



Next Generation Hydrogen Station Composite Data Products: Retail Stations Data through Quarter 3 of 2016

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January 20, 2017

NREL/PR-5400-68013

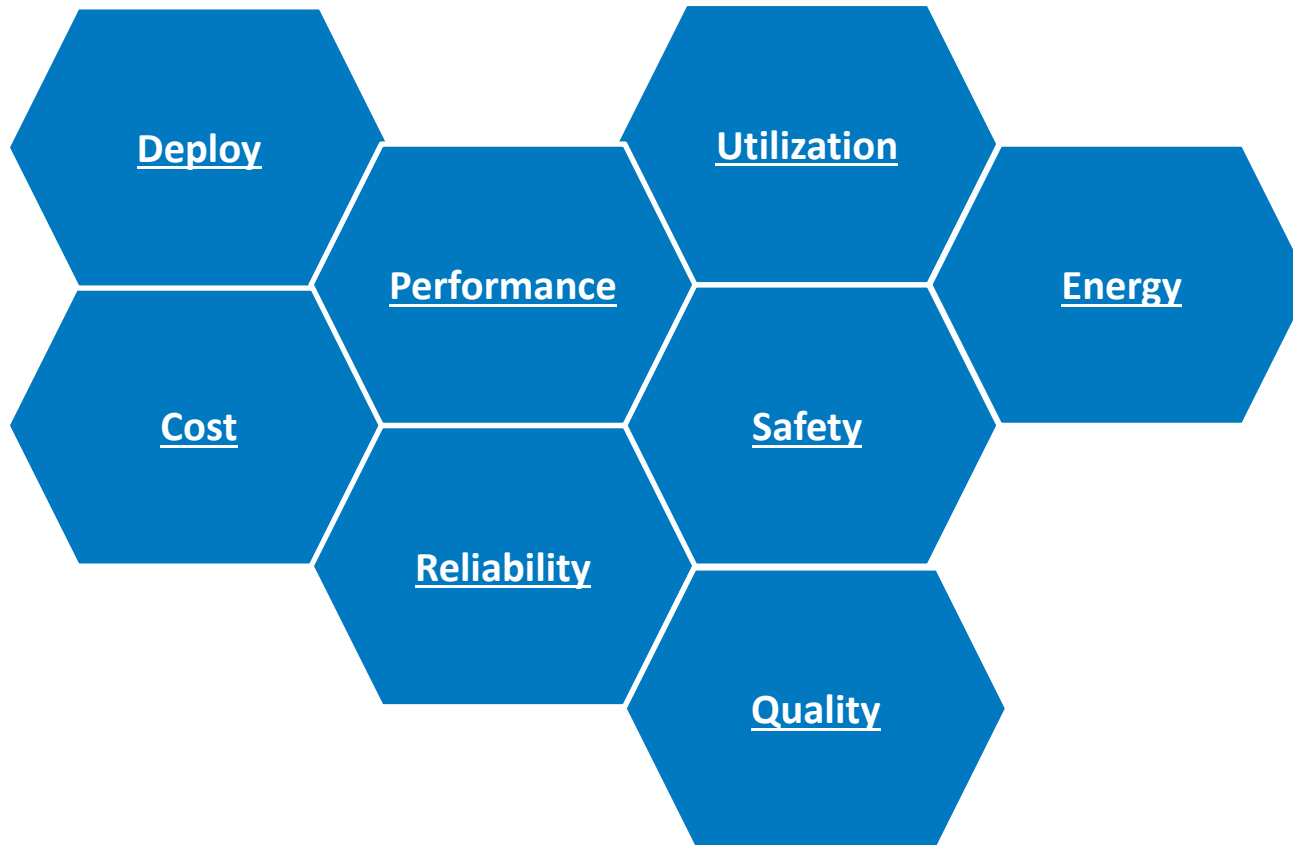
Hydrogen Station Project Partners



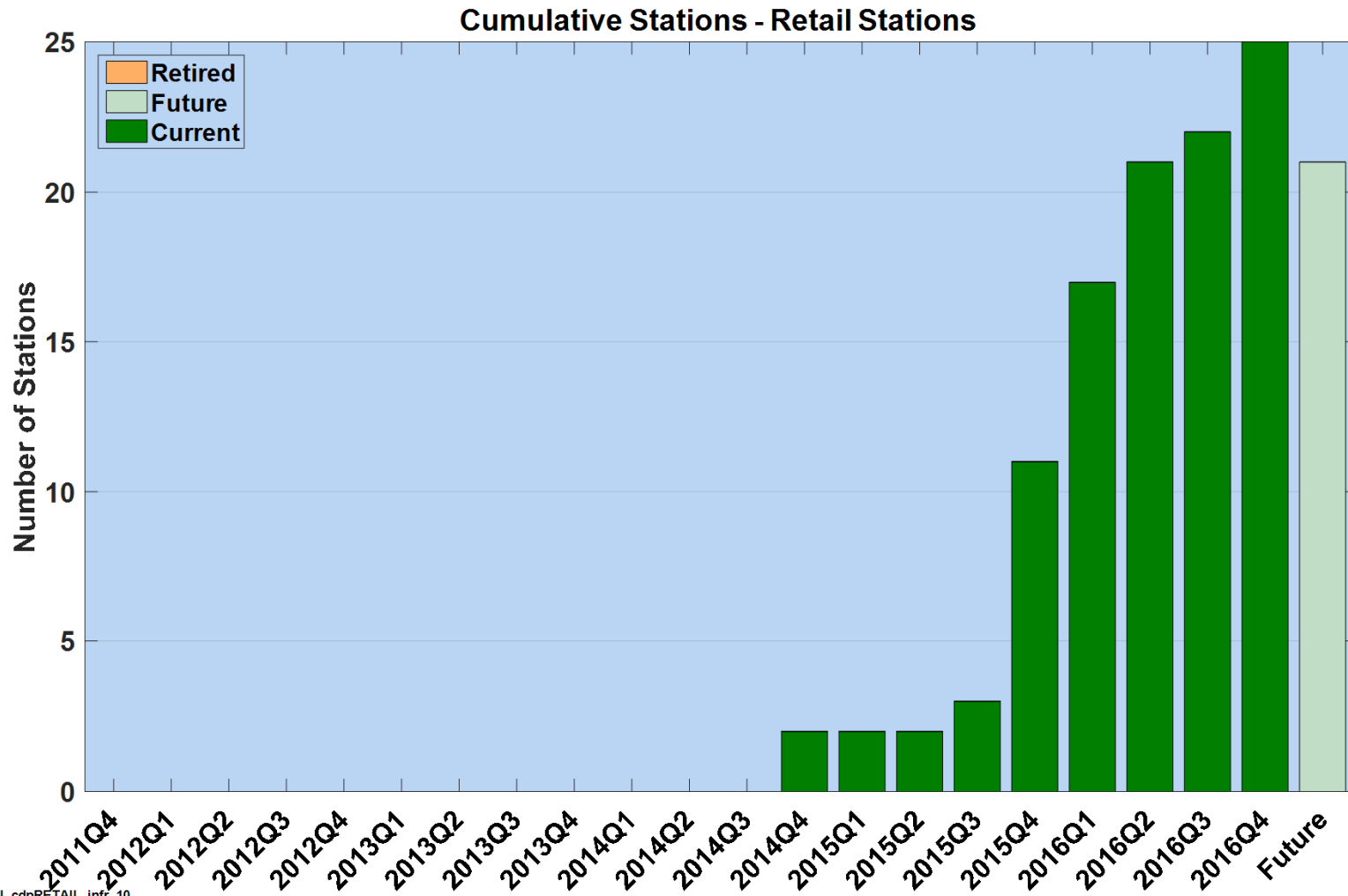
- Air Liquide
- Air Products
- California Air Resources Board
- California Energy Commission
- California State University Los Angeles
- First Element
- Gas Technology Institute
- Linde
- H2 Frontier
- Proton OnSite
- Shell
- IPHE and HySUT



Analysis Categories



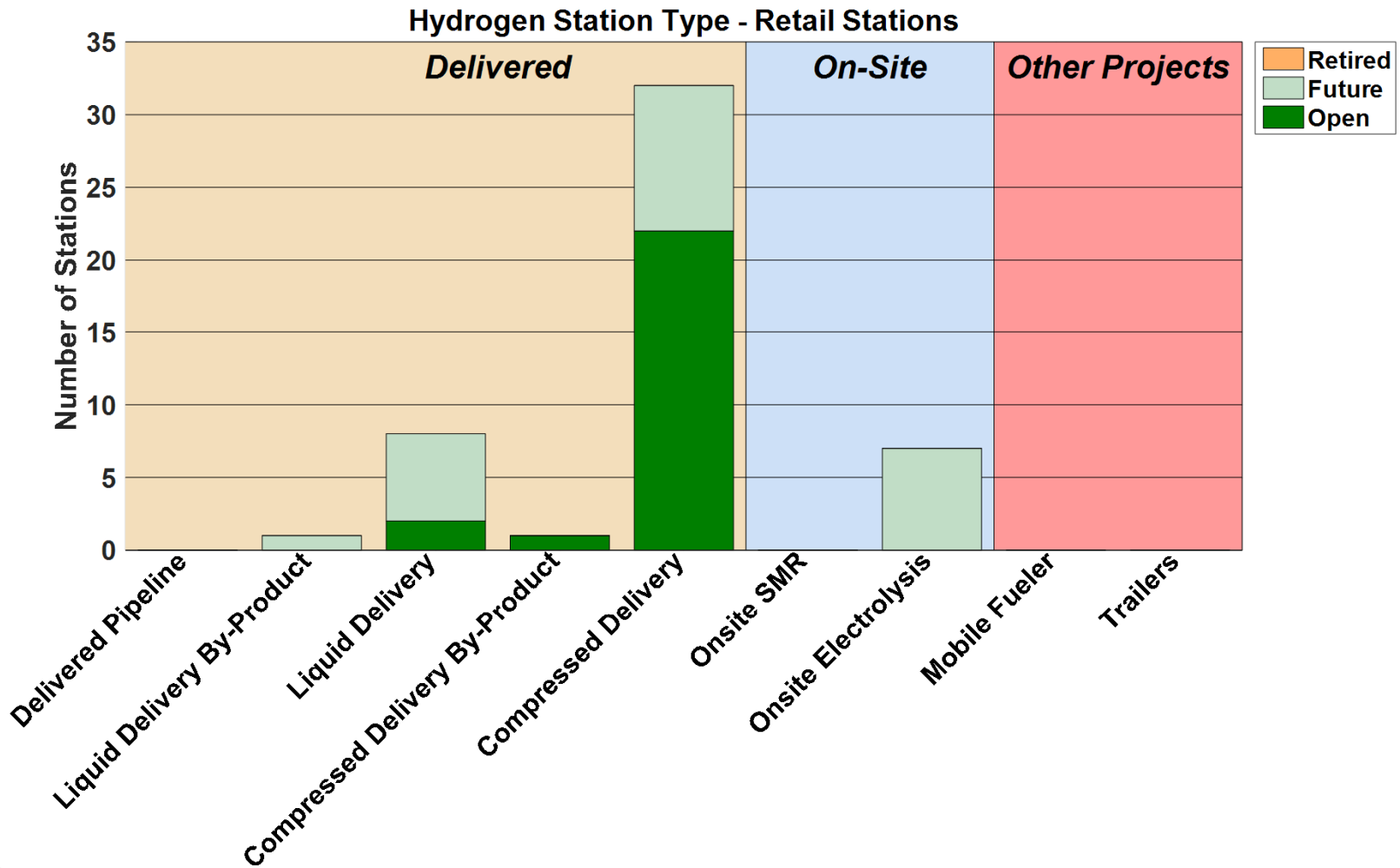
Deployment

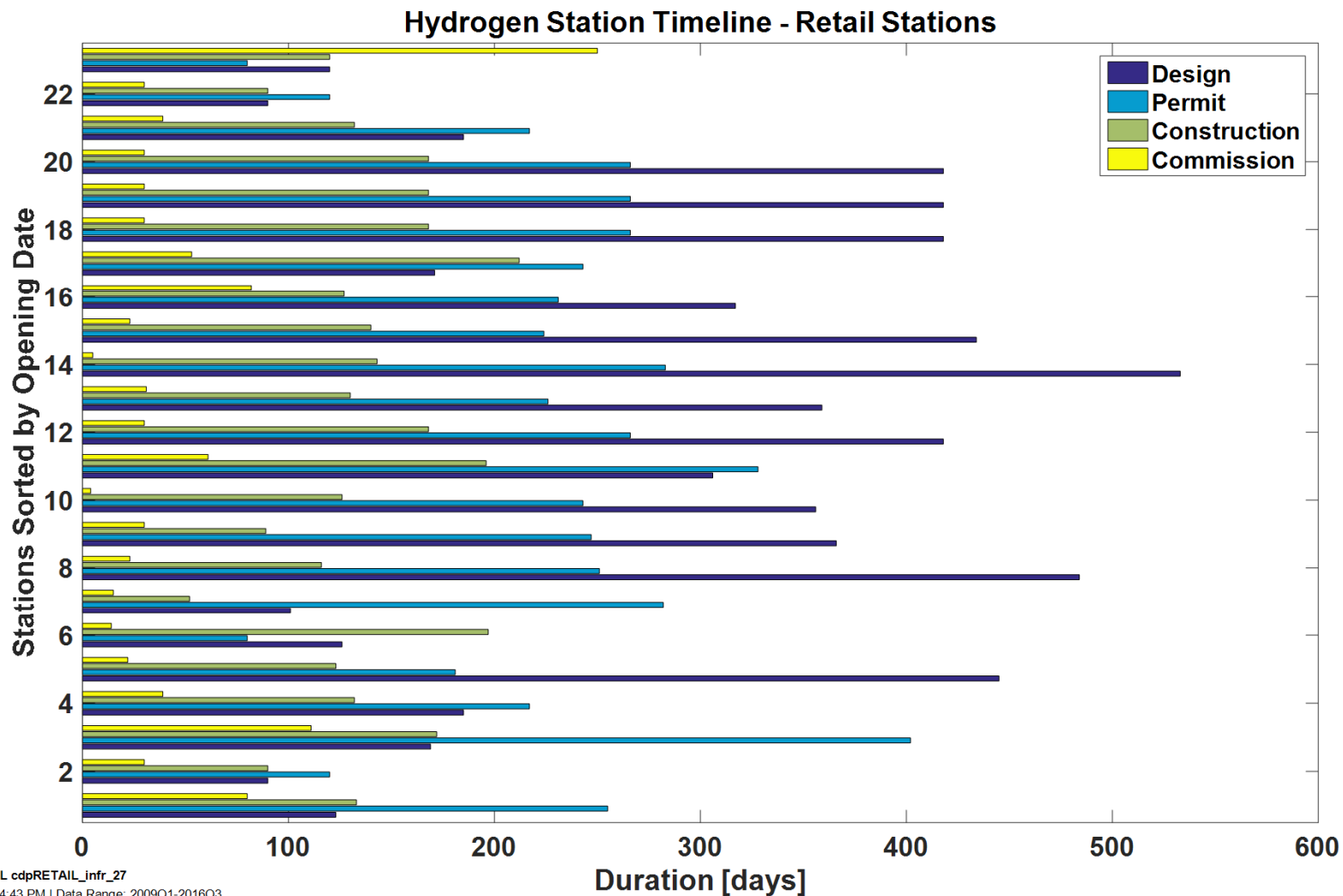


NREL cdpRETAIL_infr_10

Created: Dec-21-16 8:30 AM | Data Range: 0000Q1-2016Q3

Hydrogen Stations by Type

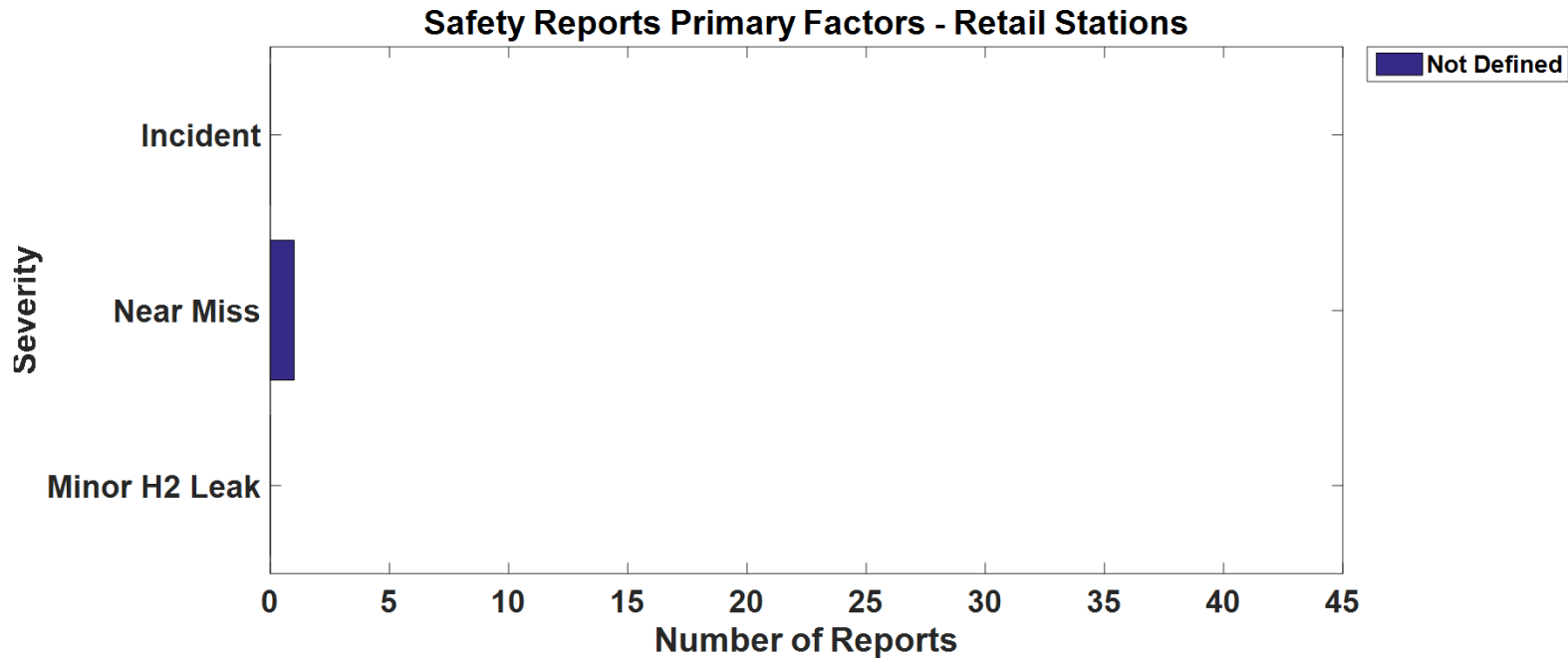




NREL cdpRETAIL_infr_27

Created: Dec-19-16 4:43 PM | Data Range: 2009Q1-2016Q3

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:

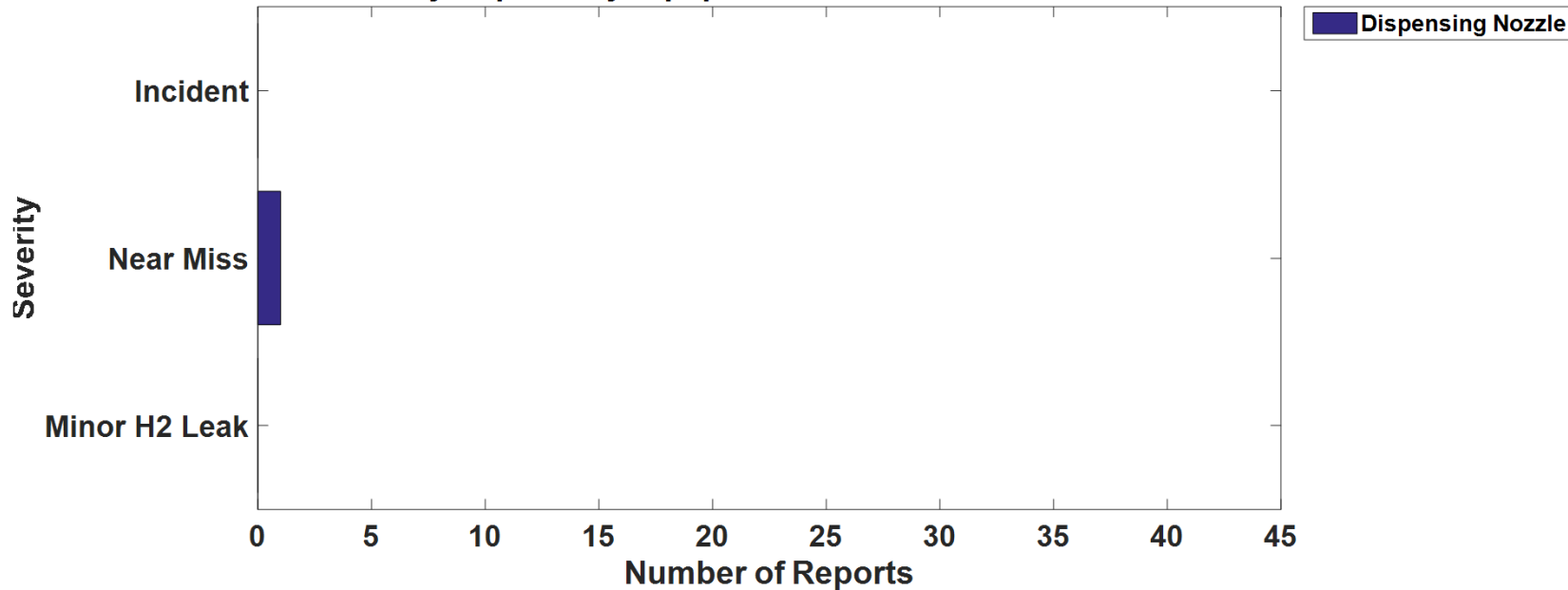
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdpRETAIL_infr_31

Created: Dec-20-16 9:22 AM | Data Range: 2015Q3-2016Q3

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
- any hydrogen release sufficient to sustain a flame if ignited

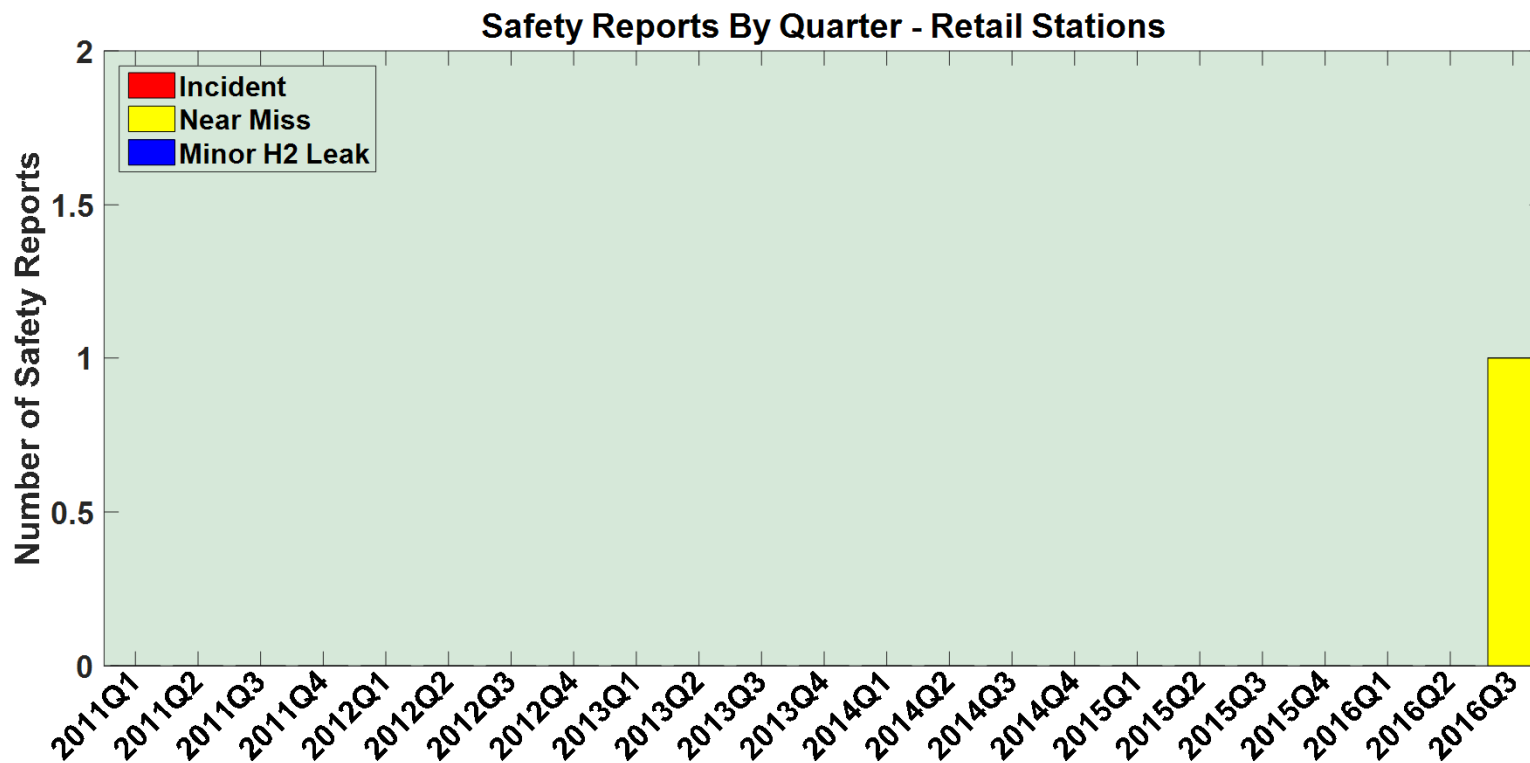
A Minor H2 Leak is:

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



NREL cdpRETAIL_infr_32

Created: Dec-20-16 9:22 AM | Data Range: 2015Q3-2016Q3



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:

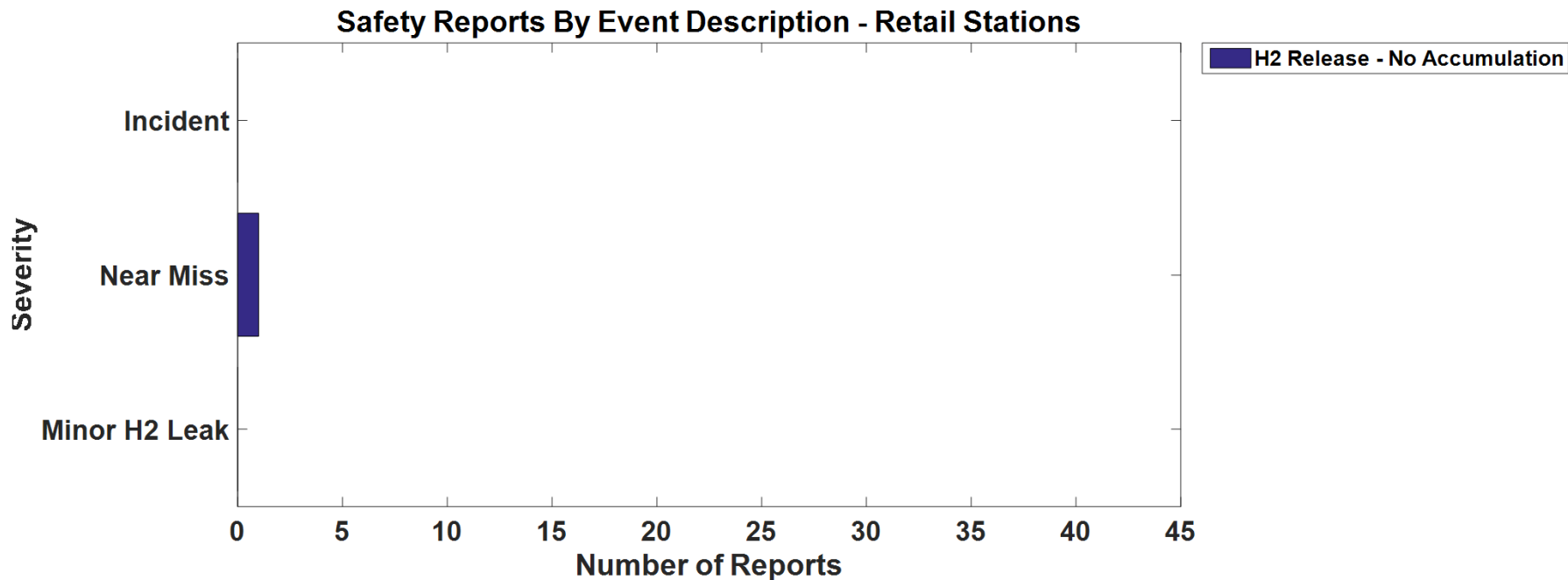
- an event that under slightly different circumstances could have become an incident
- any hydrogen release sufficient to sustain a flame if ignited

A Minor H2 Leak is:



NREL cdpRETAIL_infr_33

Created: Dec-20-16 9:14 AM | Data Range: 2015Q3-2016Q3



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:

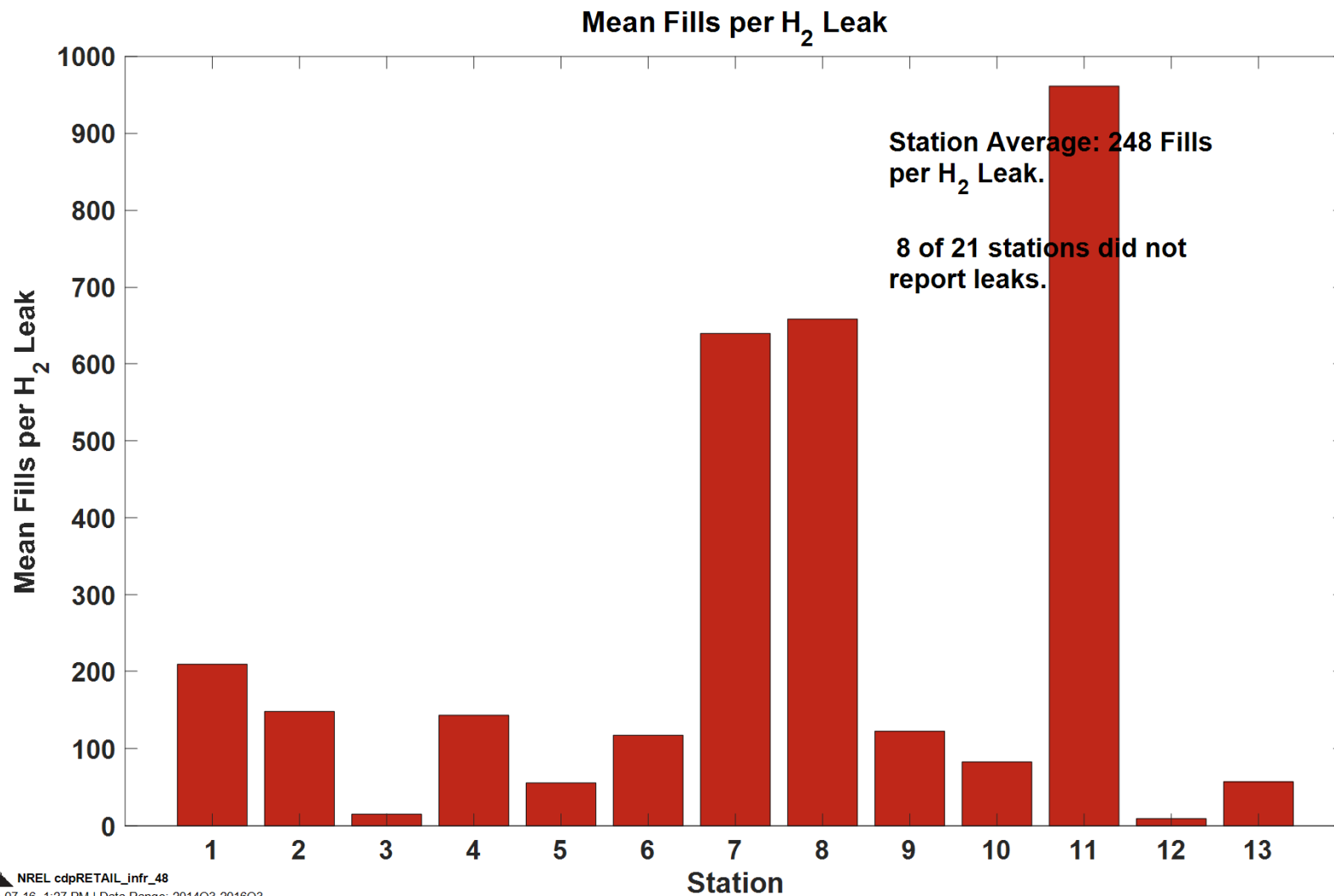
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdpRETAIL_infr_34

Created: Dec-20-16 9:22 AM | Data Range: 2015Q3-2016Q3

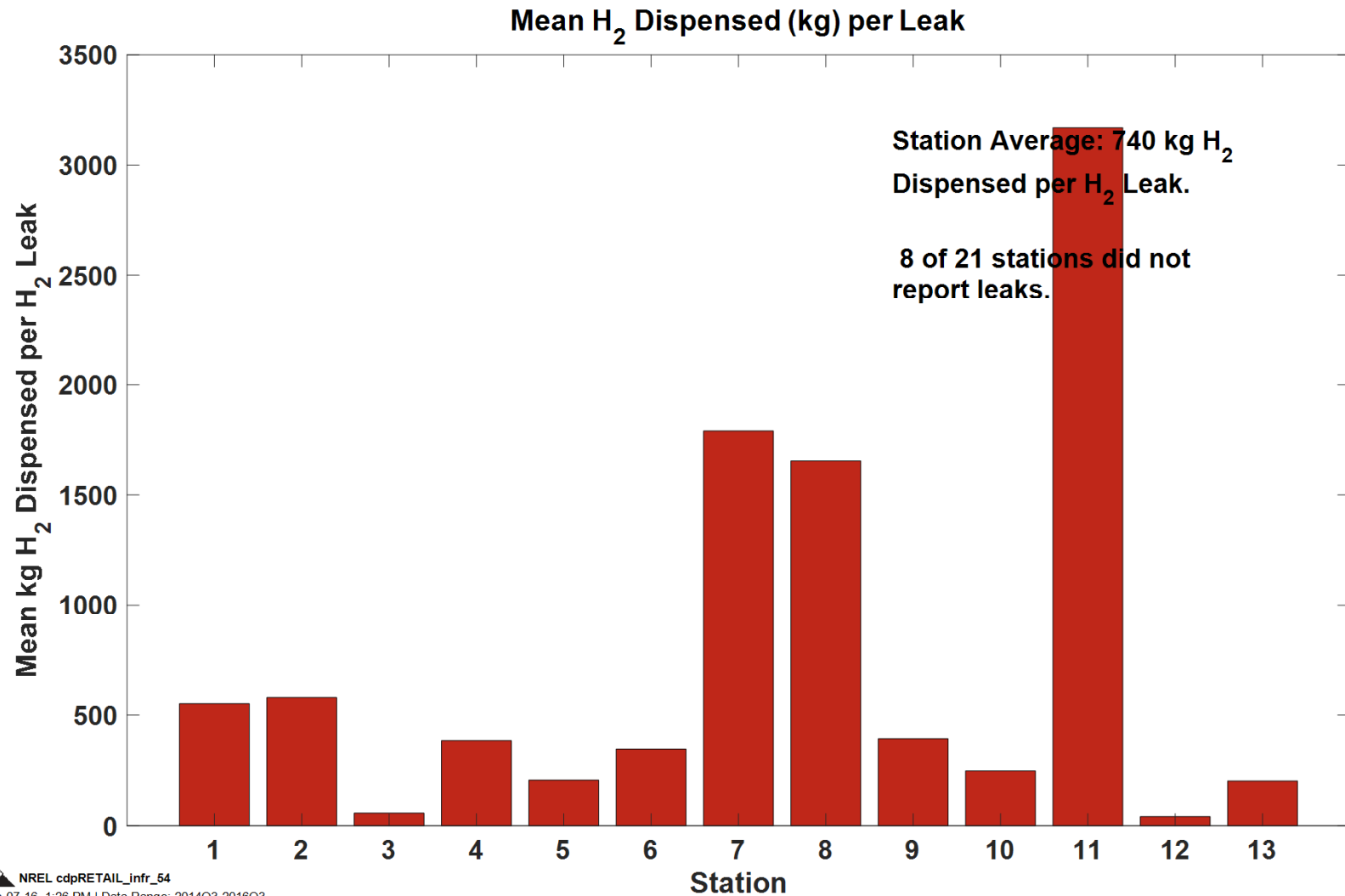
Mean Fills per Hydrogen Leak



NREL cdpRETAIL_infr_48

Created: Dec-07-16 1:27 PM | Data Range: 2014Q3-2016Q3

Mean Hydrogen Dispensed per Hydrogen Leak

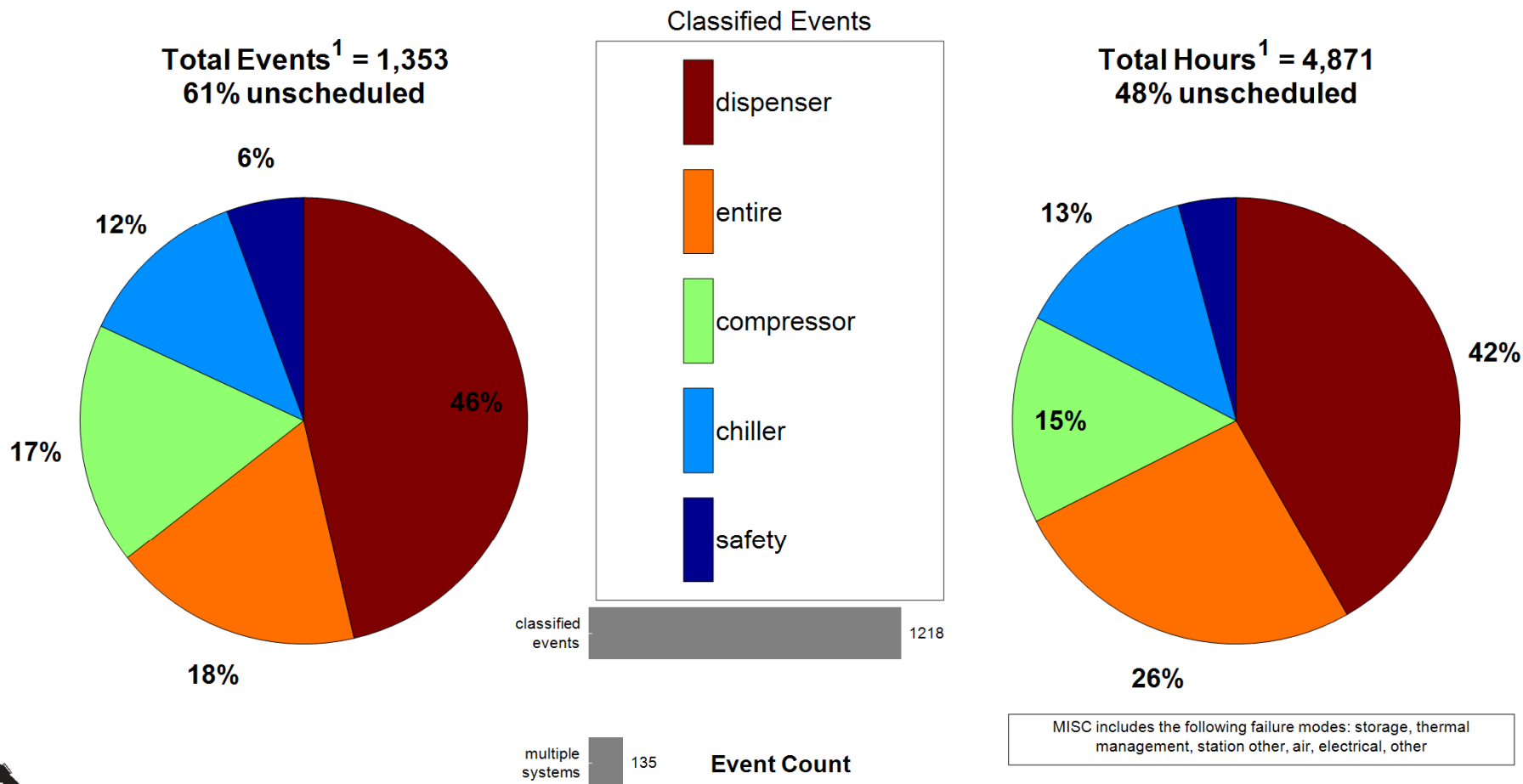


NREL cdpRETAIL_infr_54

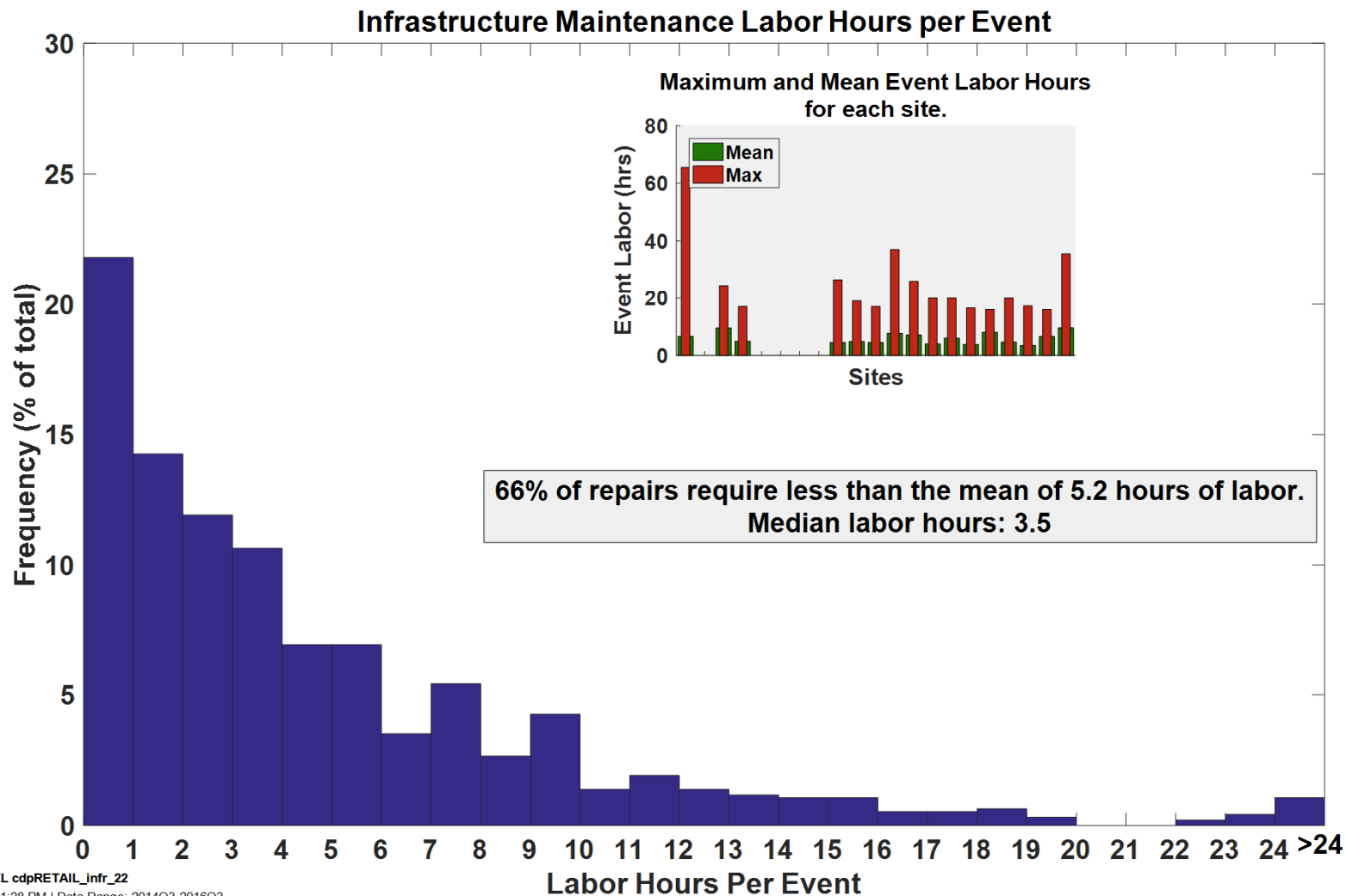
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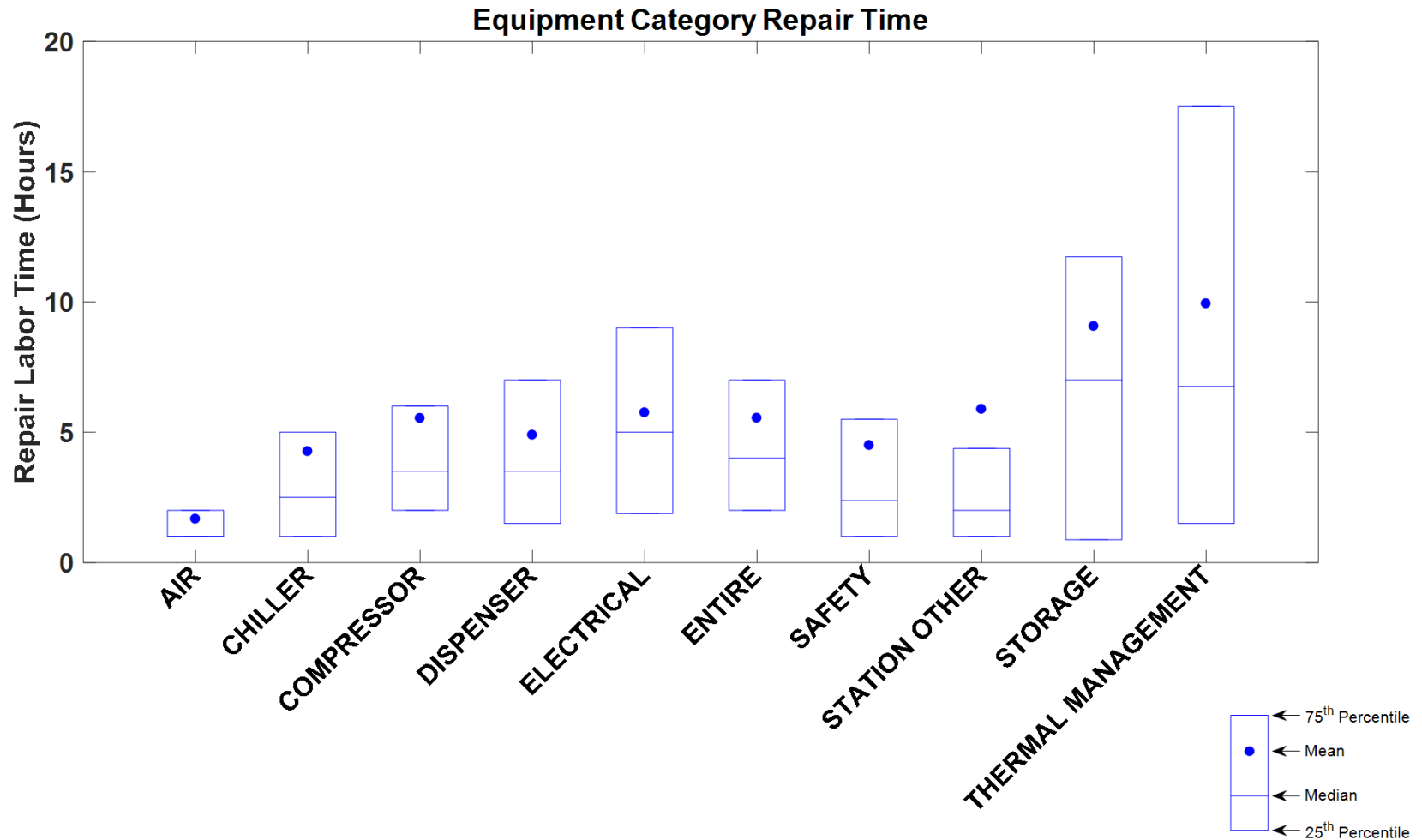
Maintenance and Reliability

Maintenance by Equipment Type - Retail Stations

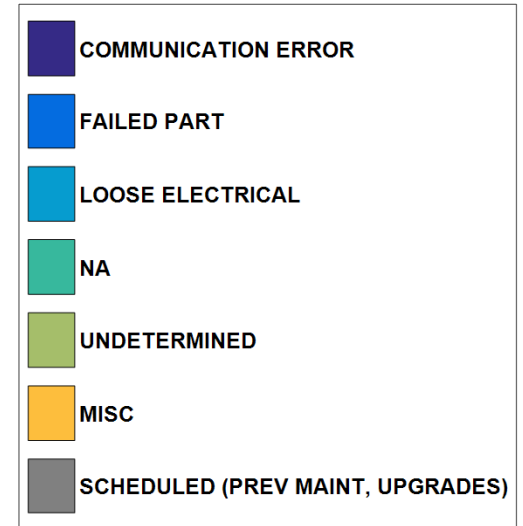
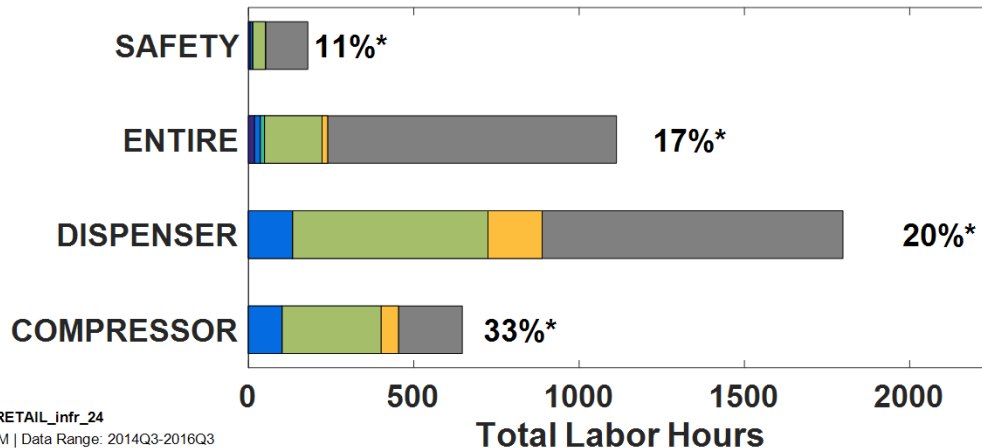
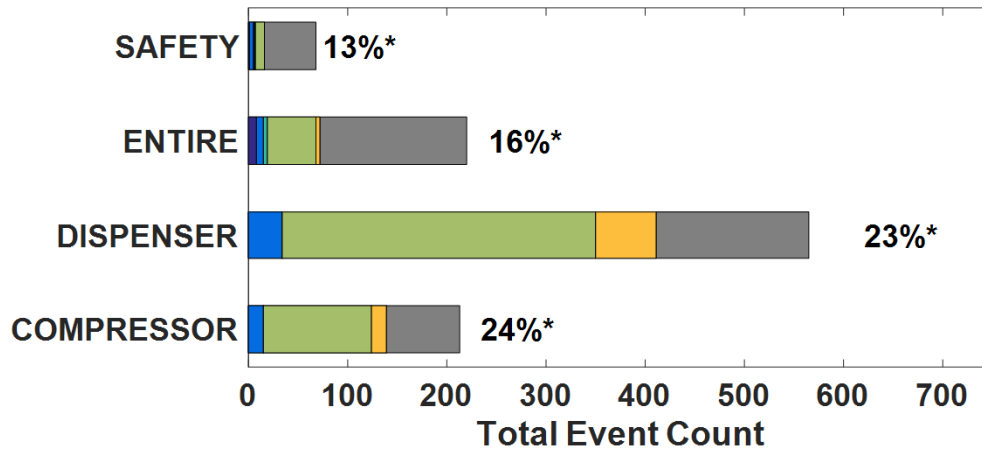


1. Total includes classified events (plotted) and unclassified events.





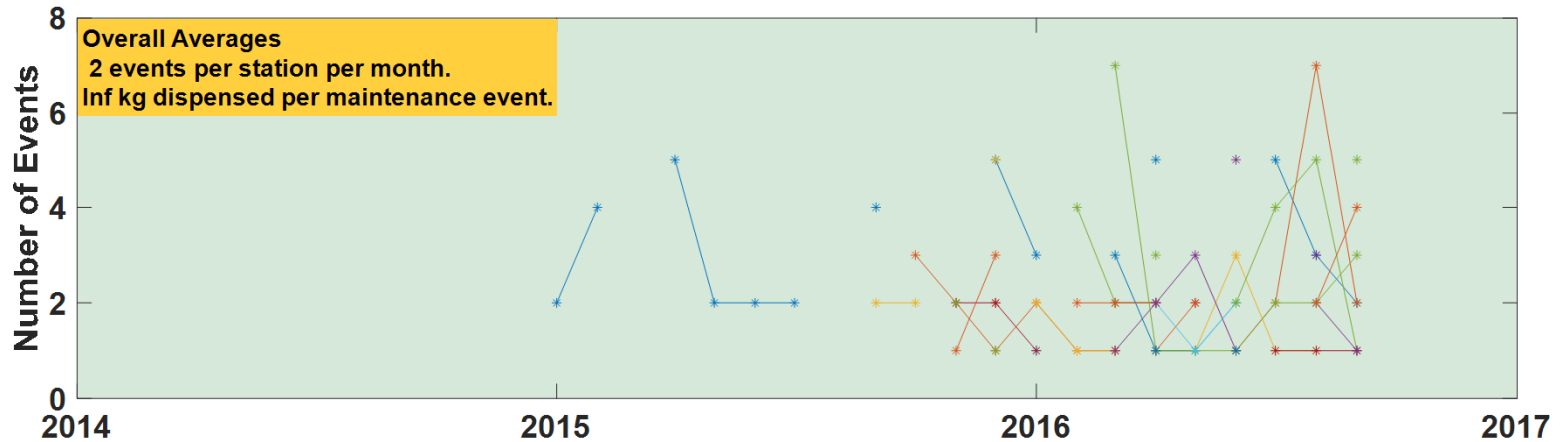
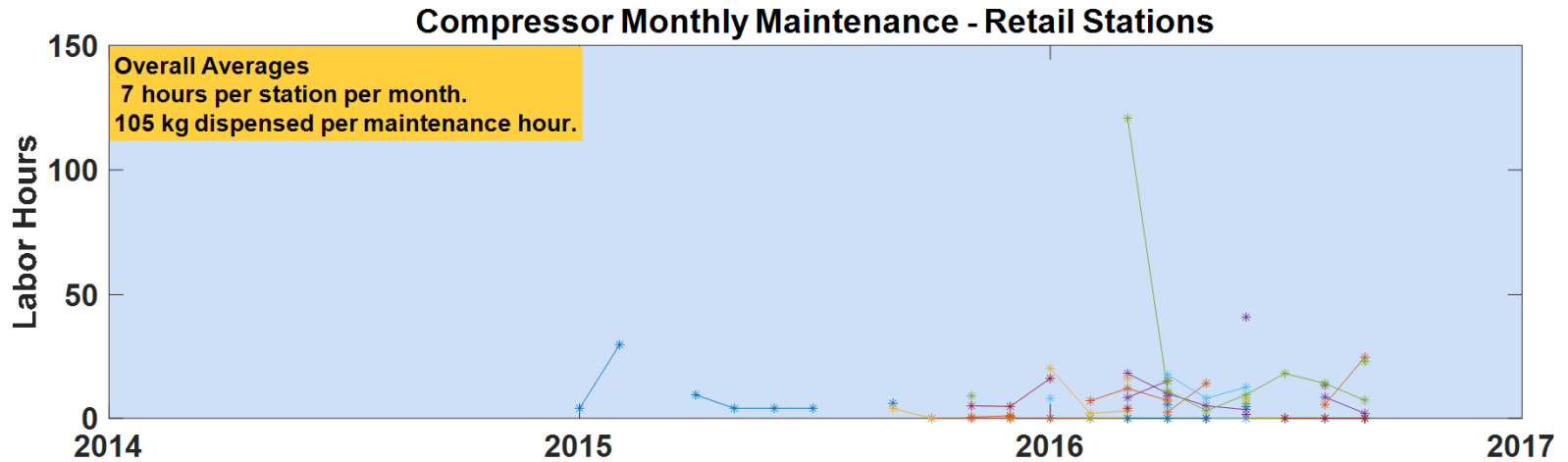
Failure Modes for Top Equipment Categories



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

* Percentage of total events or hours.



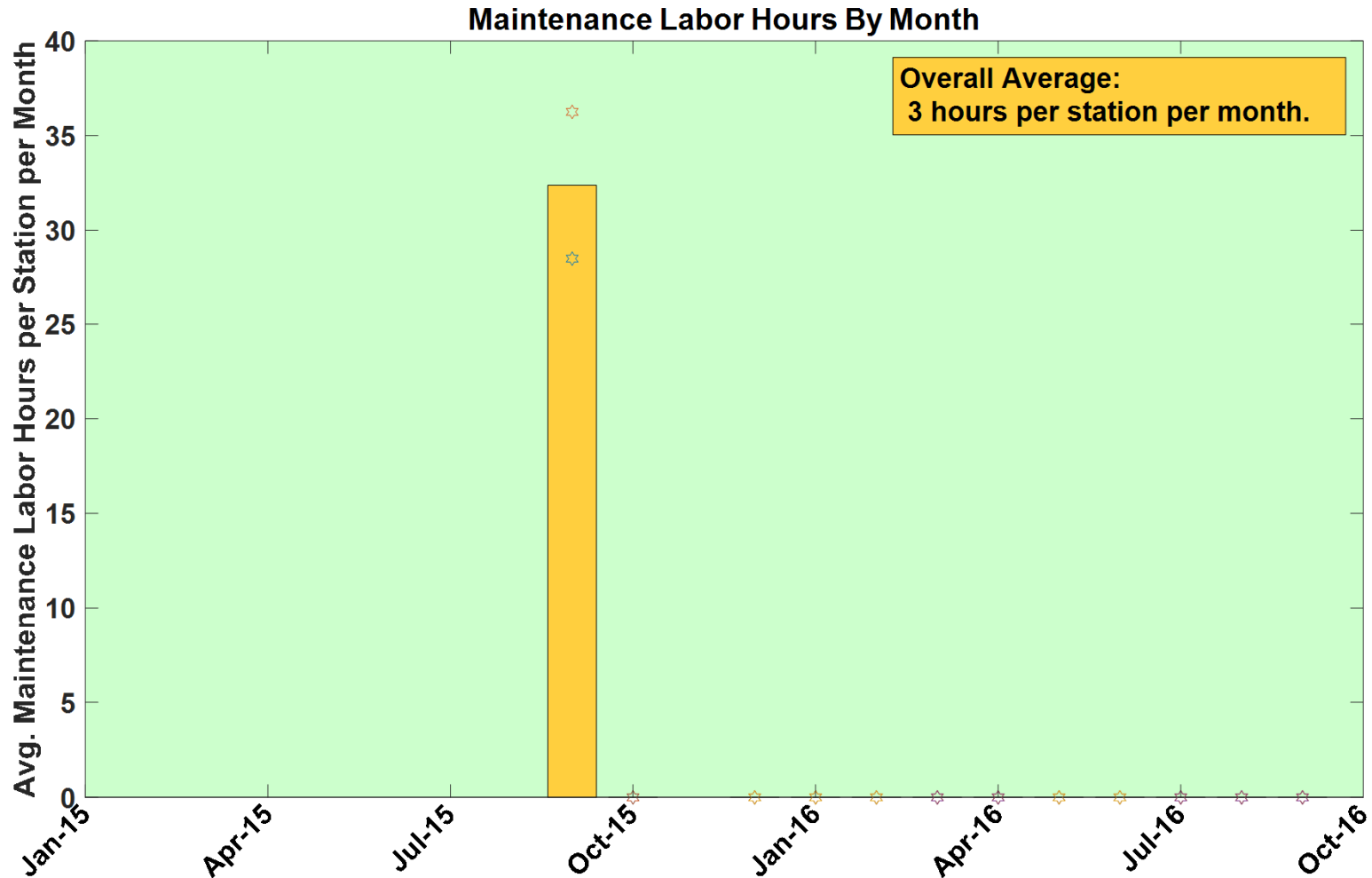


NREL cdpRETAIL_infr_26

Created: Dec-19-16 10:35 AM | Data Range: 2014Q3-2016Q3

* 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.

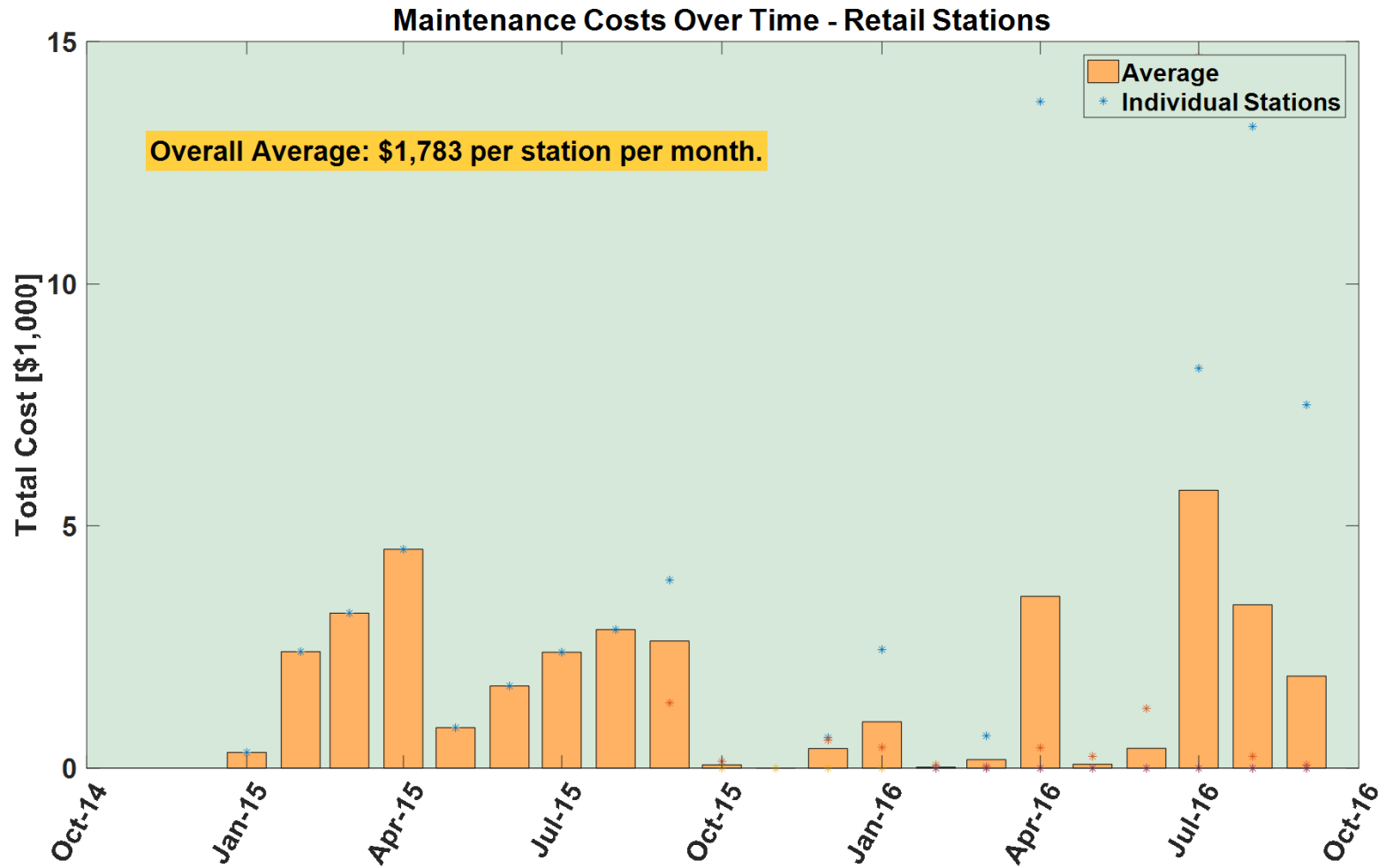
Maintenance Labor Hours by Month



NREL cdpRETAIL_infr_28

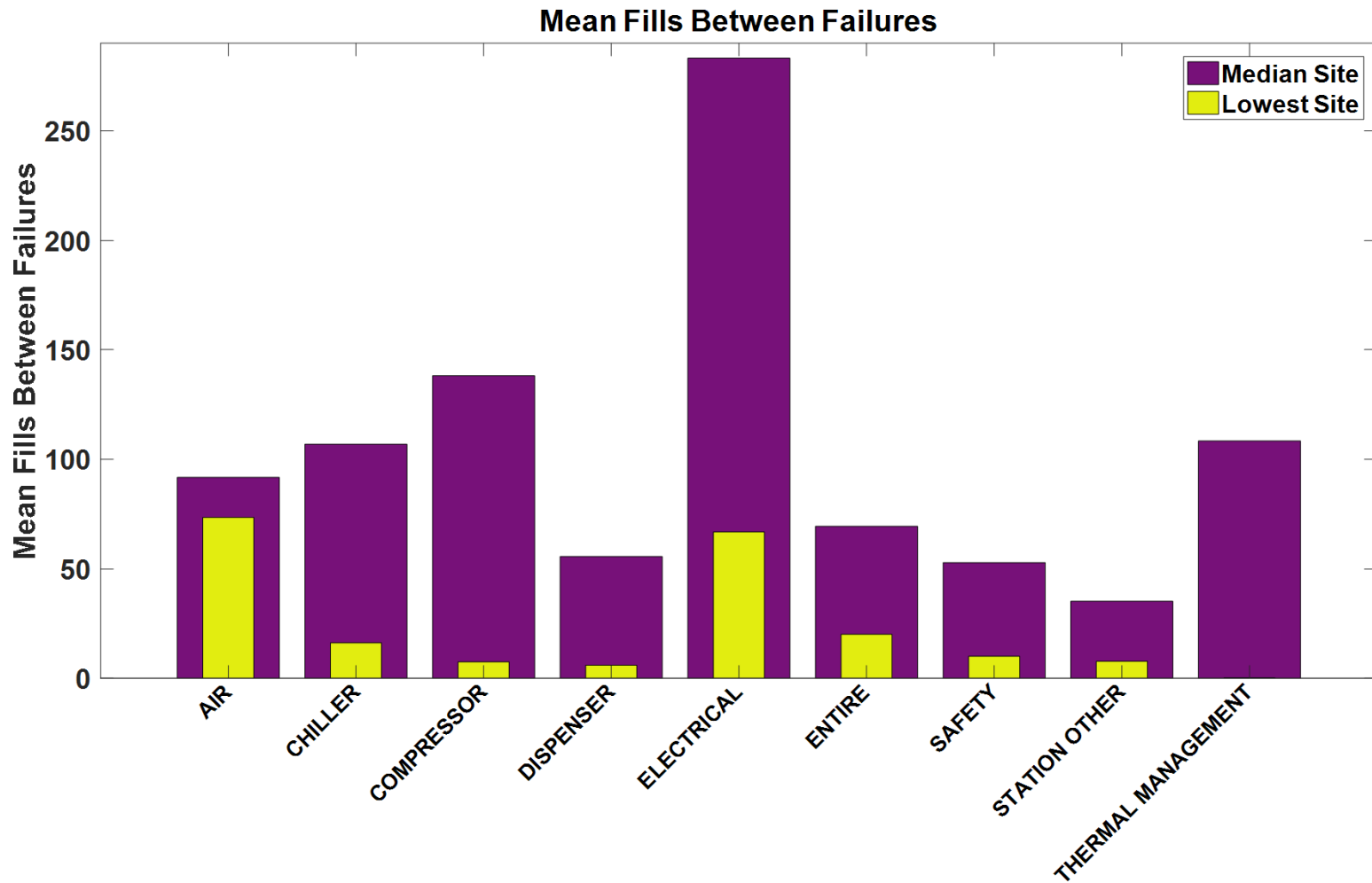
Created: Dec-07-16 1:25 PM | Data Range: 2014Q3-2016Q3

Stars represent individual station maintenance hours in a given month.

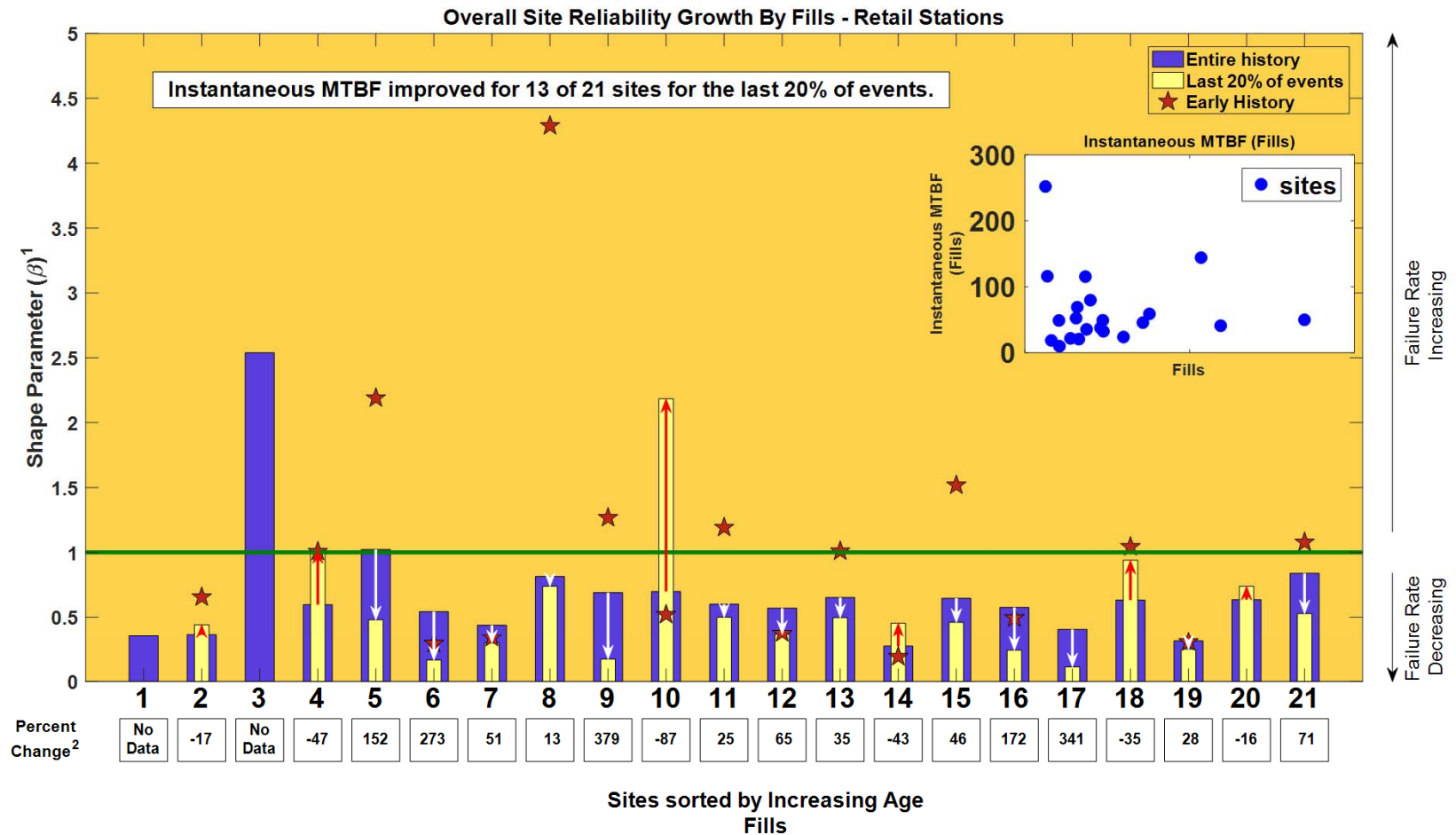


*Each color represents a unique station.





NREL cdpRETAIL_infr_49
Created: Dec-07-16 1:28 PM | Data Range: 2014Q3-2016Q3



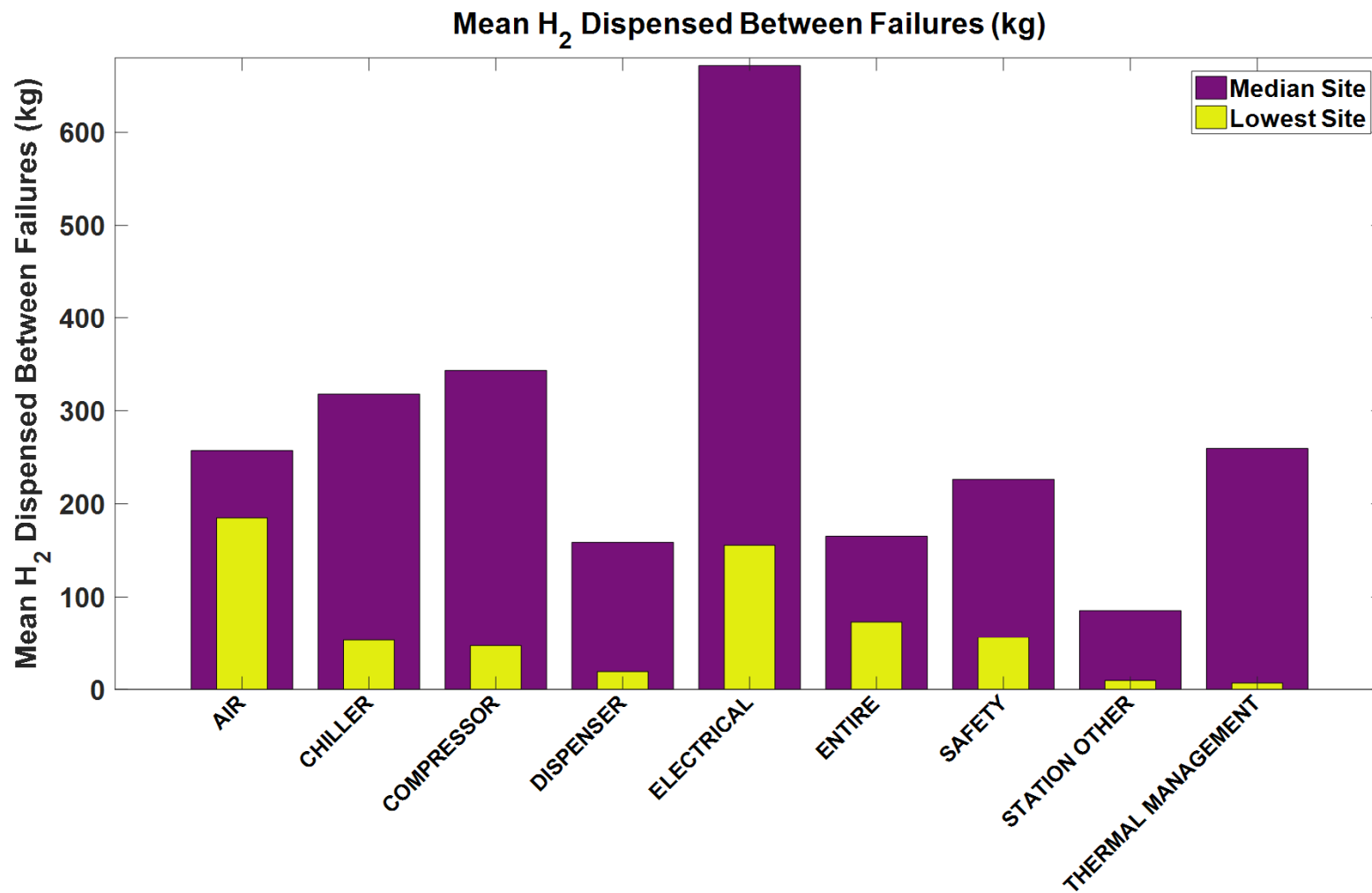
NREL cdpRETAIL_infr_50

Created: Dec-20-16 9:43 AM | Data Range: 2014Q3-2016Q3

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

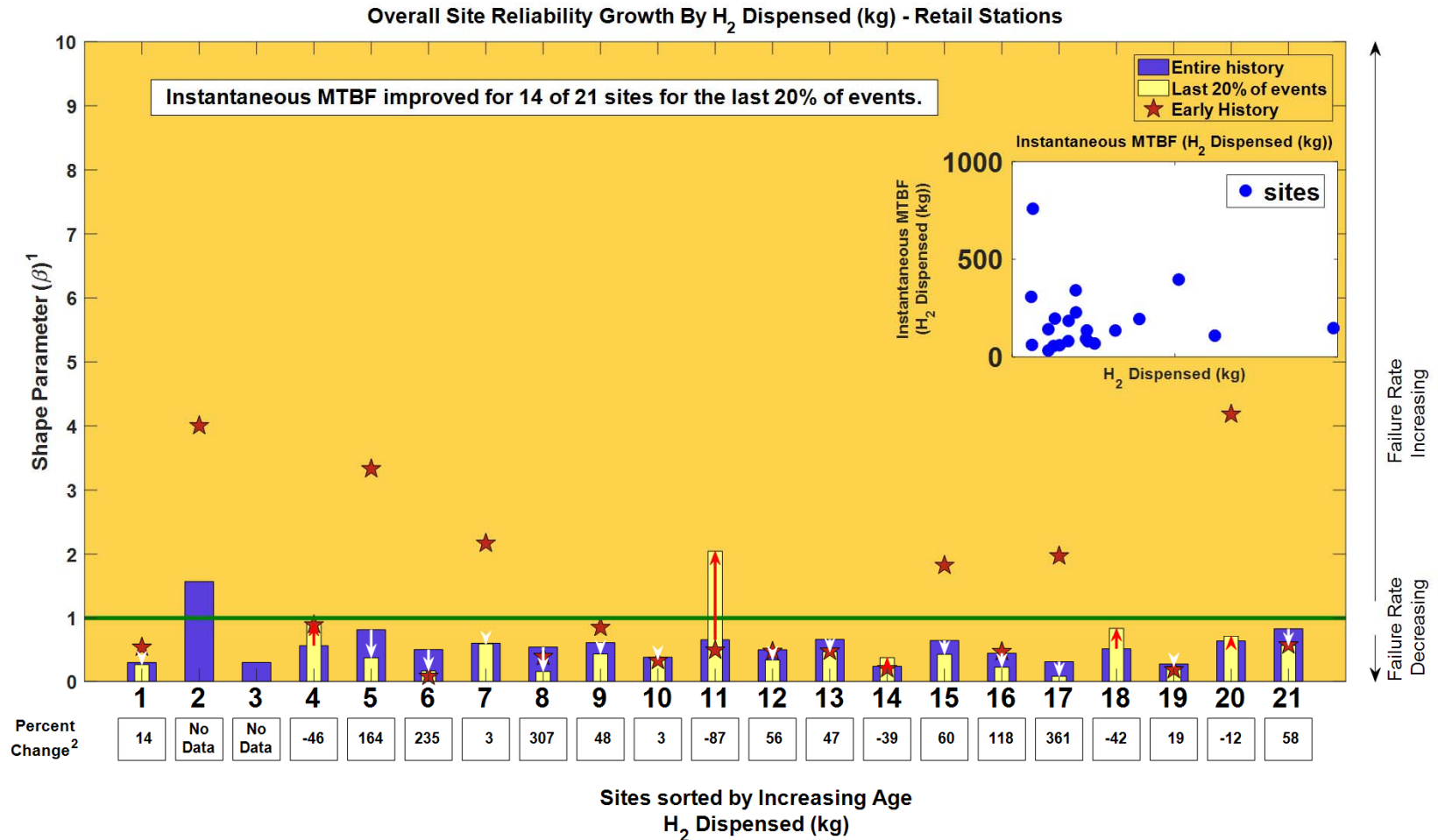
2. % change in instantaneous mean Fills between failures

Mean Amount Dispensed Between Failures



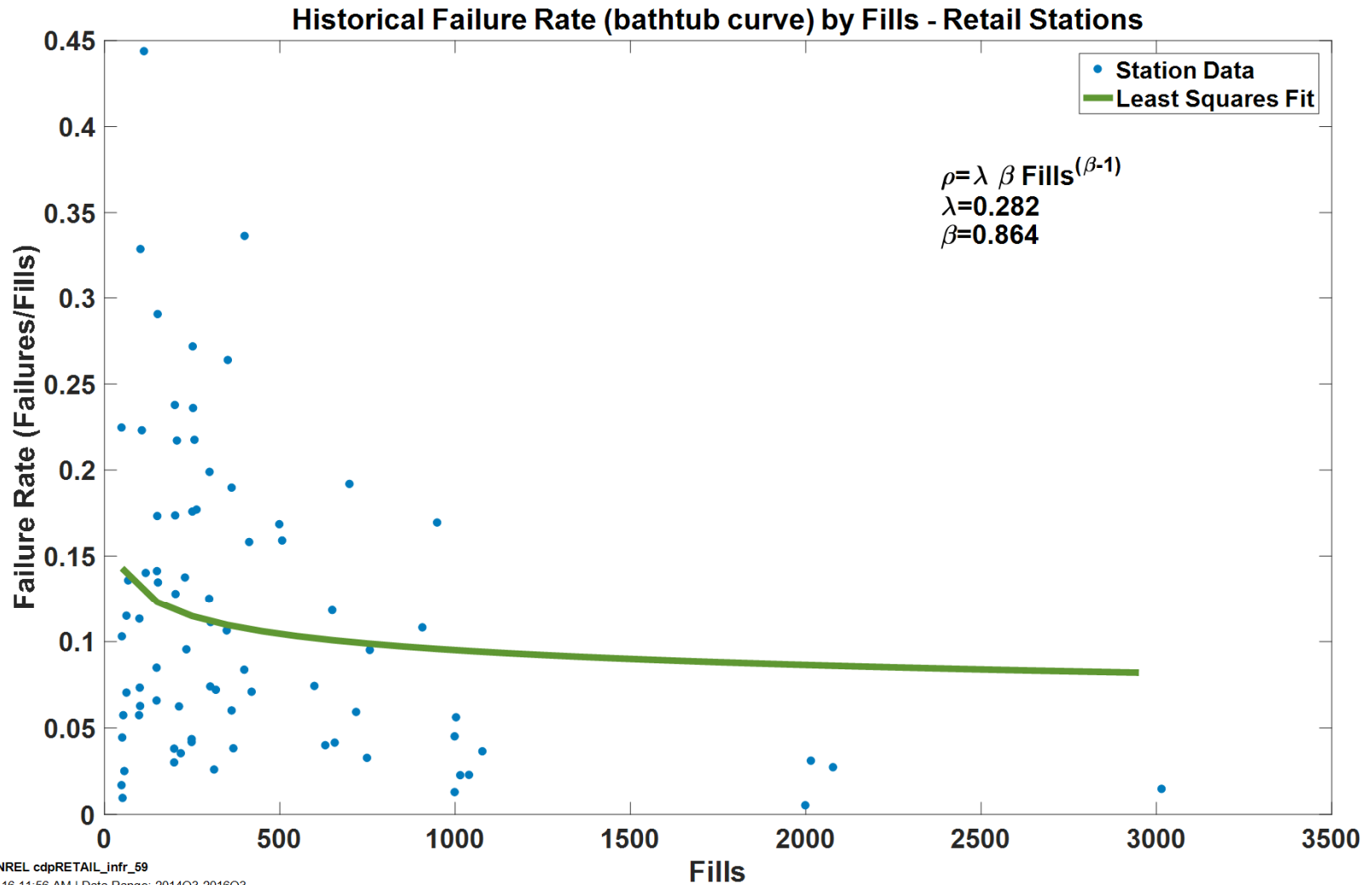
NREL cdpRETAIL_infr_51
Created: Dec-07-16 1:27 PM | Data Range: 2014Q3-2016Q3

Reliability Growth by Amount Dispensed



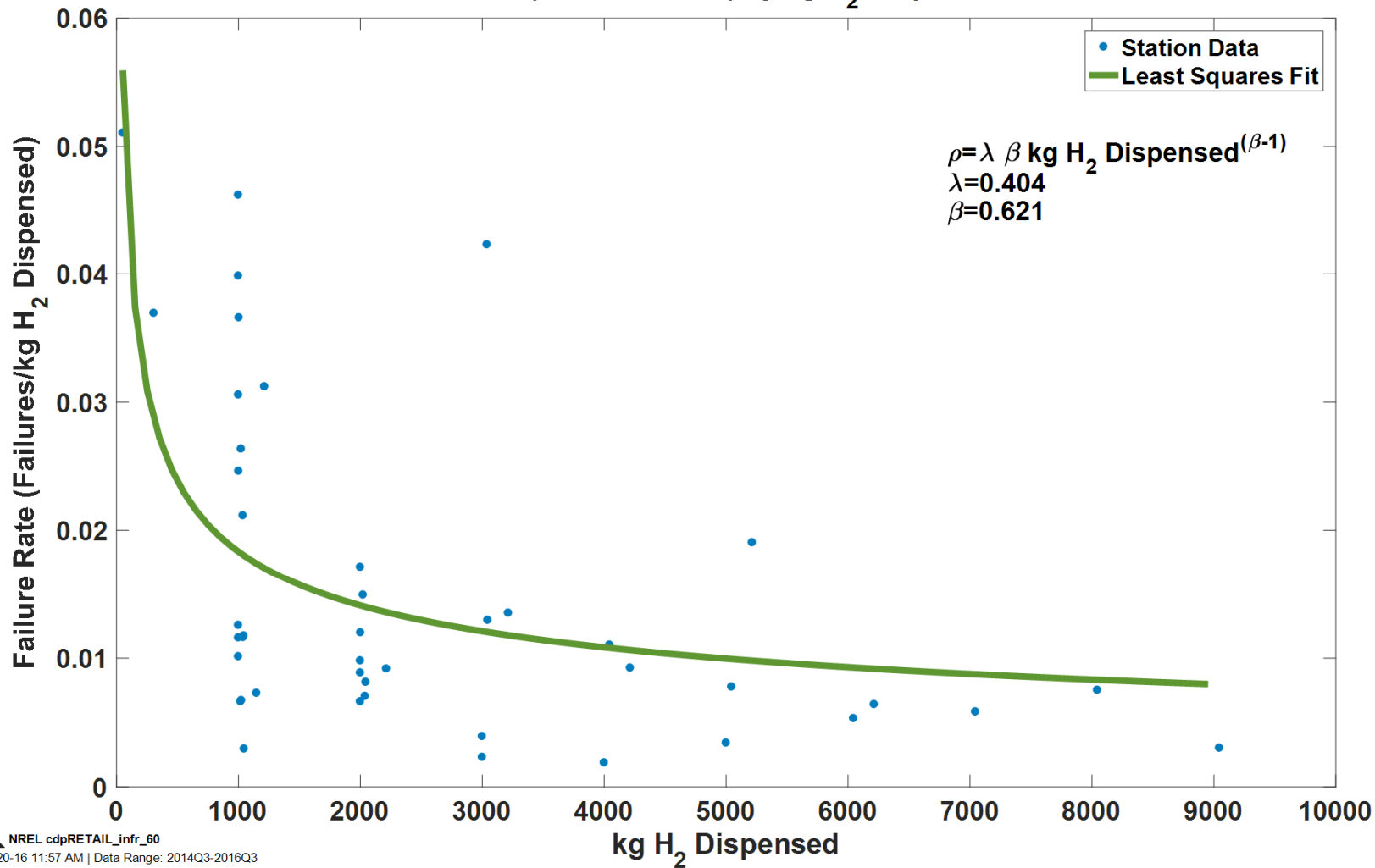
1. IEC 61164:2004(E), Reliability Growth - Statistical Test and Evaluation Methods, IEC. 2004.
2. % change in instantaneous mean H₂ Dispensed (kg) between failures


Historical Failure Rate by Fills



Historical Failure Rate by Amount Dispensed

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

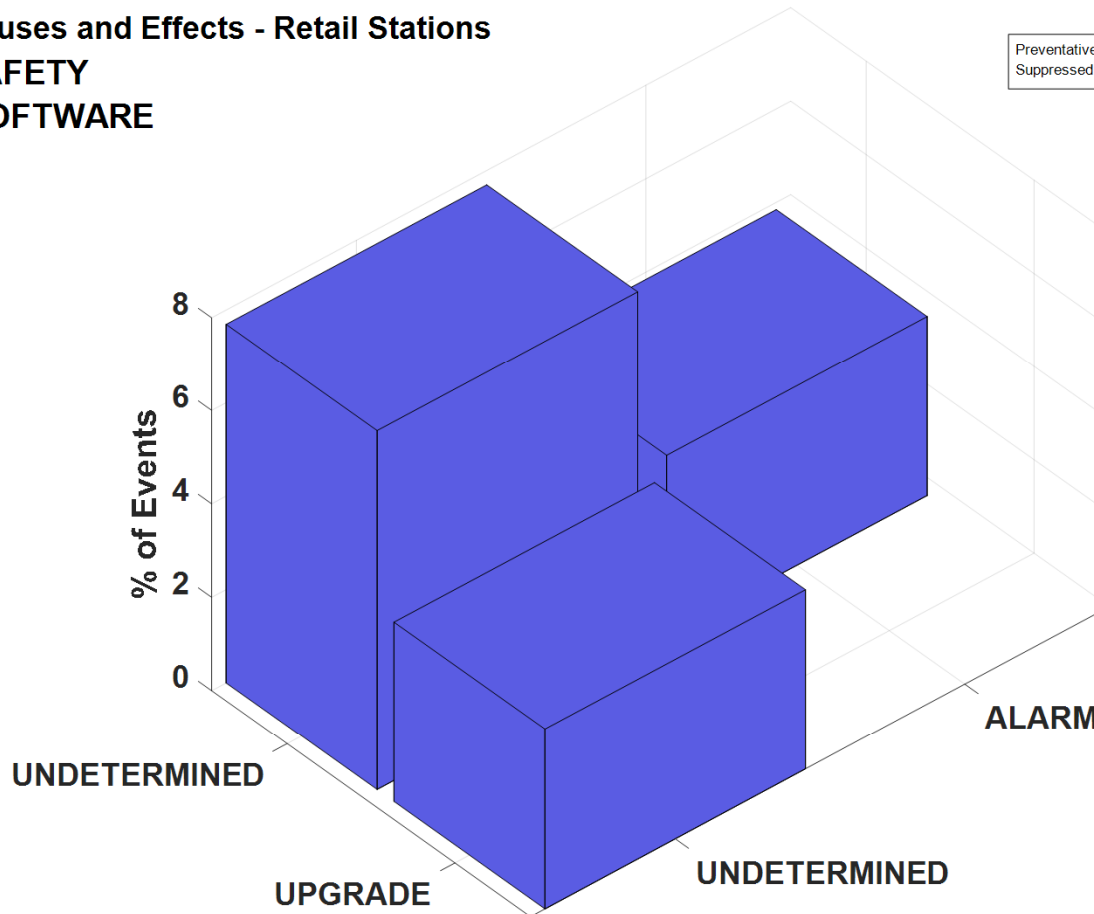



 NREL cdpRETAIL_infr_60
 Created: Dec-20-16 11:57 AM | Data Range: 2014Q3-2016Q3

Maintenance Causes and Effects - Retail Stations

Subsystem: SAFETY

Component: SOFTWARE



Preventative Maintenance accounted for 85% of all events.
Suppressed in the plot to show detail for other causes.

Causes

Effects



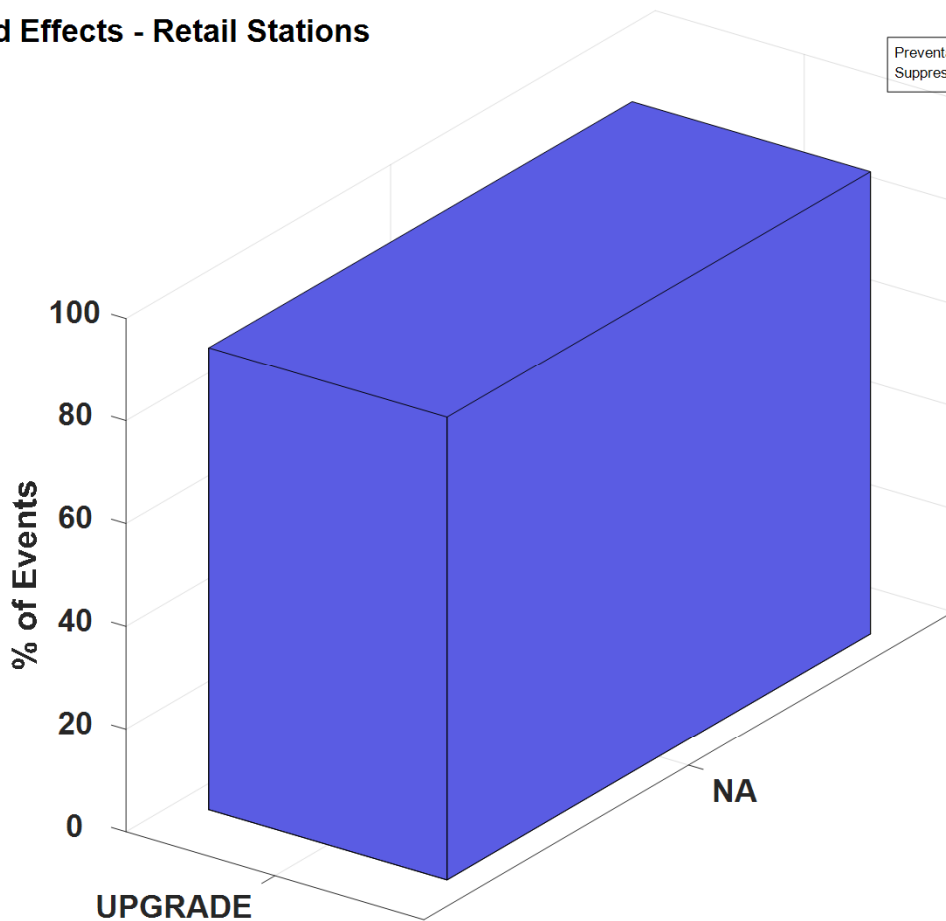
NREL cdpRETAIL_infr_64

Created: Dec-20-16 12:29 PM | Data Range: 2014Q3-2016Q3

Maintenance Causes and Effects - Retail Stations

Subsystem: SAFETY

Component: ENTIRE



Causes

Effects



NREL cdpRETAIL_infr_65

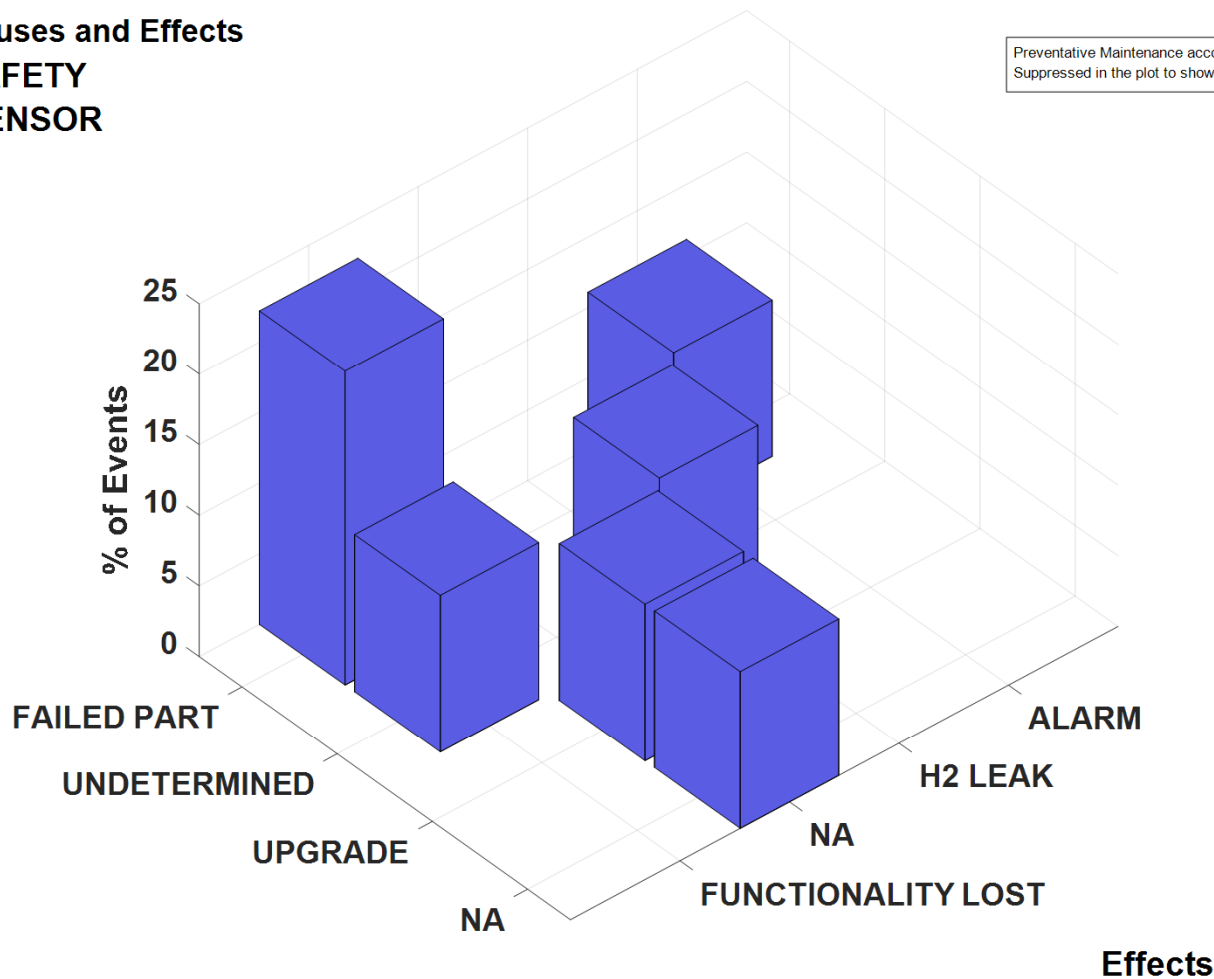
Created: Dec-20-16 12:29 PM | Data Range: 2014Q3-2016Q3

Maintenance Causes and Effects

Subsystem: SAFETY

Component: SENSOR

Preventative Maintenance accounted for 22% of all events.
Suppressed in the plot to show detail for other causes.



Causes

Effects



NREL cdpRETAIL_infr_66

Created: Dec-20-16 12:29 PM | Data Range: 2014Q3-2016Q3

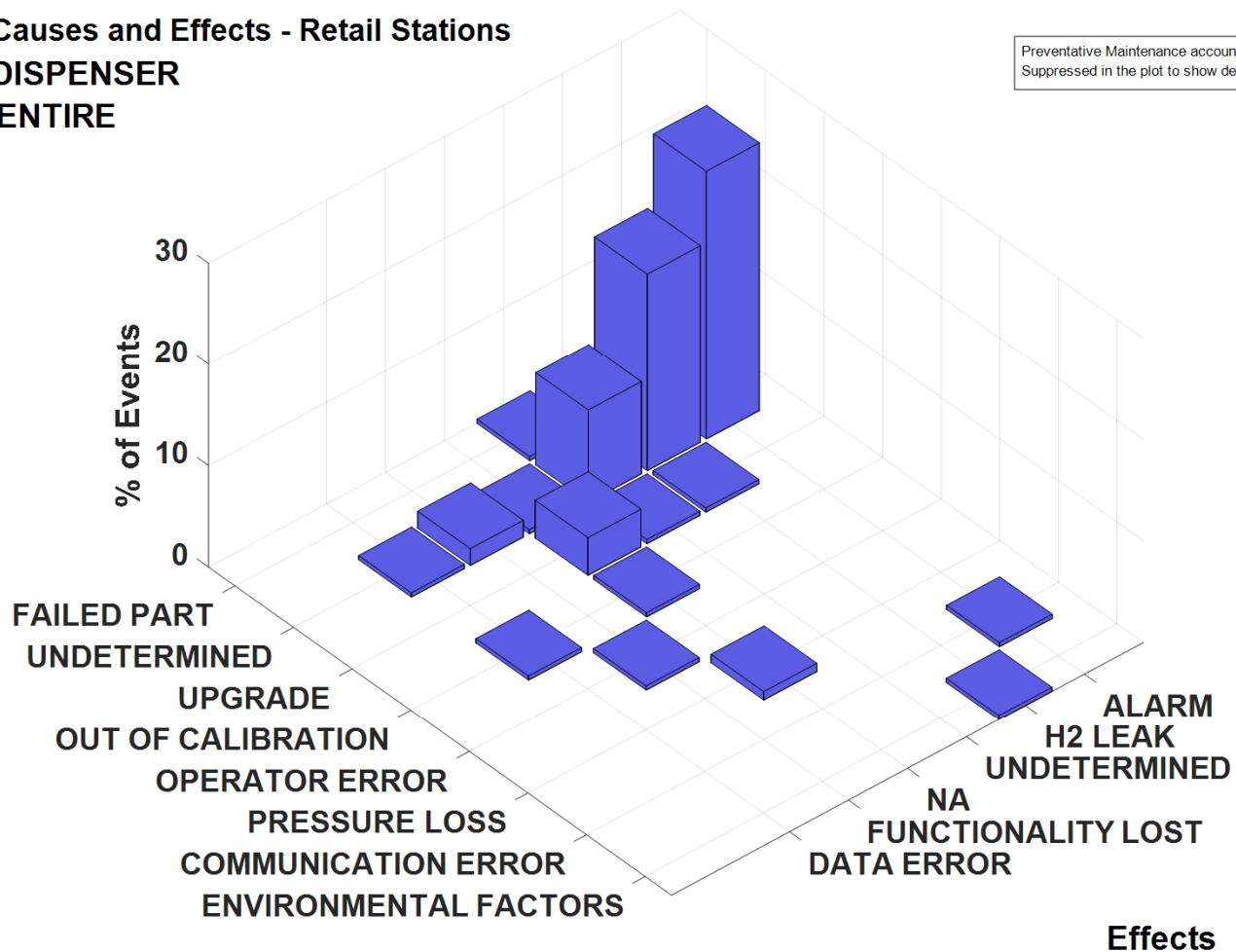
Maintenance Causes and Effects: Dispenser (Entire)

Maintenance Causes and Effects - Retail Stations

Subsystem: DISPENSER

Component: ENTIRE

Preventative Maintenance accounted for 34% of all events.
Suppressed in the plot to show detail for other causes.



Causes

Effects



NREL cdpRETAIL_infr_67

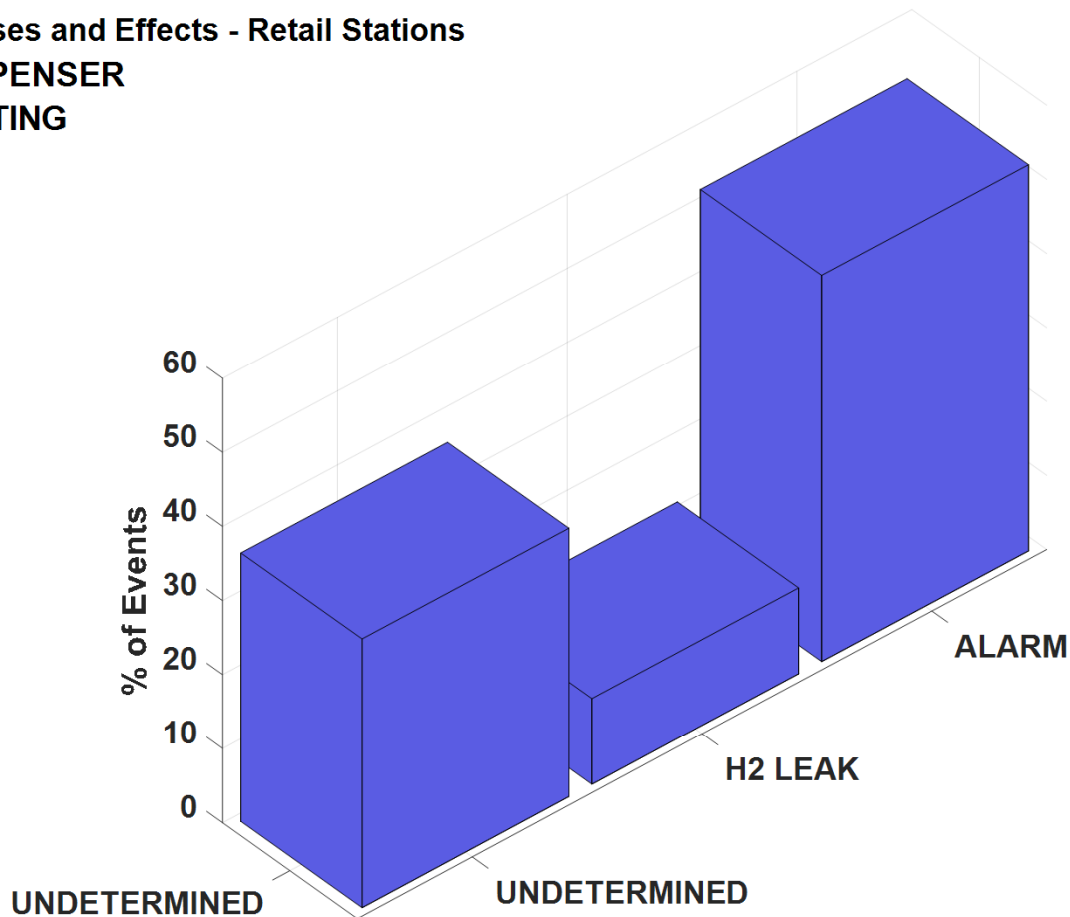
Created: Dec-20-16 12:29 PM | Data Range: 2014Q3-2016Q3

Maintenance Causes and Effects: Dispenser (Fitting)

Maintenance Causes and Effects - Retail Stations

Subsystem: DISPENSER

Component: FITTING



Causes

Effects



NREL cdpRETAIL_infr_68

Created: Dec-20-16 12:30 PM | Data Range: 2014Q3-2016Q3

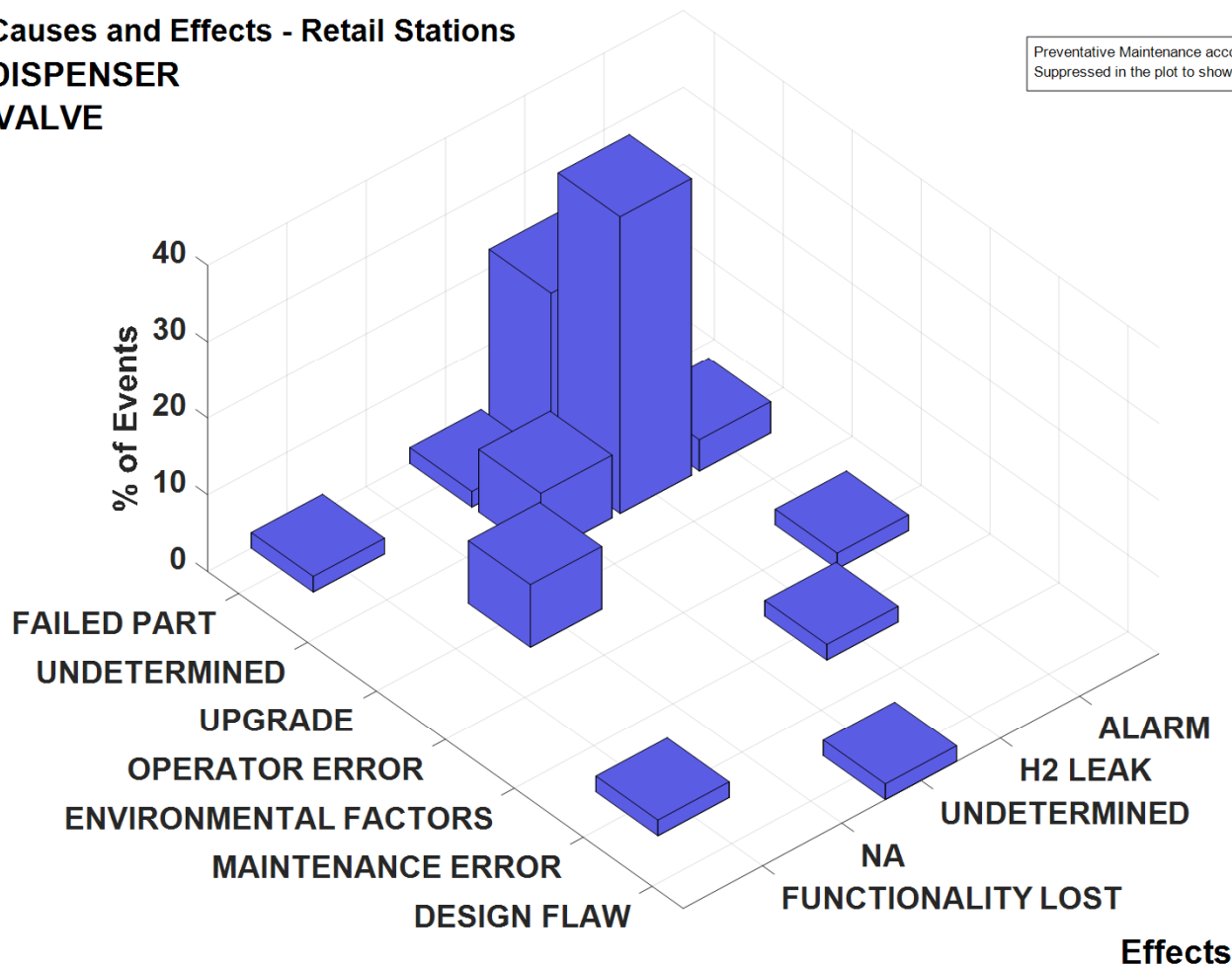
Maintenance Causes and Effects: Dispenser (Valve)

Maintenance Causes and Effects - Retail Stations

Subsystem: DISPENSER

Component: VALVE

Preventative Maintenance accounted for 6% of all events.
Suppressed in the plot to show detail for other causes.



Causes

Effects



NREL cdpRETAIL_infr_69

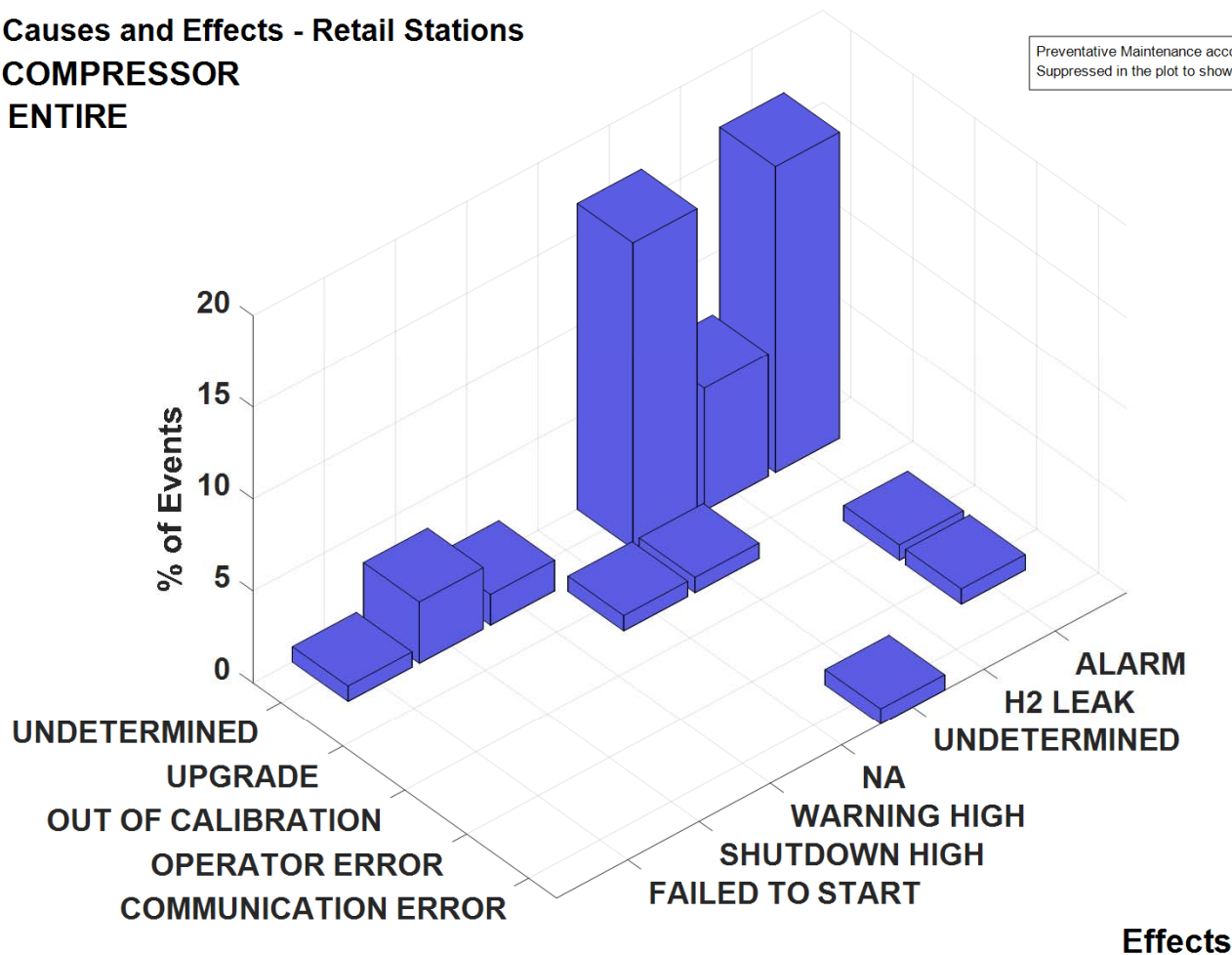
Created: Dec-20-16 12:29 PM | Data Range: 2014Q3-2016Q3

Maintenance Causes and Effects - Retail Stations

Subsystem: COMPRESSOR

Component: ENTIRE

Preventative Maintenance accounted for 50% of all events.
Suppressed in the plot to show detail for other causes.



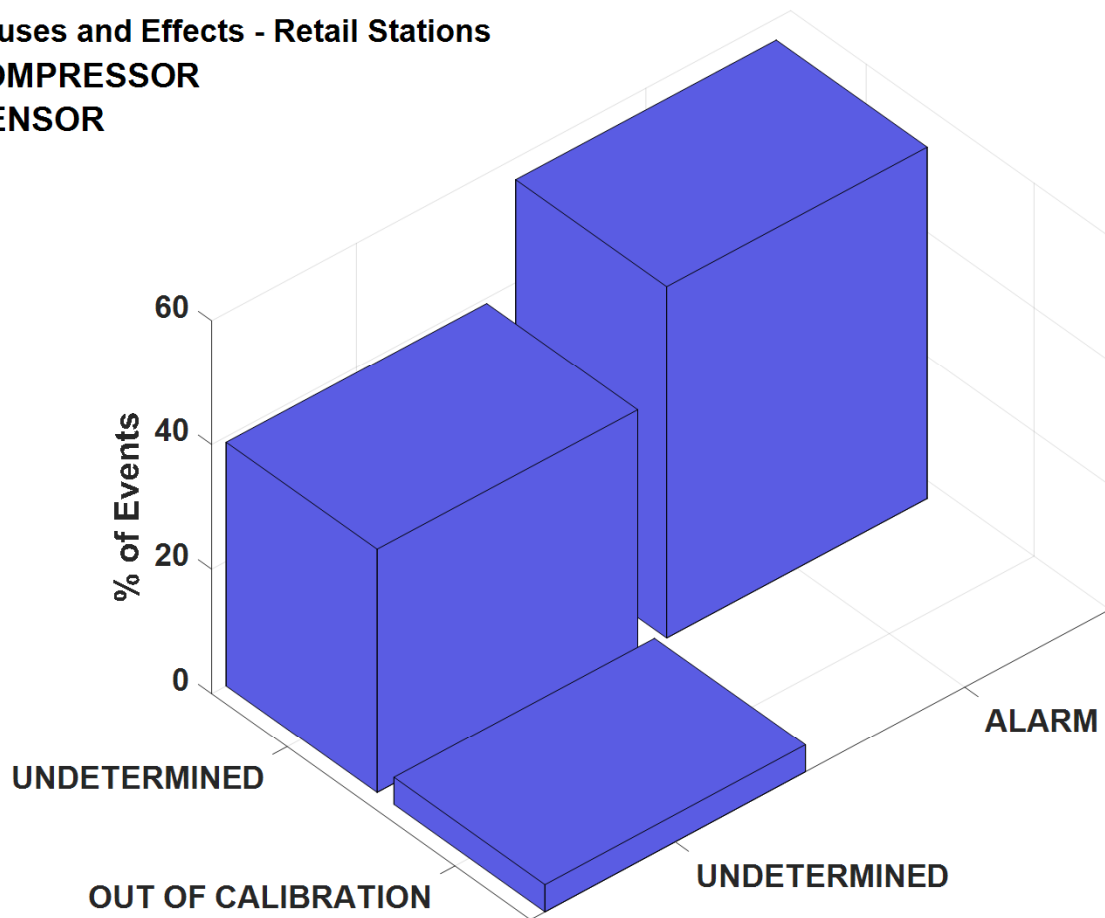
Causes

Effects

Maintenance Causes and Effects - Retail Stations

Subsystem: COMPRESSOR

Component: SENSOR



Causes

Effects



NREL cdpRETAIL_infr_71

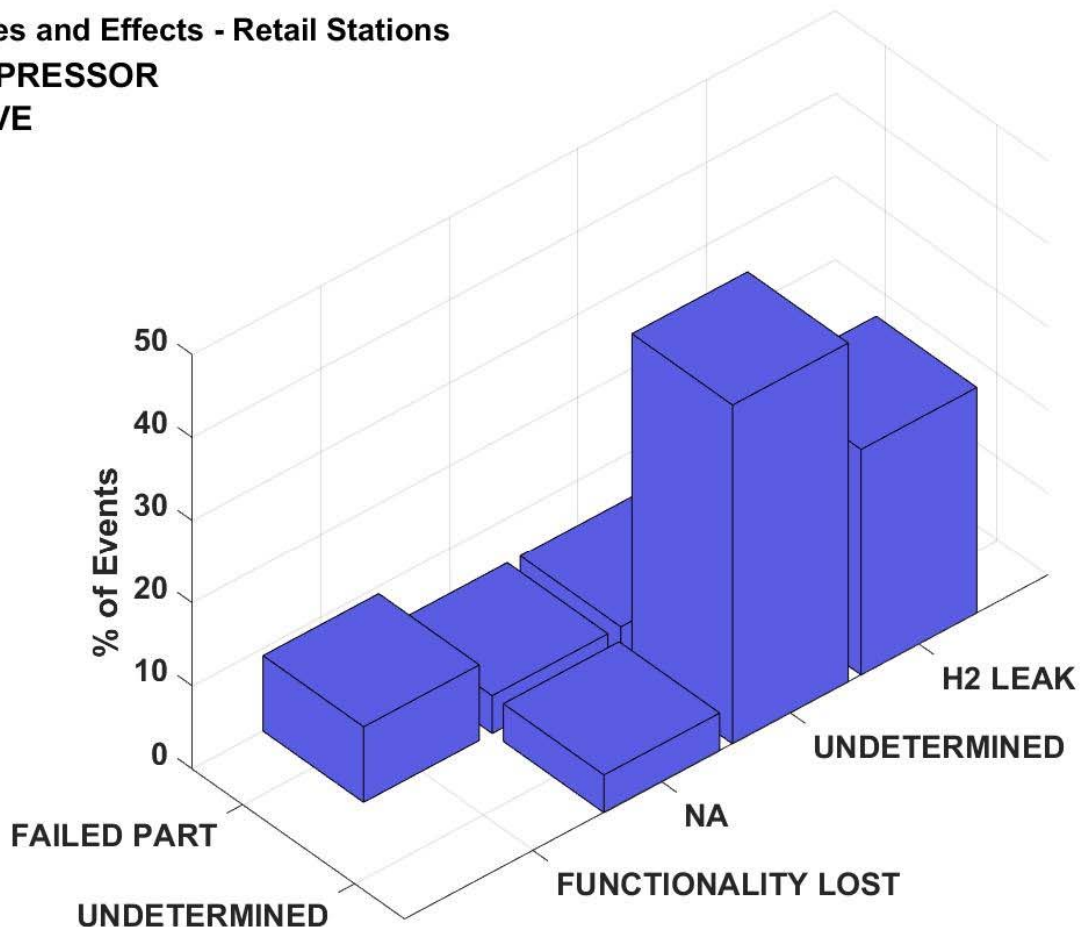
Created: Dec-20-16 12:29 PM | Data Range: 2014Q3-2016Q3

Maintenance Causes and Effects: Compressor (Valve)

Maintenance Causes and Effects - Retail Stations

Subsystem: COMPRESSOR

Component: VALVE



Causes

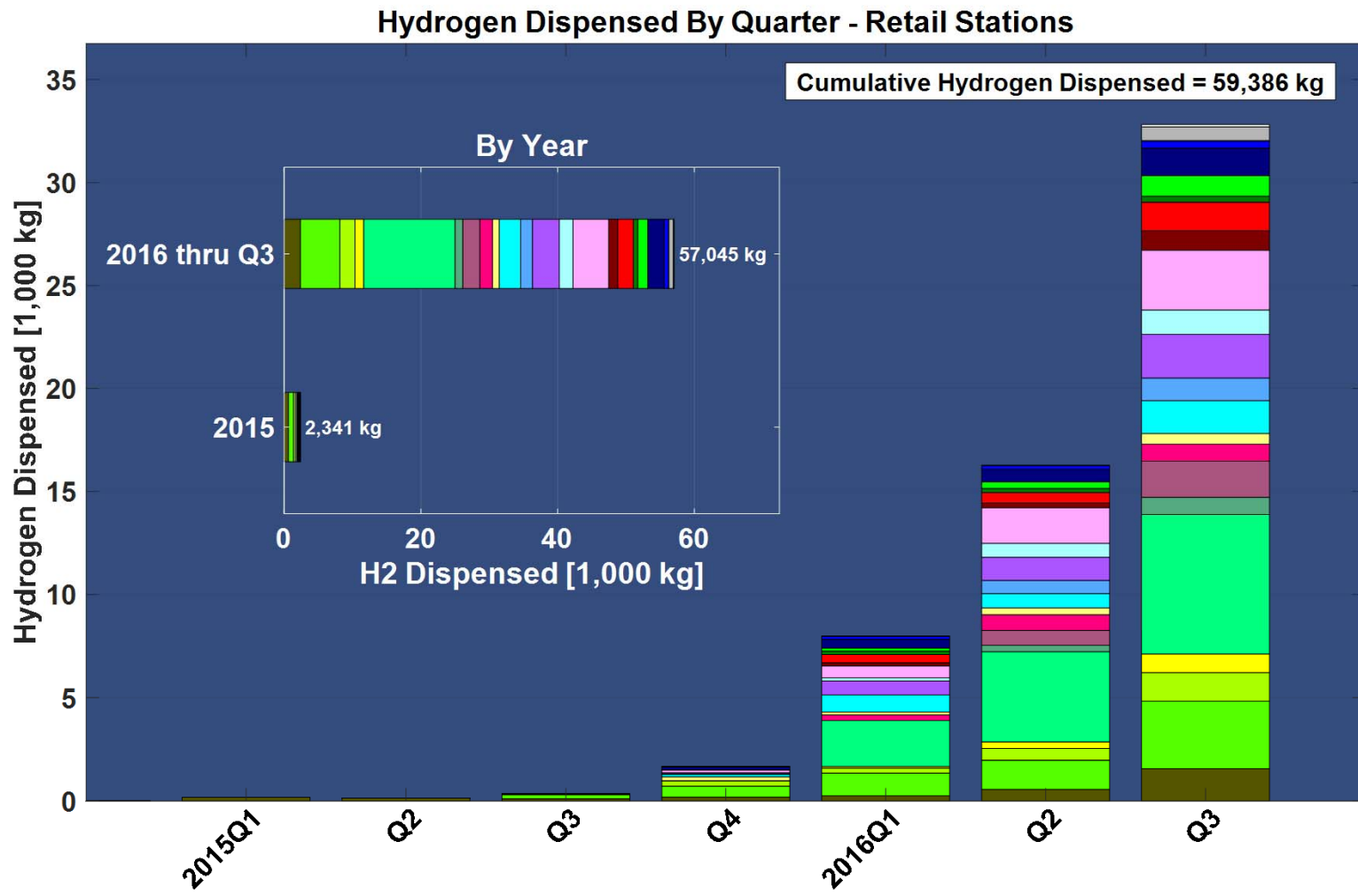
Effects



NREL cdpRETAIL_infr_72

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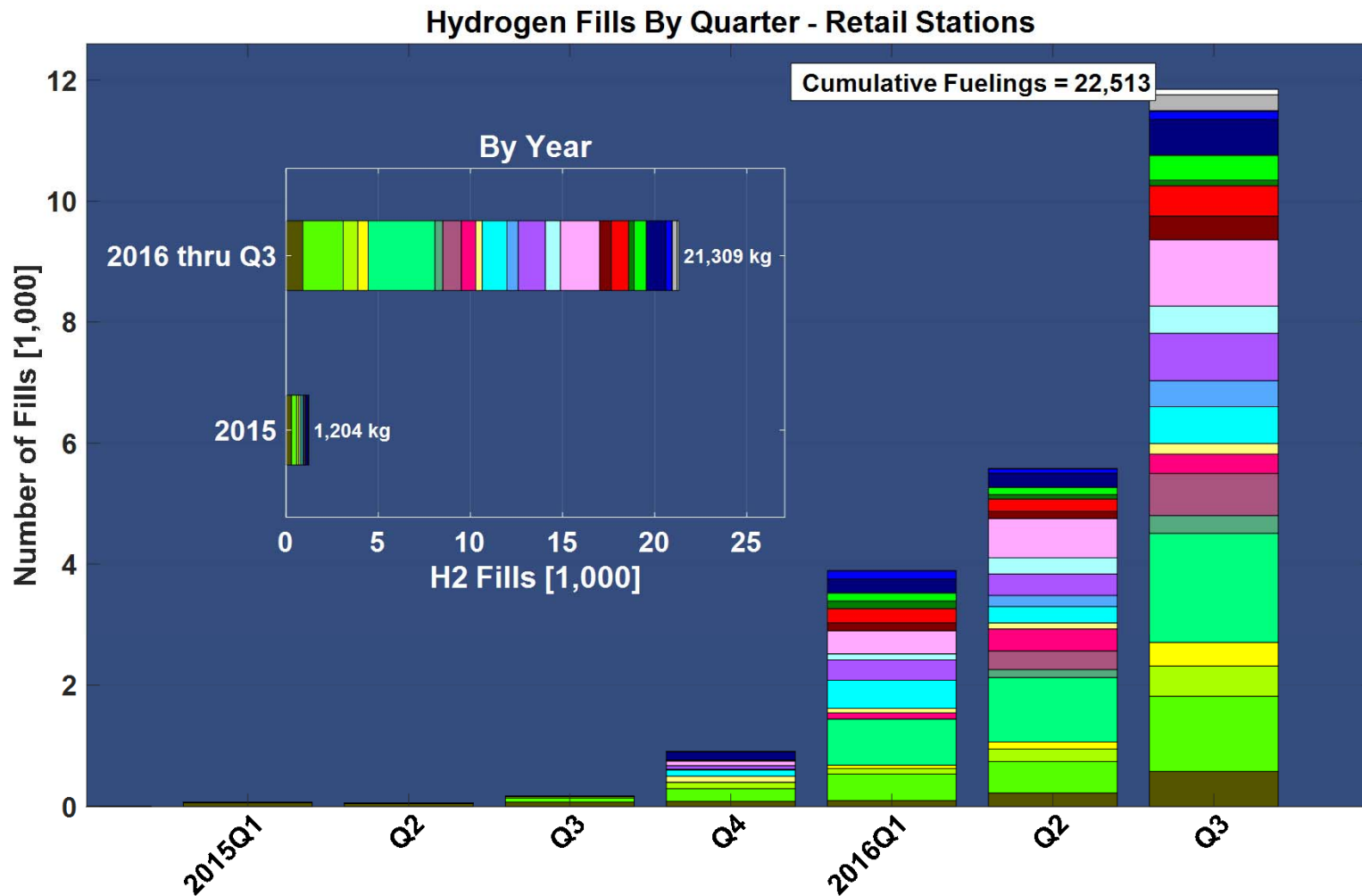
Performance



NREL cdpRETAIL_infr_01

Created: Dec-09-16 2:24 PM | Data Range: 0000Q1-2016Q3

Note: Colors represent individual stations

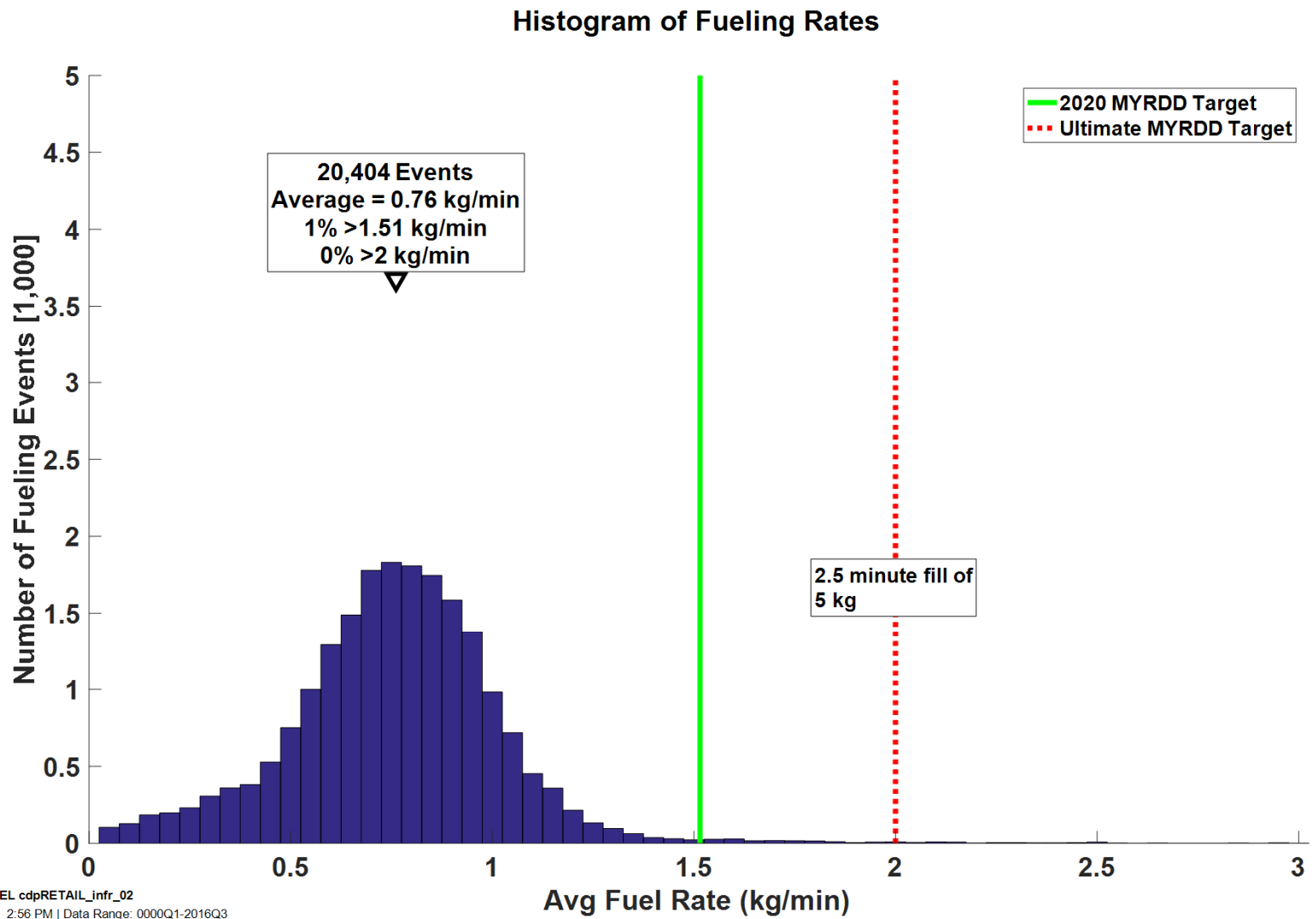


NREL cdpRETAIL_infr_58

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Note: Colors represent individual stations

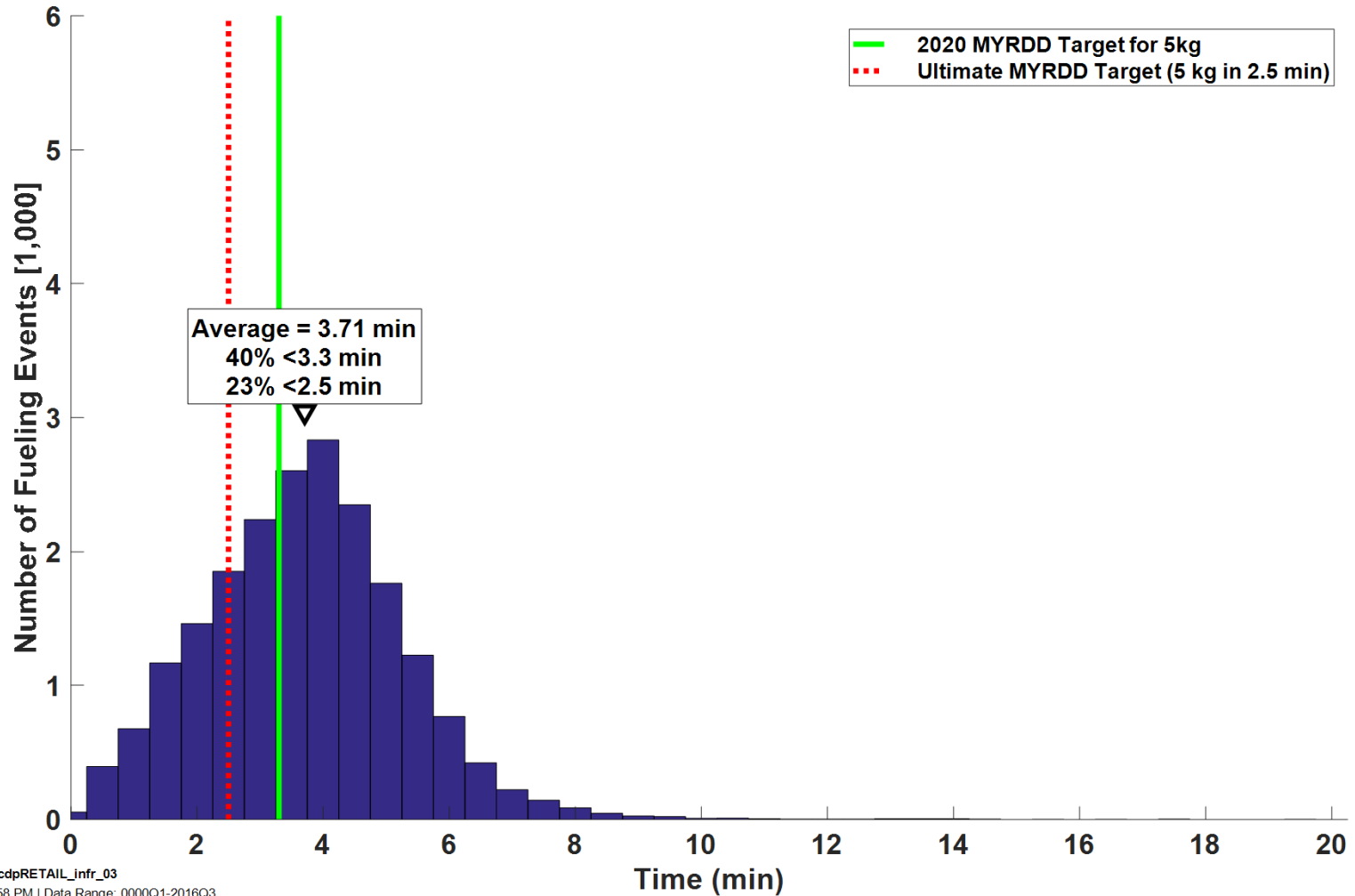
Histogram of Fueling Rates



NREL cdpRETAIL_infr_02

Created: Dec-09-16 2:56 PM | Data Range: 0000Q1-2016Q3

Histogram of Fueling Times

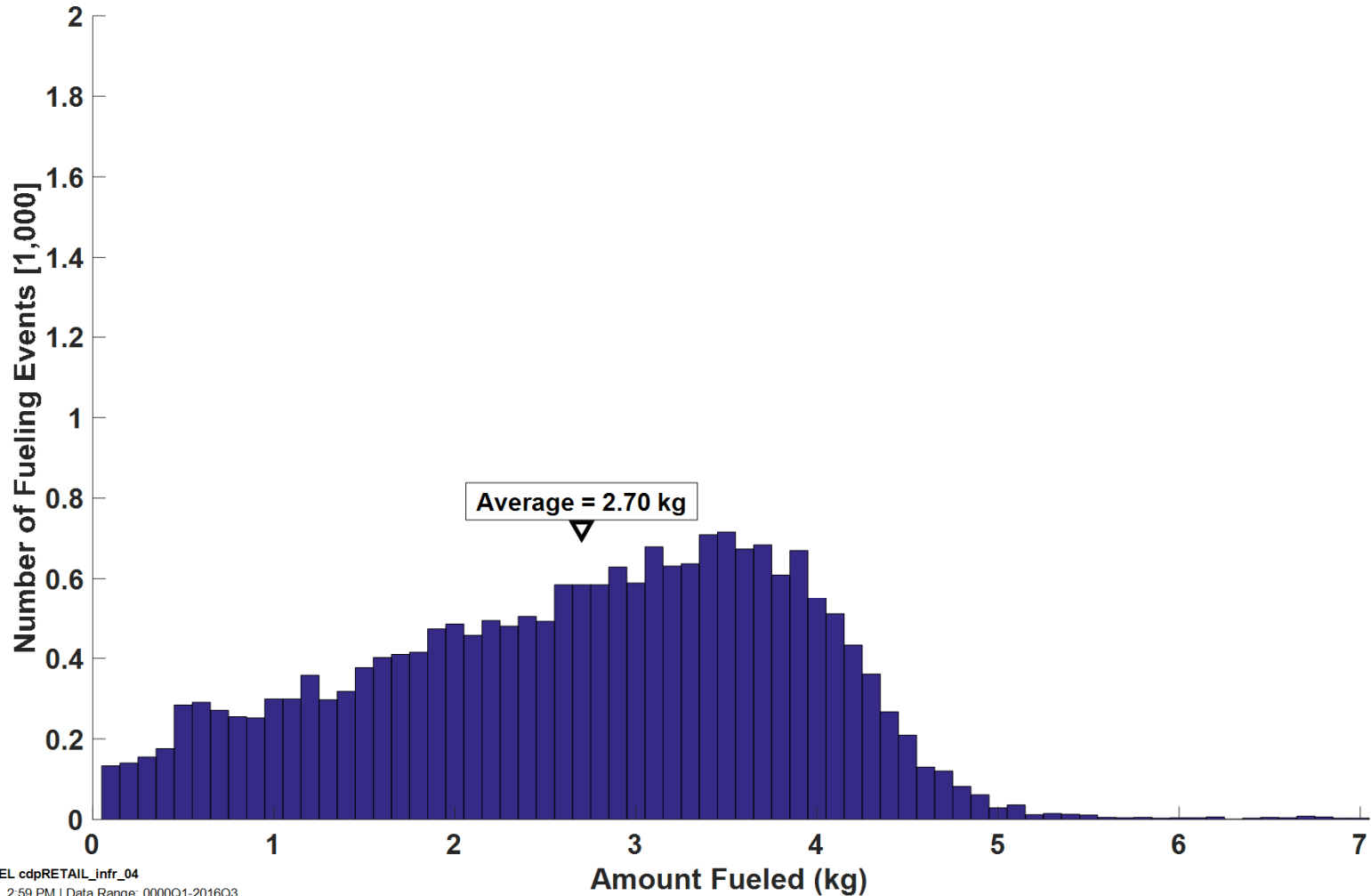



NREL cdpRETAIL_infr_03

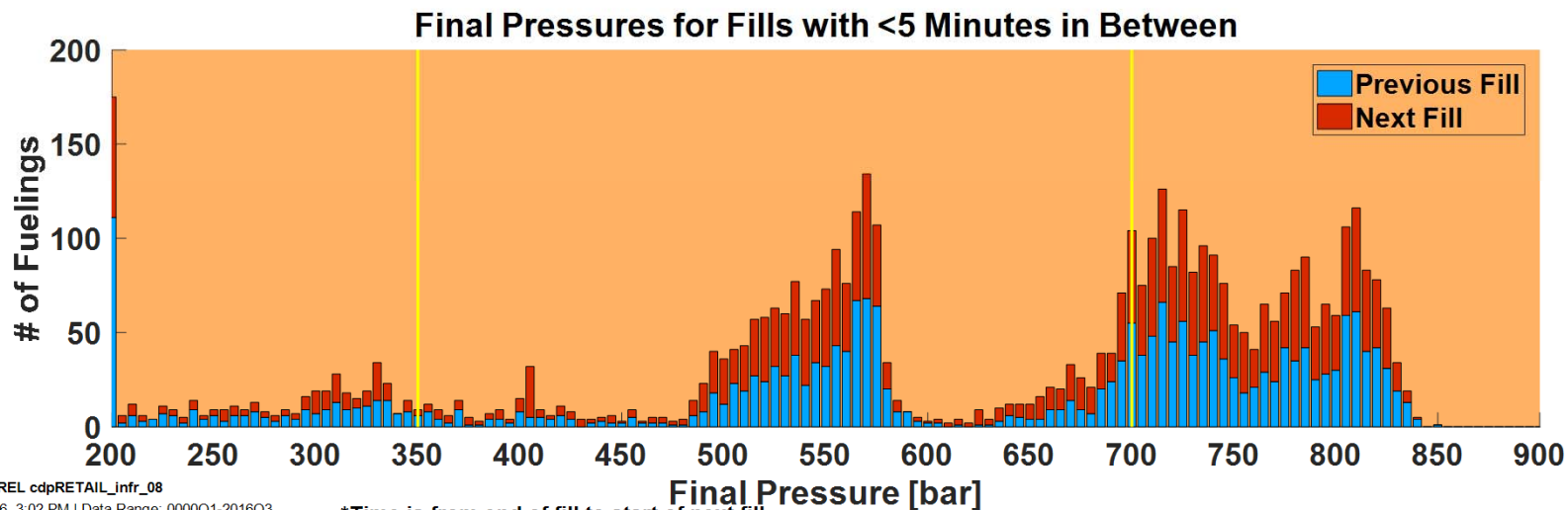
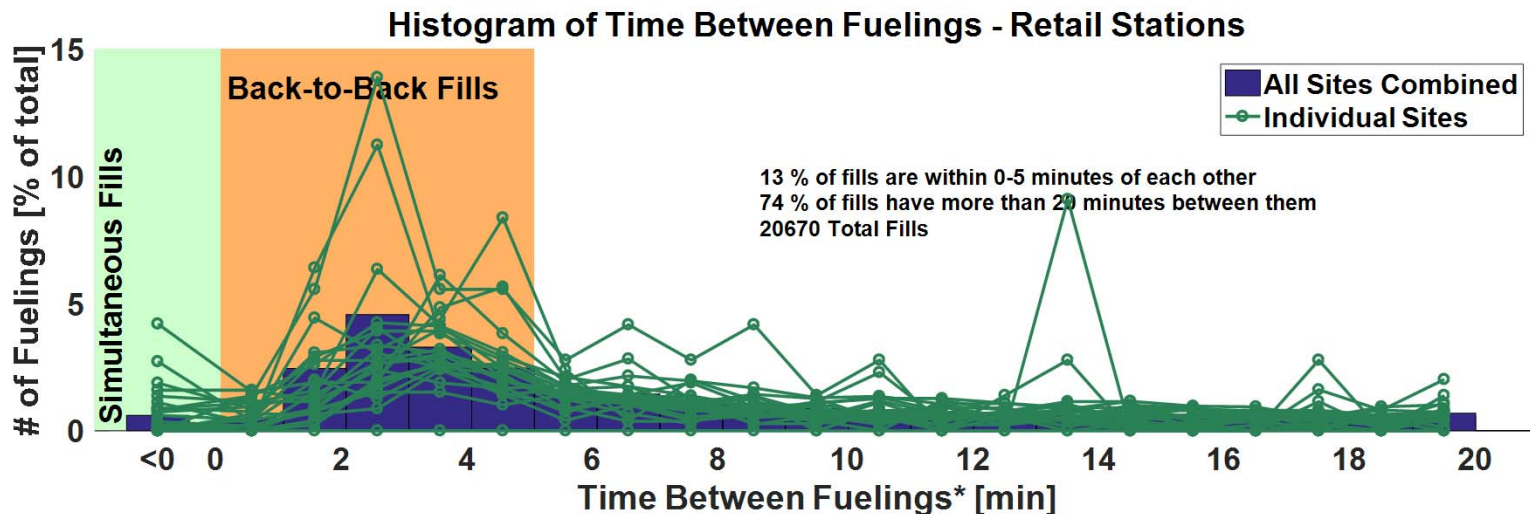
Created: Dec-09-16 2:58 PM | Data Range: 0000Q1-2016Q3

Histogram of Fueling Amounts

Histogram of Fueling Amounts

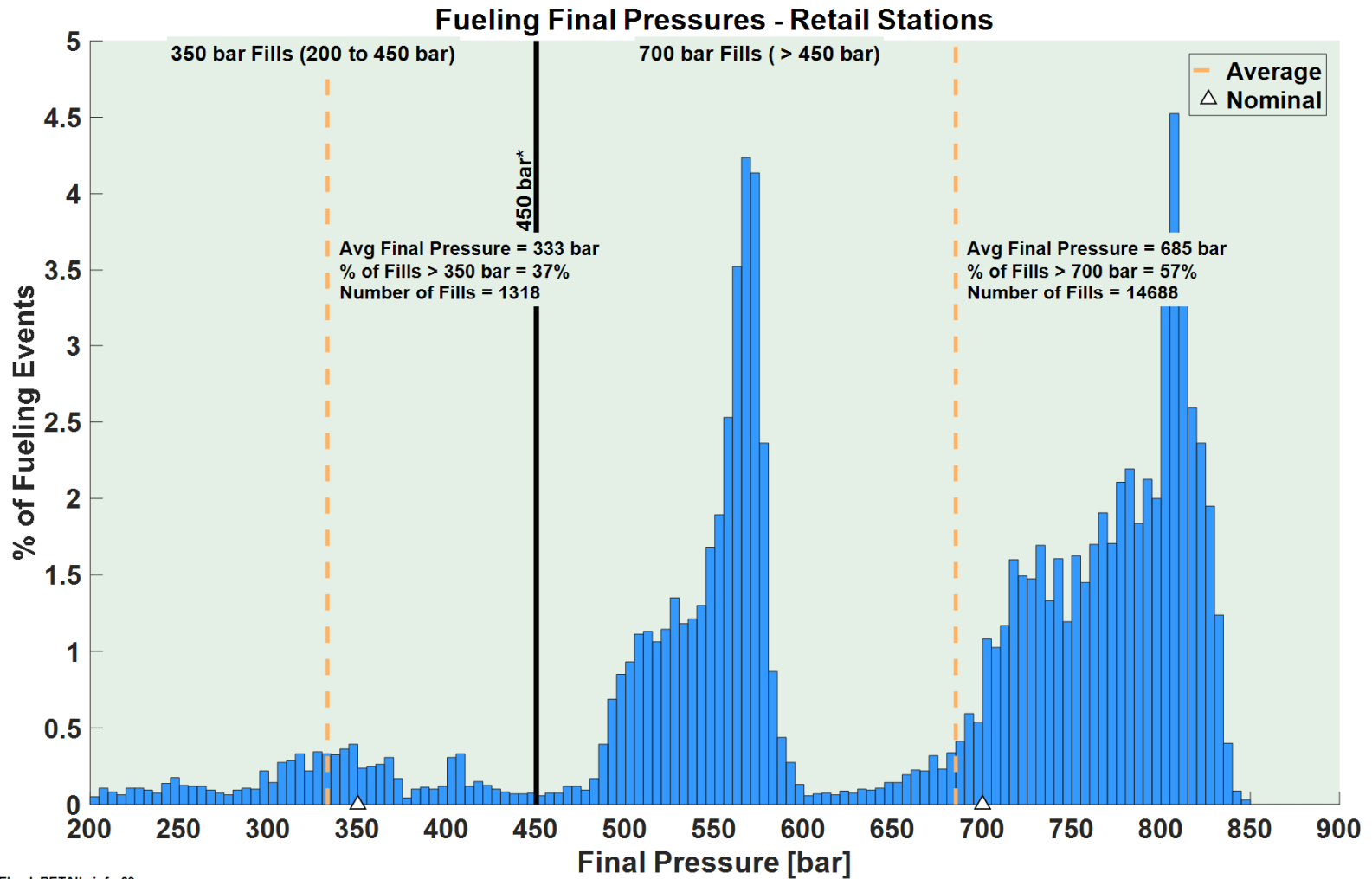


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NREL cdpRETAIL_infr_08

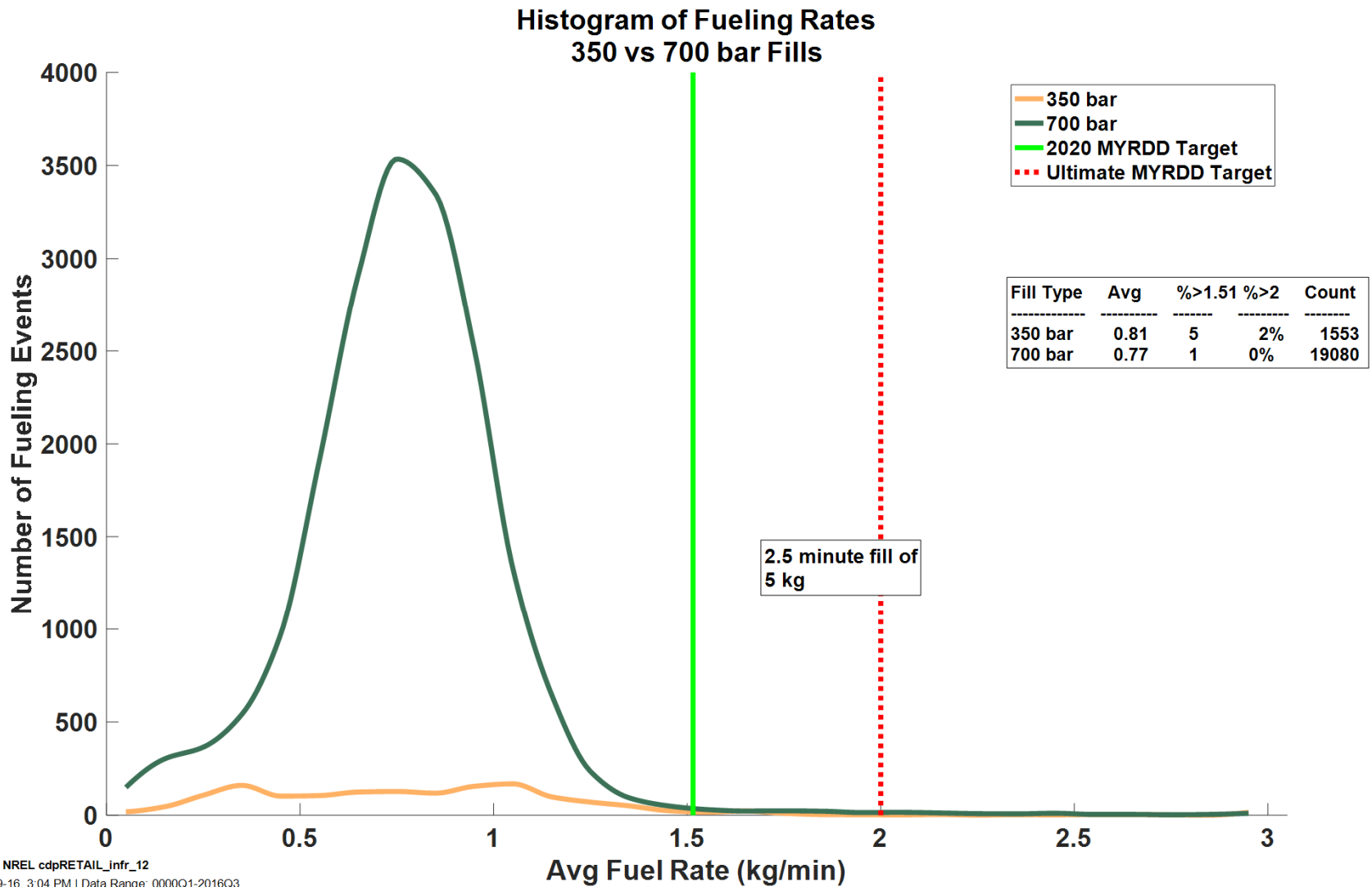
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NREL cdpRETAIL_infr_09

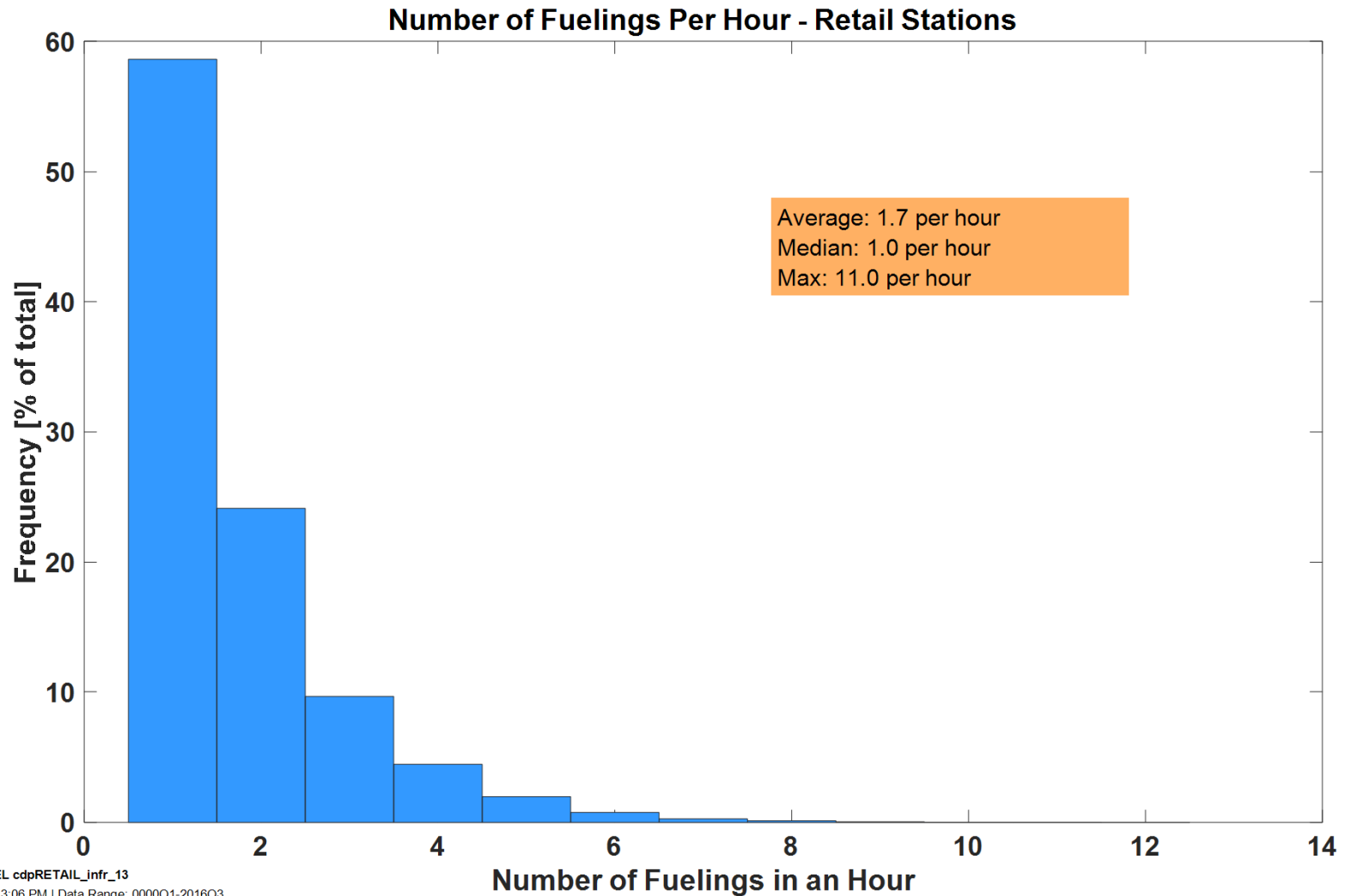
Created: Dec-09-16 3:04 PM | Data Range: 0000Q1-2016Q3

*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.



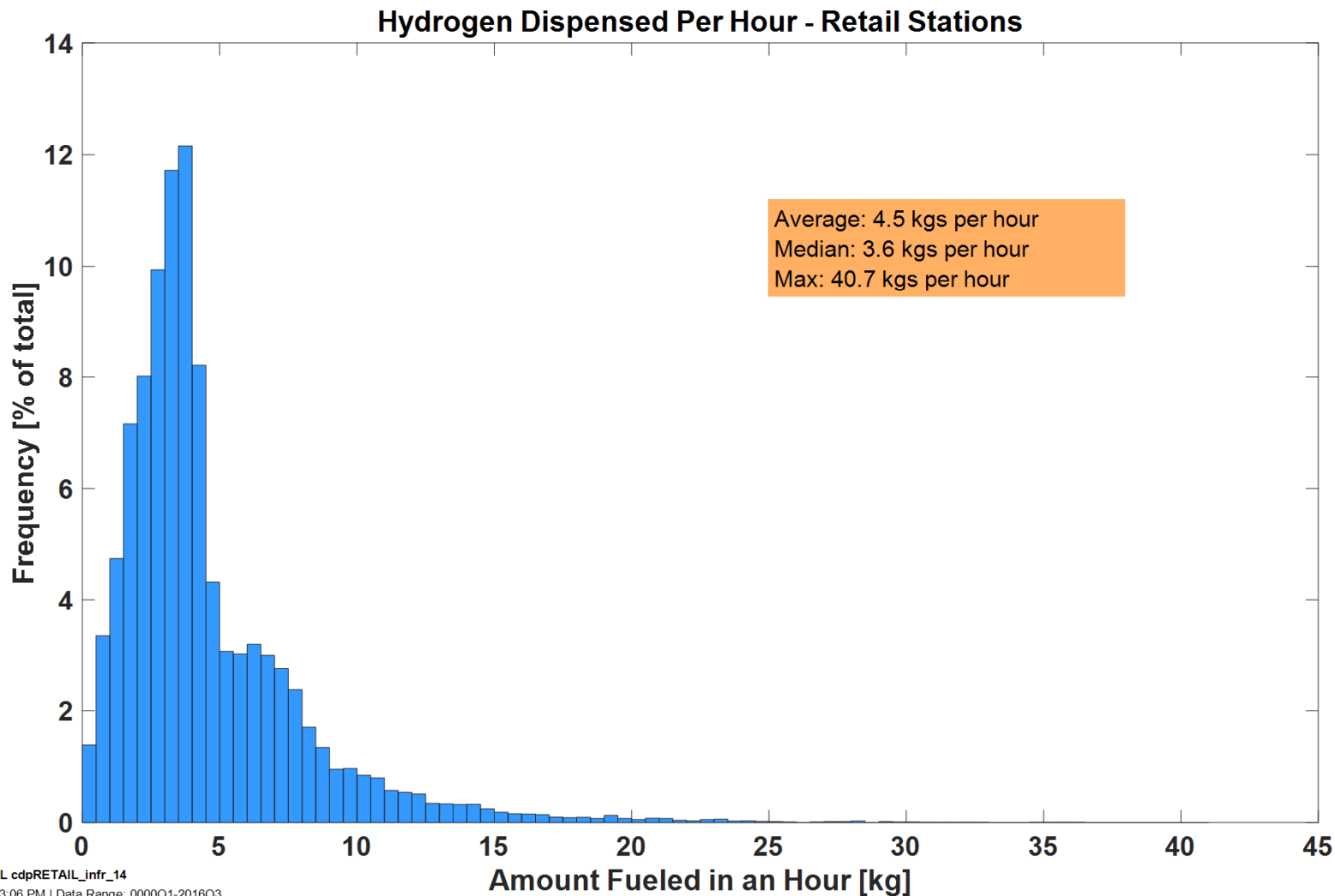
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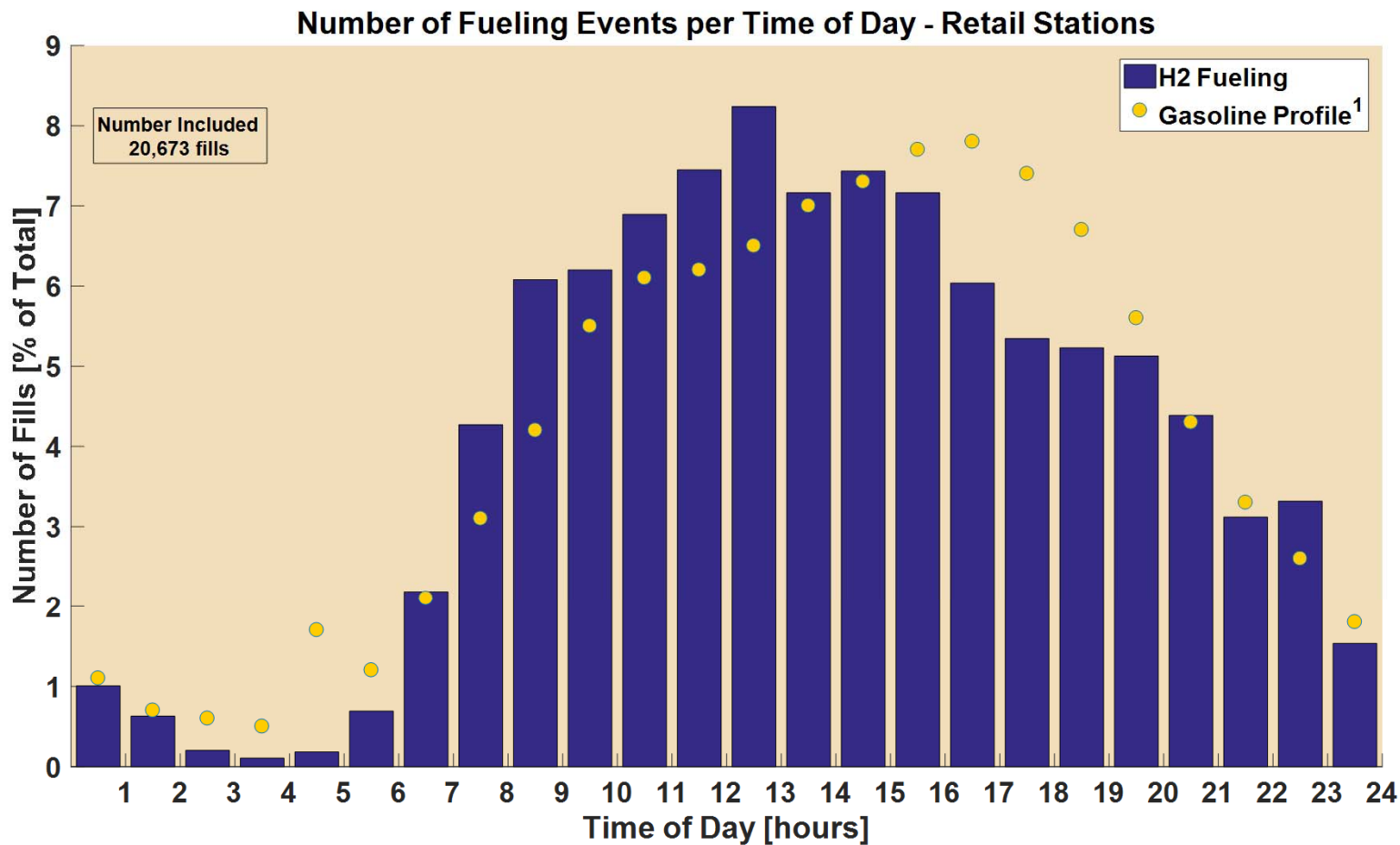
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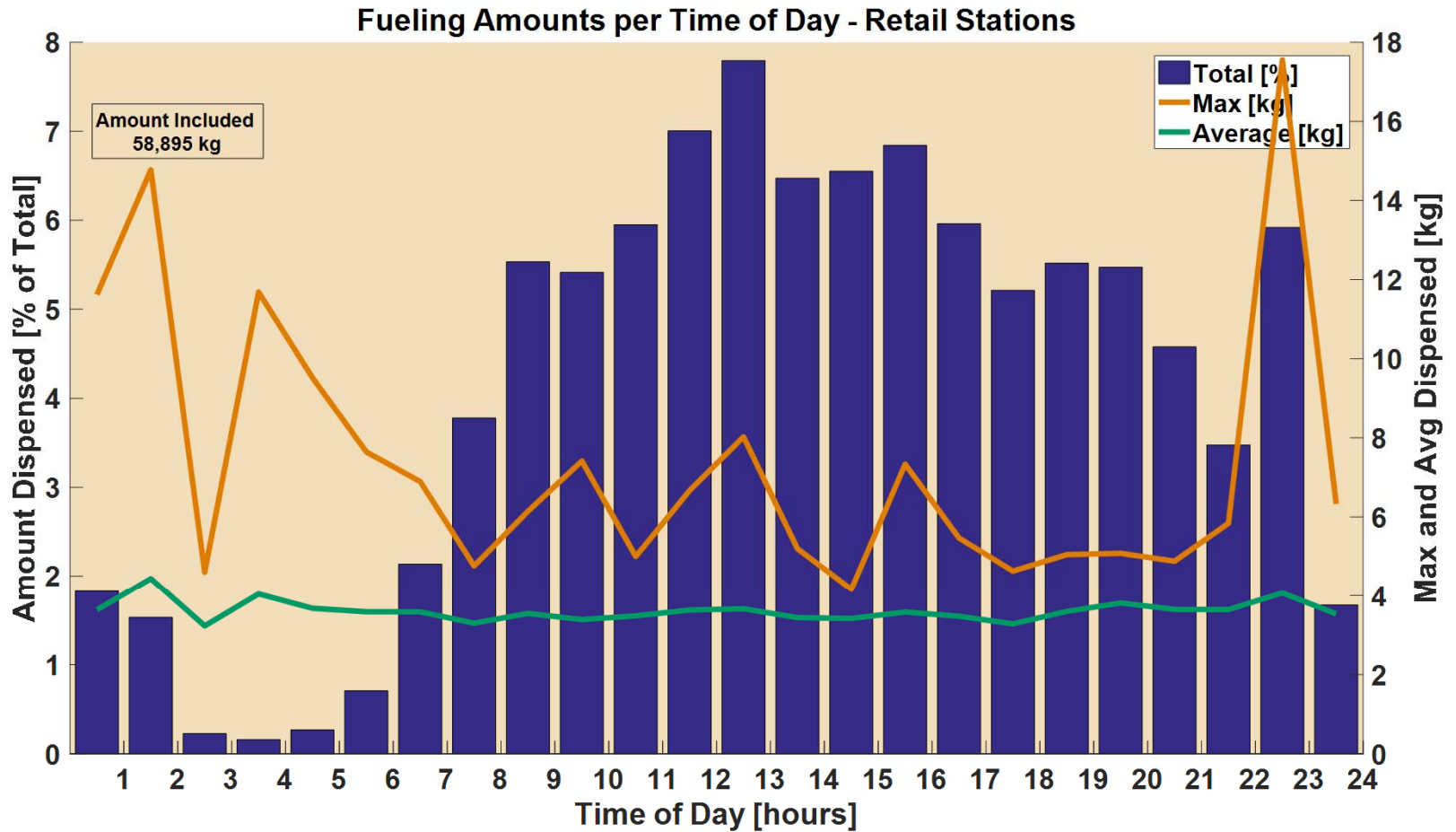


NREL cdpRETAIL_infr_14

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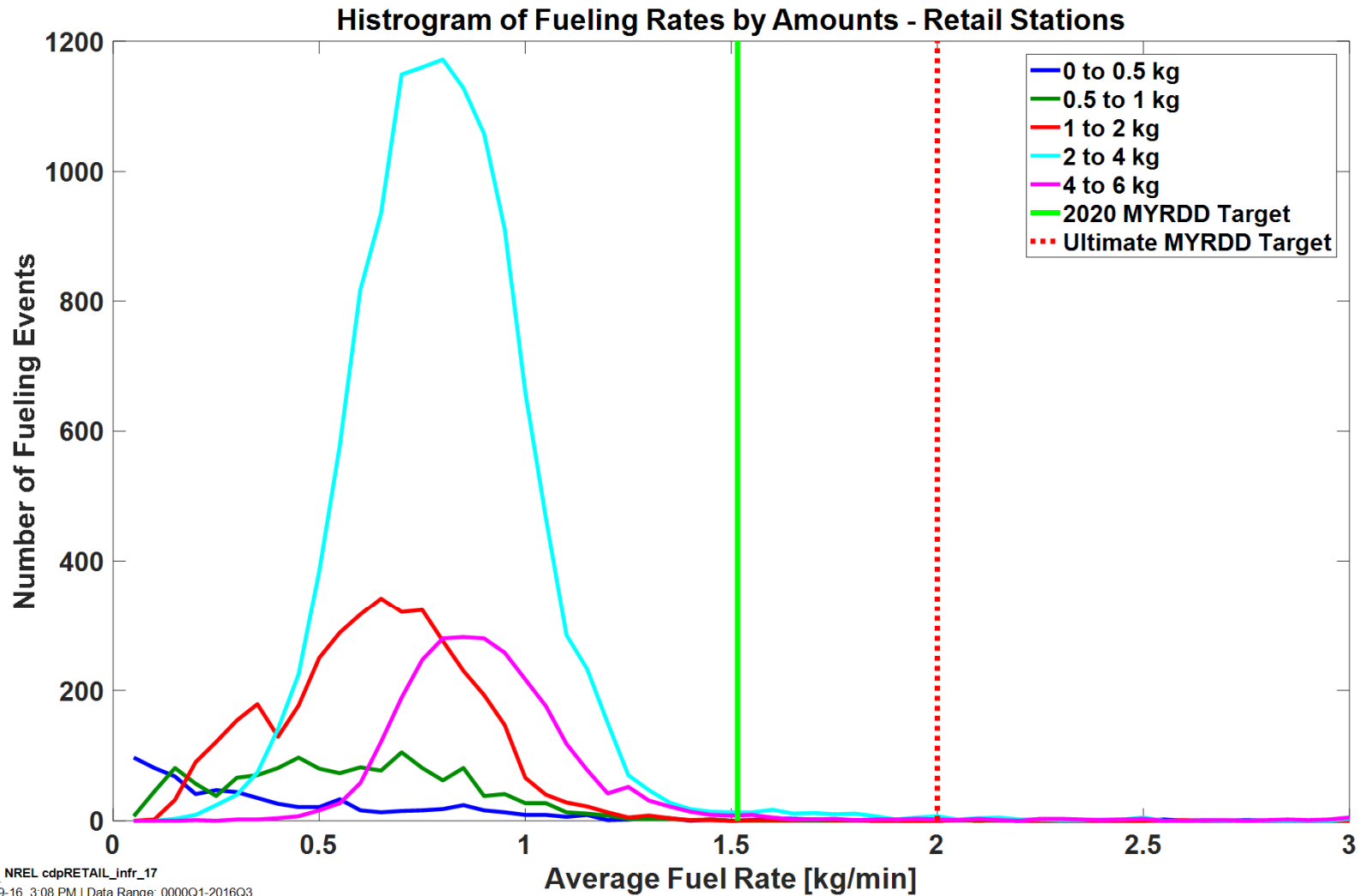


1. Friday Chevron profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.

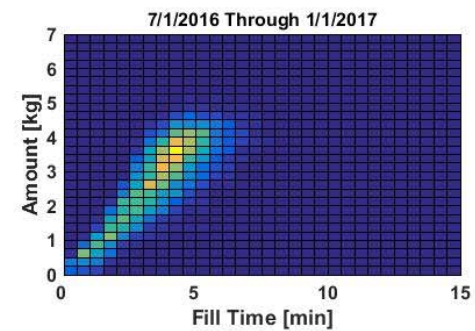
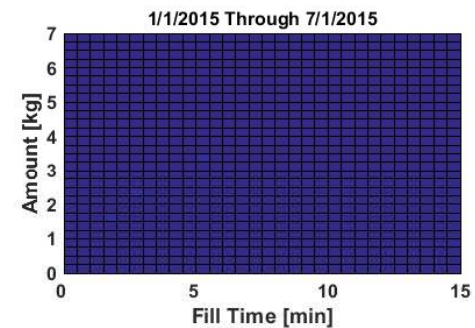
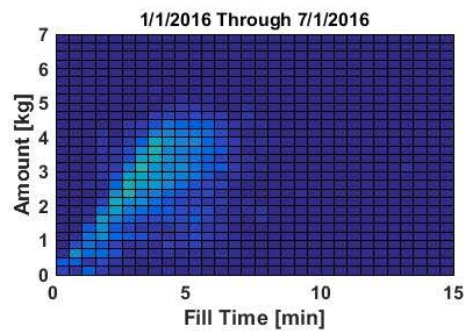
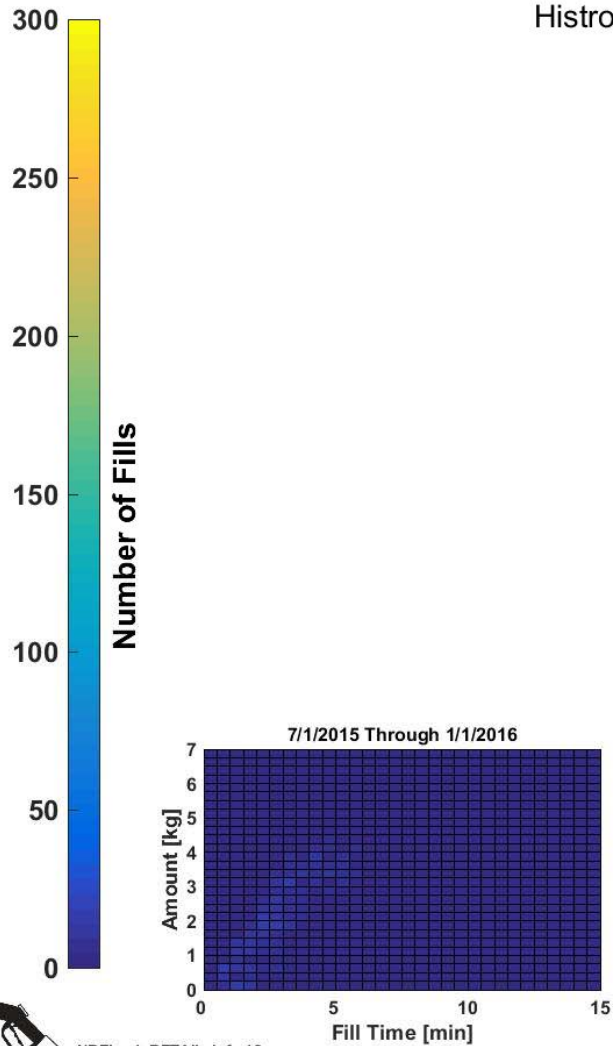


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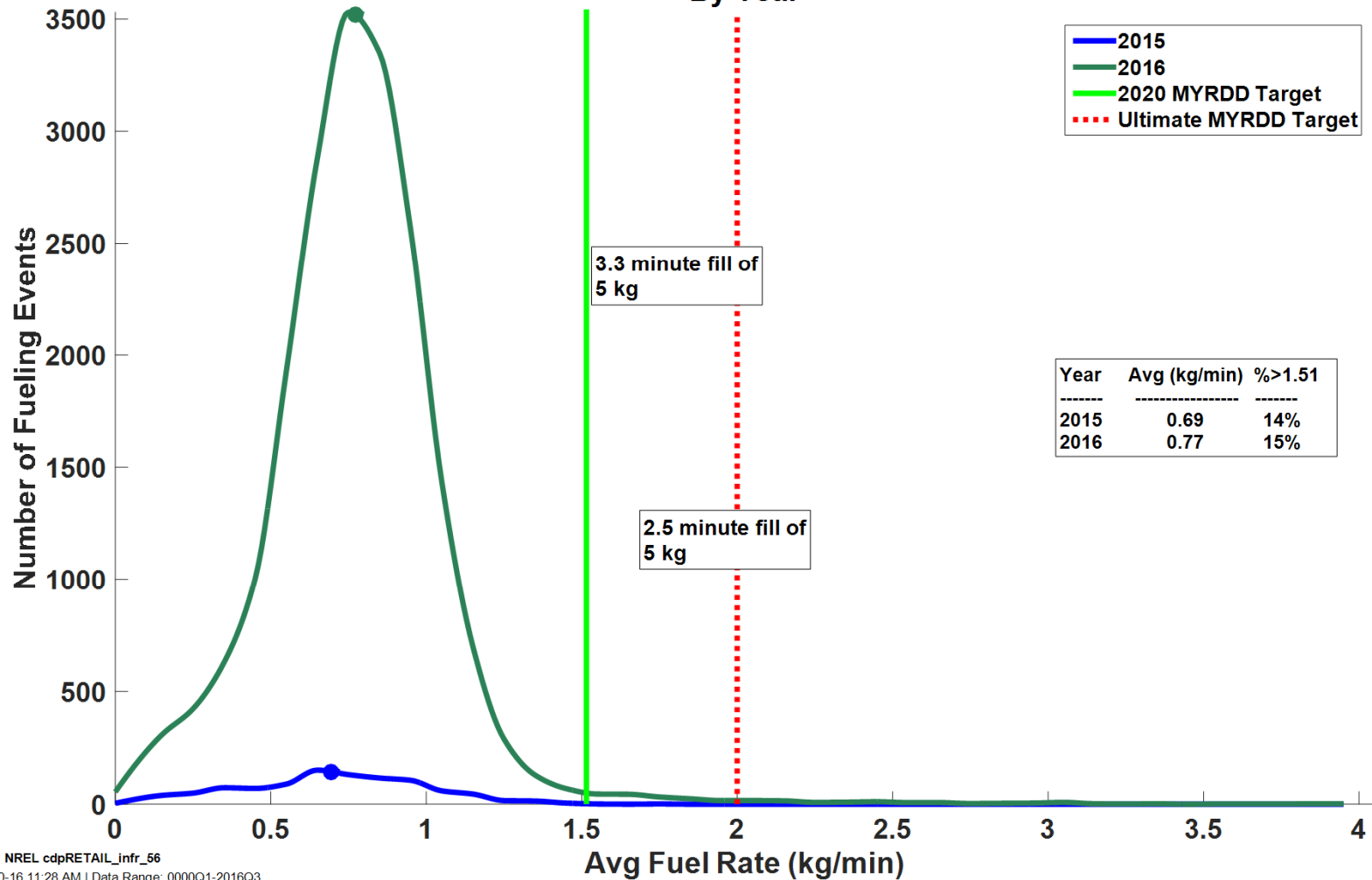



Histogram of Fueling Amount Vs Time - Retail Stations



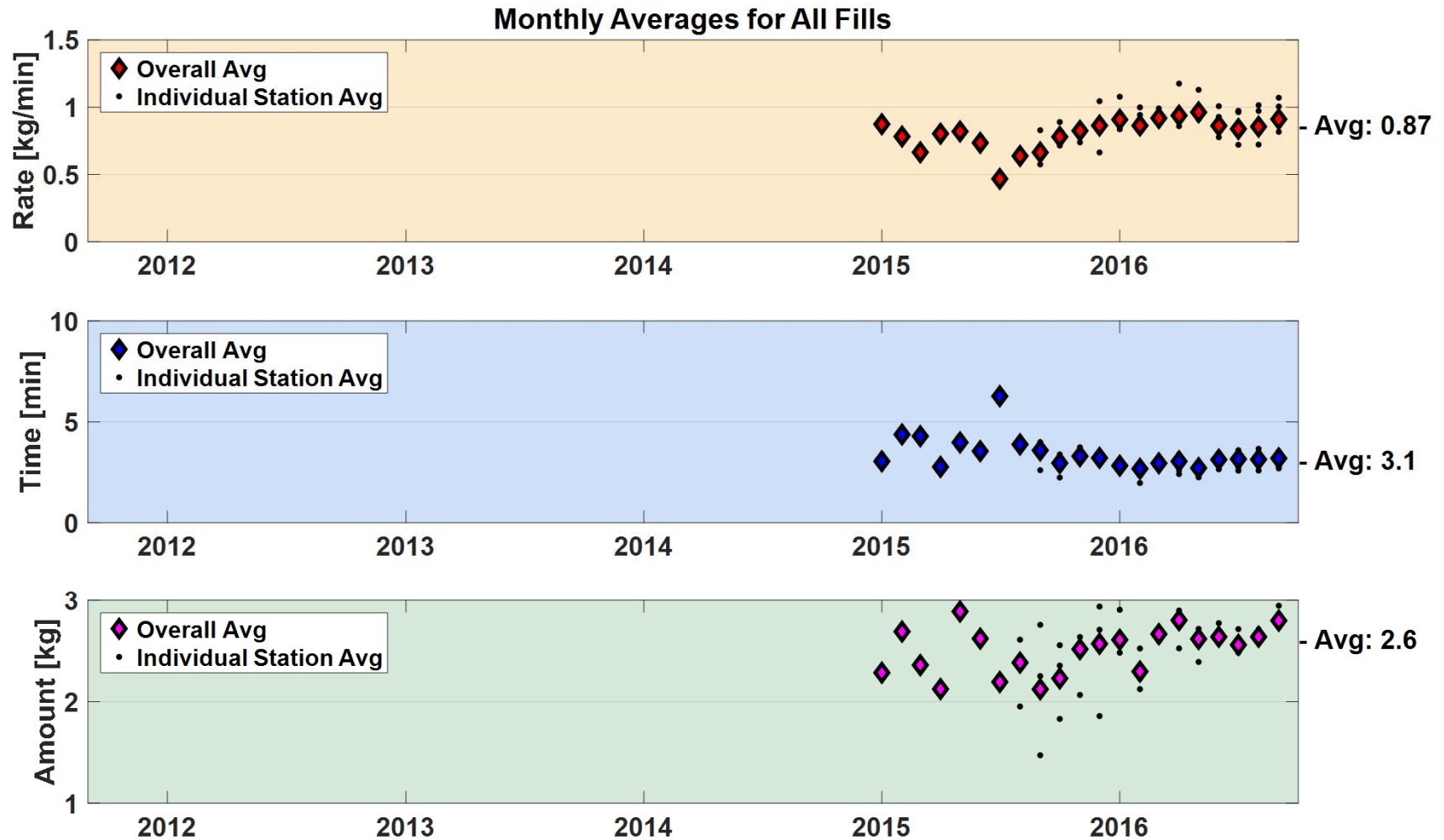
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Created: Dec-21-16 9:44 AM | Data Range: 0000Q1-2016Q3

Histogram of Fueling Rates By Year



 NREL cdpRETAIL_infr_56
 Created: Dec-20-16 11:28 AM | Data Range: 0000Q1-2016Q3

Monthly Averages: All Fills

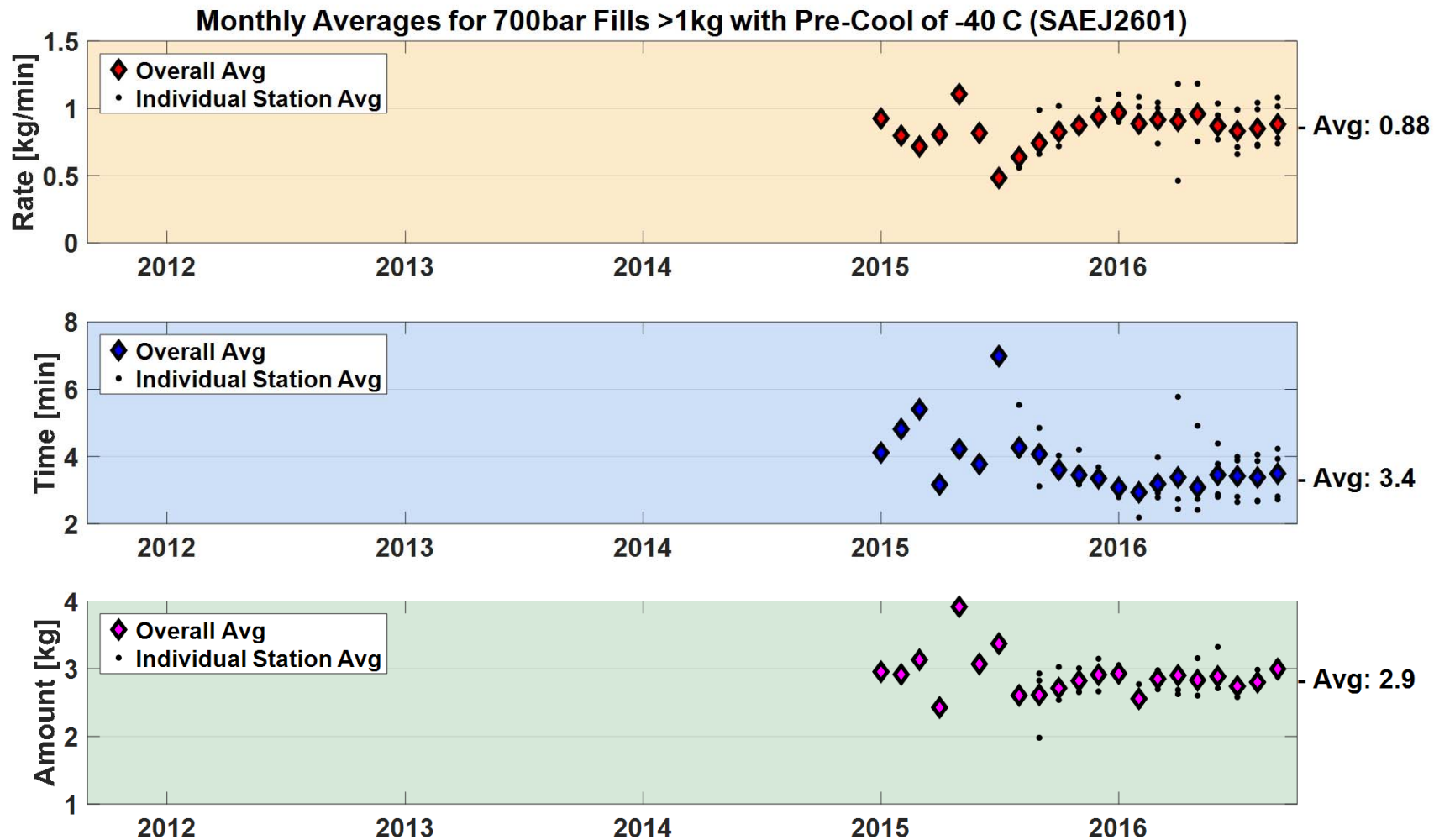


NREL cdpRETAIL_infr_55

Created: Dec-07-16 1:25 PM | Data Range: 2014Q3-2016Q3

CDP-INFR-57

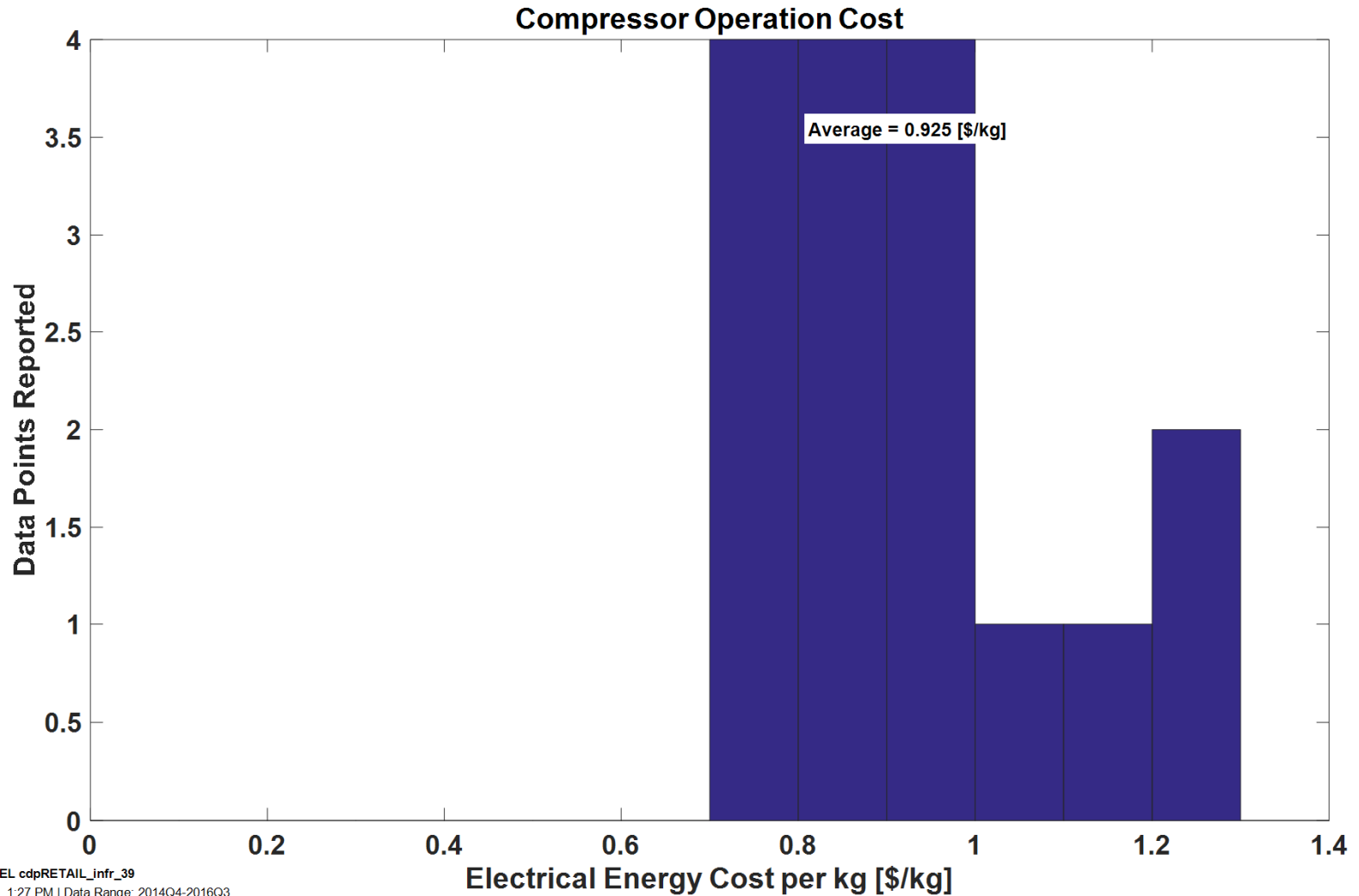
Monthly Averages: 700 bar Fills >1 kg with Pre-Cool of -40°C



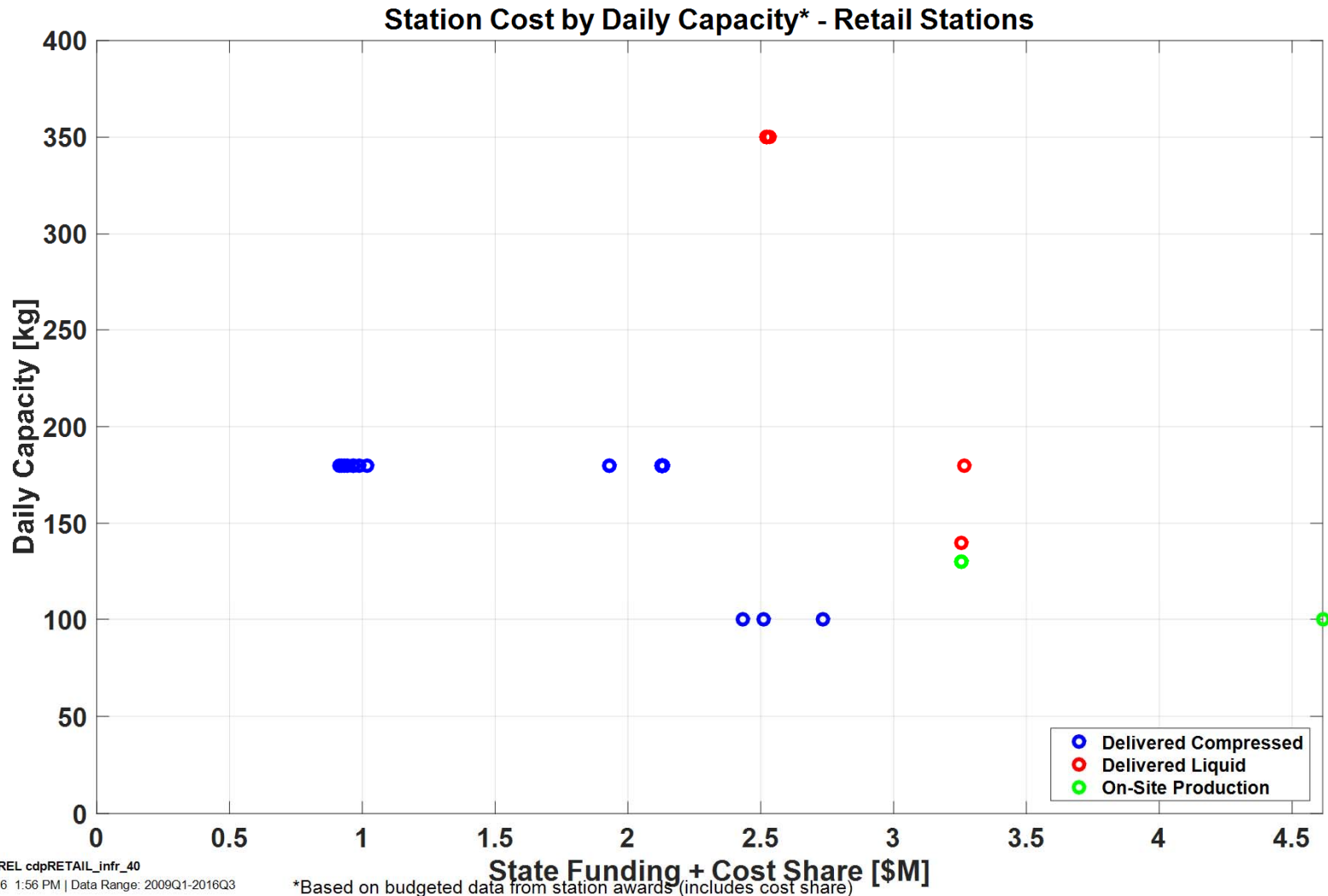
NREL cdpRETAIL_infr_57

Created: Dec-09-16 3:15 PM | Data Range: 2014Q3-2016Q3

Cost

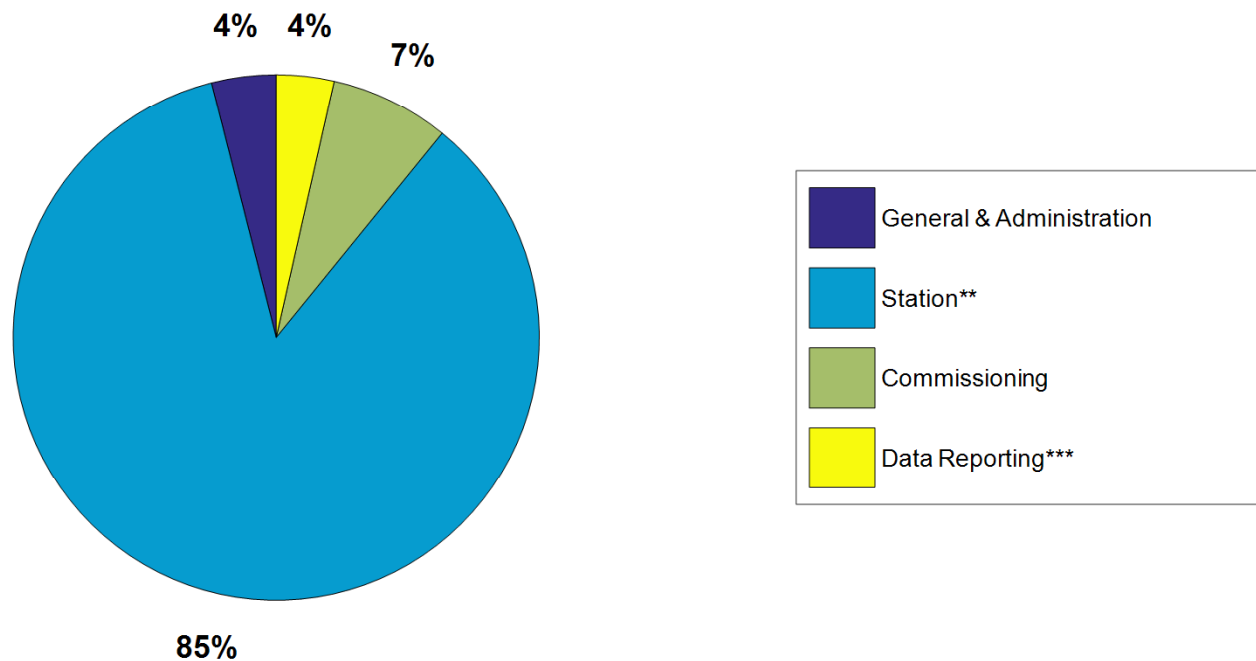


Station Cost by Daily Capacity



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



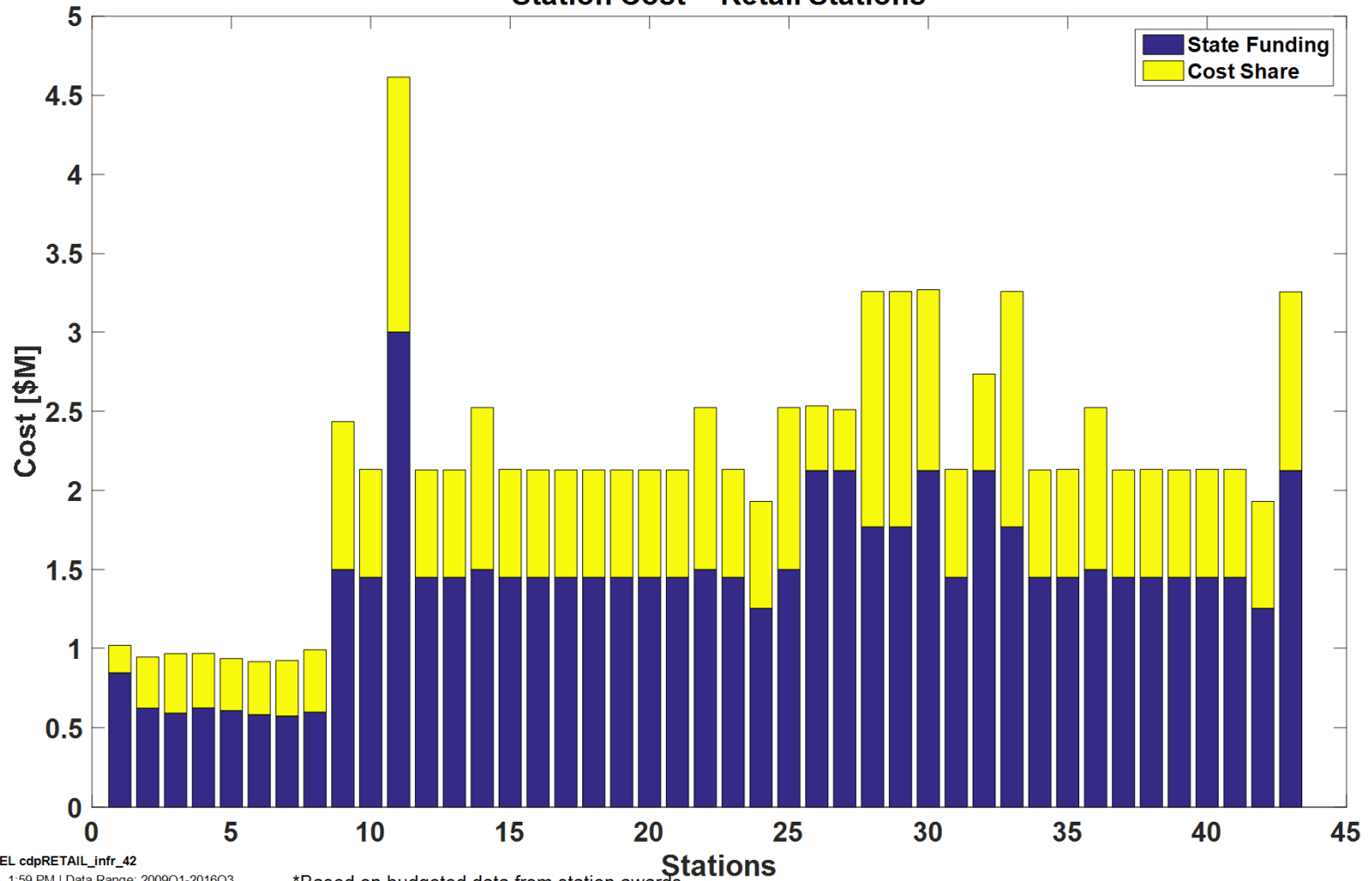
NREL cdpRETAIL_infr_41


Created: Dec-16-16 1:58 PM | Data Range: 2009Q1-2016Q3

CDP-INFR-42

Station Cost

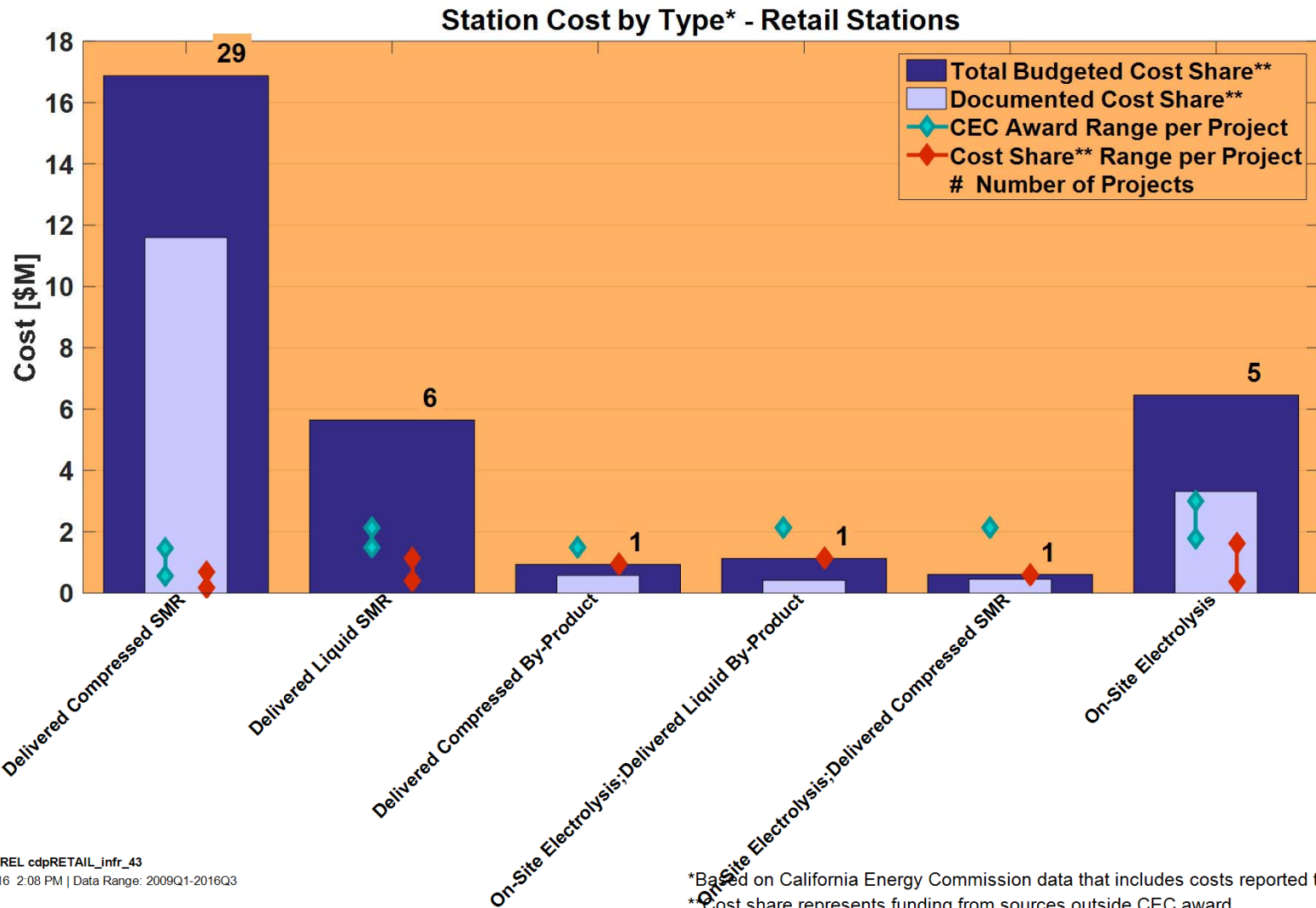
Station Cost* - Retail Stations



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

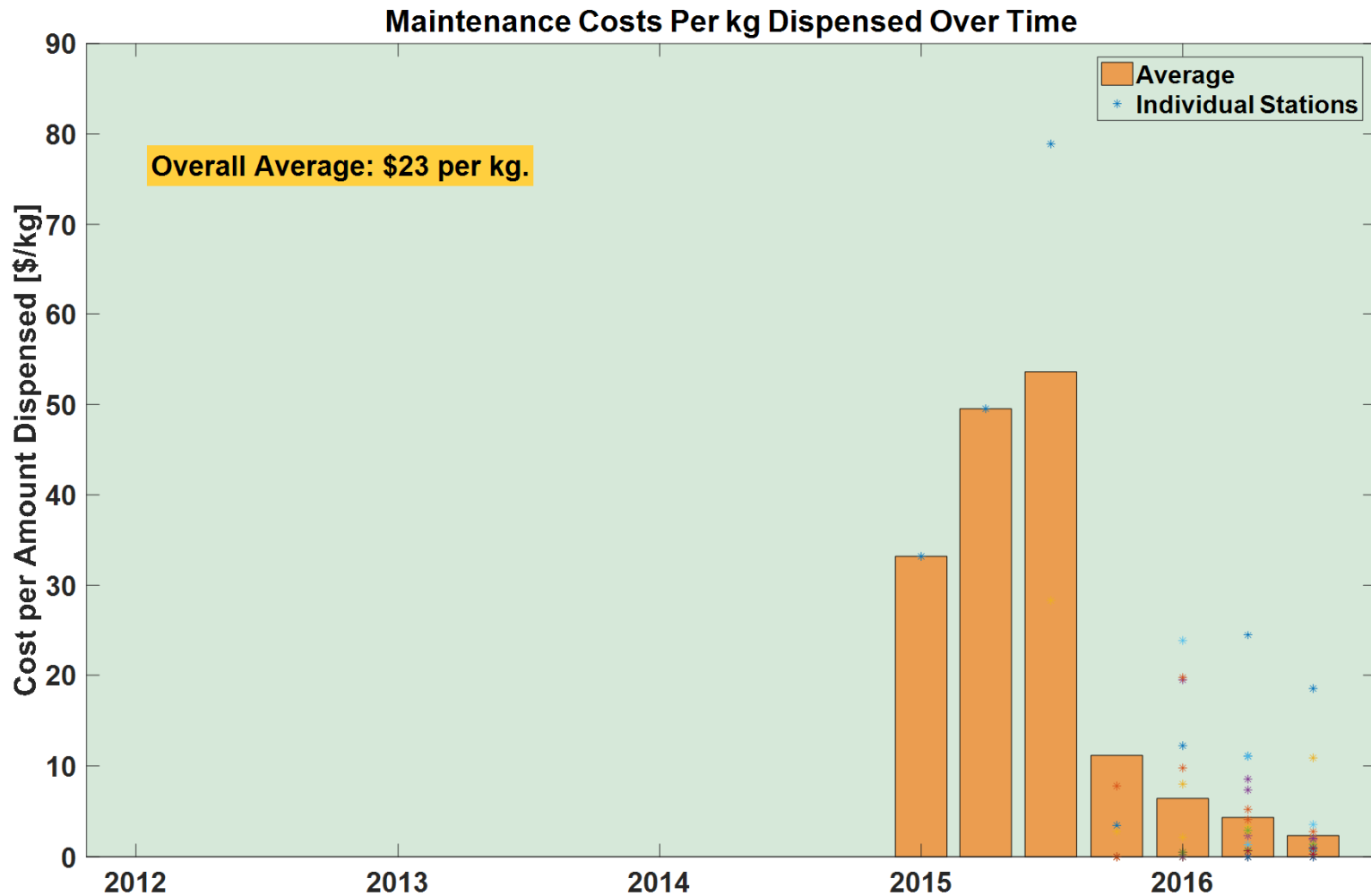
*Based on budgeted data from station awards.

Station Cost by Type



*Based on California Energy Commission data that includes costs reported through 2016Q3.
**Cost share represents funding from sources outside CEC award.

Maintenance Cost per kg of Hydrogen Dispensed

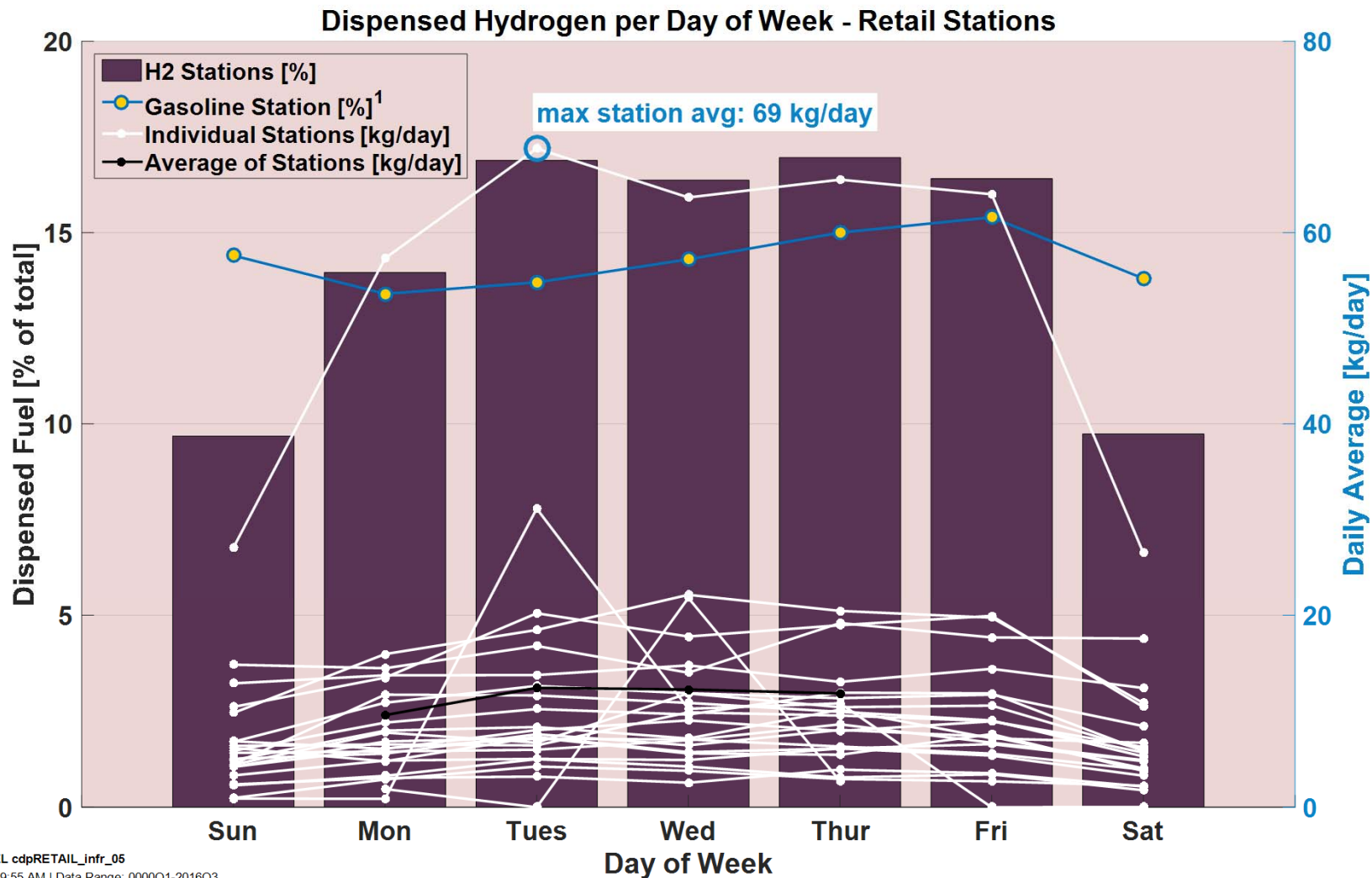


NREL cdpRETAIL_infr_53

Created: Dec-07-16 1:26 PM | Data Range: 2014Q3-2016Q3

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

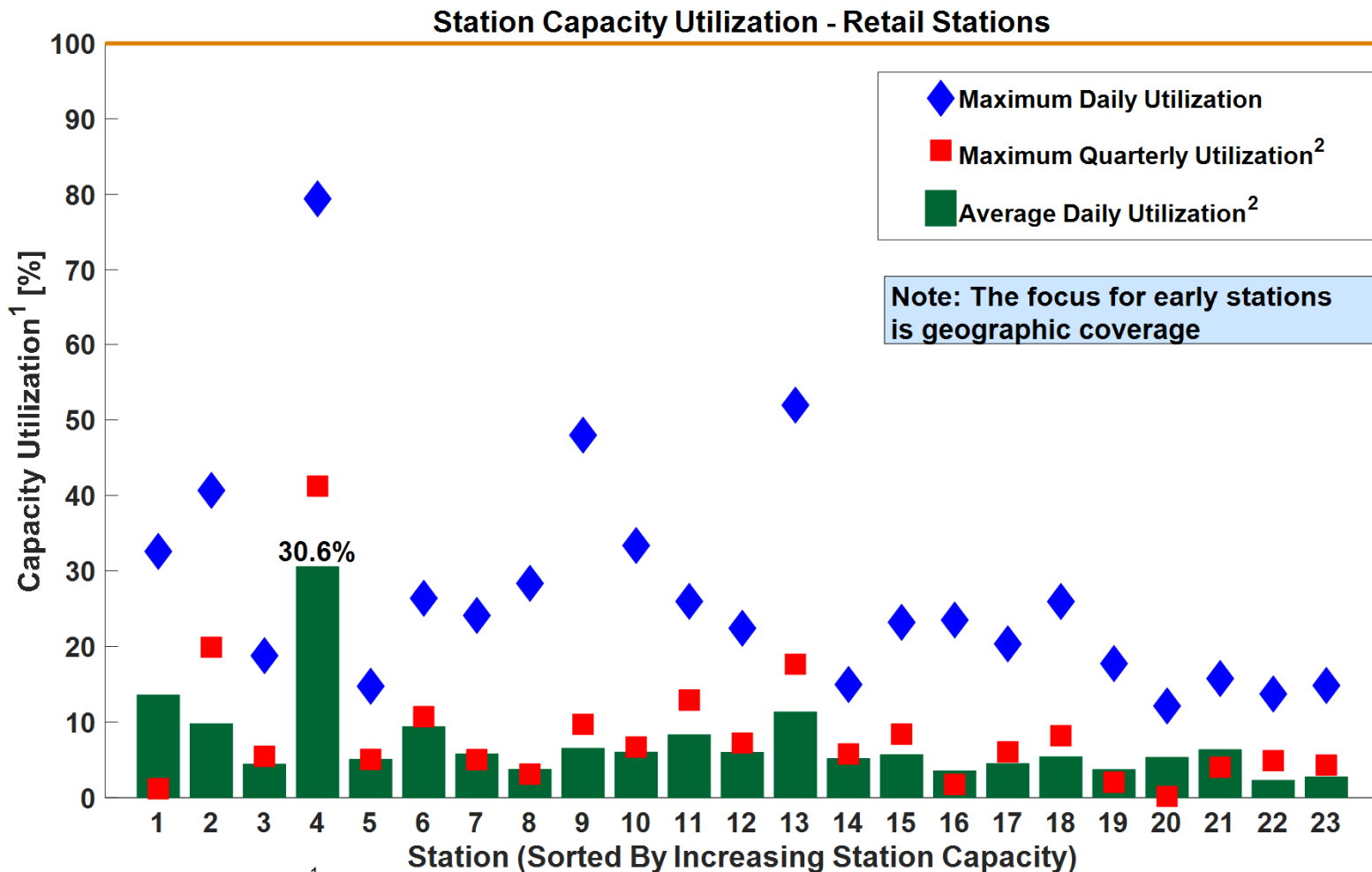
Utilization




NREL cdpRETAIL_infr_05

Created: Dec-21-16 9:55 AM | Data Range: 0000Q1-2016Q3

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



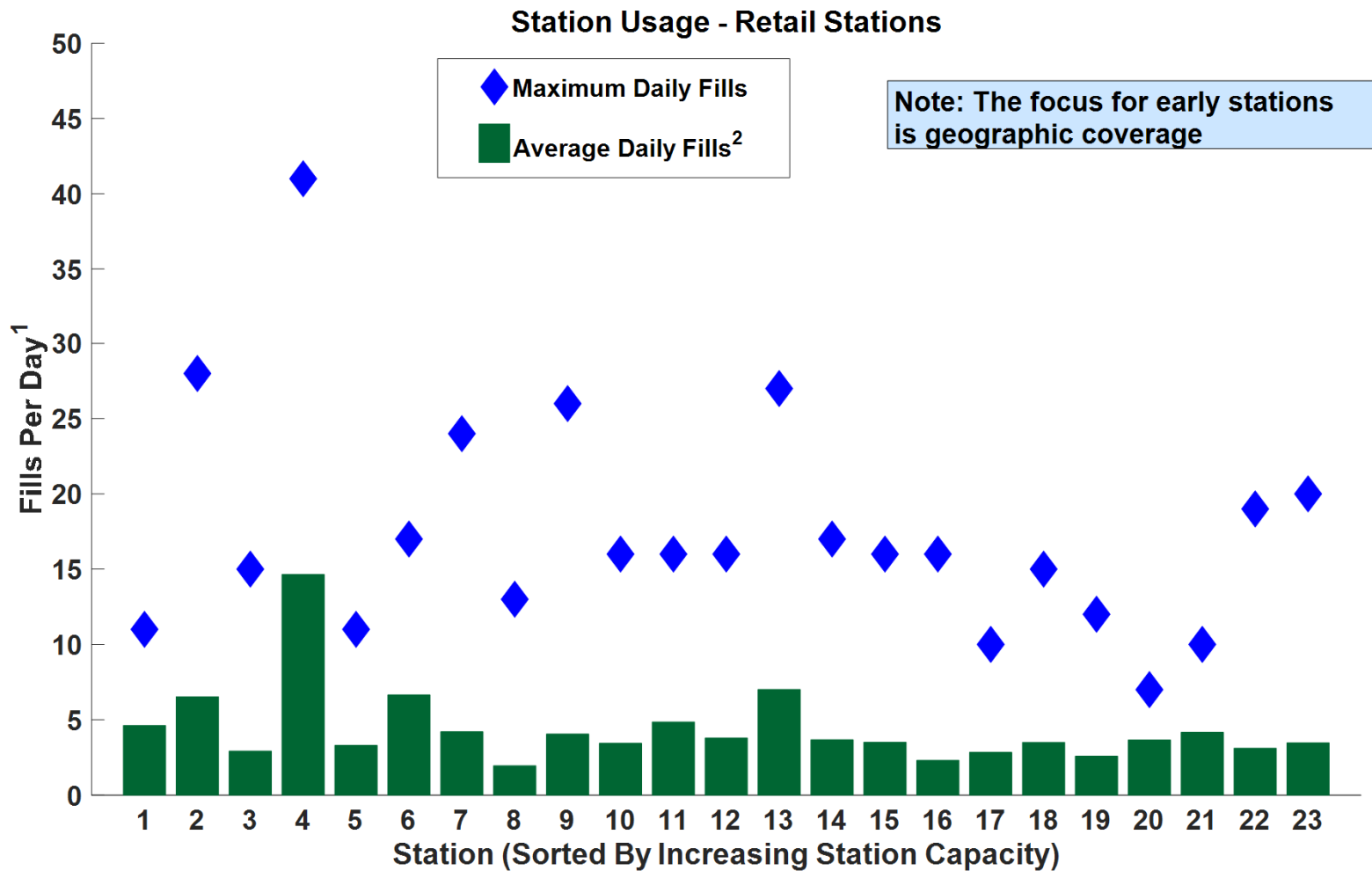
 NREL cdpRETAIL_infr_06
Created: Dec-09-16 3:01 PM | Data Range: 0000Q1-2016Q3


¹ Station 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.

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

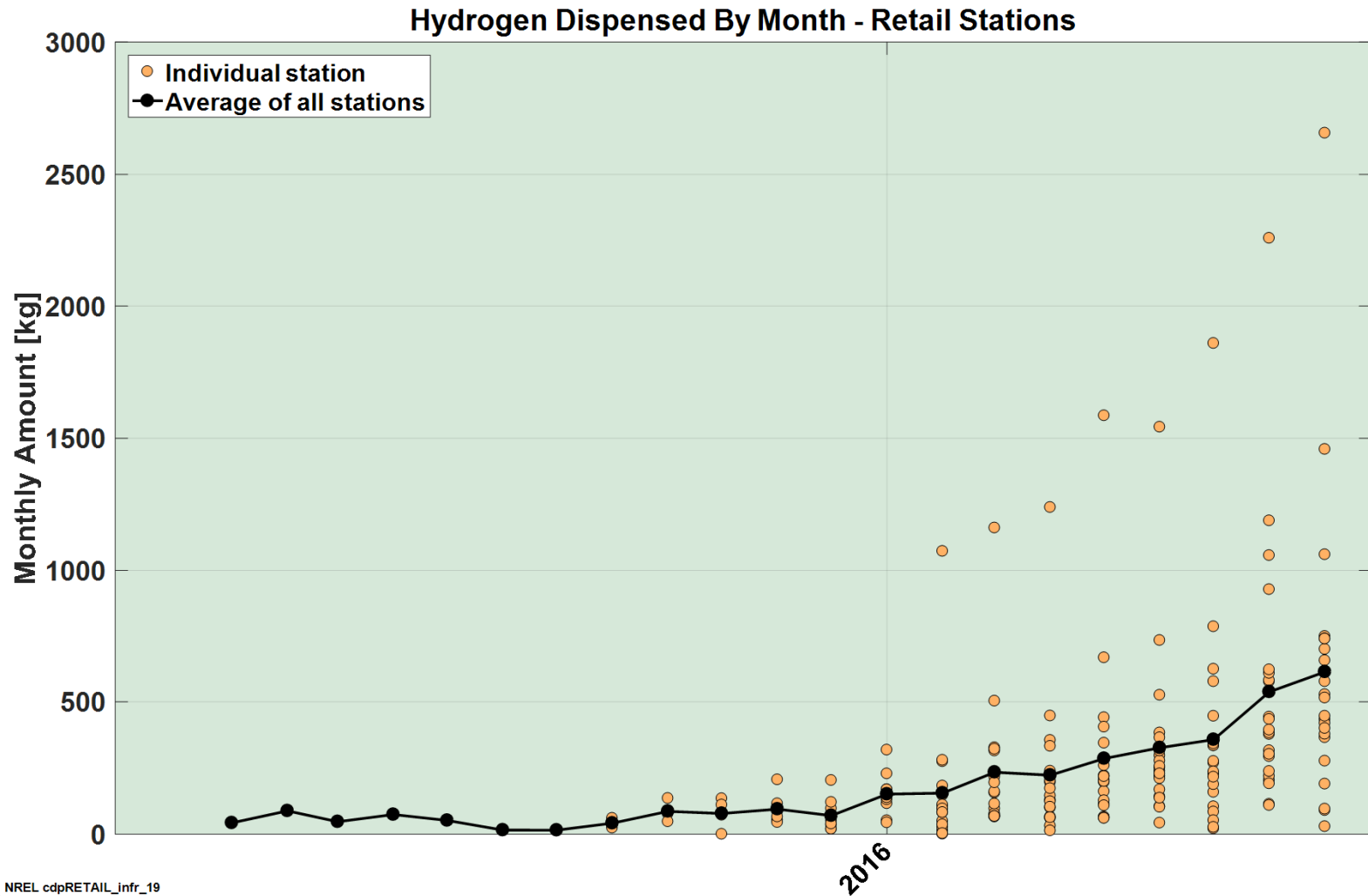
CDP-INFR-07


Station Usage



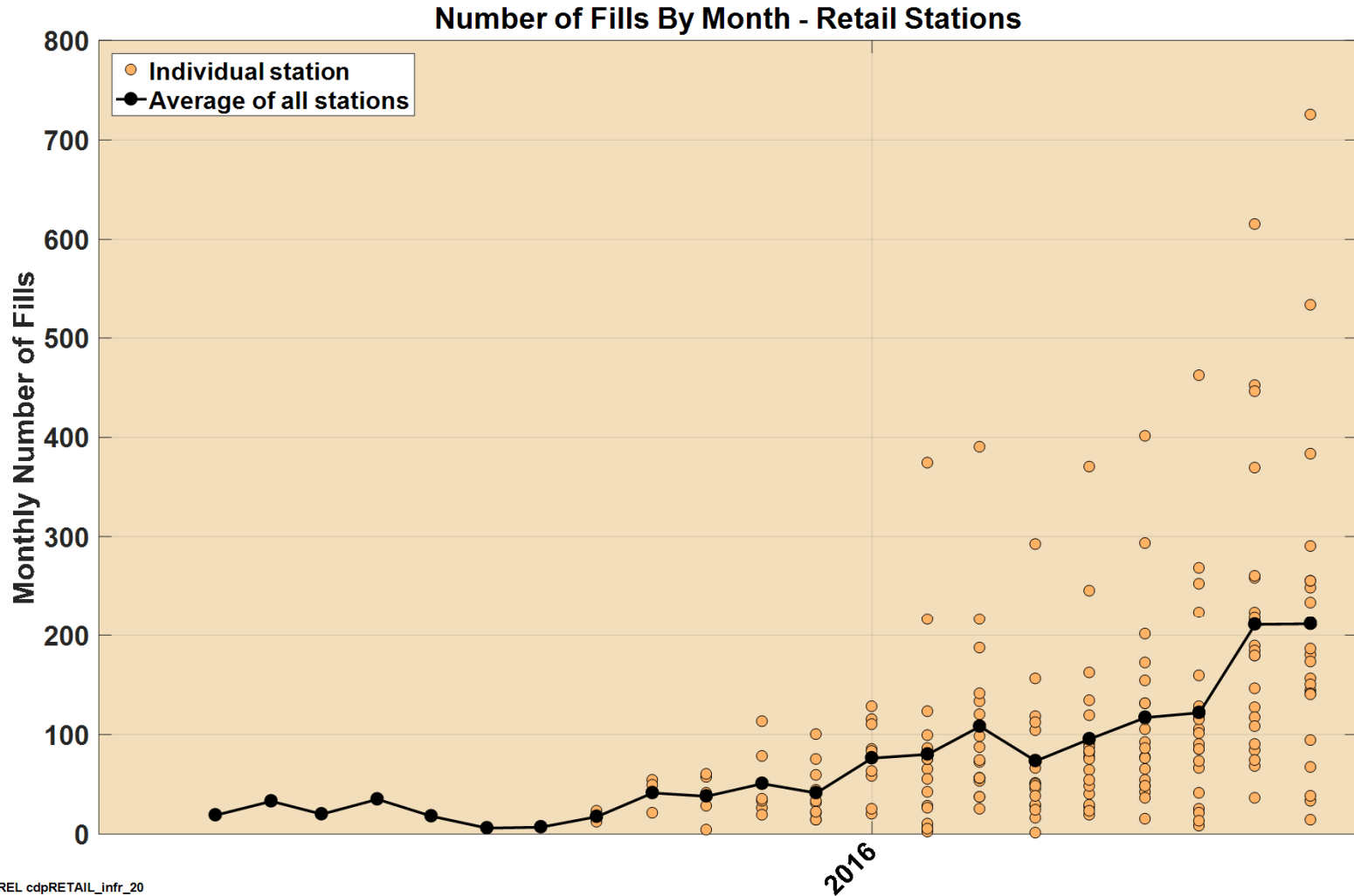
 NREL cdpRETAIL_infr_07
 Created: Dec-09-16 3:01 PM | Data Range: 0000Q1-2016Q3


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

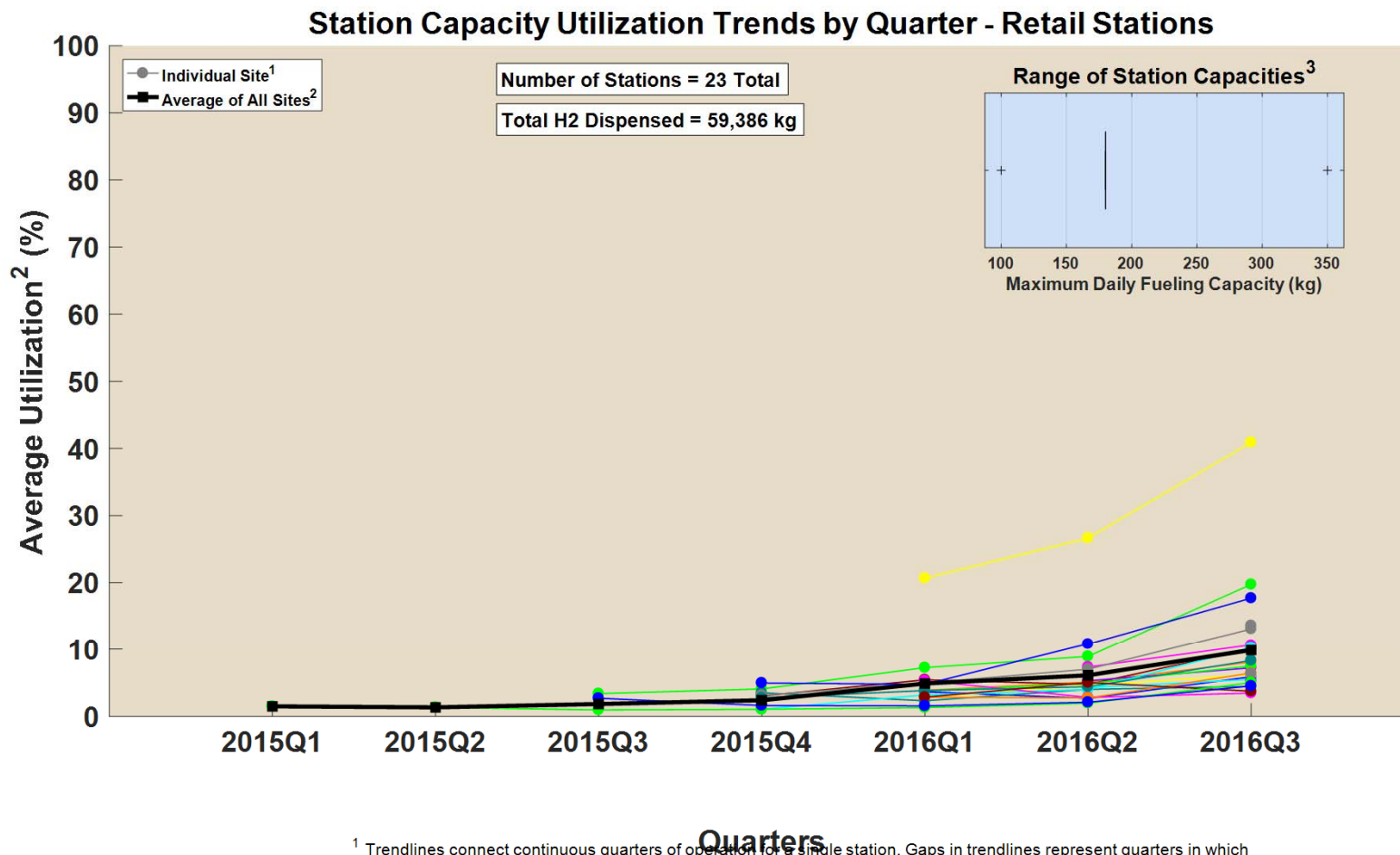


 NREL cdpRETAIL_infr_19
Created: Dec-09-16 3:09 PM | Data Range: 0000Q1-2016Q3

Number of Fills by Month



 NREL cdpRETAIL_infr_20
Created: Dec-09-16 3:10 PM | Data Range: 0000Q1-2016Q3



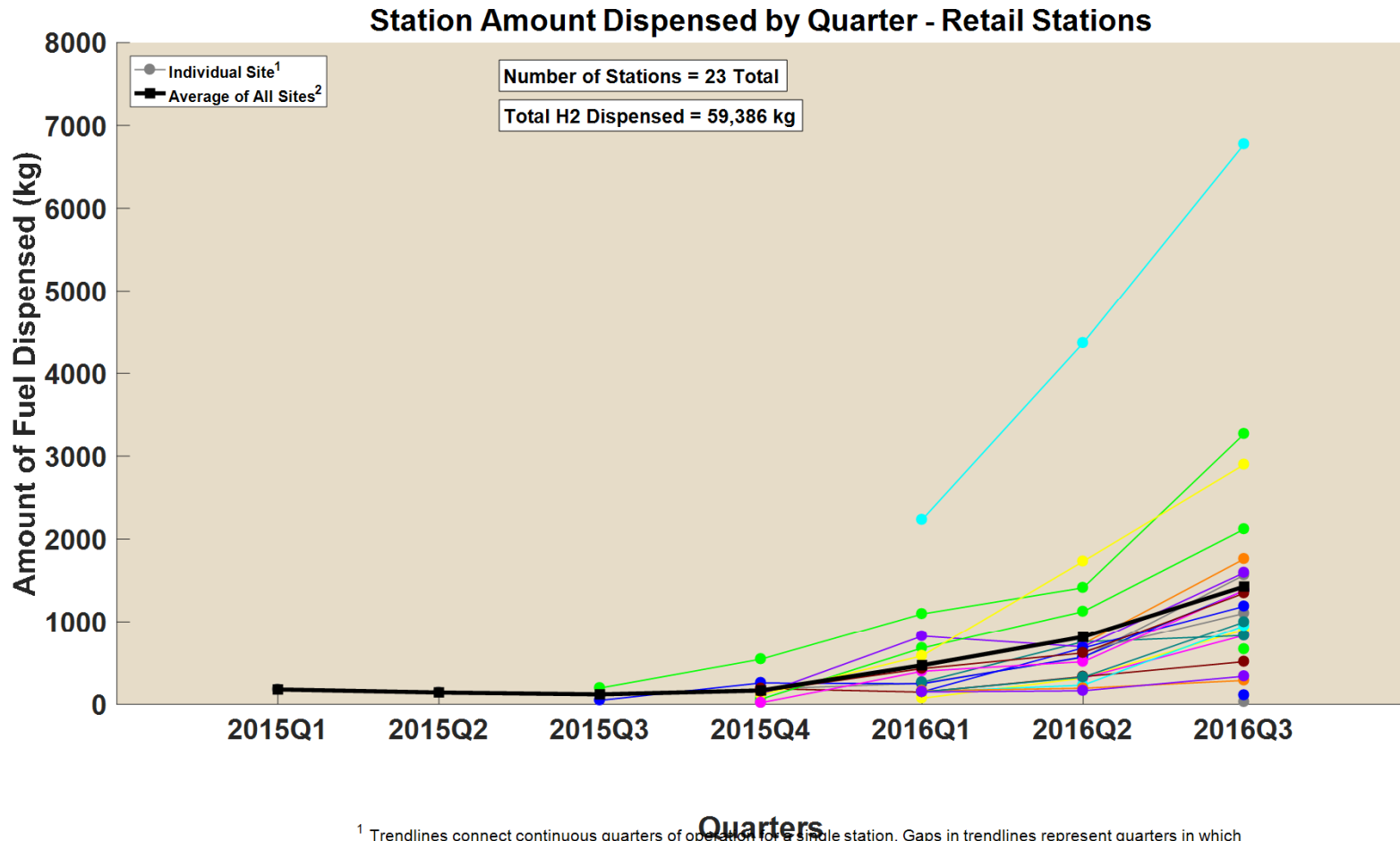
¹ Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

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



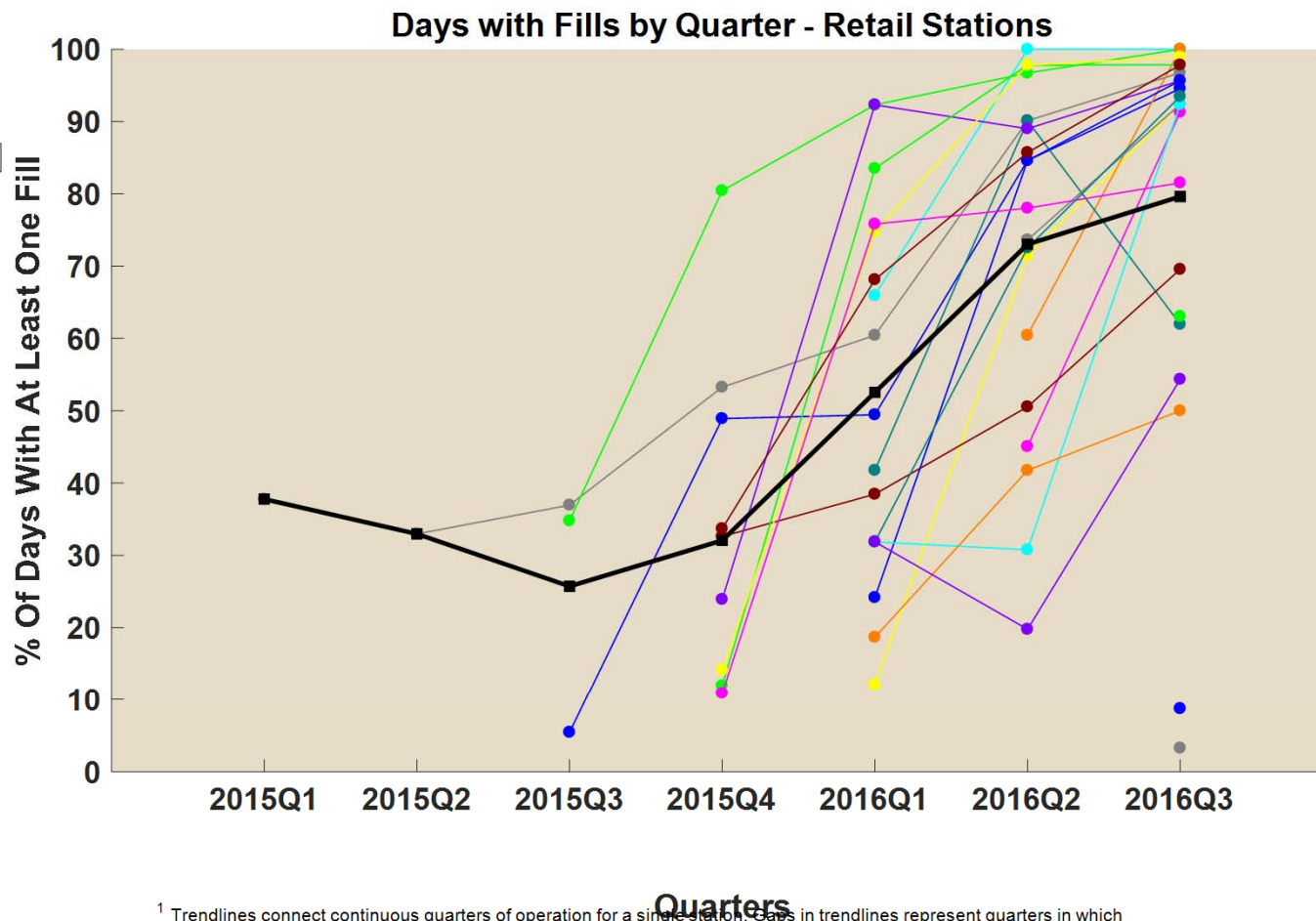
¹ Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

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



NREL cdpRETAIL_infr_45

Created: Dec-09-16 3:12 PM | Data Range: 0000Q1-2016Q3

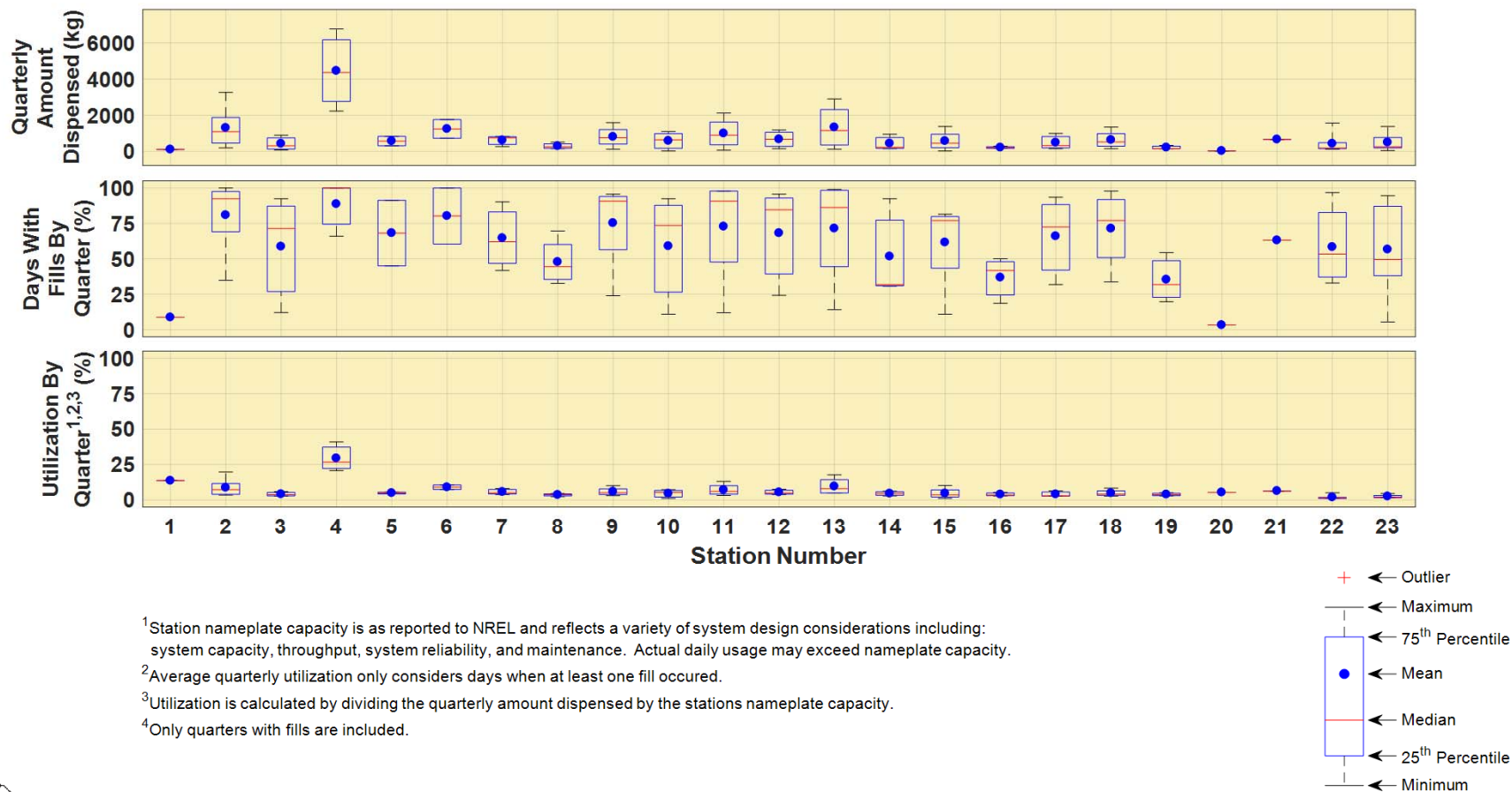


¹ Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station had no fills or was missing data. Each station is represented by a unique color.

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 Statistics - Retail Stations⁴



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.

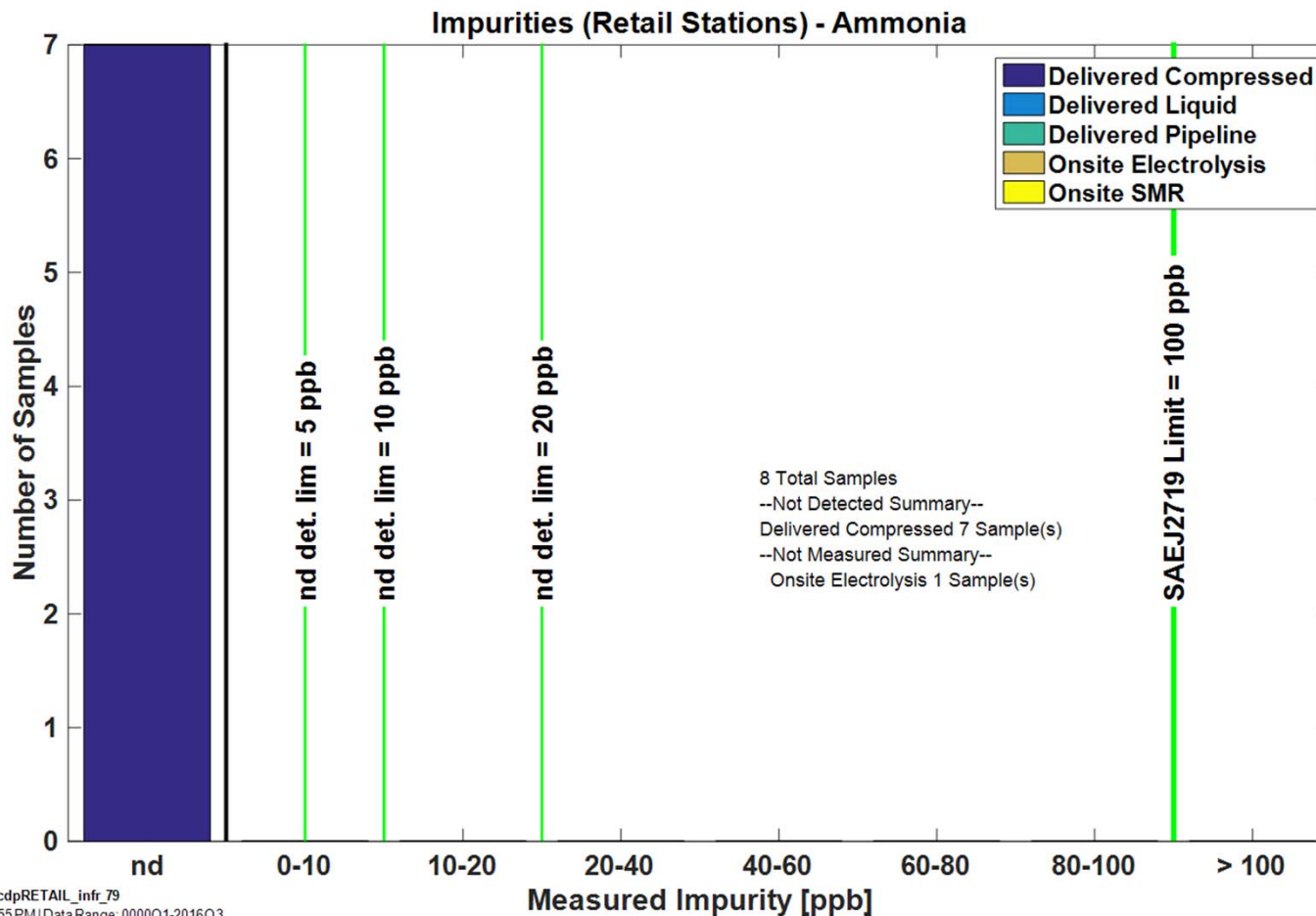
⁴Only quarters with fills are included.



NREL cdpRETAIL_infr_47

Created: Dec-09-16 3:13 PM | Data Range: 0000Q1-2016Q3

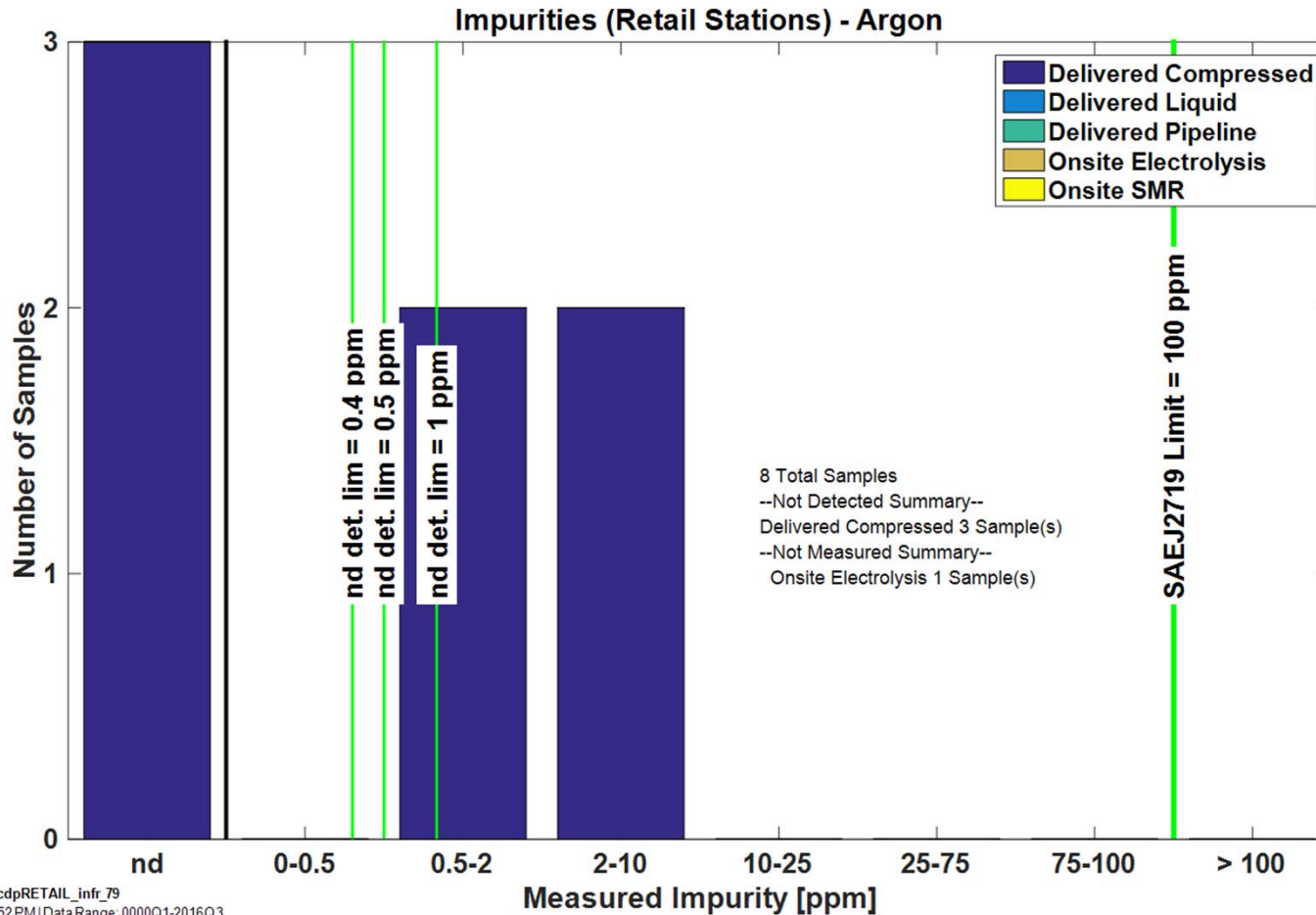
Hydrogen Quality



NREL cdpRETAIL_infr_79
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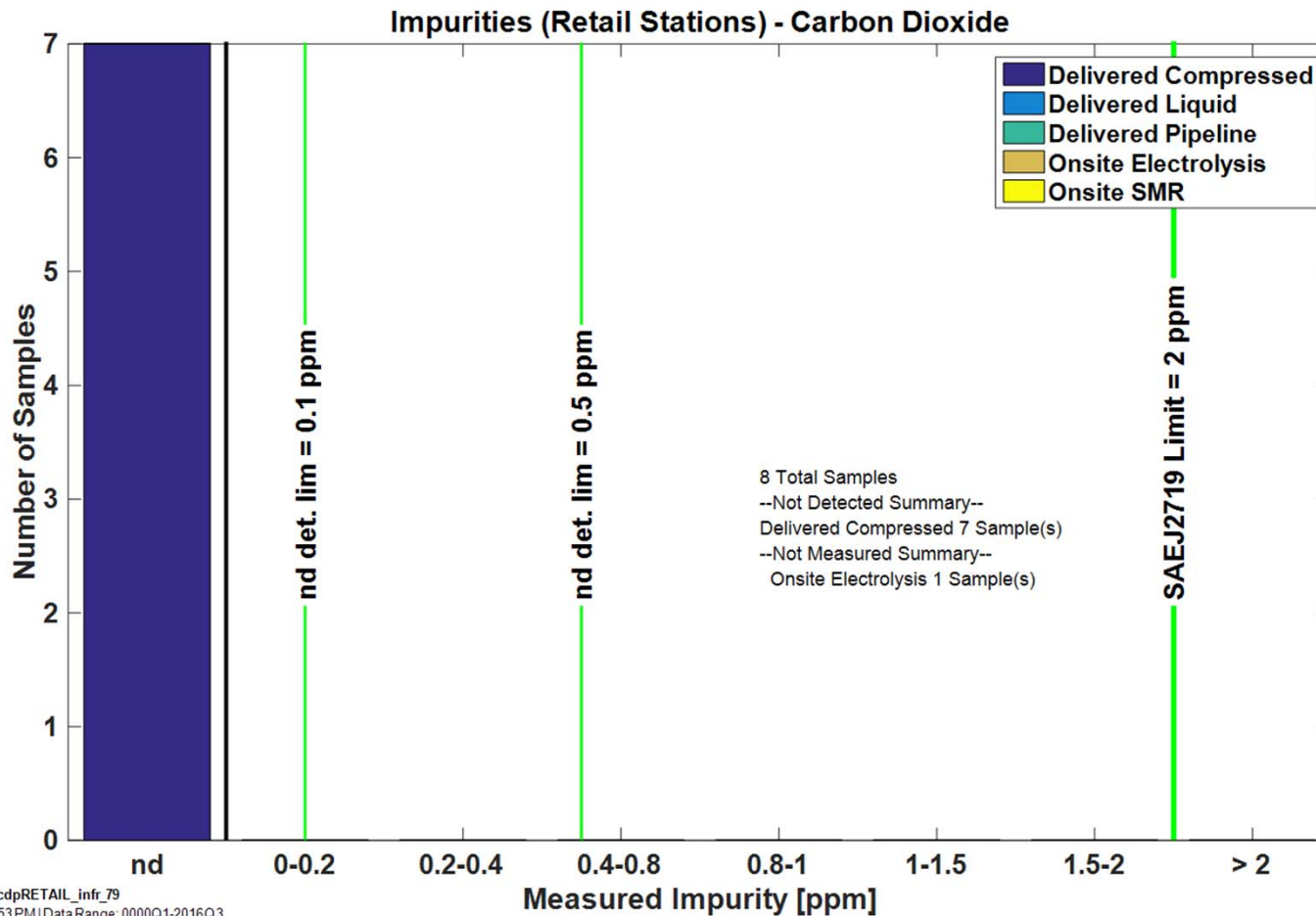
CDP-INFR-79

Impurities—Argon



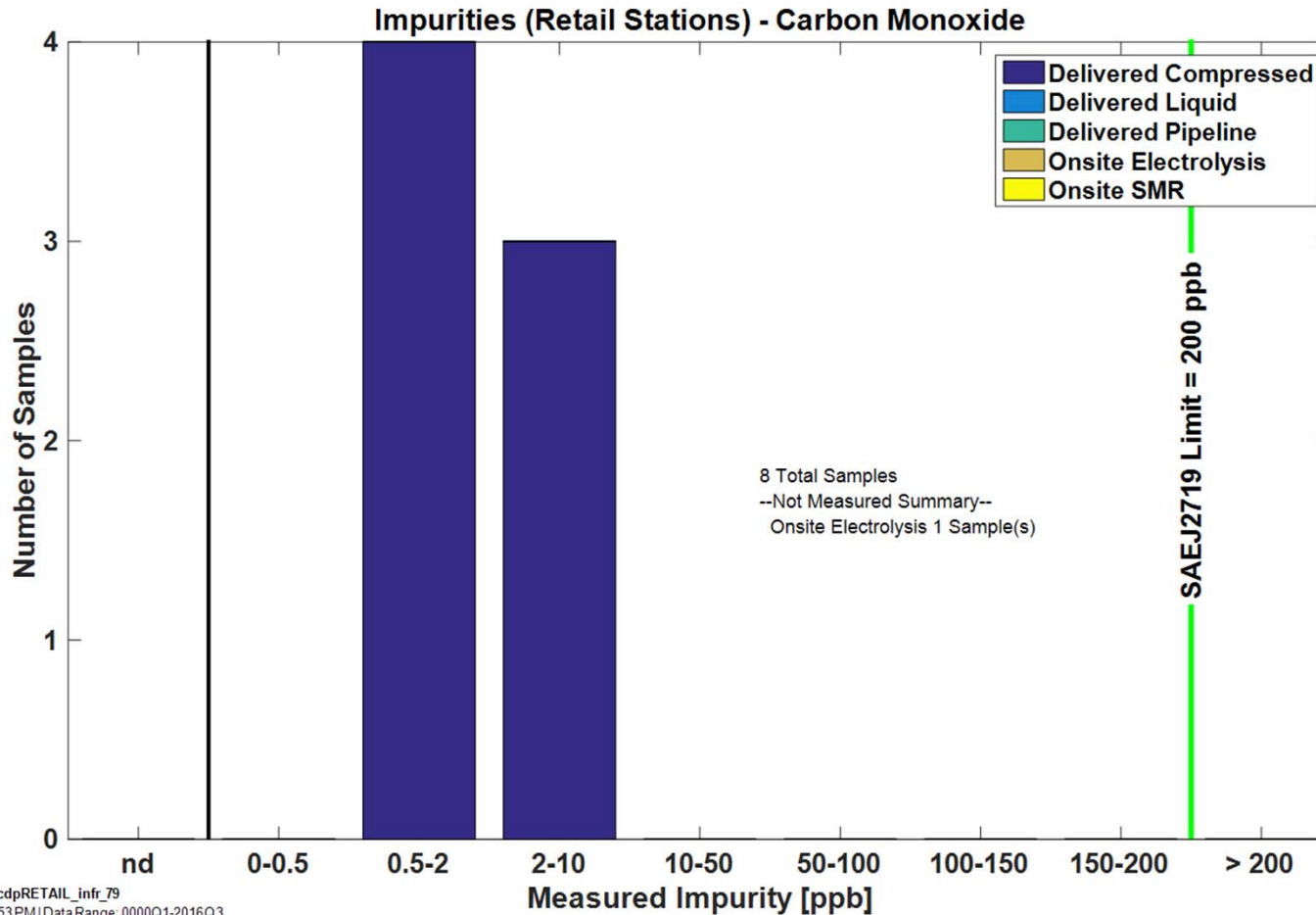
NREL cdpRETAIL_infr_79

Created: Dec-15-16 3:52 PM | Data Range: 0000Q1-2016Q3



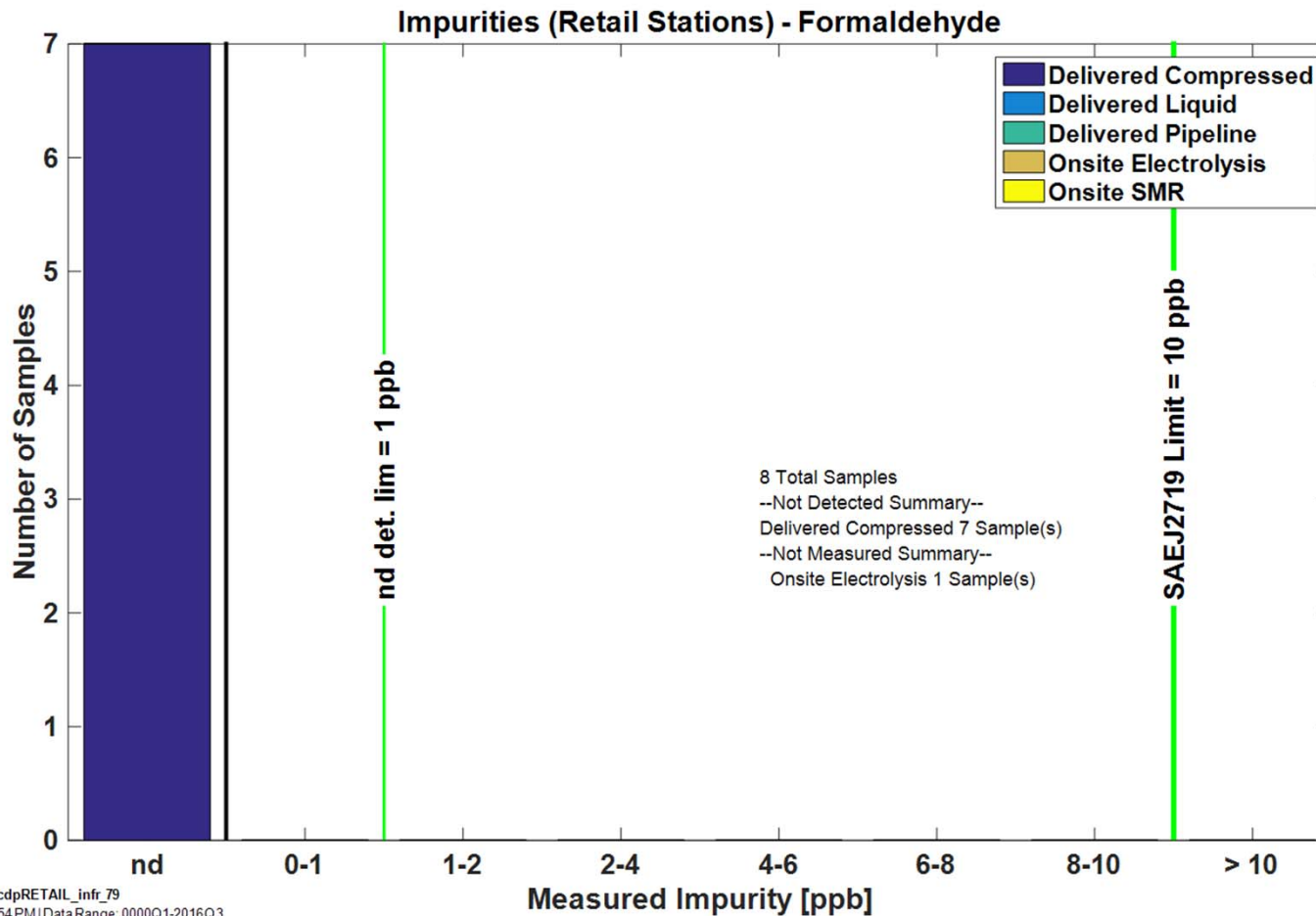
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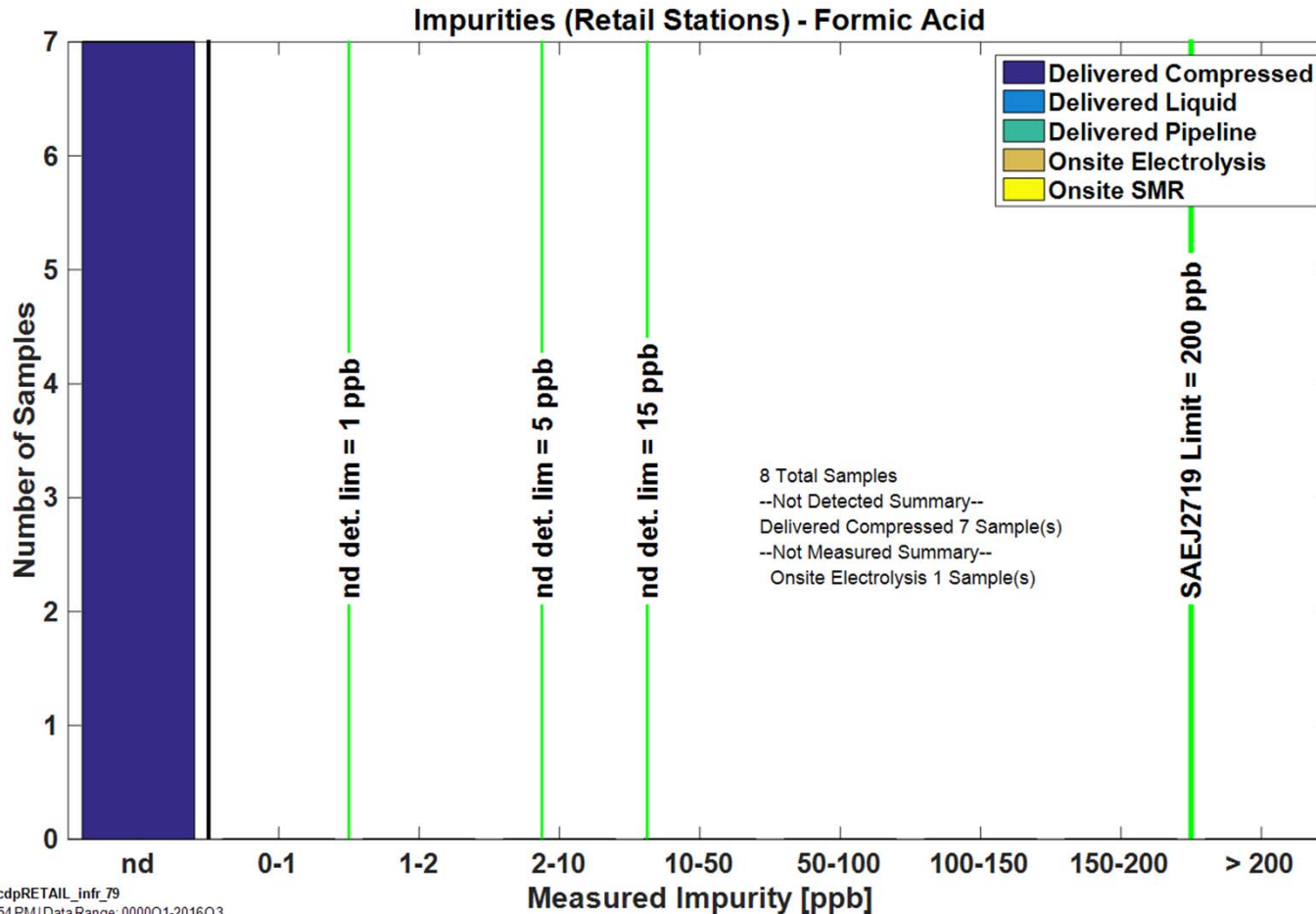
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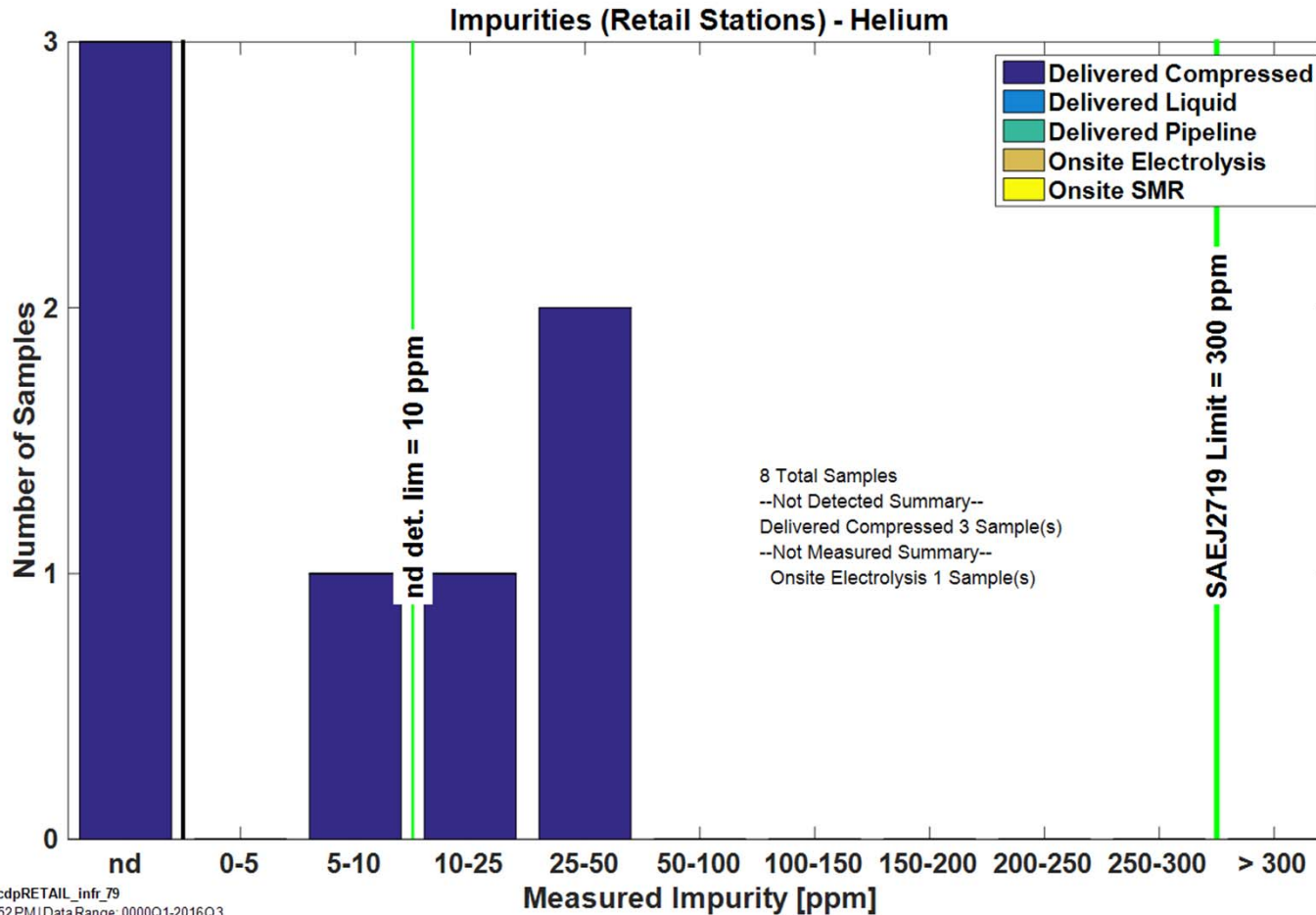
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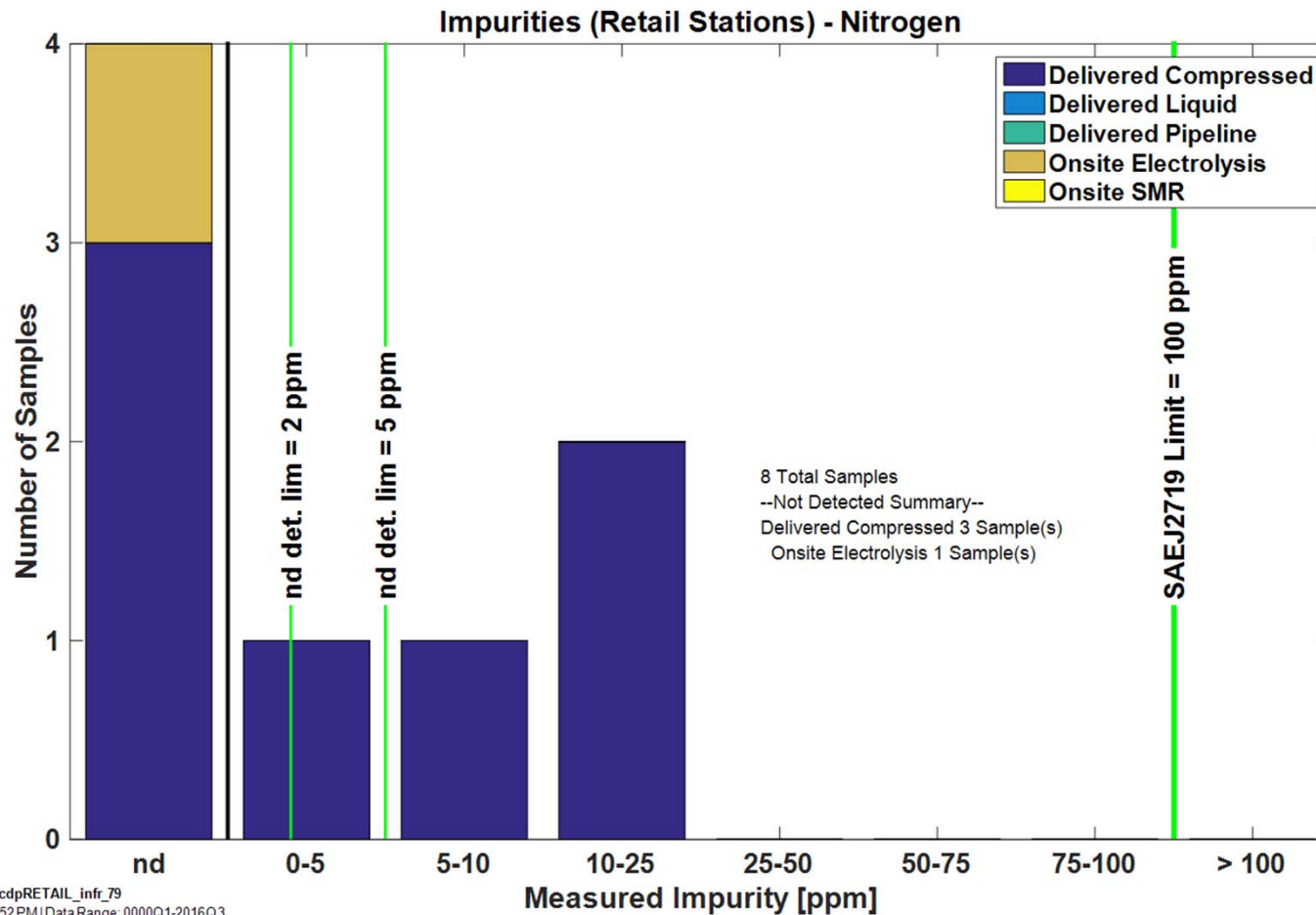
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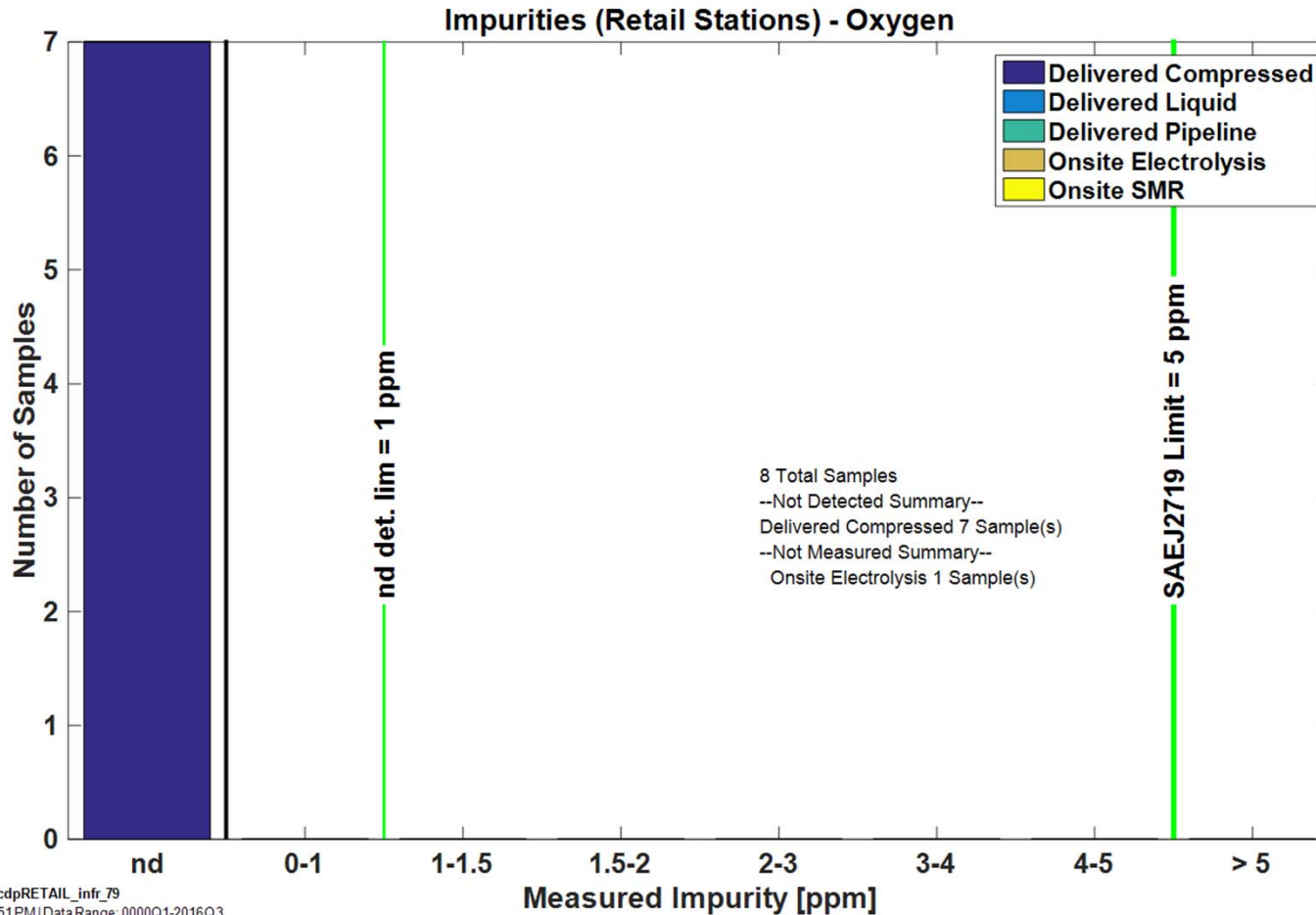
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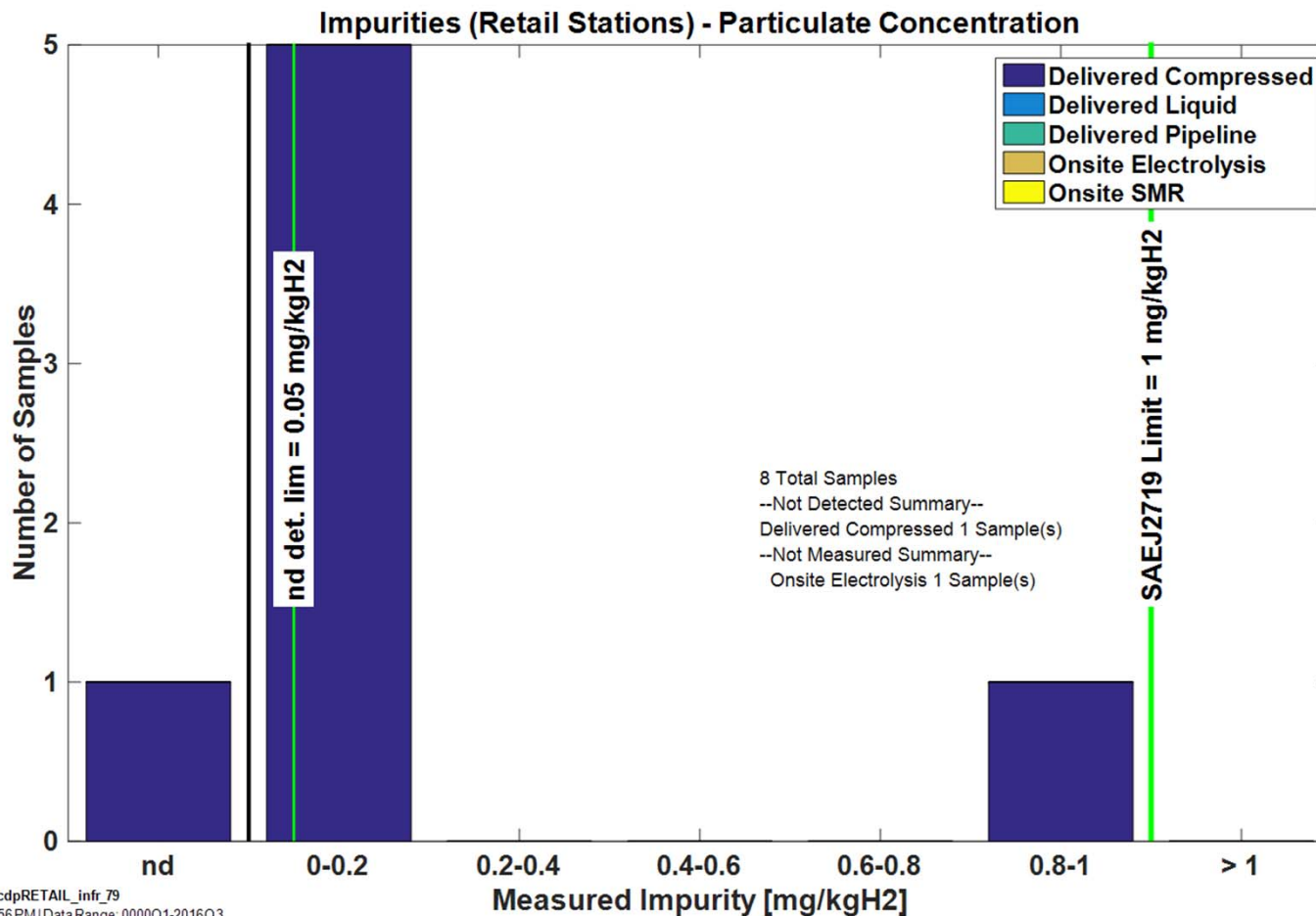
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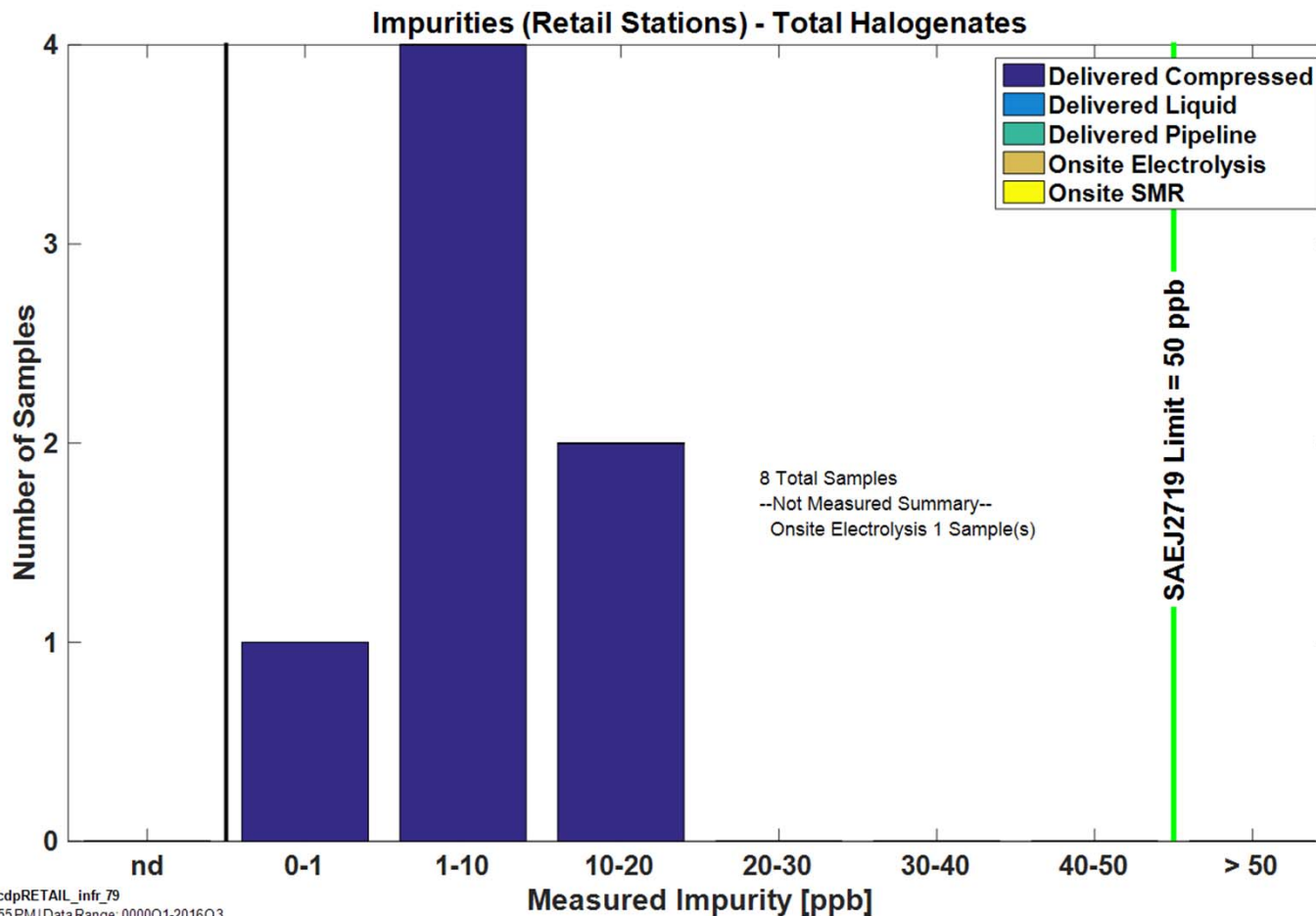
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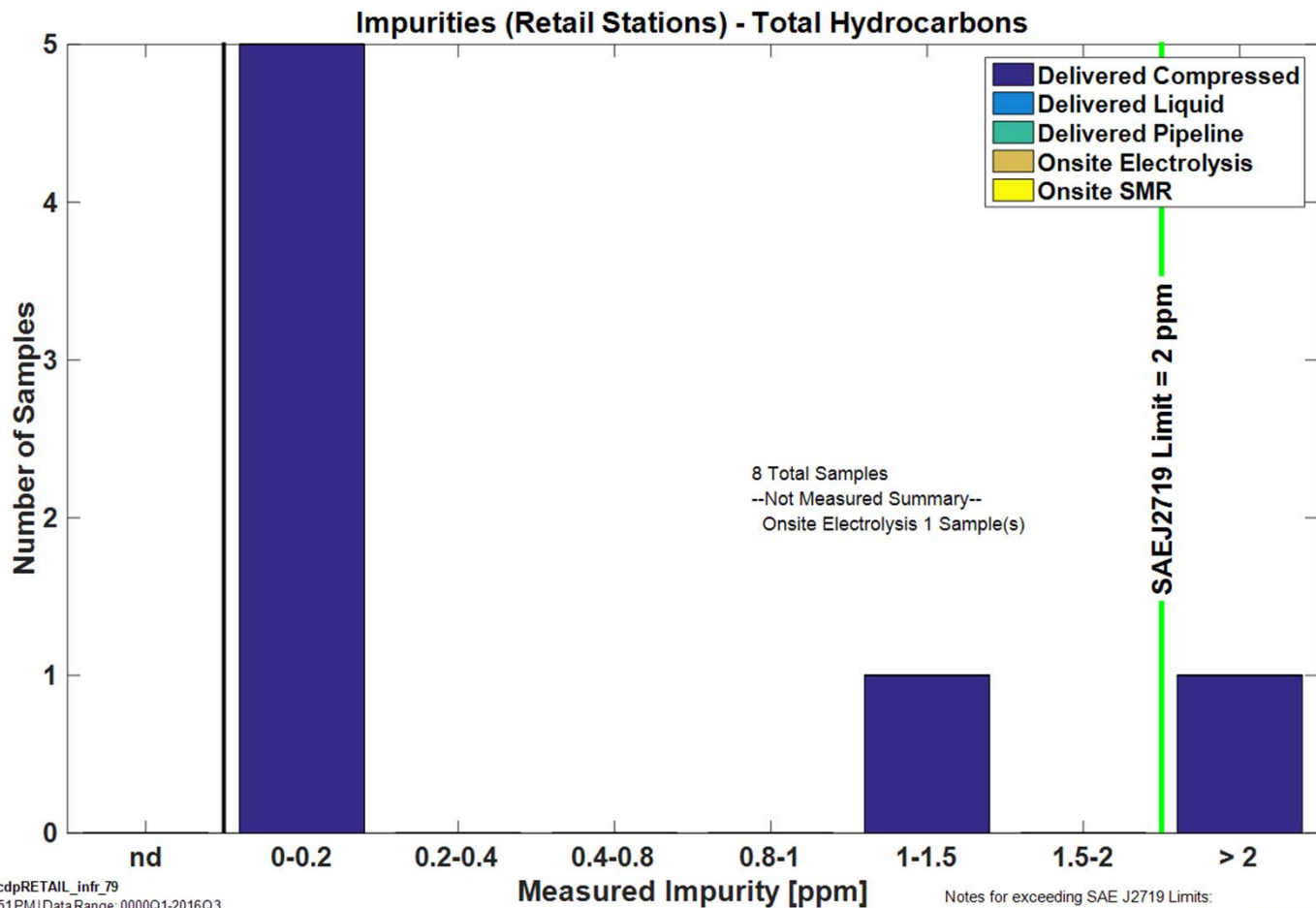
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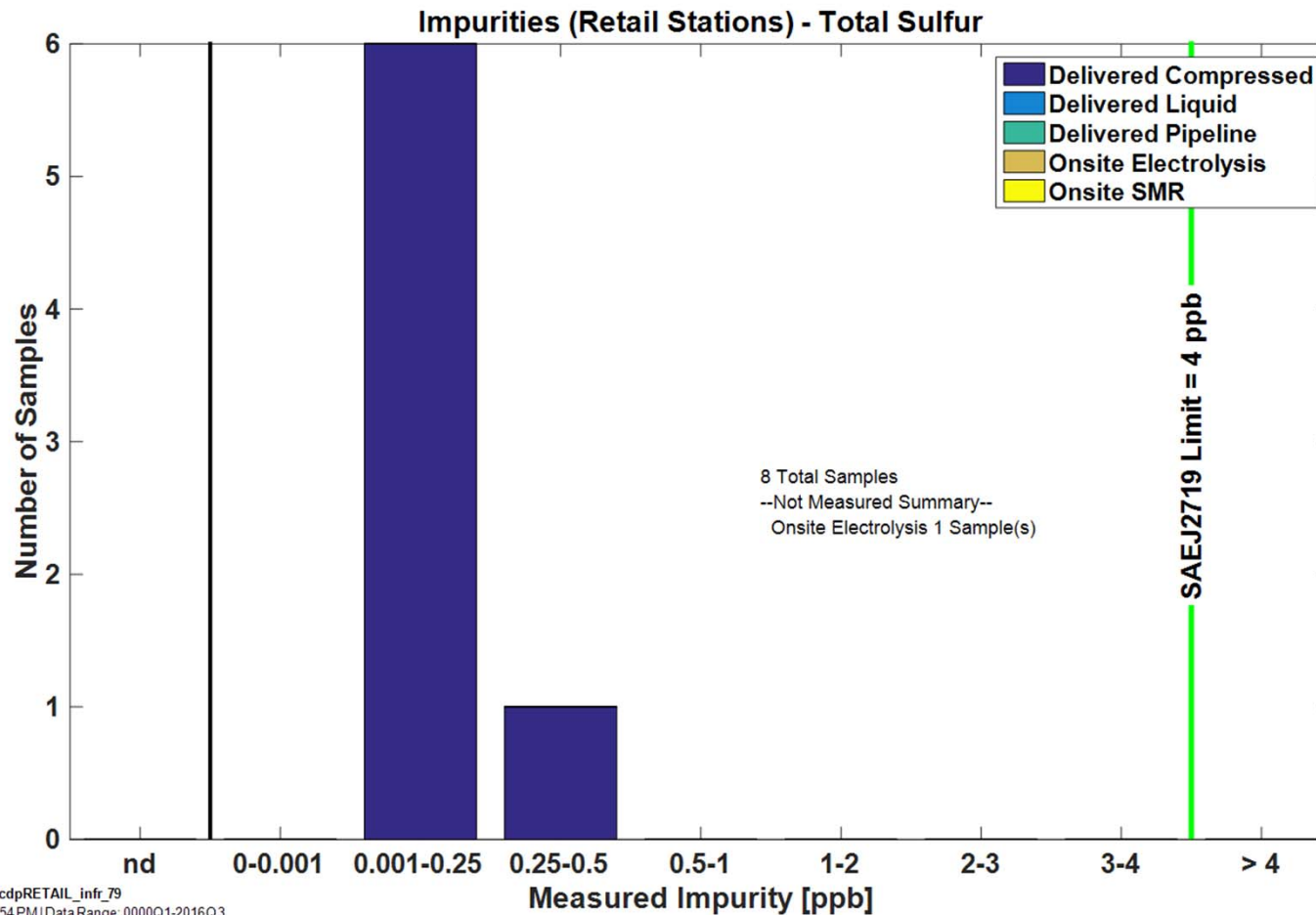


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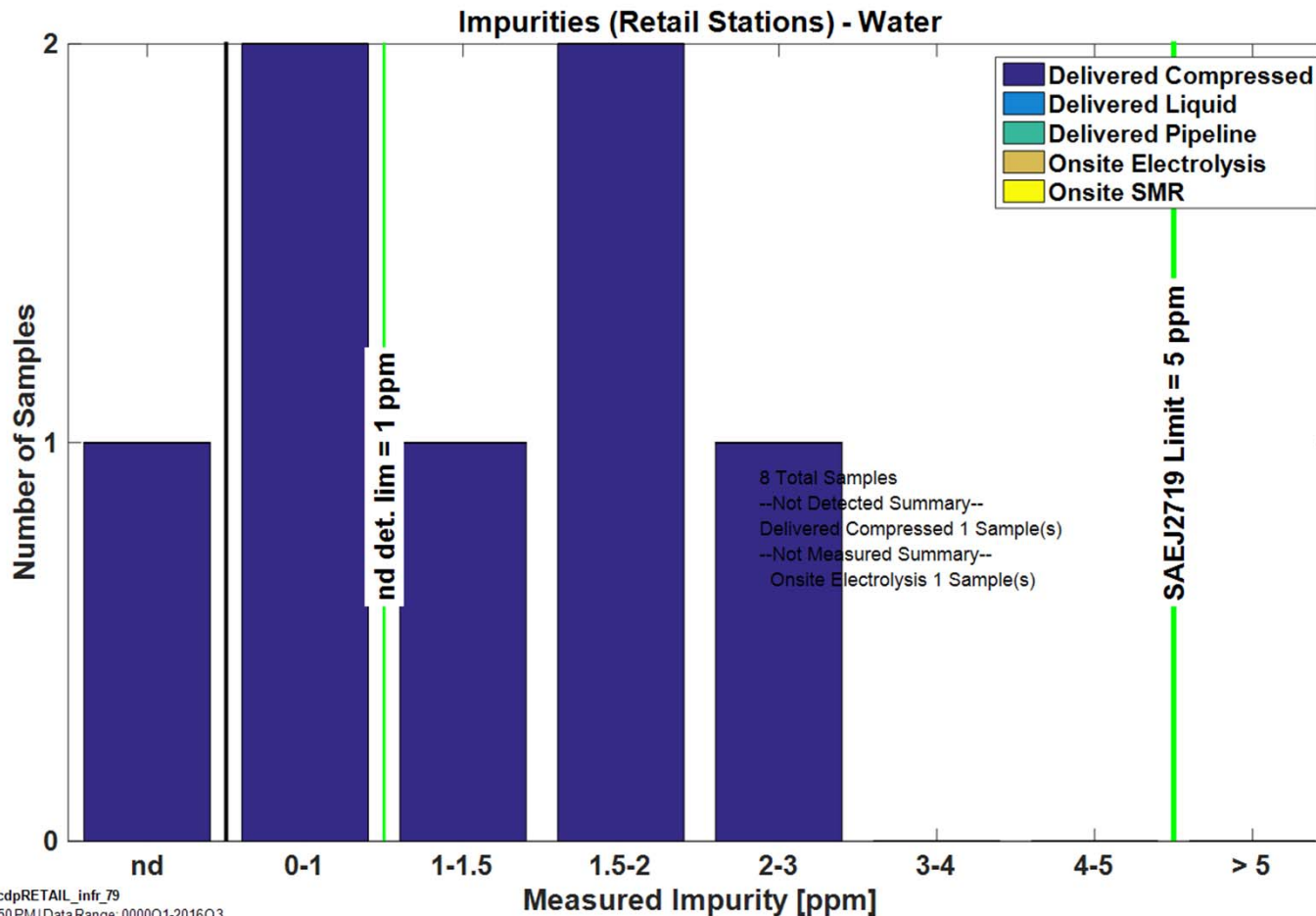


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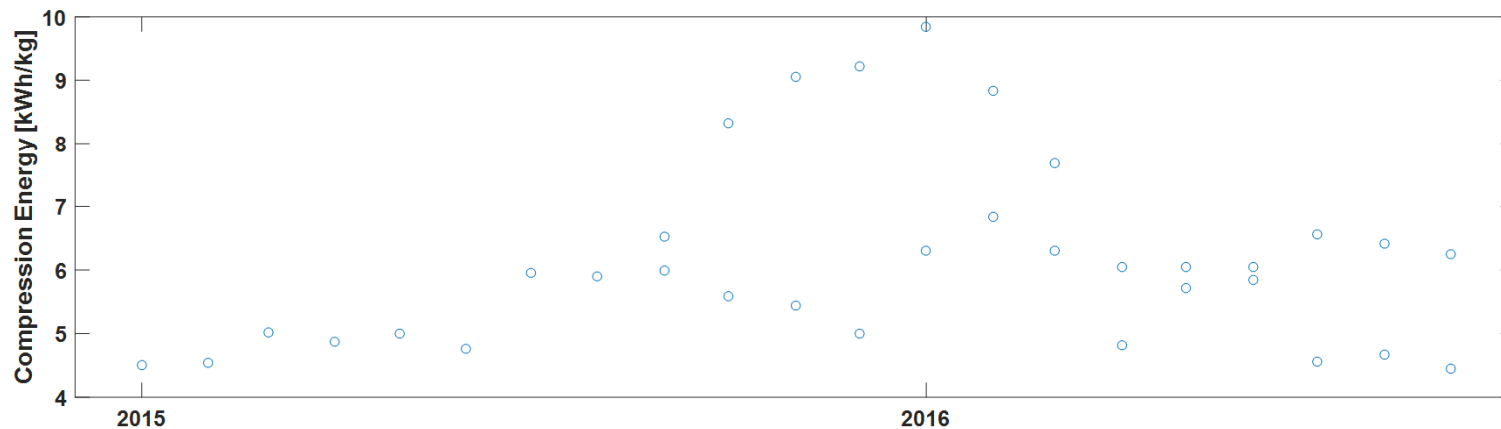
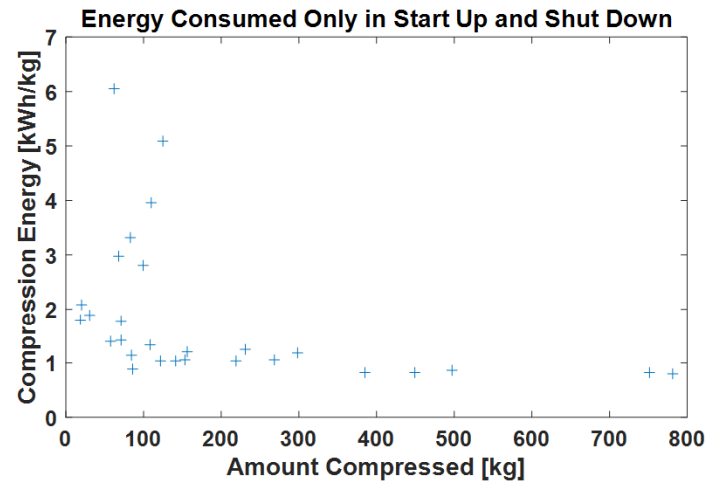
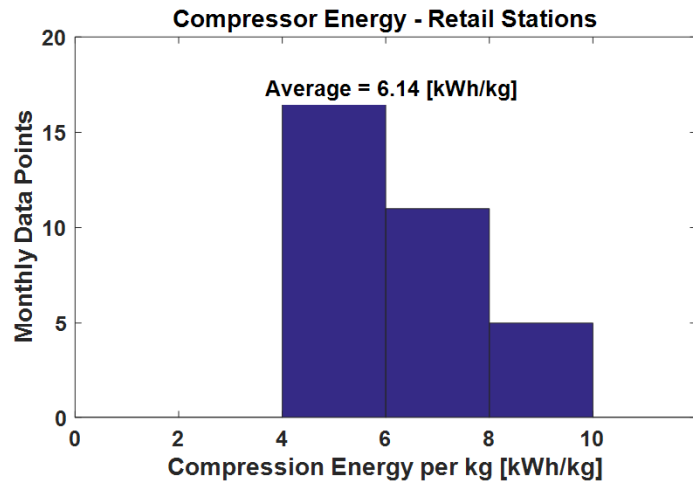
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Component Energy

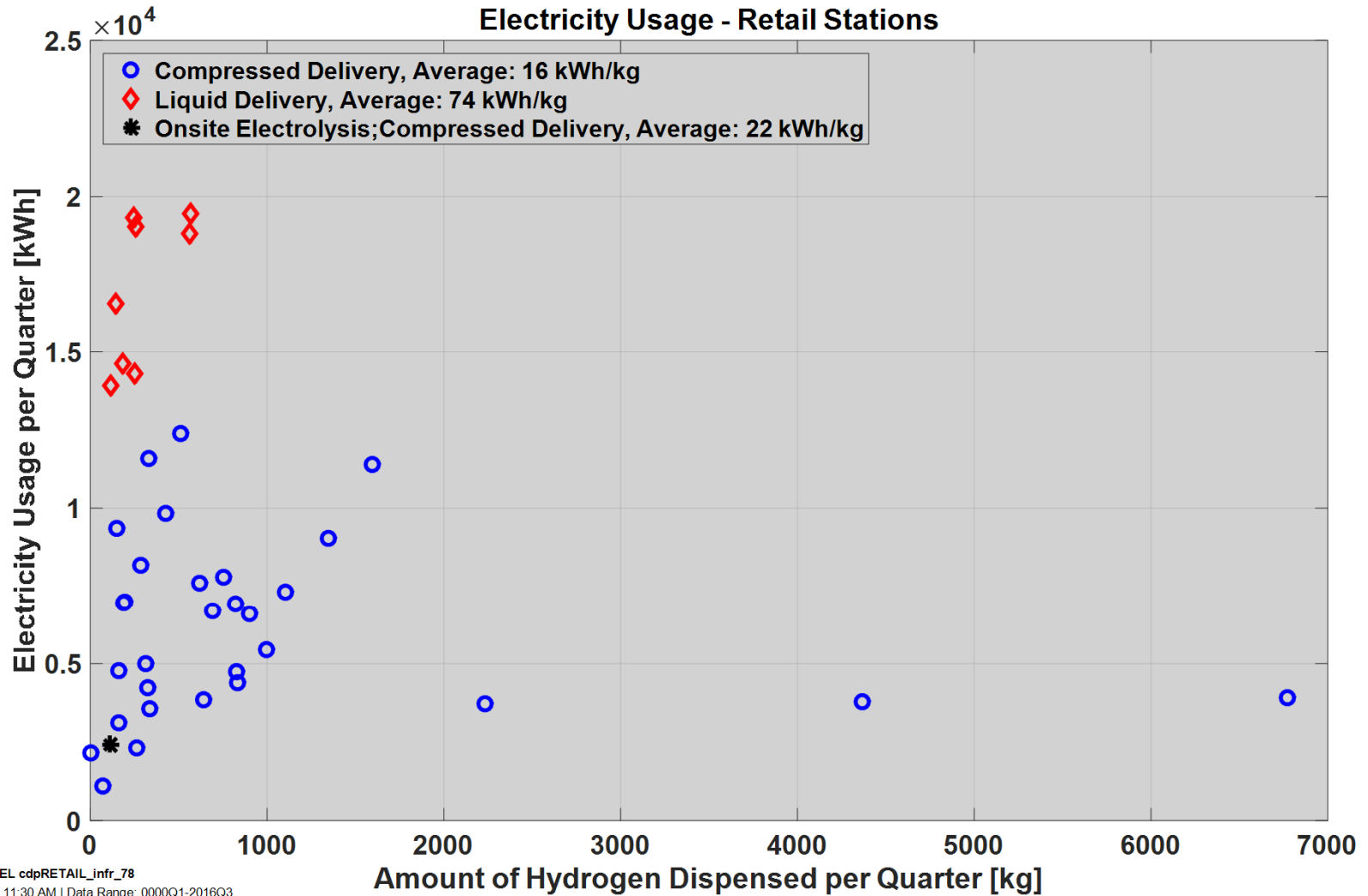
CDP-INFR-35

Compressor Energy



NREL cdpRETAIL_infr_35

Created: Dec-21-16 11:15 AM | Data Range: 2014Q4-2016Q3



NREL cdpRETAIL_infr_78

Created: Dec-21-16 11:30 AM | Data Range: 0000Q1-2016Q3