NREL
NATIONAL RENEWABLE ENERGY LABORATORY





Next Generation Hydrogen Station Composite Data Products: Retail Stations

Data through Quarter 2 of 2017

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Genevieve Saur, and Michael Peters

November 2017

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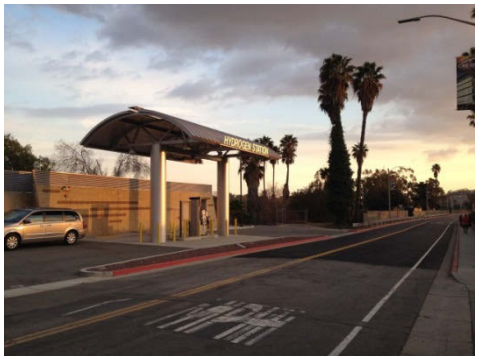
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

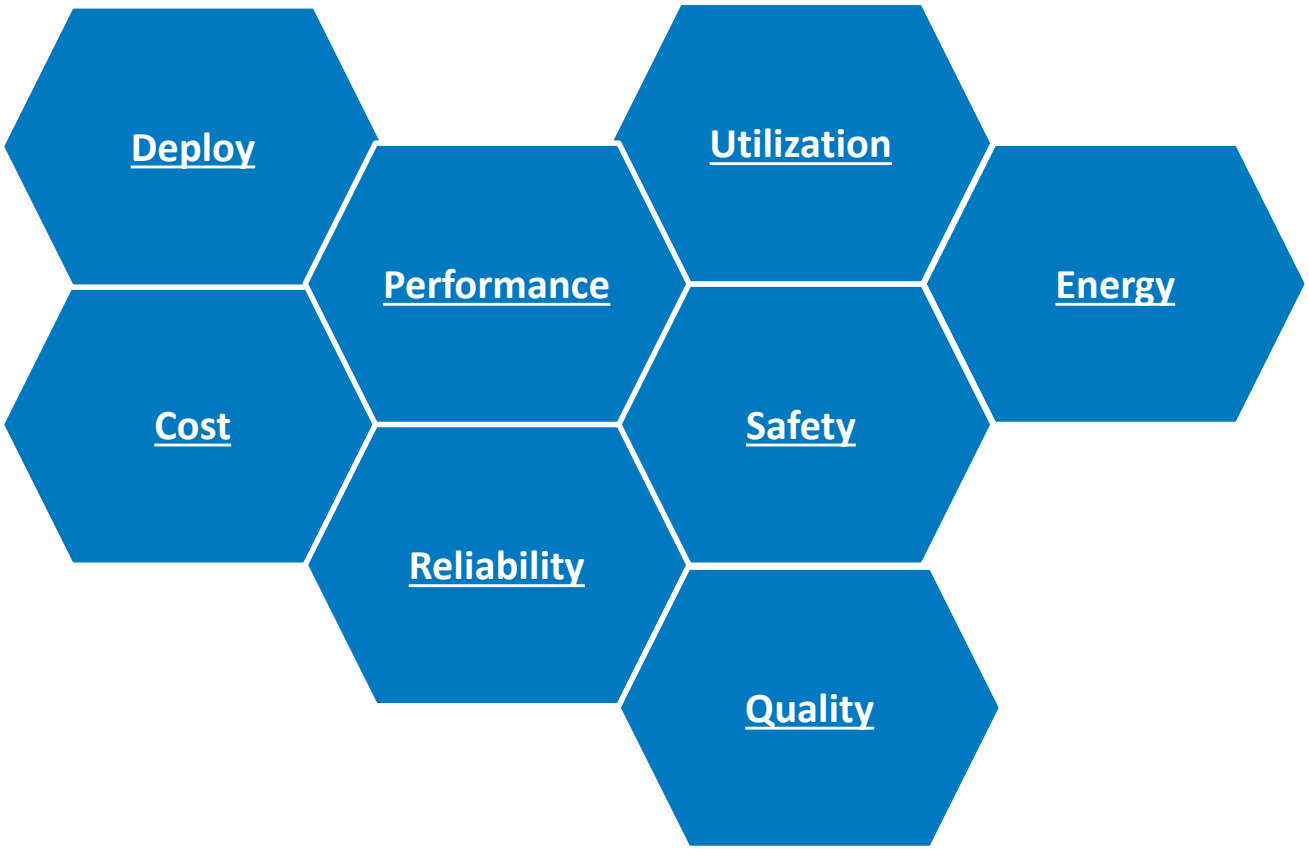
Hydrogen Station Project Partners

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



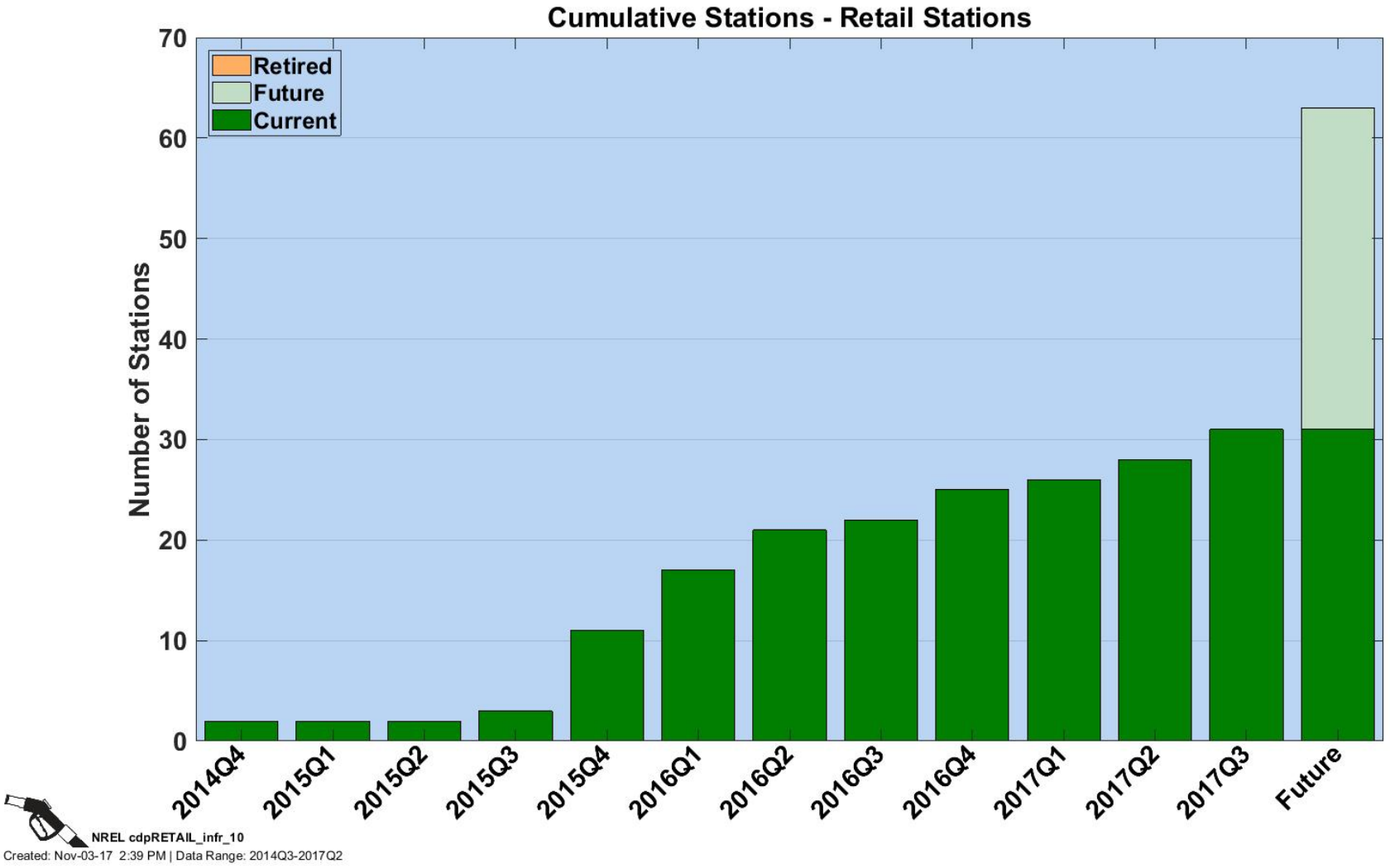
Photos by NREL

Analysis Categories

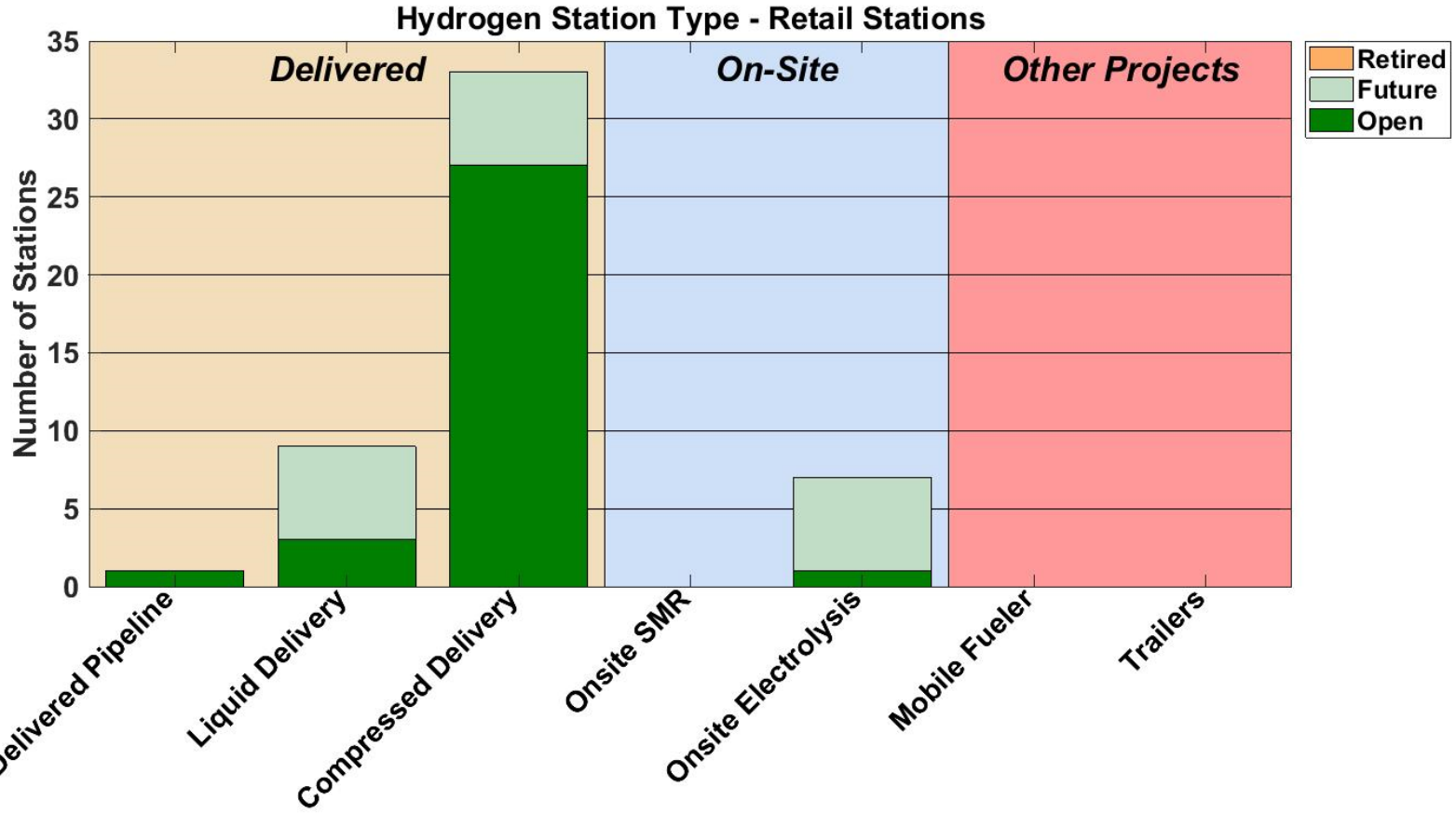


Deployment

CDP-INFR-10
Cumulative Number of Stations



CDP-INFR-11
Hydrogen Stations by Type



NREL cdpRETAIL_infr_11
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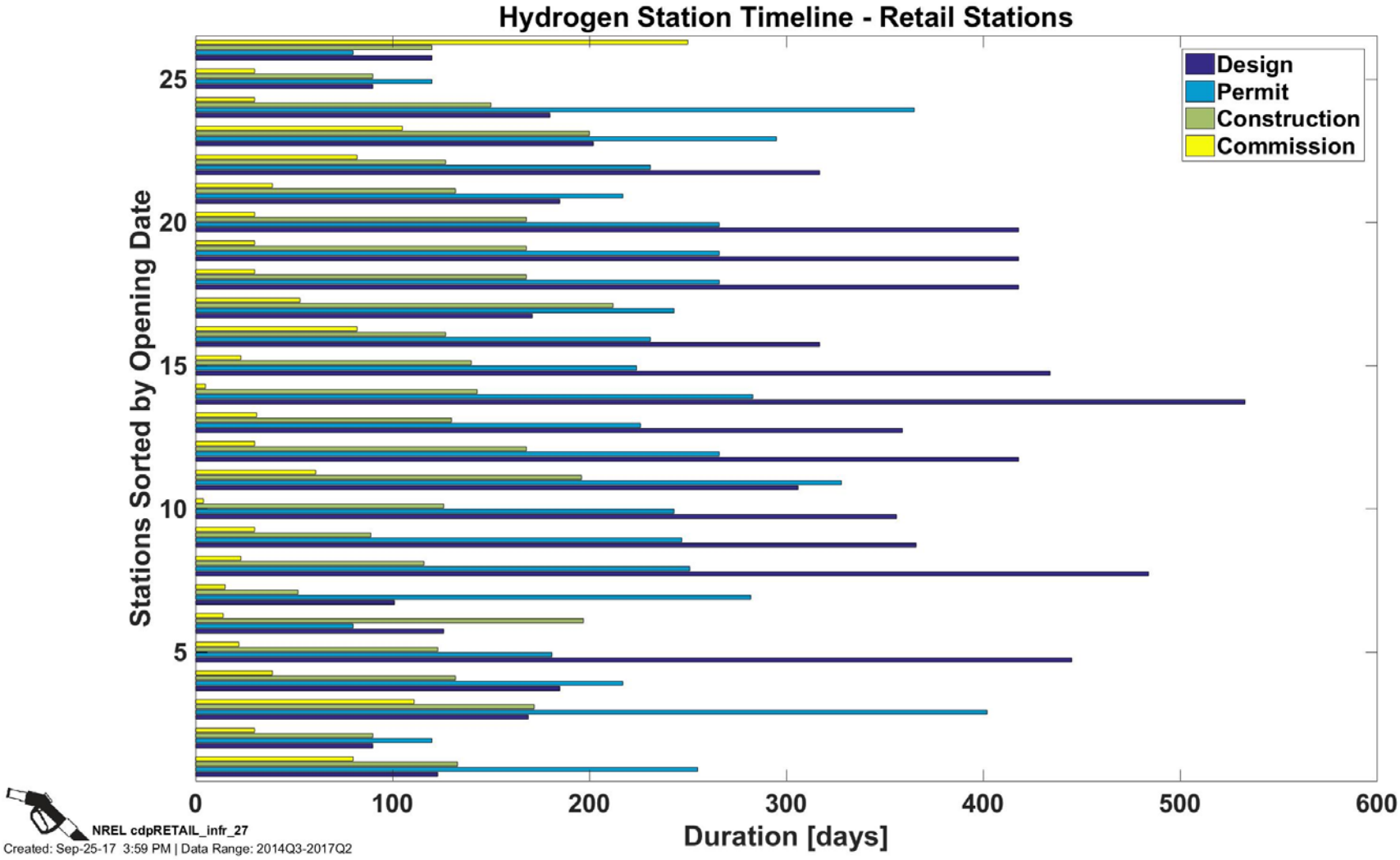
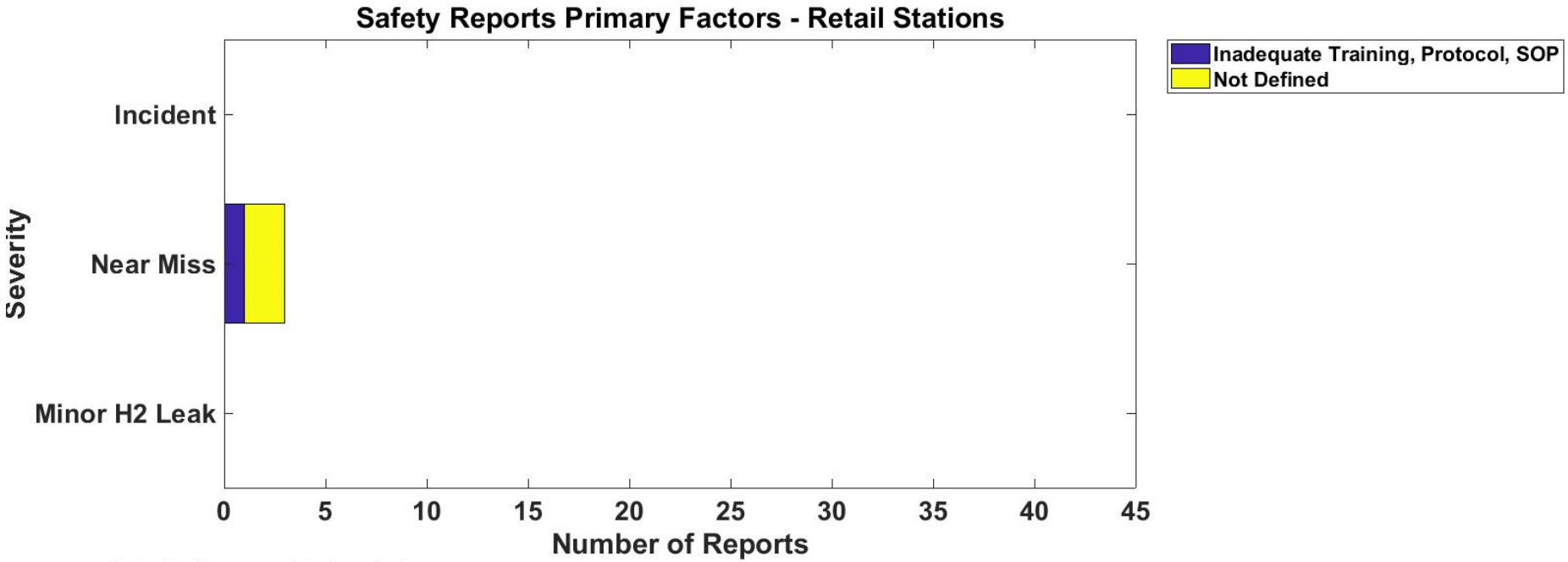
CDP-INFR-27
Hydrogen Station Timeline



Safety

CDP-INFR-31
Safety Reports Primary Factors



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:

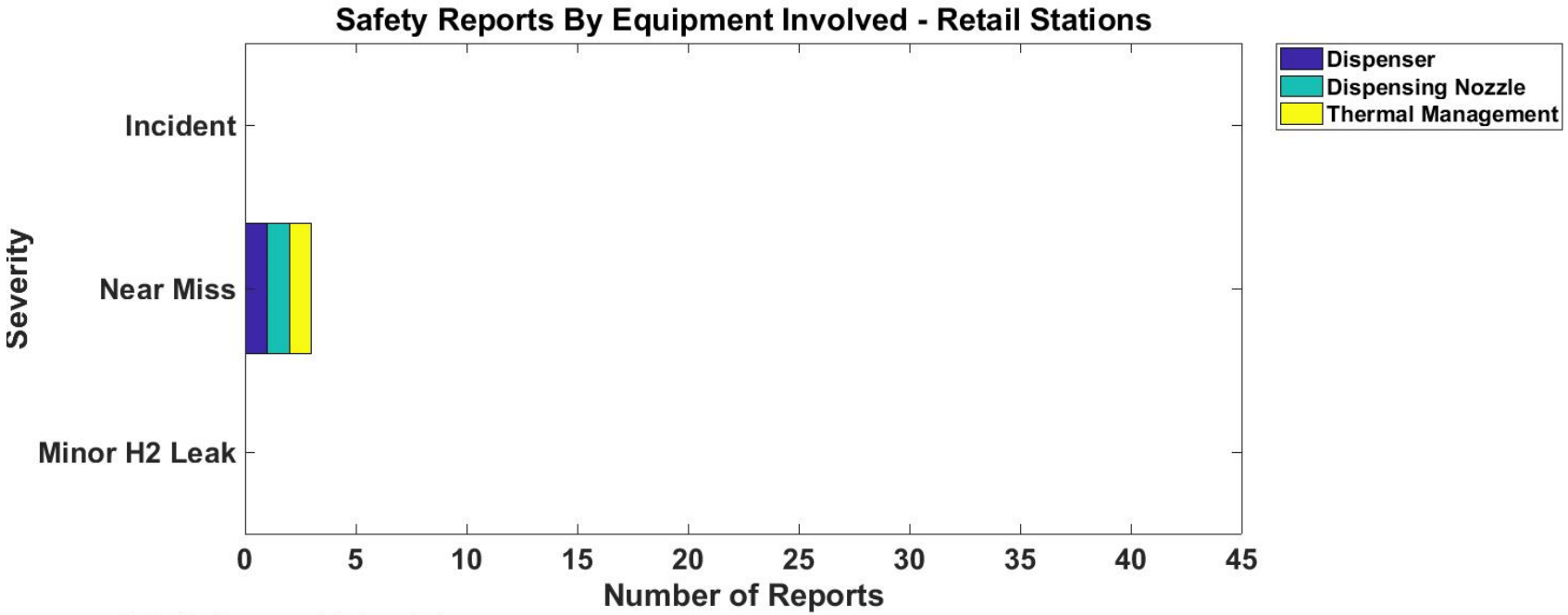
- an event that under slightly different circumstances could have become an incident
- any hydrogen release sufficient to sustain a flame if ignited

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: Sep-29-17 12:45 PM | Data Range: 2015Q3-2017Q2

CDP-INFR-32
Safety Reports by Equipment Involved



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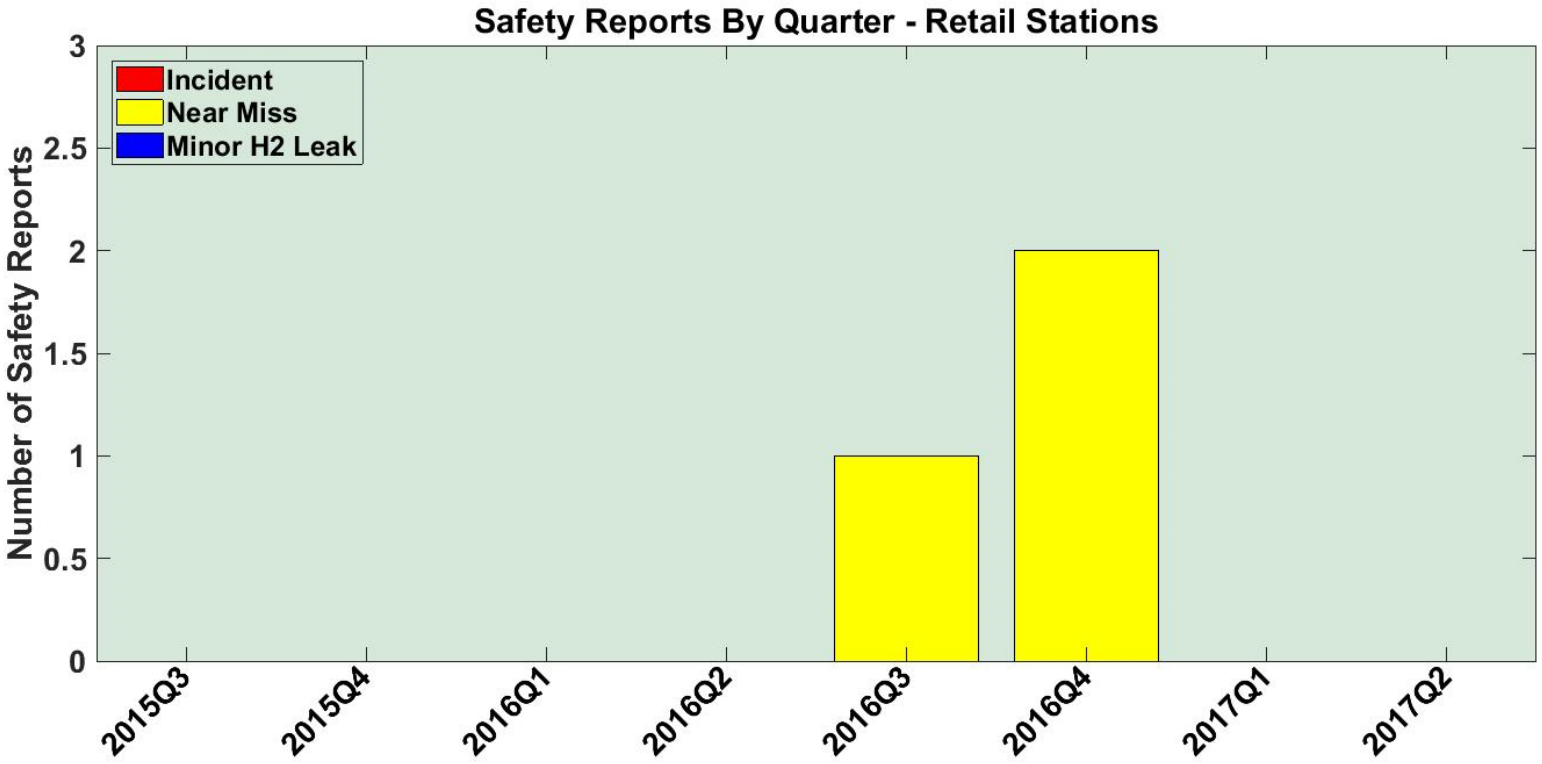
NREL cdpRETAIL_infr_32
Created: Sep-29-17 12:45 PM | Data Range: 2015Q3-2017Q2

CDP-INFR-33
Safety Reports by Quarter



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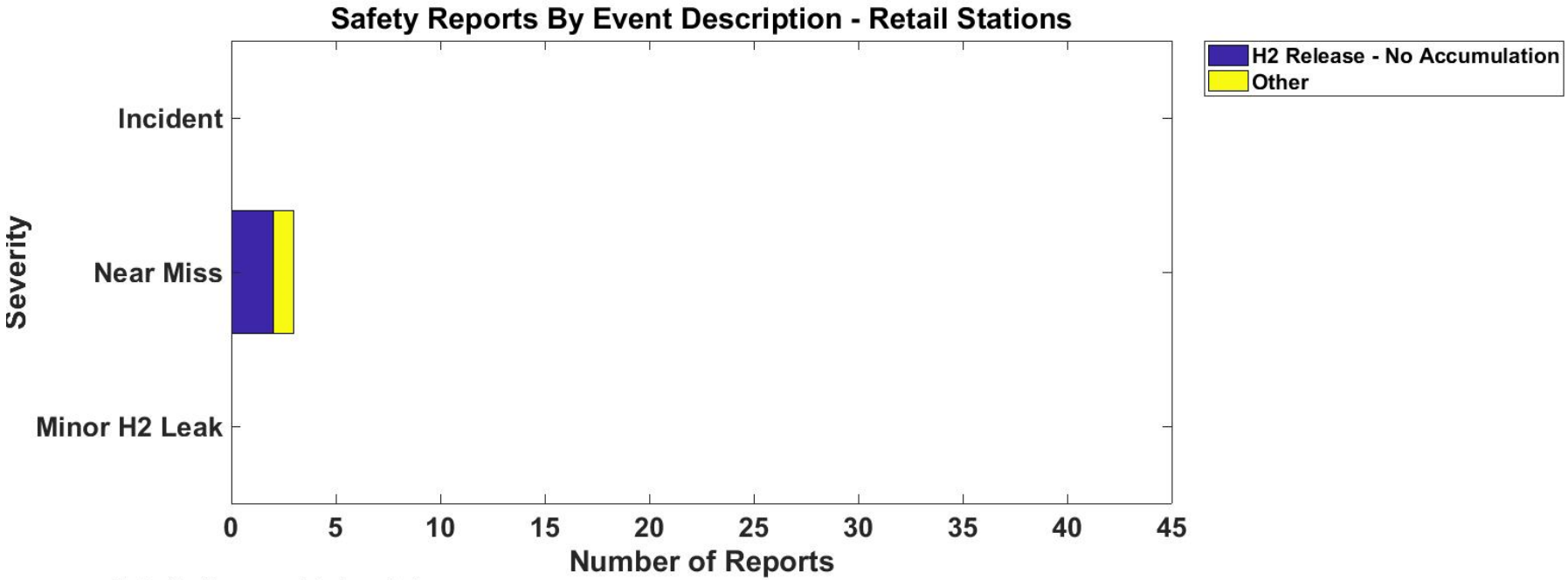
A Minor H2 Leak is:

NREL cdpRETAIL_infr_33
Created: Sep-29-17 12:46 PM | Data Range: 2015Q3-2017Q2

CDP-INFR-34
Safety Reports by Event Description



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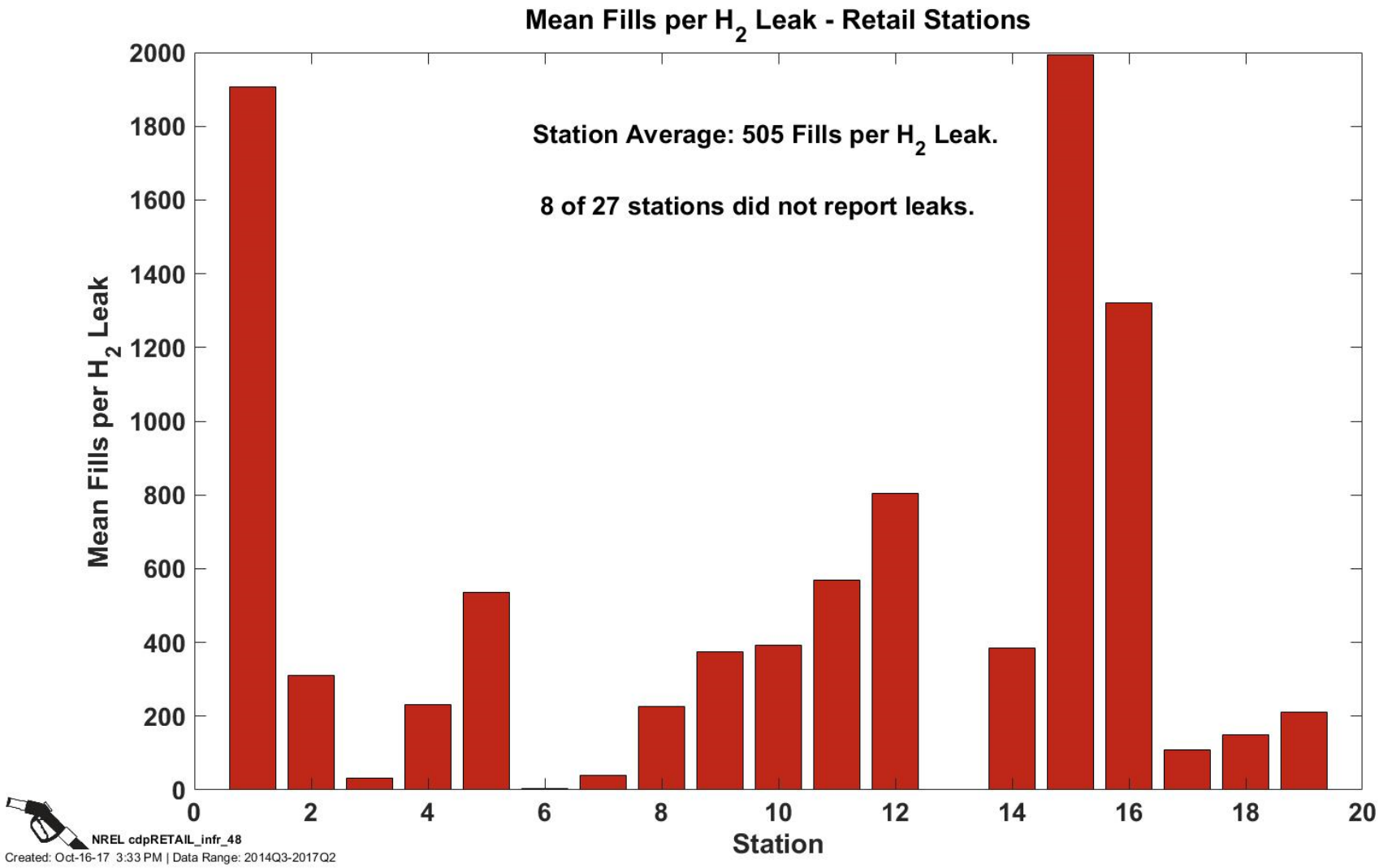
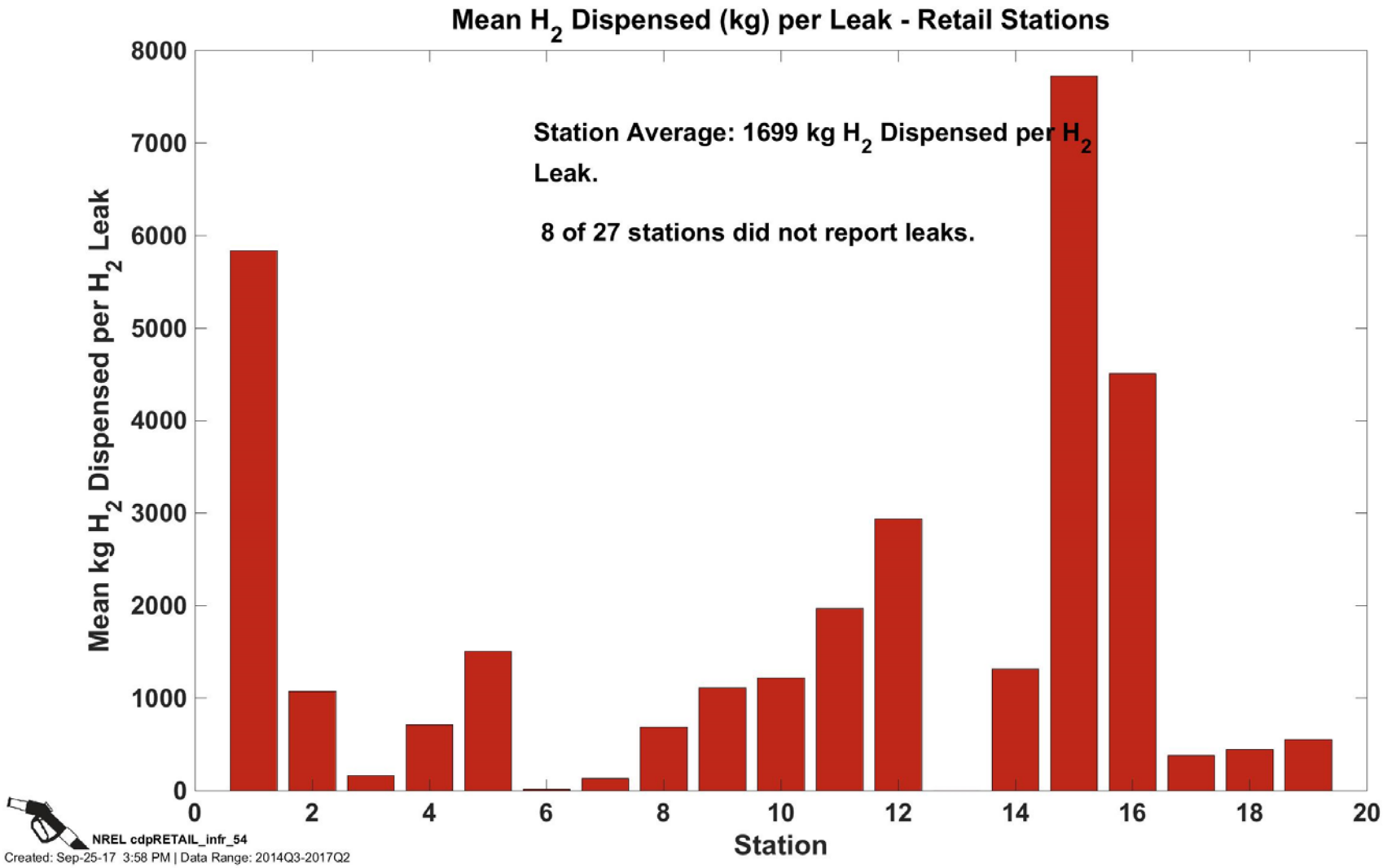
NREL cdpRETAIL_infr_34
Created: Sep-29-17 12:46 PM | Data Range: 2015Q3-2017Q2

CDP-INFR-48
Mean Fills per Hydrogen Leak

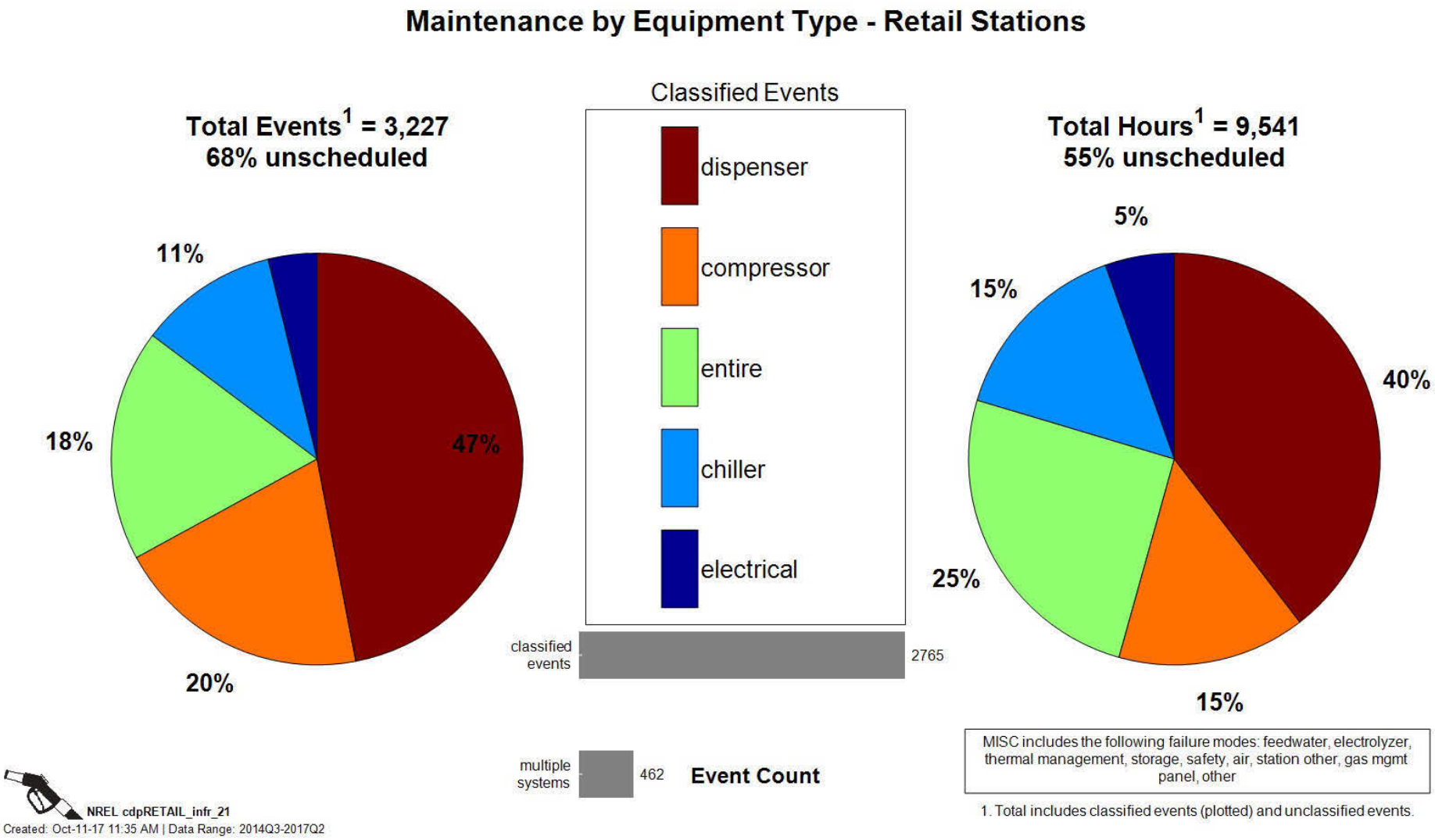


CDP-INFR-54
Mean Hydrogen Dispensed per Hydrogen Leak

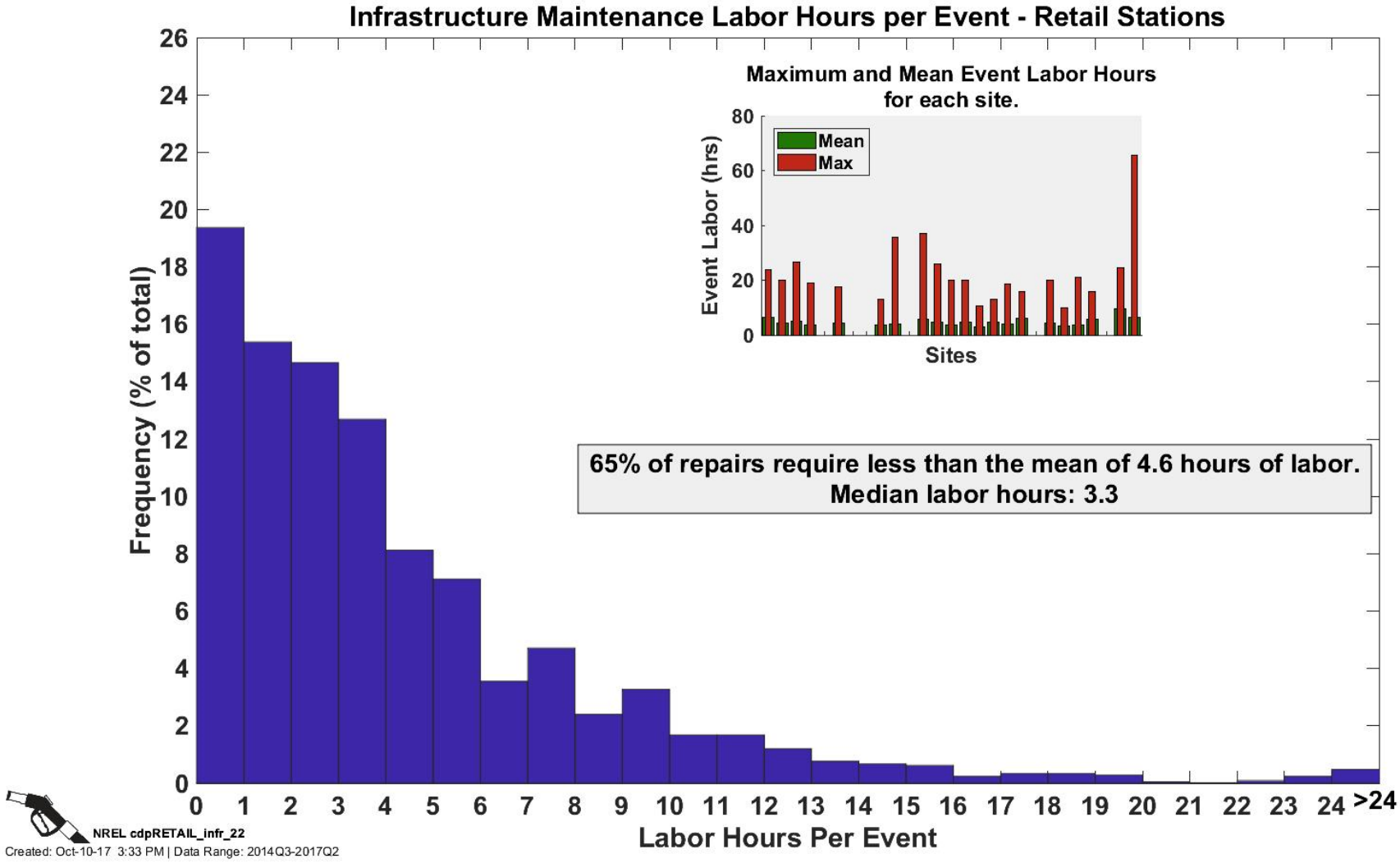


Maintenance and Reliability

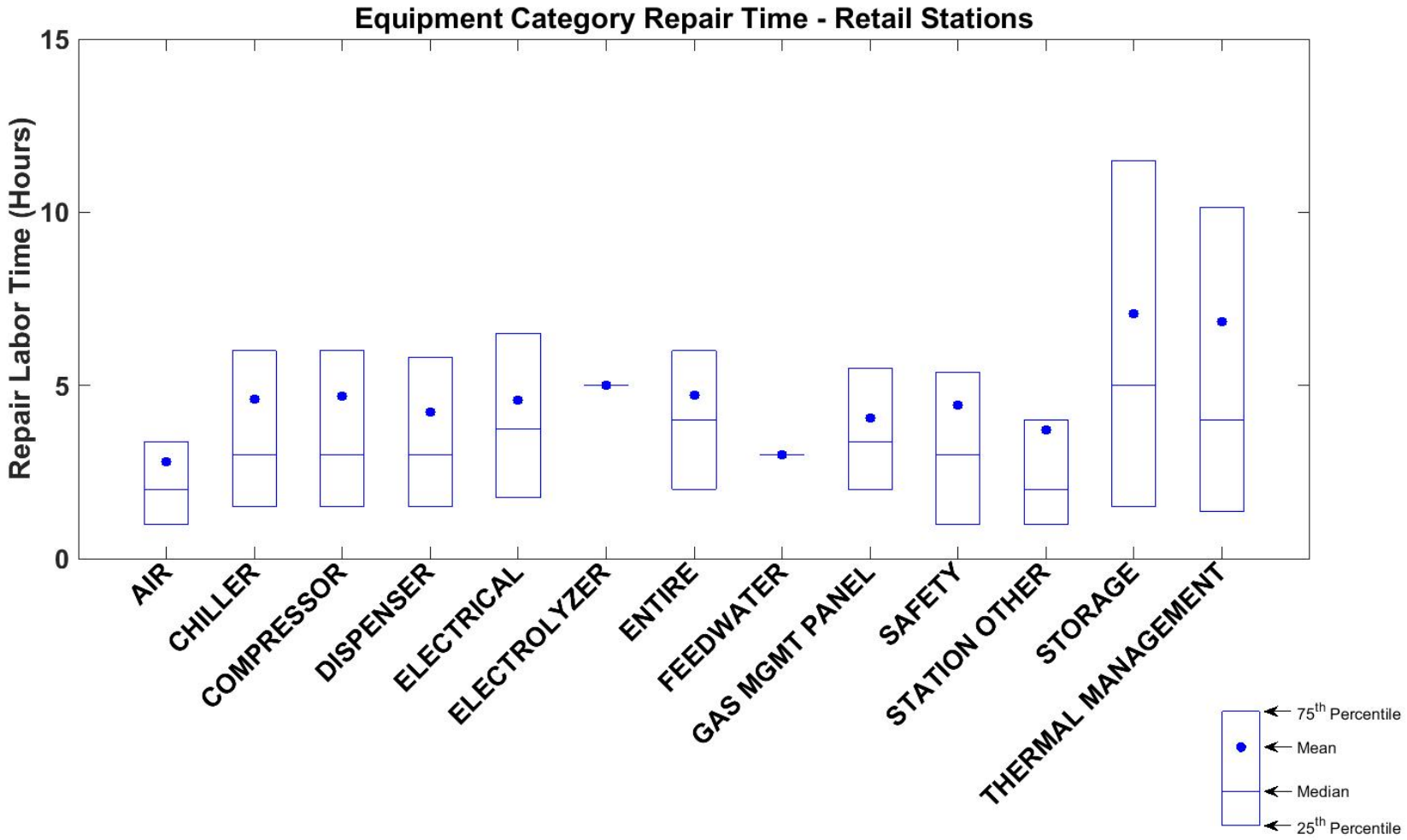
CDP-INFR-21
Maintenance by Equipment Type



CDP-INFR-22
Maintenance Labor Hours per Event



CDP-INFR-23
Equipment Category Repair Time



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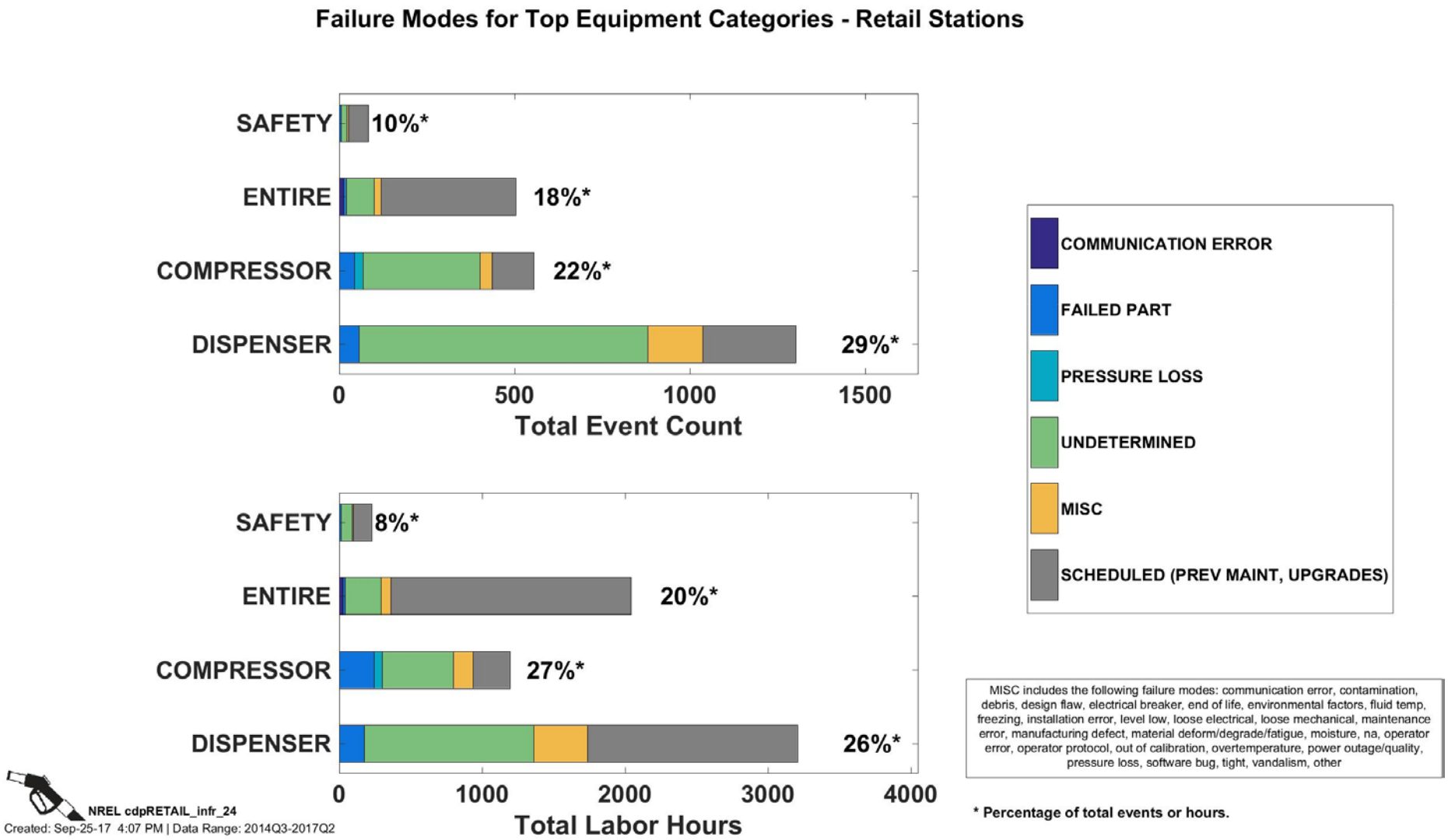
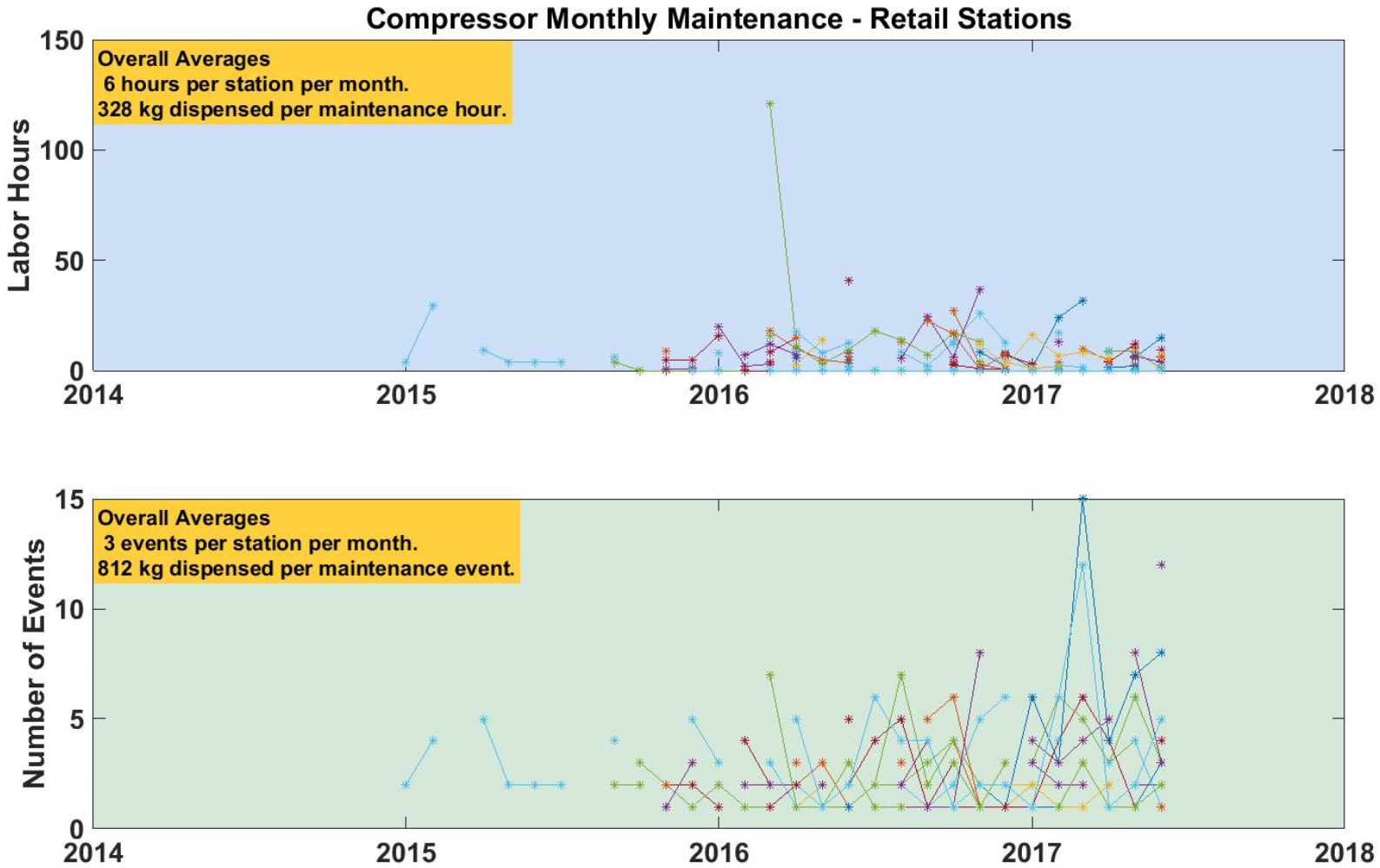
CDP-INFR-24
Failure Modes for Top Equipment Categories



MISC includes the following failure modes: communication error, contamination, 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, material deform/degrade/fatigue, moisture, na, operator error, operator protocol, out of calibration, overtemperature, power outage/quality, pressure loss, software bug, tight, vandalism, other

*** Percentage of total events or hours.**

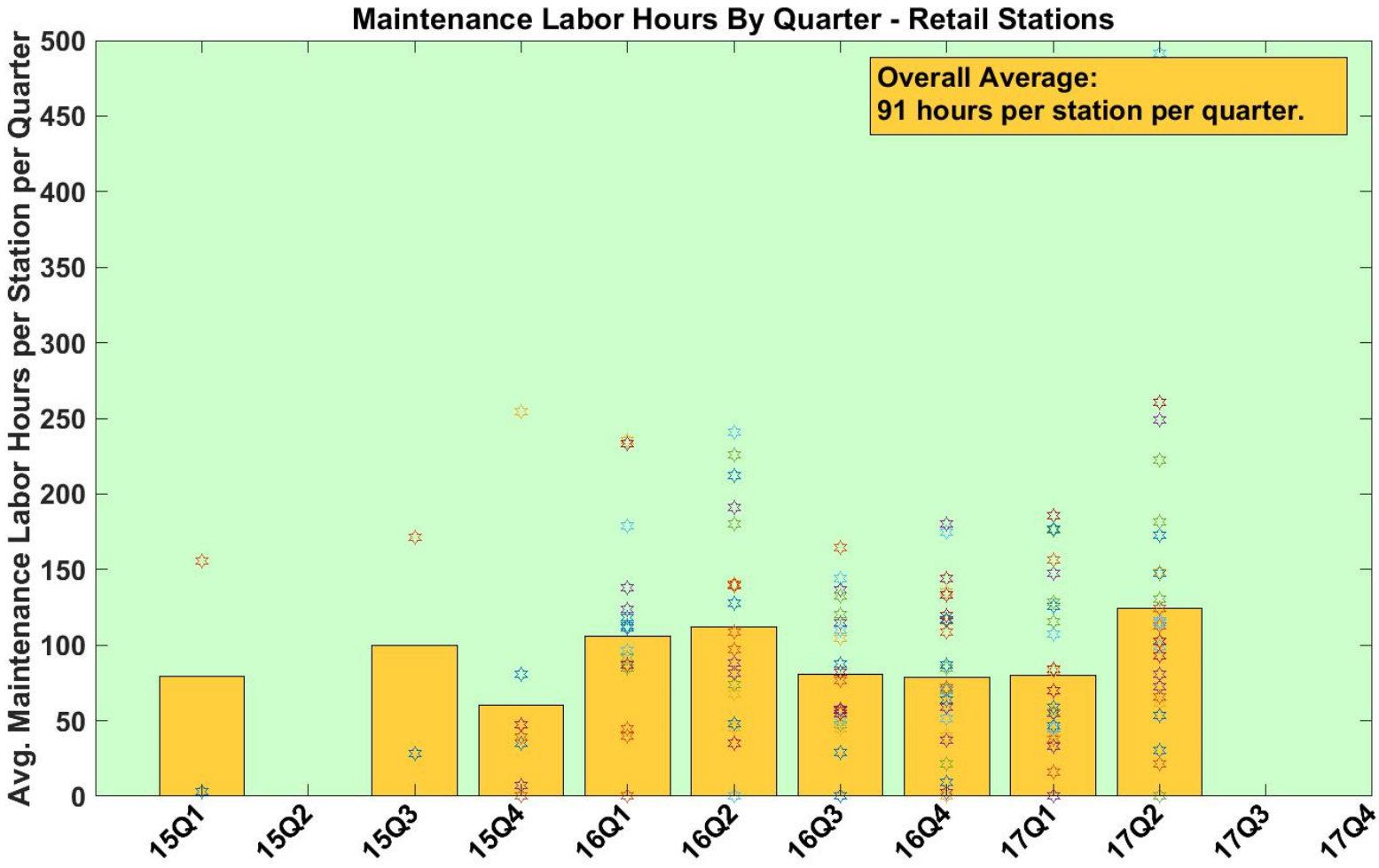
CDP-INFR-26
Compressor Monthly Maintenance



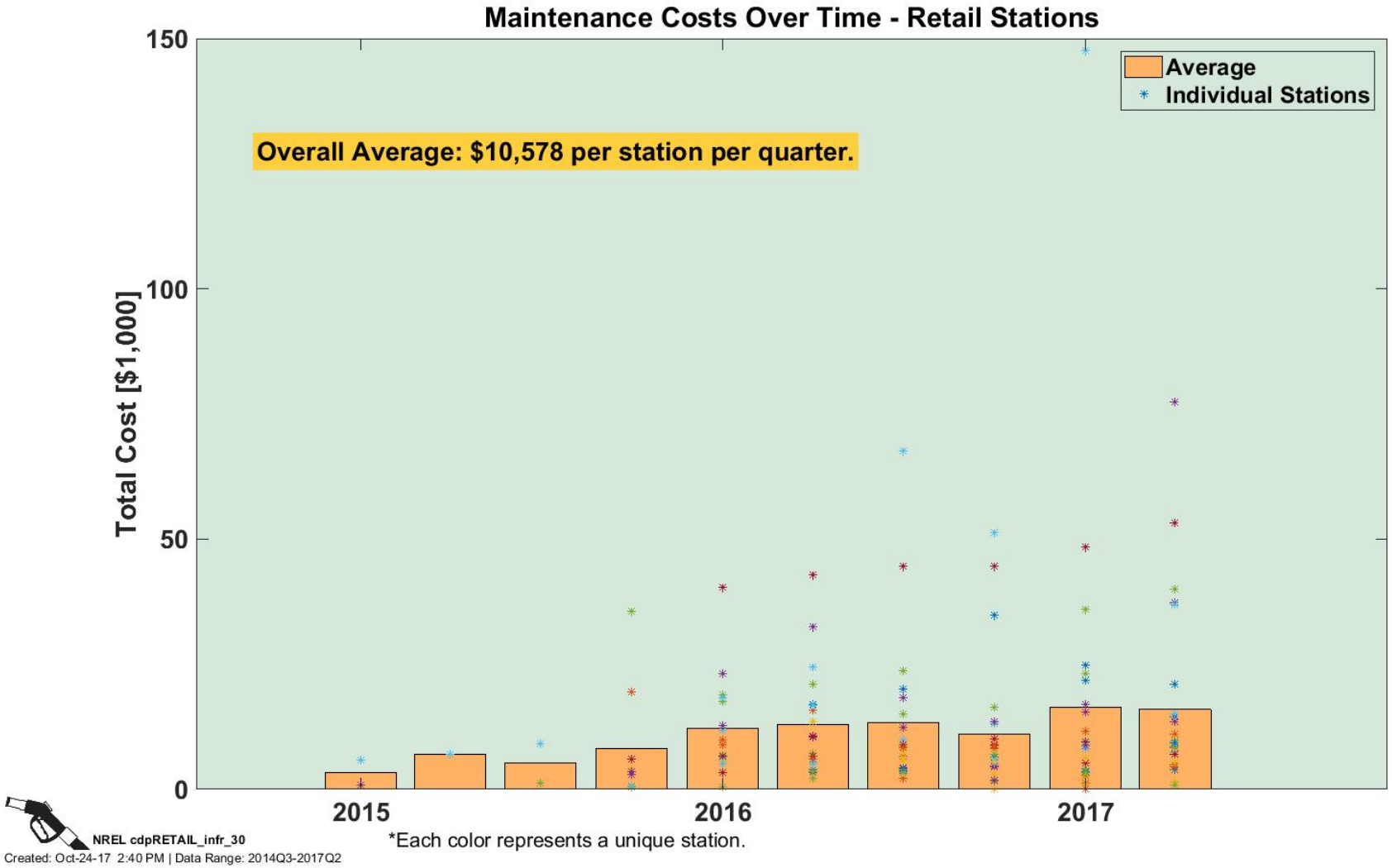
NREL cdpRETAIL_infr_26
Created: Oct-10-17 3:12 PM | Data Range: 2014Q3-2017Q2

* 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.

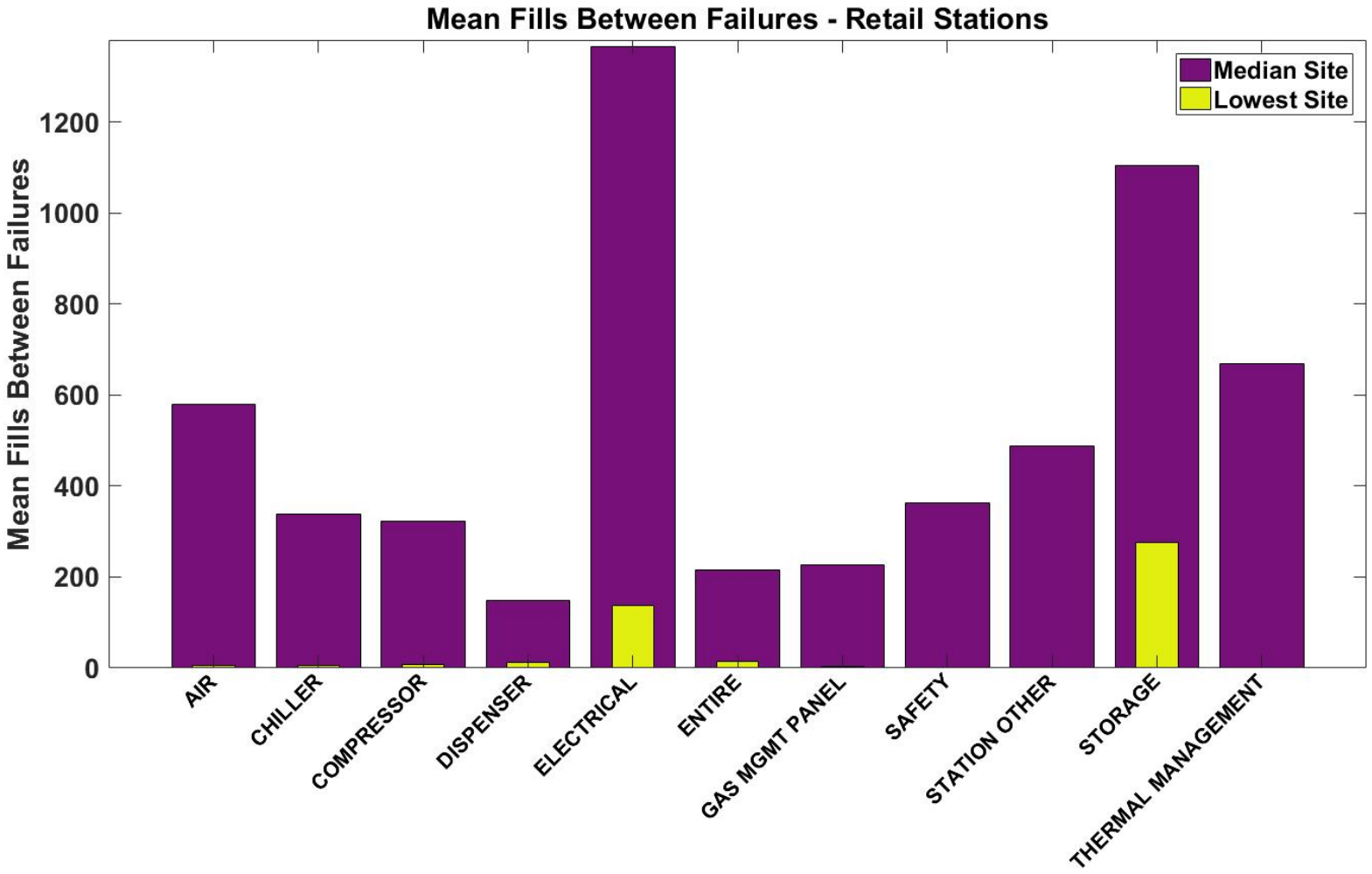
CDP-INFR-28
Maintenance Labor Hours by Quarter



CDP-INFR-30
Maintenance Costs Over Time



CDP-INFR-49
Mean Fills Between Failures



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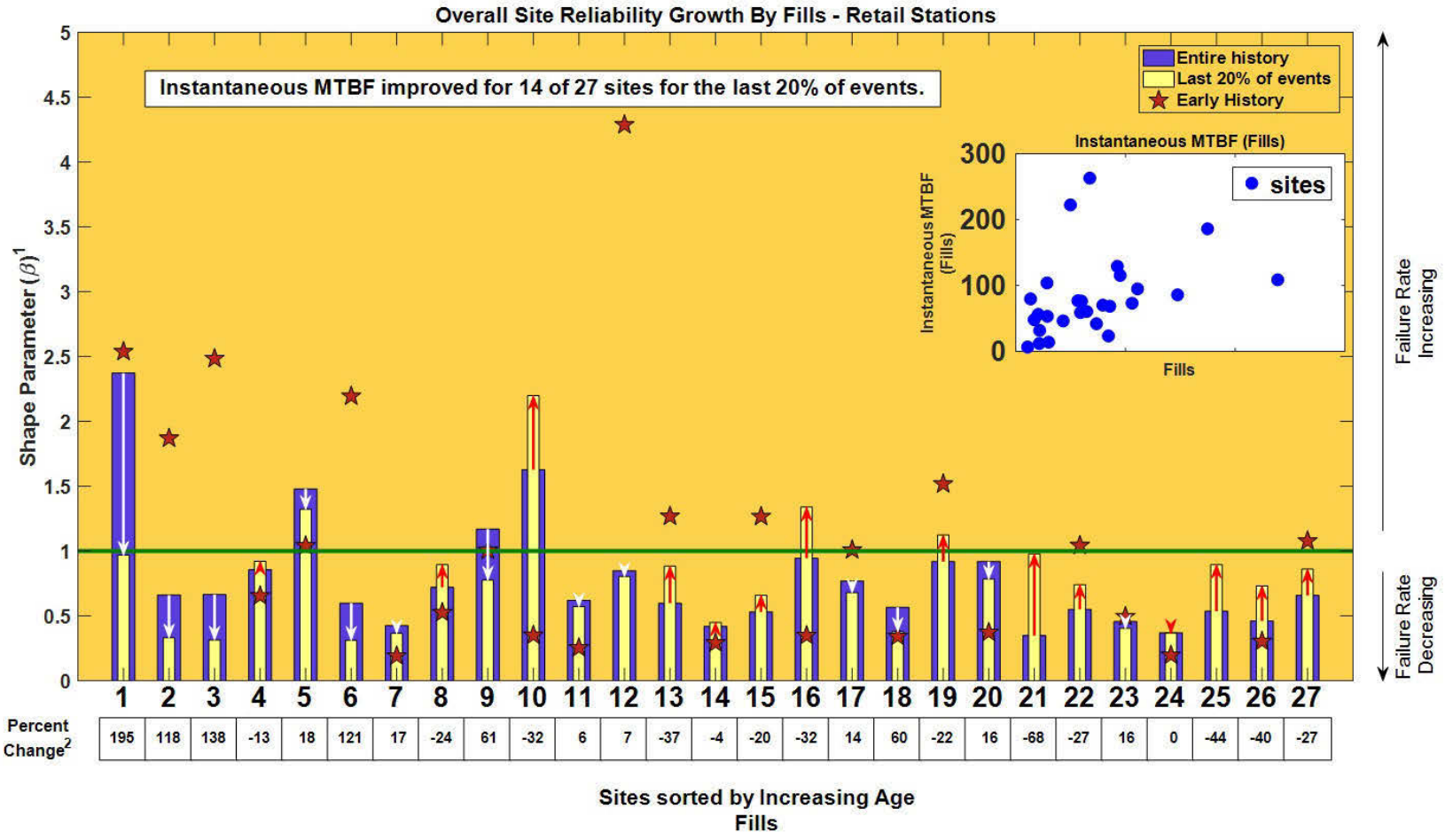
CDP-INFR-50
Reliability Growth by Fills



NREL cdpRETAIL_infr_50
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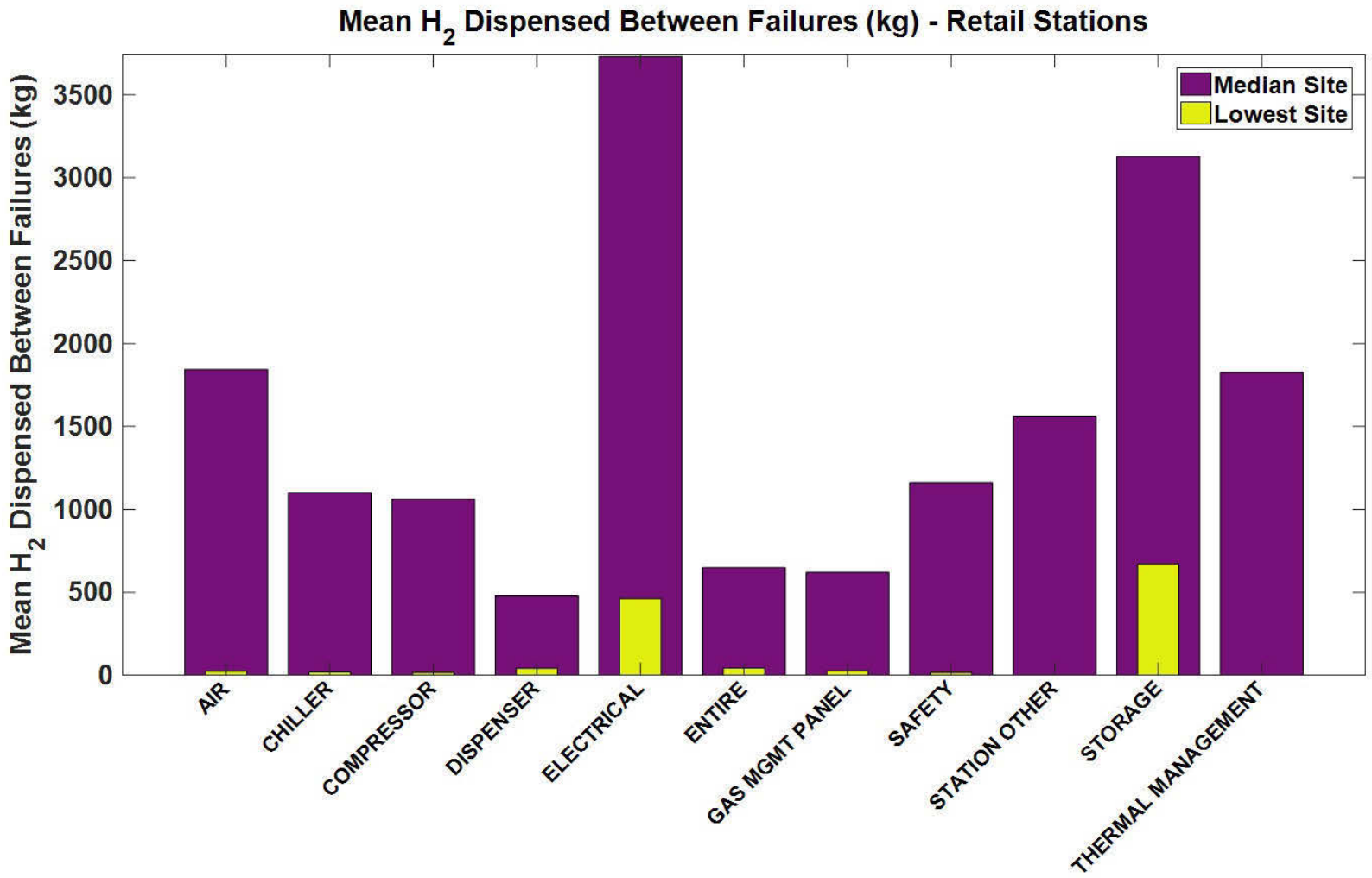
1. IEC 61164:2004(E)., Reliability Growth - Statistical Test and Evaluation Methods, IEC. 2004.
2. % change in instantaneous mean Fills between failures

CDP-INFR-51
Mean Amount Dispensed Between Failures



NREL cdpRETAIL_infr_51
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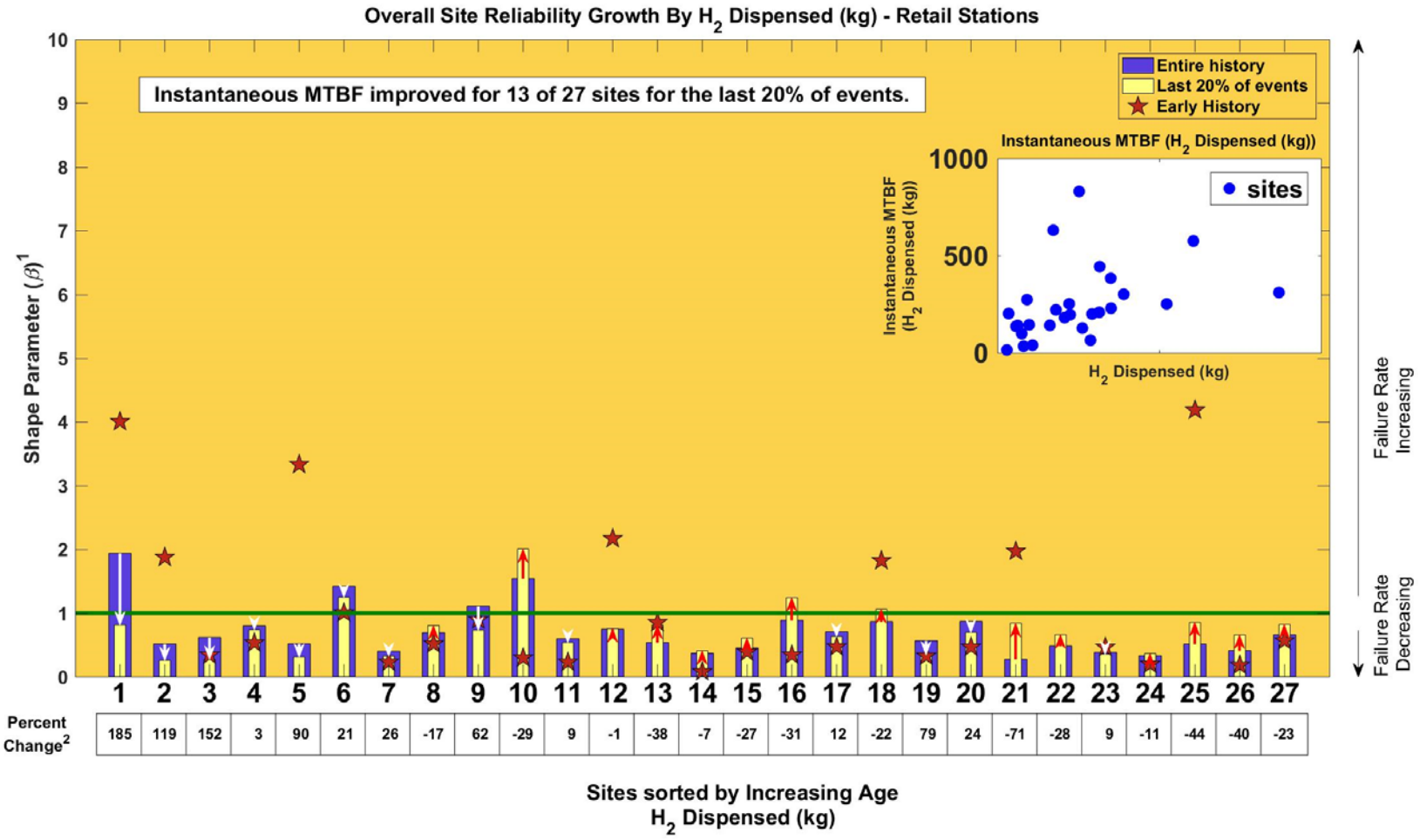
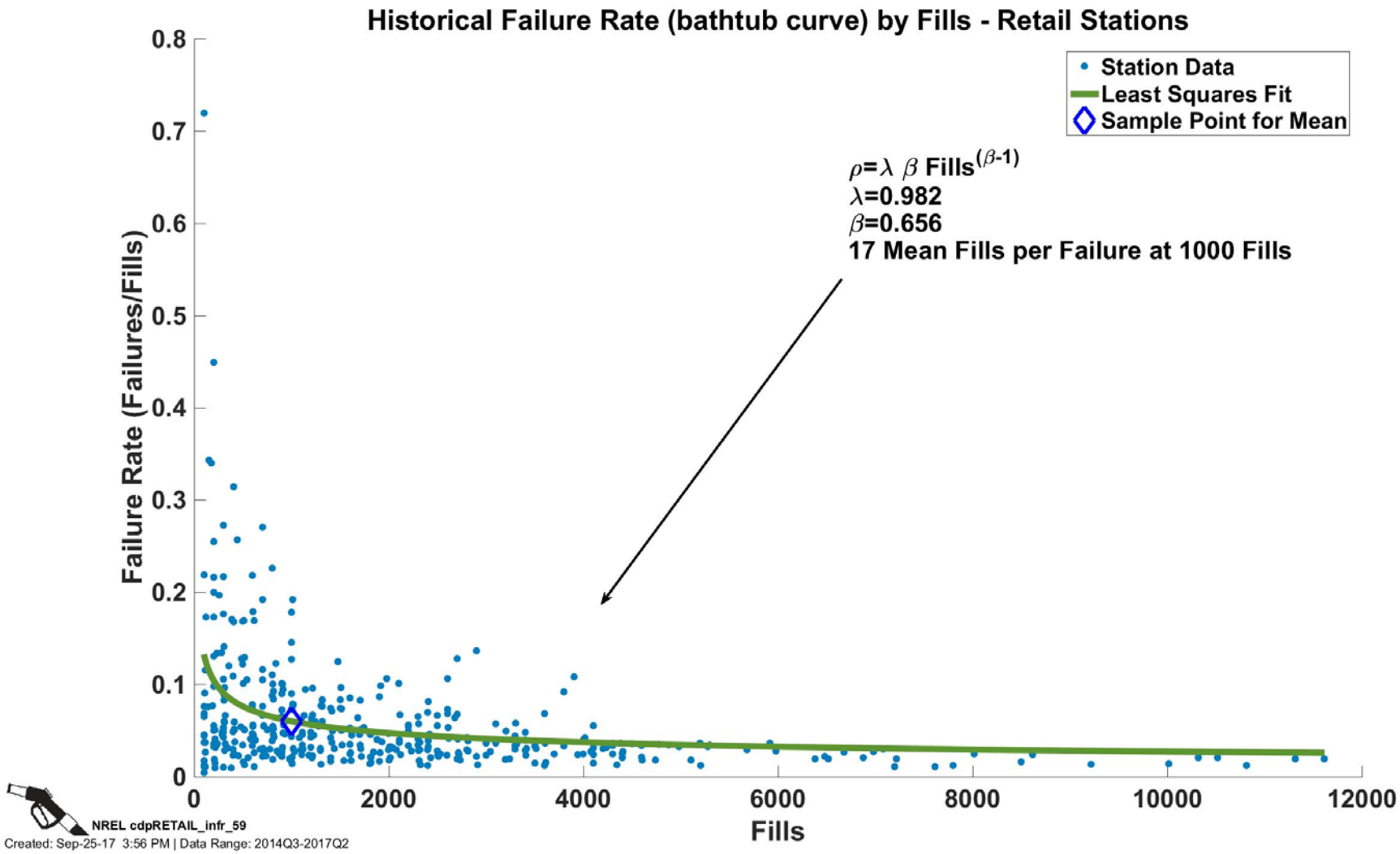
CDP-INFR-52
Reliability Growth by Amount Dispensed



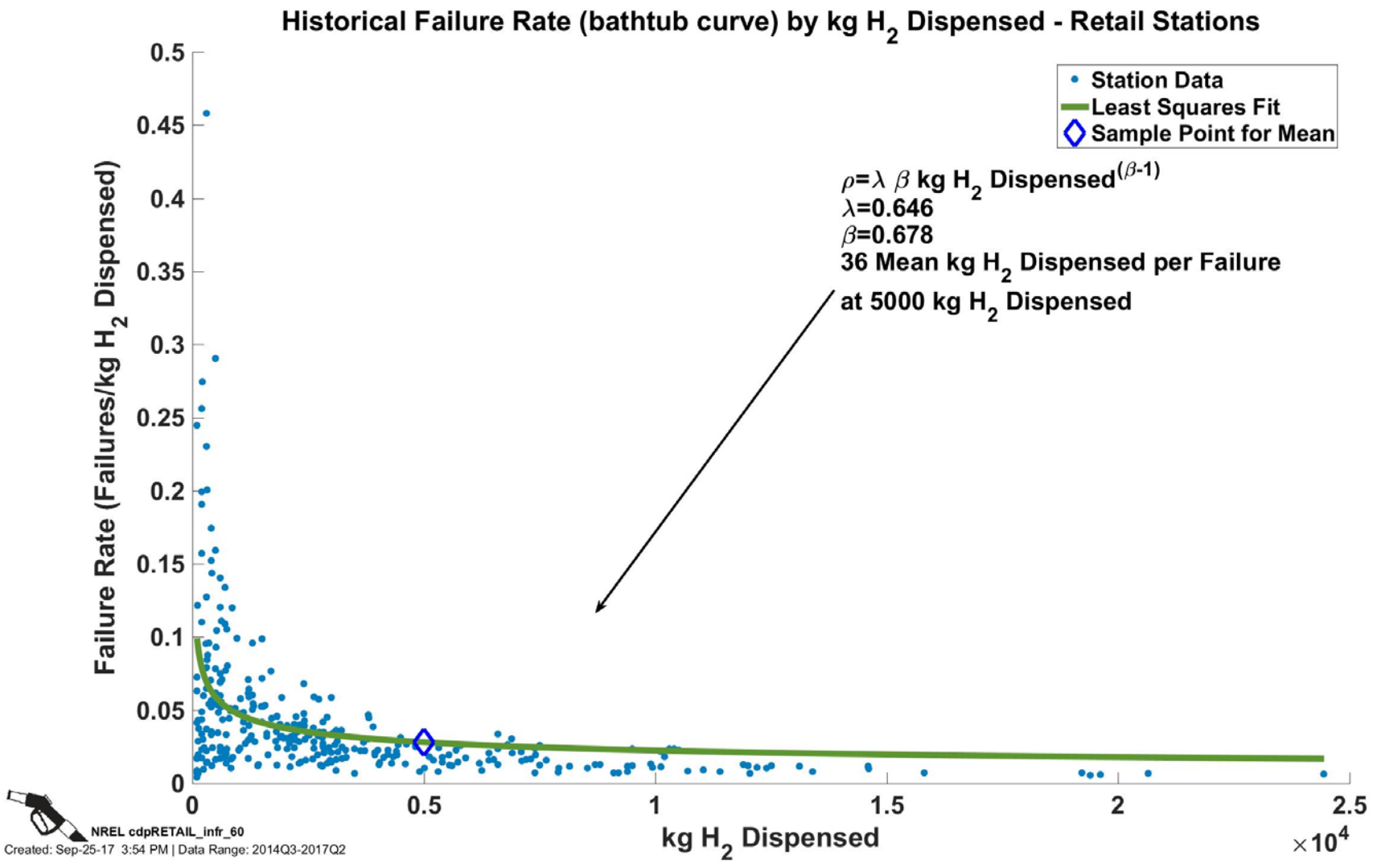
NREL cdpRETAIL_infr_52
Created: Sep-25-17 4:01 PM | Data Range: 2014Q3-2017Q2

1. IEC 61164:2004(E)., Reliability Growth - Statistical Test and Evaluation Methods, IEC. 2004.
2. % change in instantaneous mean H_2 Dispensed (kg) between failures

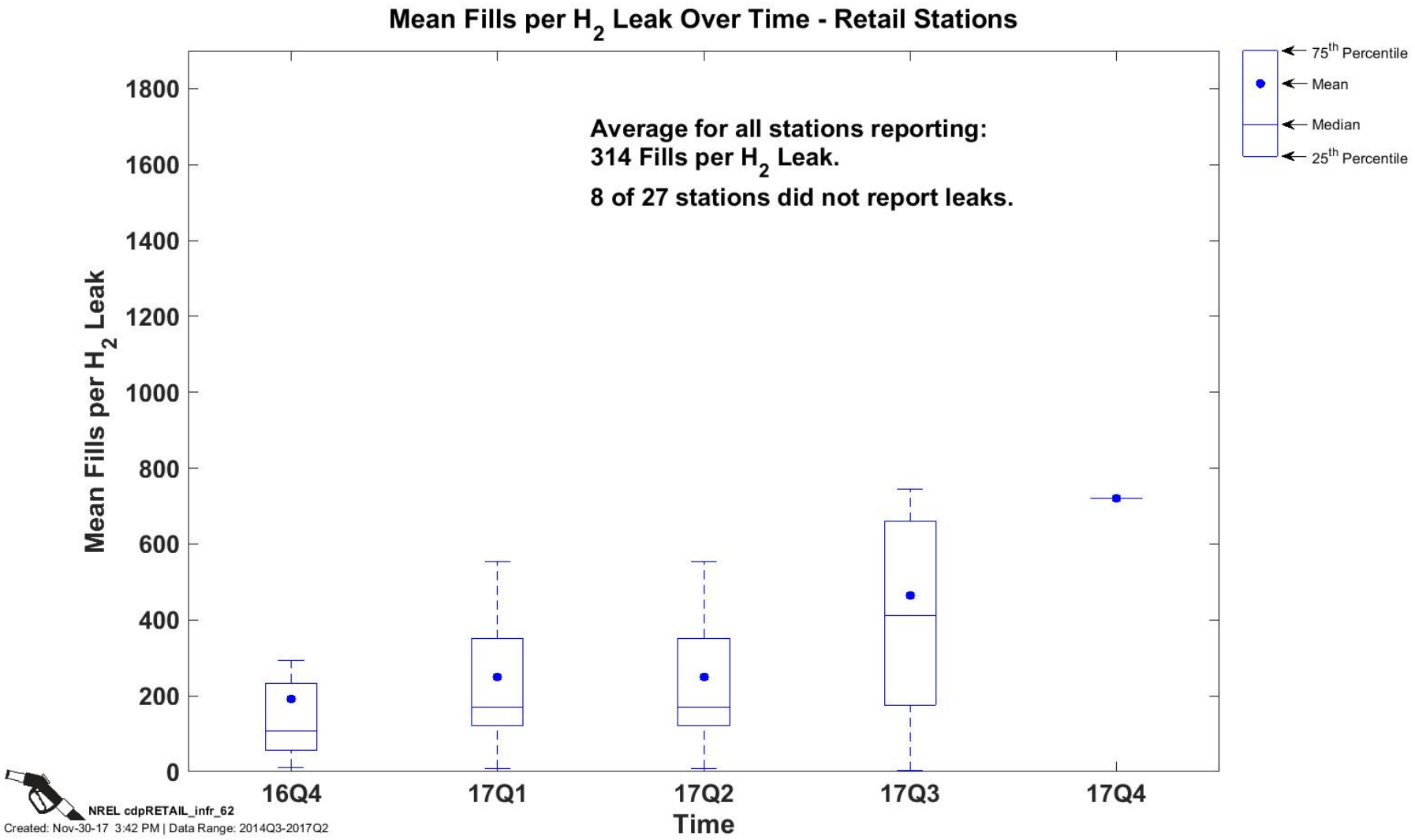
CDP-INFR-59
Historical Failure Rate by Fills



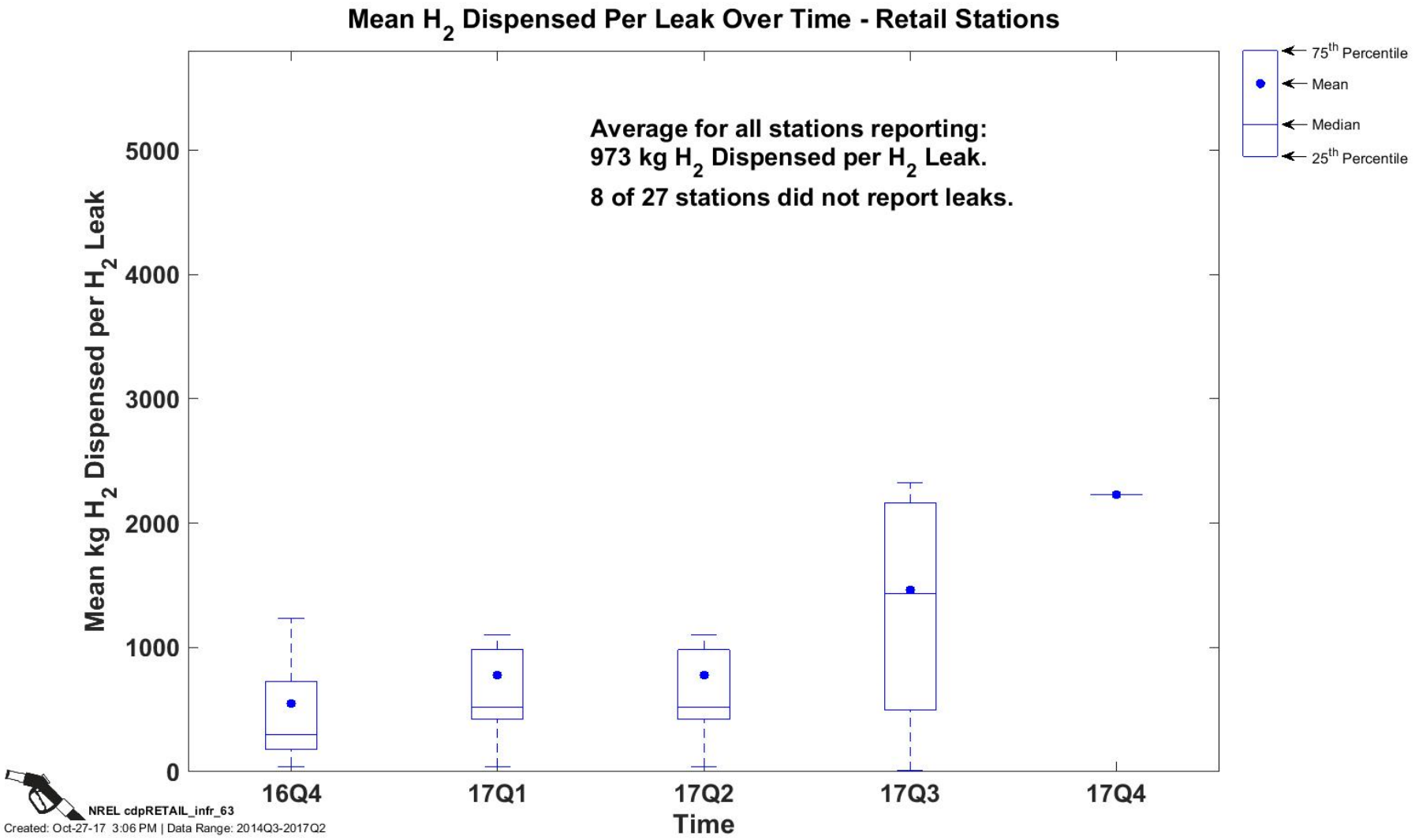
CDP-INFR-60
Historical Failure Rate by Amount Dispensed



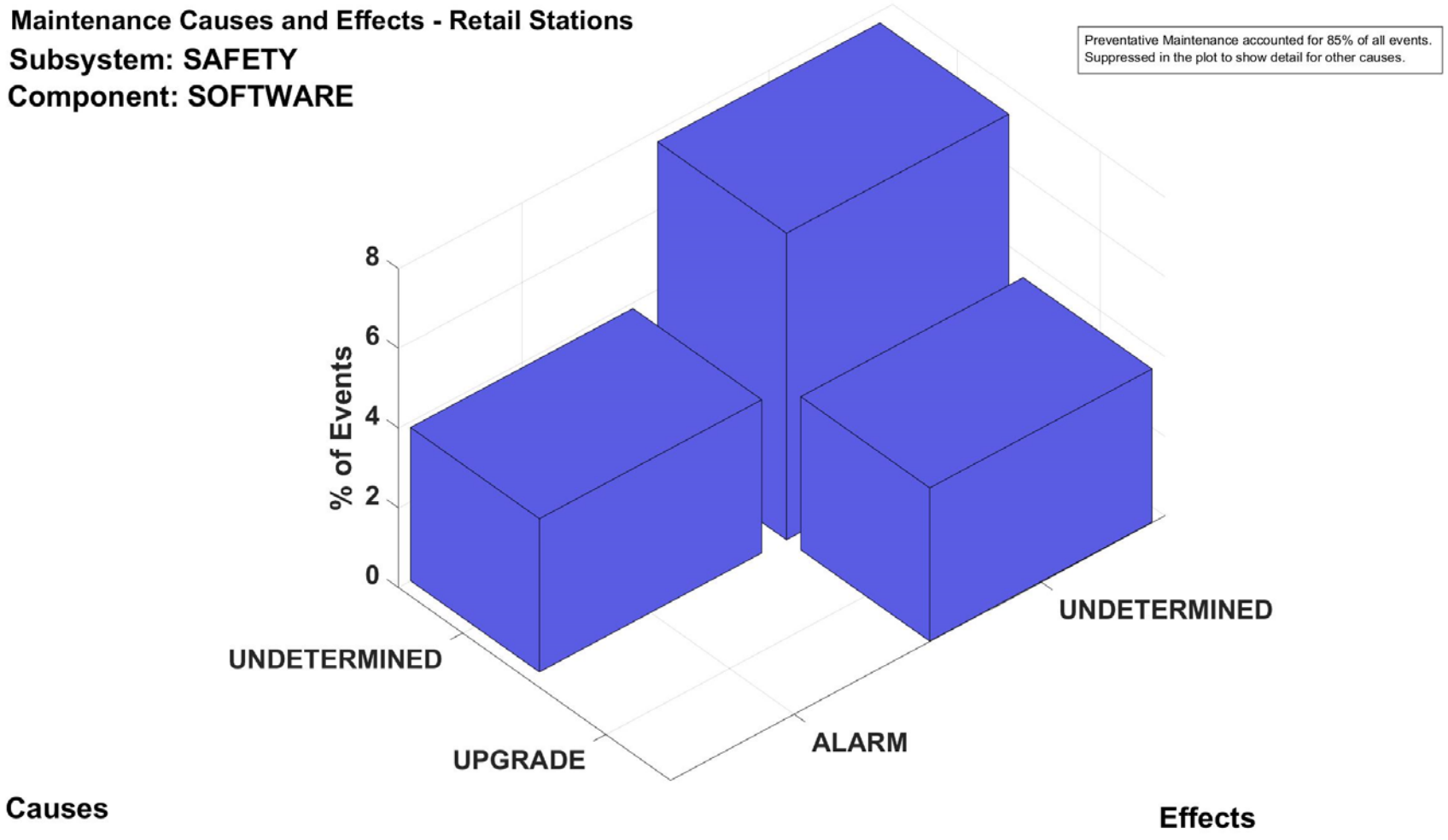
CDP-INFR-62
Mean Fills per Hydrogen Leak Over Time



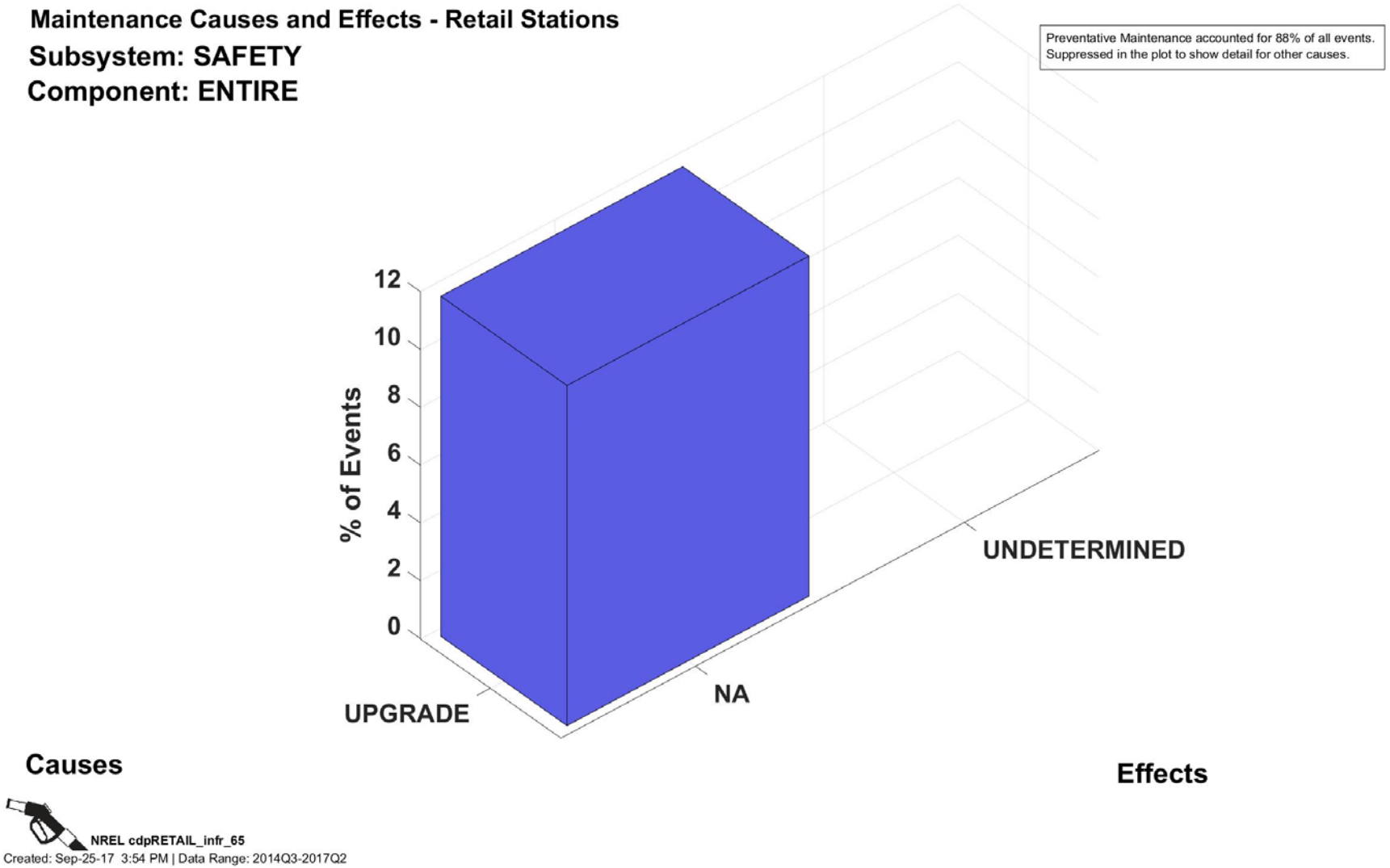
CDP-INFR-63
Mean Hydrogen Dispensed per Leak Over Time



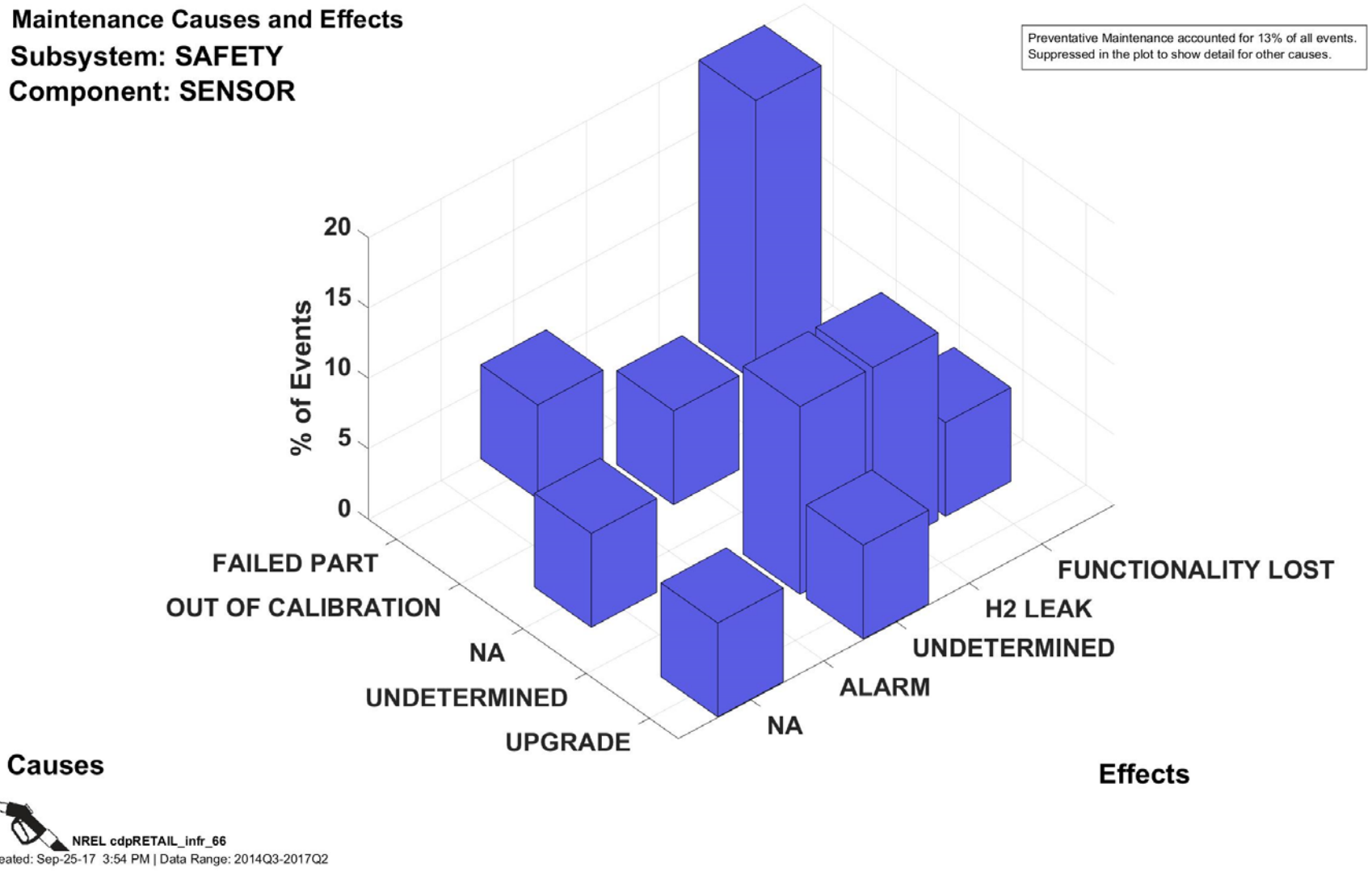
CDP-INFR-64
Maintenance Causes and Effects: Safety (Software)



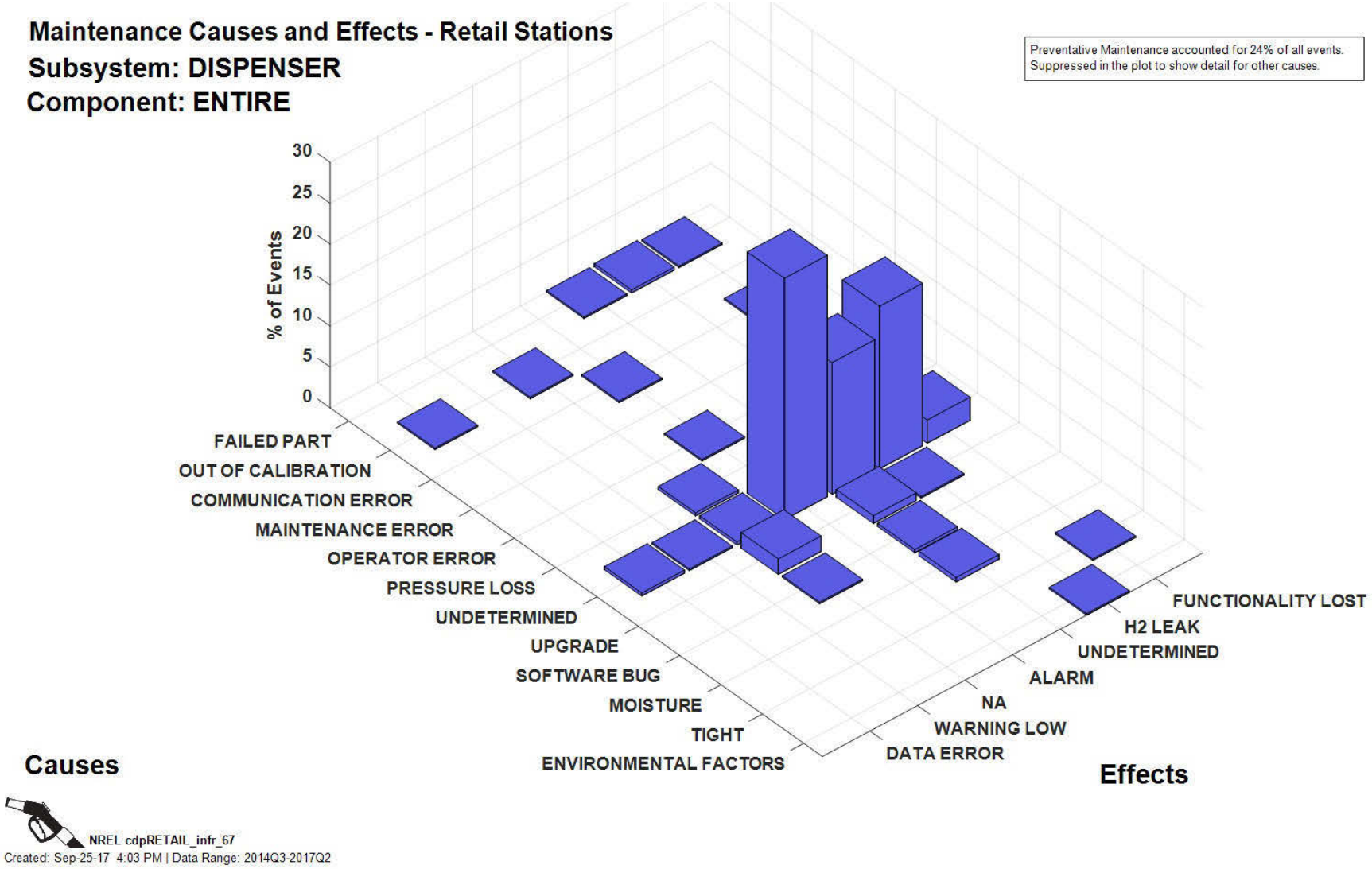
CDP-INFR-65
Maintenance Causes and Effects: Safety (Entire)



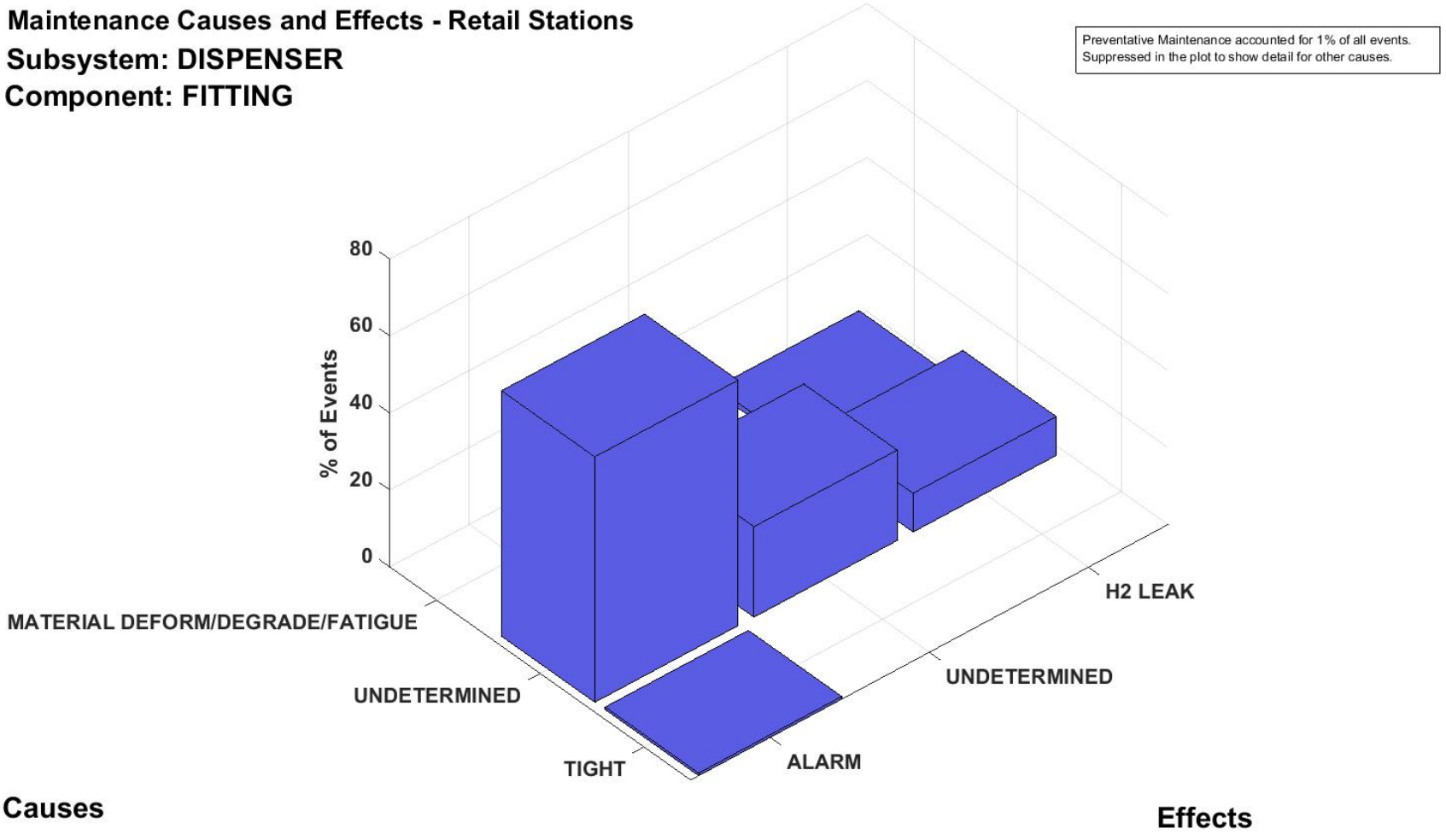
CDP-INFR-66
Maintenance Causes and Effects: Safety (Sensor)



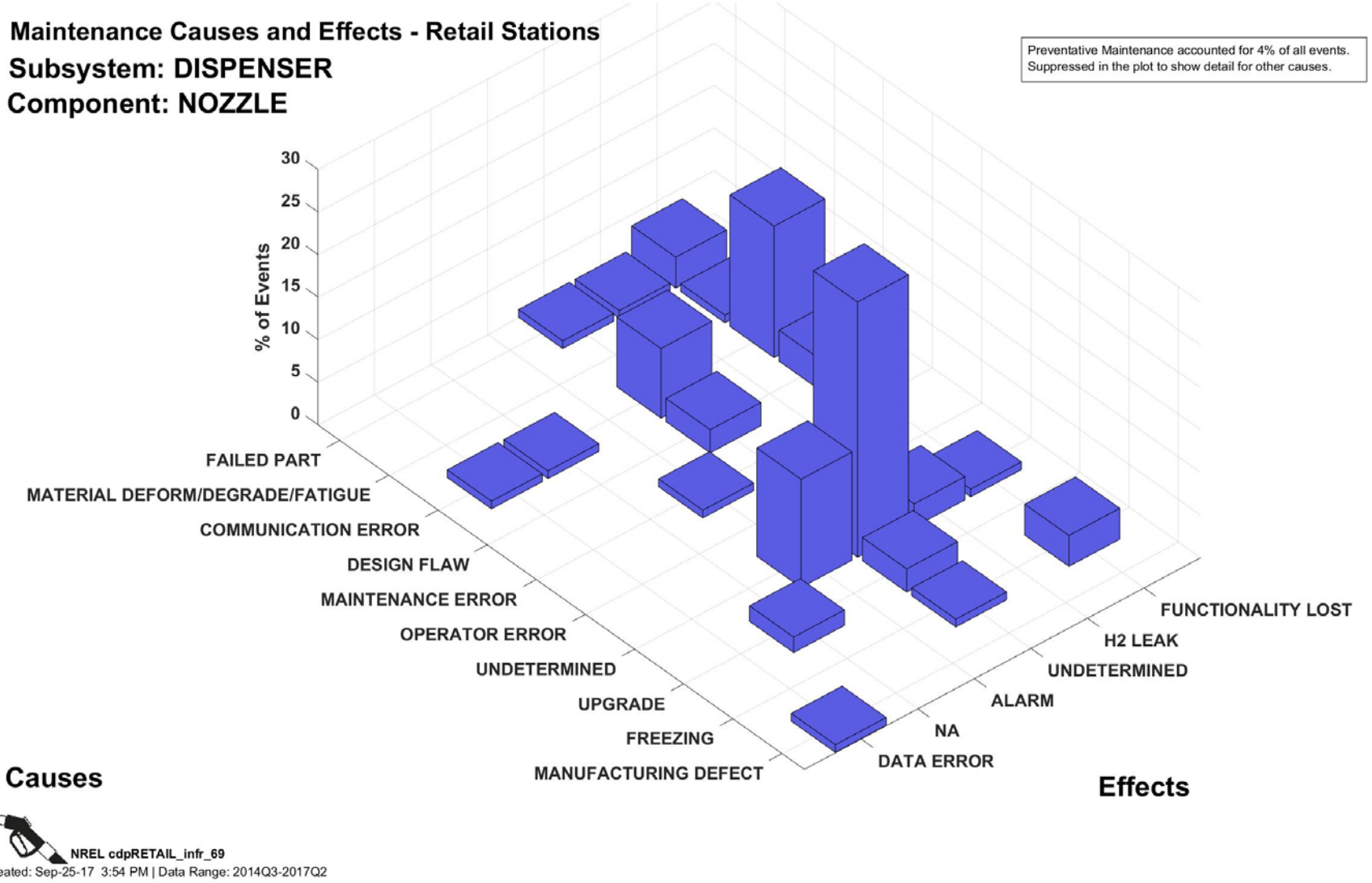
CDP-INFR-67
Maintenance Causes and Effects: Dispenser (Entire)



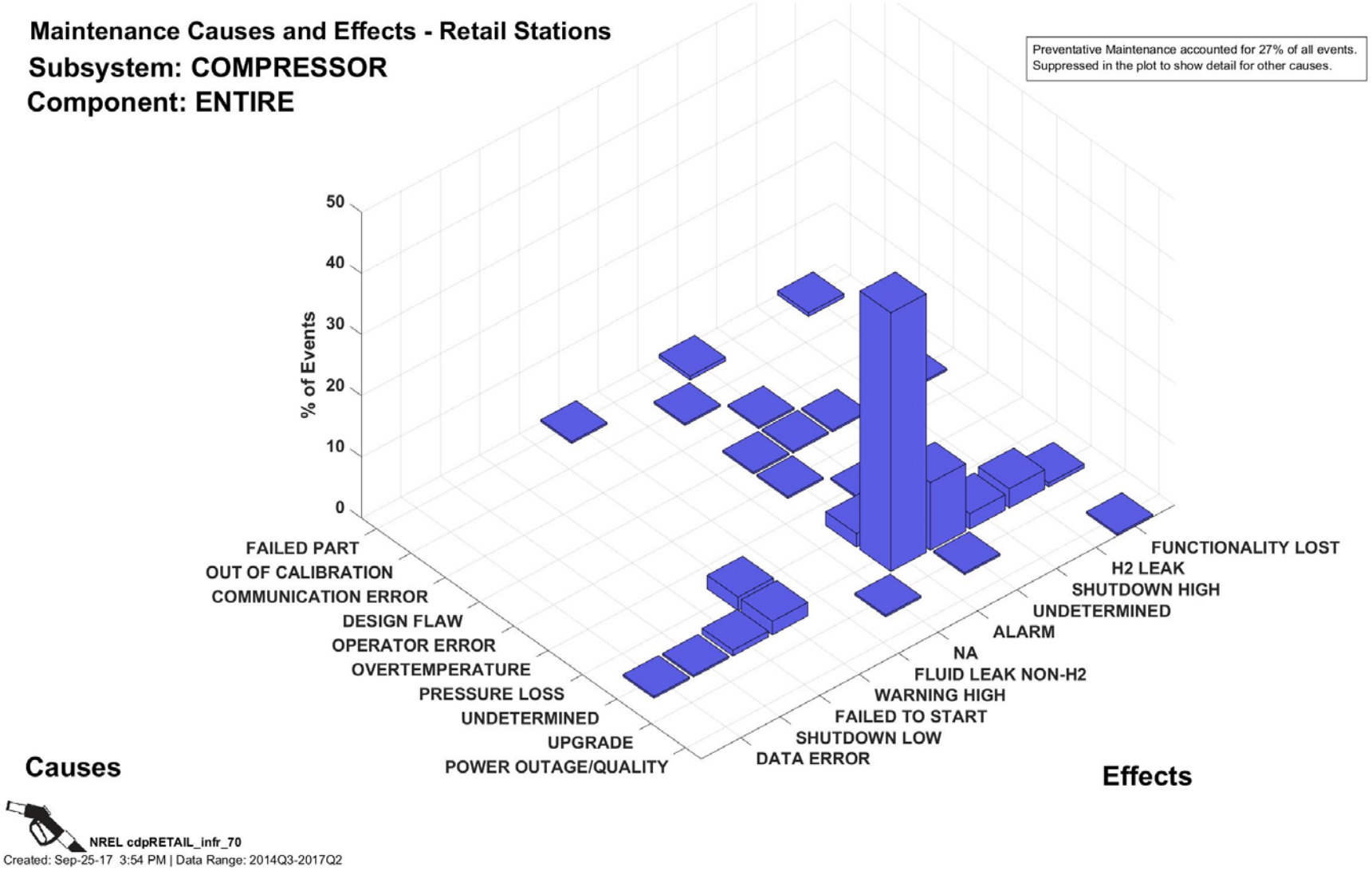
CDP-INFR-68
Maintenance Causes and Effects: Dispenser (Fitting)



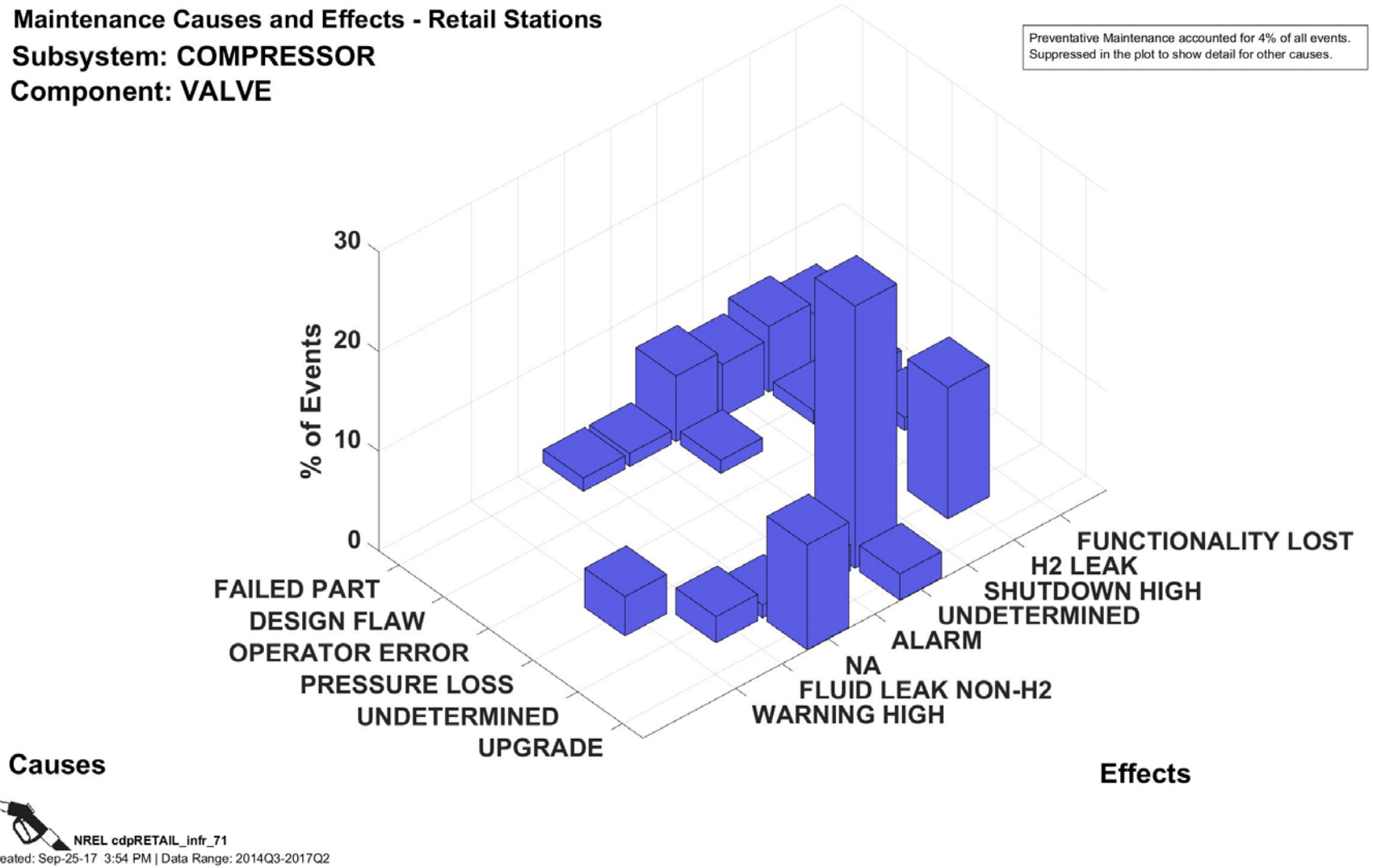
CDP-INFR-69
Maintenance Causes and Effects: Dispenser (Nozzle)



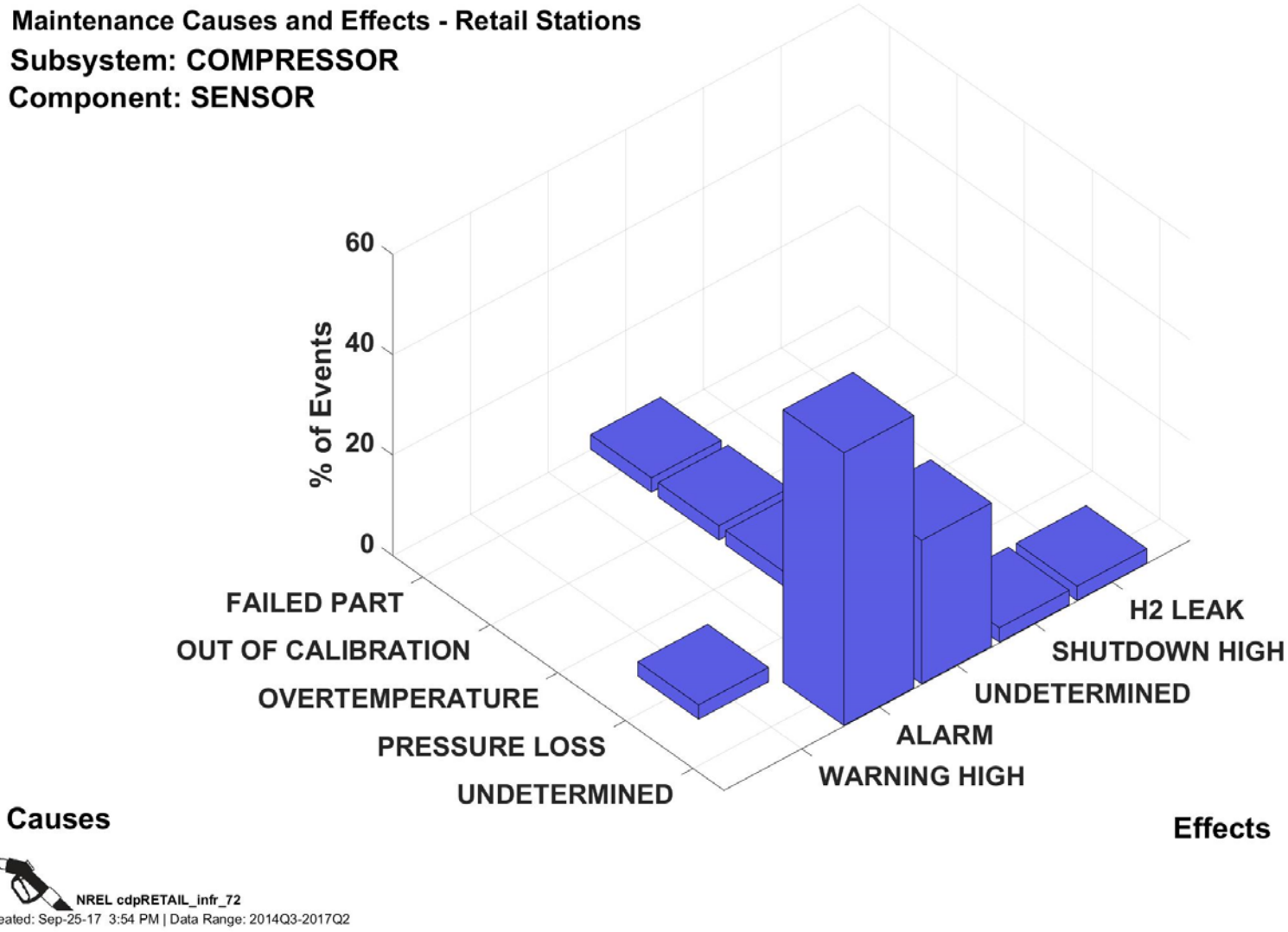
CDP-INFR-70
Maintenance Causes and Effects: Compressor (Entire)



CDP-INFR-71
Maintenance Causes and Effects: Compressor (Valve)

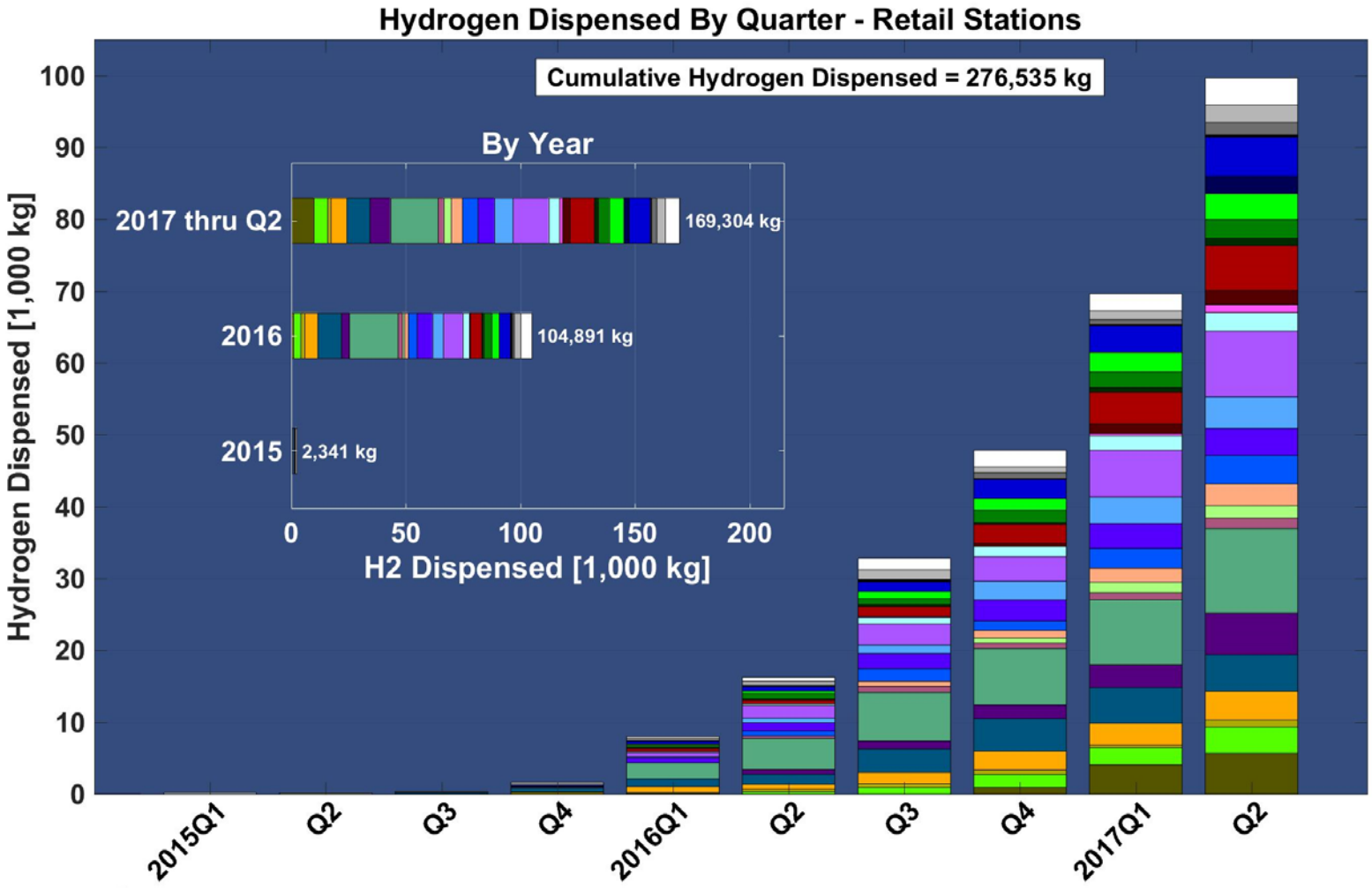


CDP-INFR-72
Maintenance Causes and Effects: Compressor (Sensor)



Performance

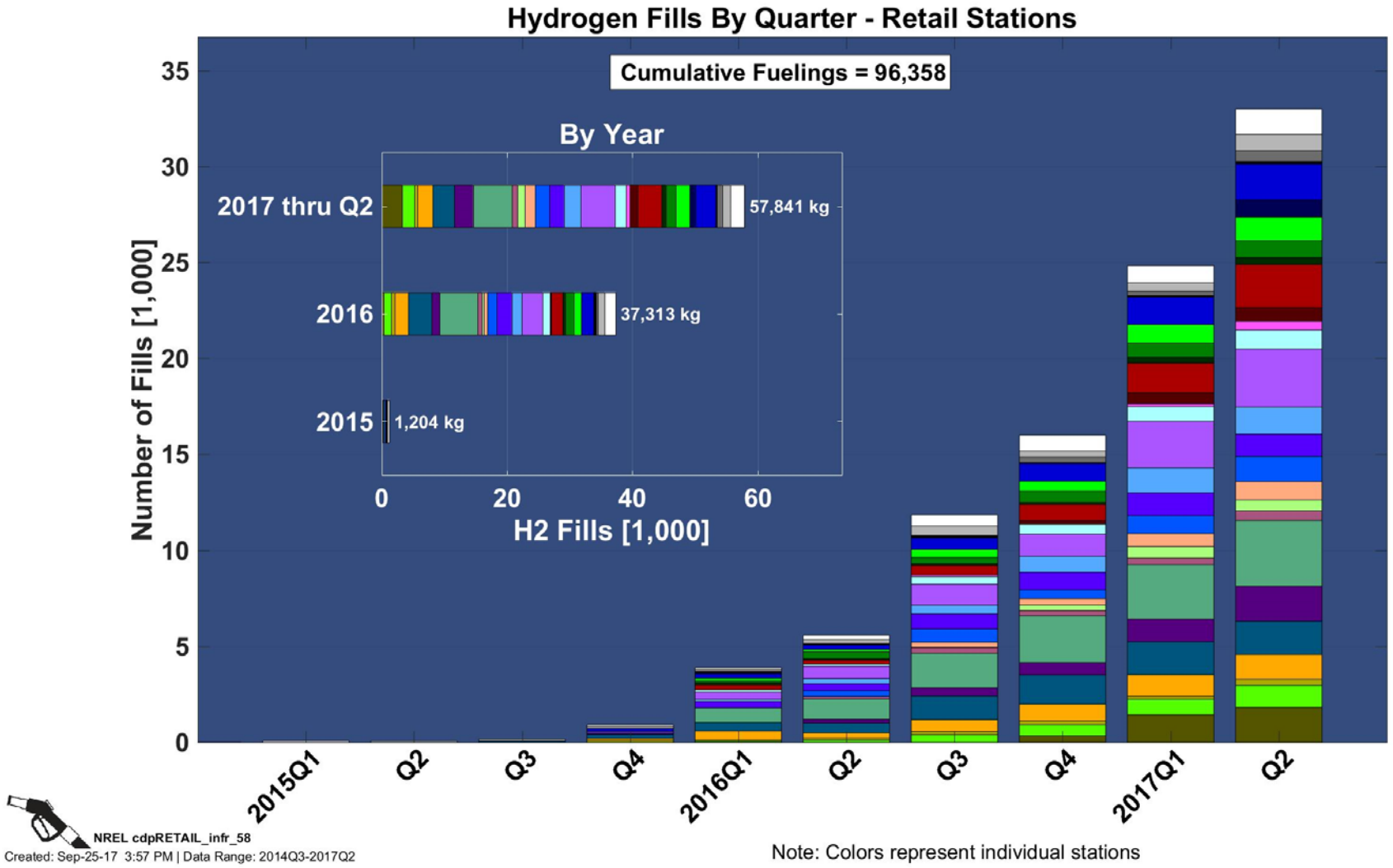
CDP-INFR-01
Hydrogen Dispensed by Quarter



NREL cdpRETAIL_infr_01
Created: Sep-25-17 4:03 PM | Data Range: 2014Q3-2017Q2

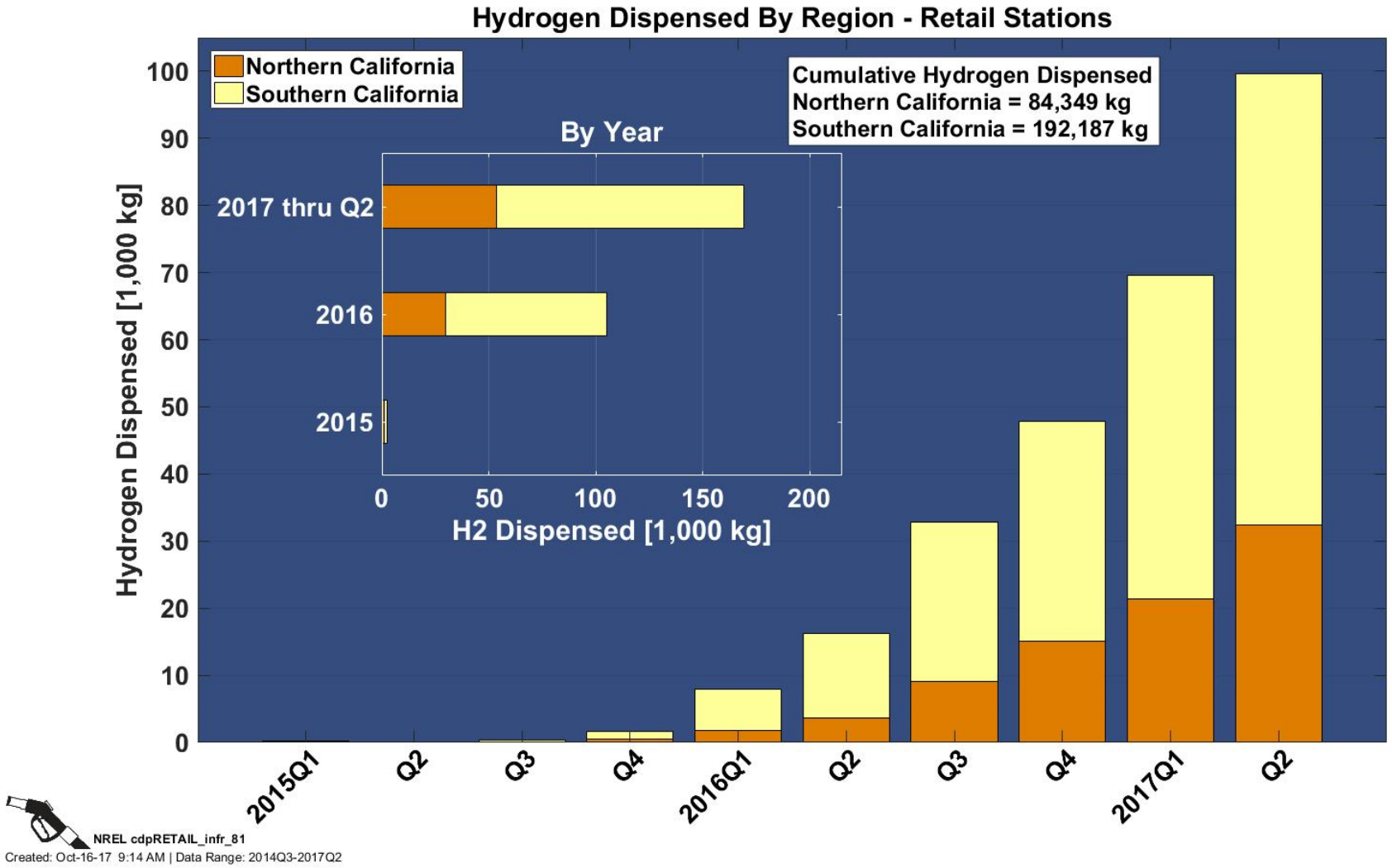
Note: Colors represent individual stations

CDP-INFR-58
Hydrogen Fills by Quarter

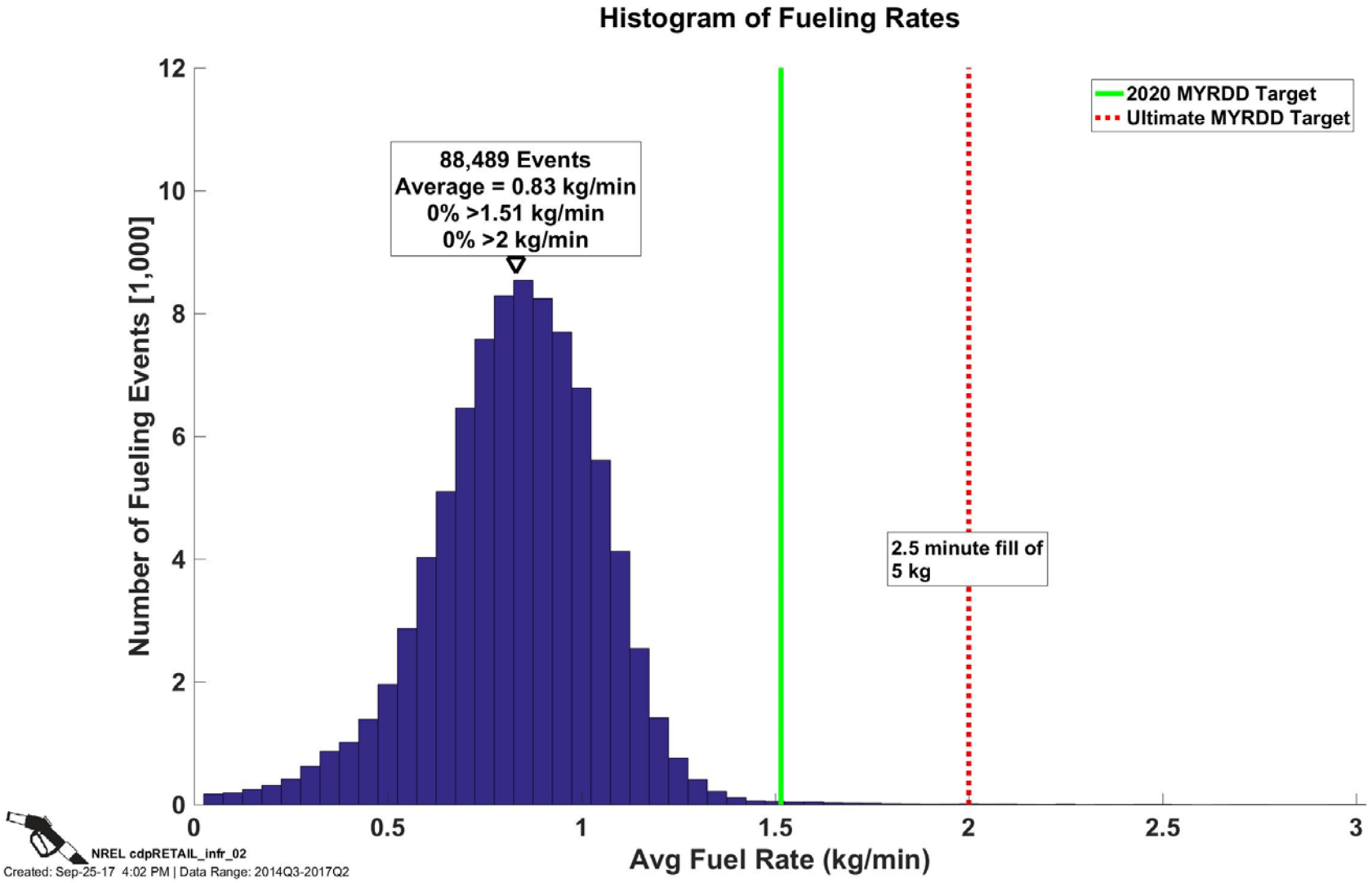


Note: Colors represent individual stations

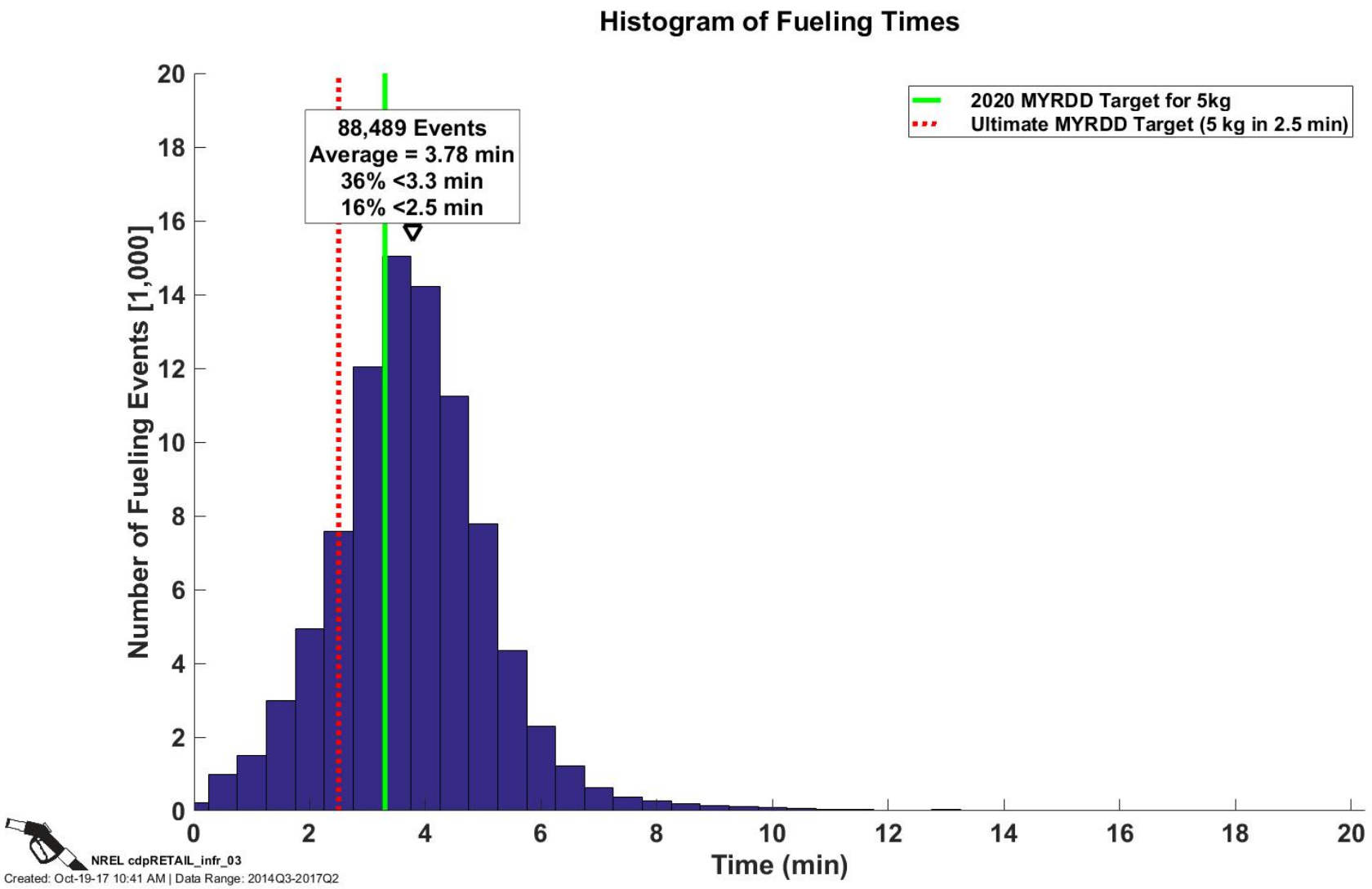
CDP-INFR-81
Hydrogen Dispensed by Region



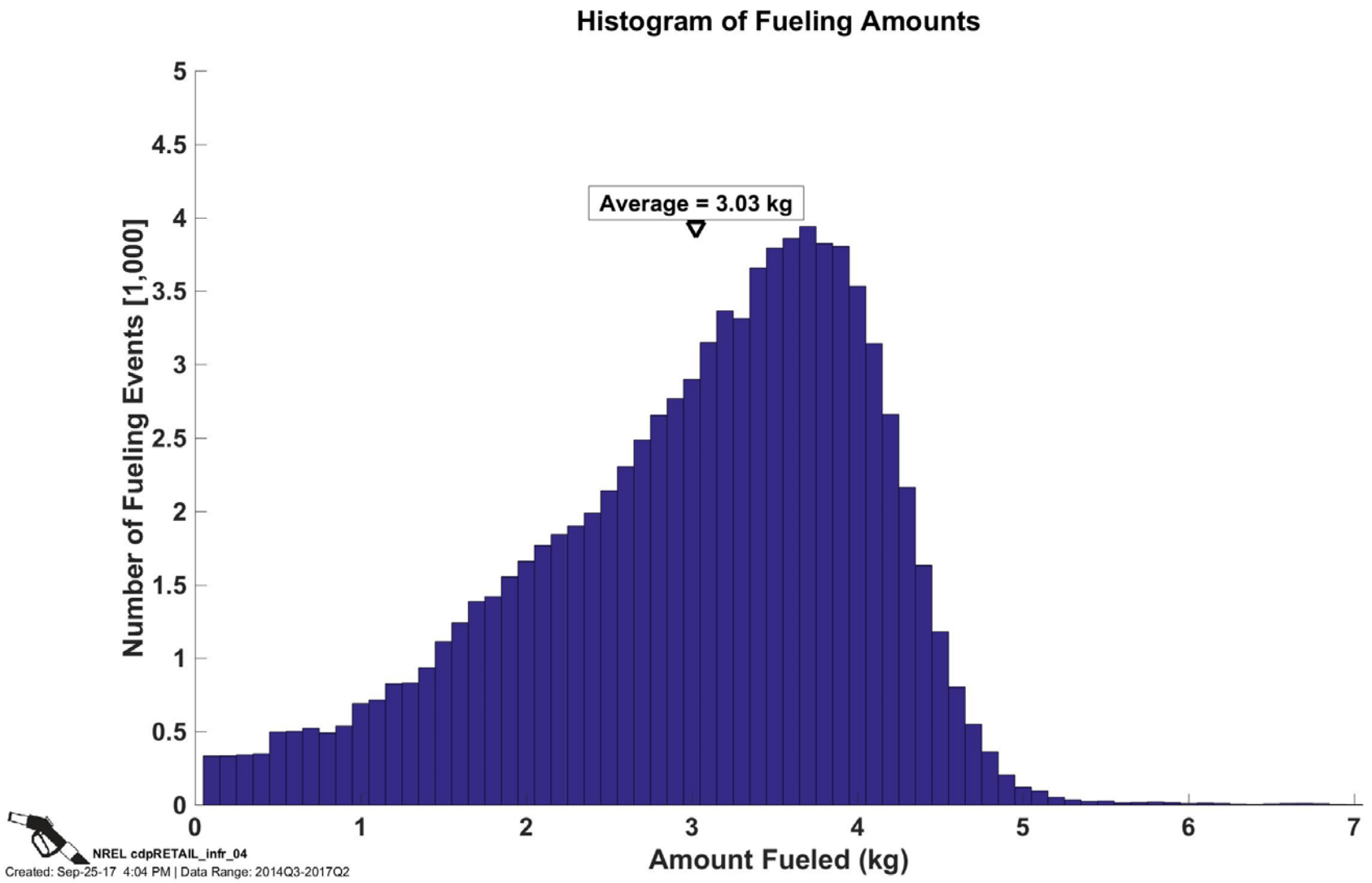
CDP-INFR-02
Histogram of Fueling Rates



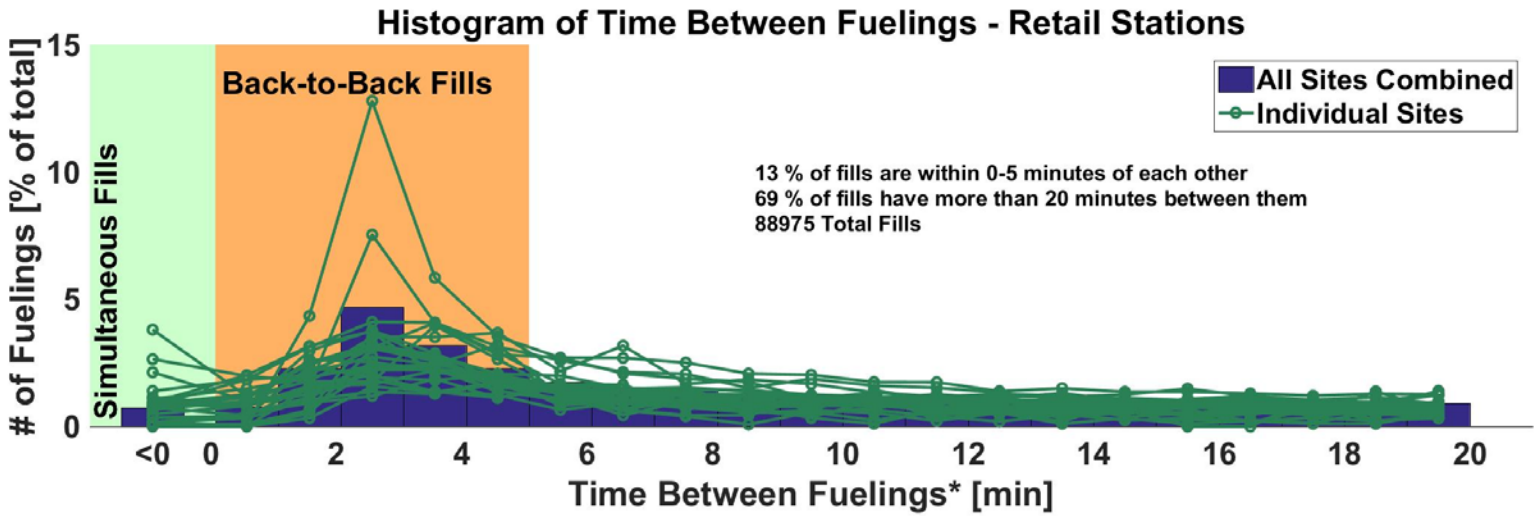
CDP-INFR-03
Histogram of Fueling Times

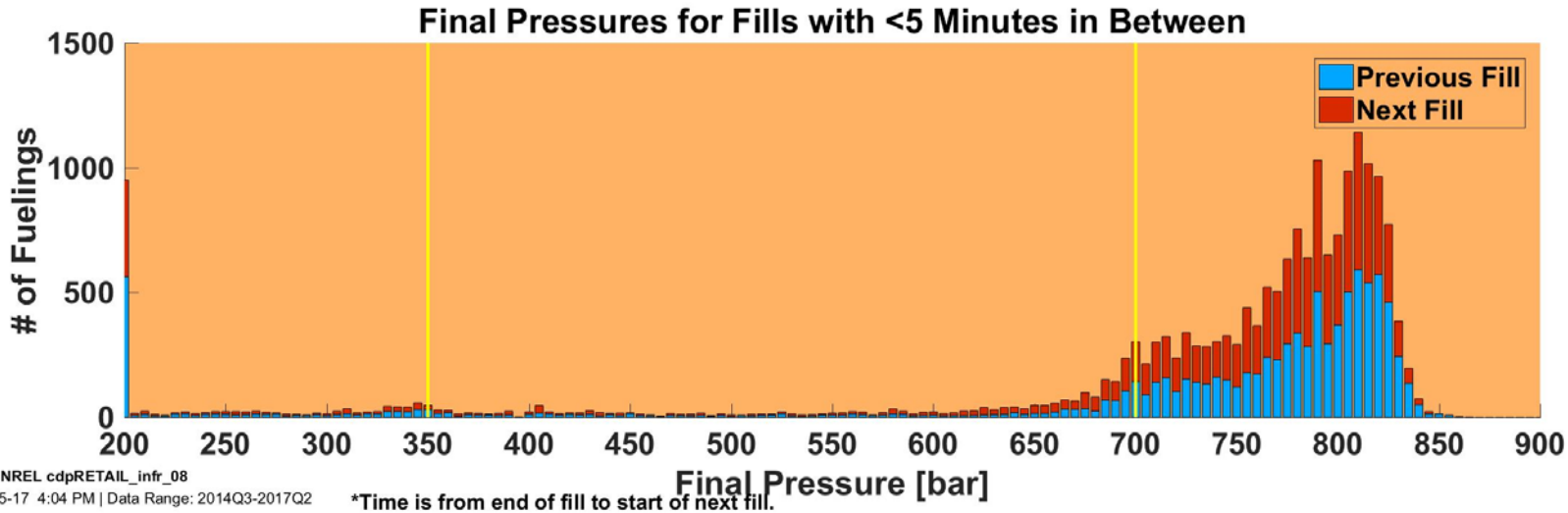


CDP-INFR-04
Histogram of Fueling Amounts



CDP-INFR-08
Time Between Fueling

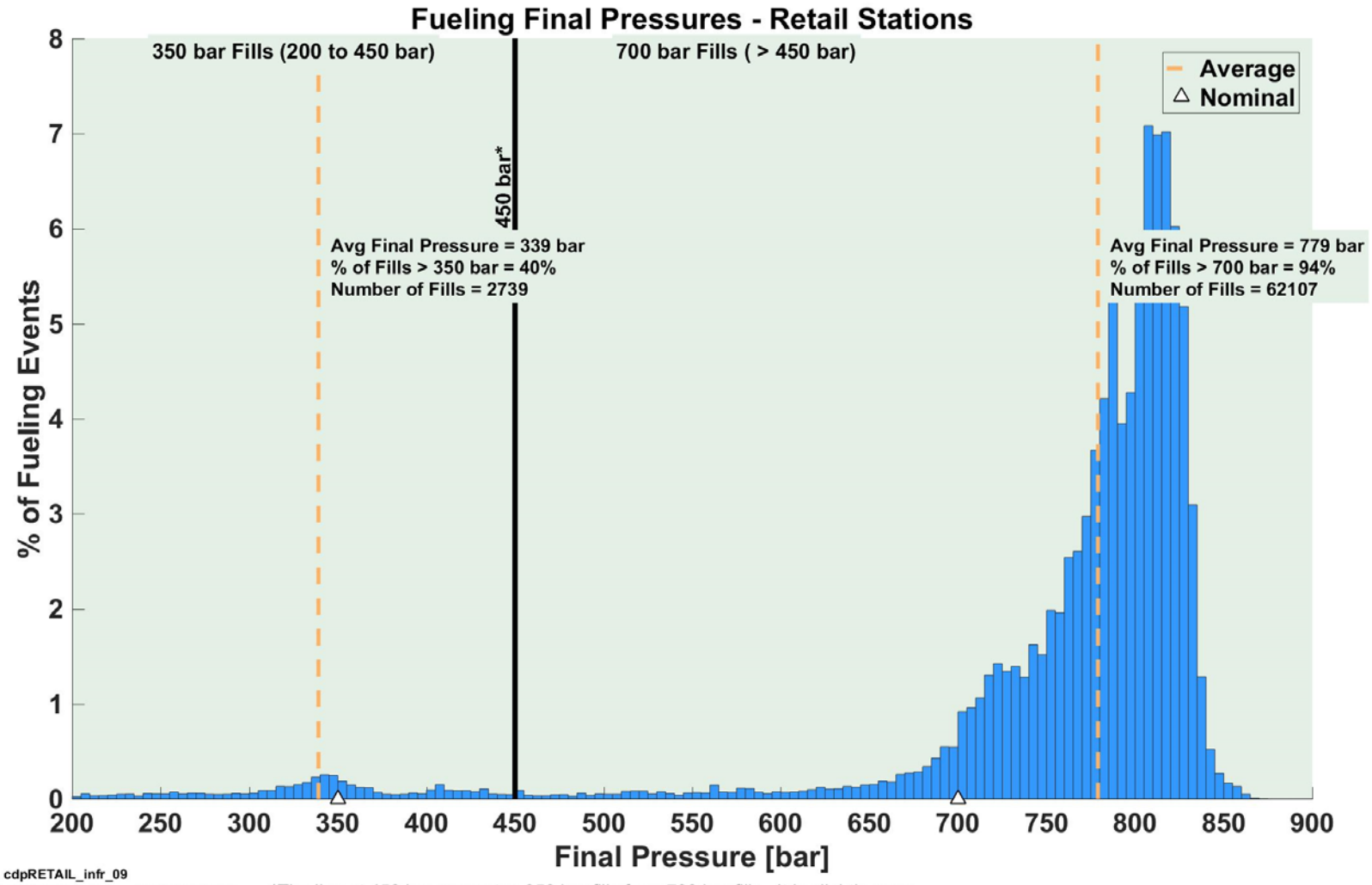




NREL cdpRETAIL_infr_08
Created: Sep-25-17 4:04 PM | Data Range: 2014Q3-2017Q2

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

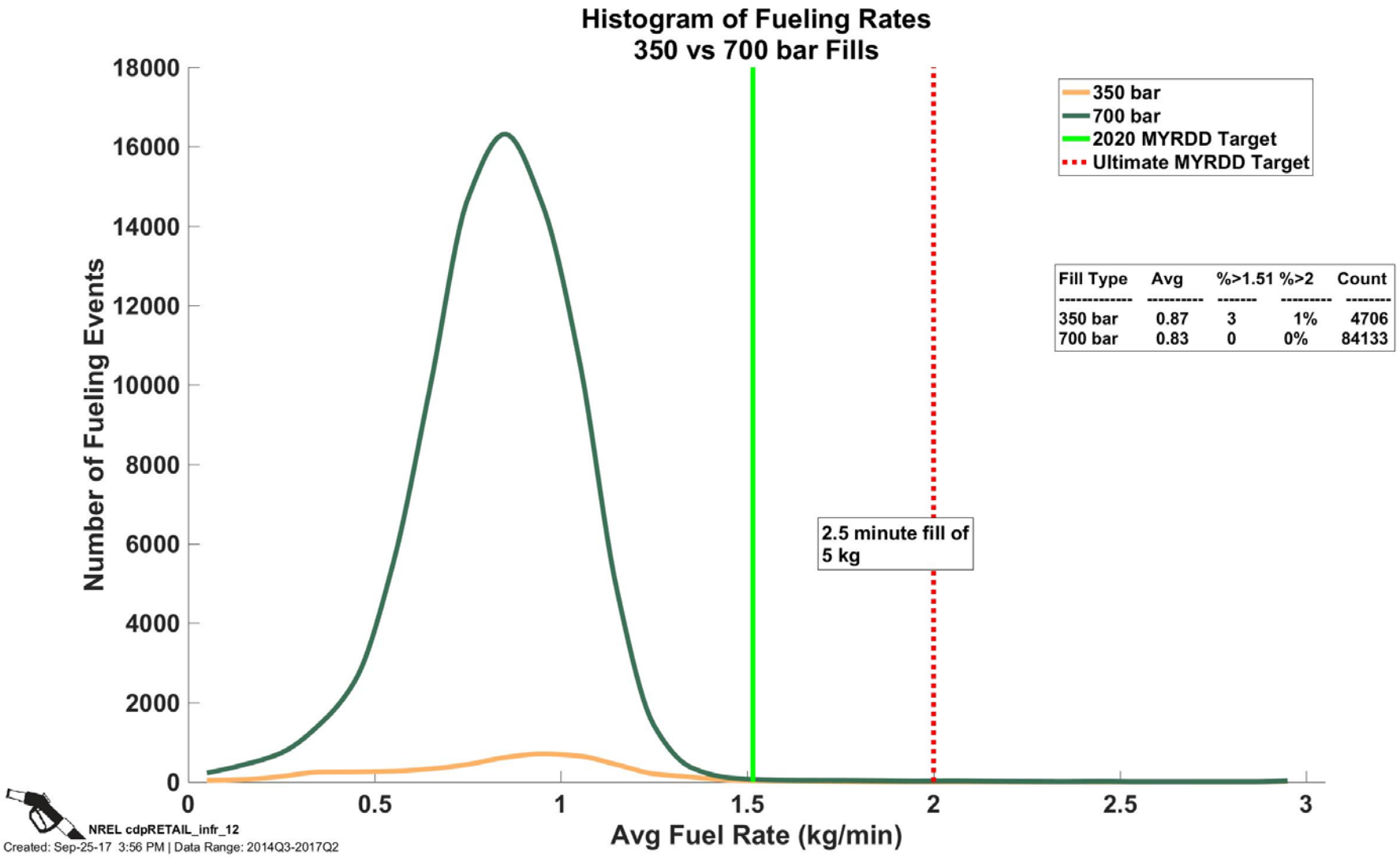
CDP-INFR-09
Fueling Final Pressures



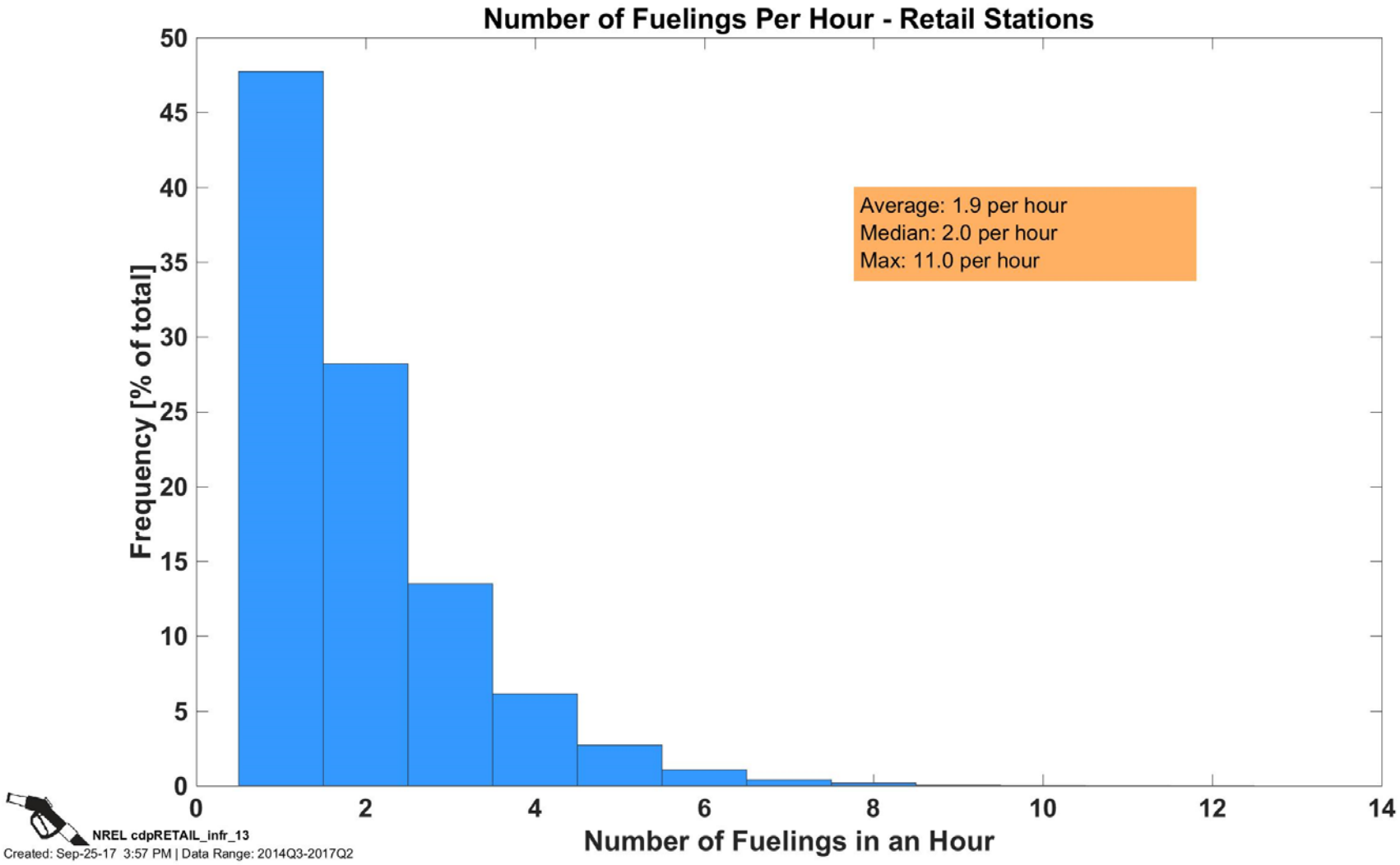
NREL cdpRETAIL_infr_09
Created: Sep-25-17 4:00 PM | Data Range: 2014Q3-2017Q2

*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.

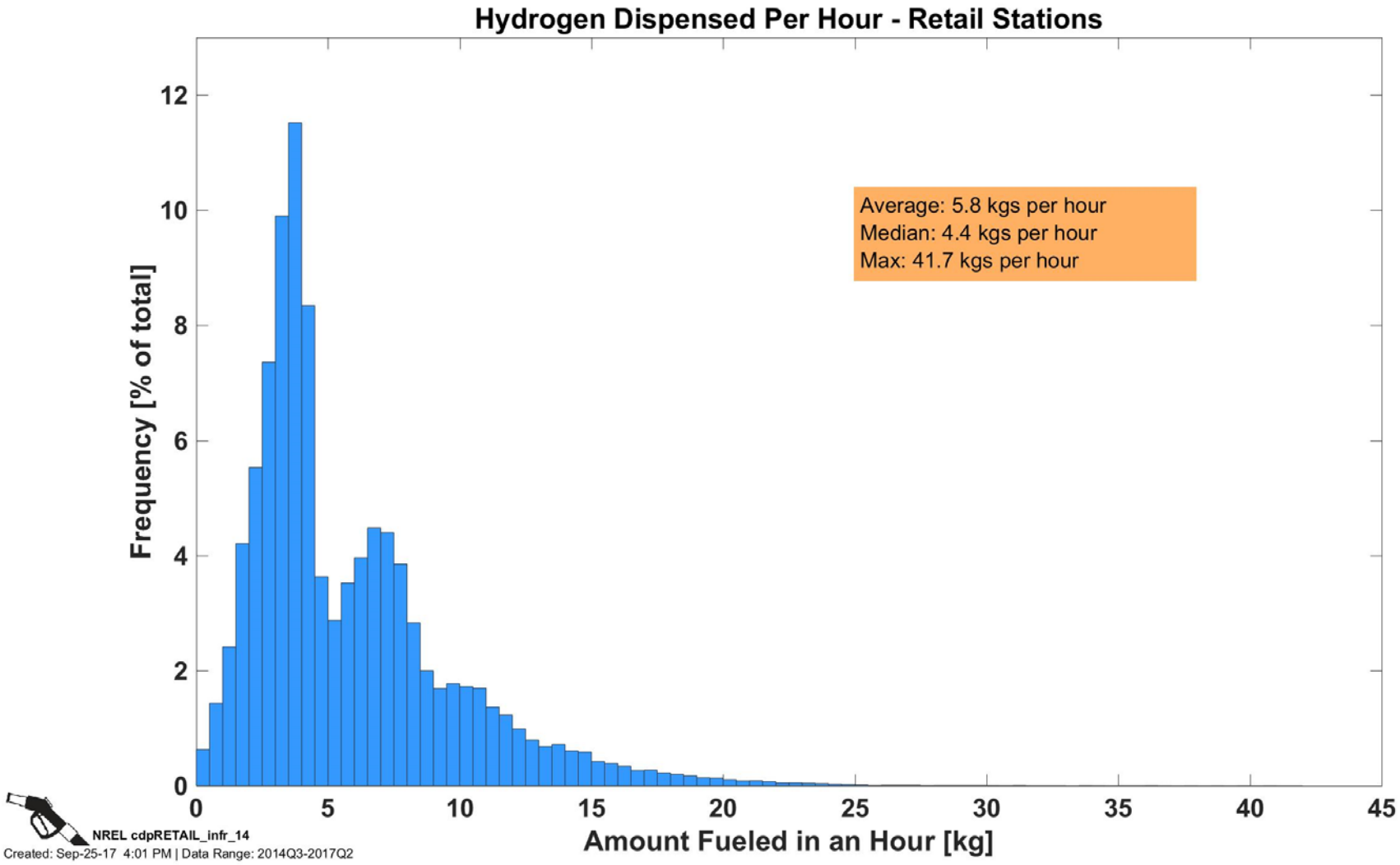
CDP-INFR-12
Fueling Rates 350 bar vs. 700 bar



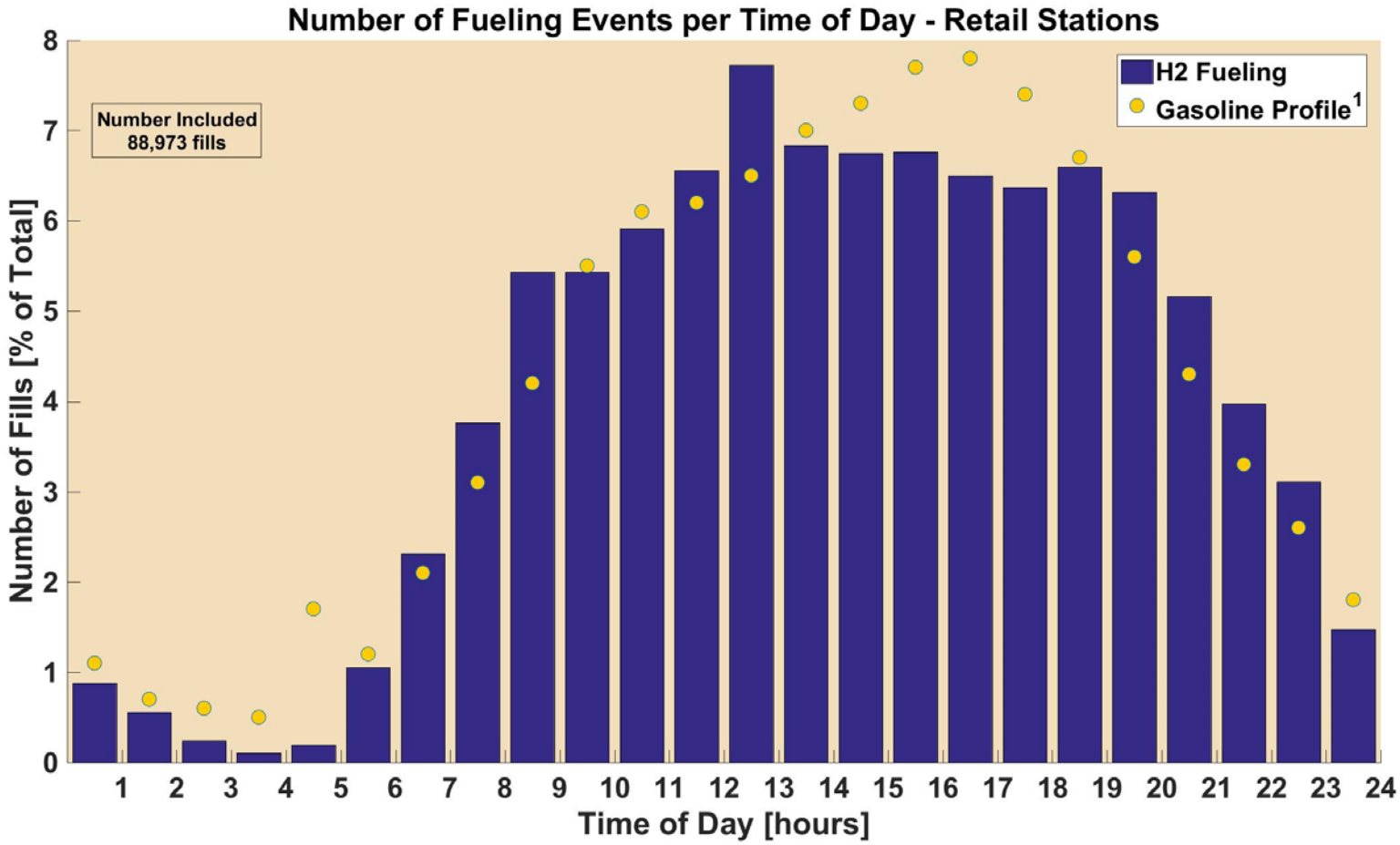
CDP-INFR-13
Number of Fueling Events per Hour



CDP-INFR-14
Hydrogen Dispensed per Hour



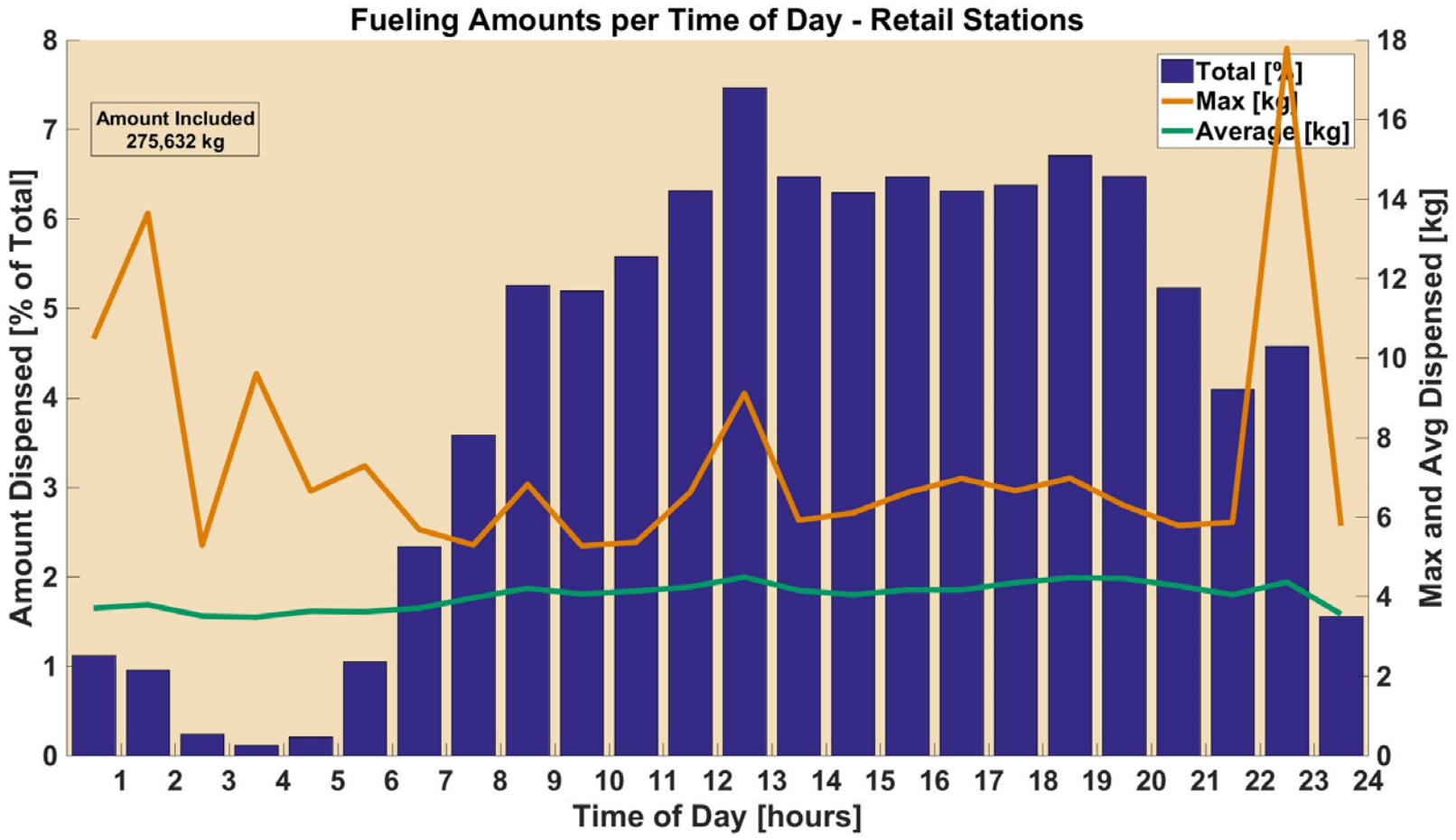
CDP-INFR-15
Number of Fills by Time of Day



NREL cdpRETAIL_infr_15
Created: Sep-25-17 3:55 PM | Data Range: 2014Q3-2017Q2

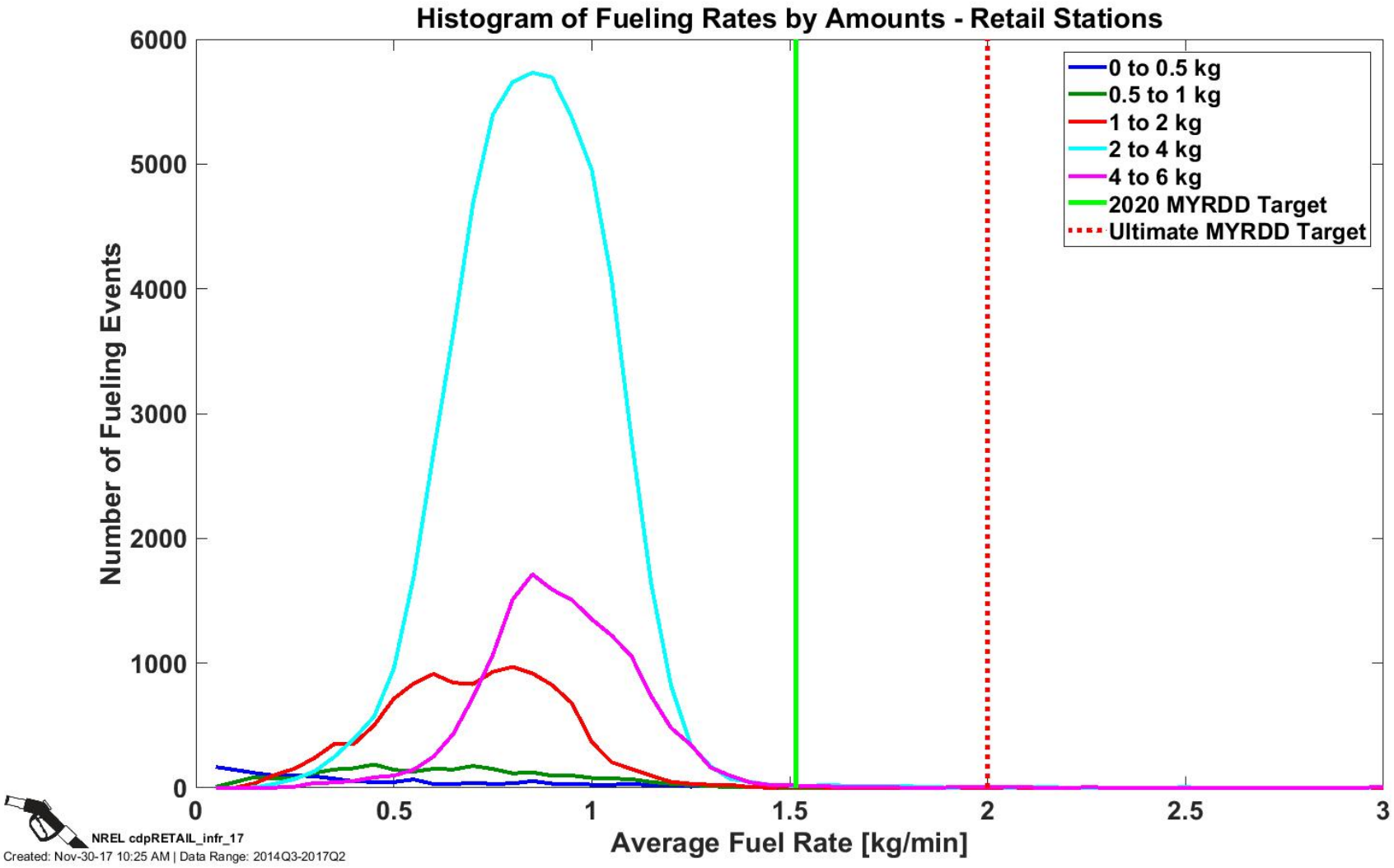
1. Friday Chevron profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.

CDP-INFR-16
Fueling Amounts per Time of Day

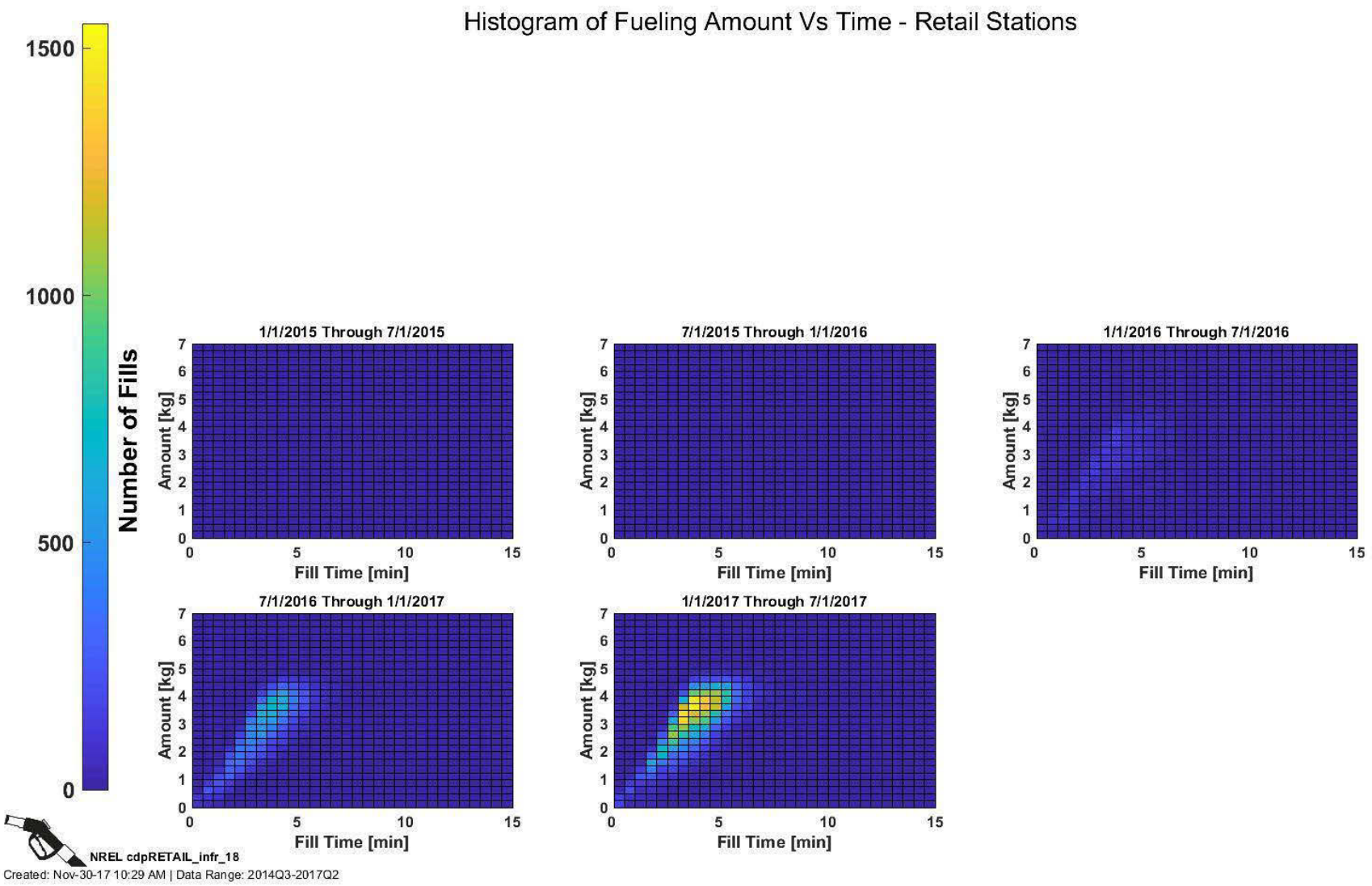


NREL cdpRETAIL_infr_16
Created: Sep-25-17 4:01 PM | Data Range: 2014Q3-2017Q2

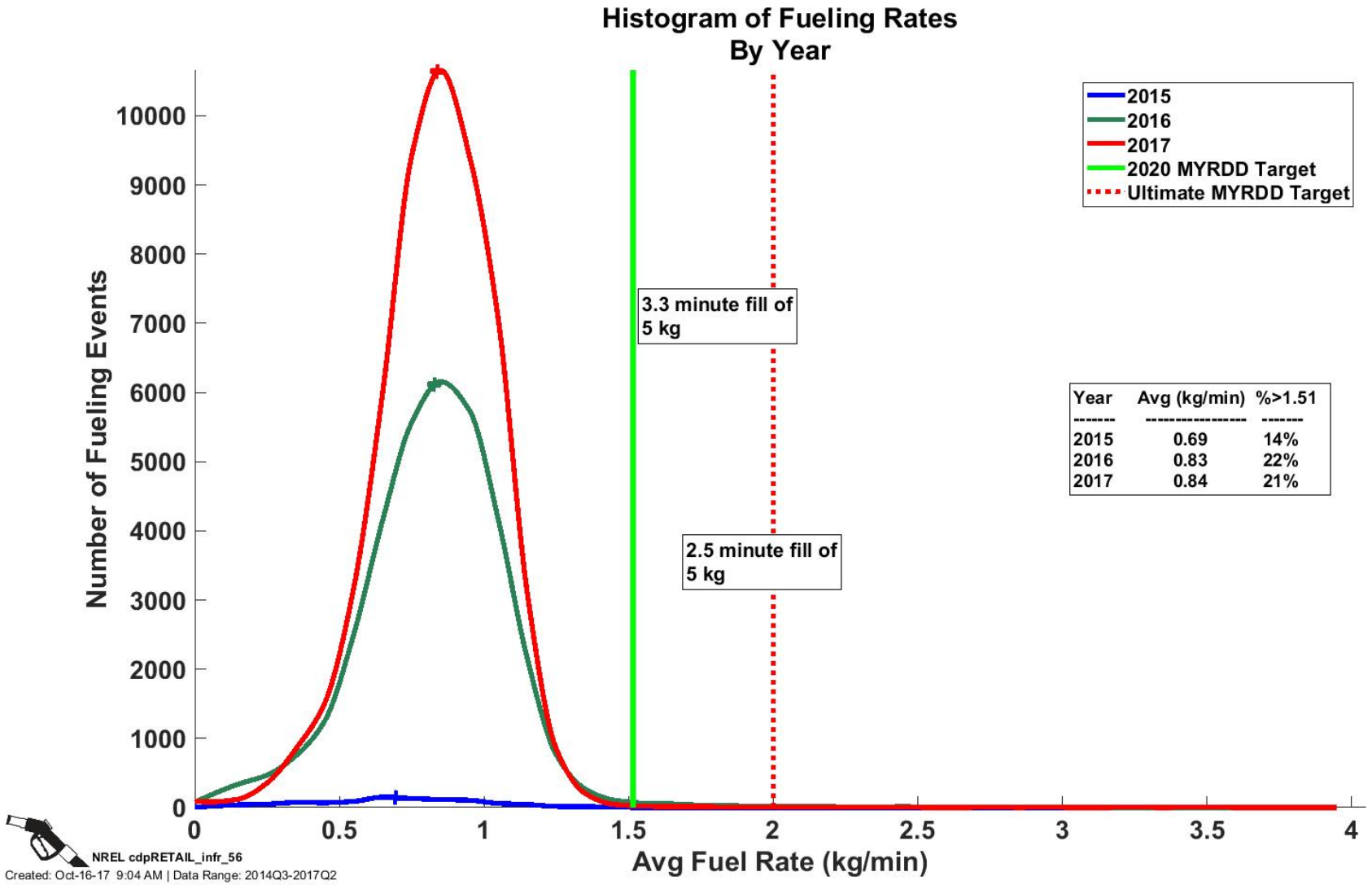
CDP-INFR-17
Fueling Rates by Amount Filled



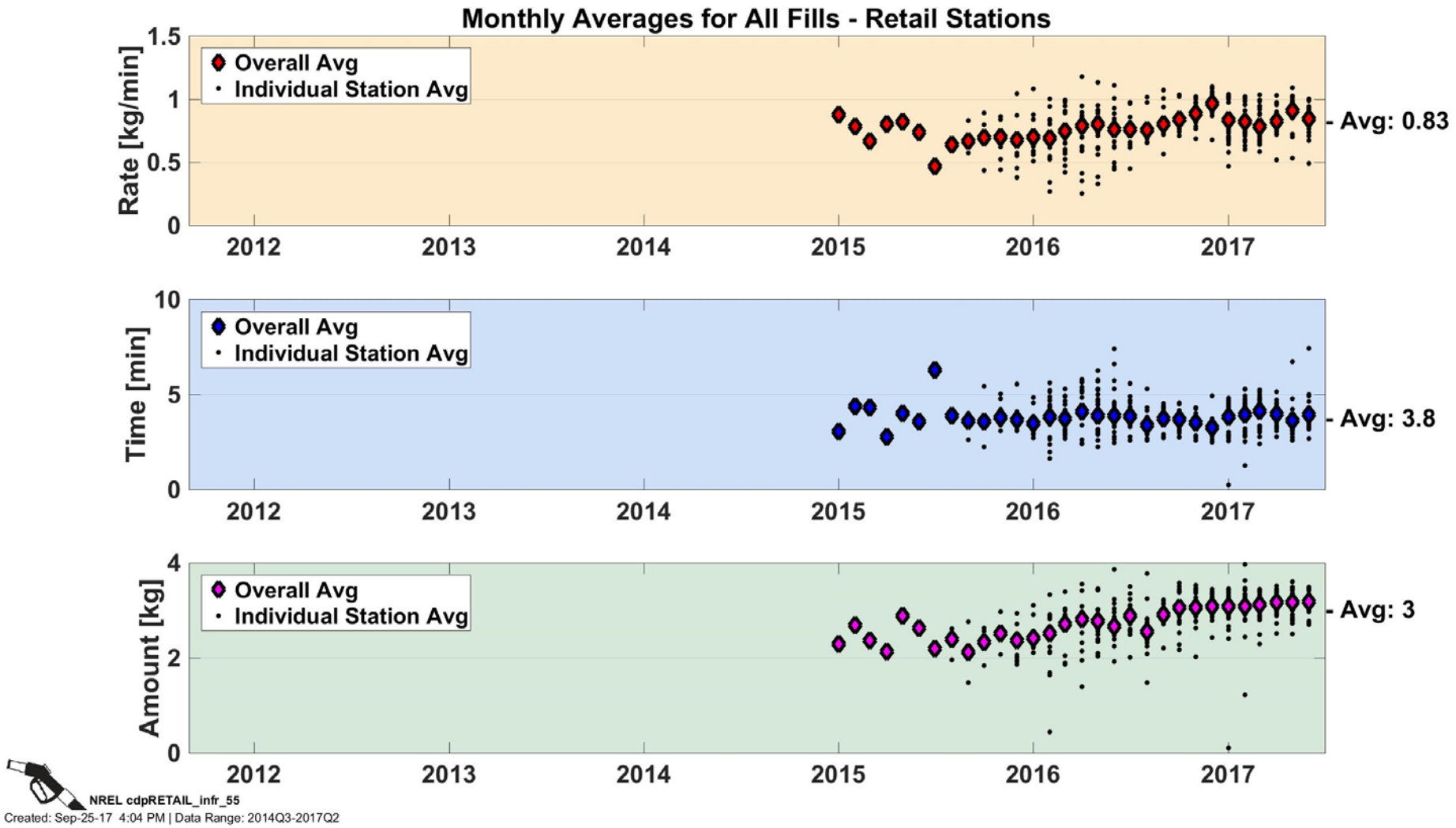
CDP-INFR-18
Fueling Amount vs. Time to Fill



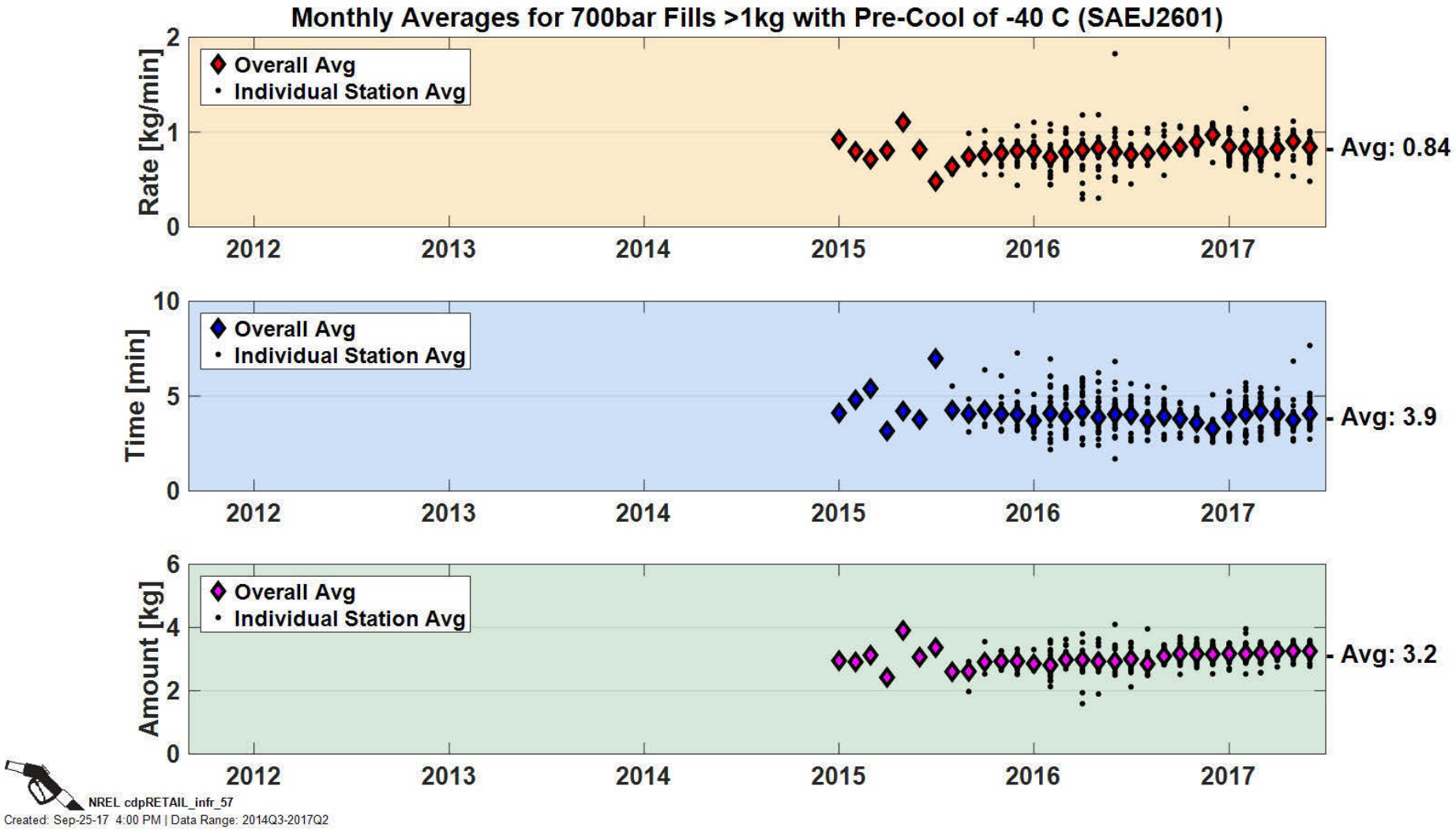
CDP-INFR-56
Fueling Rates by Year



CDP-INFR-55
Monthly Averages: All Fills

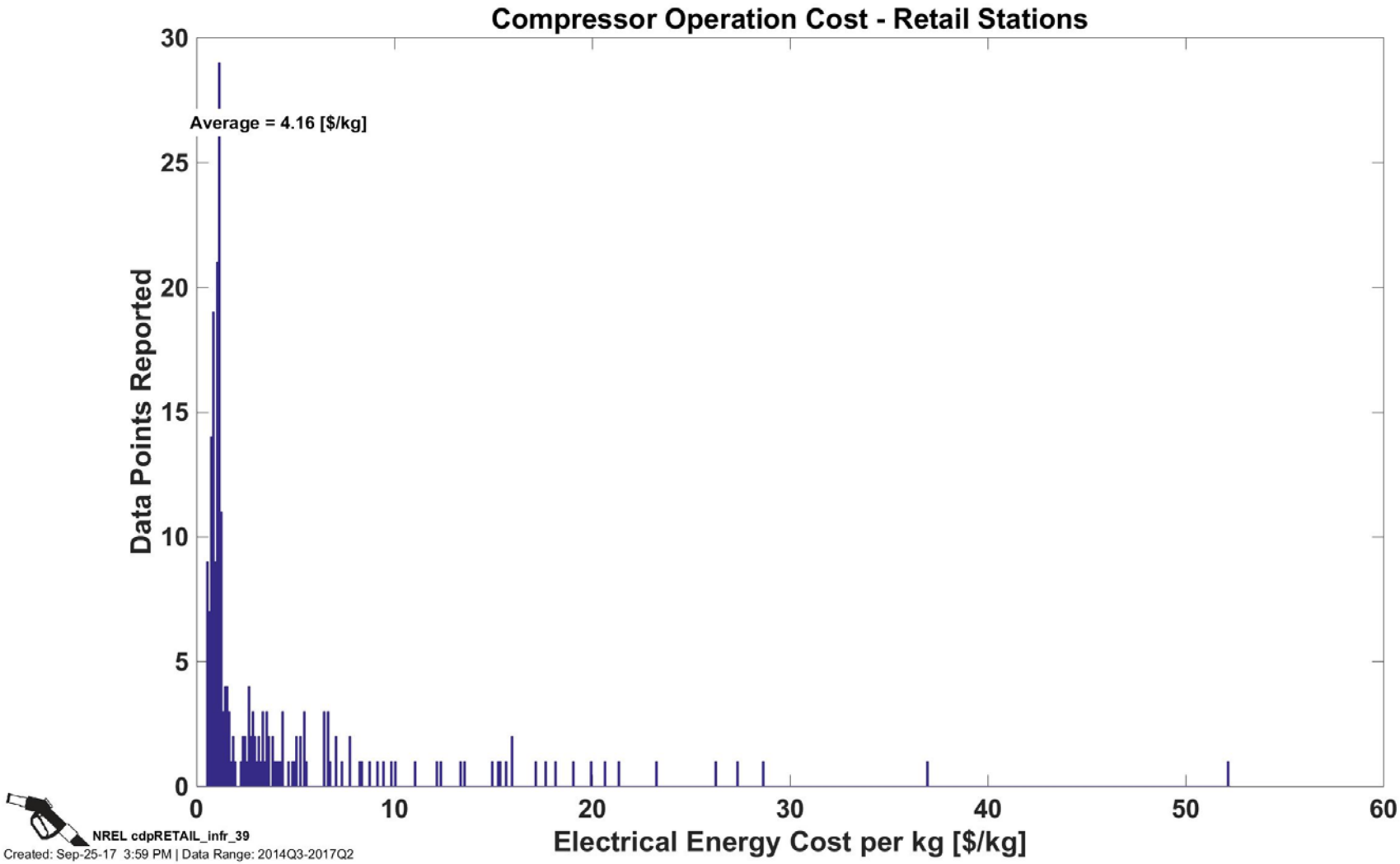


CDP-INFR-57
Monthly Averages: 700 bar Fills >1 kg with Pre-Cool of -40°C

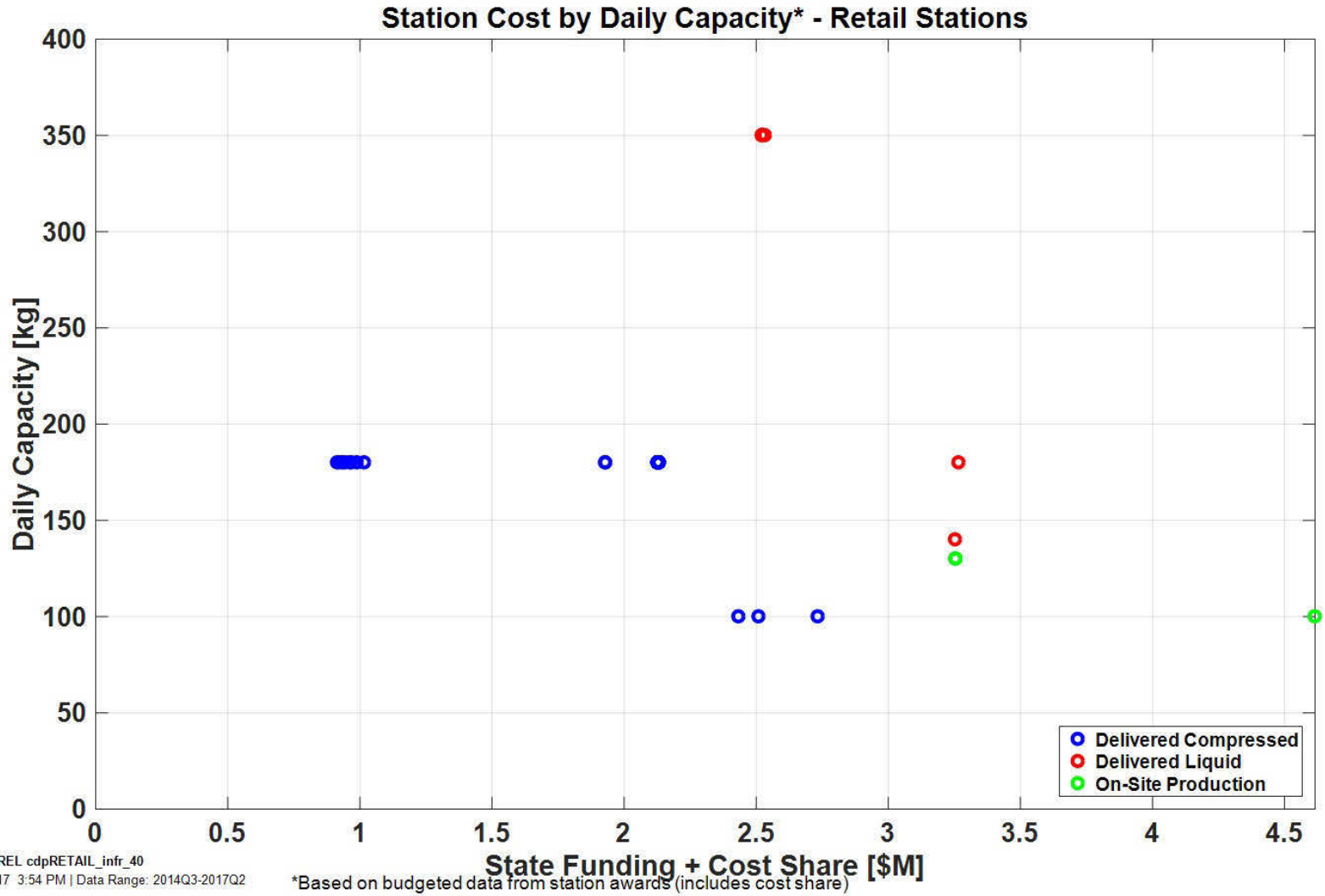


Cost

CDP-INFR-39
Compressor Operation Cost



CDP-INFR-40
Station Cost by Daily Capacity

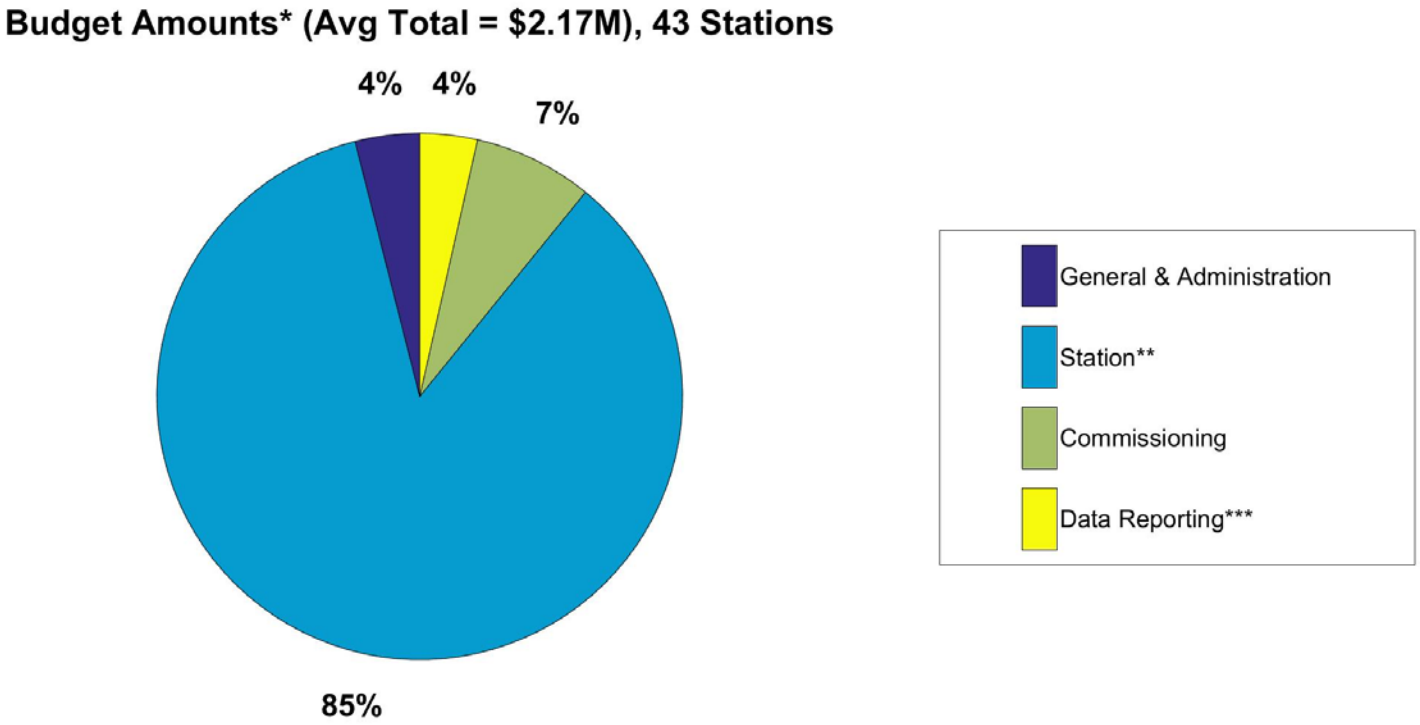


NREL cdpRETAIL_infr_40
Created: Sep-25-17 3:54 PM | Data Range: 2014Q3-2017Q2

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

CDP-INFR-41
Average Station Cost by Category

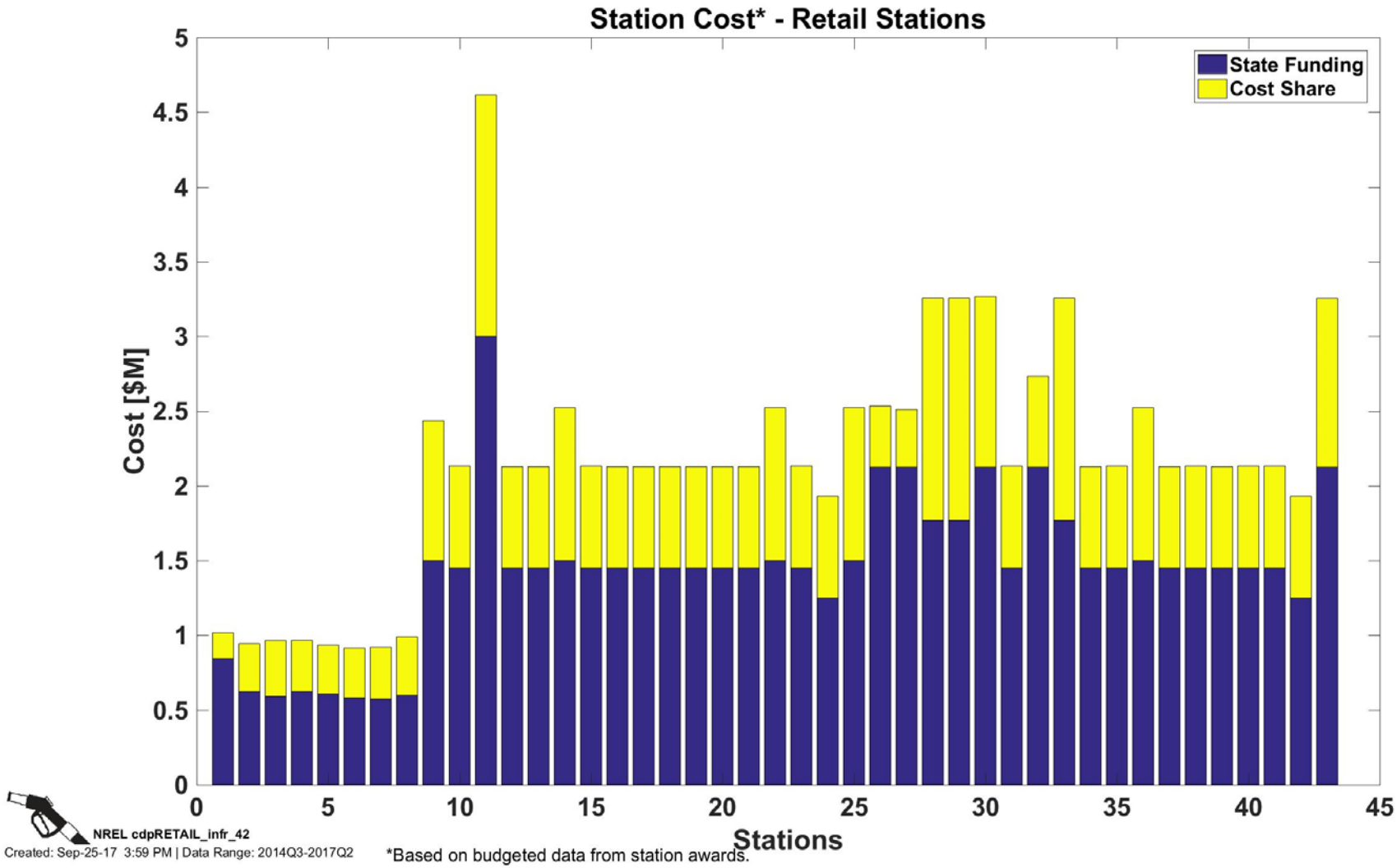
Average Station Cost by Category - Retail Stations



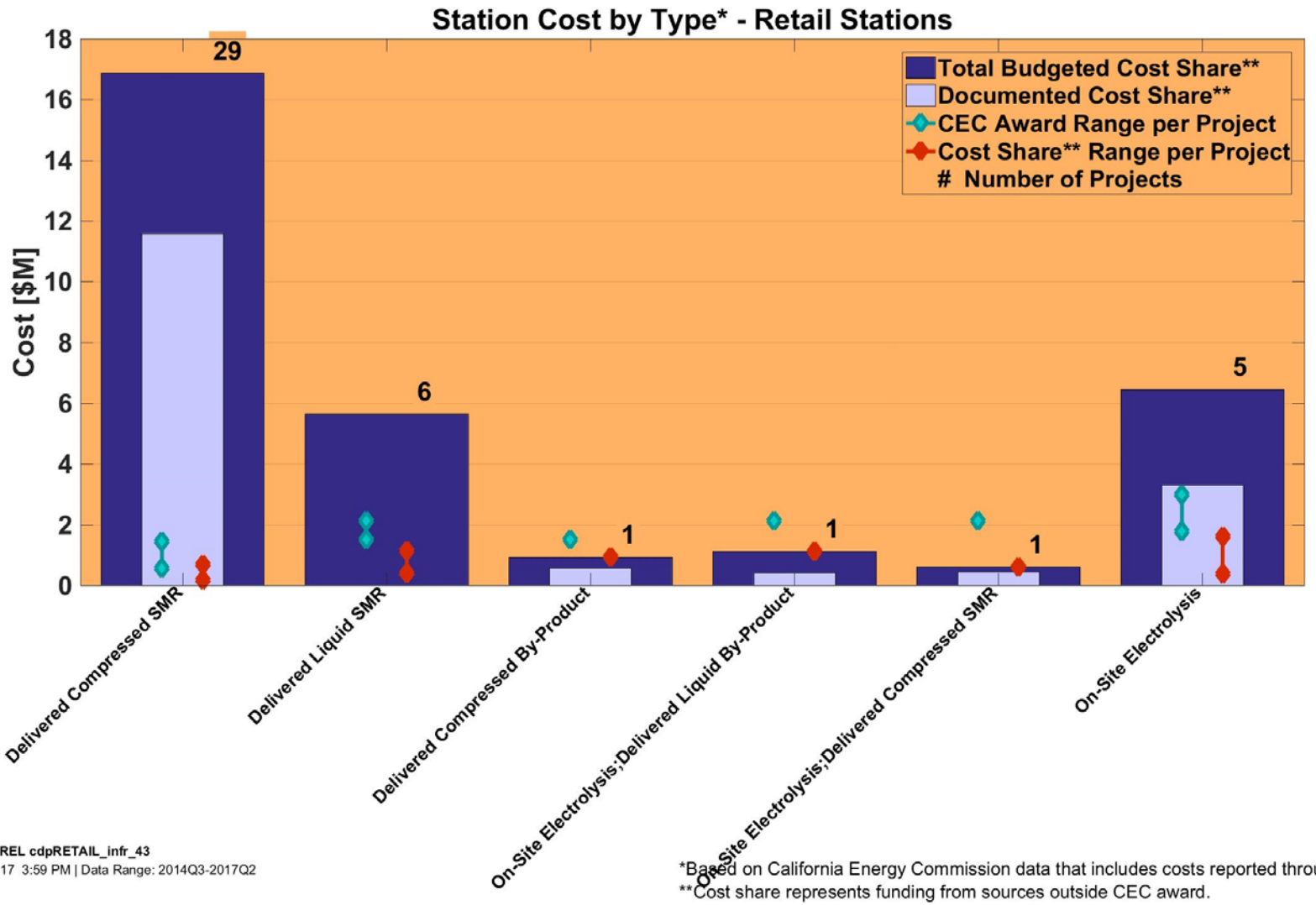
NREL cdpRETAIL_infr_41
Created: Sep-25-17 3:54 PM | Data Range: 2014Q3-2017Q2

*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



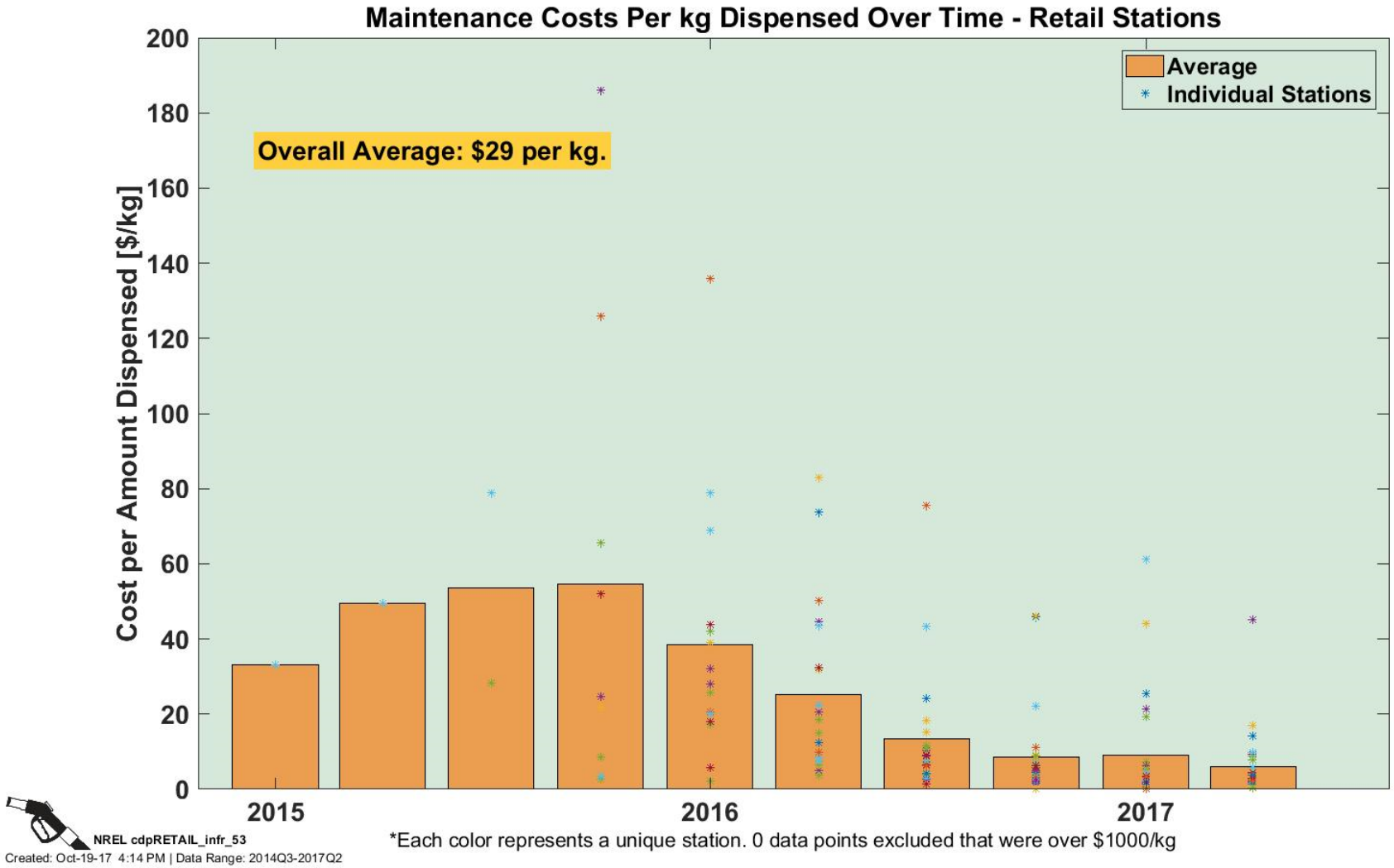
CDP-INFR-43
Station Cost by Type



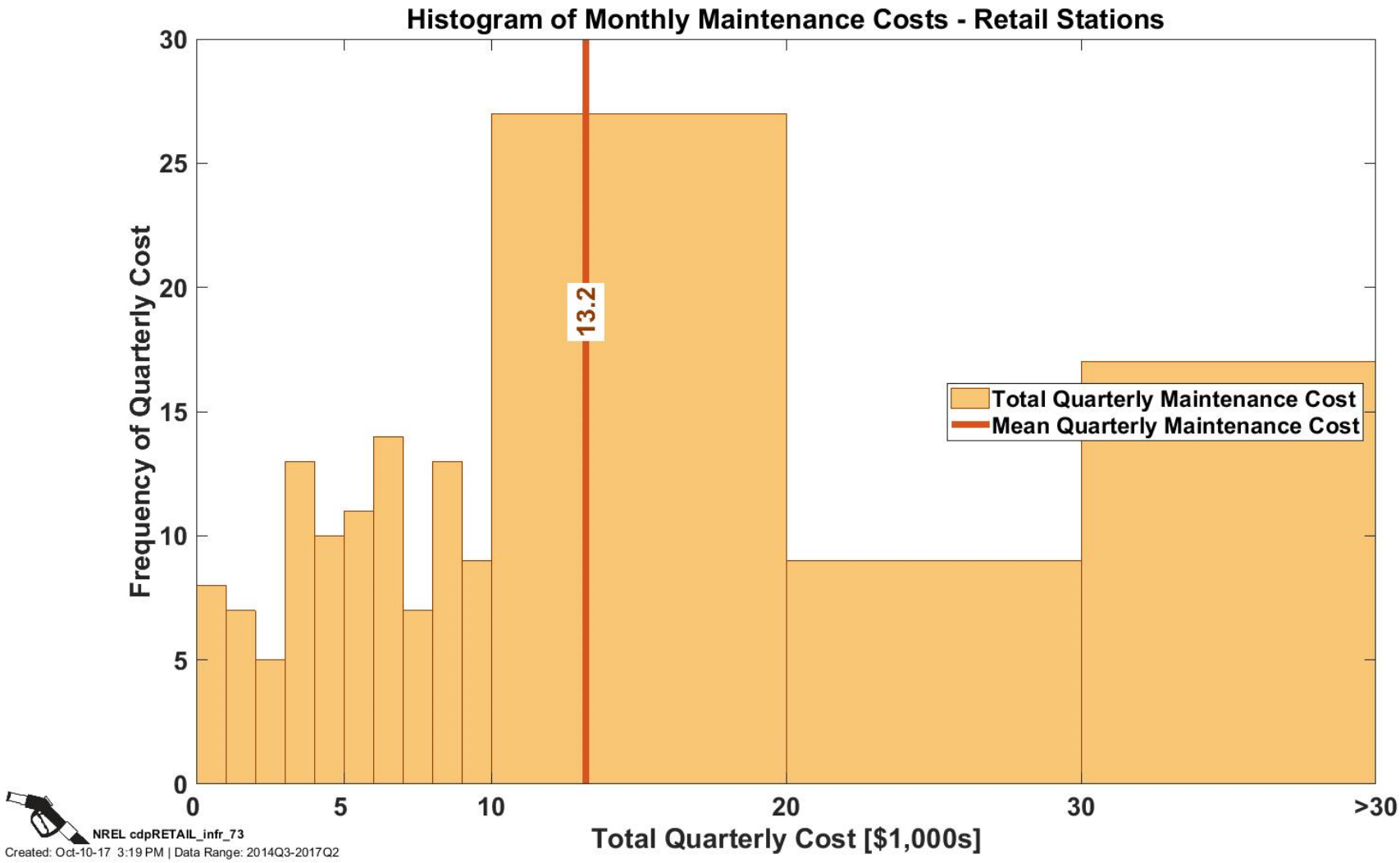
NREL cdpRETAIL_infr_43
Created: Sep-25-17 3:59 PM | Data Range: 2014Q3-2017Q2

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

CDP-INFR-53
Maintenance Cost per kg of Hydrogen Dispensed

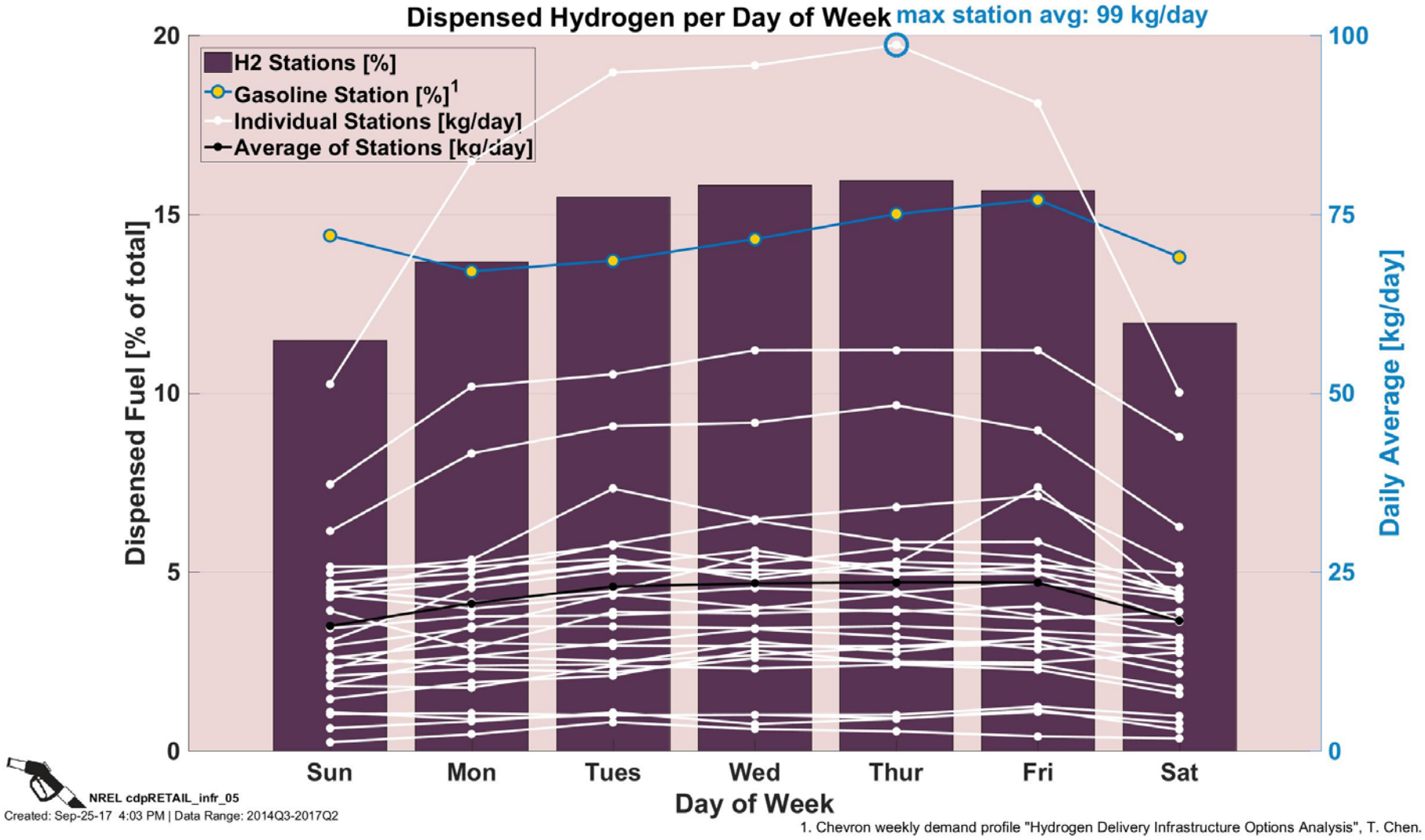


CDP-INFR-73
Histogram of Monthly Maintenance Costs



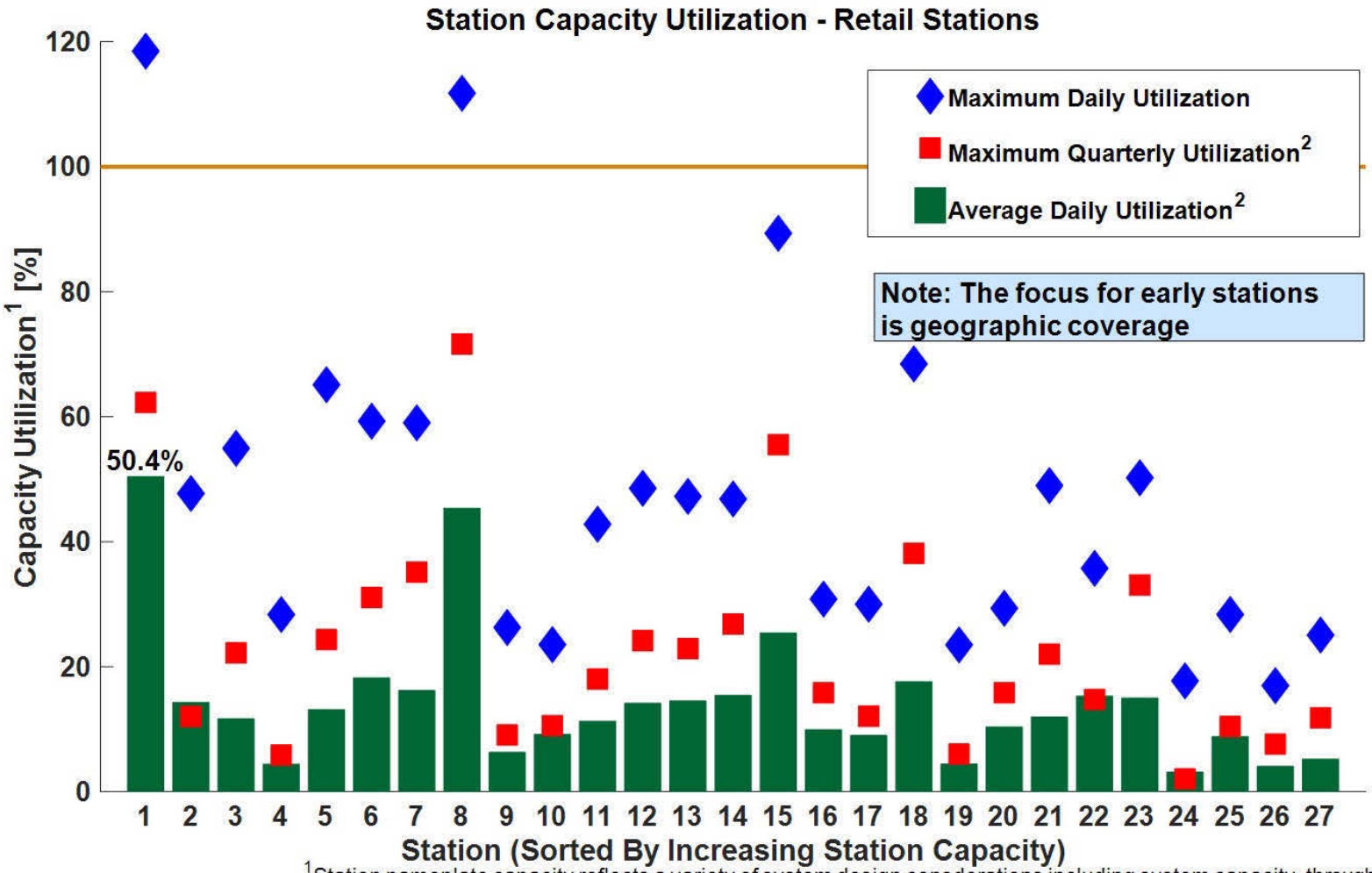
Utilization

CDP-INFR-05
Dispensed Hydrogen per Day of Week



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

CDP-INFR-06
Station Capacity Utilization

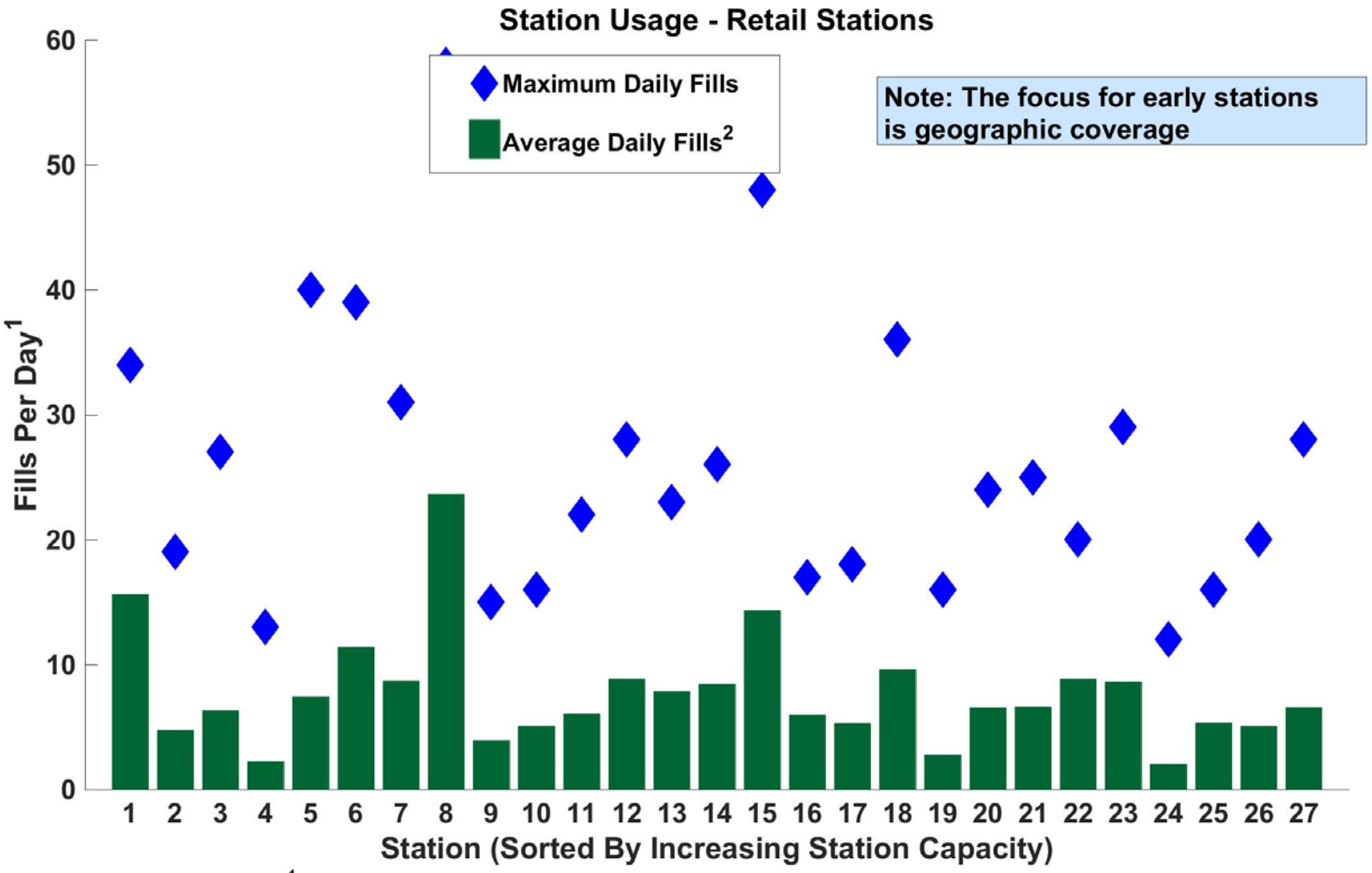


NREL cdpRETAIL_infr_06
Created: Sep-25-17 3:58 PM | Data Range: 2014Q3-2017Q2

[1] Station nameplate capacity reflects a variety of system design consderations 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

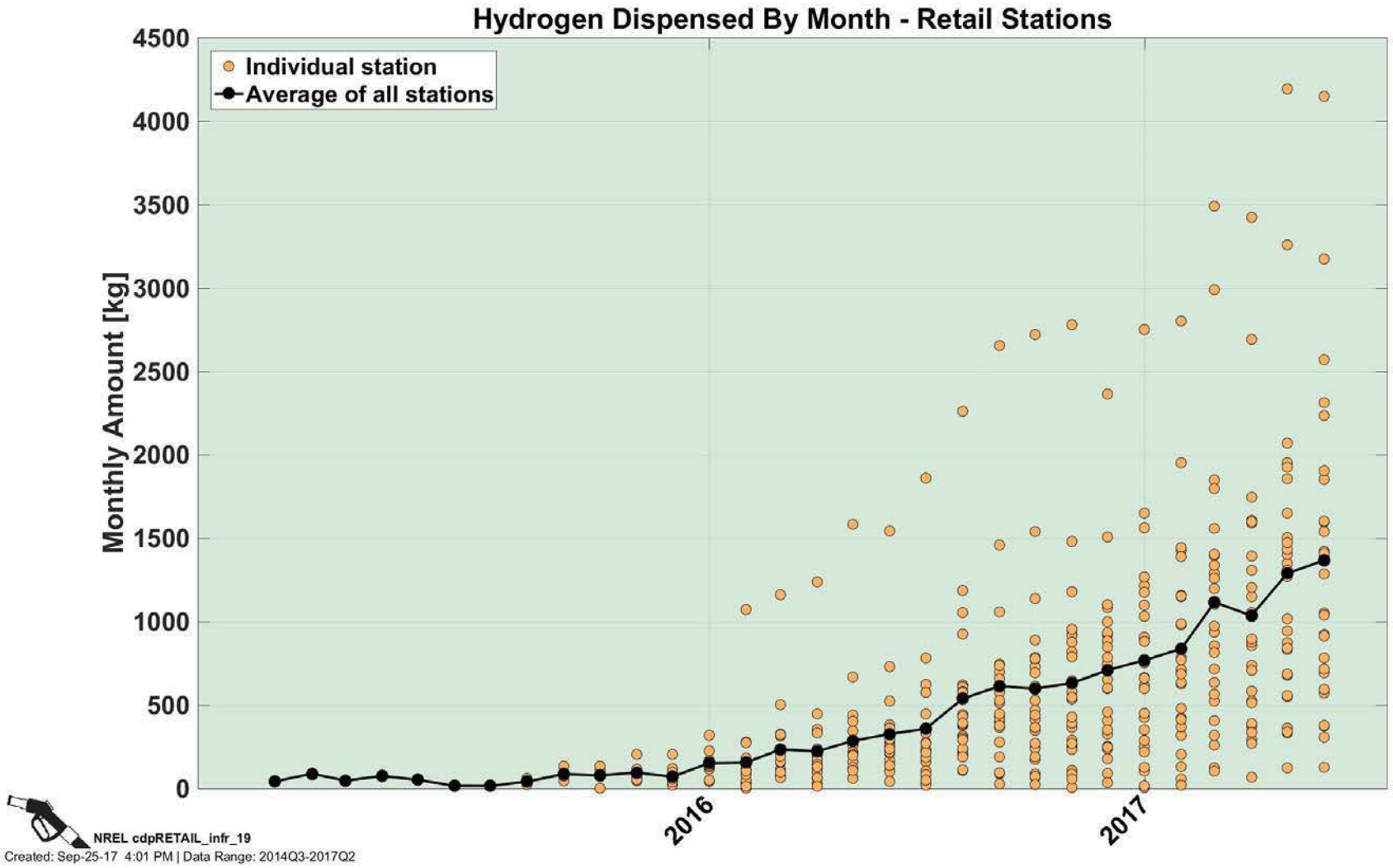


NREL cdpRETAIL_infr_07
Created: Sep-25-17 3:57 PM | Data Range: 2014Q3-2017Q2

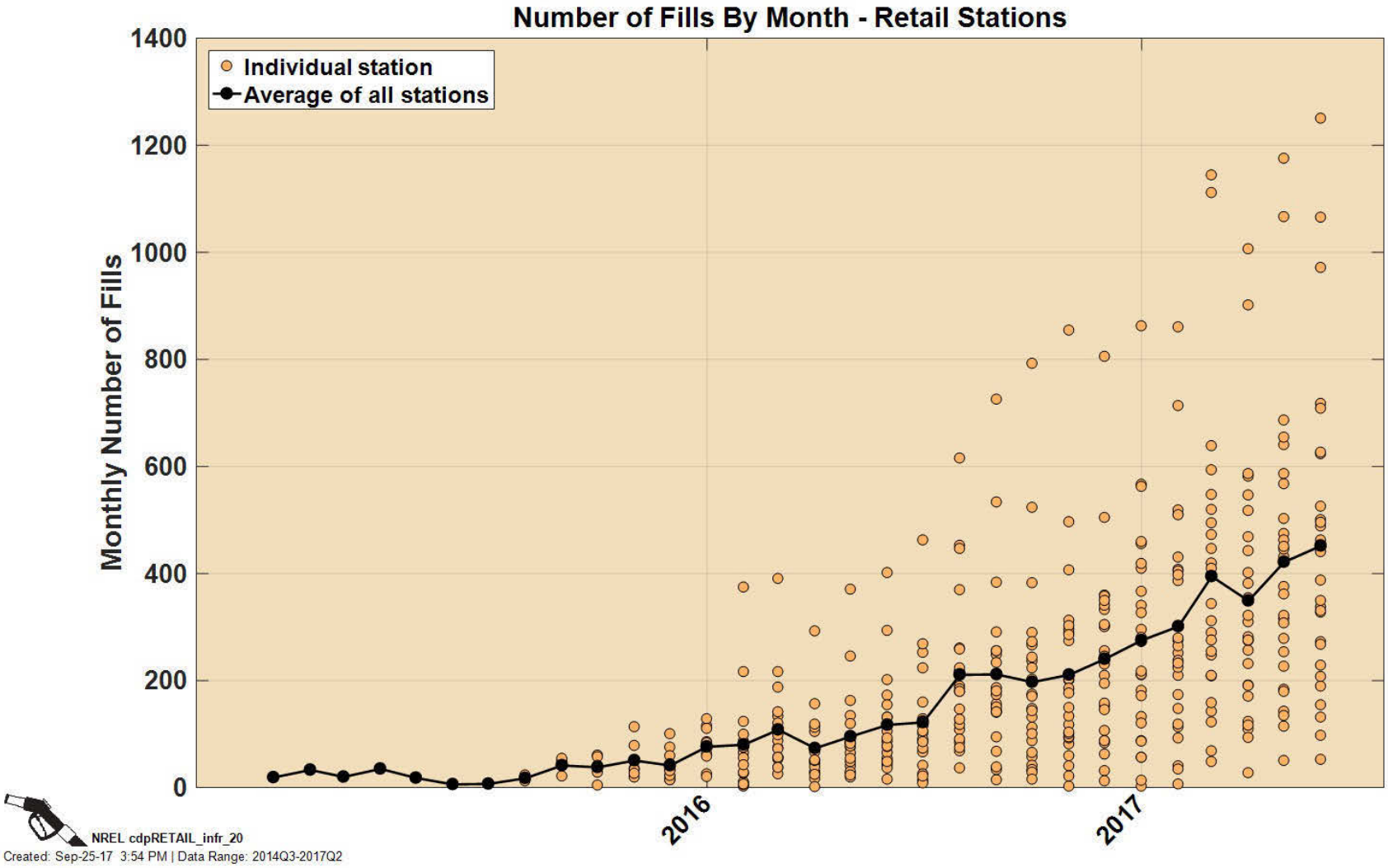
[1]Excludes hydrogen fills of < 0.5 kg

[2]Average daily fills considers only days when at least one fill occurred

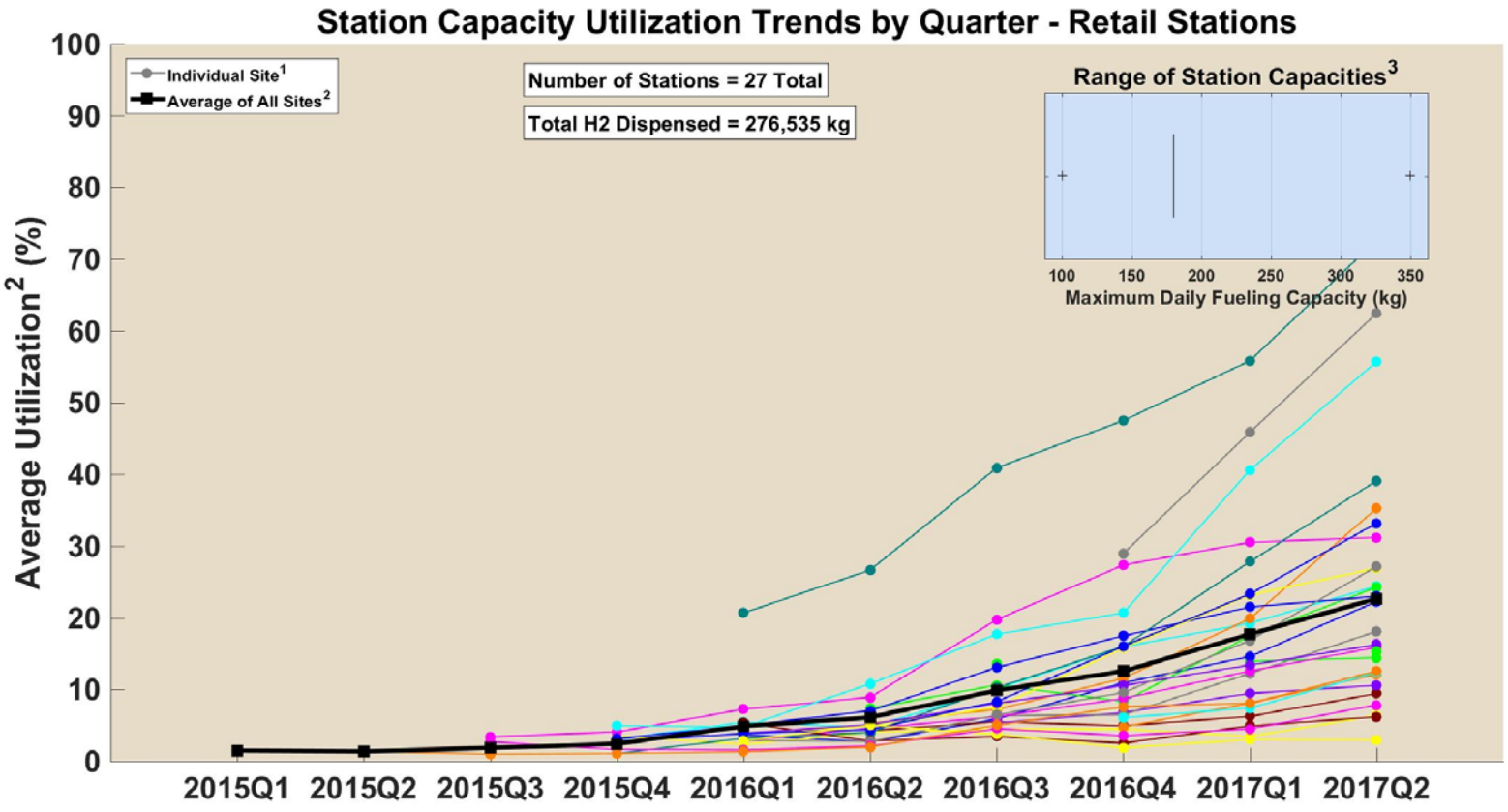
CDP-INFR-19
Hydrogen Dispensed by Month



CDP-INFR-20
Number of Fills by Month



CDP-INFR-44
Station Capacity Utilization Trends by Quarter



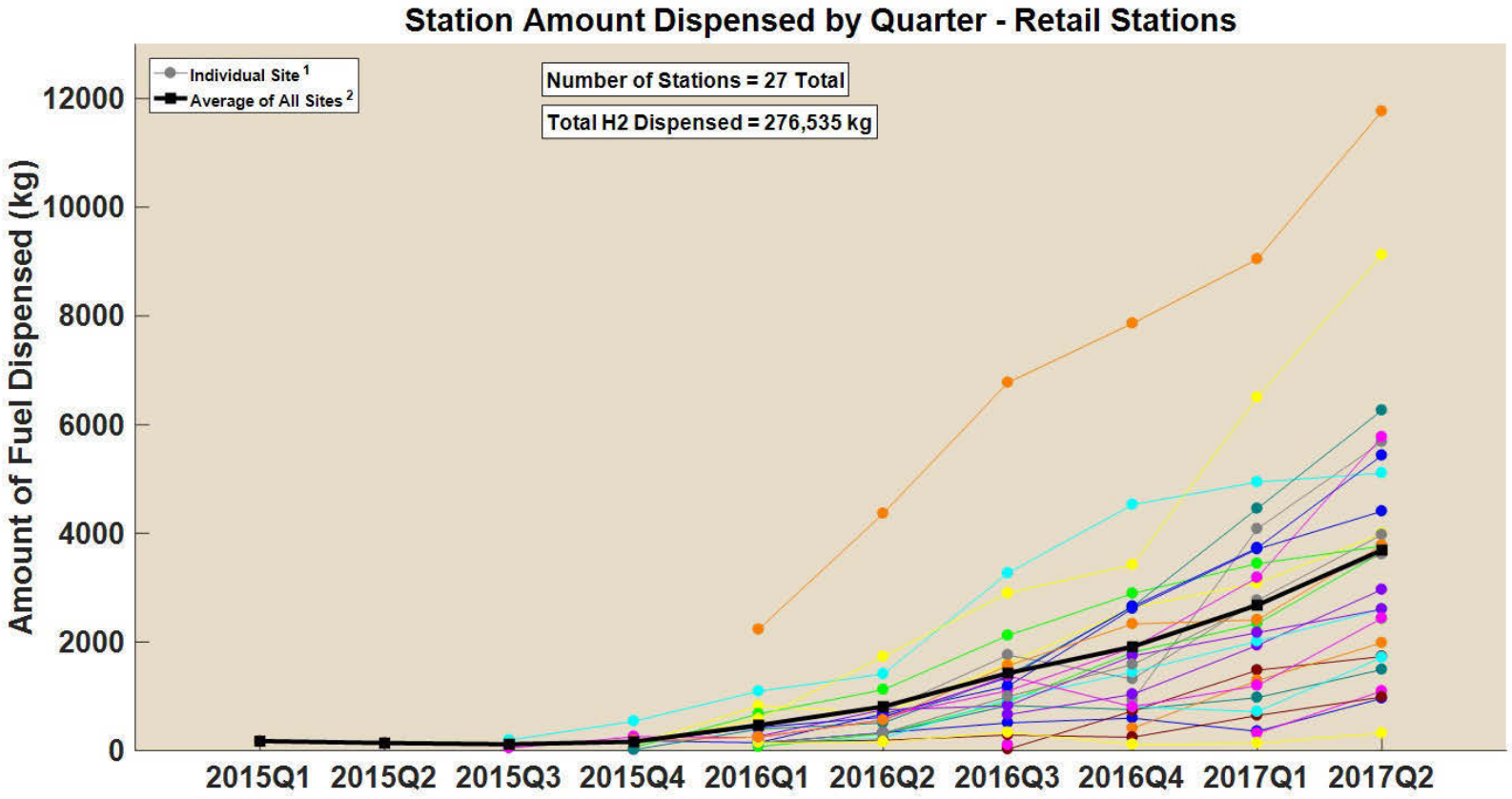
[1] Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

[2] Average quarterly 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.

NREL cdpRETAIL_infr_44
Created: Sep-25-17 4:03 PM | Data Range: 2014Q3-2017Q2

CDP-INFR-45
Station Amount Dispensed by Quarter

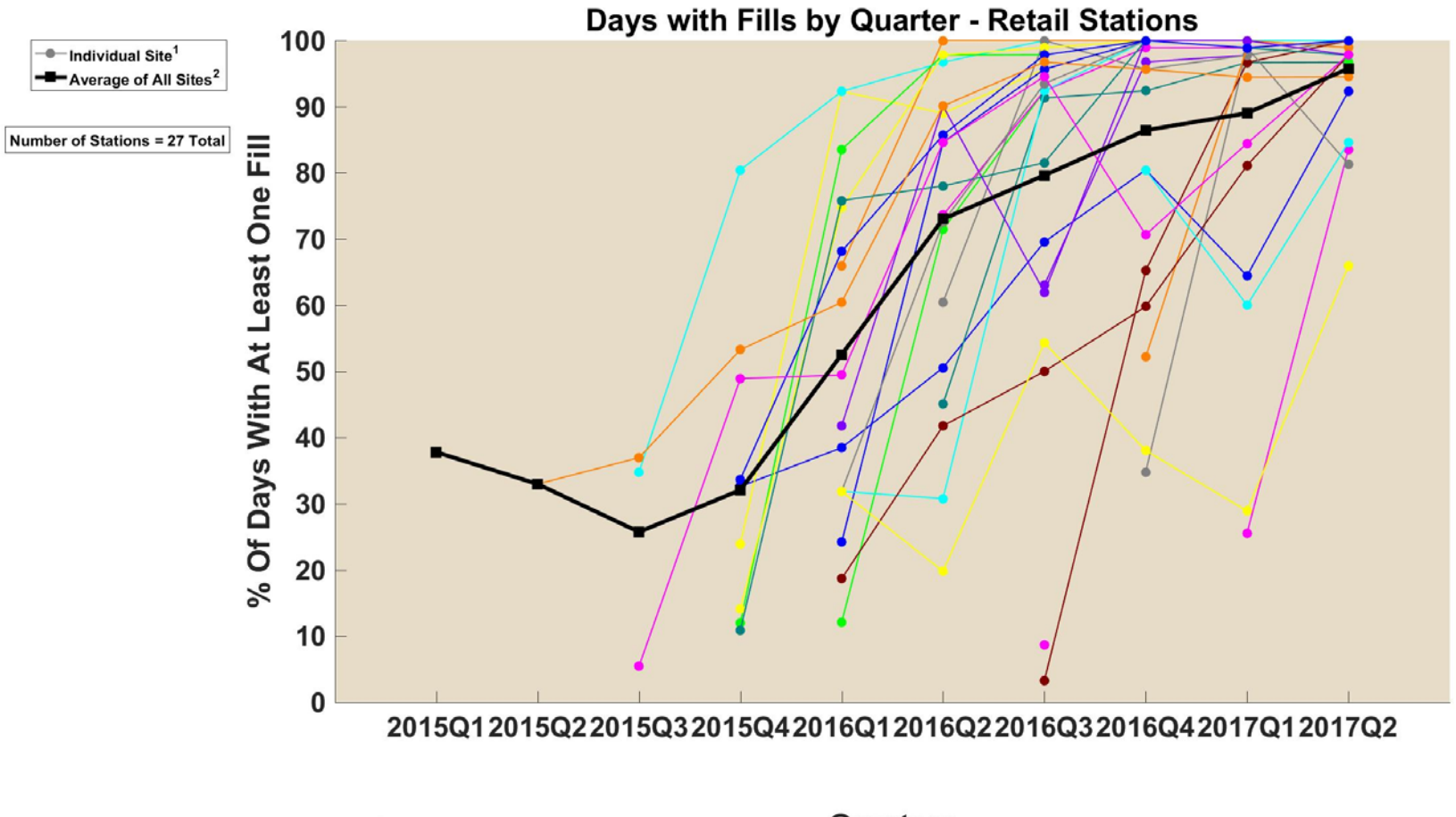


[1] Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

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

NREL cdpRETAIL_infr_45
Created: Sep-25-17 3:55 PM | Data Range: 2014Q3-2017Q2

CDP-INFR-46
Days with Fills by Quarter

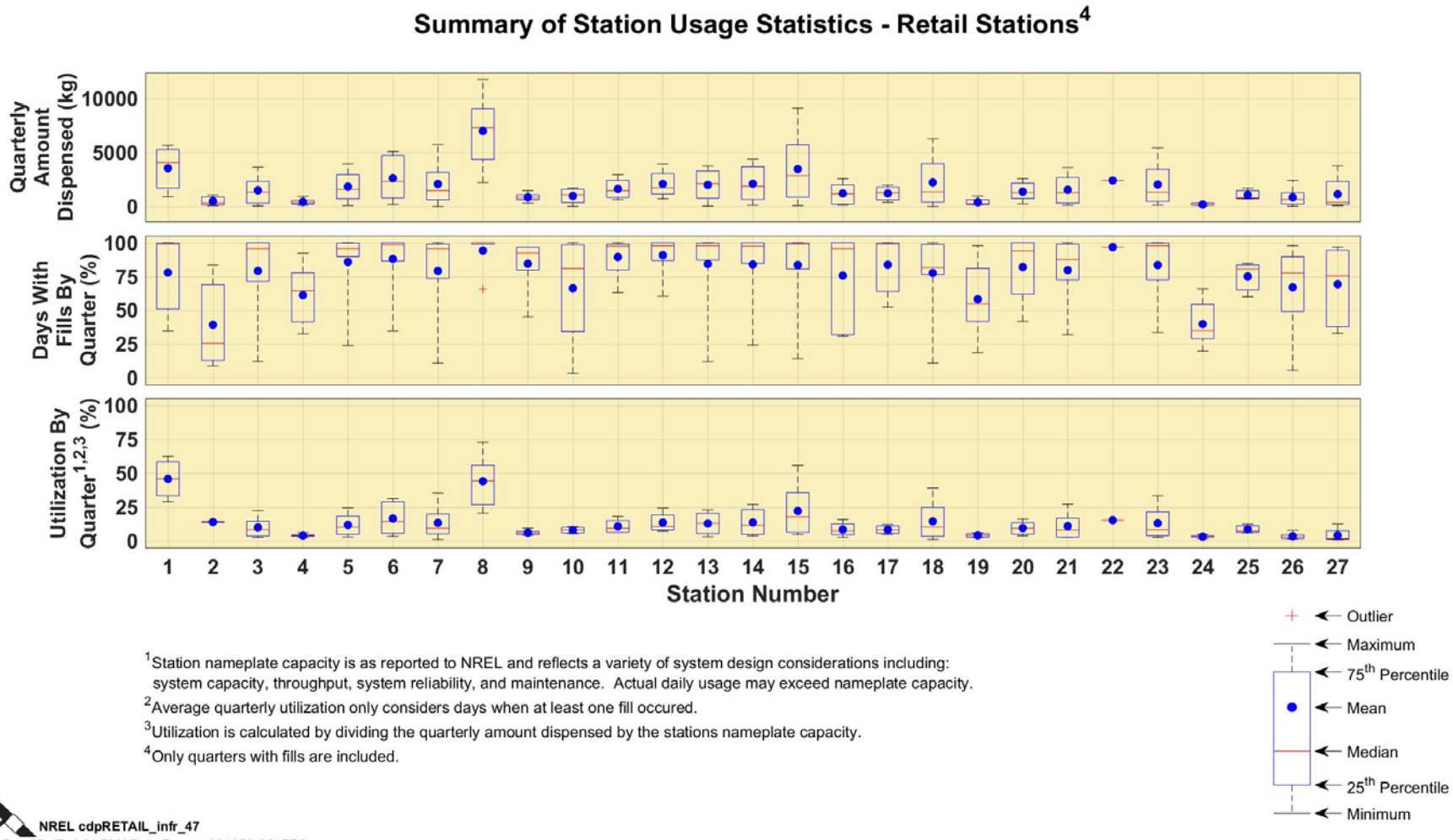


[1] Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station had no fills or was missing data. Each station is represented by a unique color.

[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.

NREL cdpRETAIL_infr_46
Created: Sep-25-17 3:58 PM | Data Range: 2014Q3-2017Q2

CDP-INFR-47
Summary of Station Usage Statistics



[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.

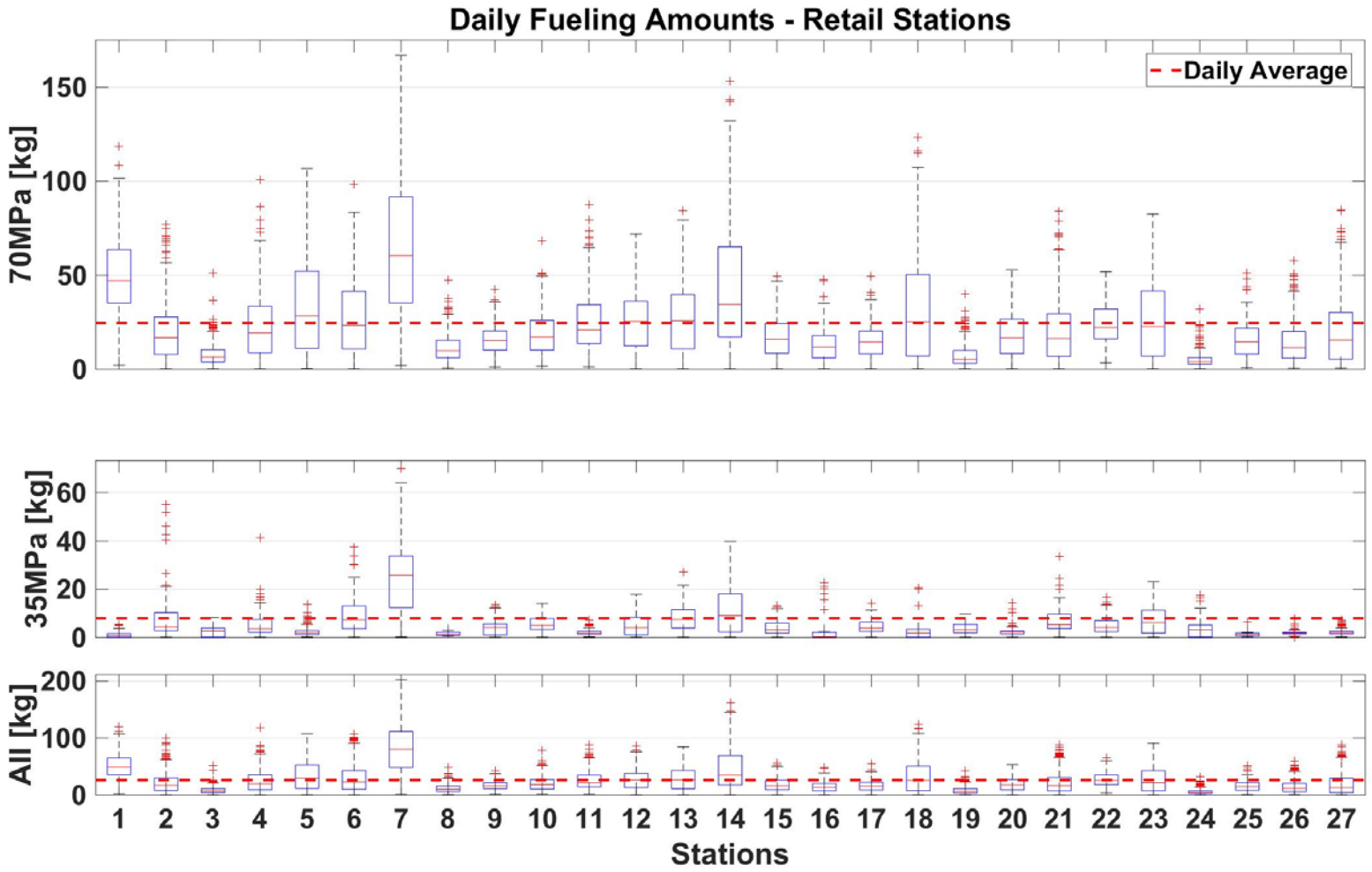
[2]Average quarterly utilization only considers days when at least one fill occured.

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

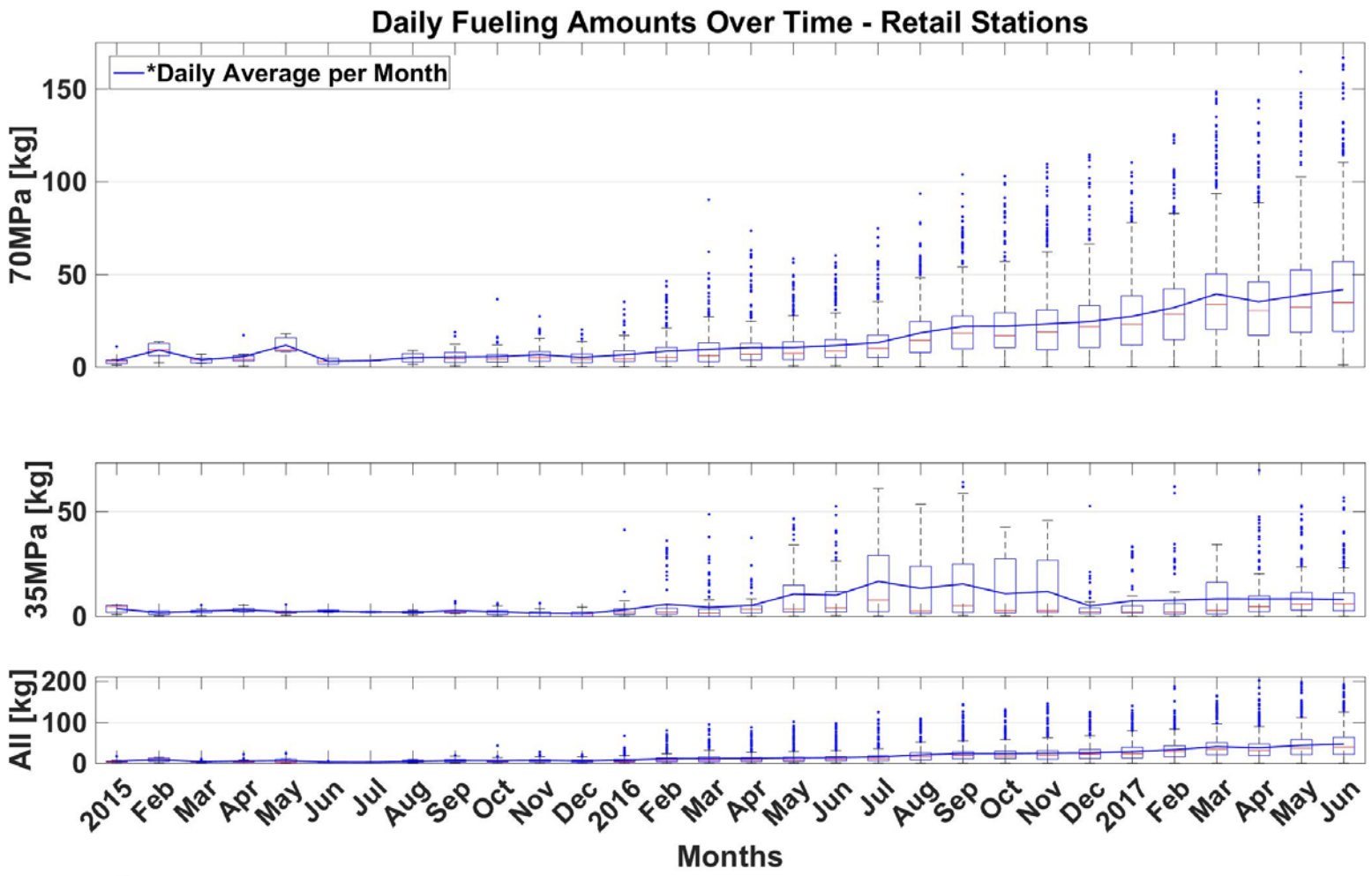
[4]Only quarters with fills are included.

NREL cdpRETAIL_infr_47
Created: Sep-25-17 4:01 PM | Data Range: 2014Q3-2017Q2

CDP-INFR-80
Daily Fueling Amounts by Station



CDP-INFR-82
Daily Fueling Amounts by Month

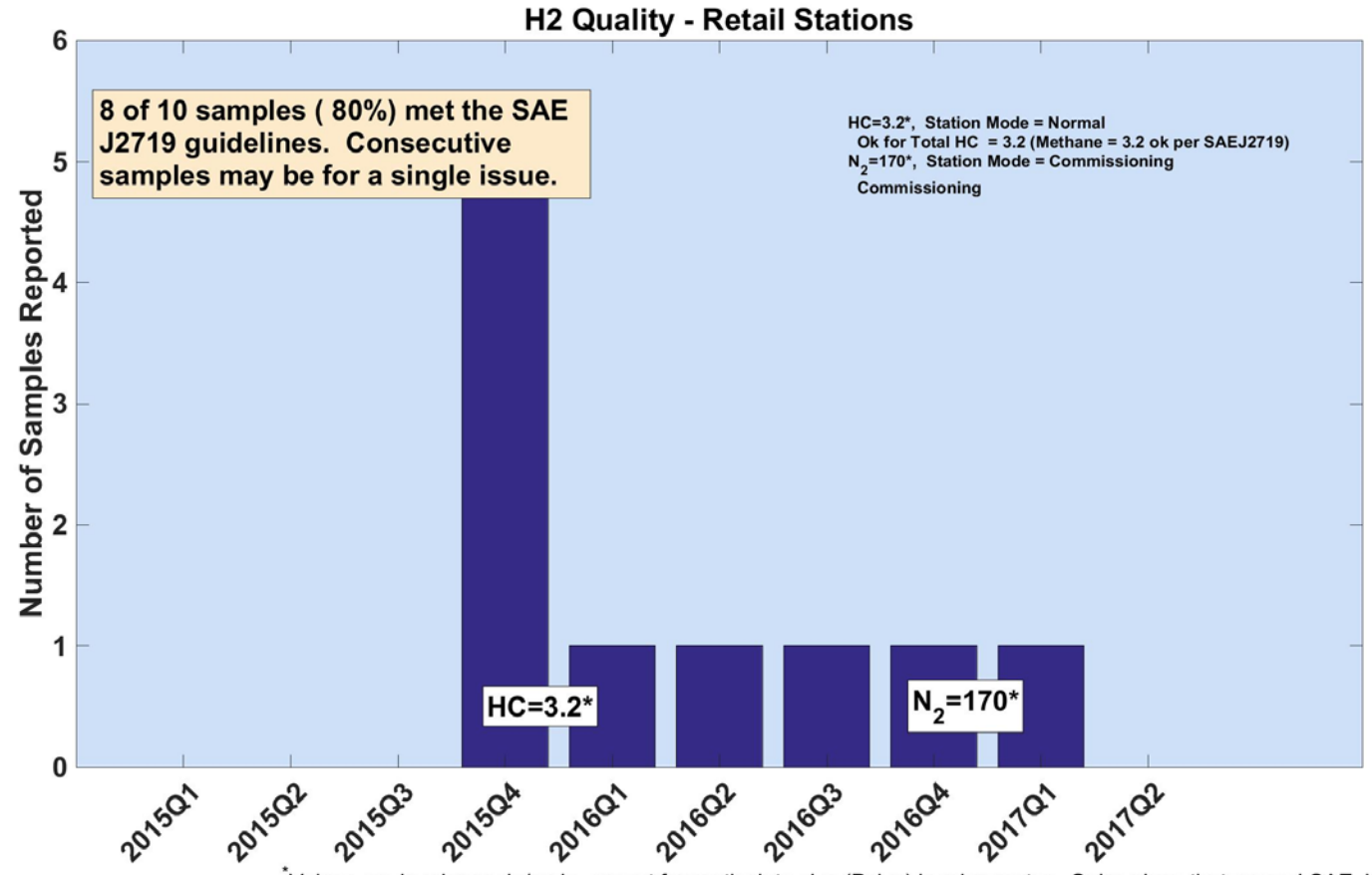


NREL cdpRETAIL_infr_82
Created: Sep-25-17 3:59 PM | Data Range: 2014Q3-2017Q2

*Daily average only includes days with fills.

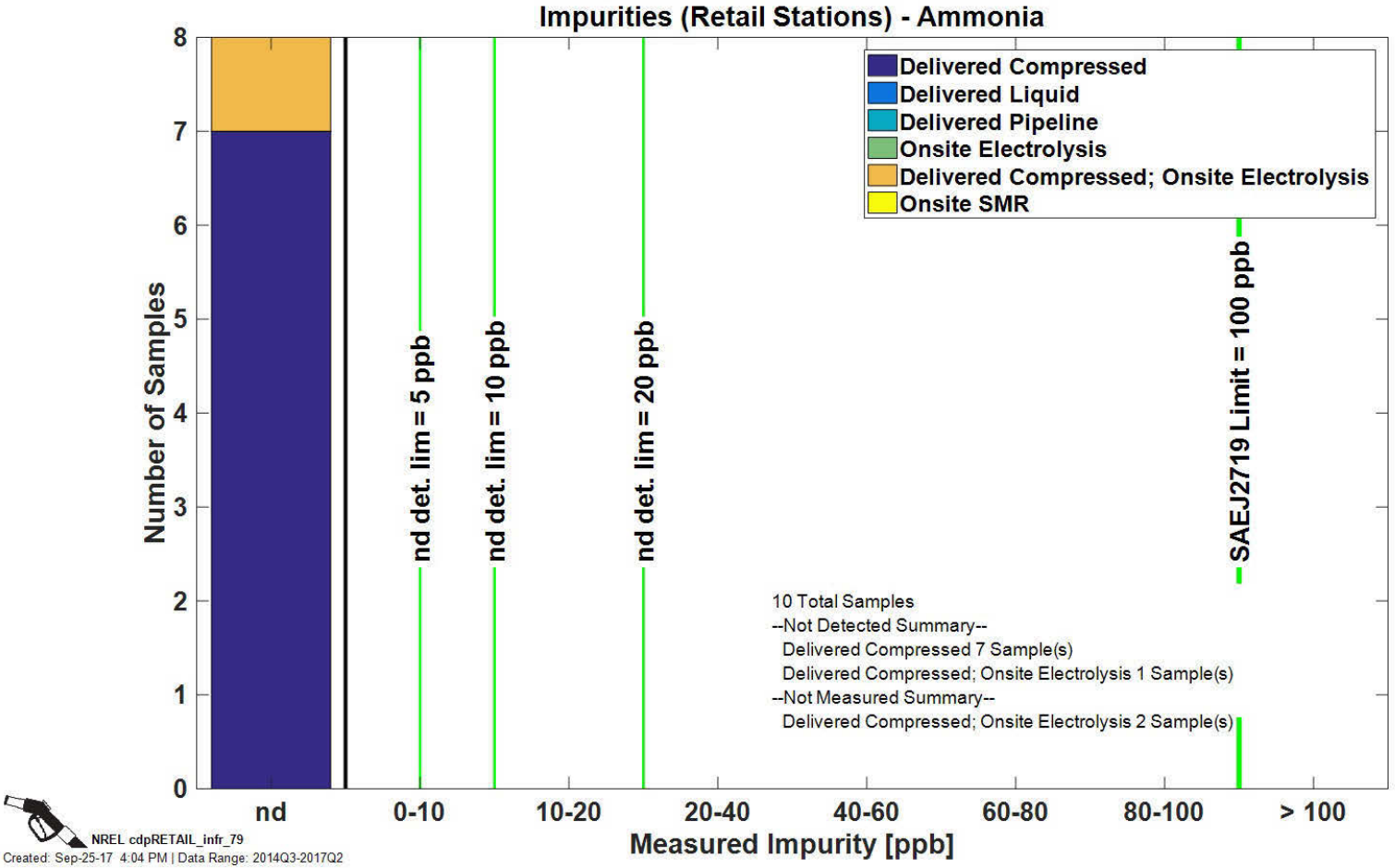
Hydrogen Quality

CDP-INFR-25
Hydrogen Quality

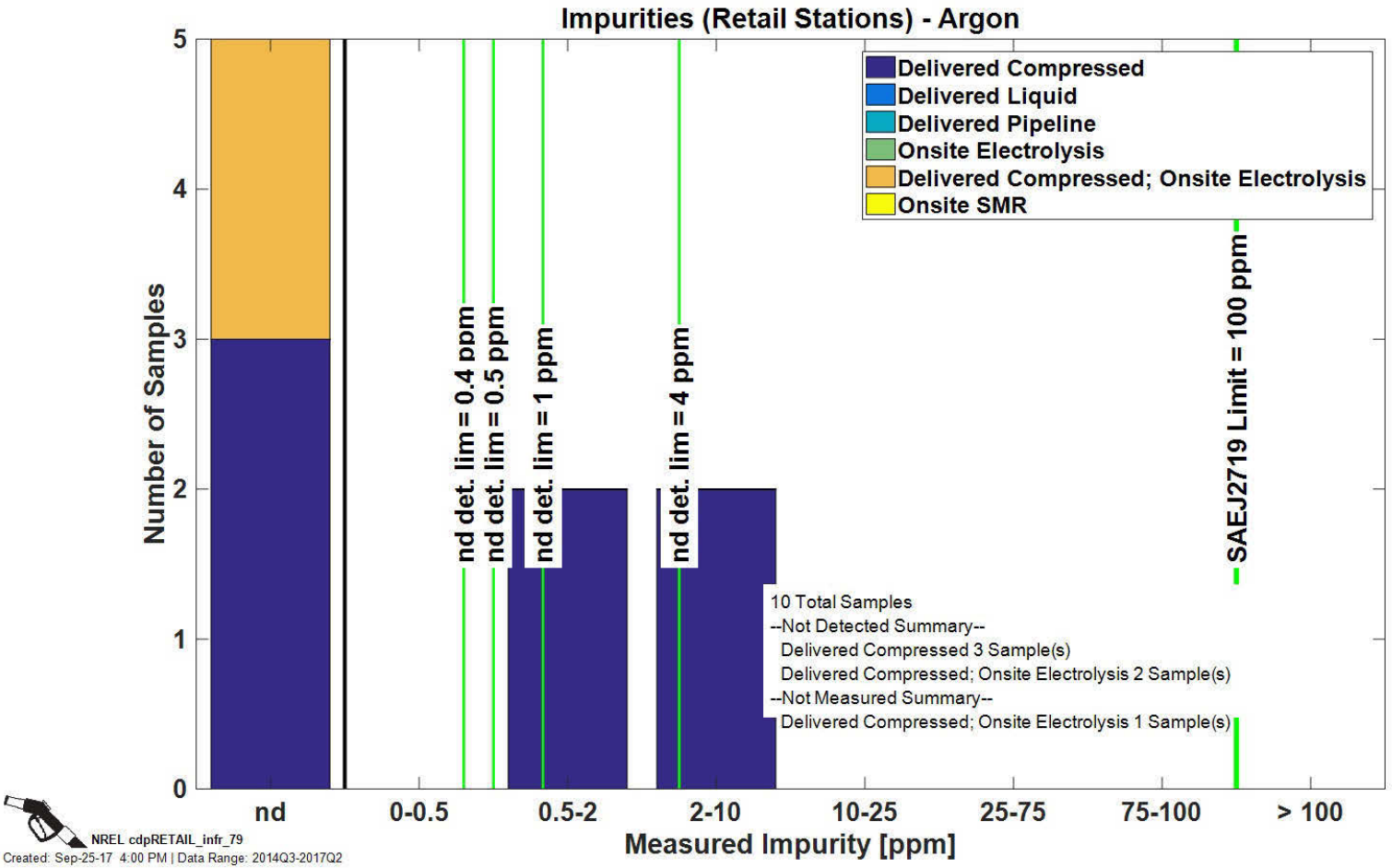


*Values are in micromole/mole, except for particulate size (Psize) in micrometer. Only values that exceed SAE J2719 guideline are shown in text. Left edge of text box aligns with sample date.

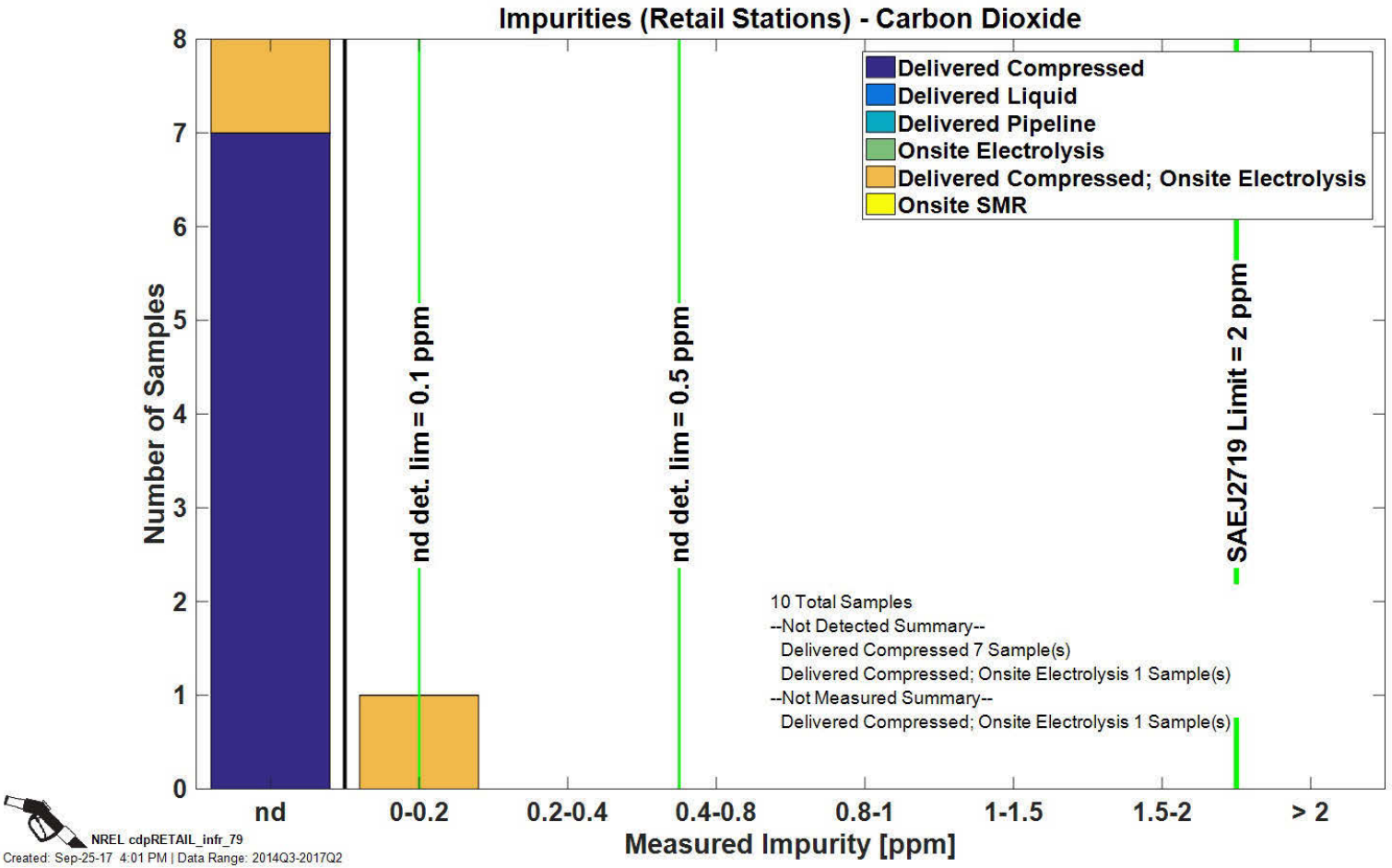
CDP-INFR-79
Impurities—Ammonia



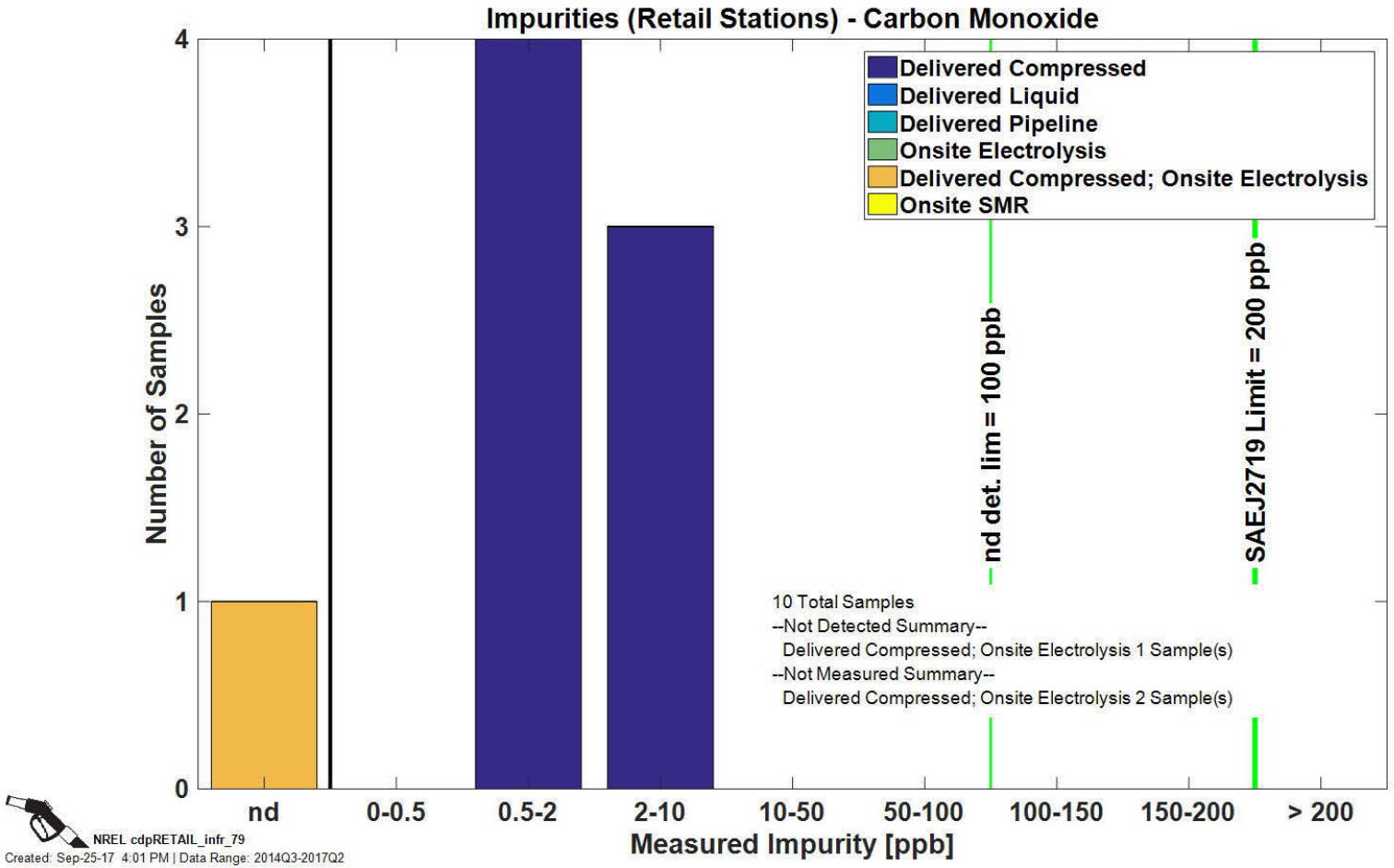
CDP-INFR-79
Impurities—Argon



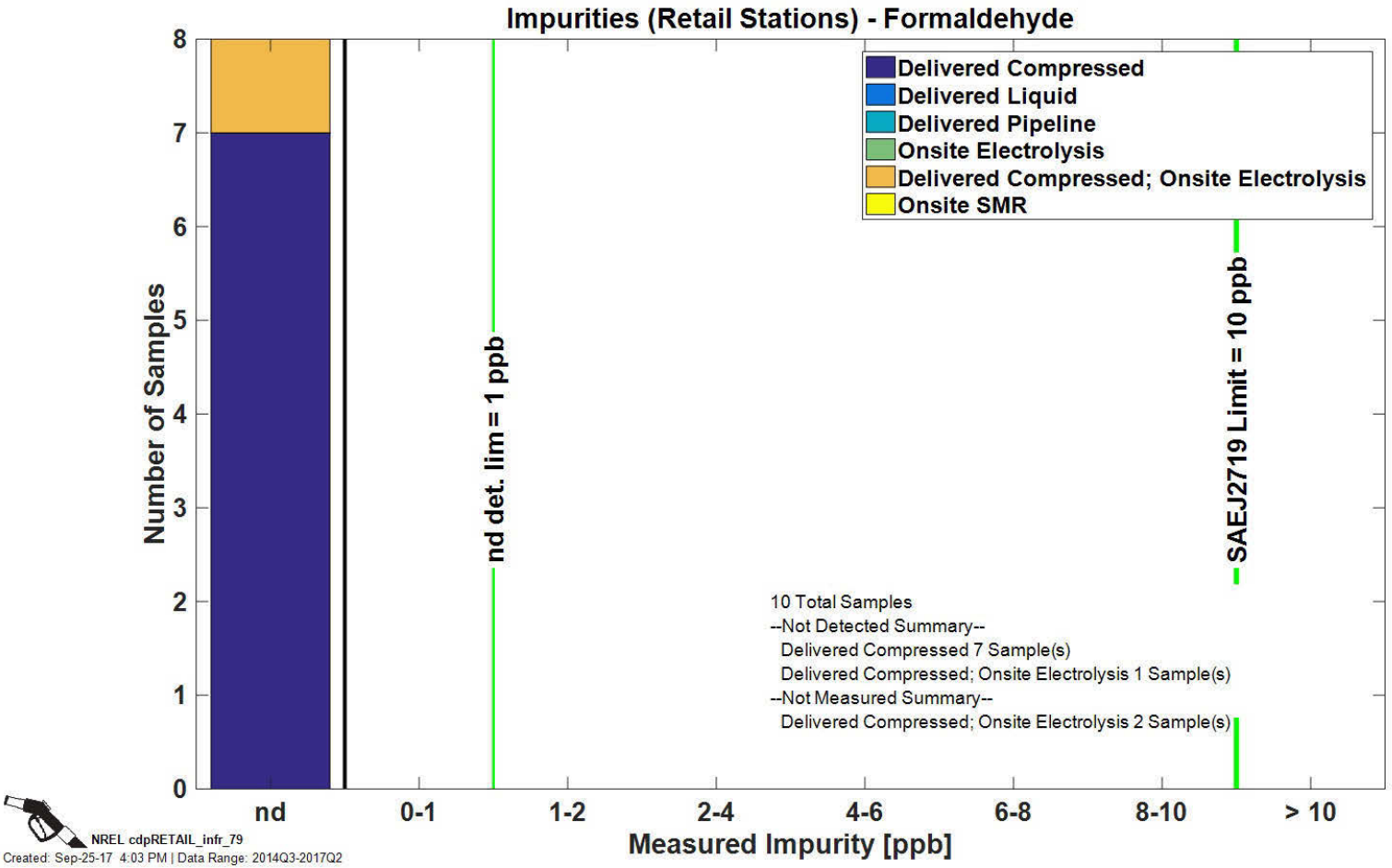
CDP-INFR-79
Impurities—Carbon Dioxide



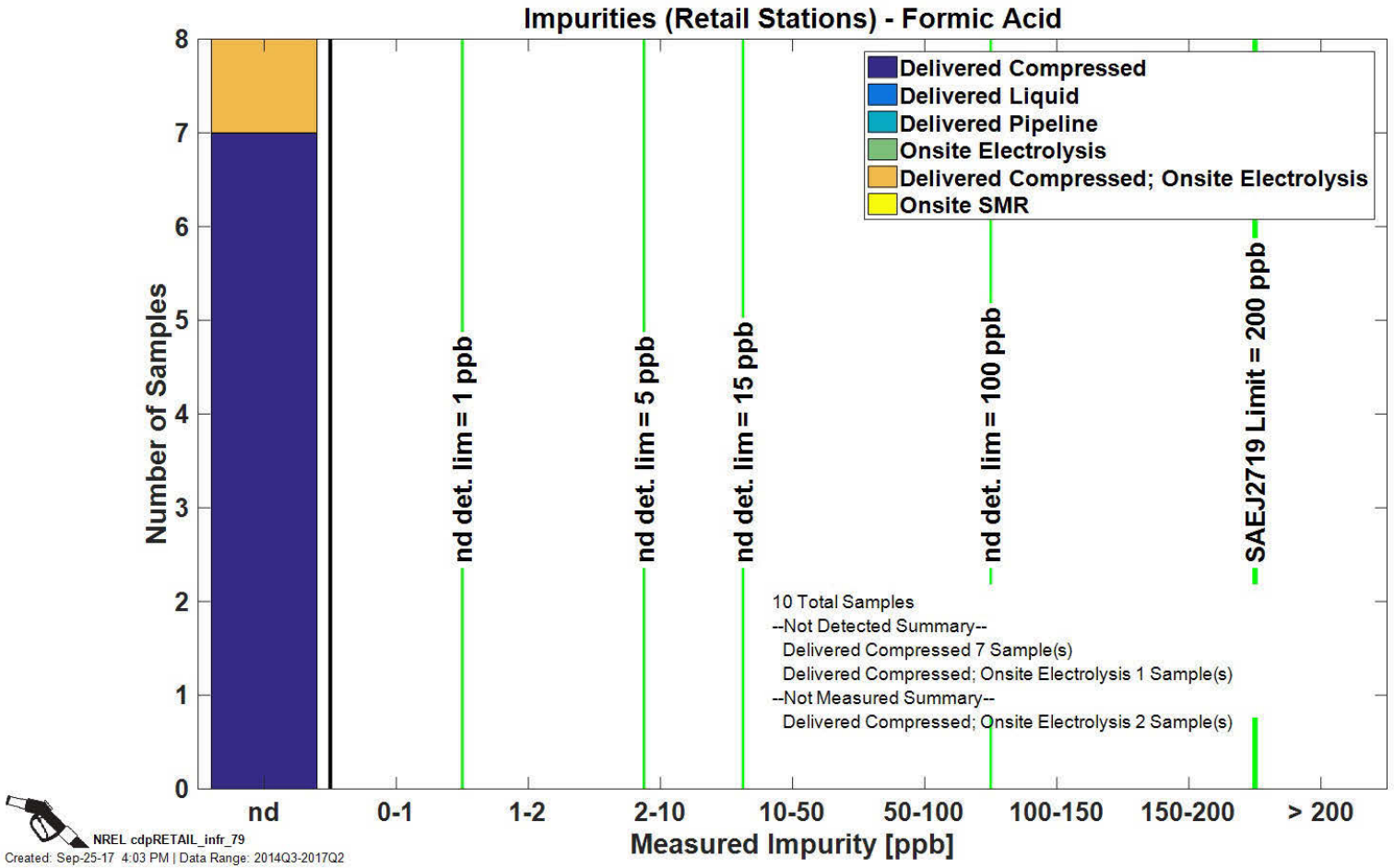
CDP-INFR-79
Impurities—Carbon Monoxide



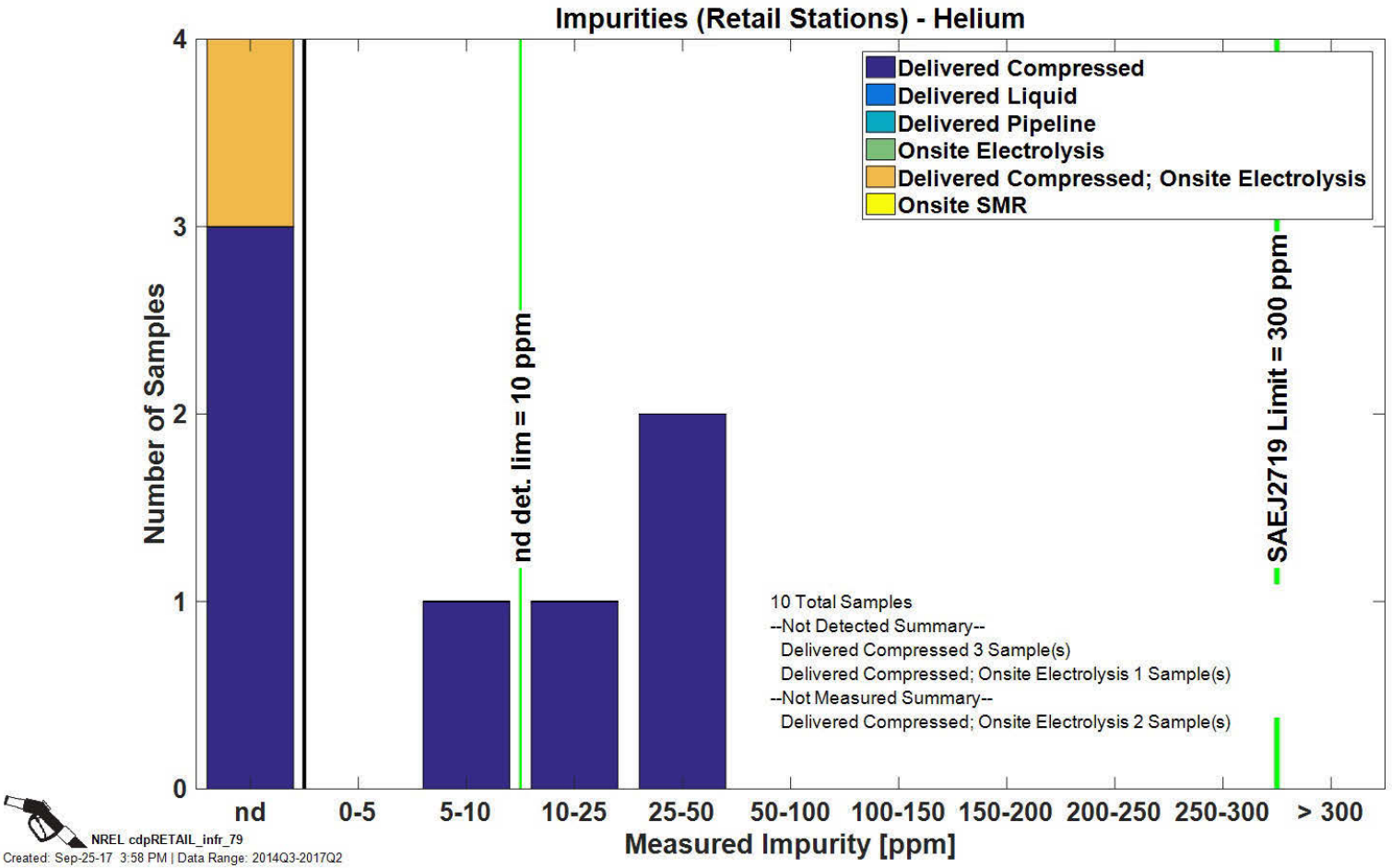
CDP-INFR-79
Impurities—Formaldehyde



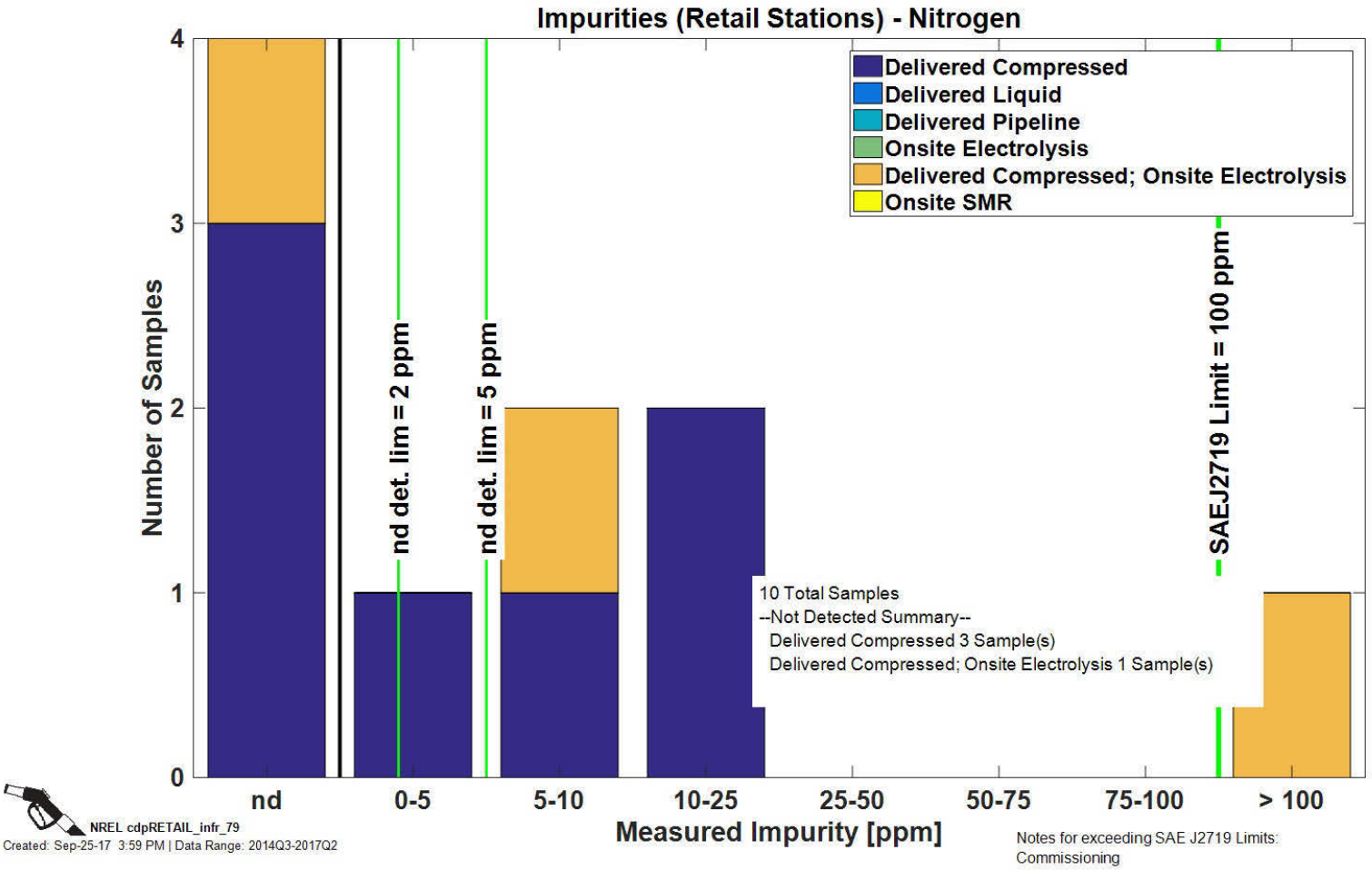
CDP-INFR-79
Impurities—Formic Acid



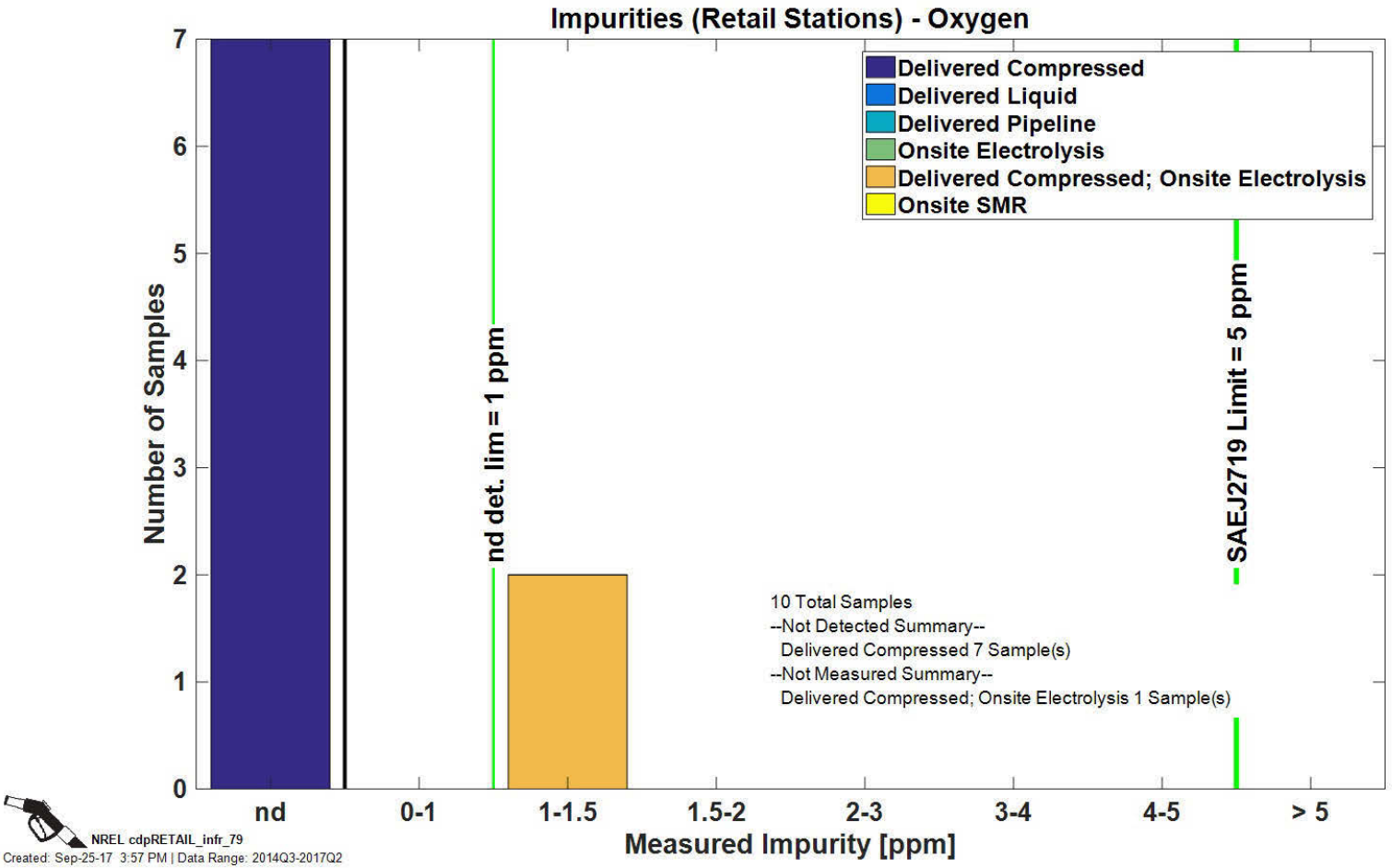
CDP-INFR-79
Impurities—Helium



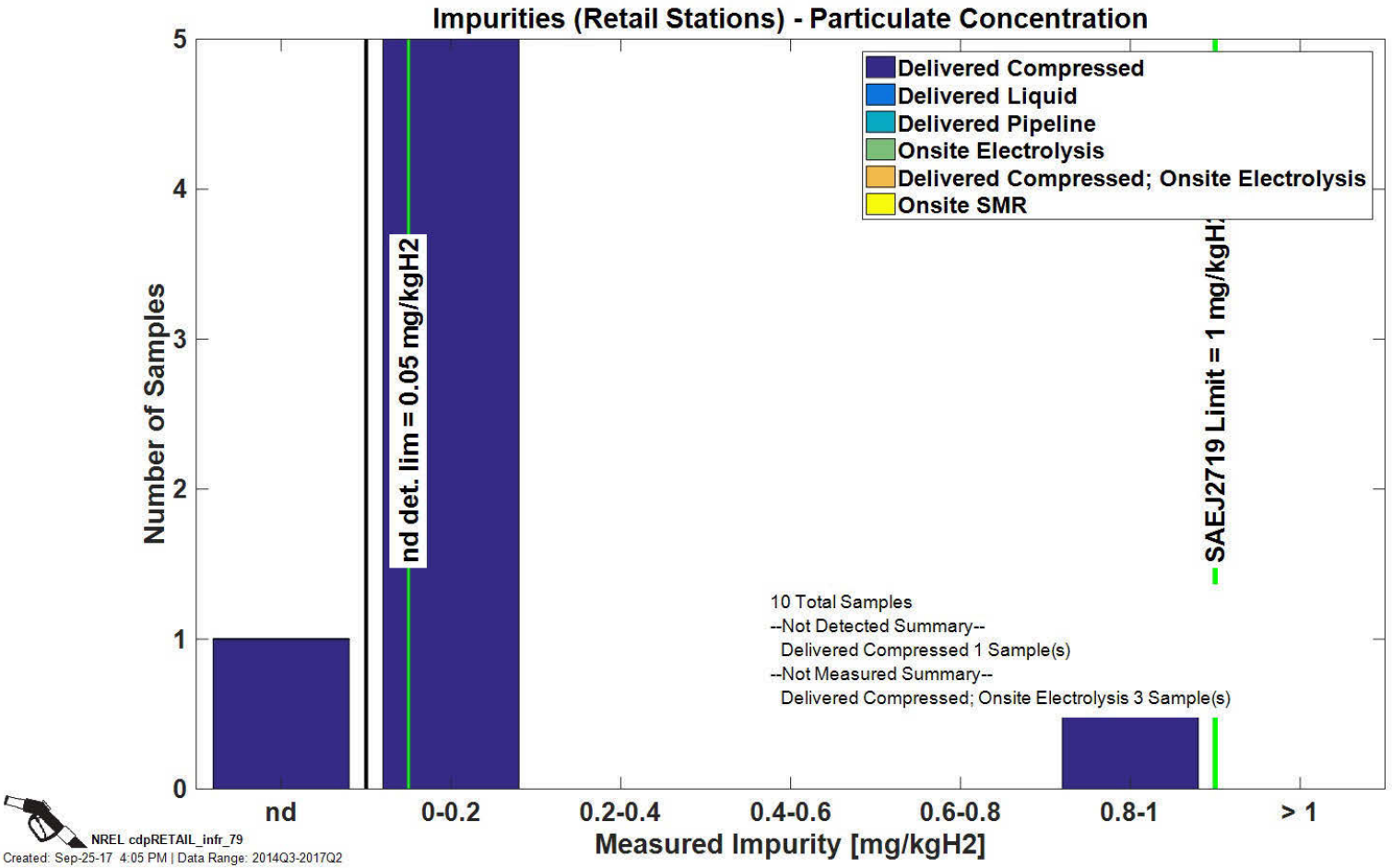
CDP-INFR-79
Impurities—Nitrogen



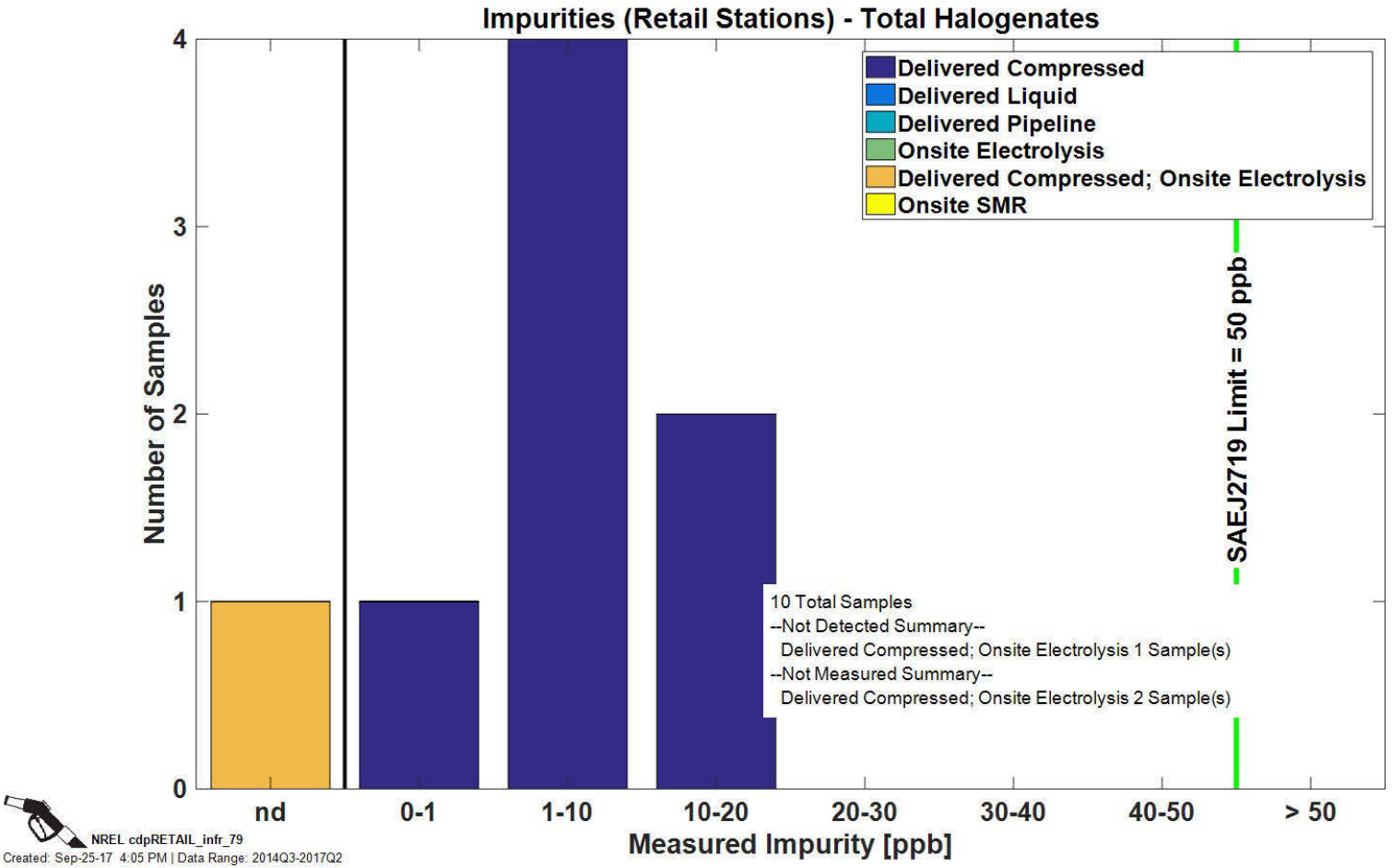
CDP-INFR-79
Impurities—Oxygen



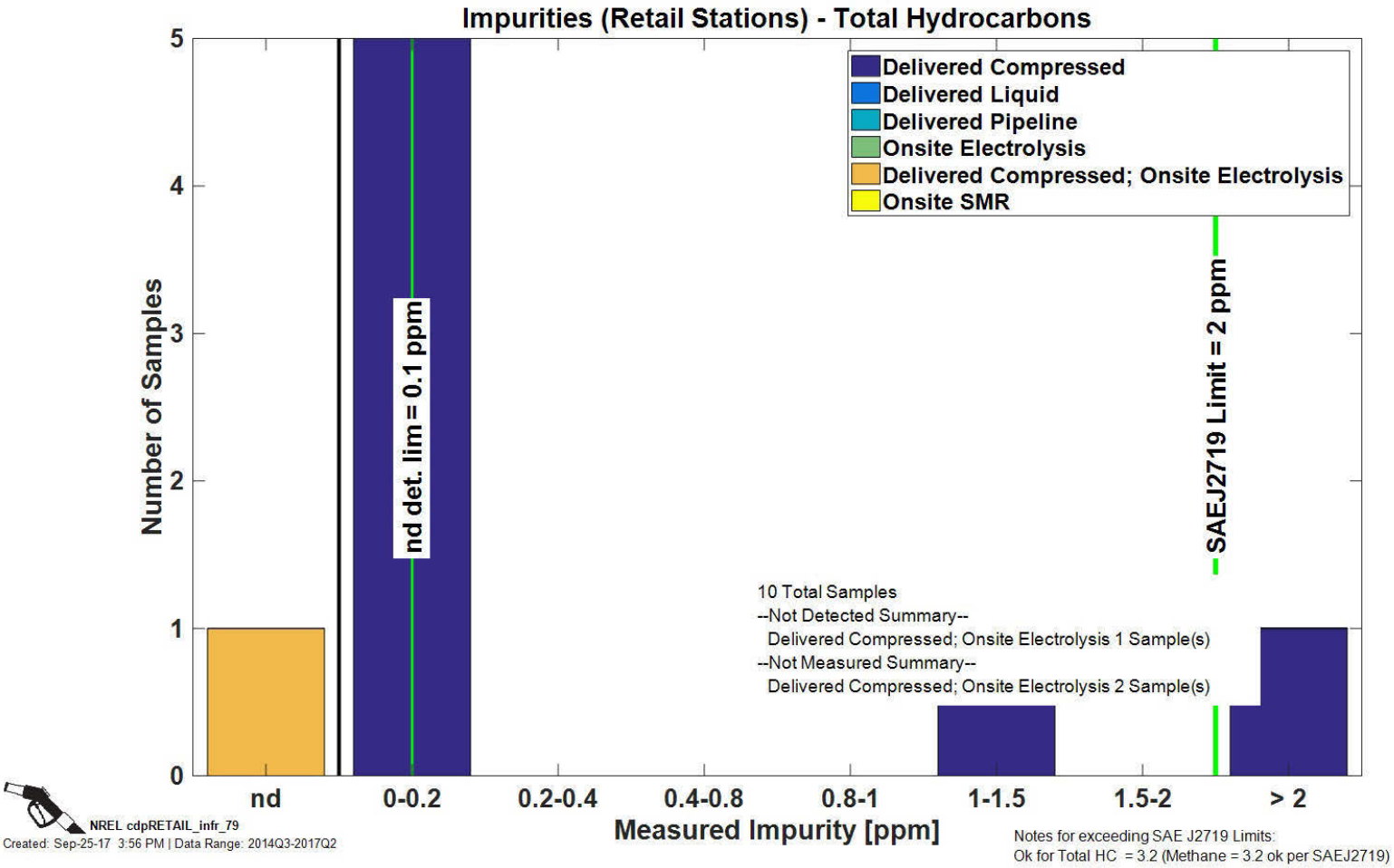
CDP-INFR-79
Impurities—Particulate Concentration



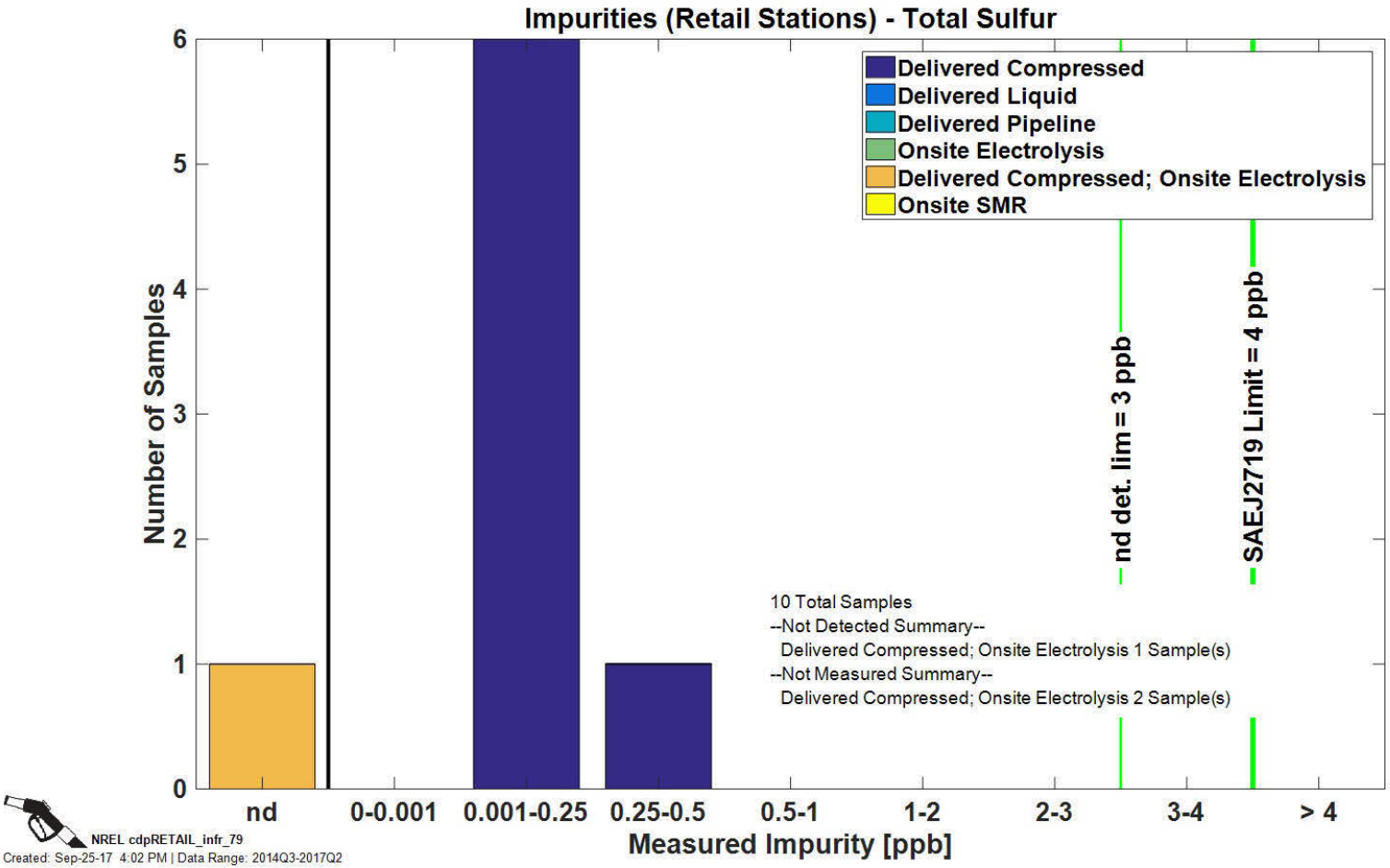
CDP-INFR-79
Impurities—Total Halogenates



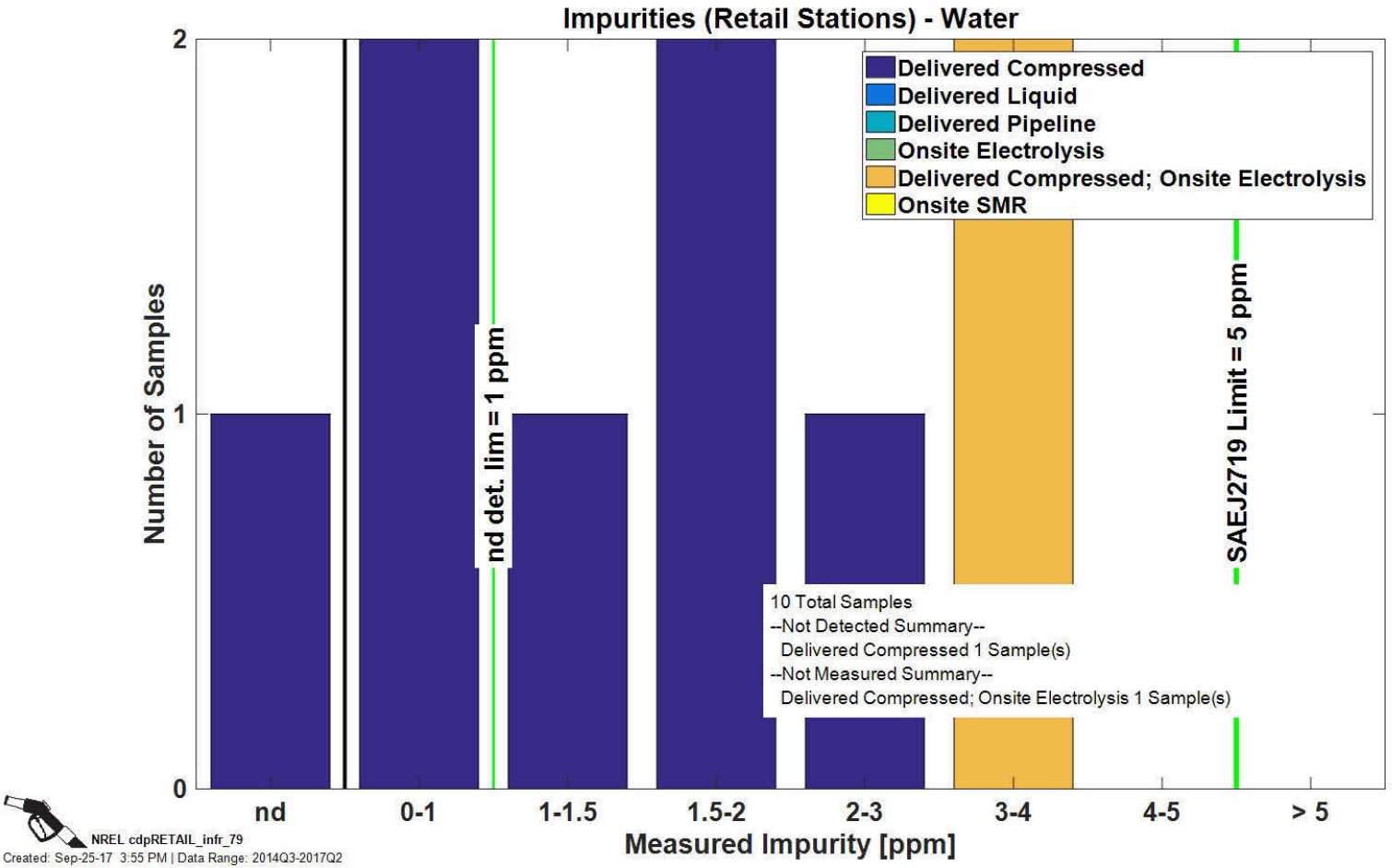
CDP-INFR-79
Impurities—Total Hydrocarbons



CDP-INFR-79
Impurities—Total Sulfur

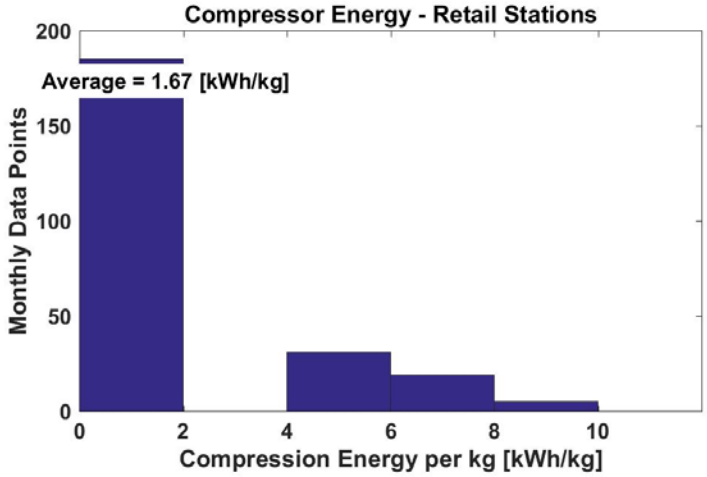


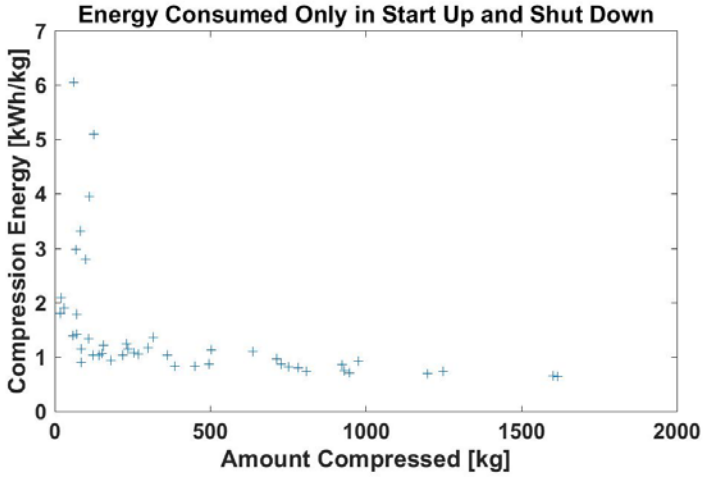
CDP-INFR-79
Impurities—Water

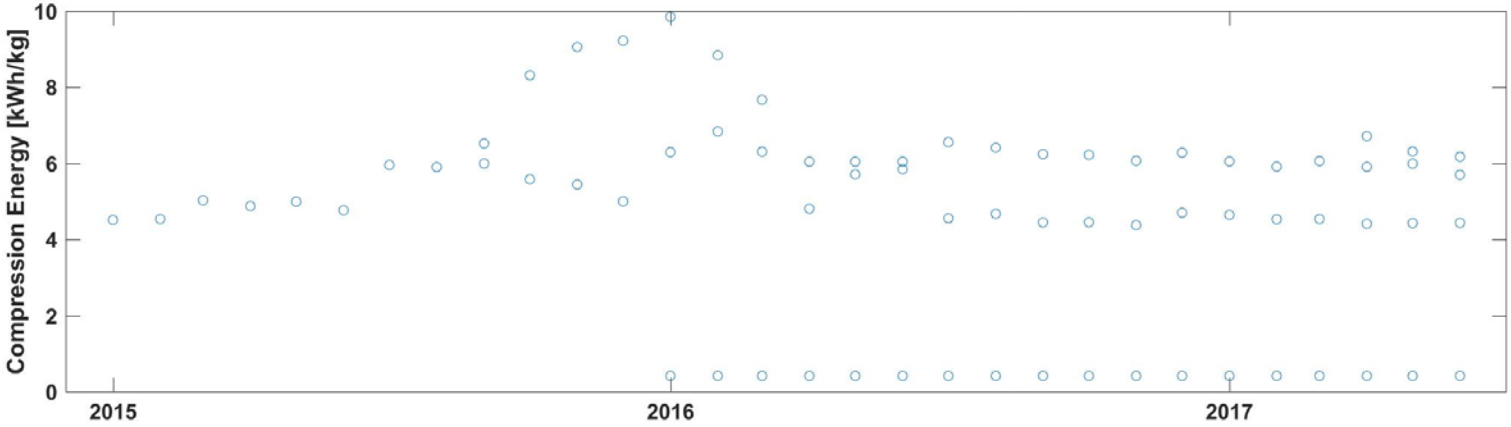


Component Energy

CDP-INFR-35
Compressor Energy

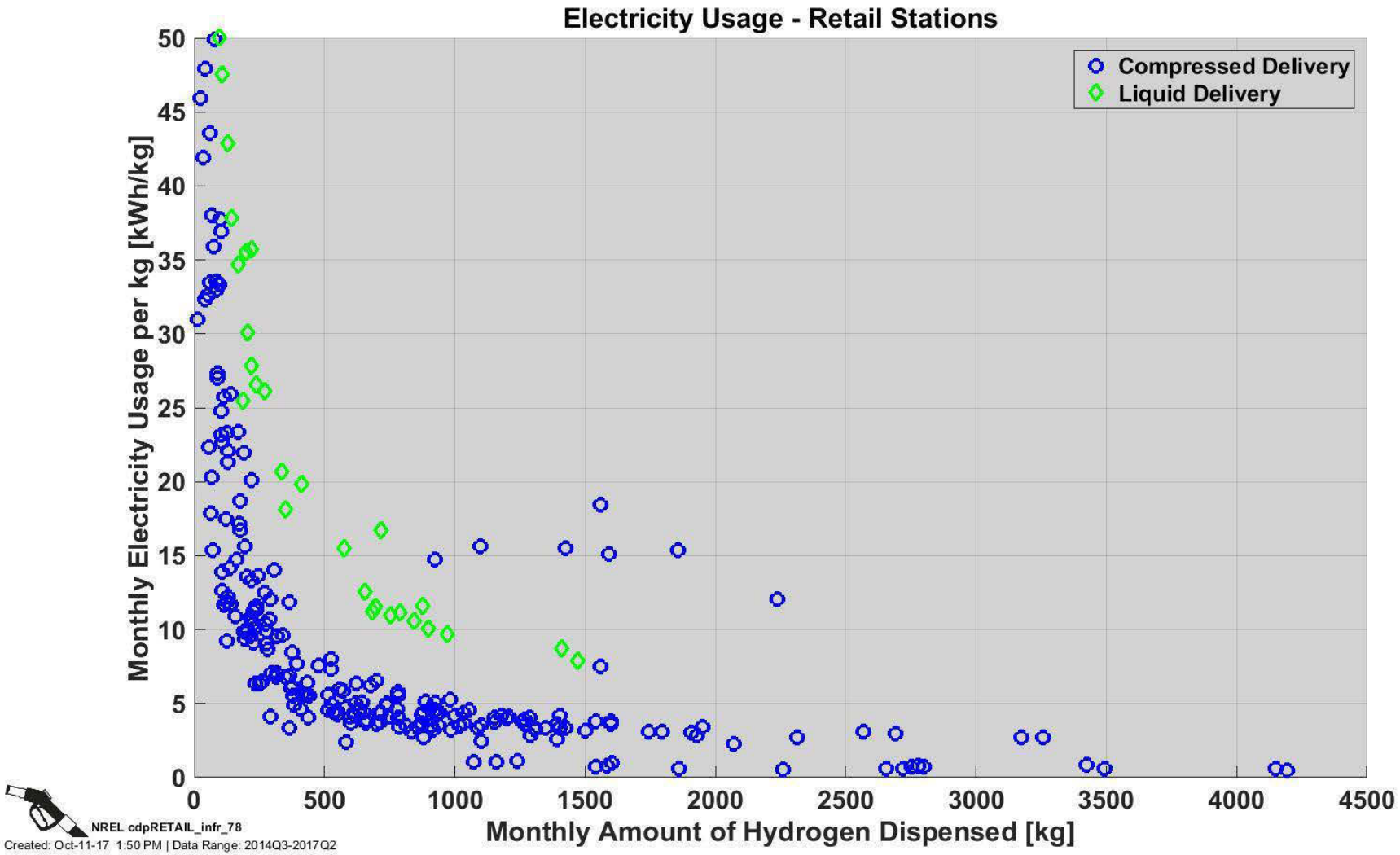




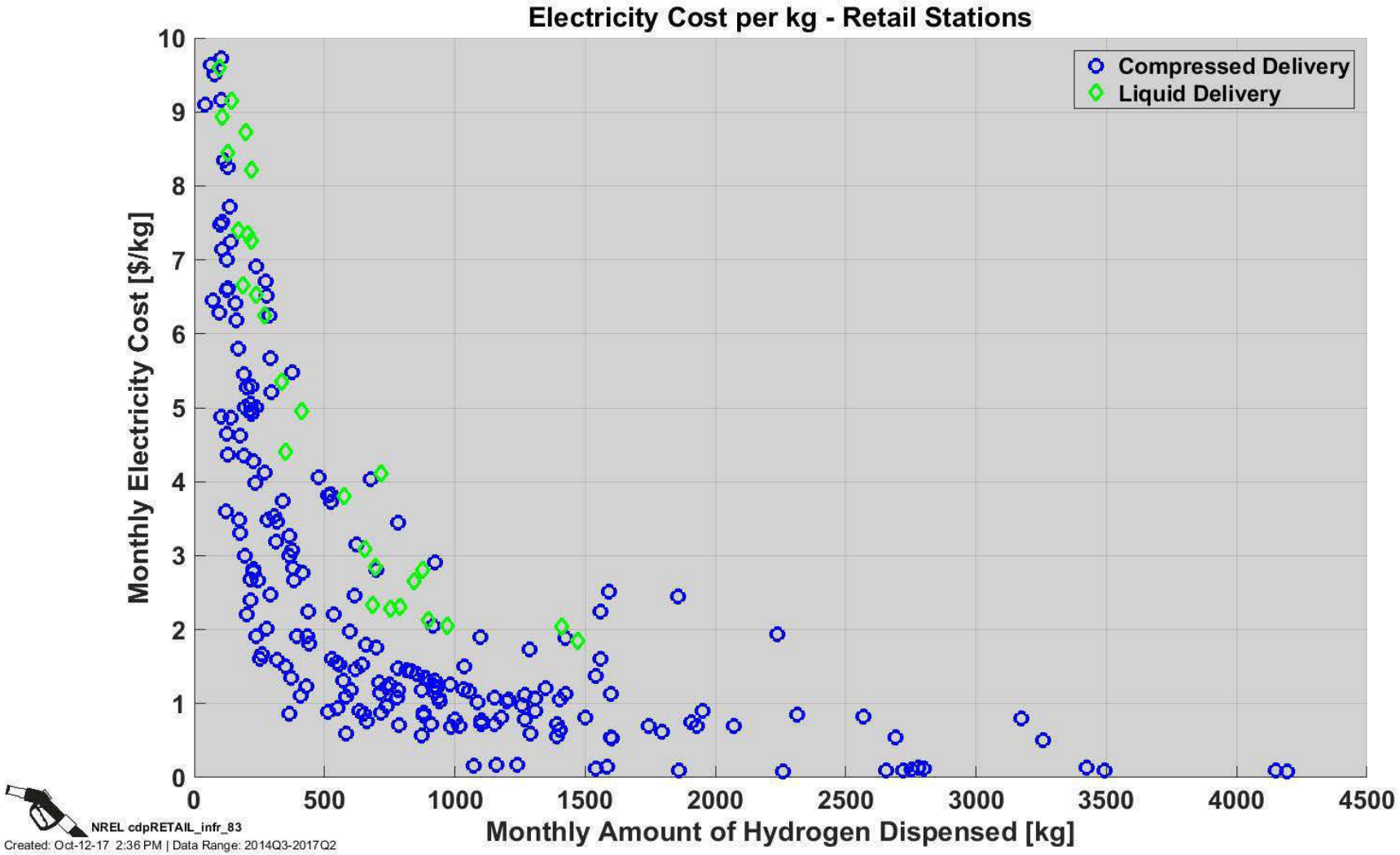


NREL cdpRETAIL_infr_35
Created: Sep-25-17 4:01 PM | Data Range: 2014Q3-2017Q2

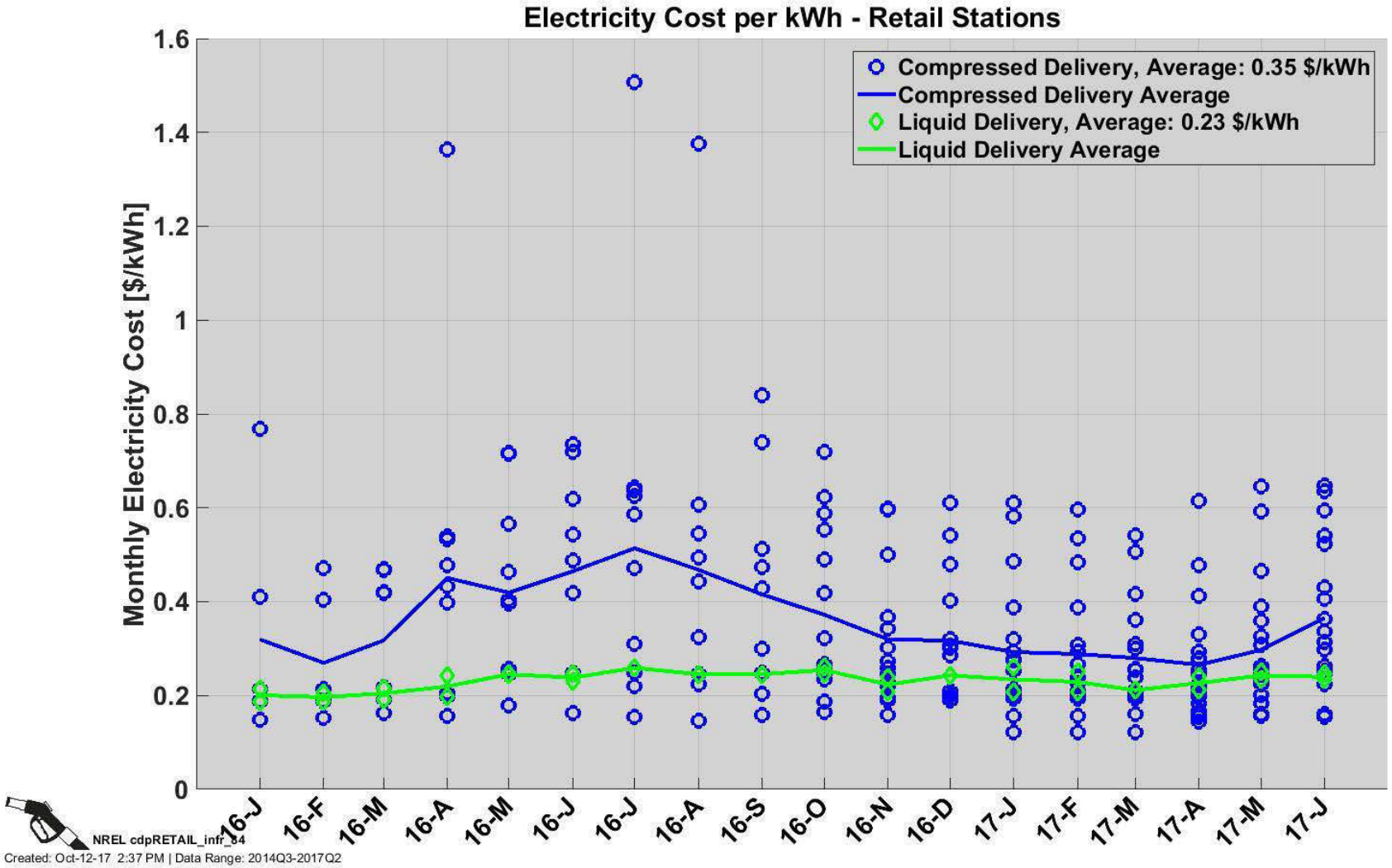
CDP-INFR-78
Station Energy per kg Dispensed



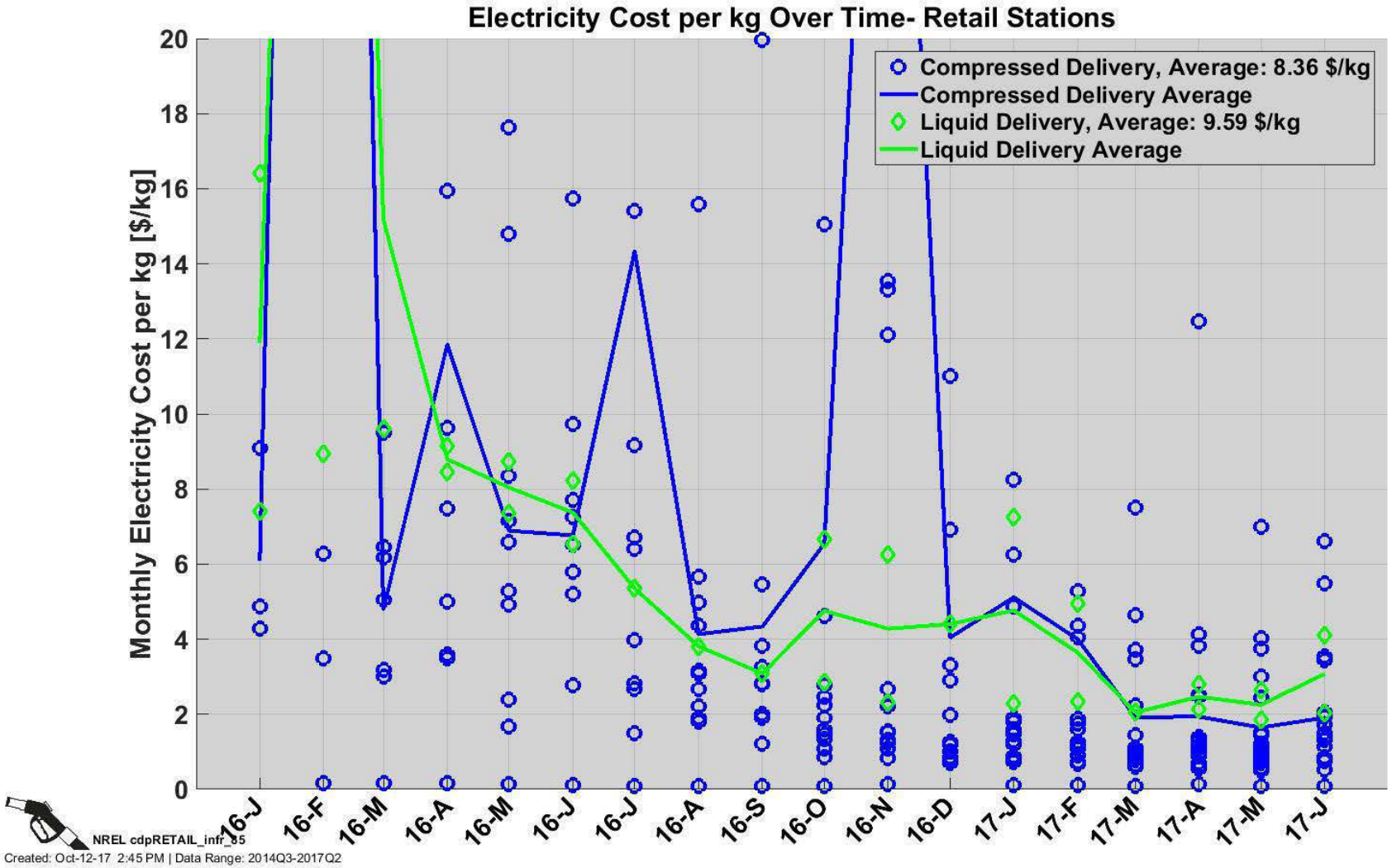
CDP-INFR-83
Station Energy Cost per kg Dispensed



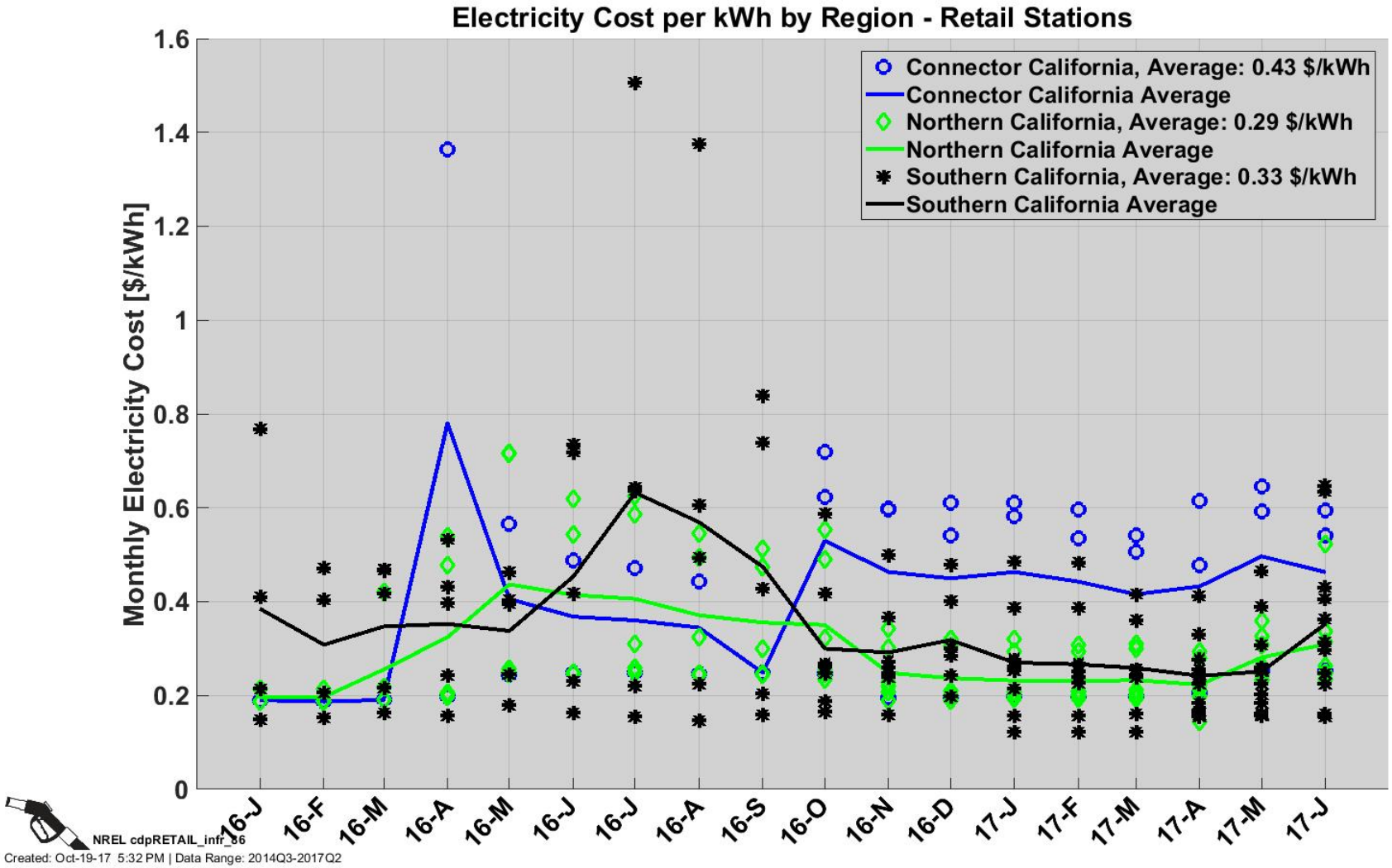
CDP-INFR-84
Station Electricity Cost per kWh



CDP-INFR-85
Station Electricity Cost per kg Over Time



CDP-INFR-86
Station Electricity Cost per kWh by Region



CDP-INFR-87
Station Electricity Cost per kWh by Utility