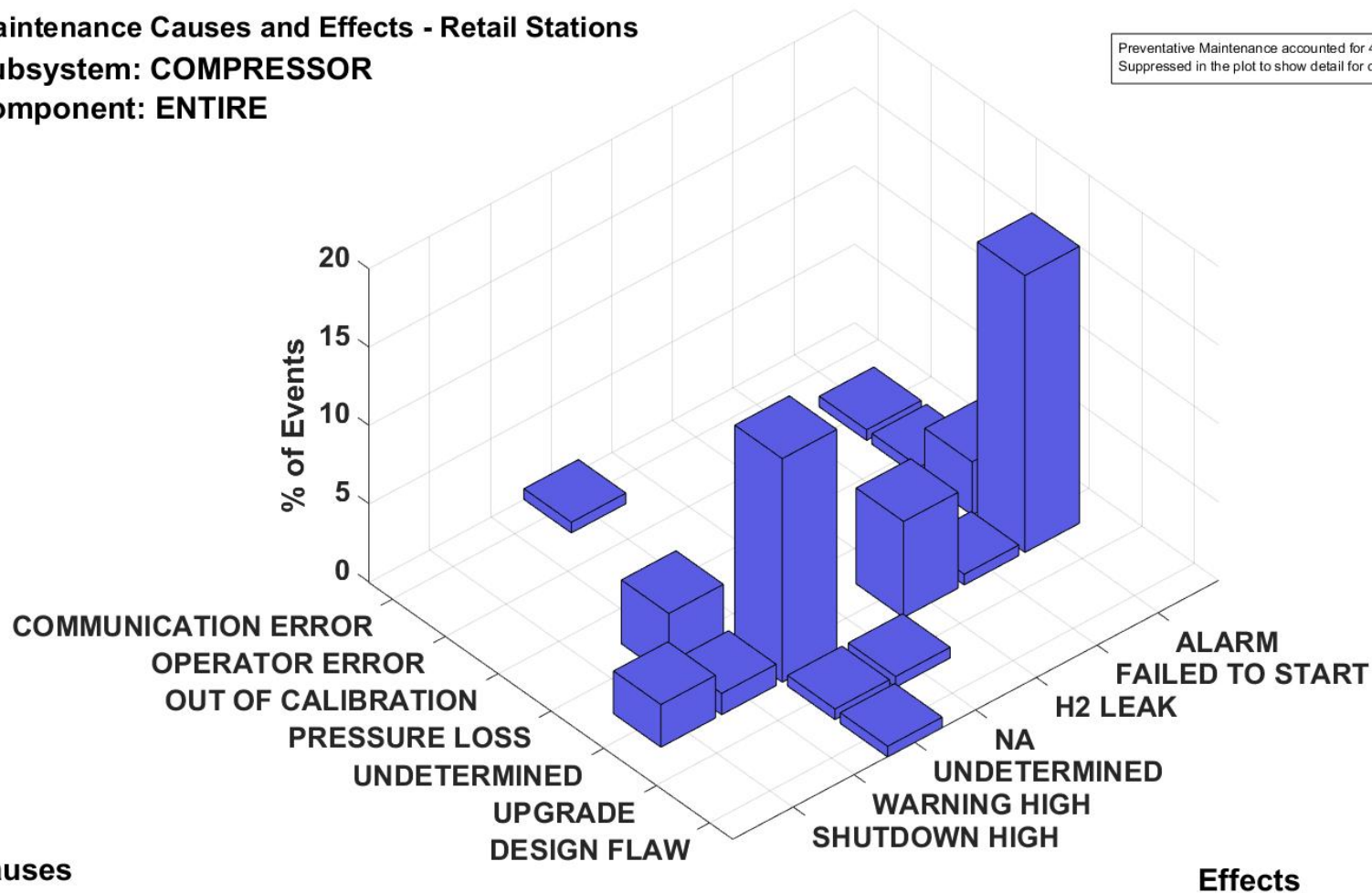
Maintenance Causes and Effects: Compressor (Entire)

Maintenance Causes and Effects - Retail Stations

Subsystem: COMPRESSOR

Component: ENTIRE

Preventative Maintenance accounted for 46% of all events.
Suppressed in the plot to show detail for other causes.



Causes

Effects



NREL cdpRETAIL_infr_70

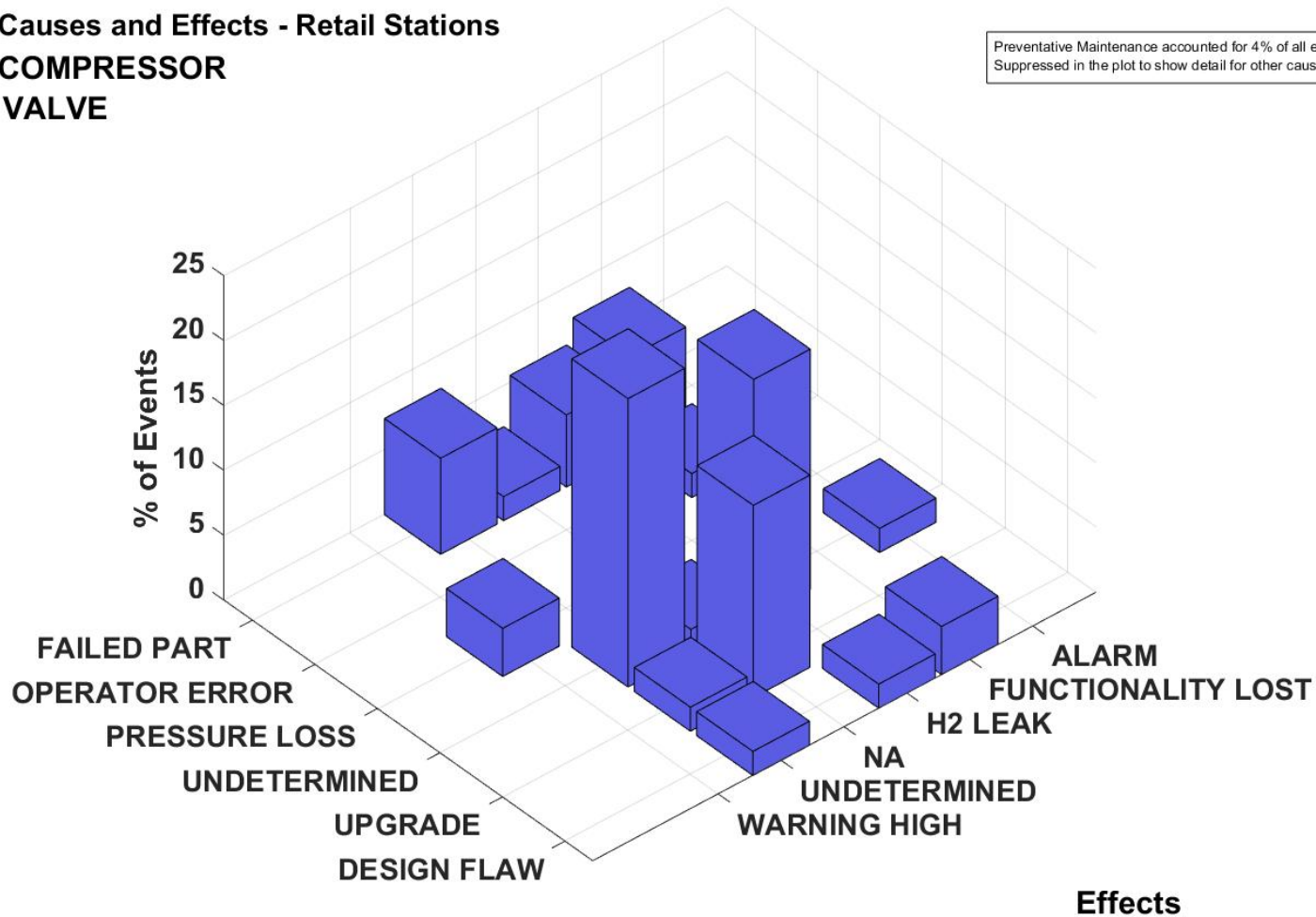
Created: Mar-24-17 1:49 PM | Data Range: 2014Q3-2016Q4

Maintenance Causes and Effects - Retail Stations

Subsystem: COMPRESSOR

Component: VALVE

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



Causes

Effects



NREL cdpRETAIL_infr_71

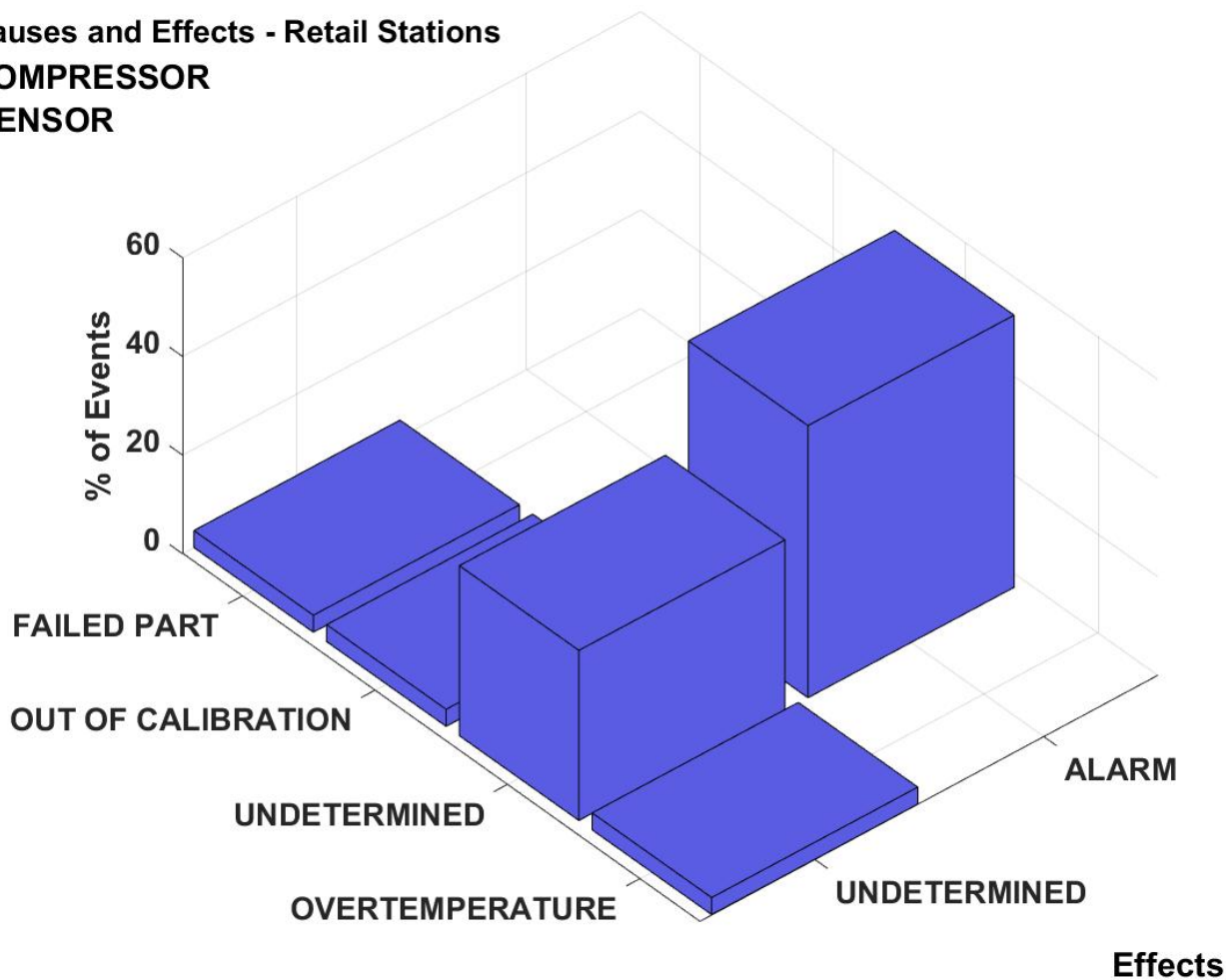
Created: Mar-24-17 1:49 PM | Data Range: 2014Q3-2016Q4

Maintenance Causes and Effects: Compressor (Valve)

Maintenance Causes and Effects - Retail Stations

Subsystem: COMPRESSOR

Component: SENSOR



Causes

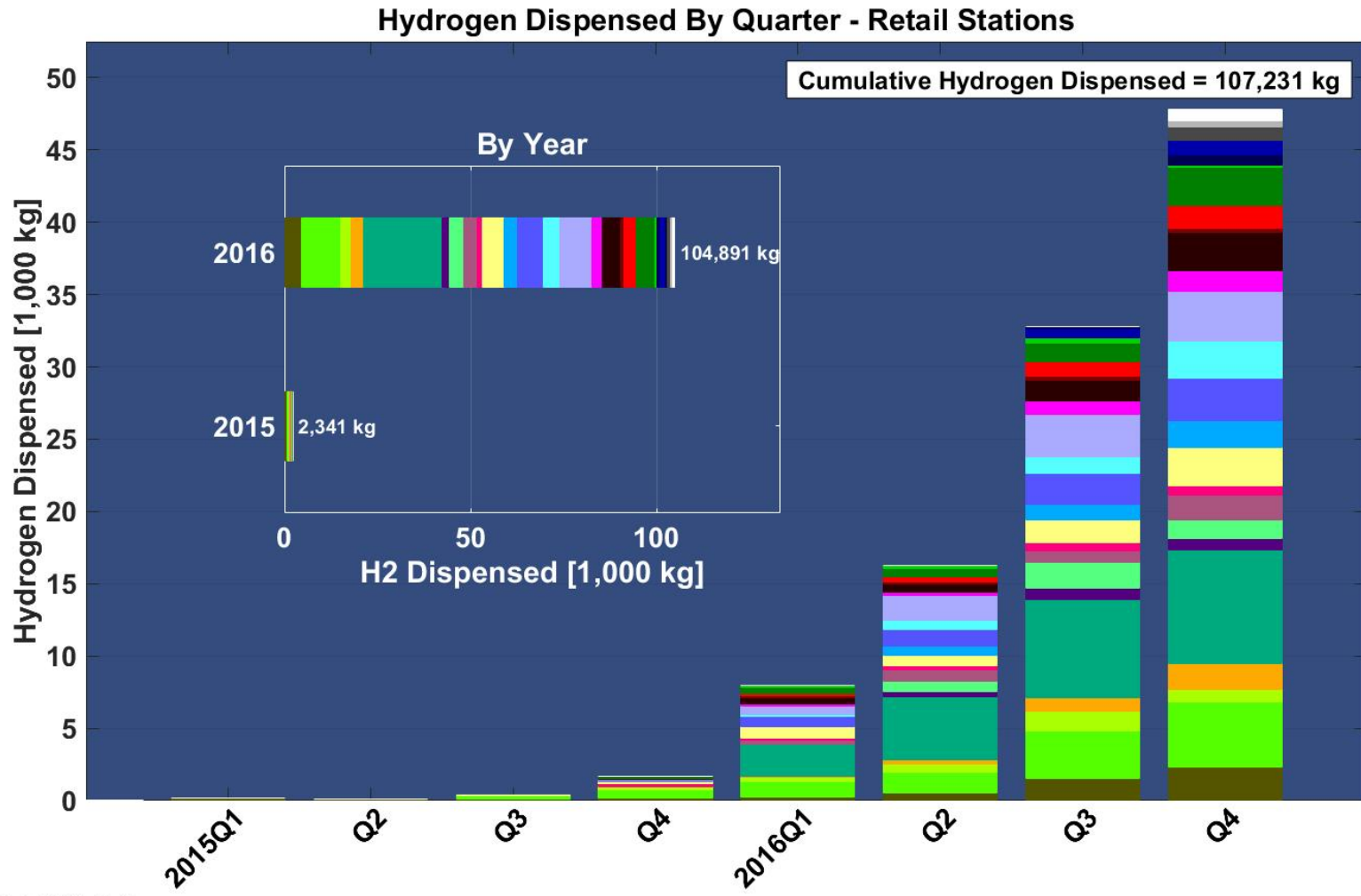
Effects



NREL cdpRETAIL_infr_72

Created: Apr-06-17 3:24 PM | Data Range: 2014Q3-2016Q4

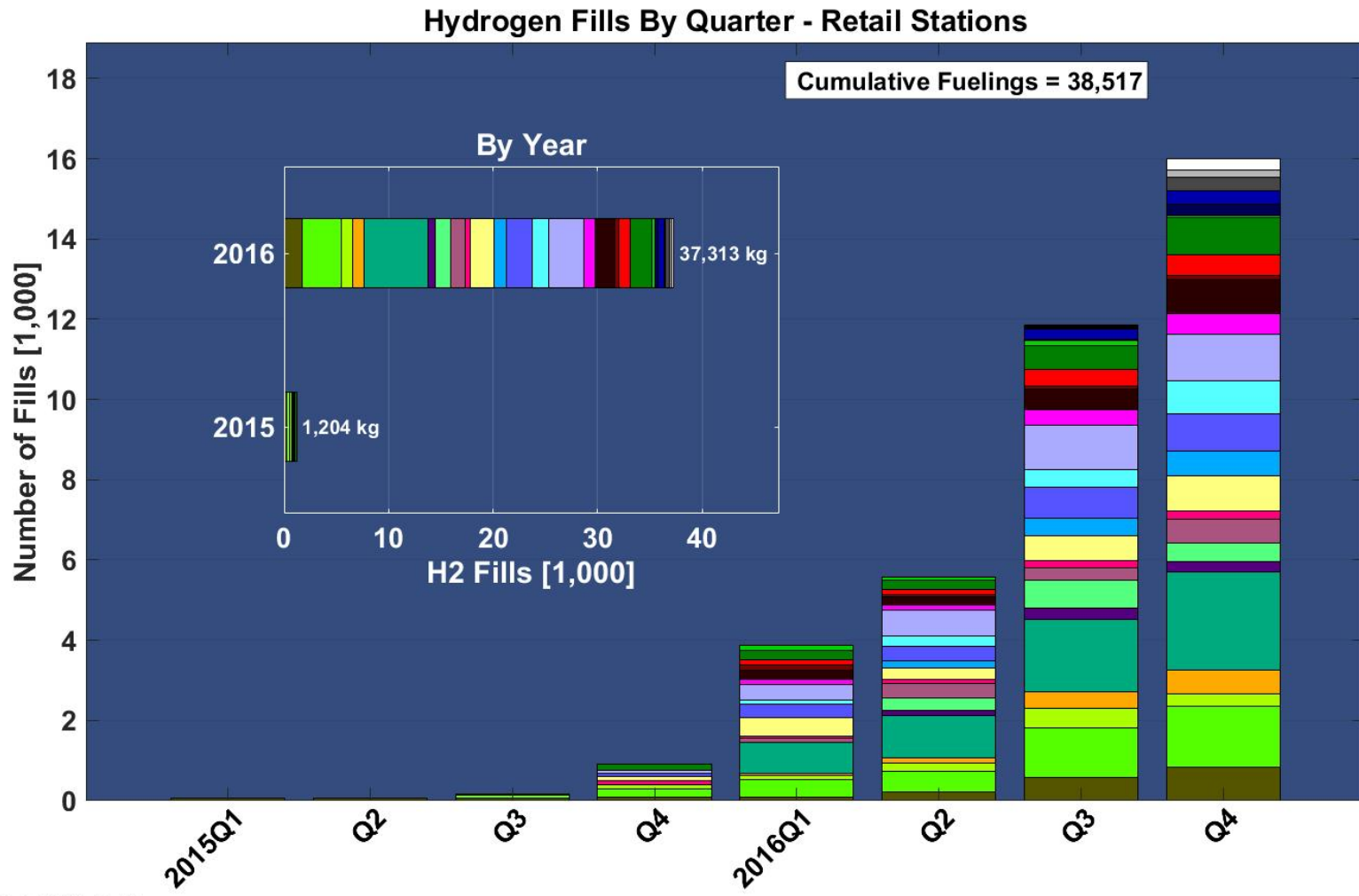
Performance



NREL cdpRETAIL_infr_01

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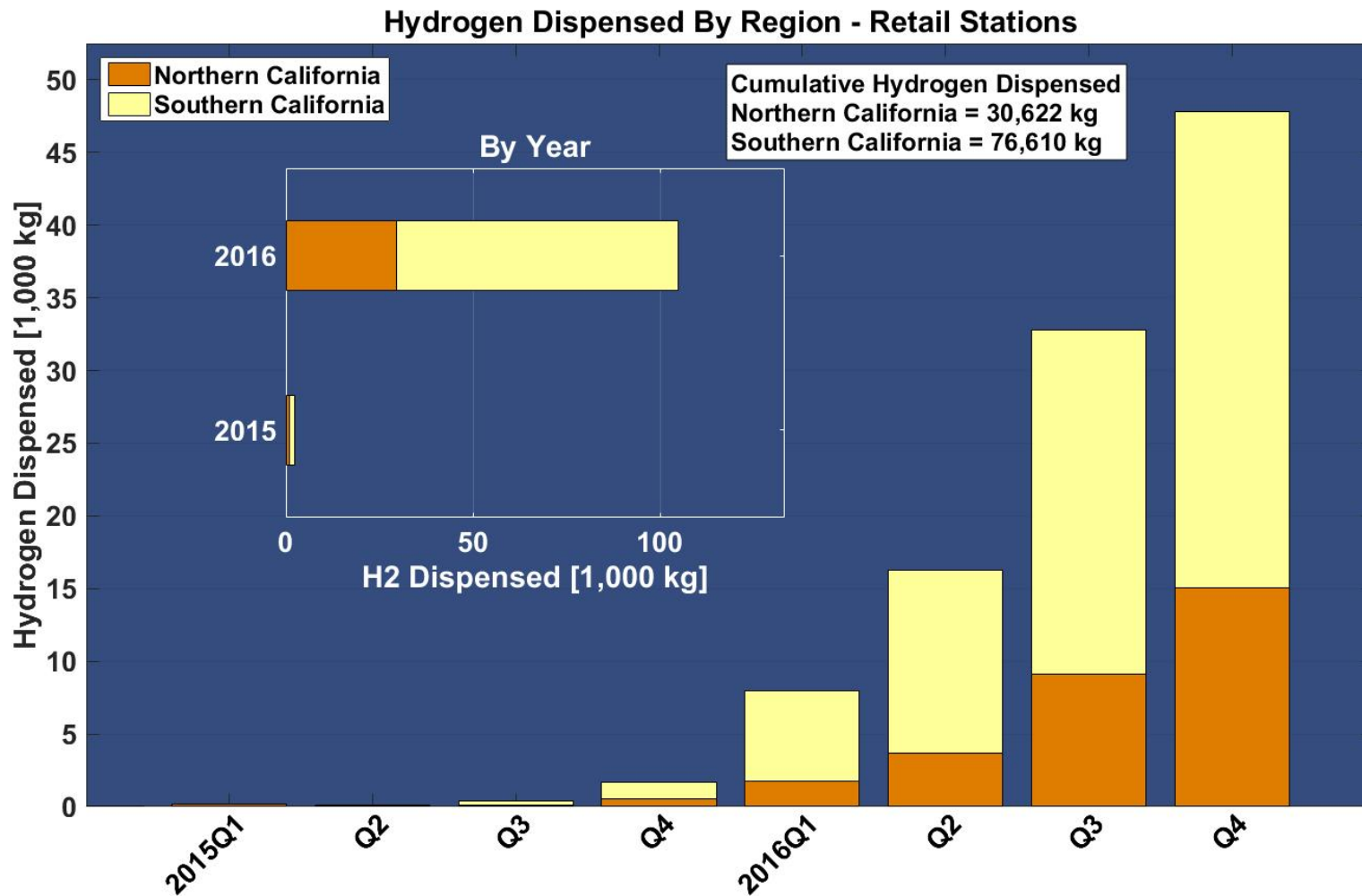
Note: Colors represent individual stations



NREL cdpRETAIL_infr_58

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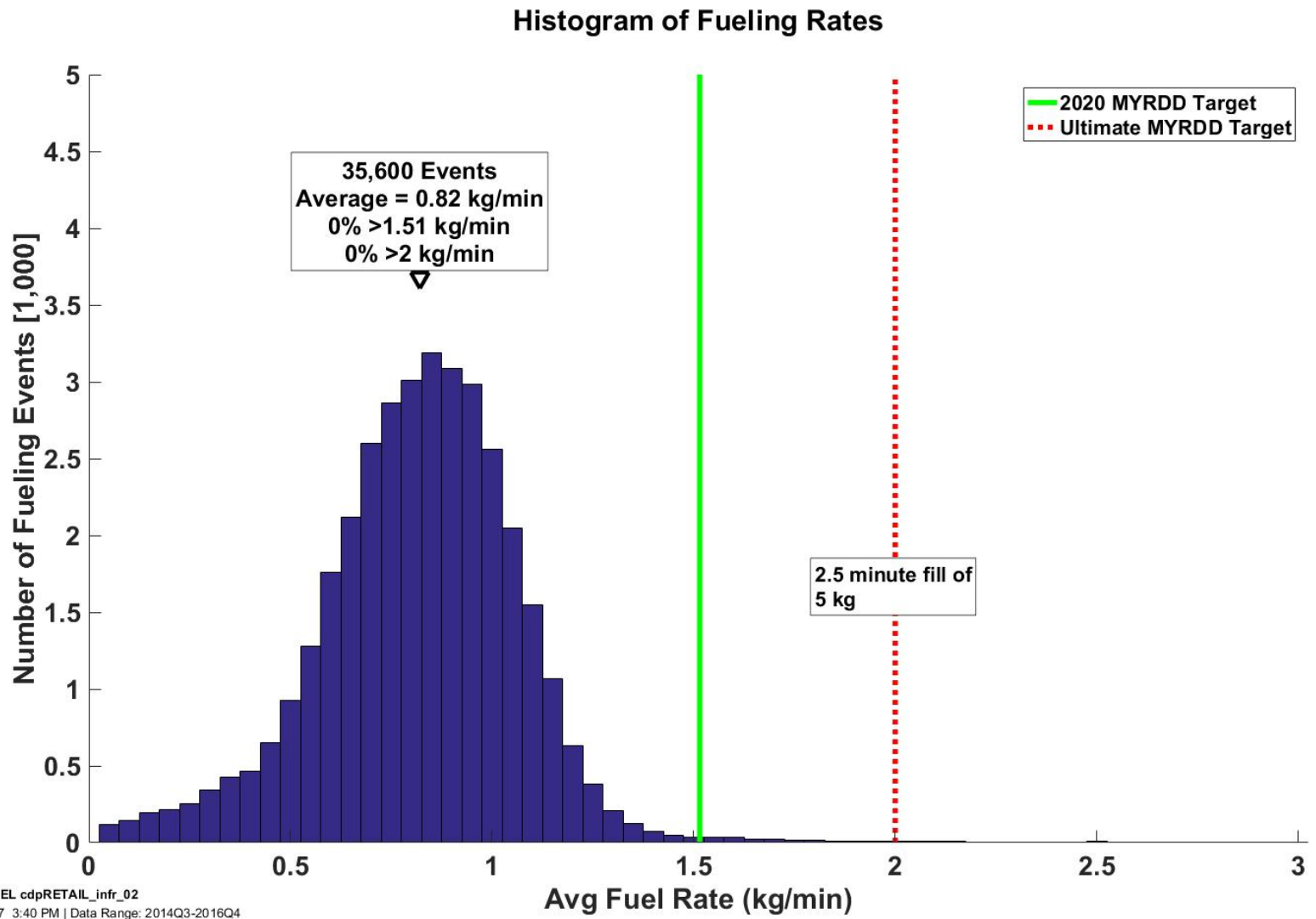
Note: Colors represent individual stations



NREL cdpRETAIL_infr_81

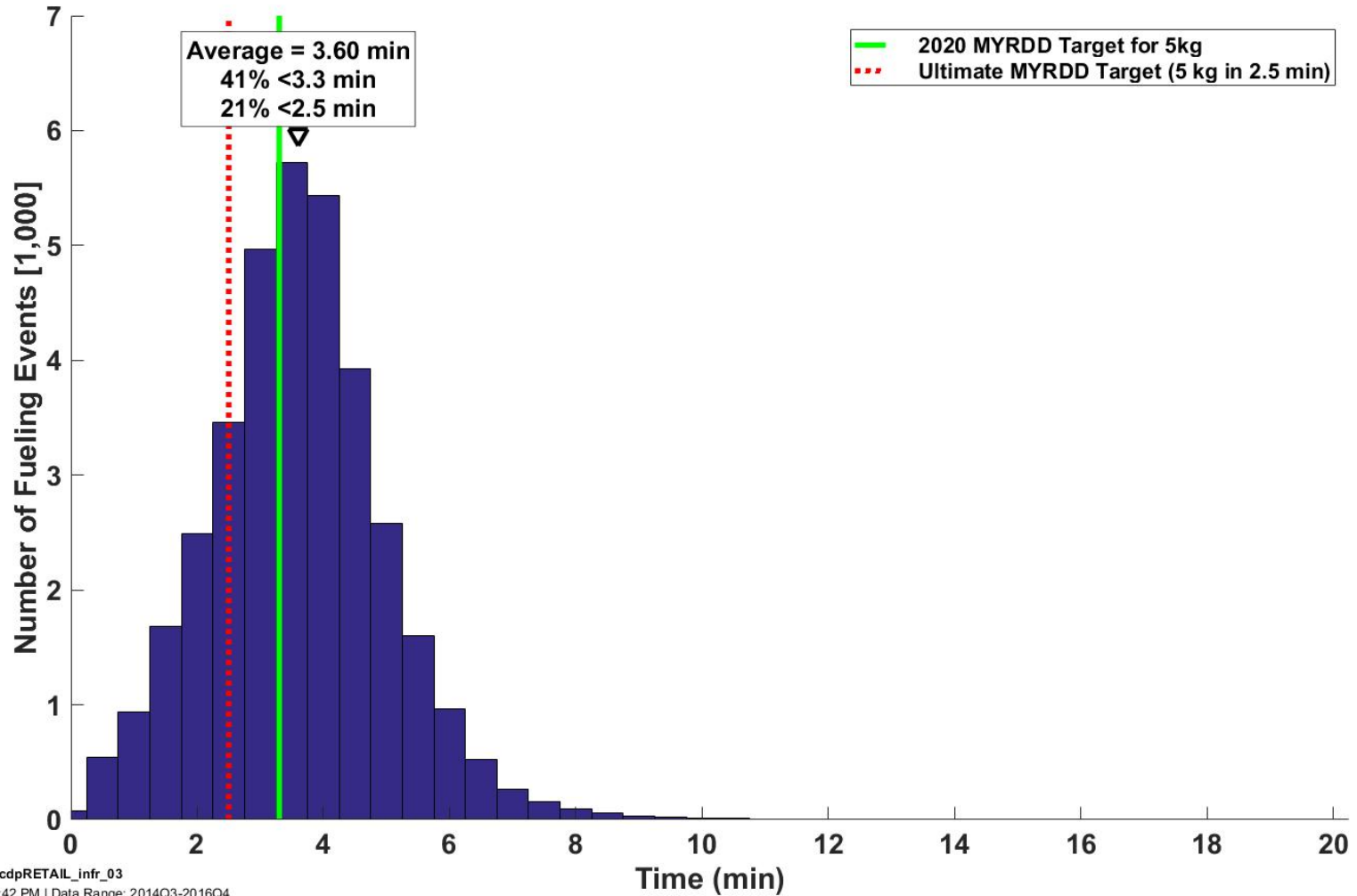
Created: May-05-17 3:32 PM | Data Range: 2014Q3-2016Q4

Histogram of Fueling Rates



Histogram of Fueling Times

Histogram of Fueling Times

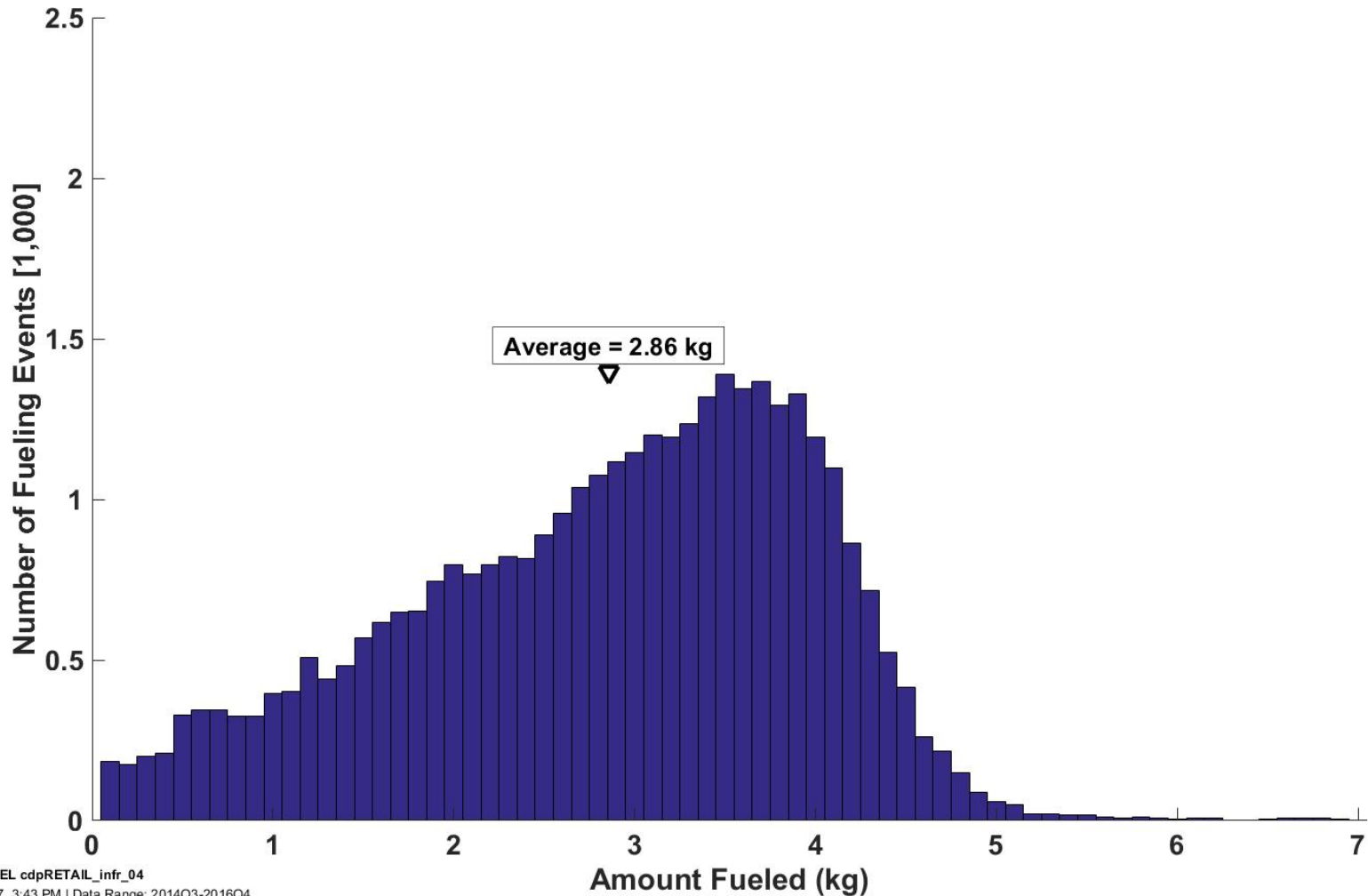


NREL cdpRETAIL_infr_03

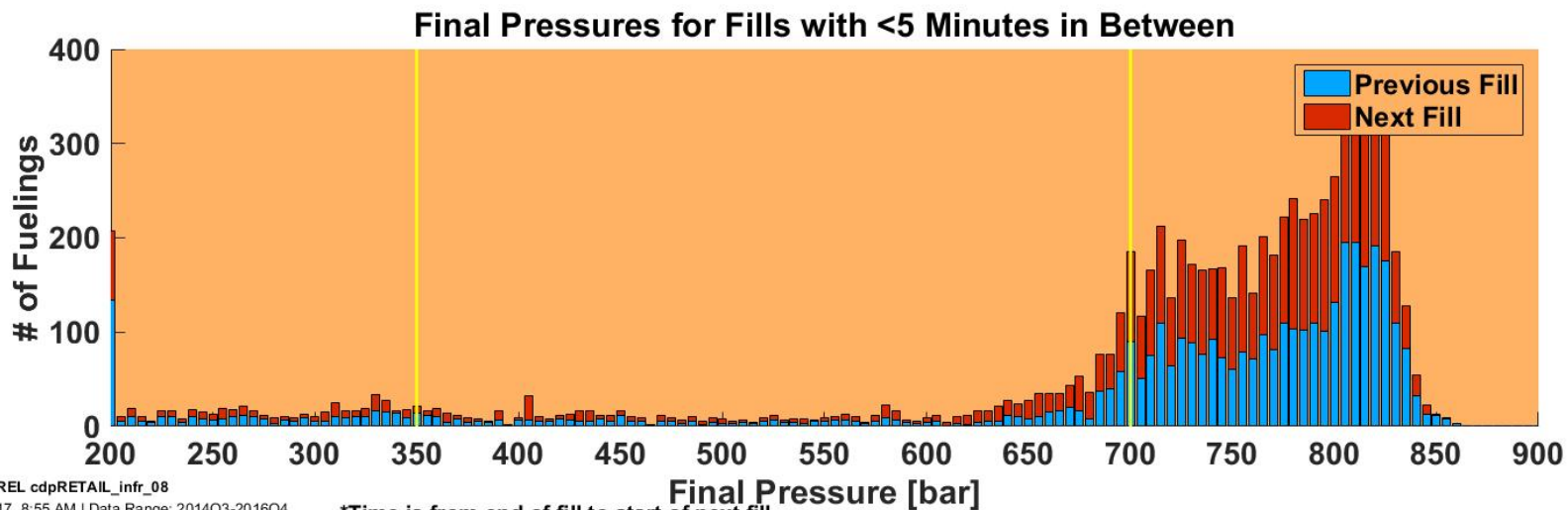
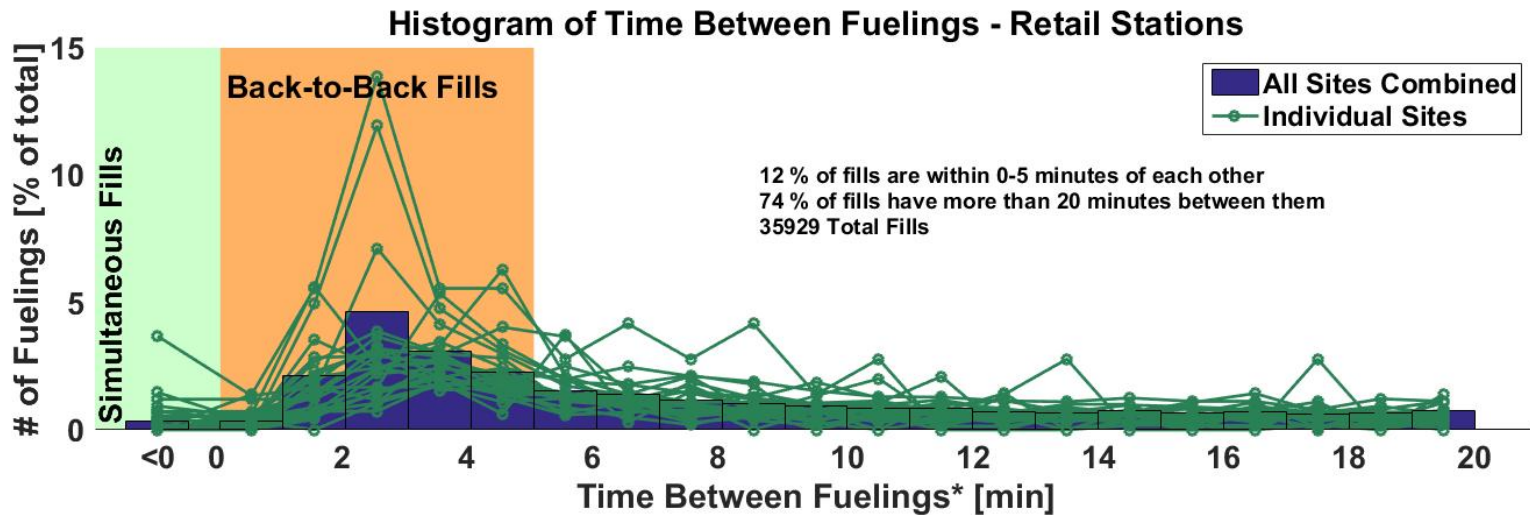
Created: May-08-17 3:42 PM | Data Range: 2014Q3-2016Q4

Histogram of Fueling Amounts

Histogram of Fueling Amounts



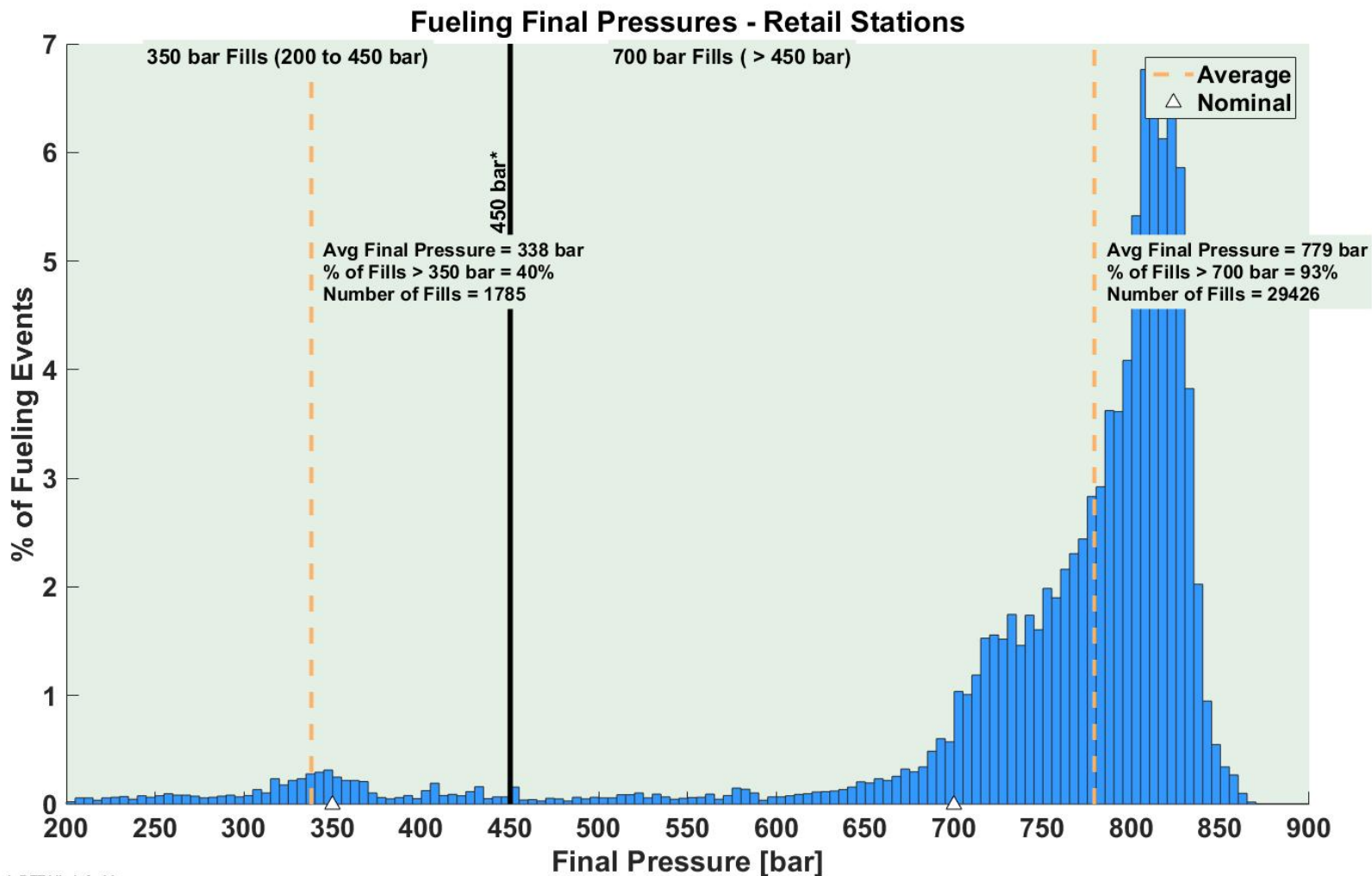
 NREL cdpRETAIL_infr_04
Created: May-08-17 3:43 PM | Data Range: 2014Q3-2016Q4



NREL cdpRETAIL_infr_08

Created: May-08-17 8:55 AM | Data Range: 2014Q3-2016Q4

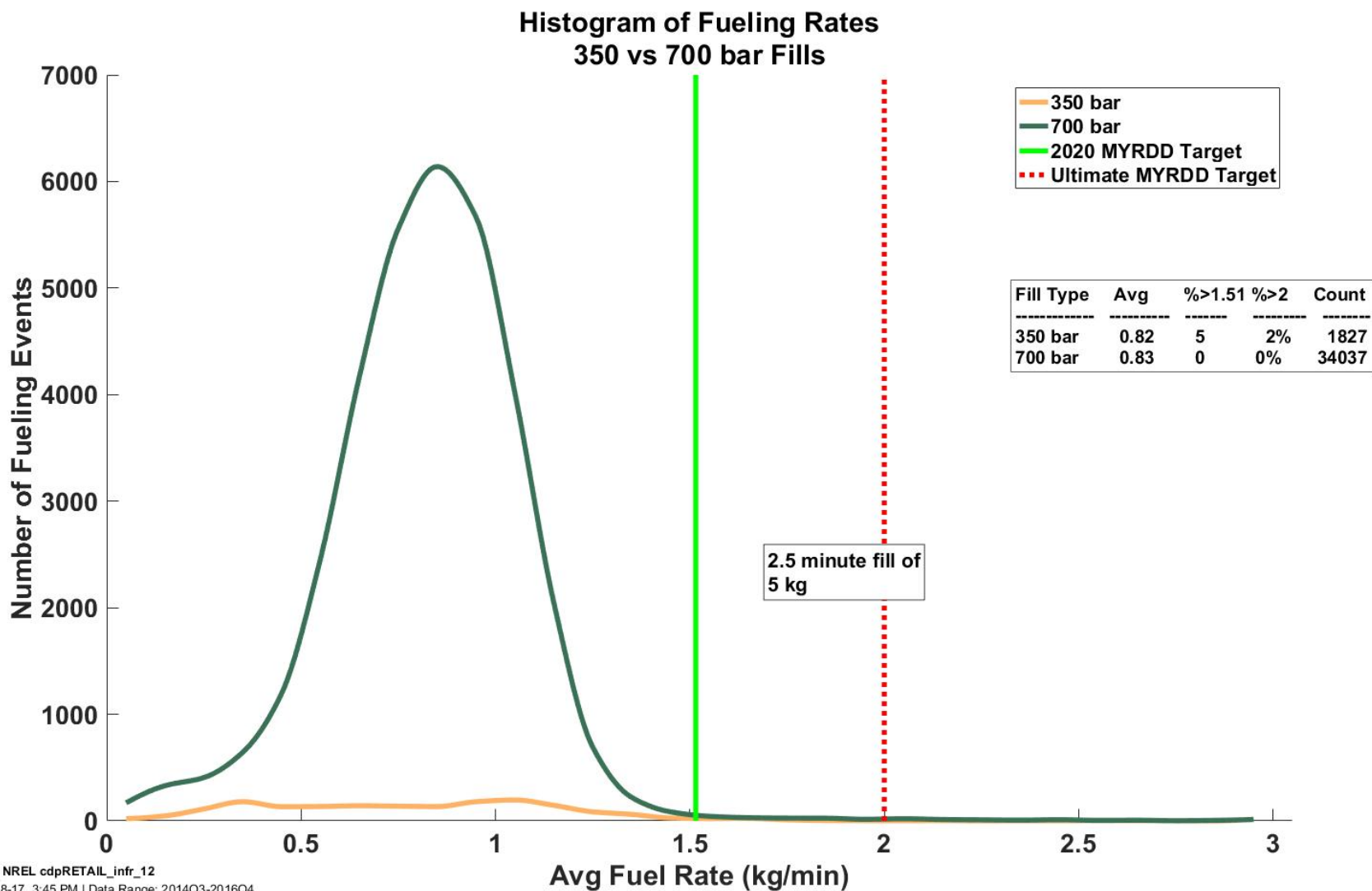
*Time is from end of fill to start of next fill.



NREL cdpRETAIL_infr_09

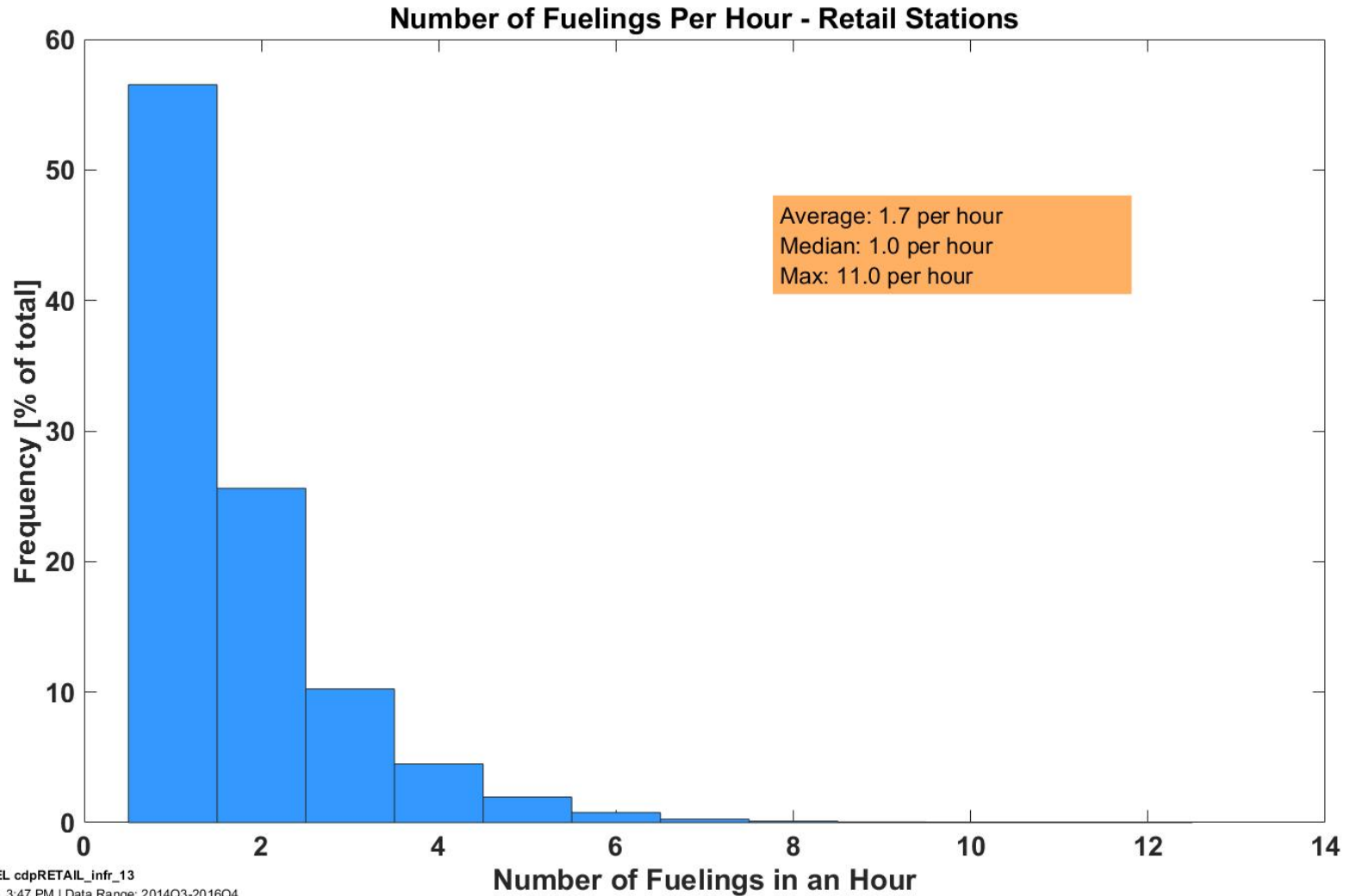
Created: May-08-17 8:58 AM | Data Range: 2014Q3-2016Q4

*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.



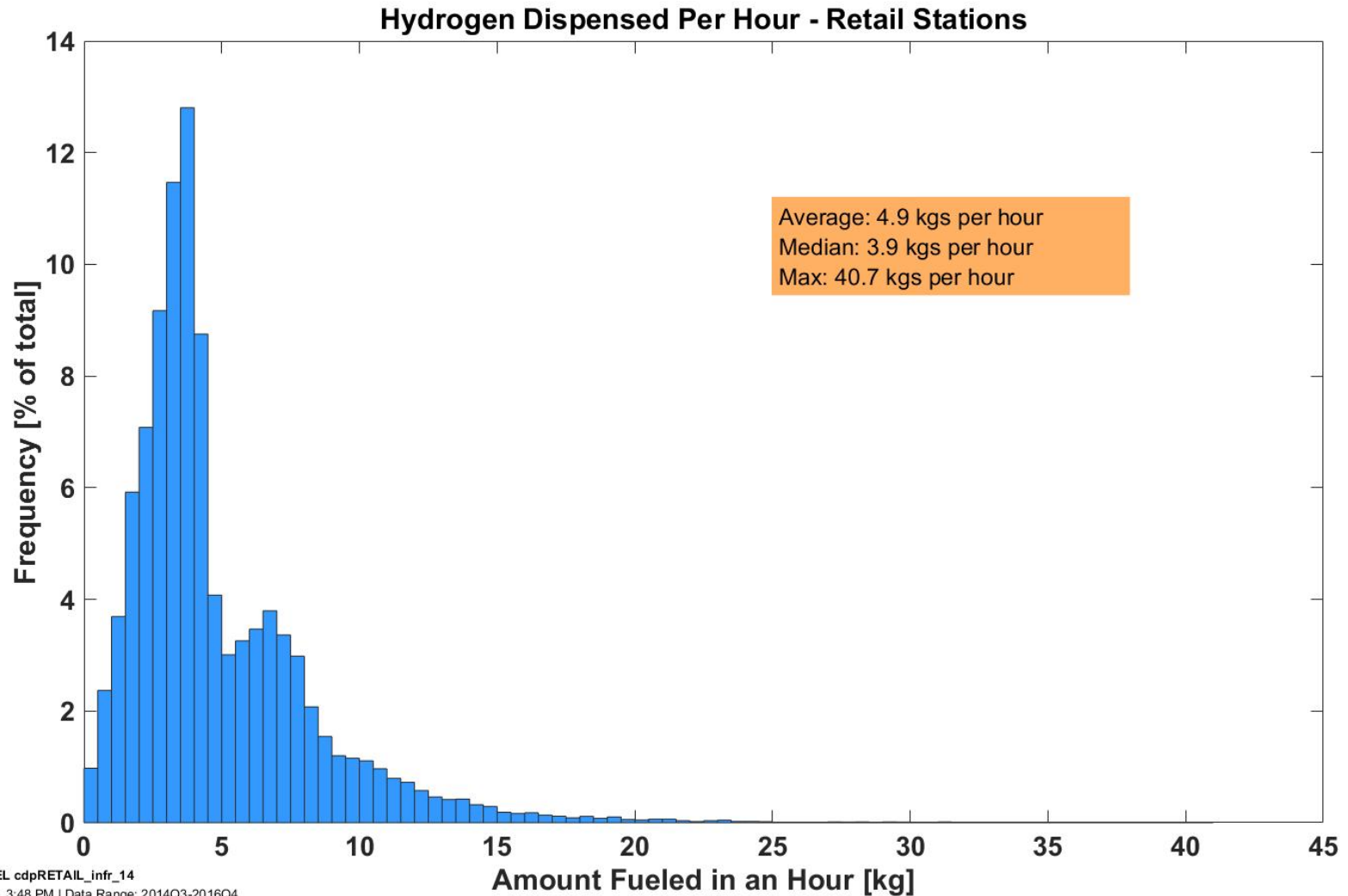
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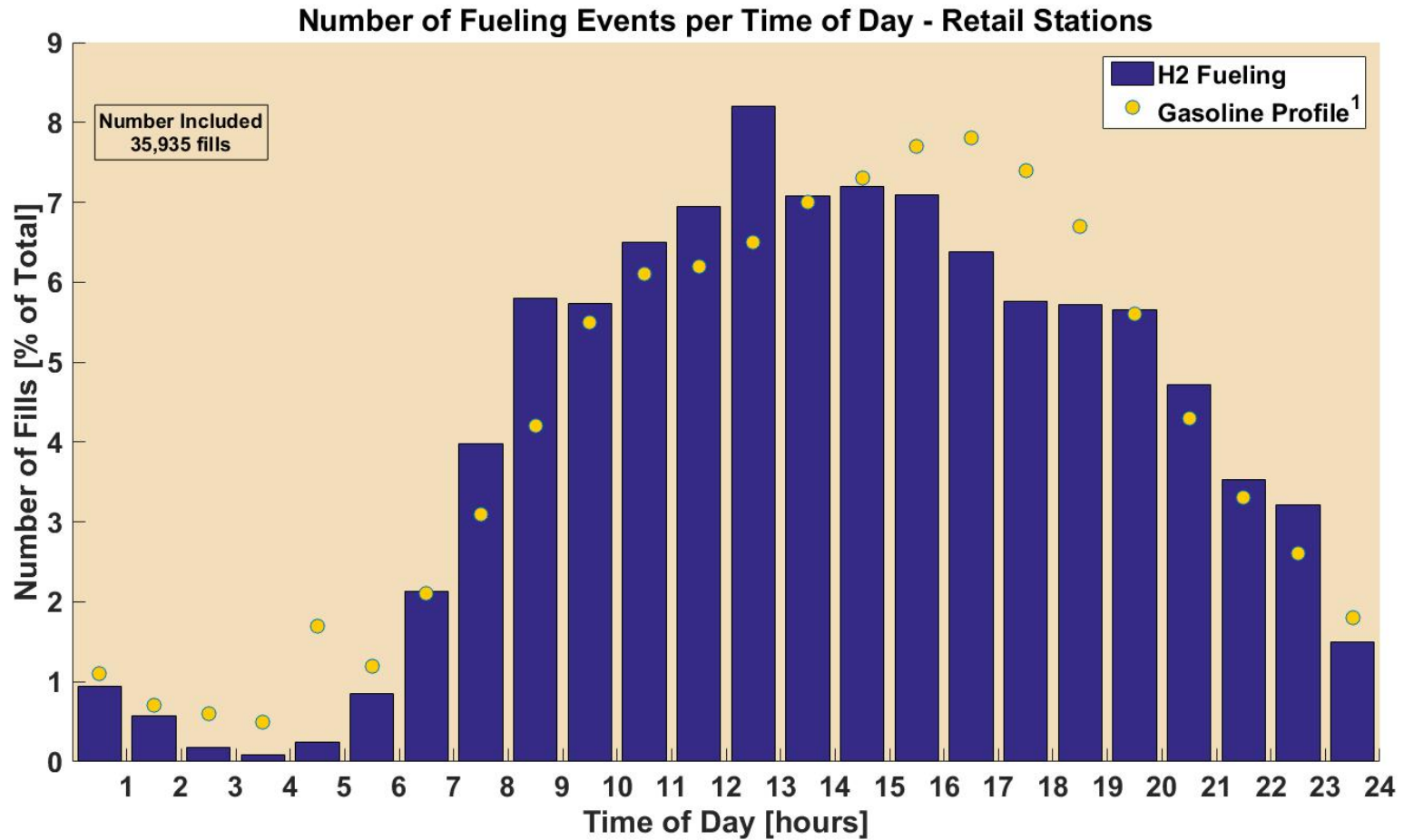
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NREL cdpRETAIL_infr_14

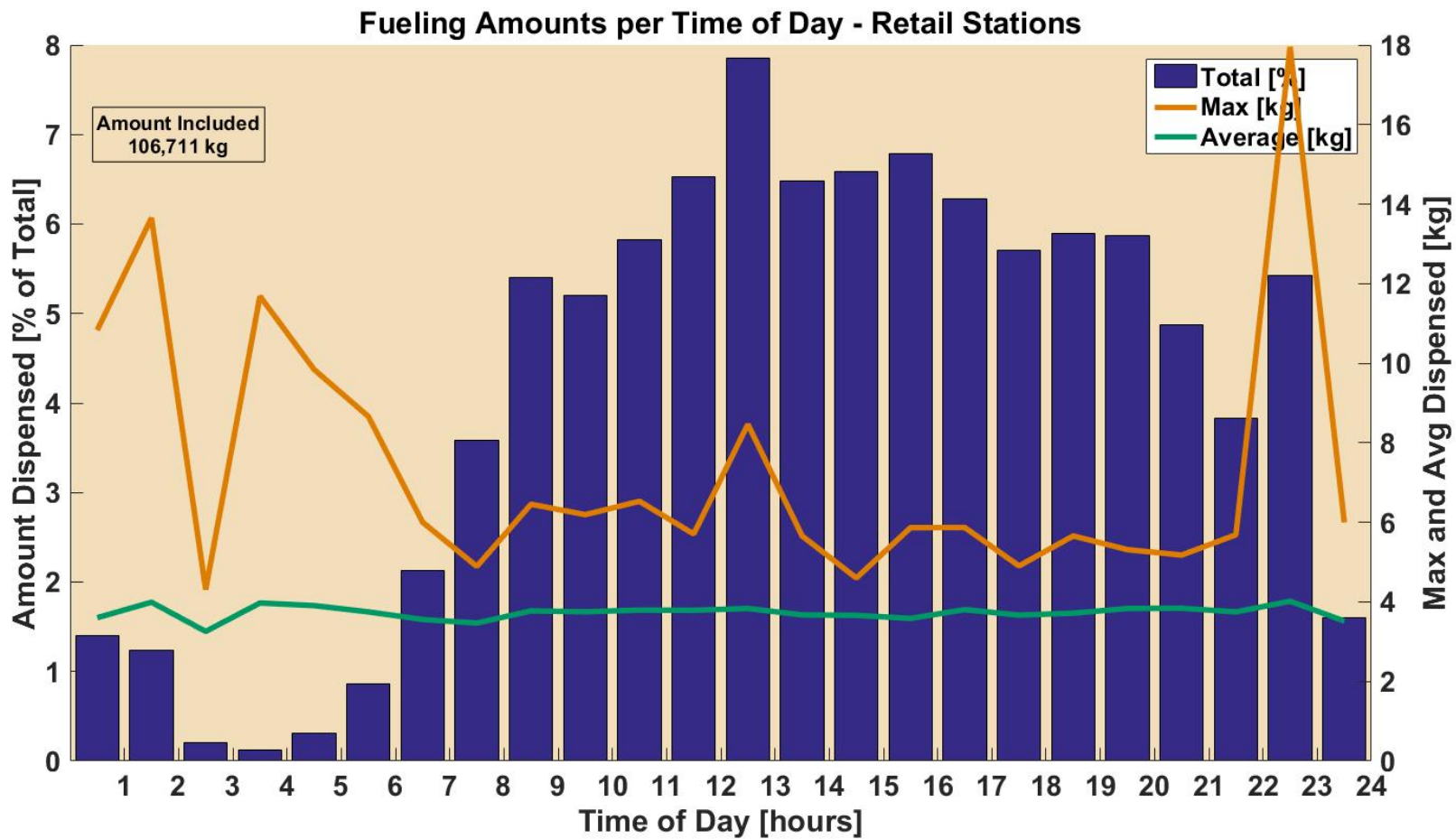
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NREL cdpRETAIL_infr_15

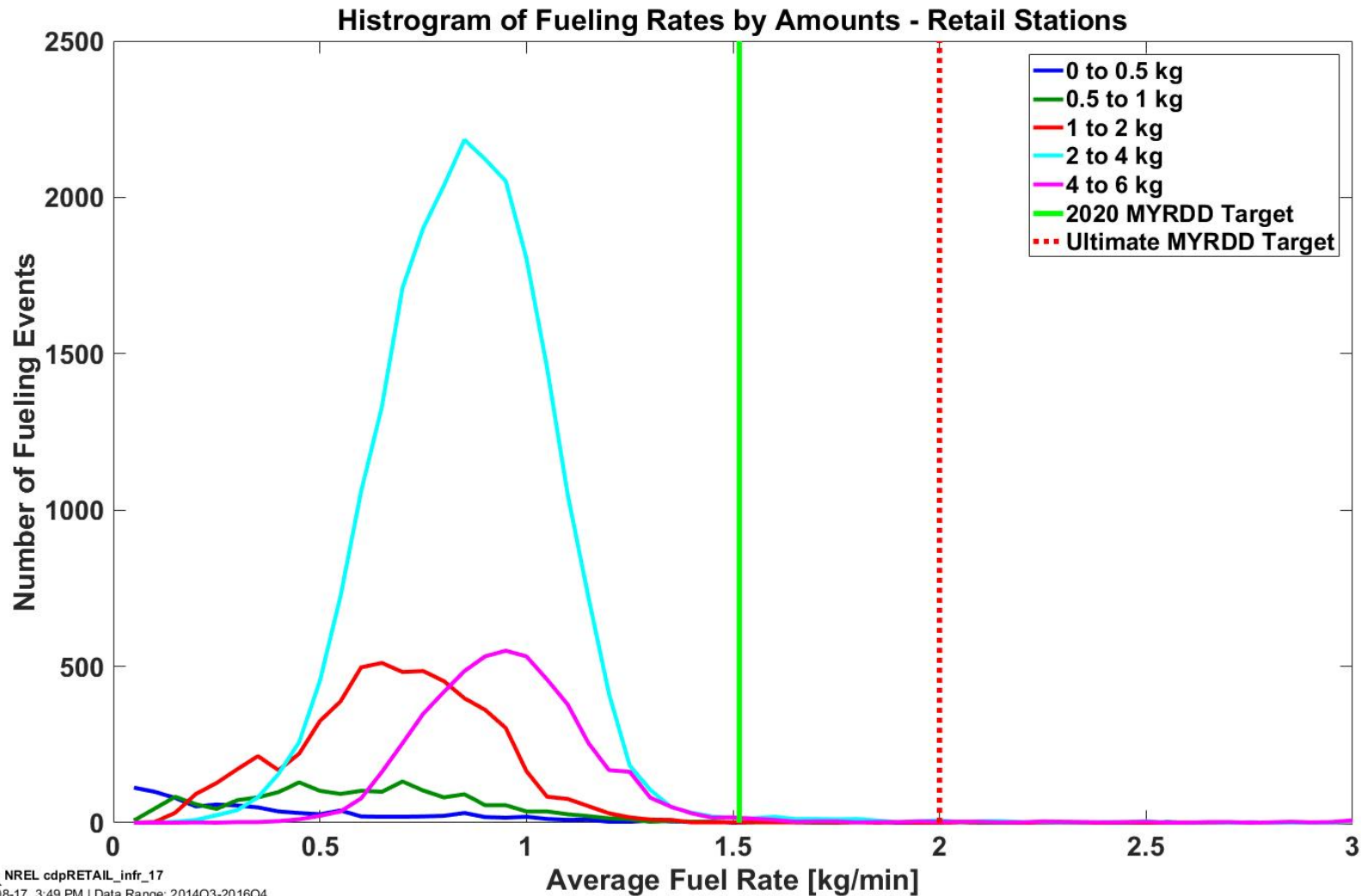
Created: May-08-17 9:00 AM | Data Range: 2014Q3-2016Q4

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



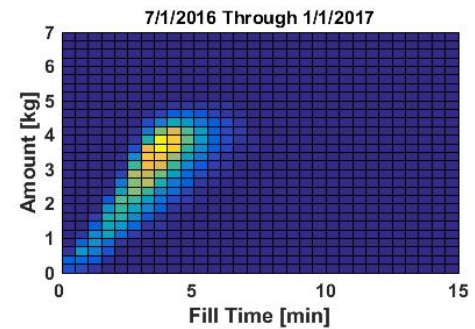
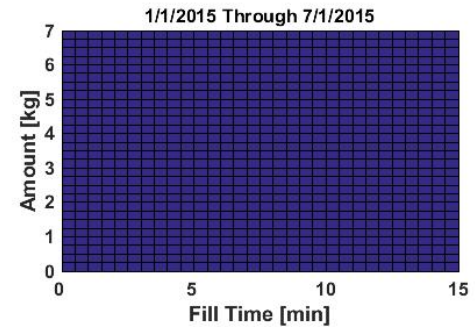
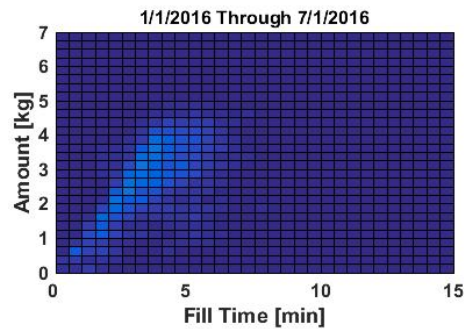
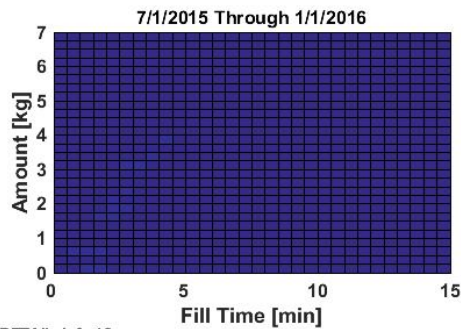
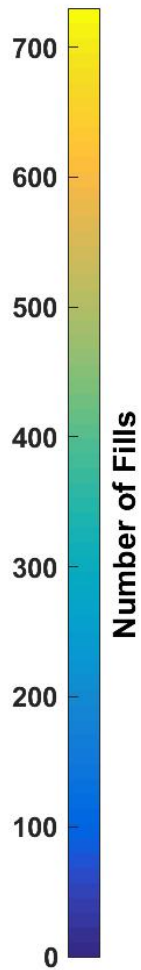
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 NREL cdpRETAIL_infr_17
Created: May-08-17 3:49 PM | Data Range: 2014Q3-2016Q4

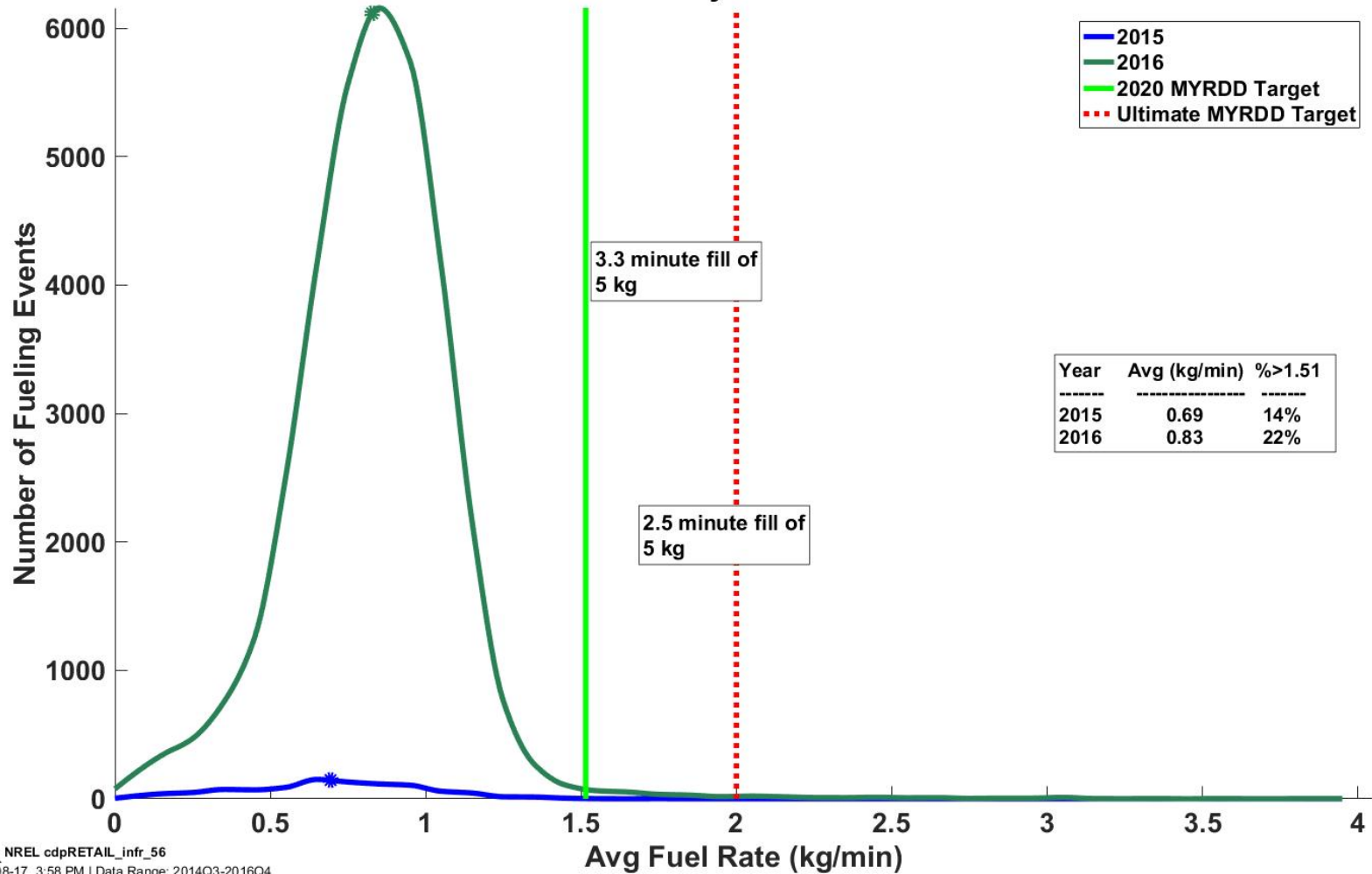
Histogram of Fueling Amount Vs Time - Retail Stations



NREL cdpRETAIL_infr_18

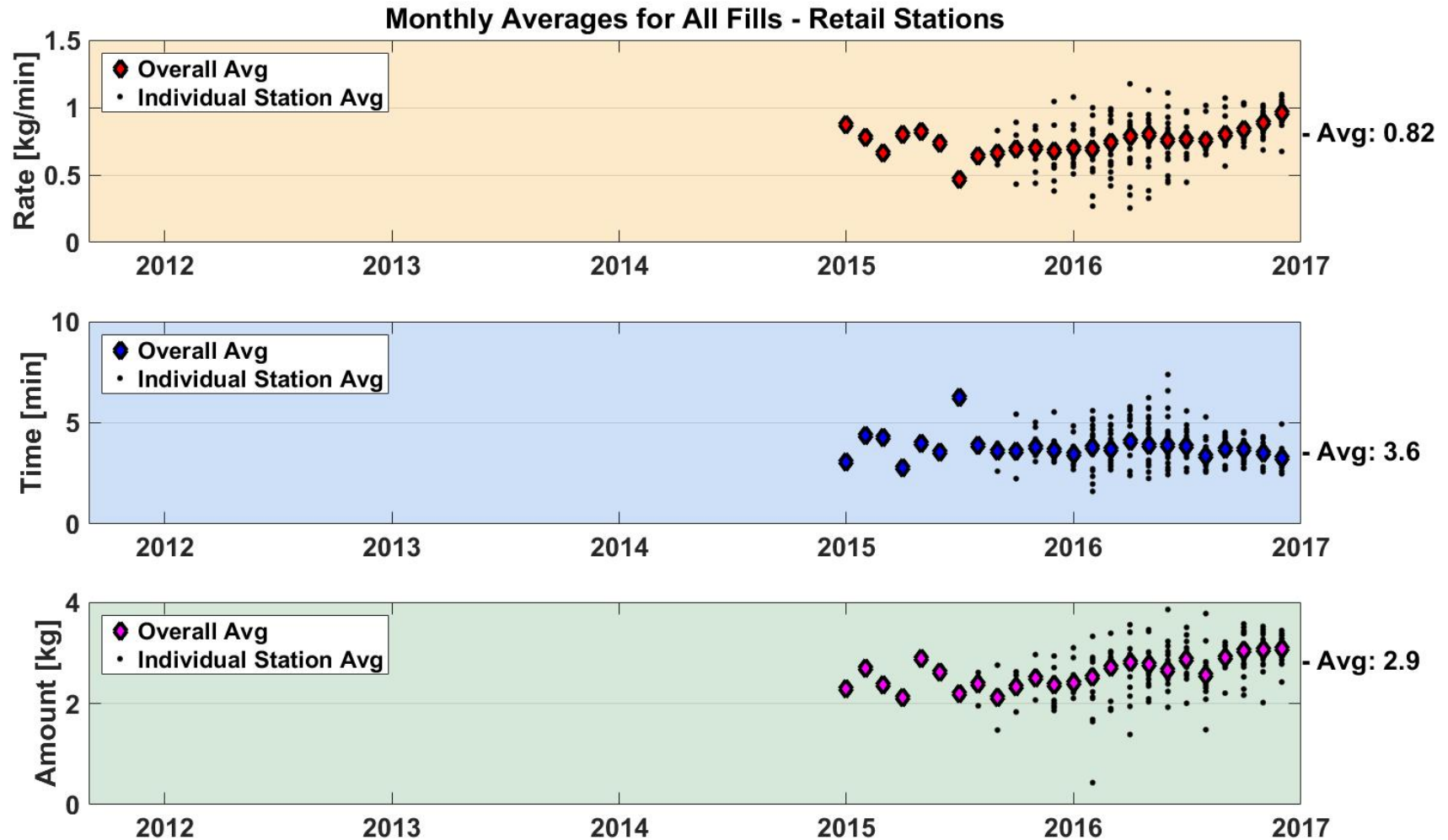
Created: May-08-17 3:50 PM | Data Range: 2014Q3-2016Q4

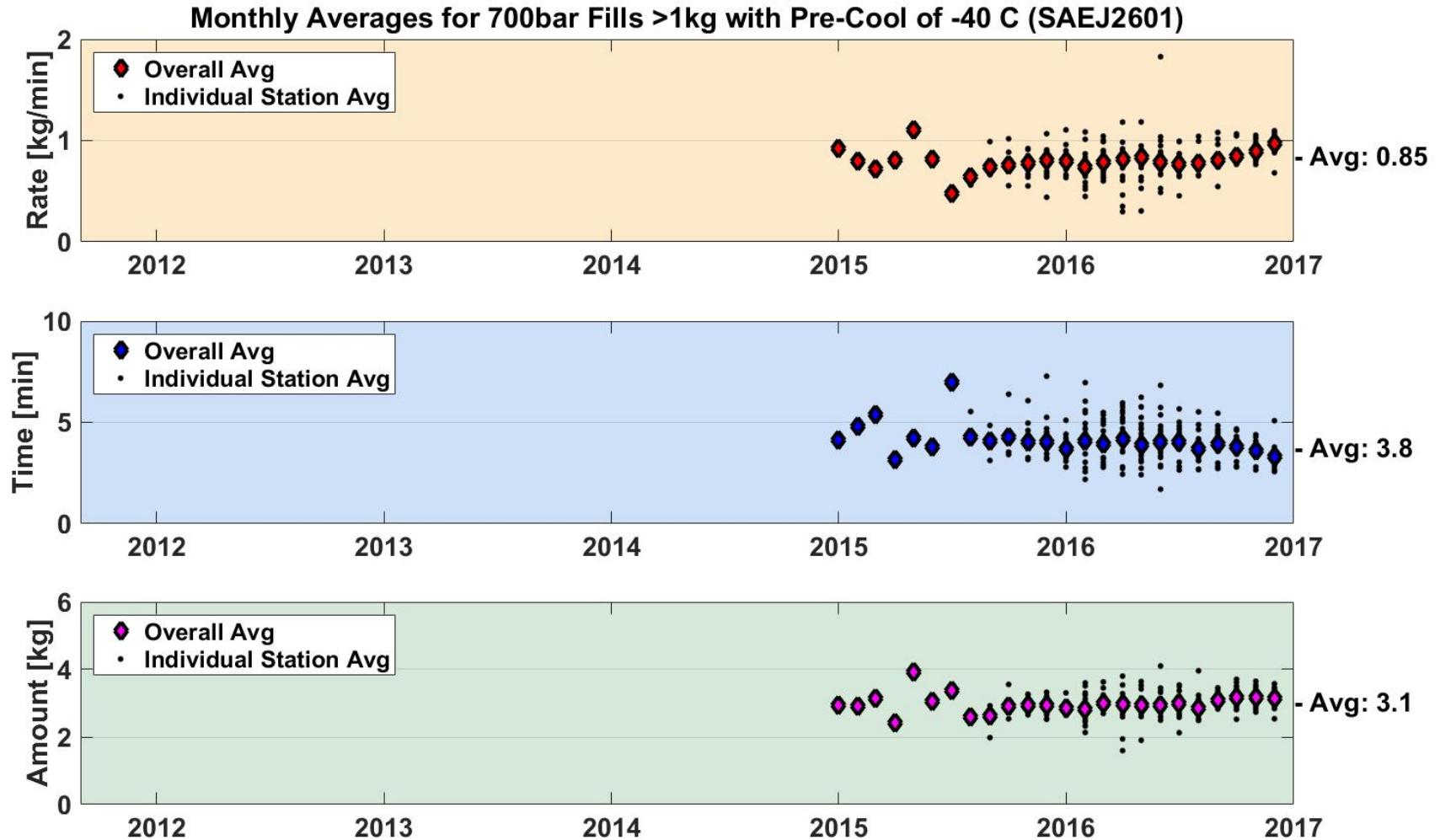
Histogram of Fueling Rates By Year



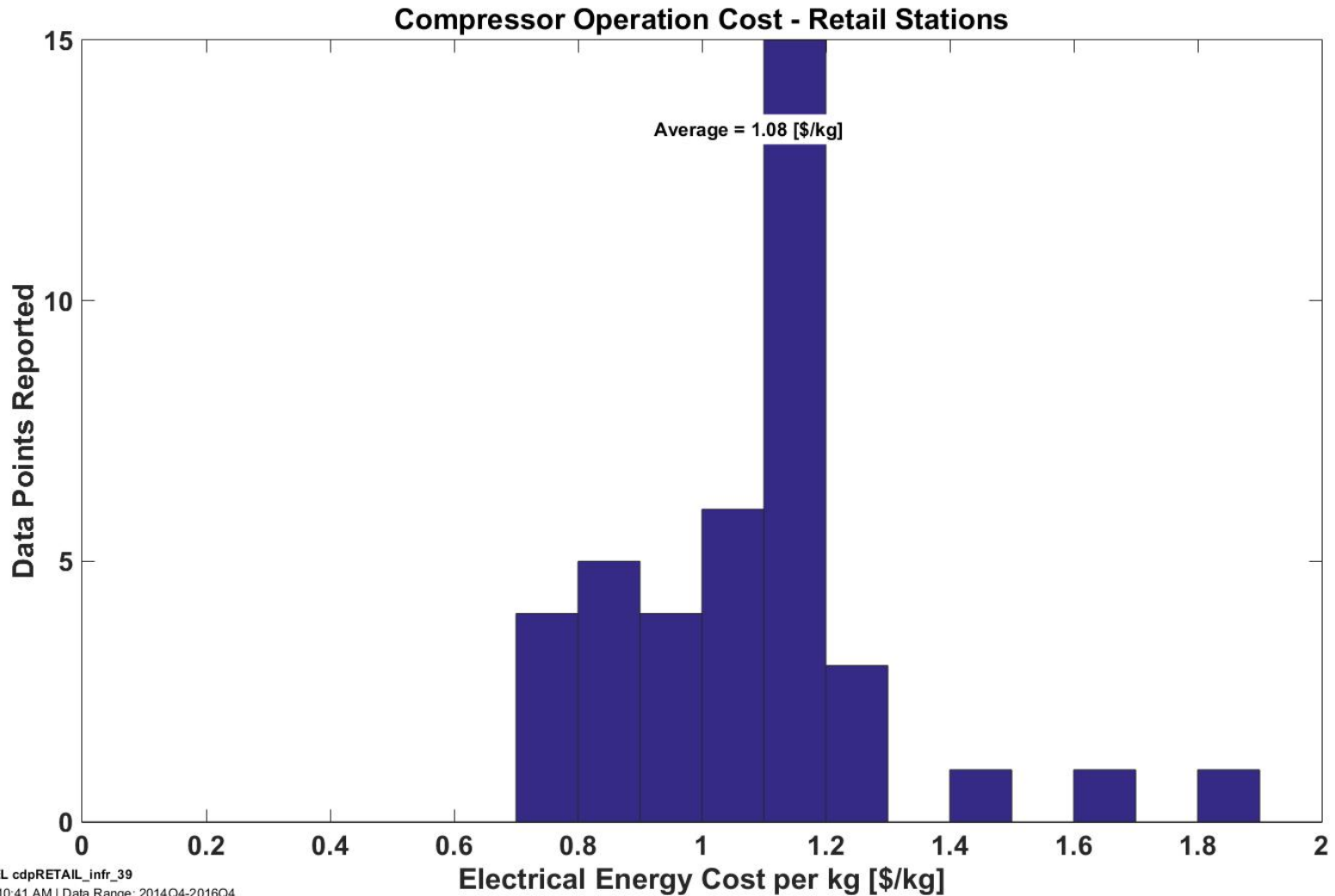

 NREL cdpRETAIL_infr_56
 Created: May-08-17 3:58 PM | Data Range: 2014Q3-2016Q4

Monthly Averages: All Fills





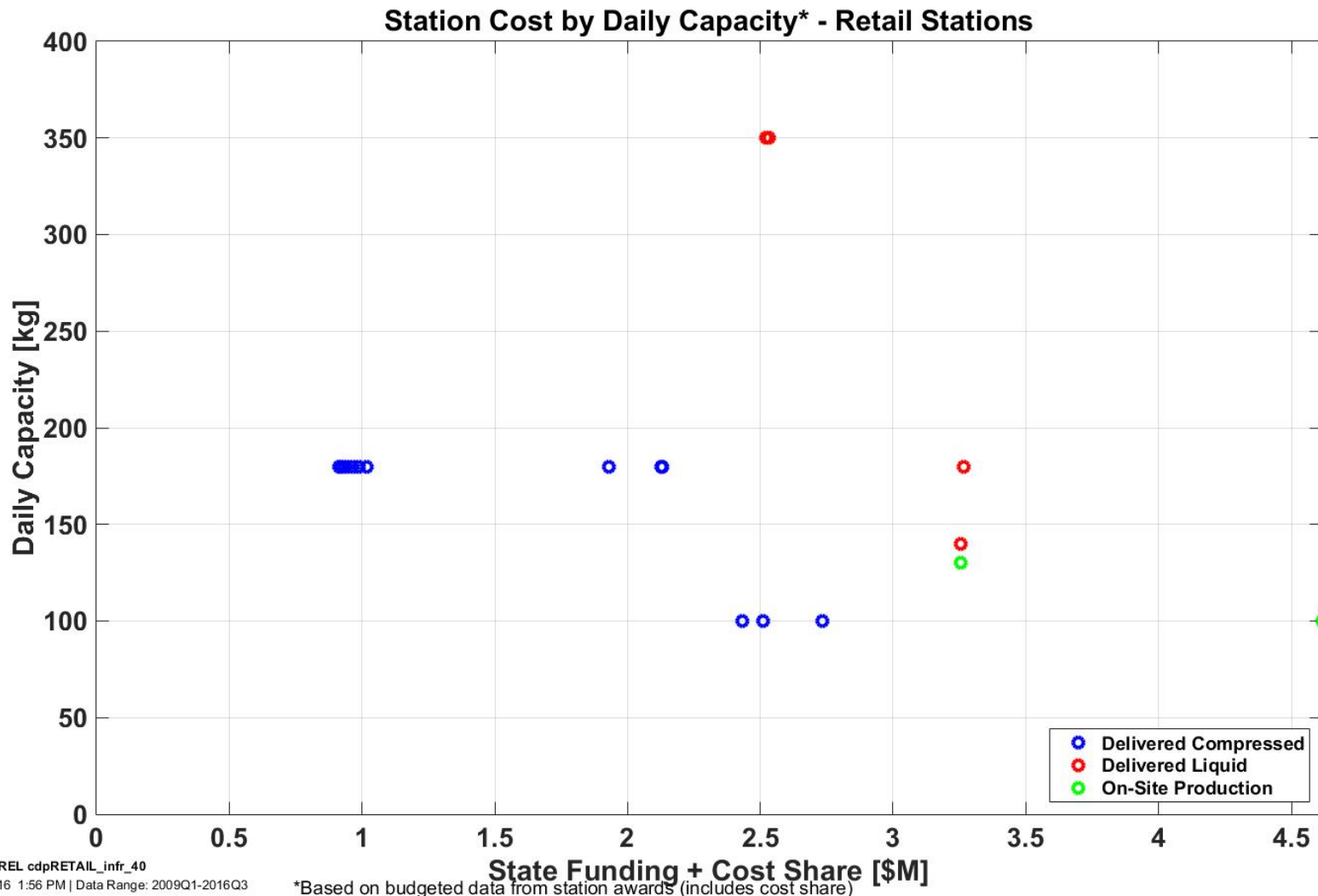
Cost



NREL cdpRETAIL_infr_39

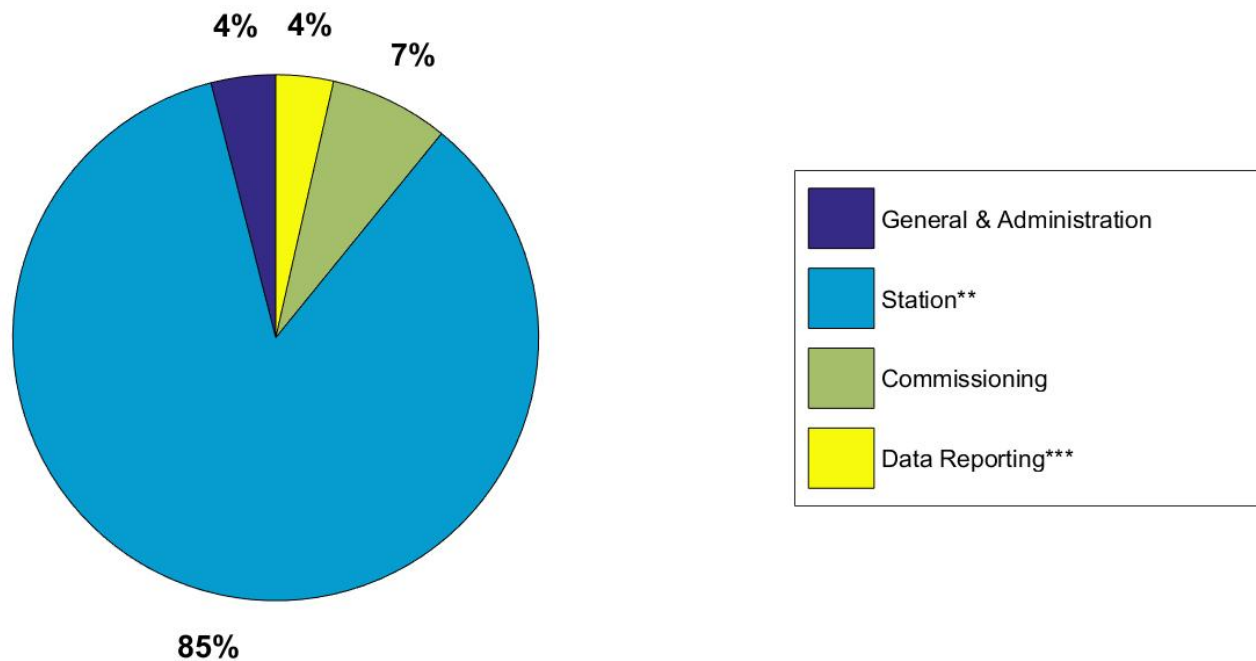
Created: Apr-18-17 10:41 AM | Data Range: 2014Q4-2016Q4

Station Cost by Daily Capacity



Average Station Cost by Category - Retail Stations

Budget Amounts* (Avg Total = \$2.17M), 43 Stations



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

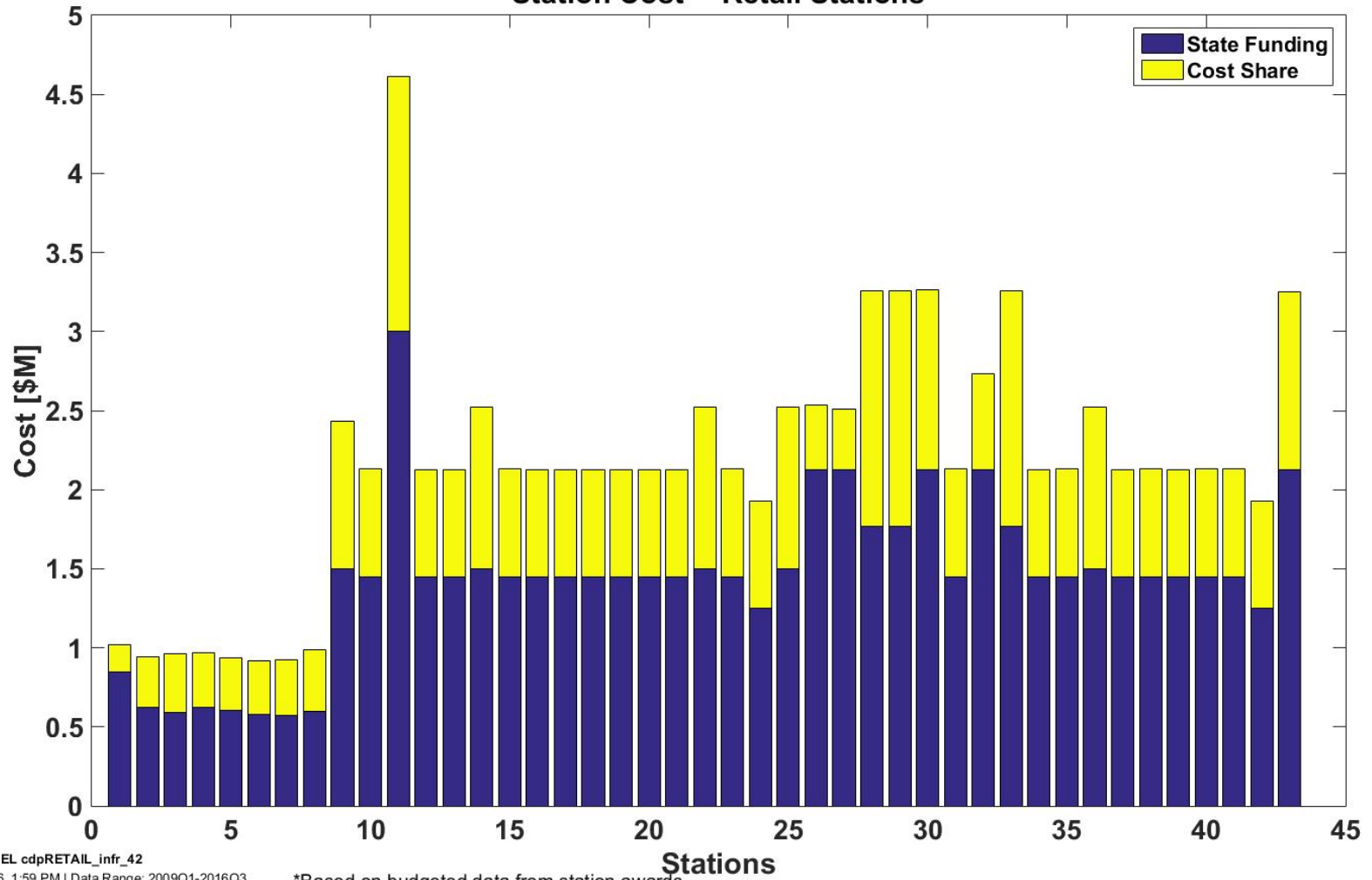
**Station includes: Hydrogen Equipment and Station Engineering, Design, Fabrication, Procurement, Site Preparation, Installation, and Construction

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

CDP-INFR-42

Station Cost

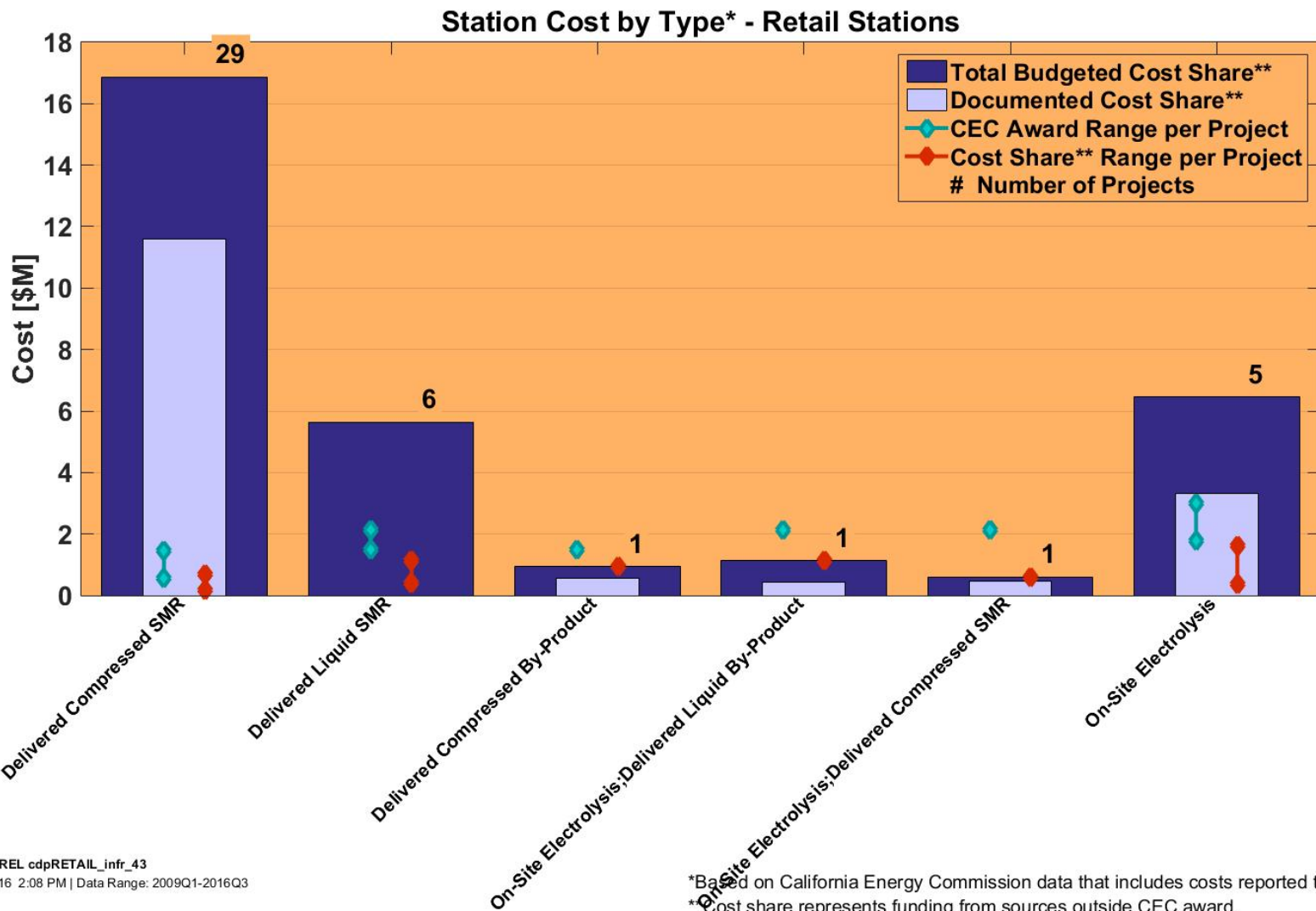
Station Cost* - Retail Stations



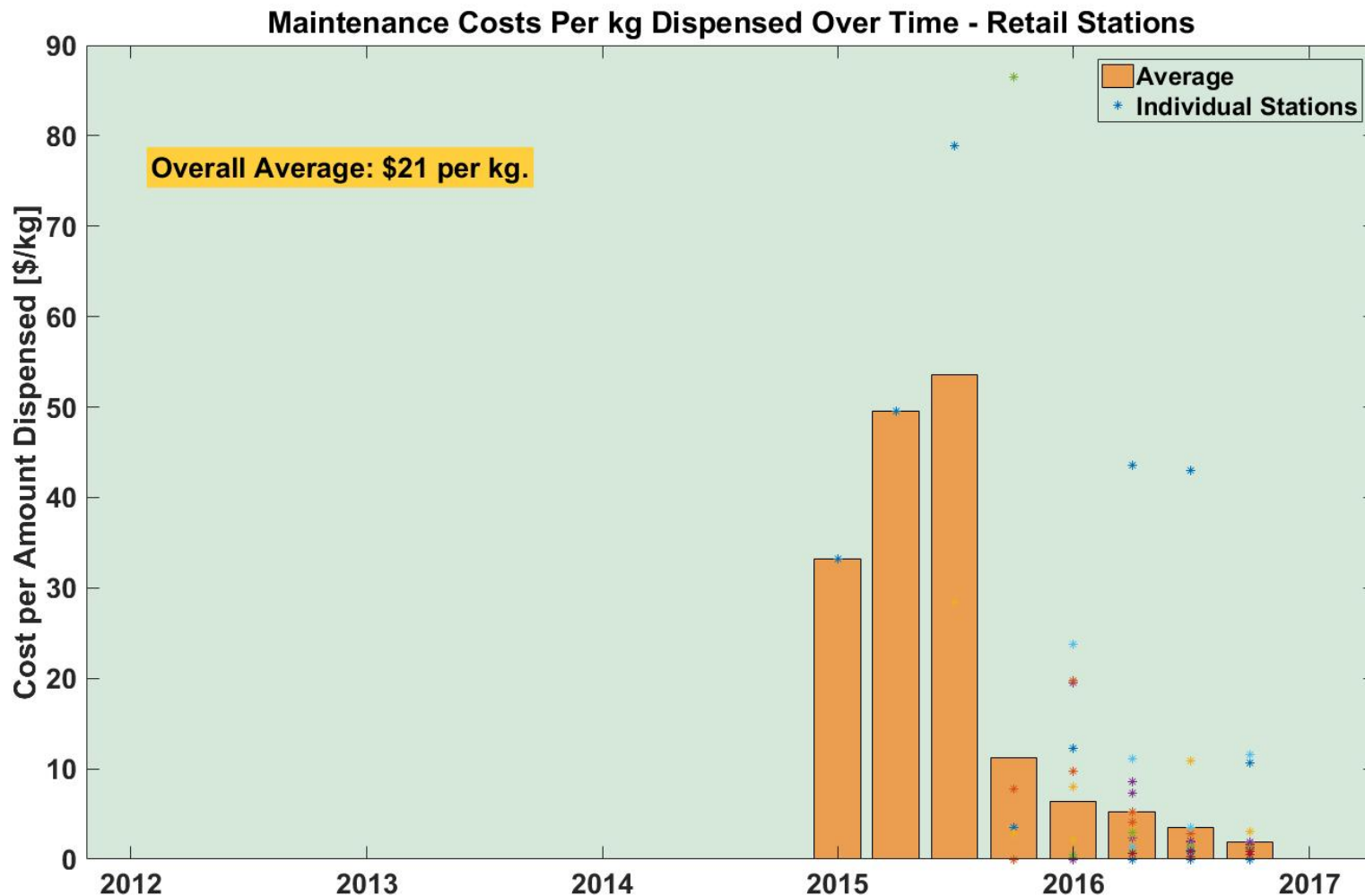
 NREL cdpRETAIL_infr_42
 Created: Dec-16-16 1:59 PM | Data Range: 2009Q1-2016Q3

*Based on budgeted data from station awards.

Station Cost by Type



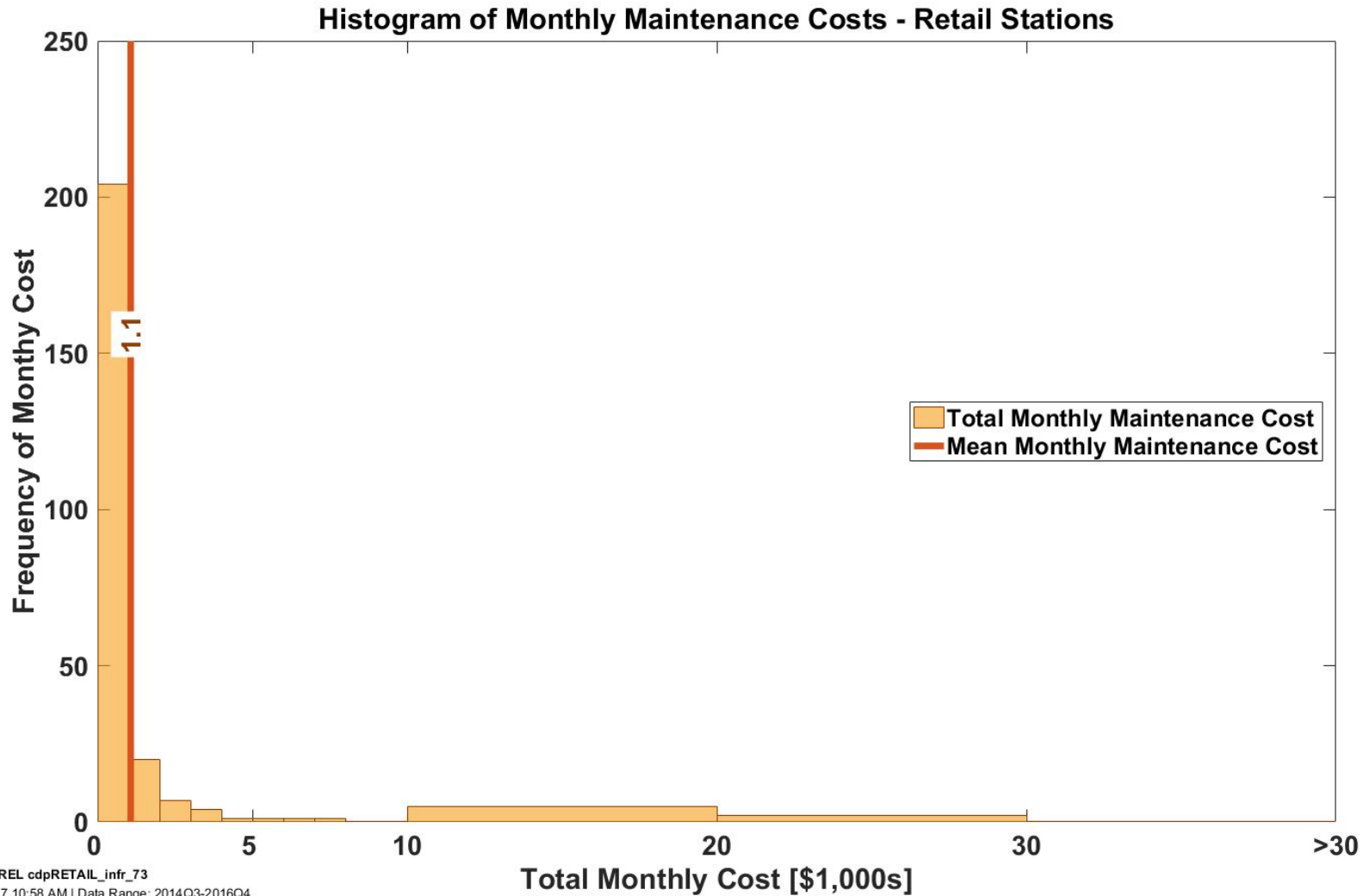
Maintenance Cost per kg of Hydrogen Dispensed



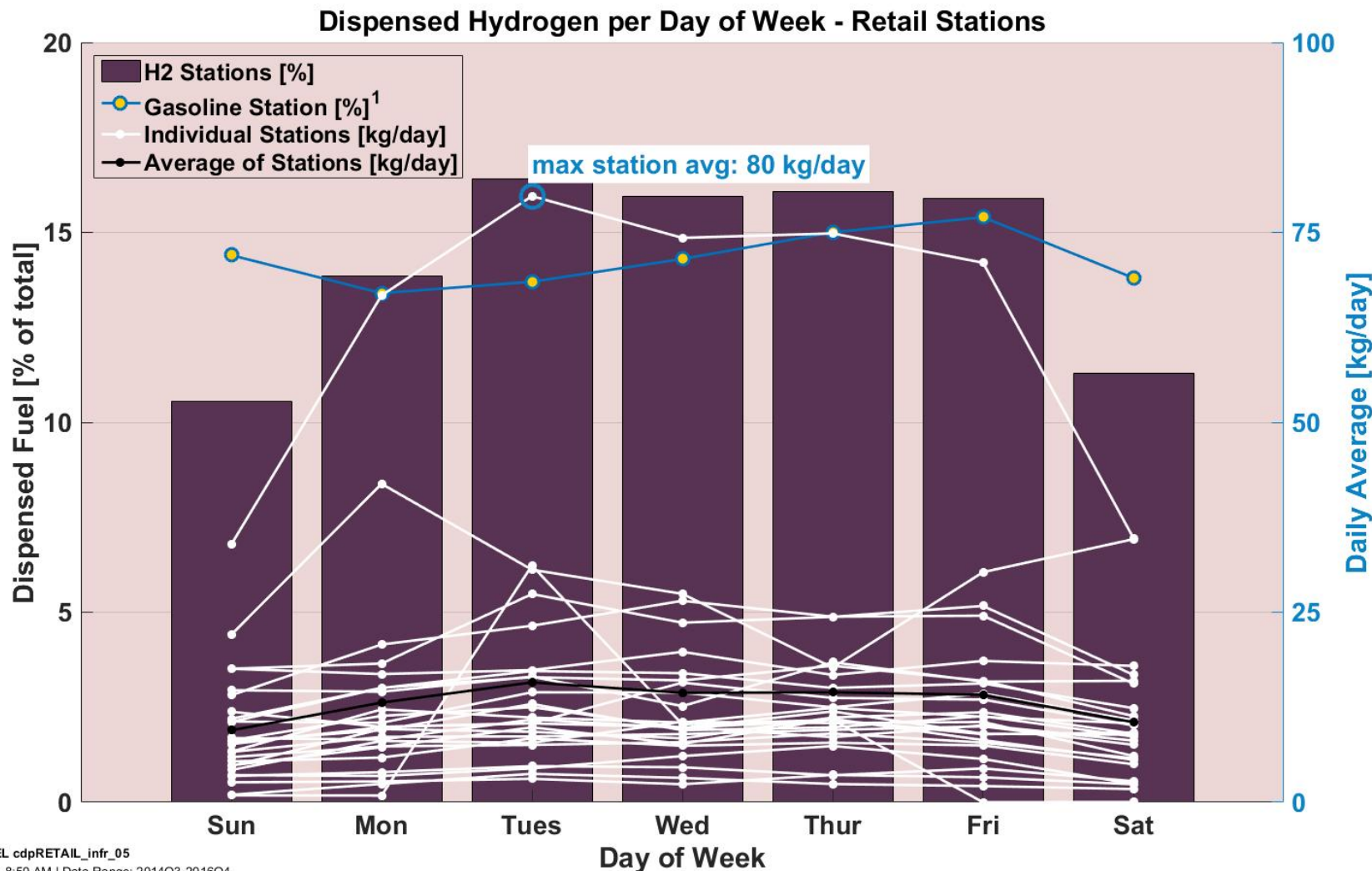
 NREL cdpRETAIL_infr_53
 Created: Mar-24-17 1:49 PM | Data Range: 2014Q3-2016Q4

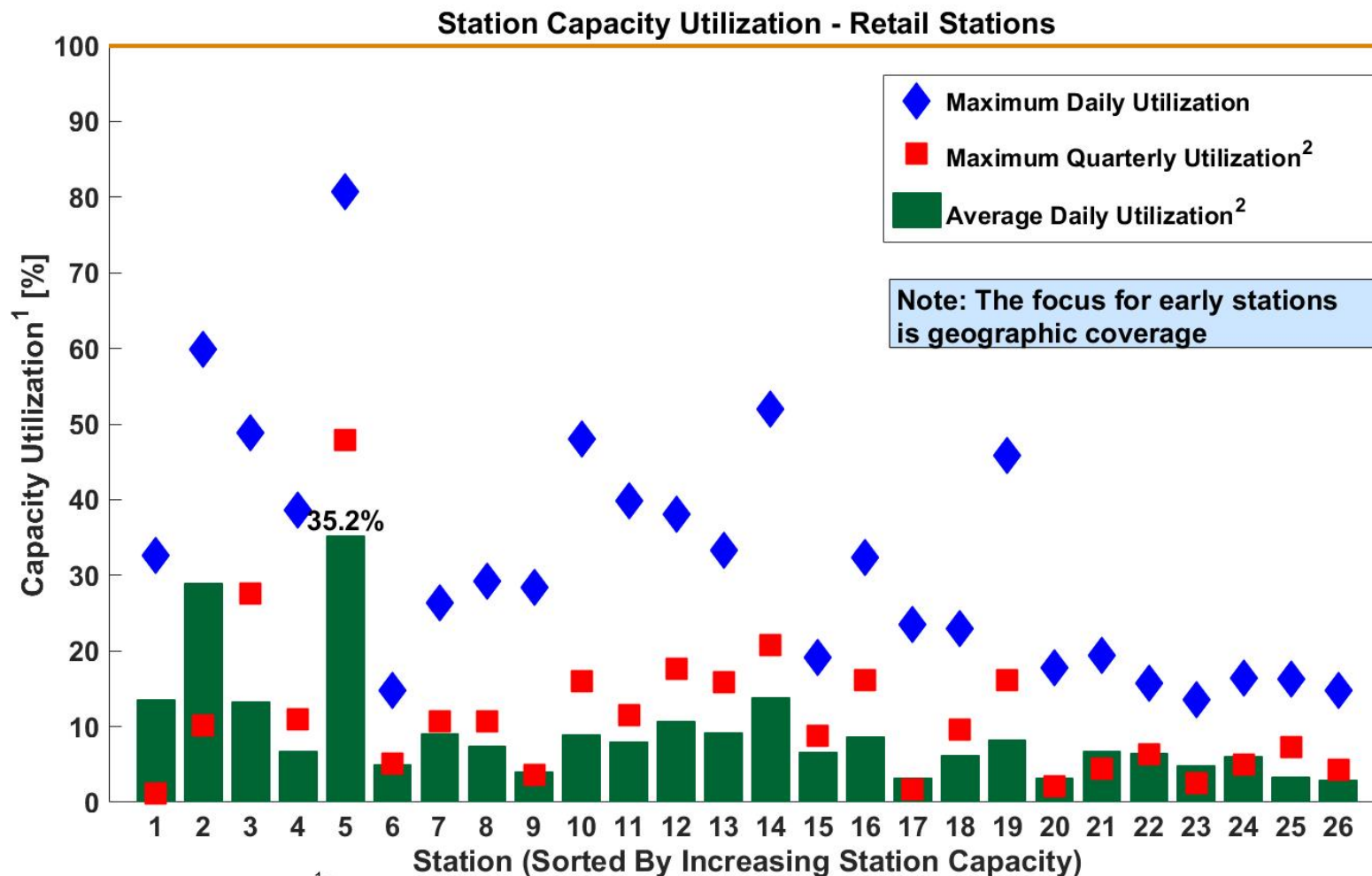
*Each color represents a unique station. 0 data points excluded that were over \$1000/kg

Histogram of Monthly Maintenance Costs



Utilization





NREL cdpRETAIL_infr_06

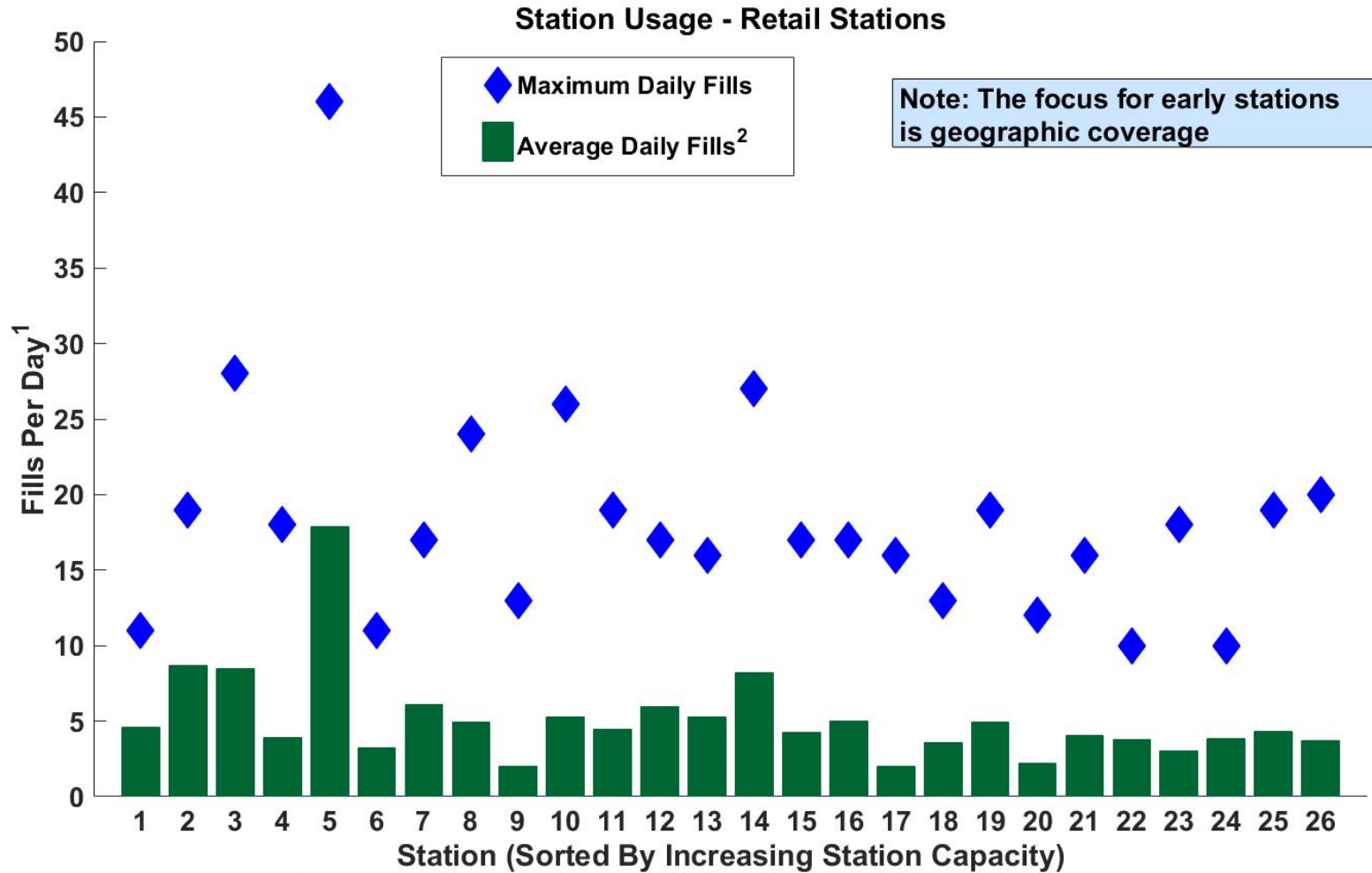
Created: May-08-17 8:52 AM | Data Range: 2014Q3-2016Q4

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

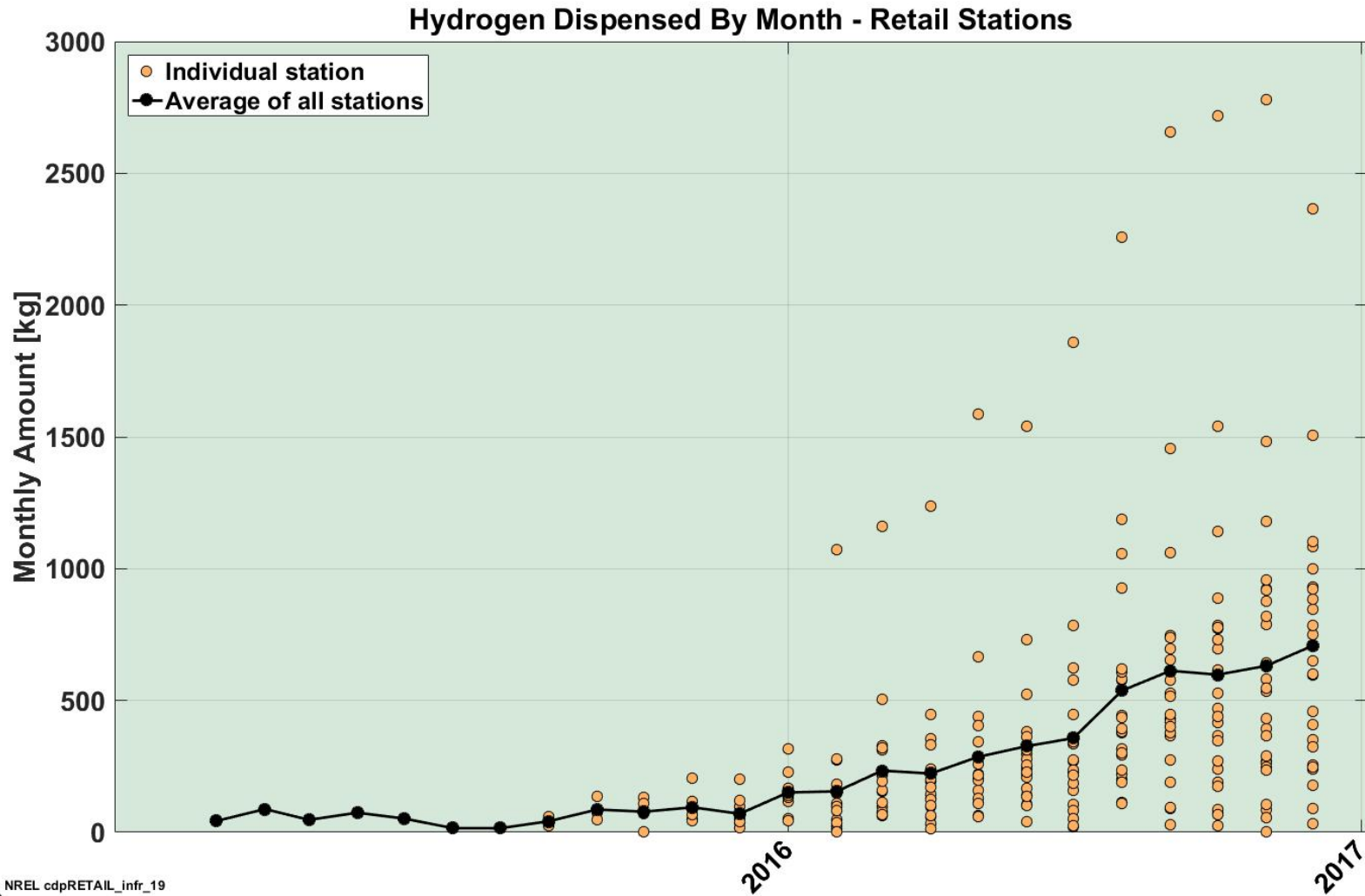
CDP-INFR-07

Station Usage



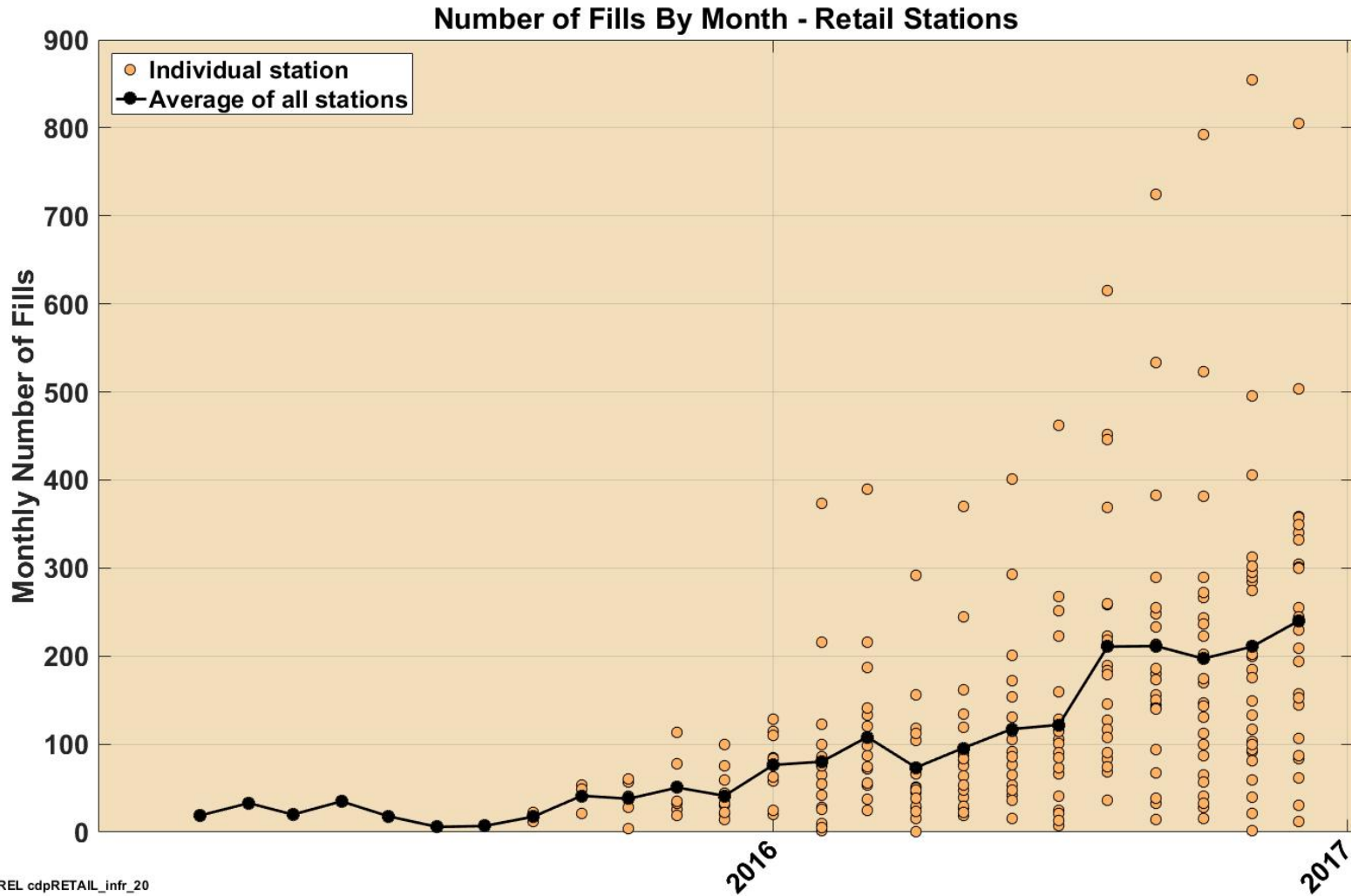
 NREL cdpRETAIL_infr_07
 Created: May-08-17 3:44 PM | Data Range: 2014Q3-2016Q4

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

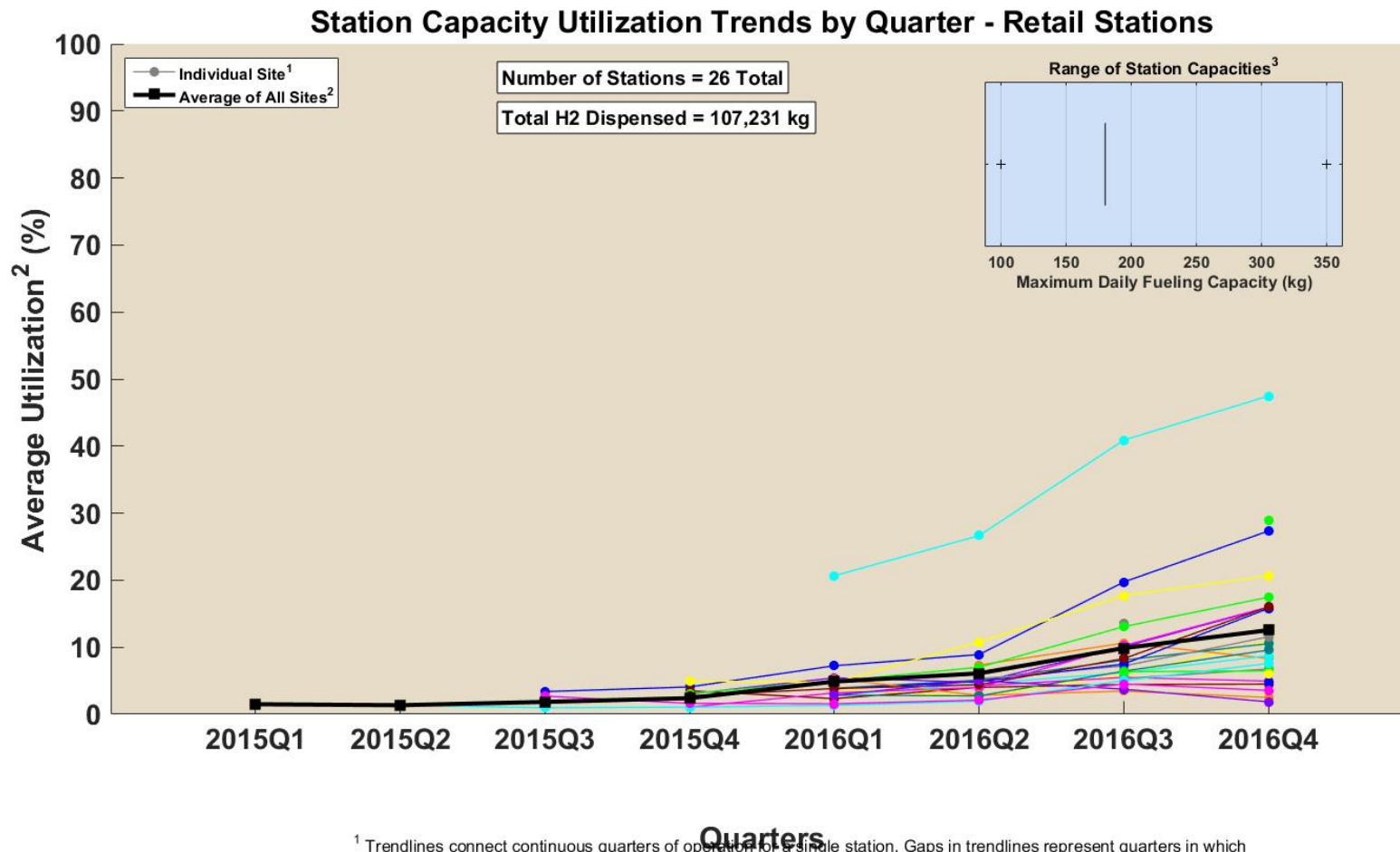


NREL cdpRETAIL_infr_19

Created: May-08-17 3:51 PM | Data Range: 2014Q3-2016Q4



 NREL cdpRETAIL_infr_20
Created: May-08-17 3:51 PM | Data Range: 2014Q3-2016Q4

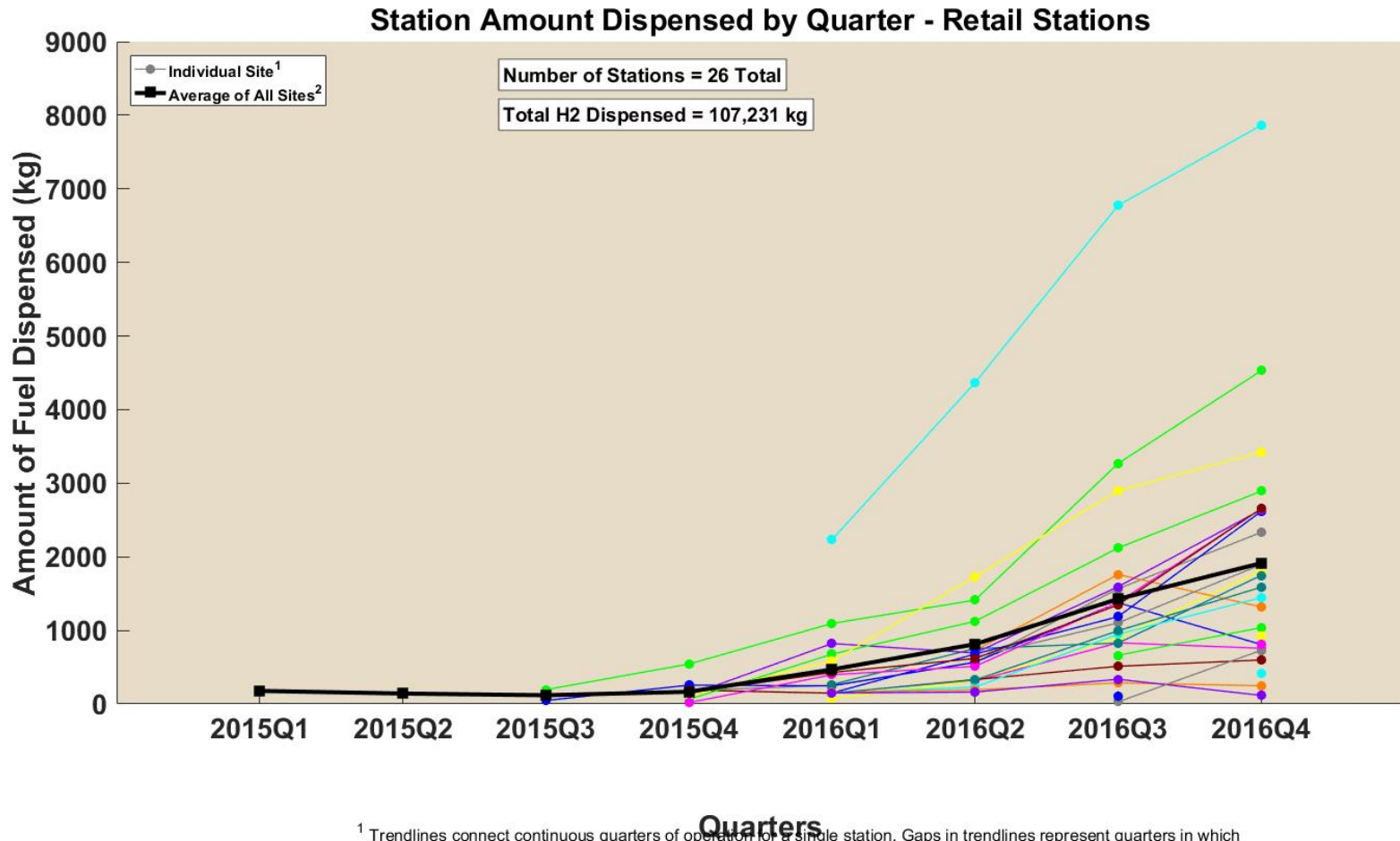


¹ Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

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



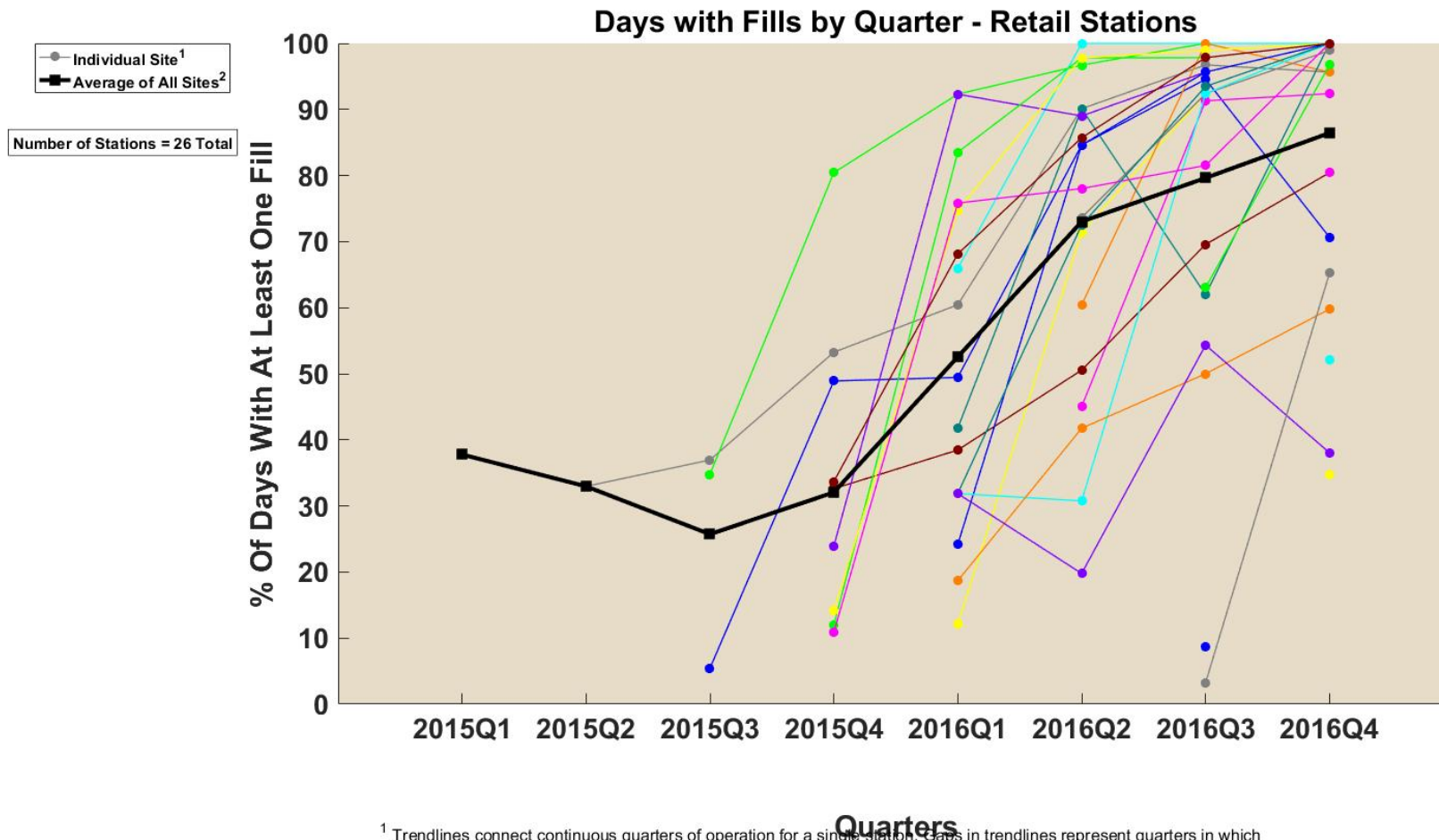
¹ Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

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



NREL cdpRETAIL_infr_45

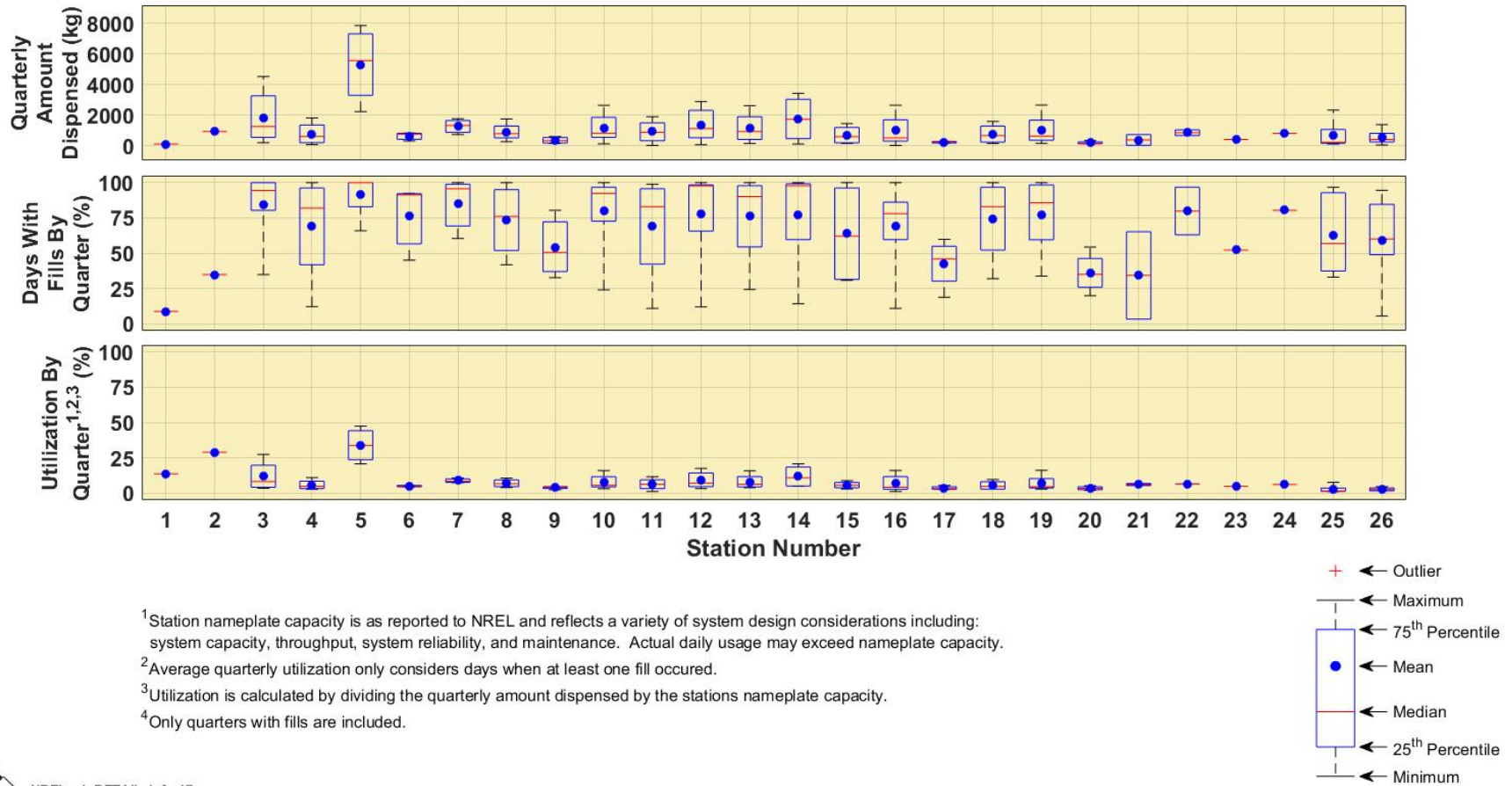
Created: May-08-17 3:53 PM | Data Range: 2014Q3-2016Q4



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 Statistics - Retail Stations⁴



¹ 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.

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

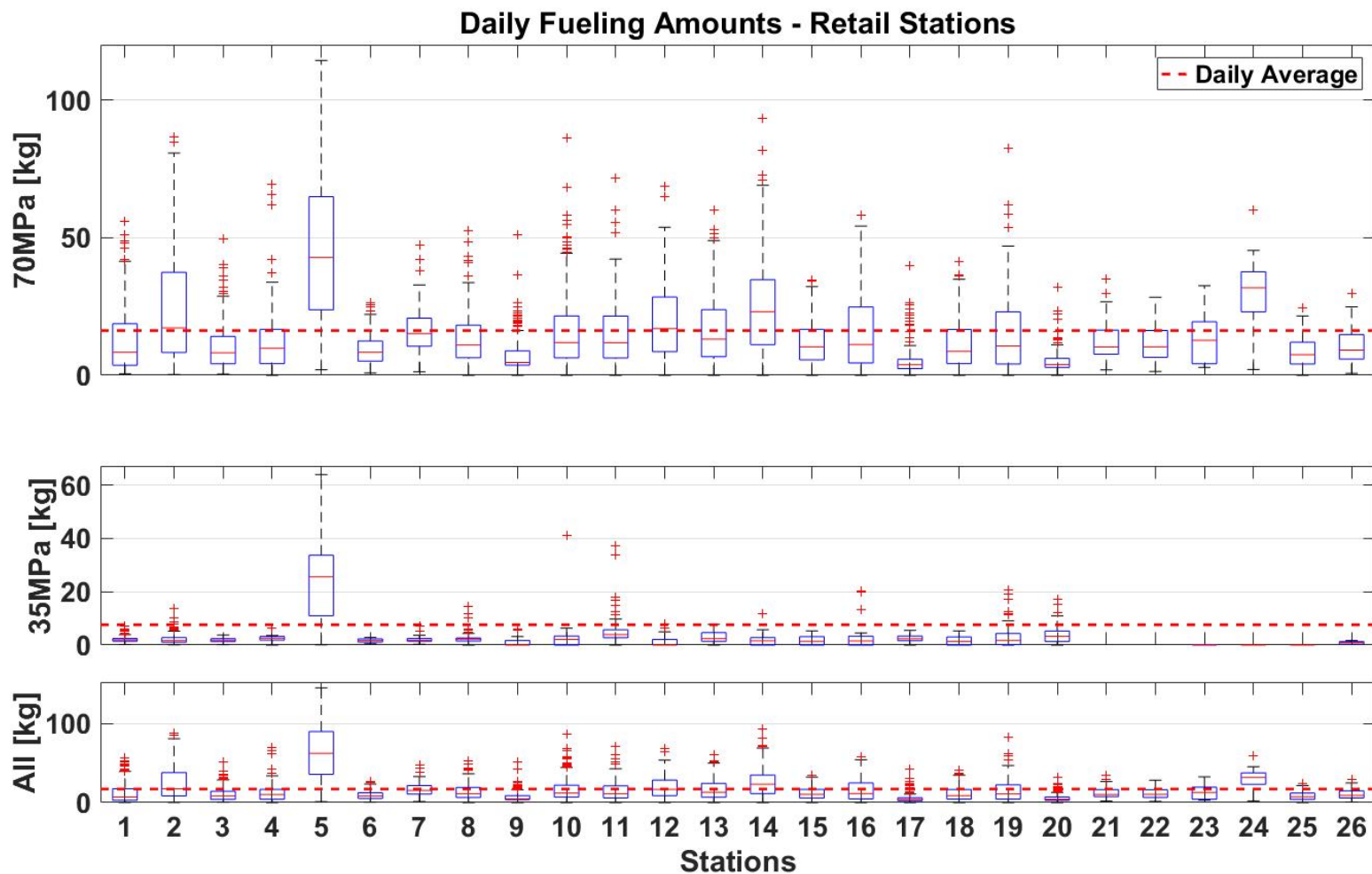
³ Utilization is calculated by dividing the quarterly amount dispensed by the stations nameplate capacity.

⁴ Only quarters with fills are included.



CDP-INFR-80

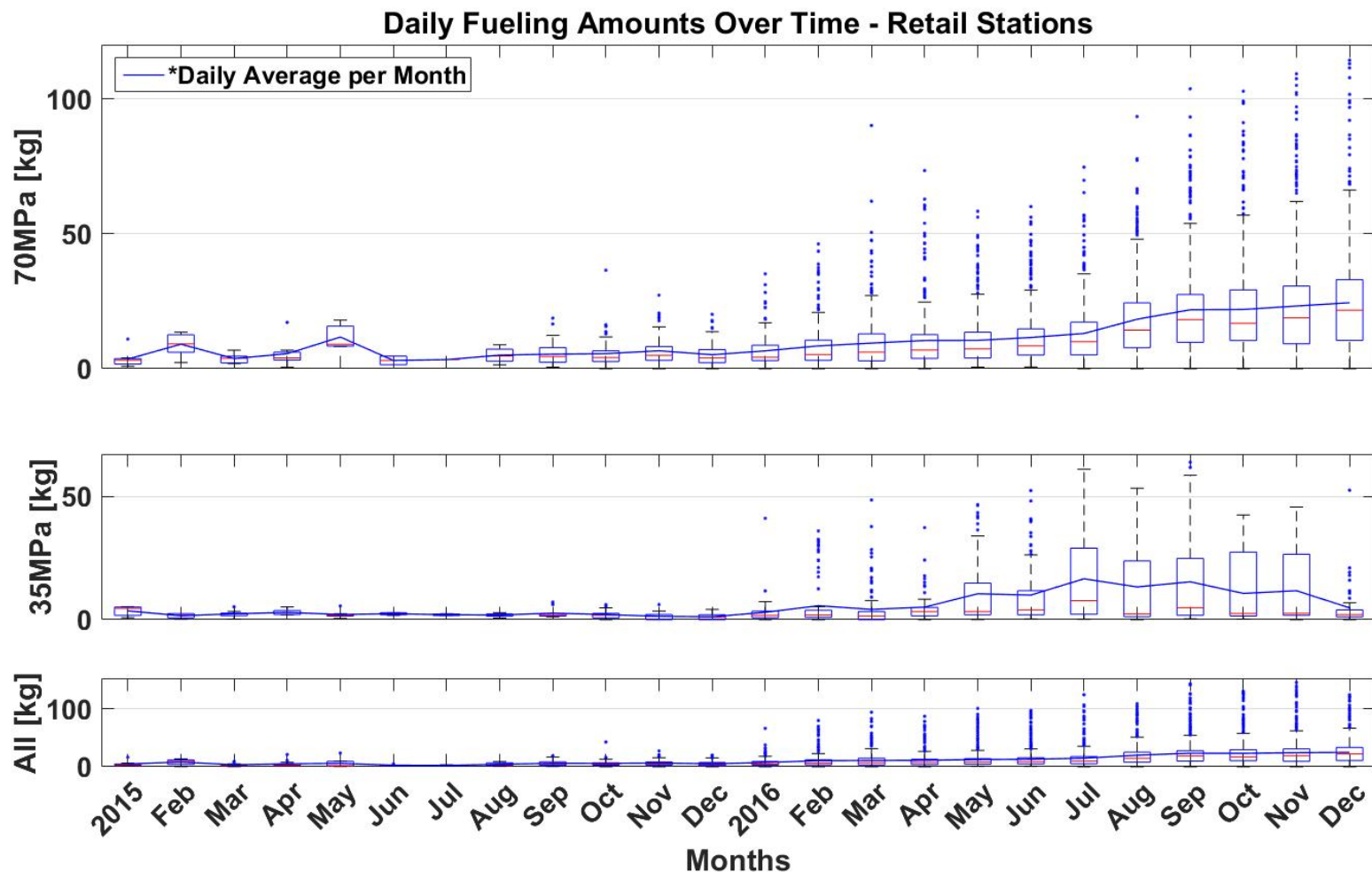
Daily Fueling Amounts by Station



NREL cdpRETAIL_infr_80

Created: May-08-17 4:01 PM | Data Range: 2014Q3-2016Q4

Daily Fueling Amounts by Month



NREL cdpRETAIL_infr_82

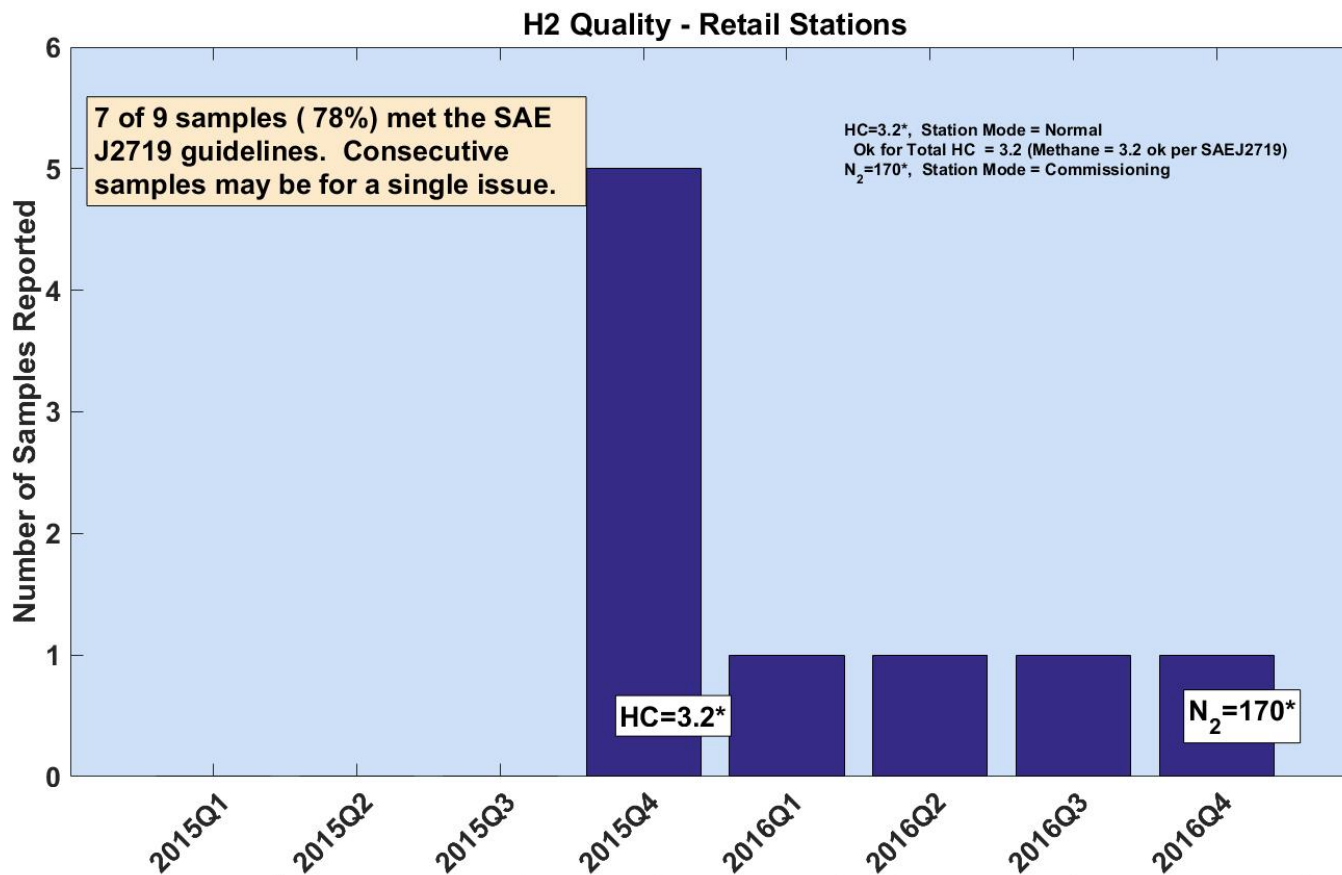
Created: May-08-17 9:12 AM | Data Range: 2014Q3-2016Q4

*Daily average only includes days with fills.

Hydrogen Quality

CDP-INFR-25

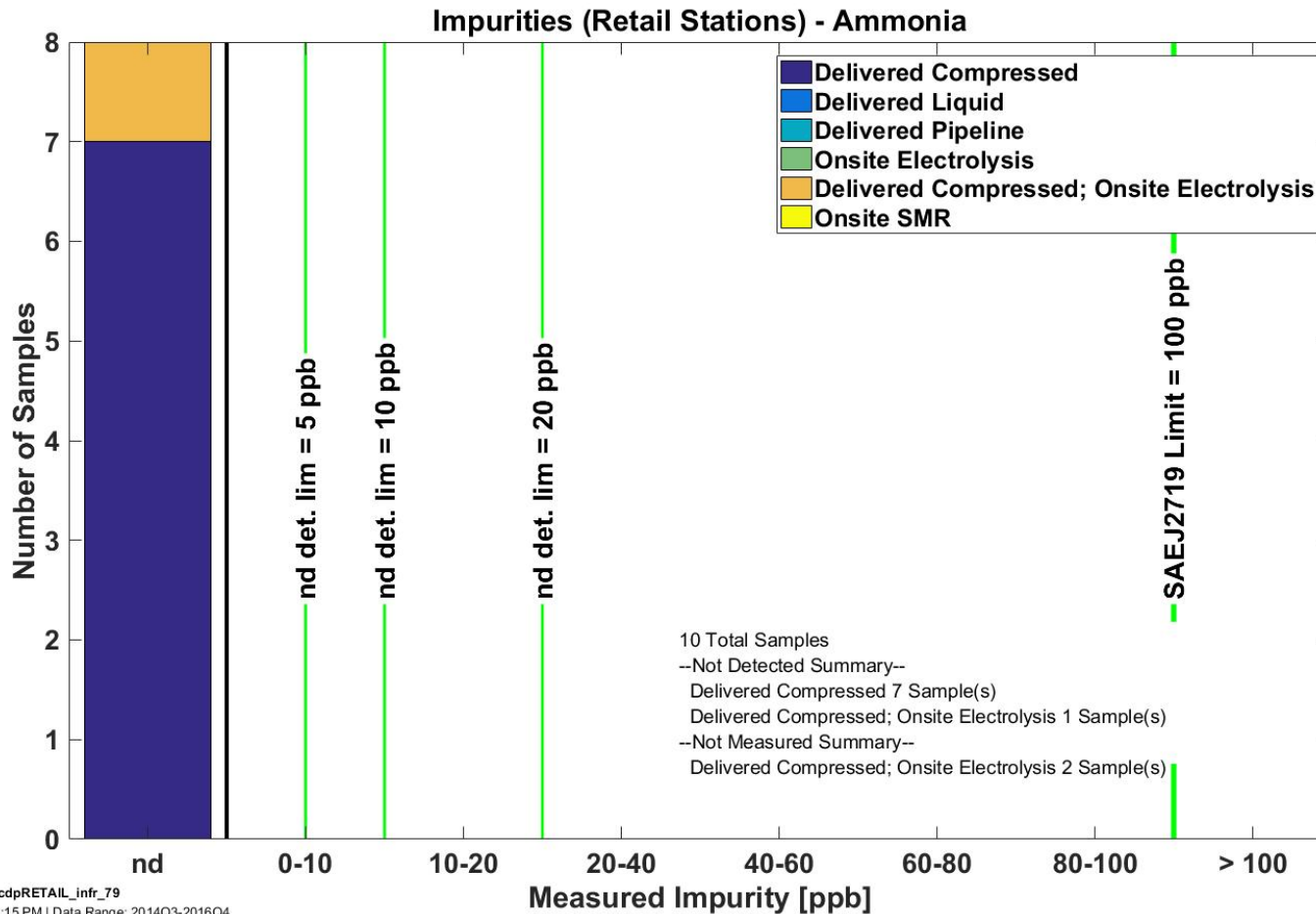
Hydrogen Quality



NREL cdpRETAIL_infr_25

Created: May-08-17 9:04 AM | Data Range: 2014Q3-2016Q4

* 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 sample date.

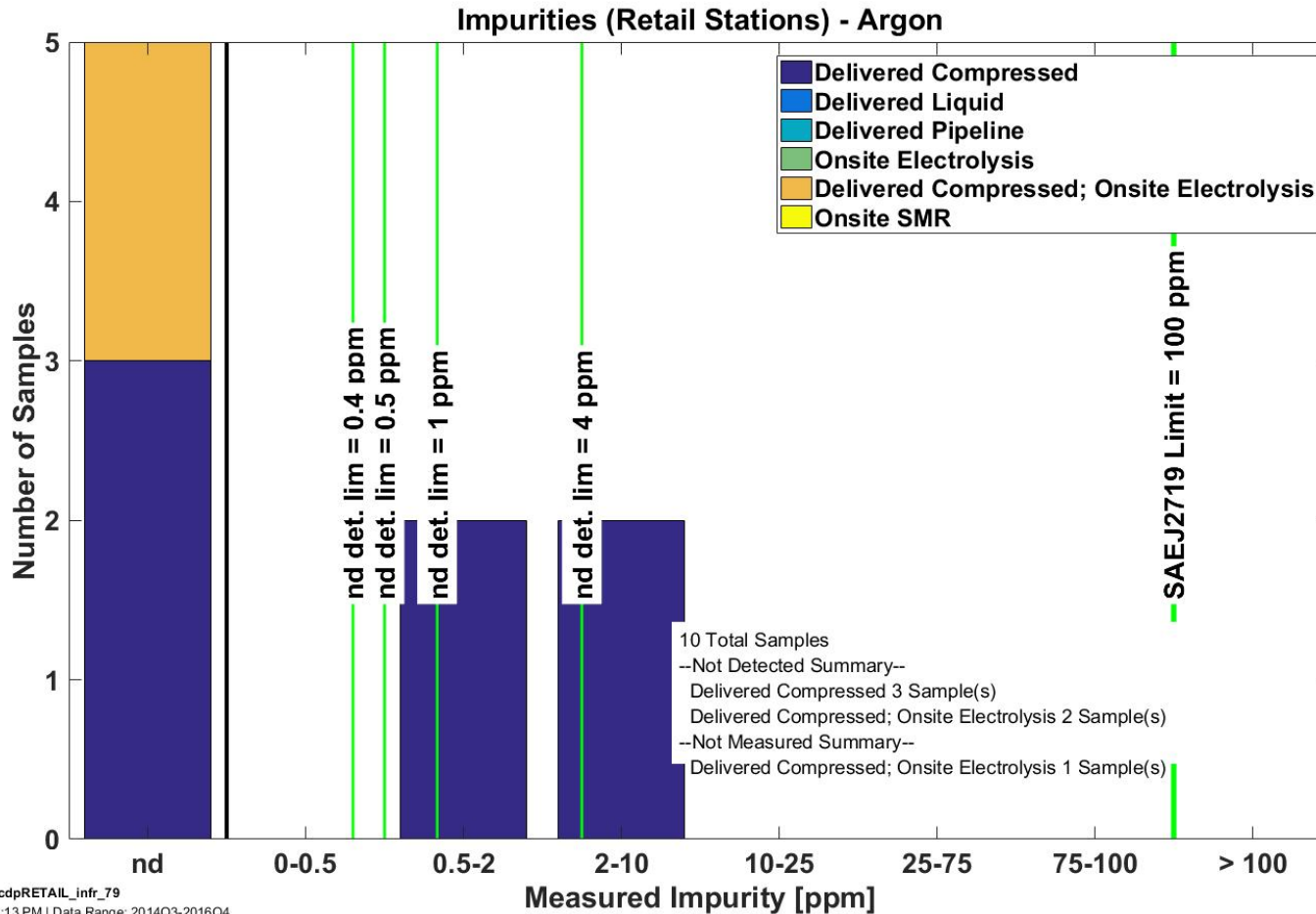


NREL cdpRETAIL_infr_79

Created: May-08-17 12:15 PM | Data Range: 2014Q3-2016Q4

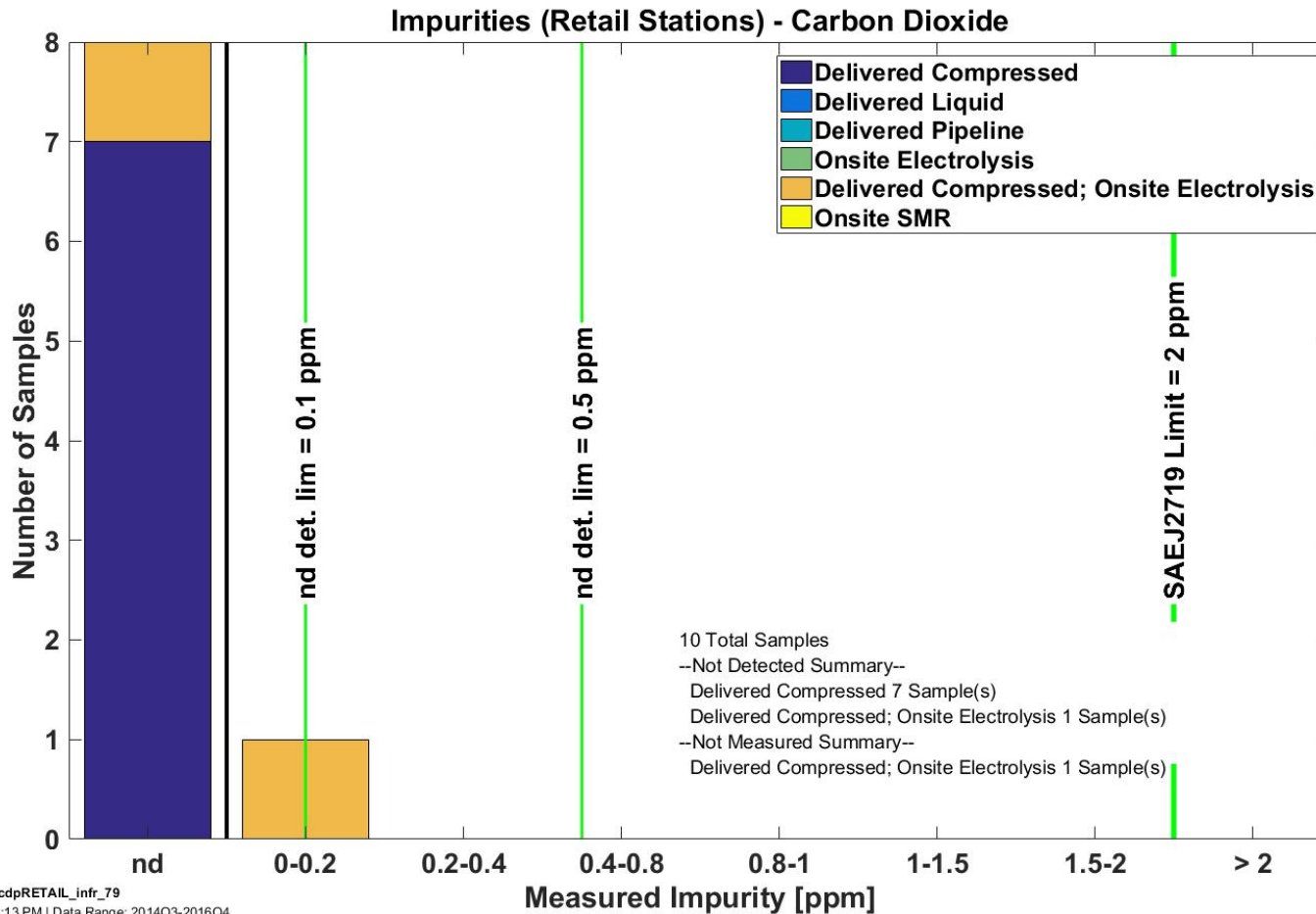
CDP-INFR-79

Impurities—Argon



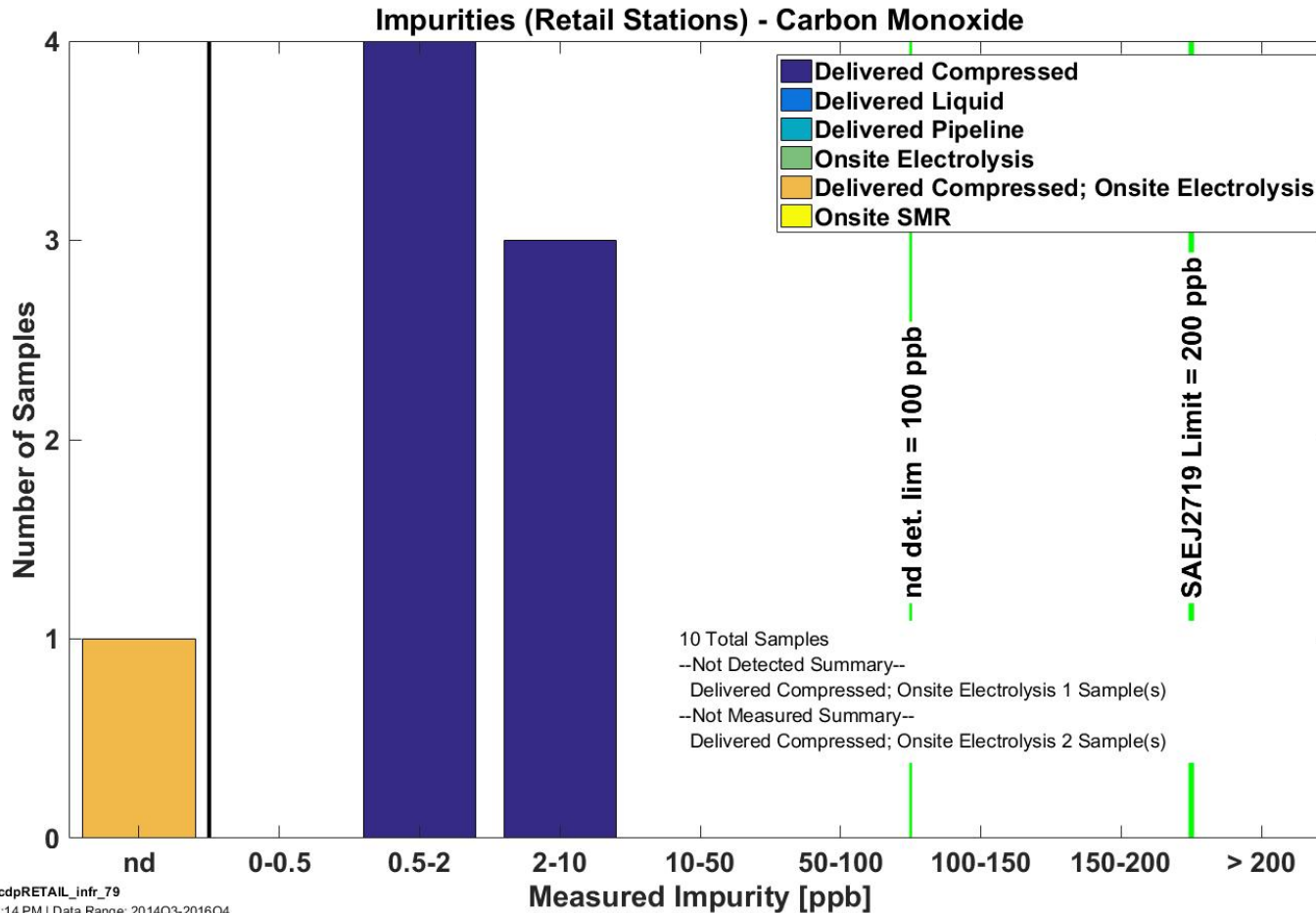
NREL cdpRETAIL_infr_79

Created: May-08-17 12:13 PM | Data Range: 2014Q3-2016Q4



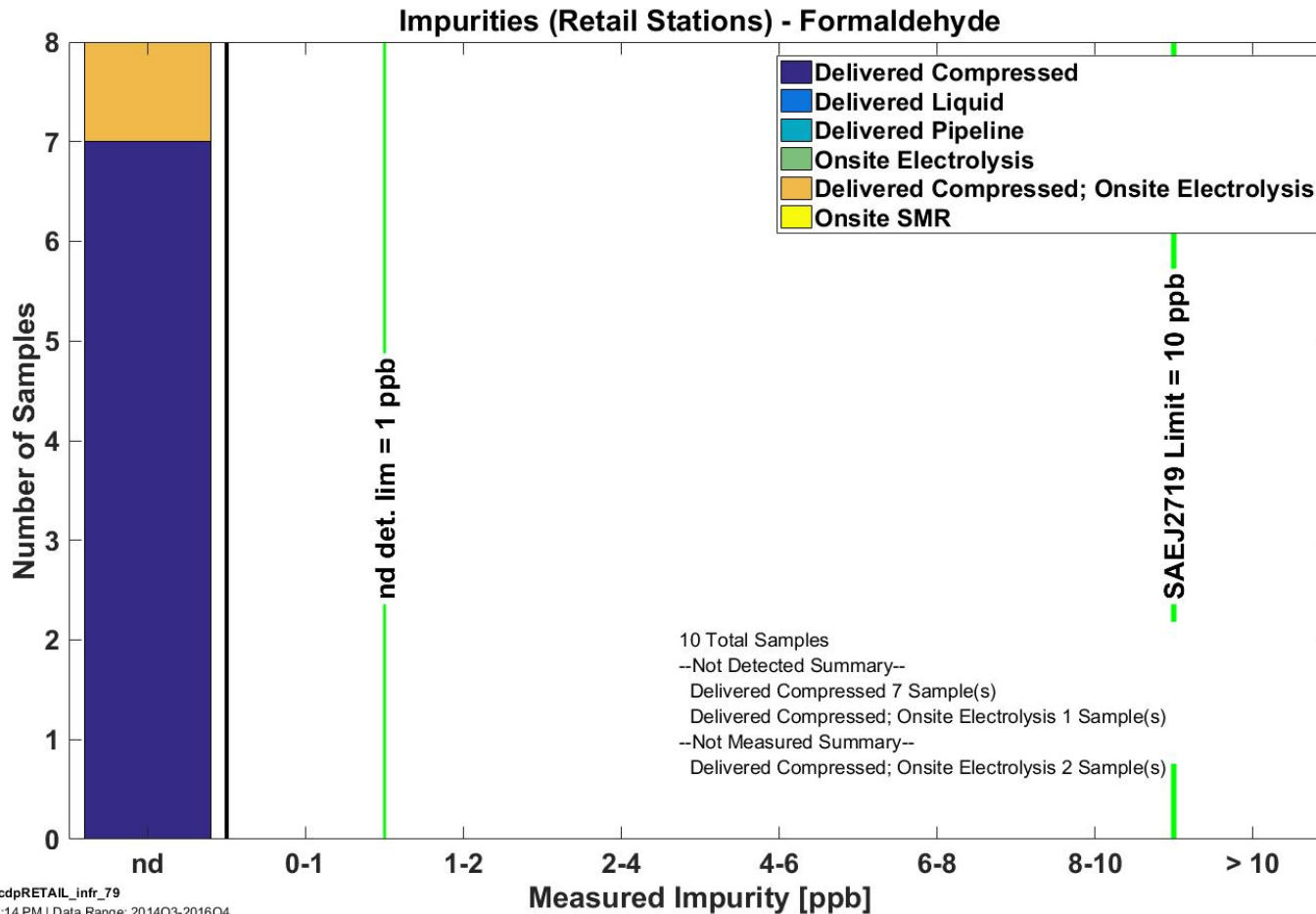
NREL cdpRETAIL_infr_79

Created: May-08-17 12:13 PM | Data Range: 2014Q3-2016Q4



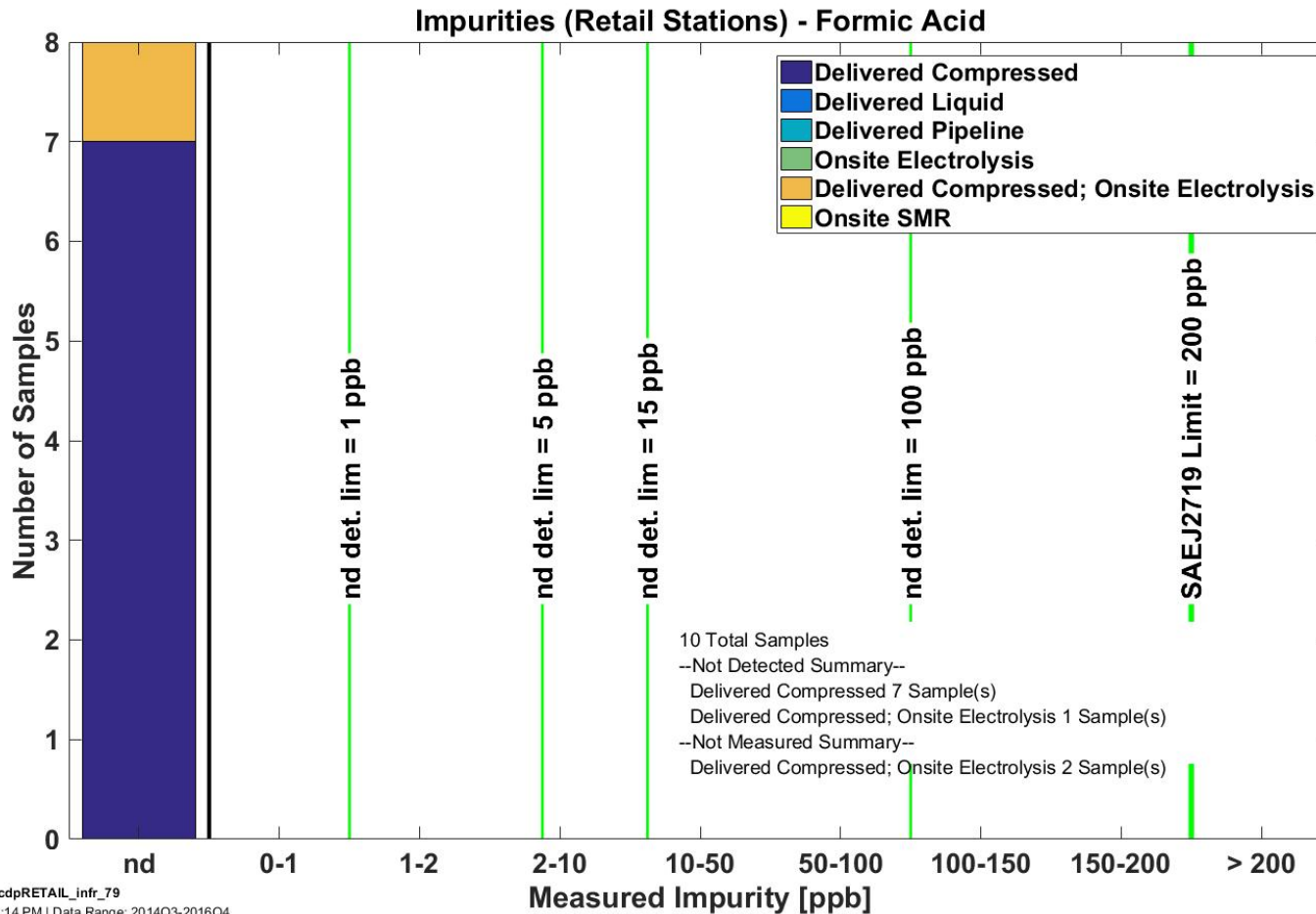
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Created: May-08-17 12:14 PM | Data Range: 2014Q3-2016Q4



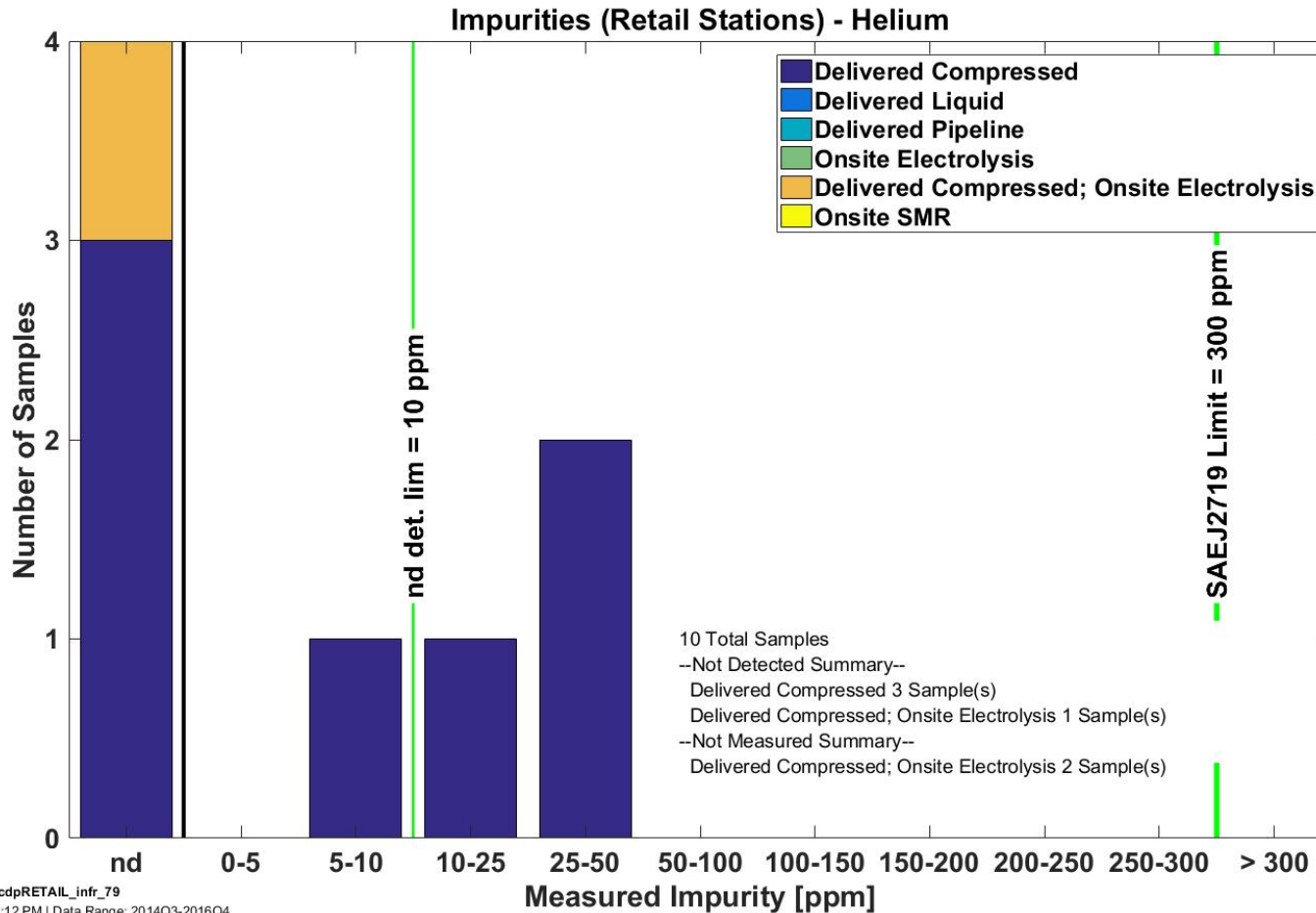
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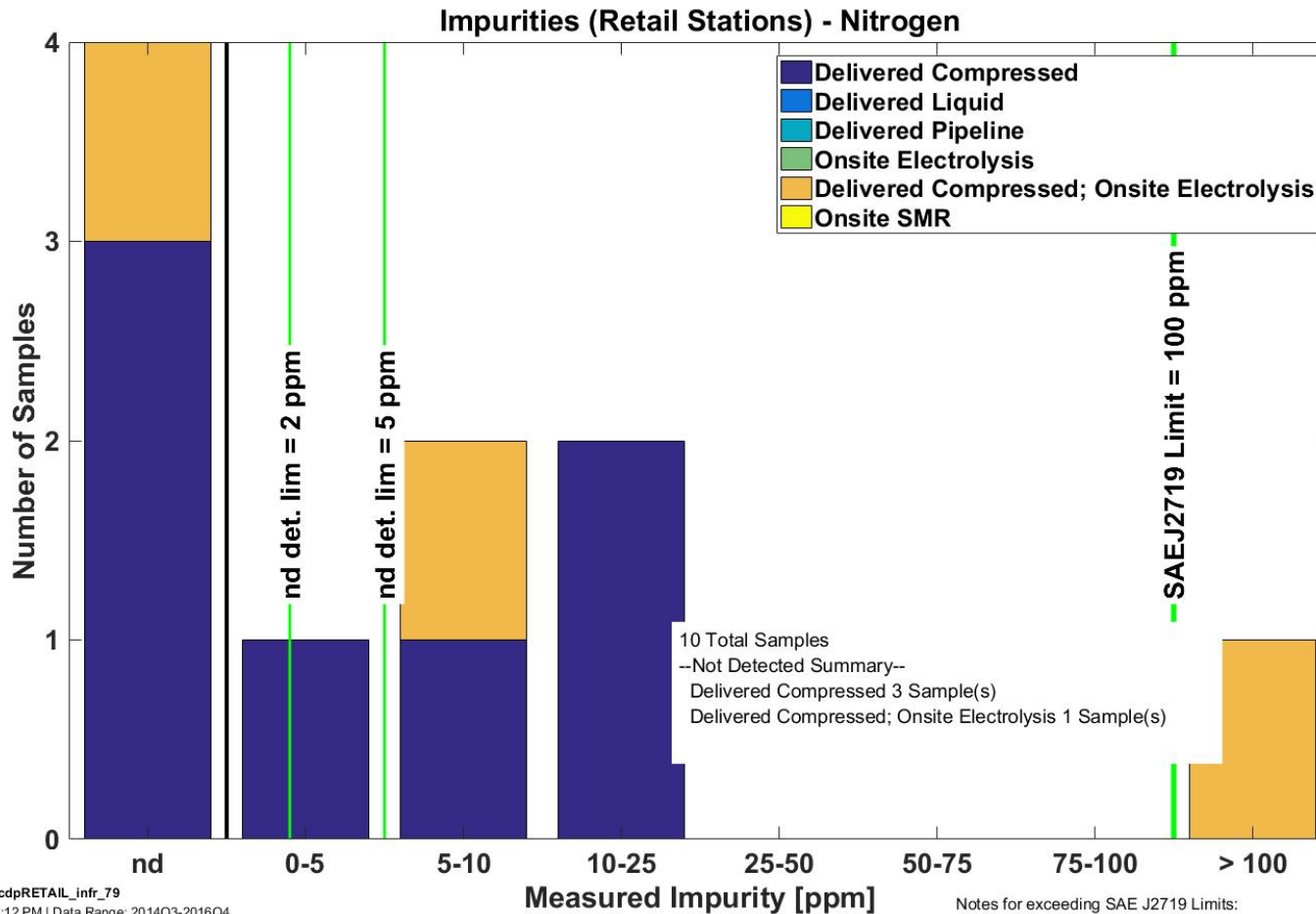
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Created: May-08-17 12:14 PM | Data Range: 2014Q3-2016Q4



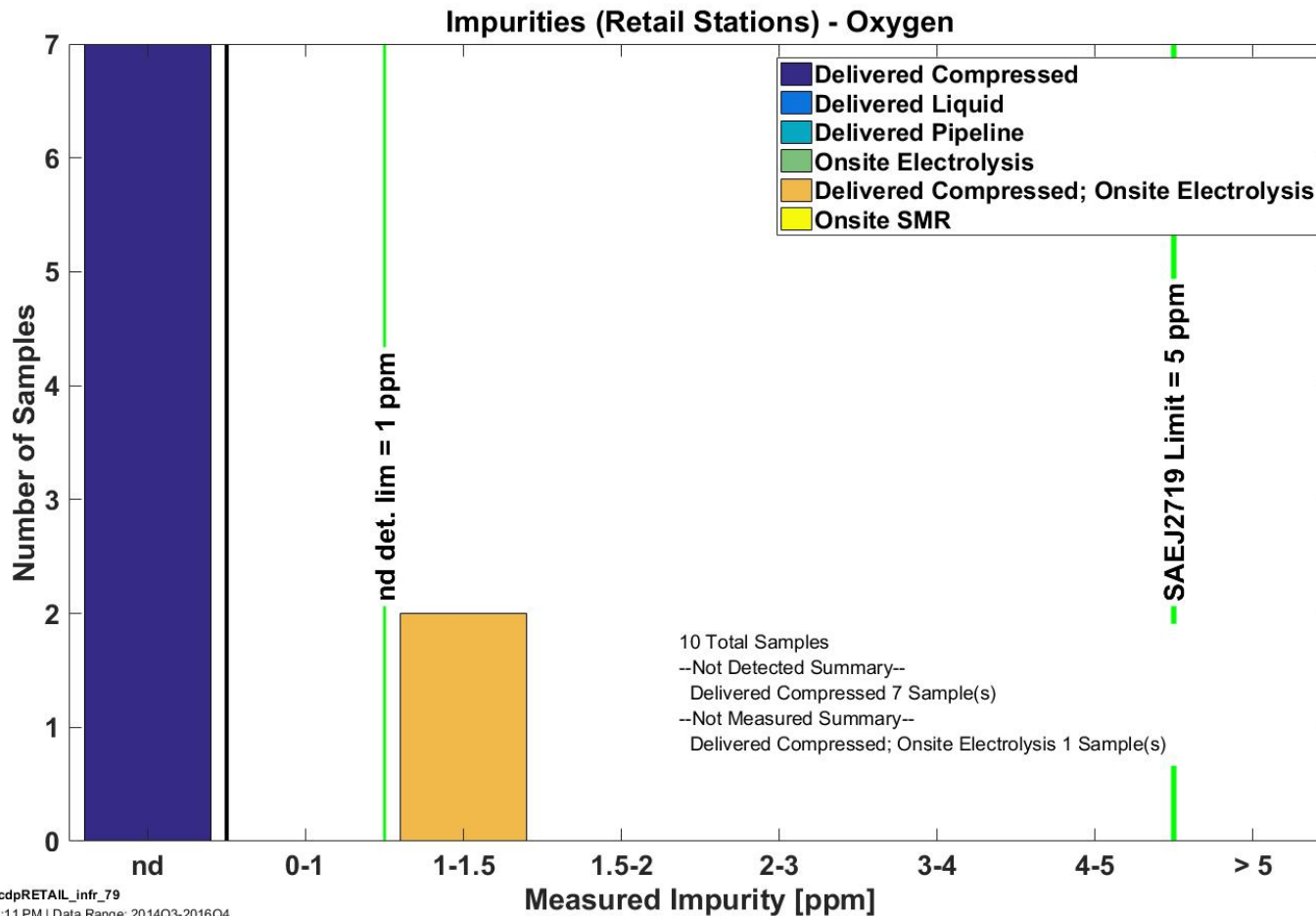
NREL cdpRETAIL_infr_79

Created: May-08-17 12:12 PM | Data Range: 2014Q3-2016Q4



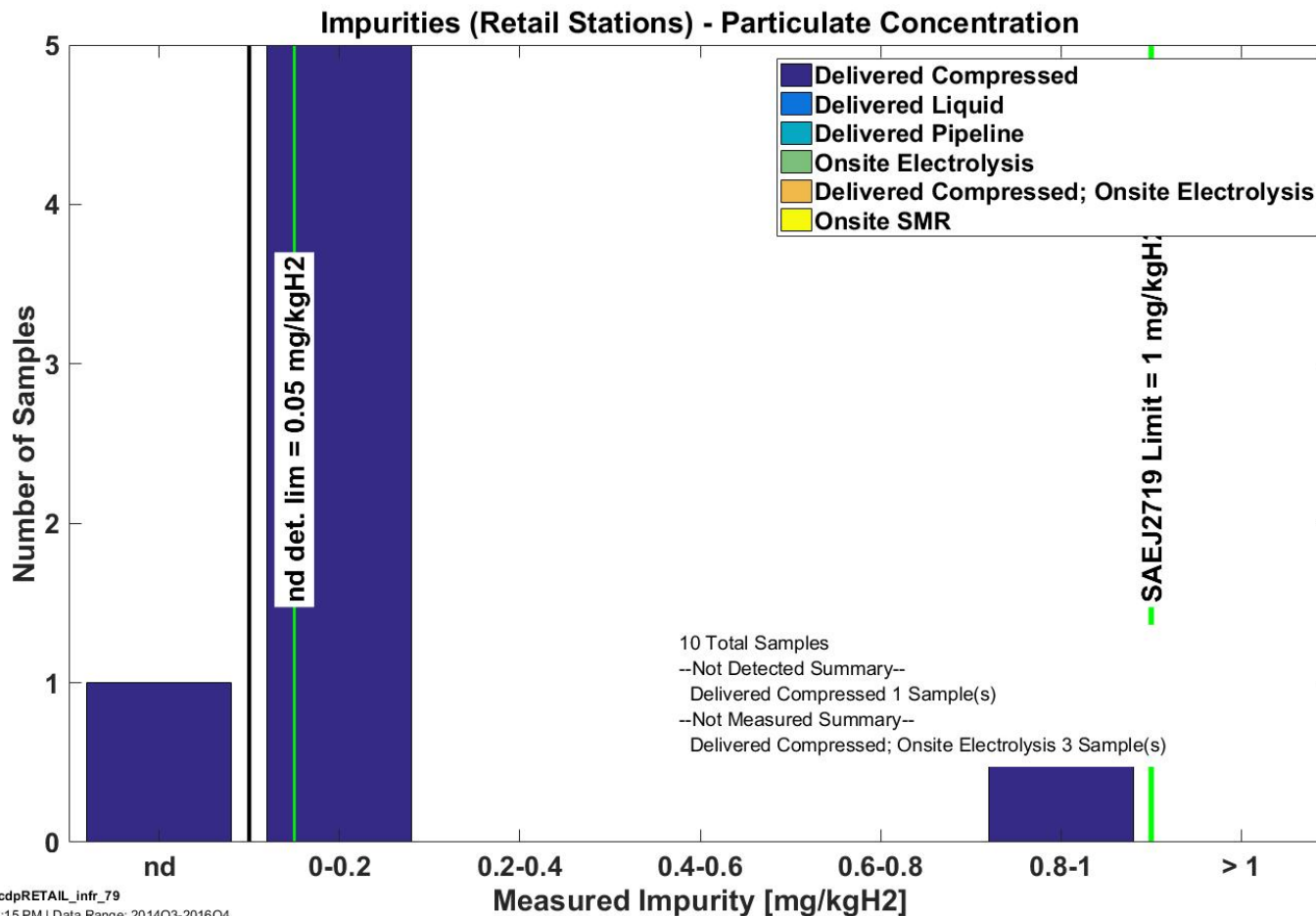
NREL cdpRETAIL_infr_79

Created: May-08-17 12:12 PM | Data Range: 2014Q3-2016Q4



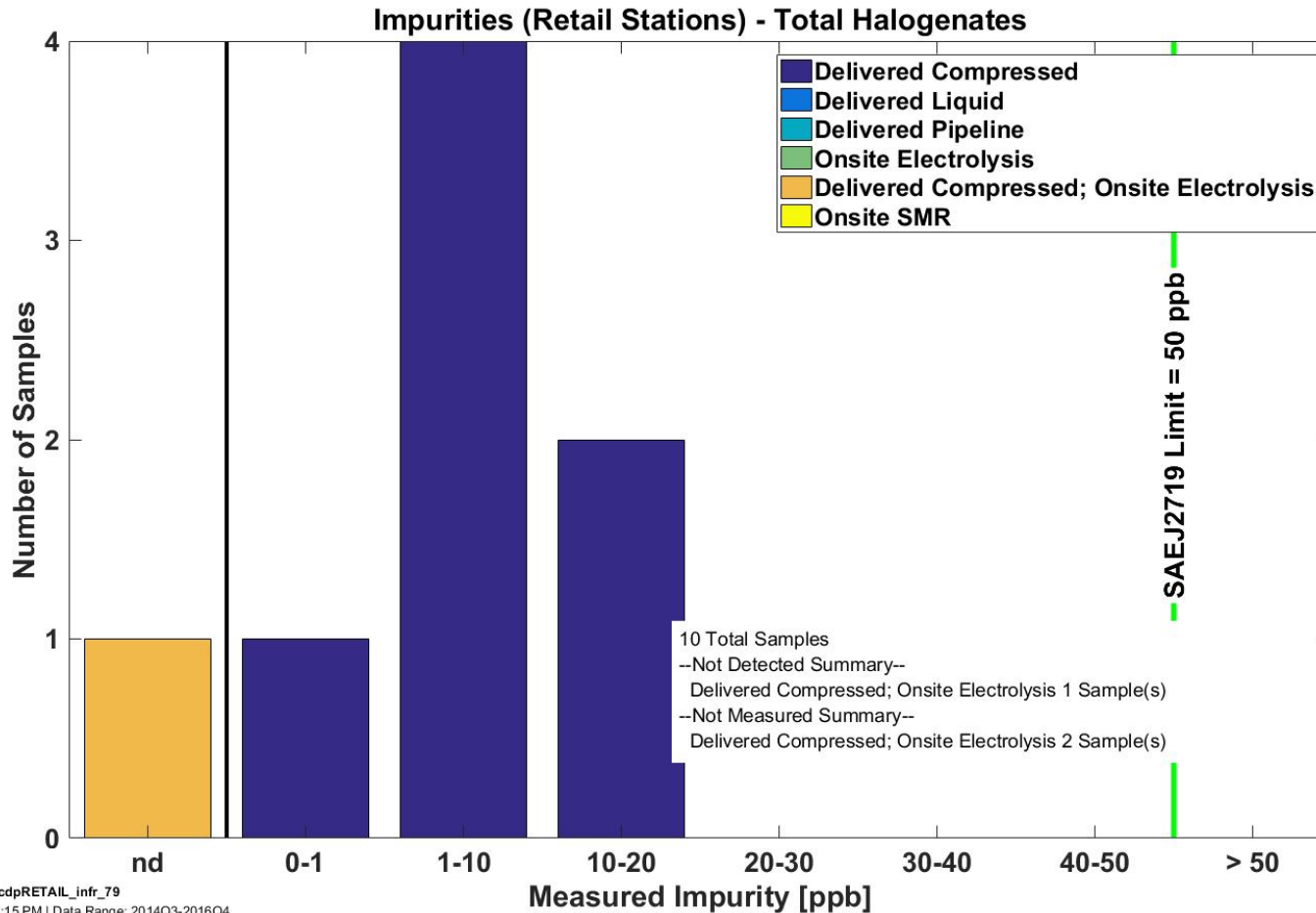
NREL cdpRETAIL_infr_79

Created: May-08-17 12:11 PM | Data Range: 2014Q3-2016Q4



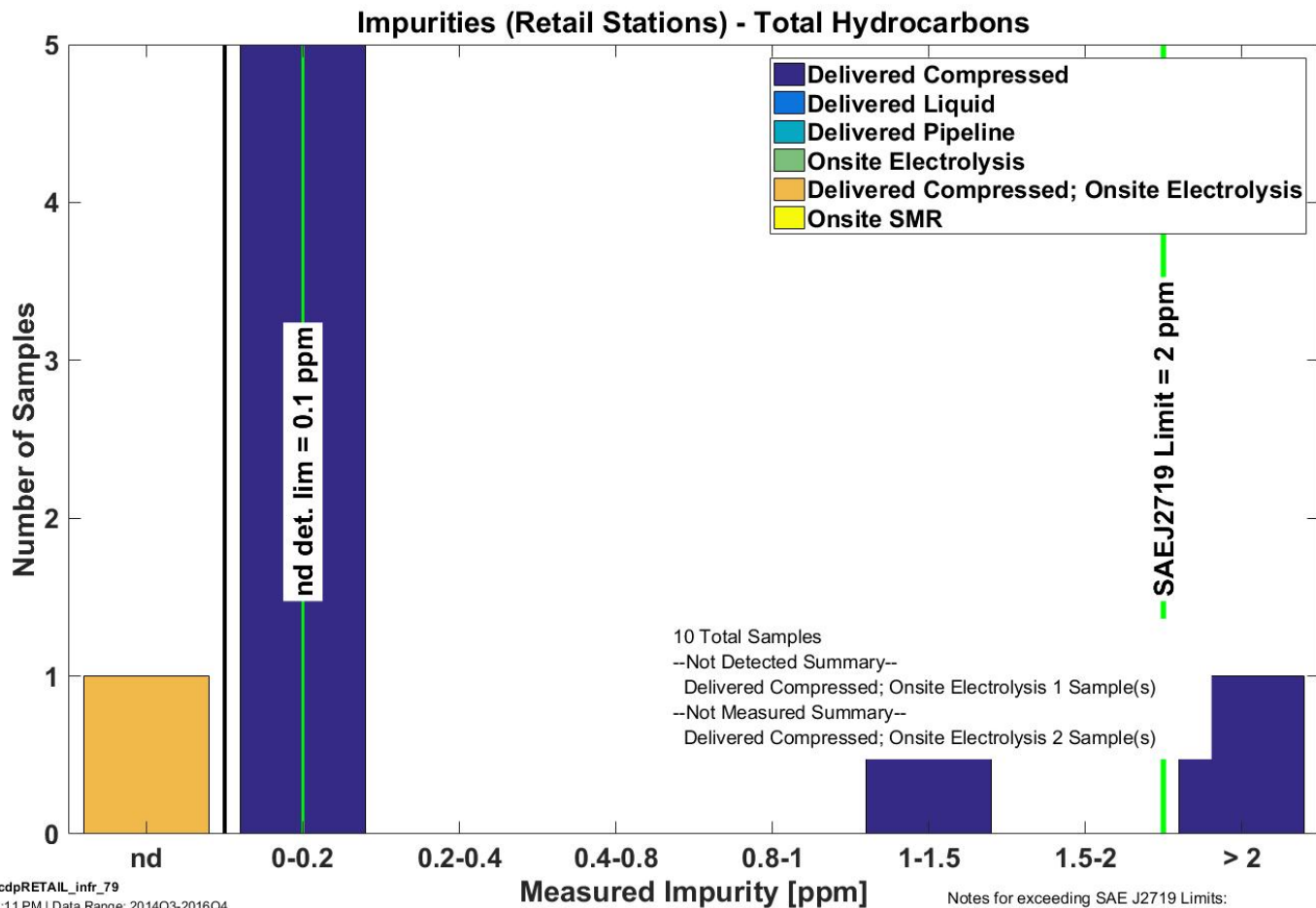
NREL cdpRETAIL_infr_79

Created: May-08-17 12:15 PM | Data Range: 2014Q3-2016Q4



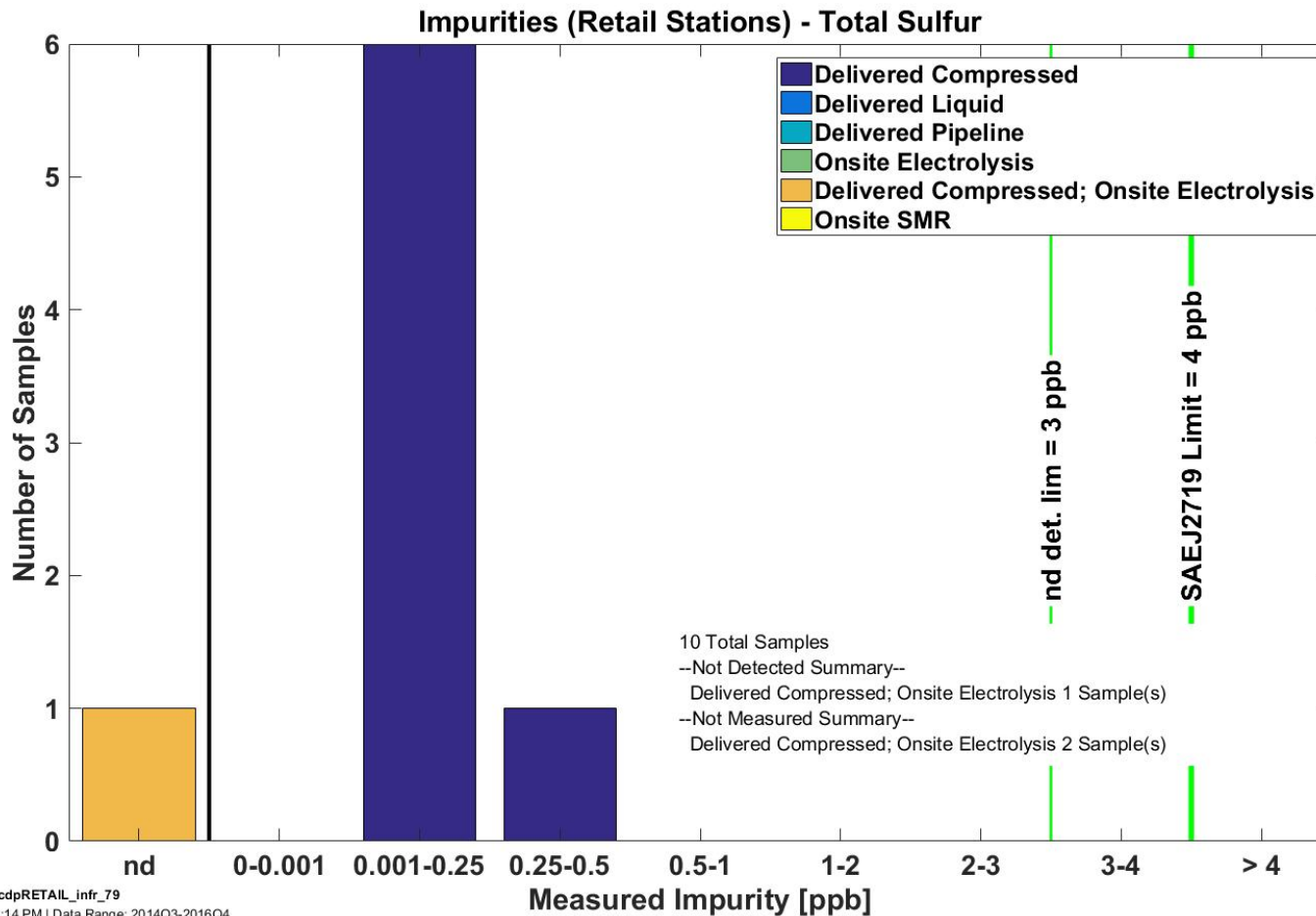
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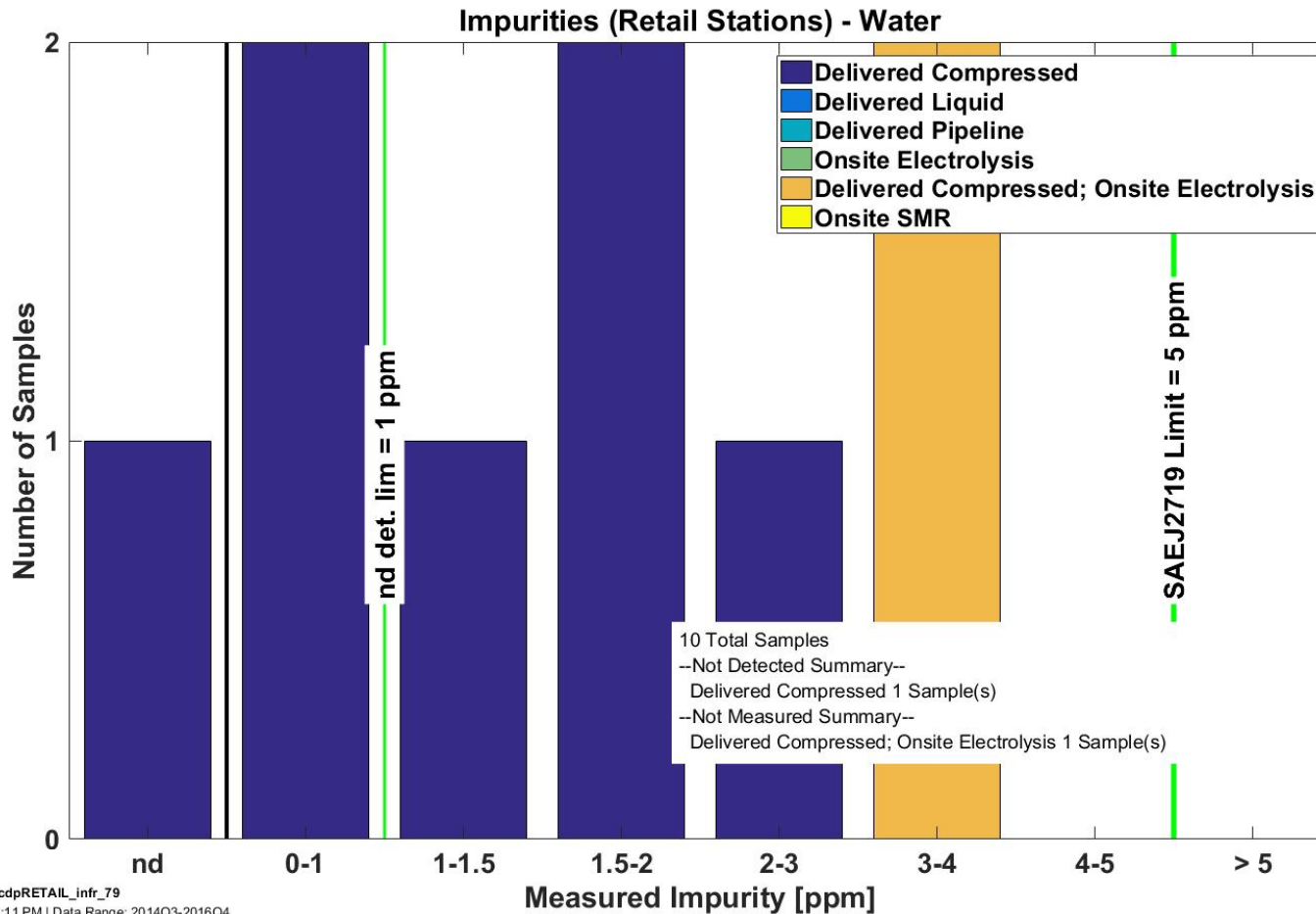
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Created: May-08-17 12:11 PM | Data Range: 2014Q3-2016Q4



NREL cdpRETAIL_infr_79

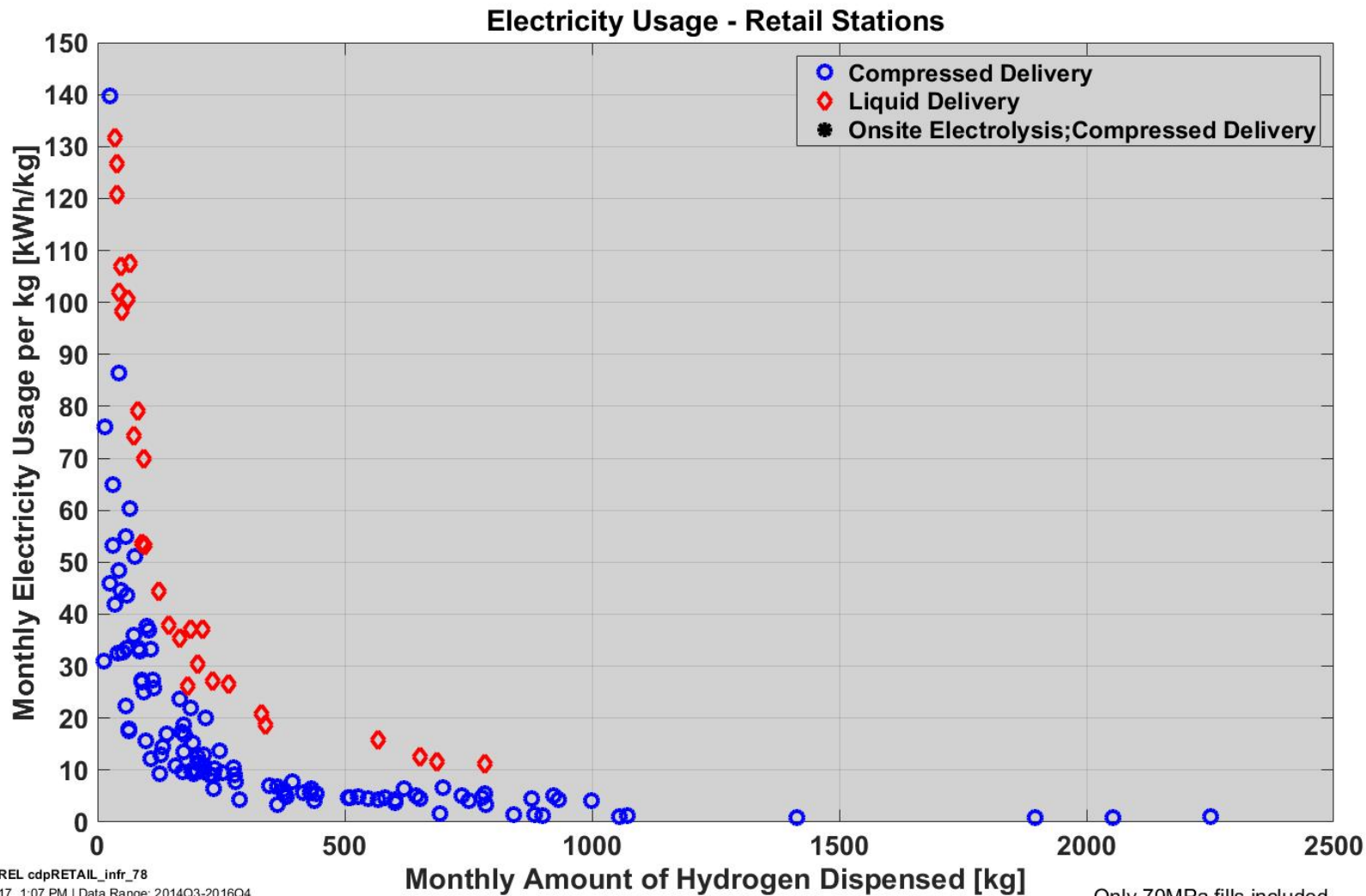
Created: May-08-17 12:14 PM | Data Range: 2014Q3-2016Q4



NREL cdpRETAIL_infr_79

Created: May-08-17 12:11 PM | Data Range: 2014Q3-2016Q4

Component Energy



NREL cdpRETAIL_infr_78

Created: May-08-17 1:07 PM | Data Range: 2014Q3-2016Q4