NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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

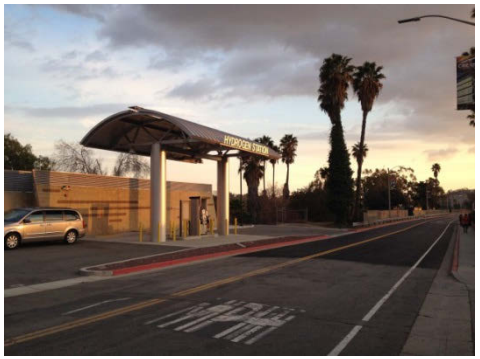
Data through Quarter 4 of 2017

Sam Sprik, Jennifer Kurtz, Genevieve Saur, Shaun Onorato, Matt Ruple, and Chris Ainscough

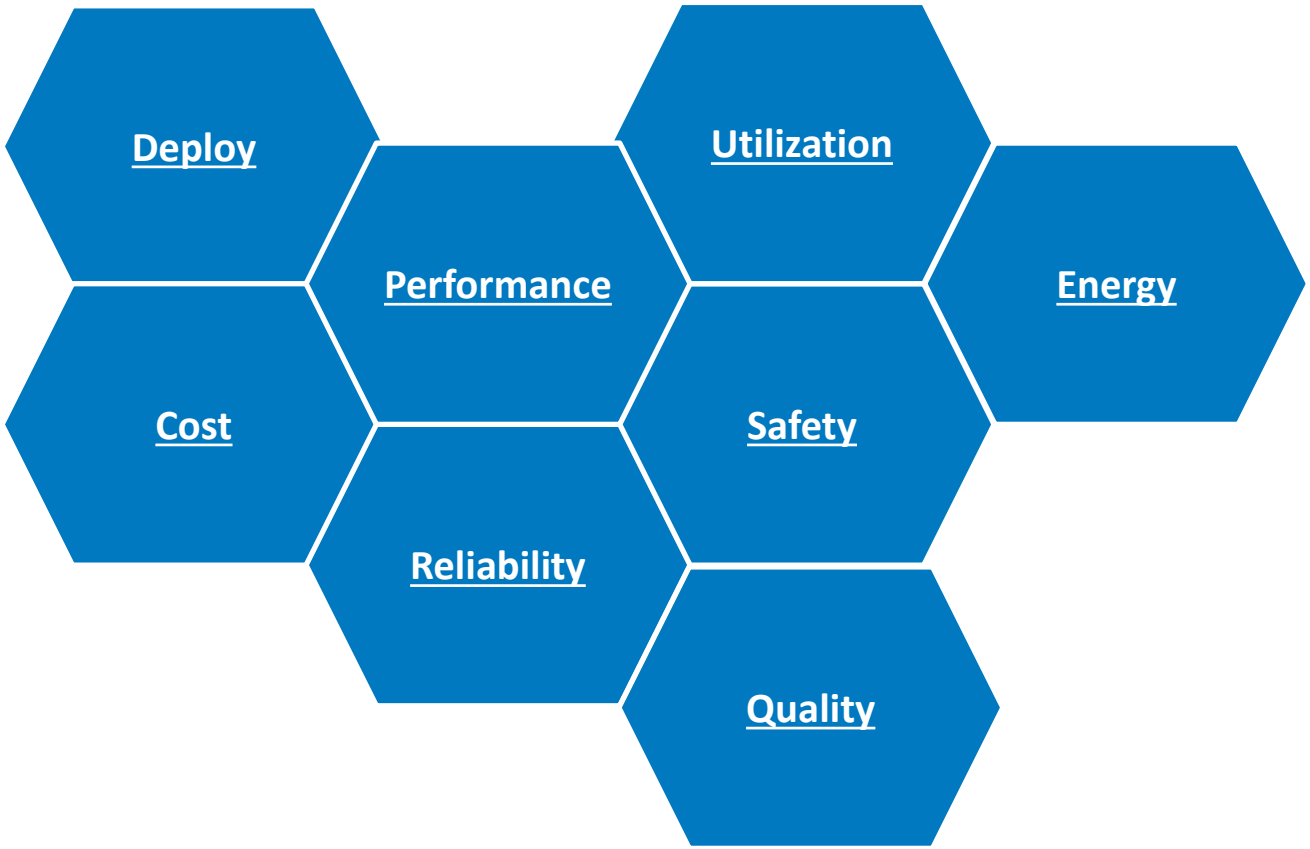
May 2018

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

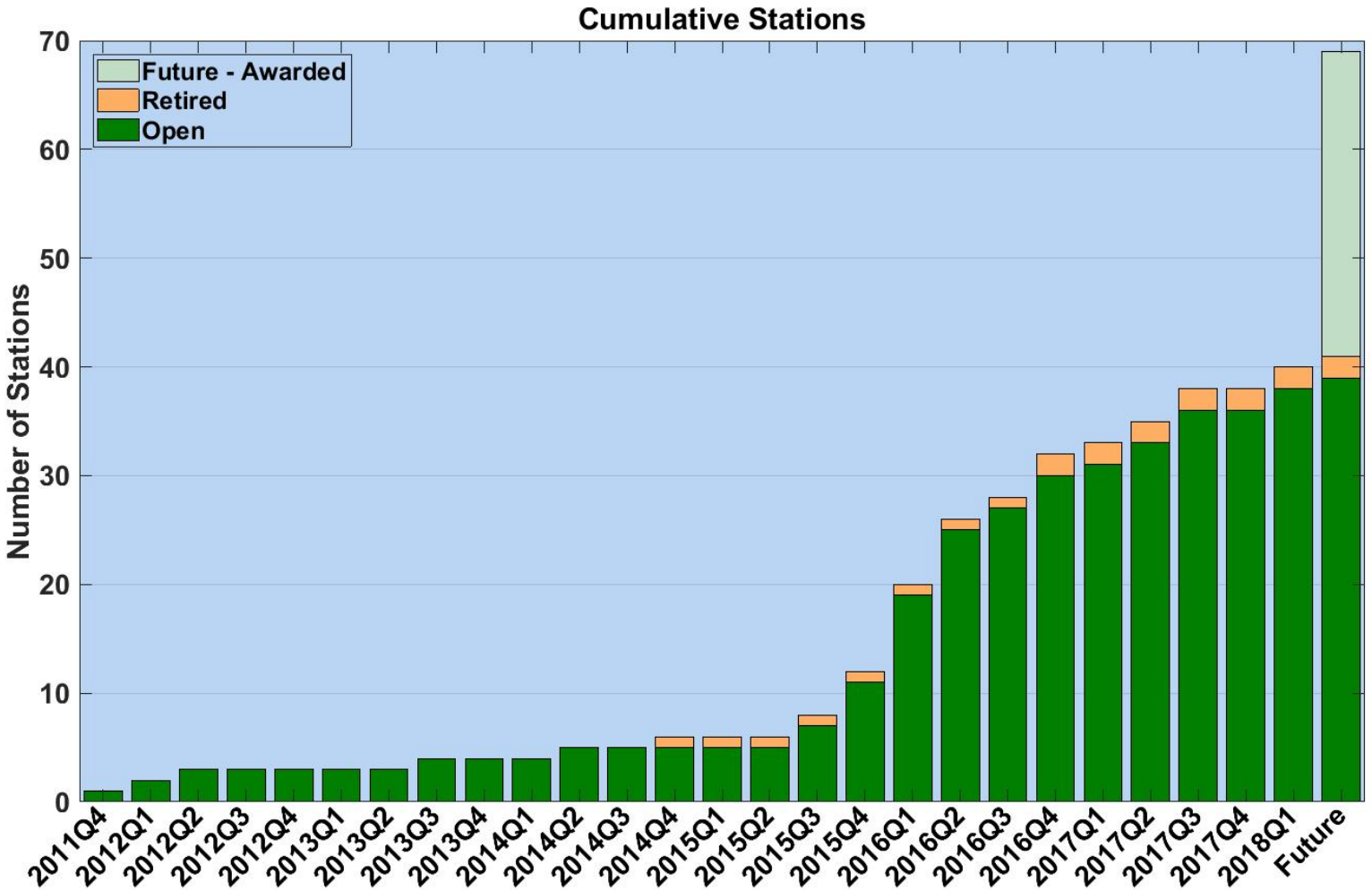


Analysis Categories



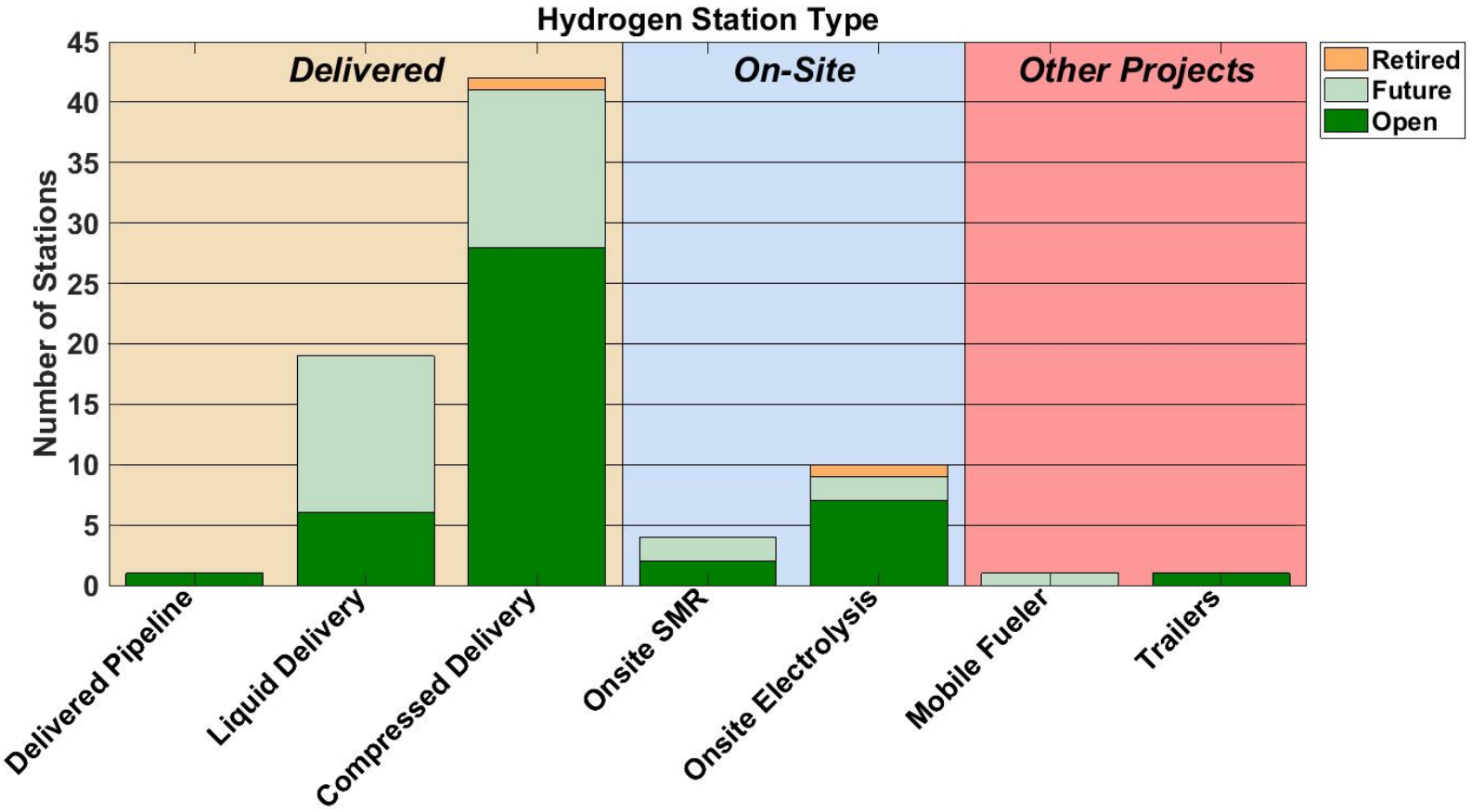
Deployment

CDP-INFR-10
Cumulative Number of Stations



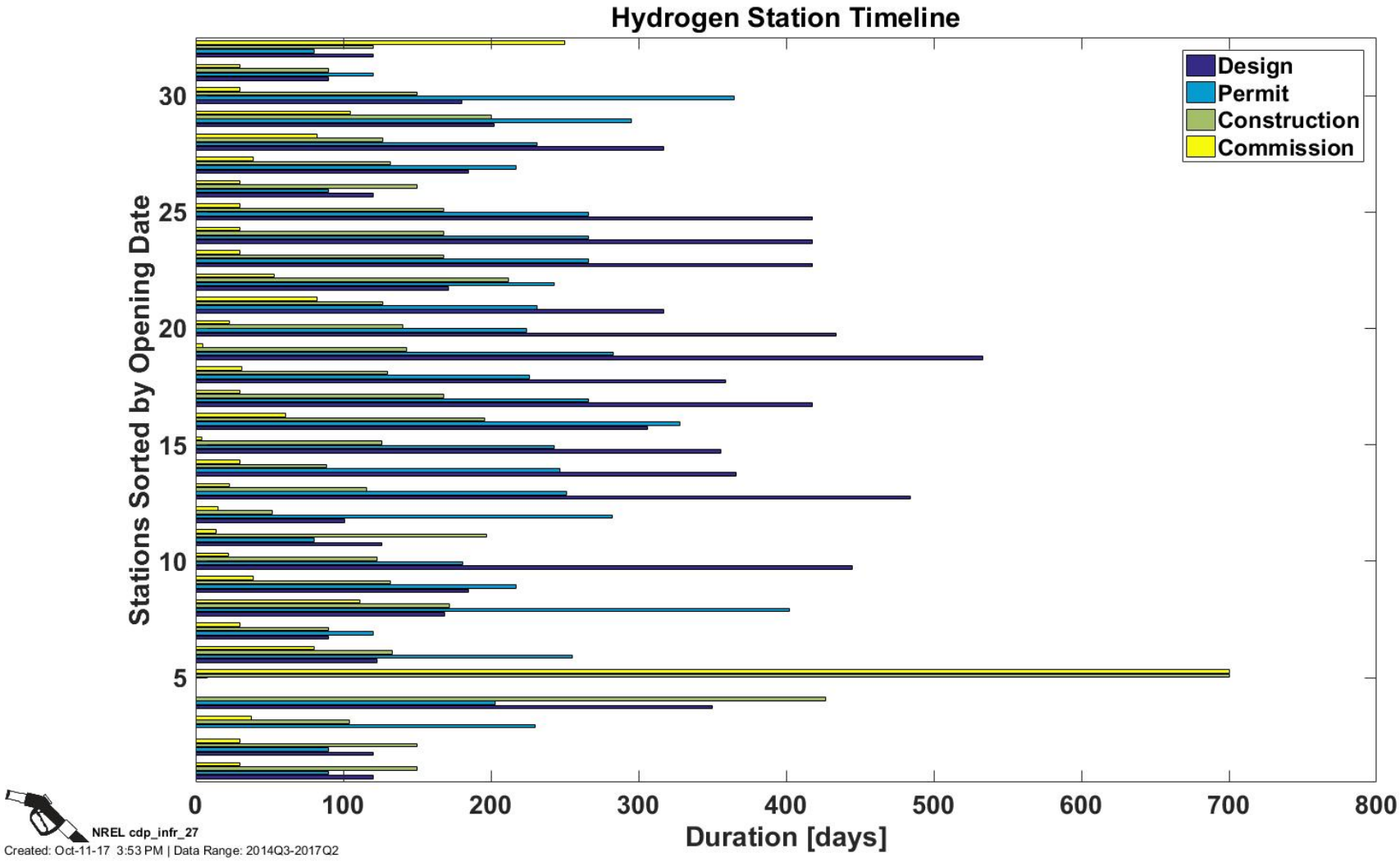
NREL cdp_infr_10
Created: May-04-18 12:24 PM | Data Range: 2008Q3-2017Q4

CDP-INFR-11
Hydrogen Stations by Type



NREL cdp_infr_11
Created: May-04-18 11:52 AM | Data Range: 2014Q3-2017Q4

CDP-INFR-27
Hydrogen Station Timeline



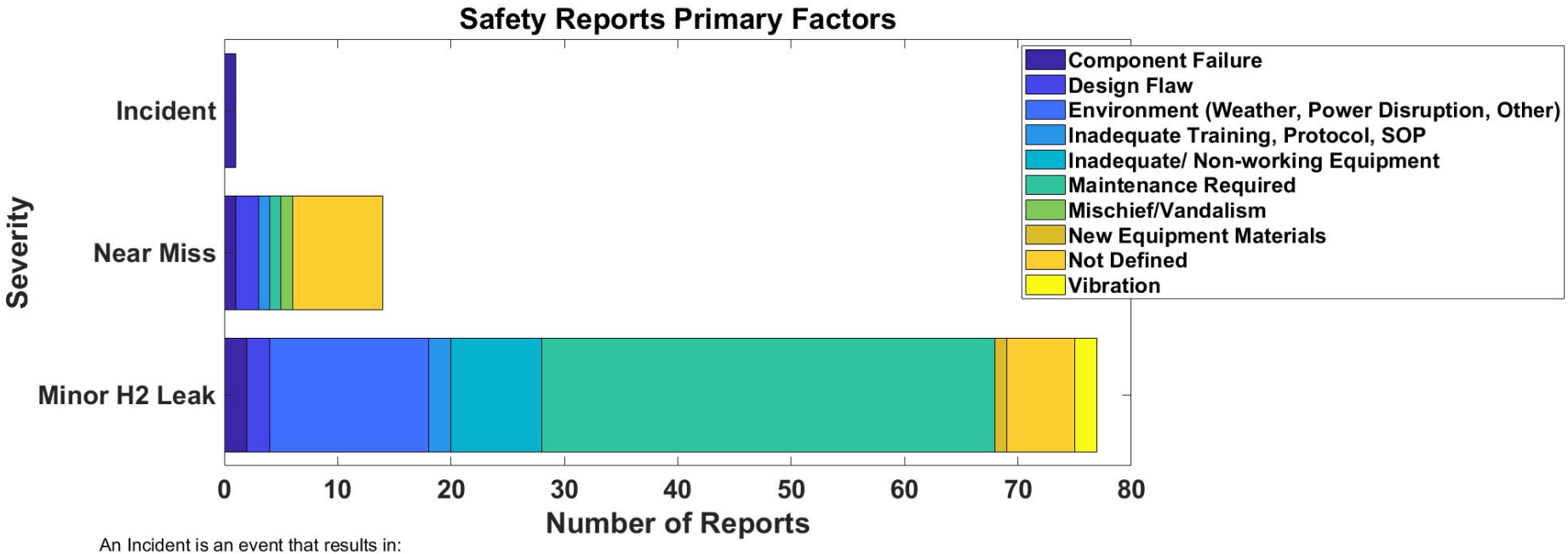
Safety

Safety (and Maintenance) Learnings

From Safety Reports Template

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

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

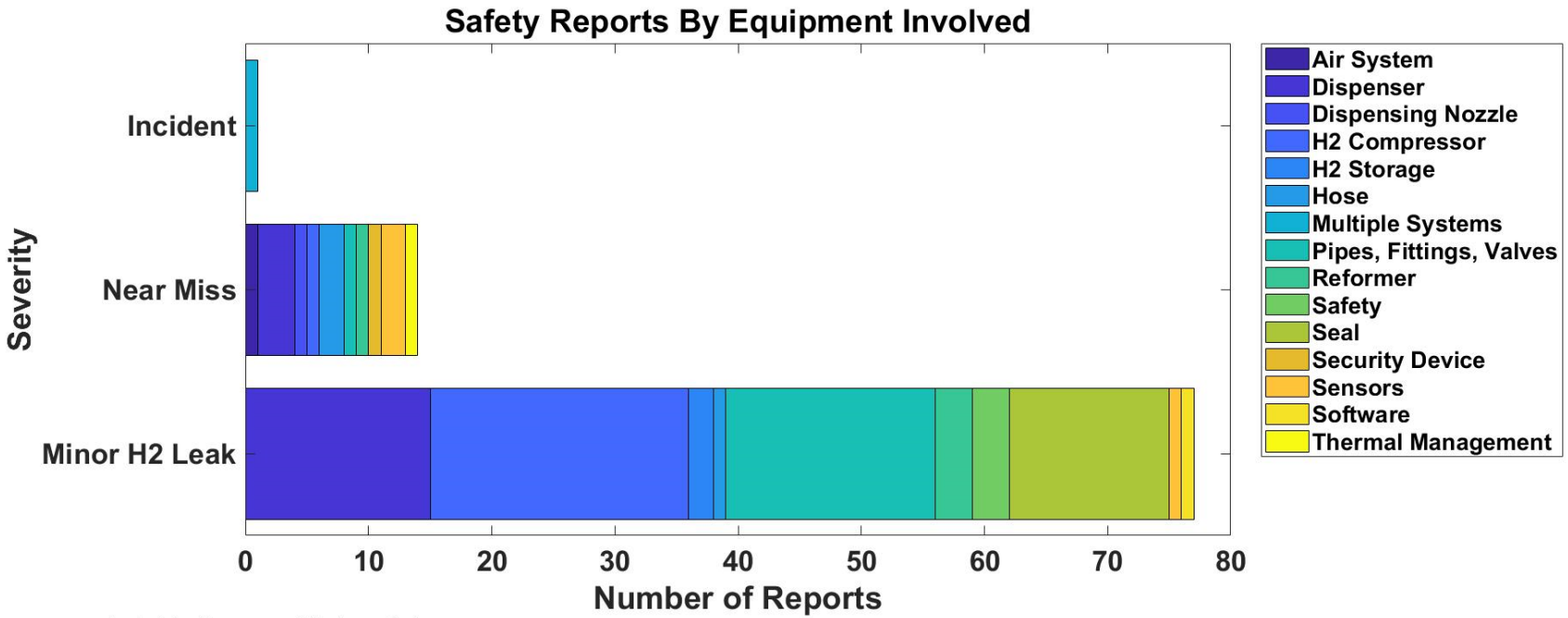
A Minor H2 Leak is:

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

NREL cdp_infr_31

Created: May-15-18 5:38 PM | Data Range: 2008Q3-2017Q4

CDP-INFR-32
Safety Reports by Equipment Involved



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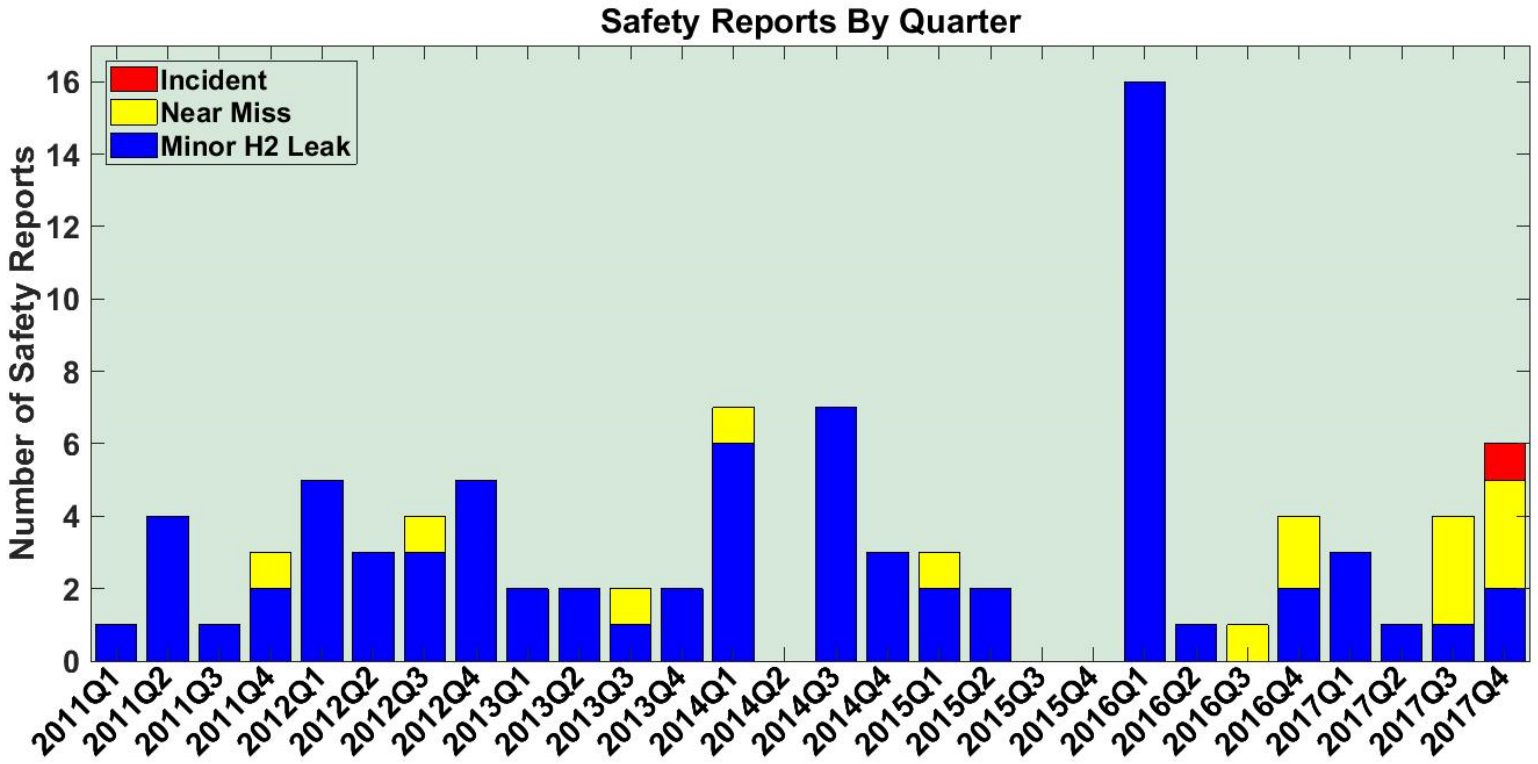
NREL cdp_infr_32

Created: May-15-18 5:39 PM | Data Range: 2008Q3-2017Q4

CDP-INFR-33
Safety Reports by Quarter



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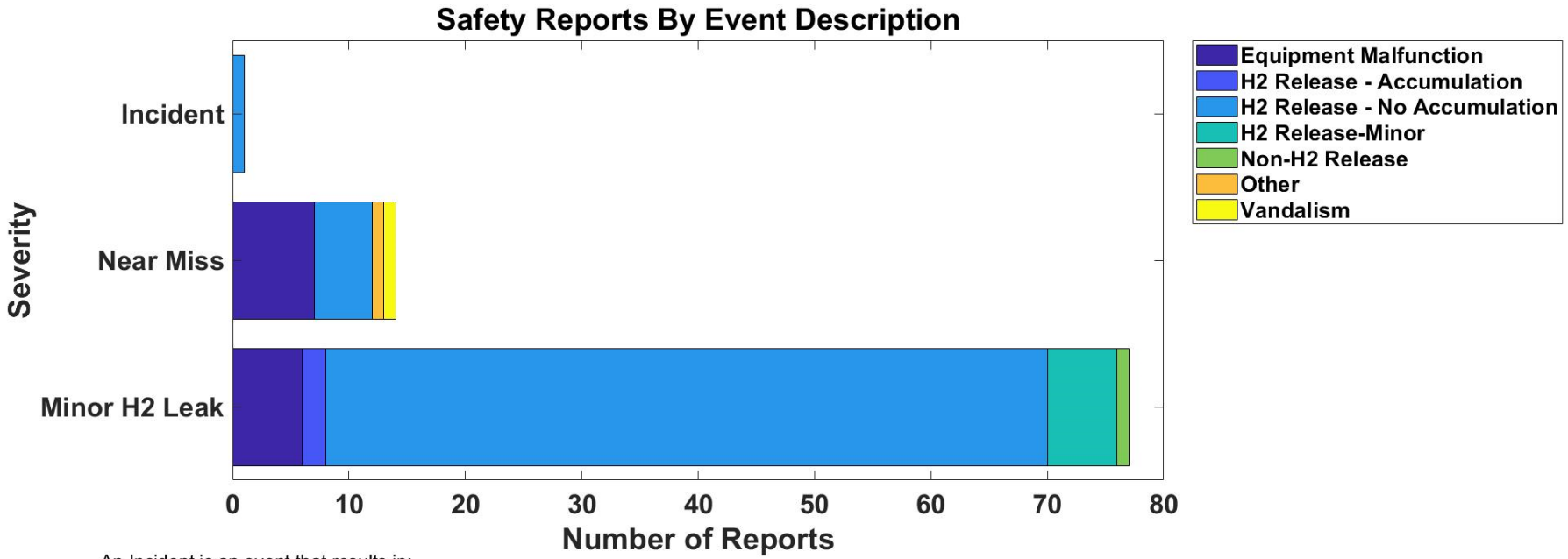
A Minor H2 Leak is:

NREL cdp_infr_33
Created: May-15-18 5:40 PM | Data Range: 2008Q3-2017Q4

CDP-INFR-34
Safety Reports by Event Description



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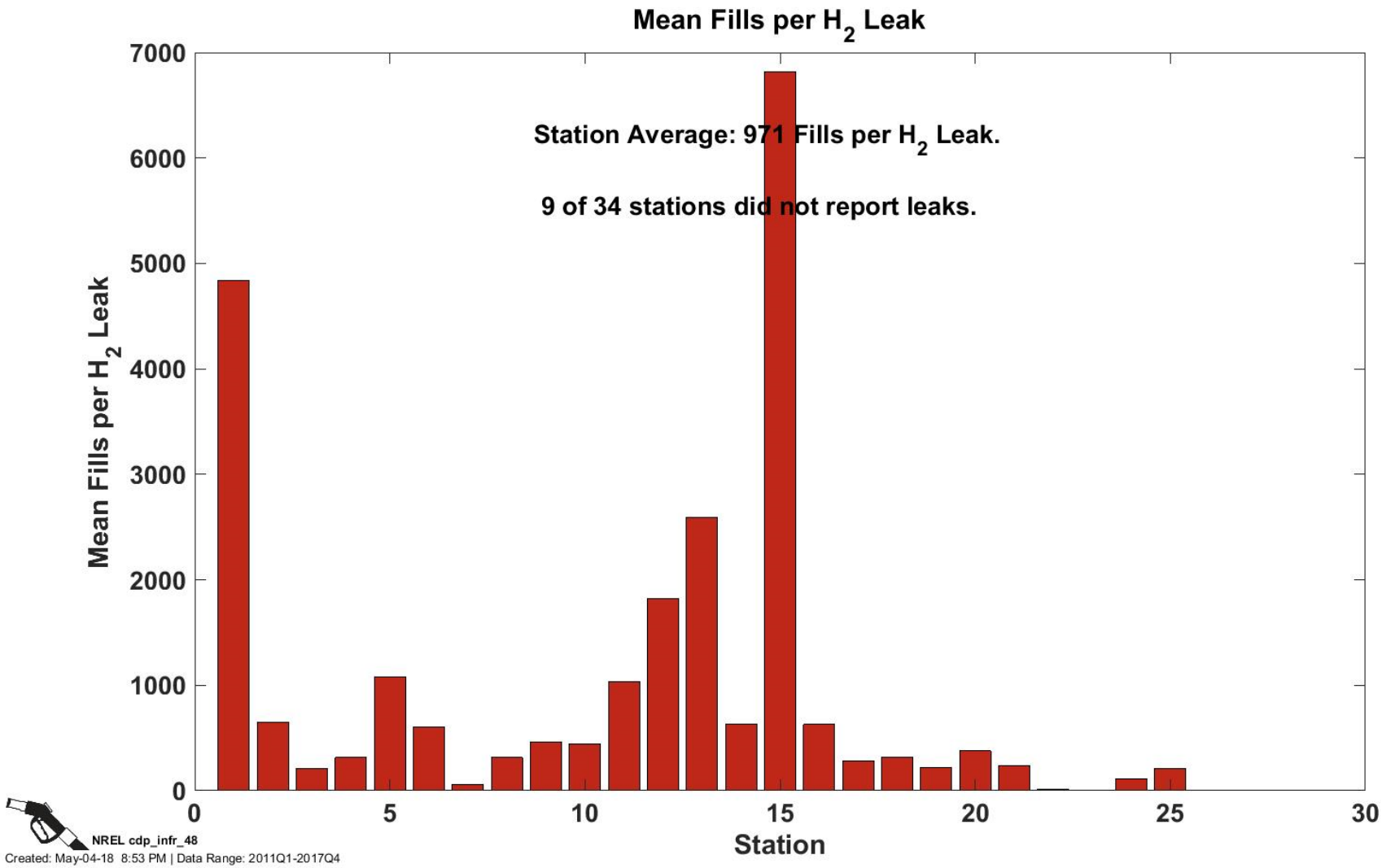
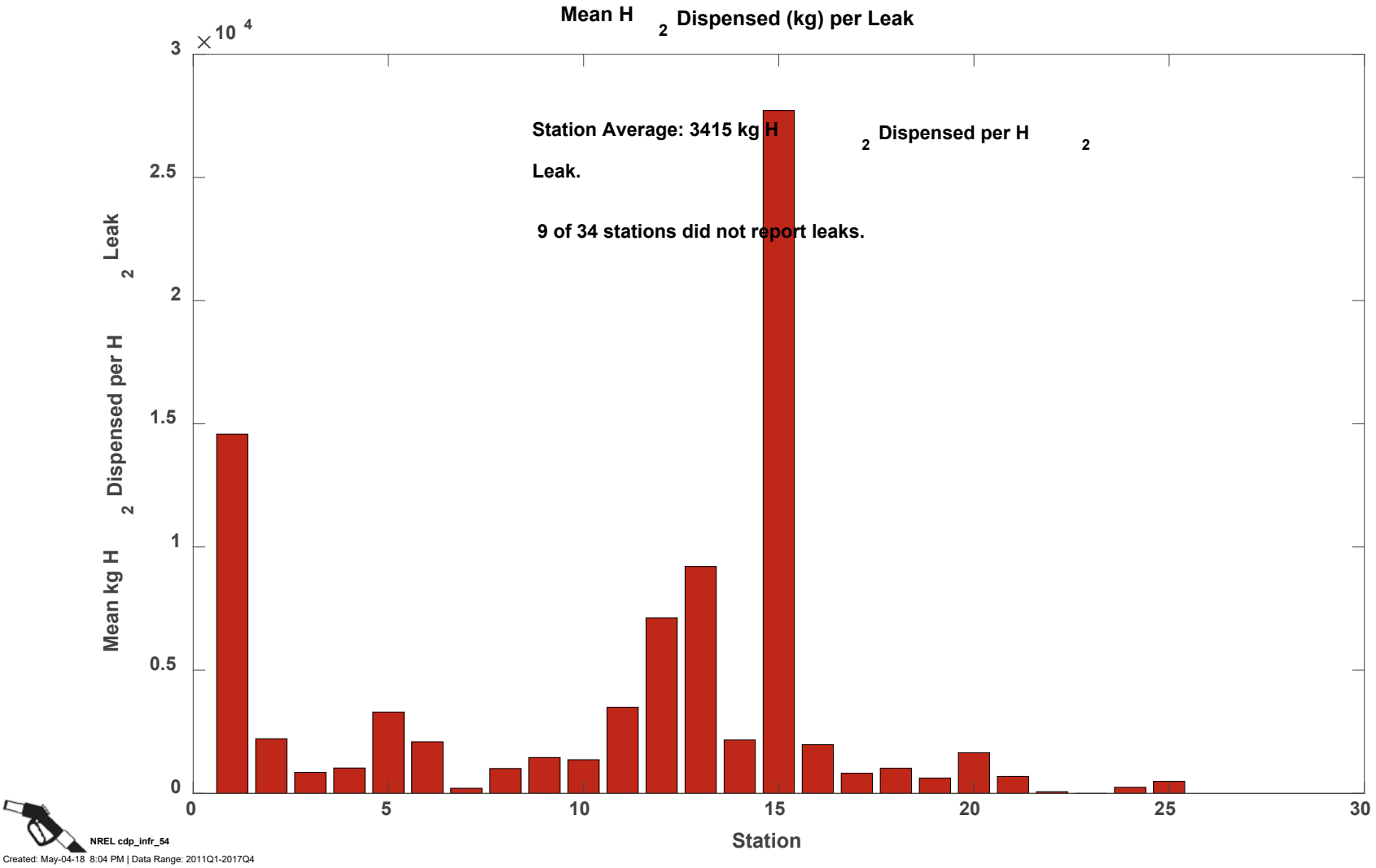
NREL cdp_infr_34

Created: May-15-18 5:41 PM | Data Range: 2008Q3-2017Q4

CDP-INFR-48
Mean Fills per Hydrogen Leak

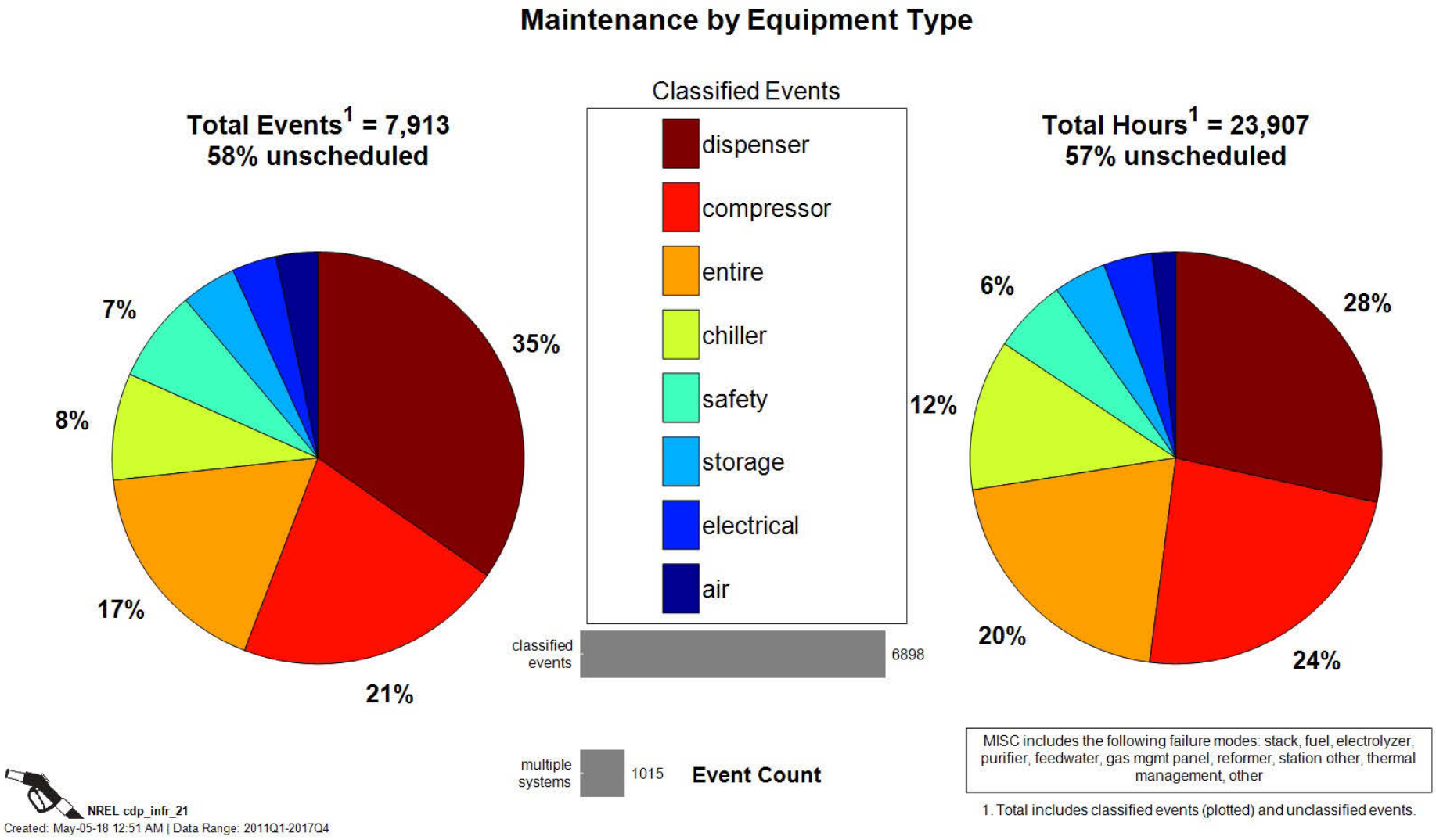


CDP-INFR-54
Mean Hydrogen Dispensed per Hydrogen Leak

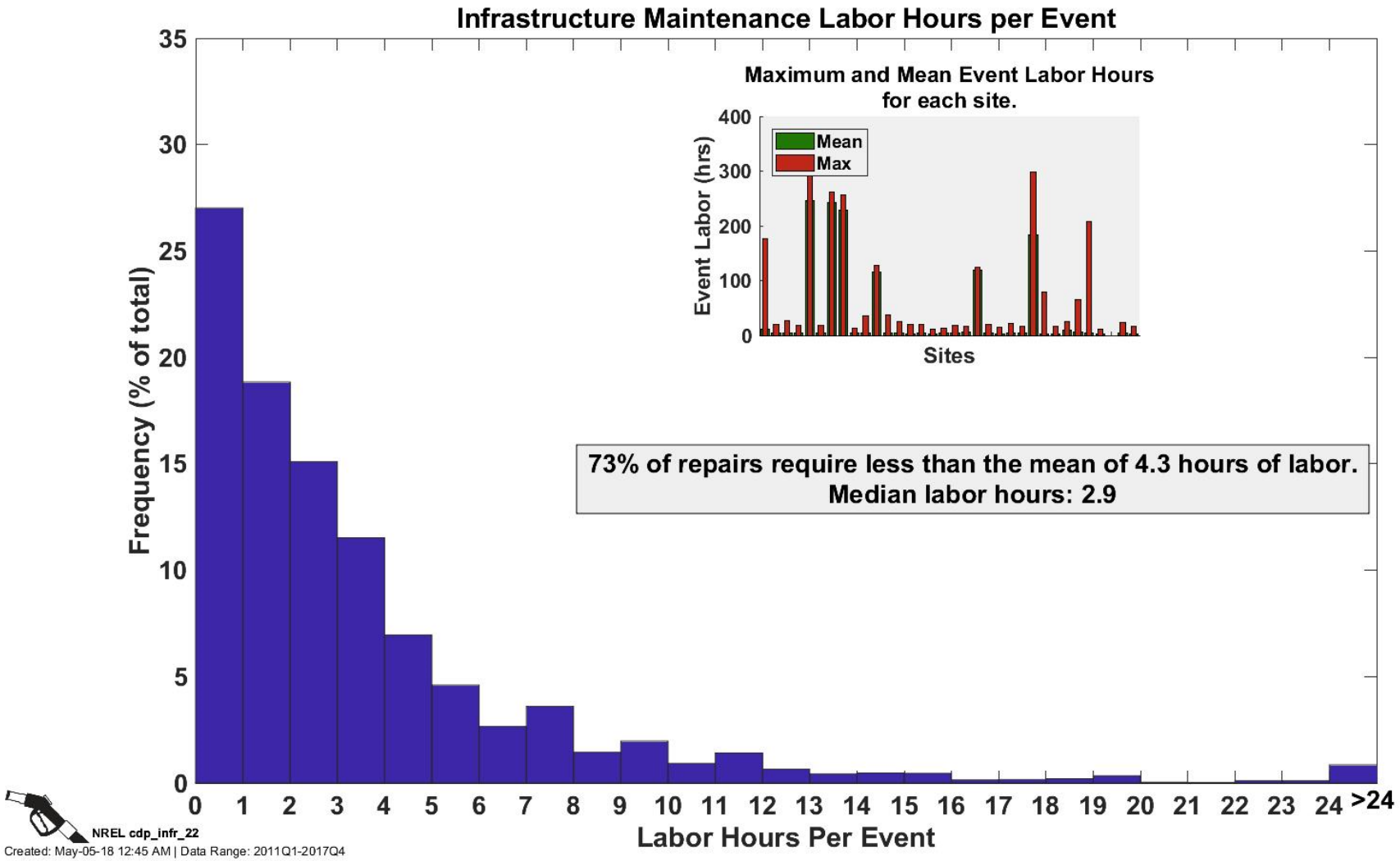


Maintenance and Reliability

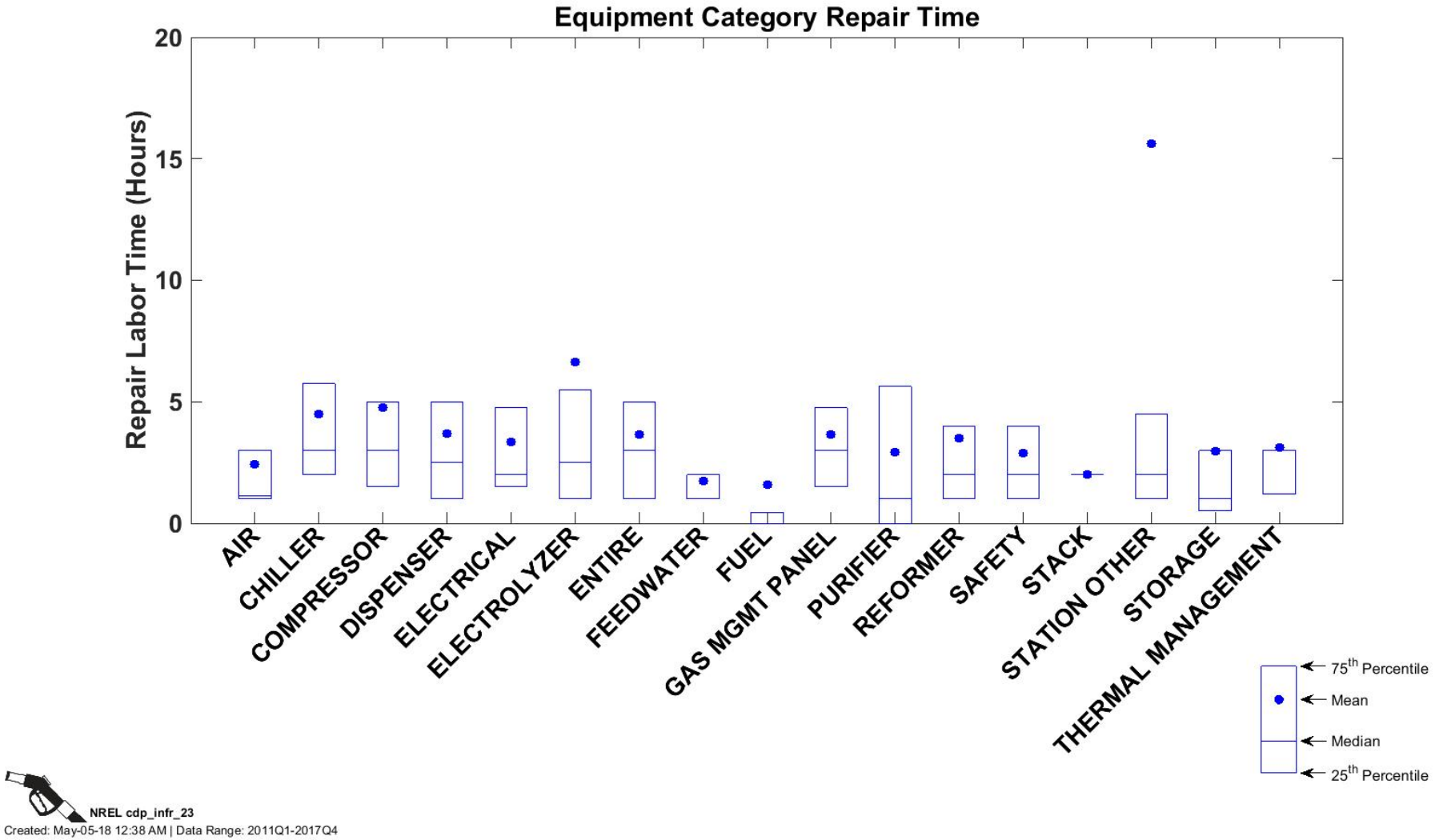
CDP-INFR-21
Maintenance by Equipment Type



CDP-INFR-22
Maintenance Labor Hours per Event

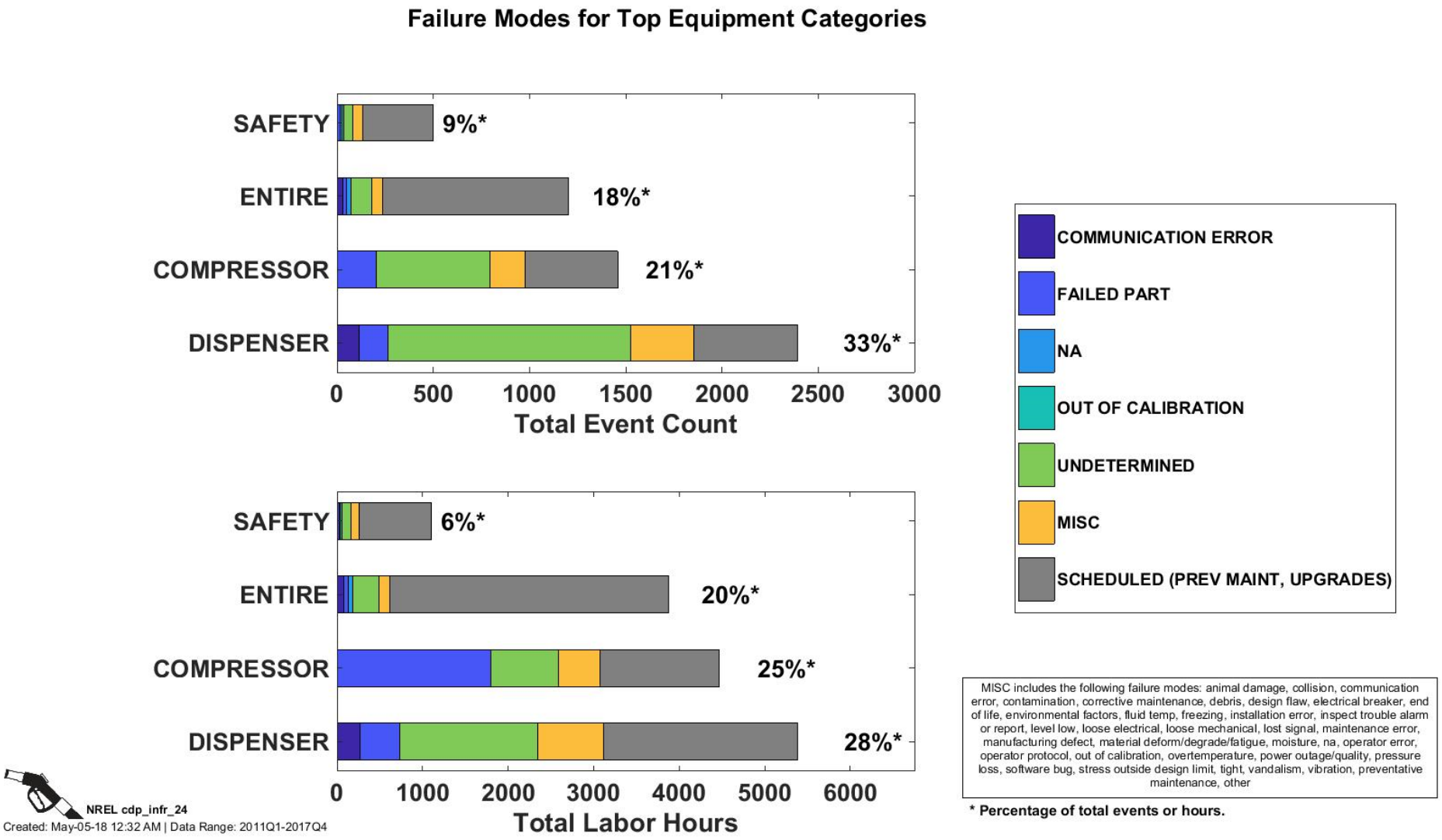


CDP-INFR-23
Equipment Category Repair Time



NREL cdp_infr_23
Created: May-05-18 12:38 AM | Data Range: 2011Q1-2017Q4

CDP-INFR-24
Failure Modes for Top Equipment Categories

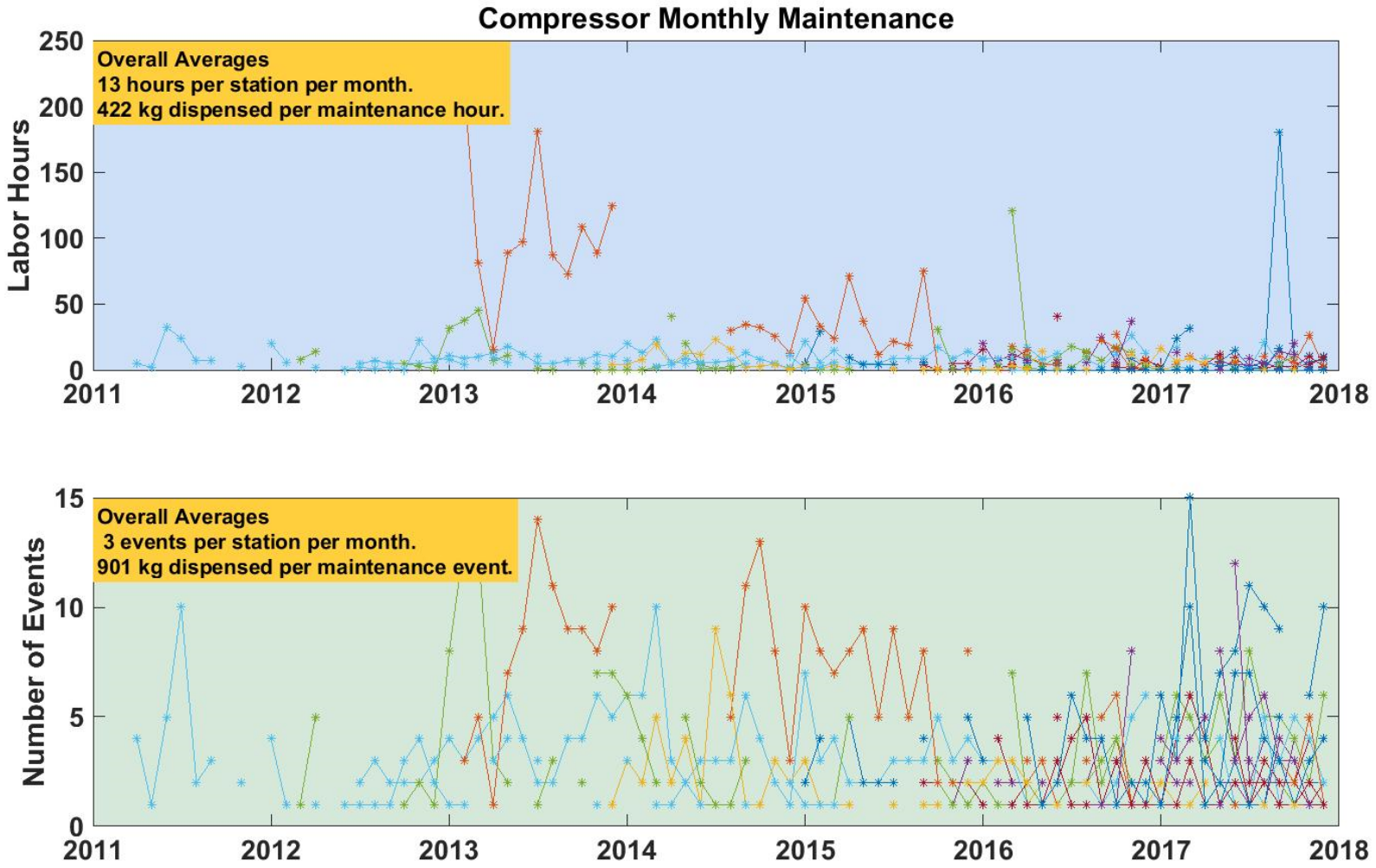


NREL cdp_infr_24
Created: May-05-18 12:32 AM | Data Range: 2011Q1-2017Q4

MISC includes the following failure modes: animal damage, collision, communication error, contamination, corrective maintenance, debris, design flaw, electrical breaker, end of life, environmental factors, fluid temp, freezing, installation error, inspect trouble alarm or report, level low, loose electrical, loose mechanical, lost signal, 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, stress outside design limit, tight, vandalism, vibration, preventative maintenance, other

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

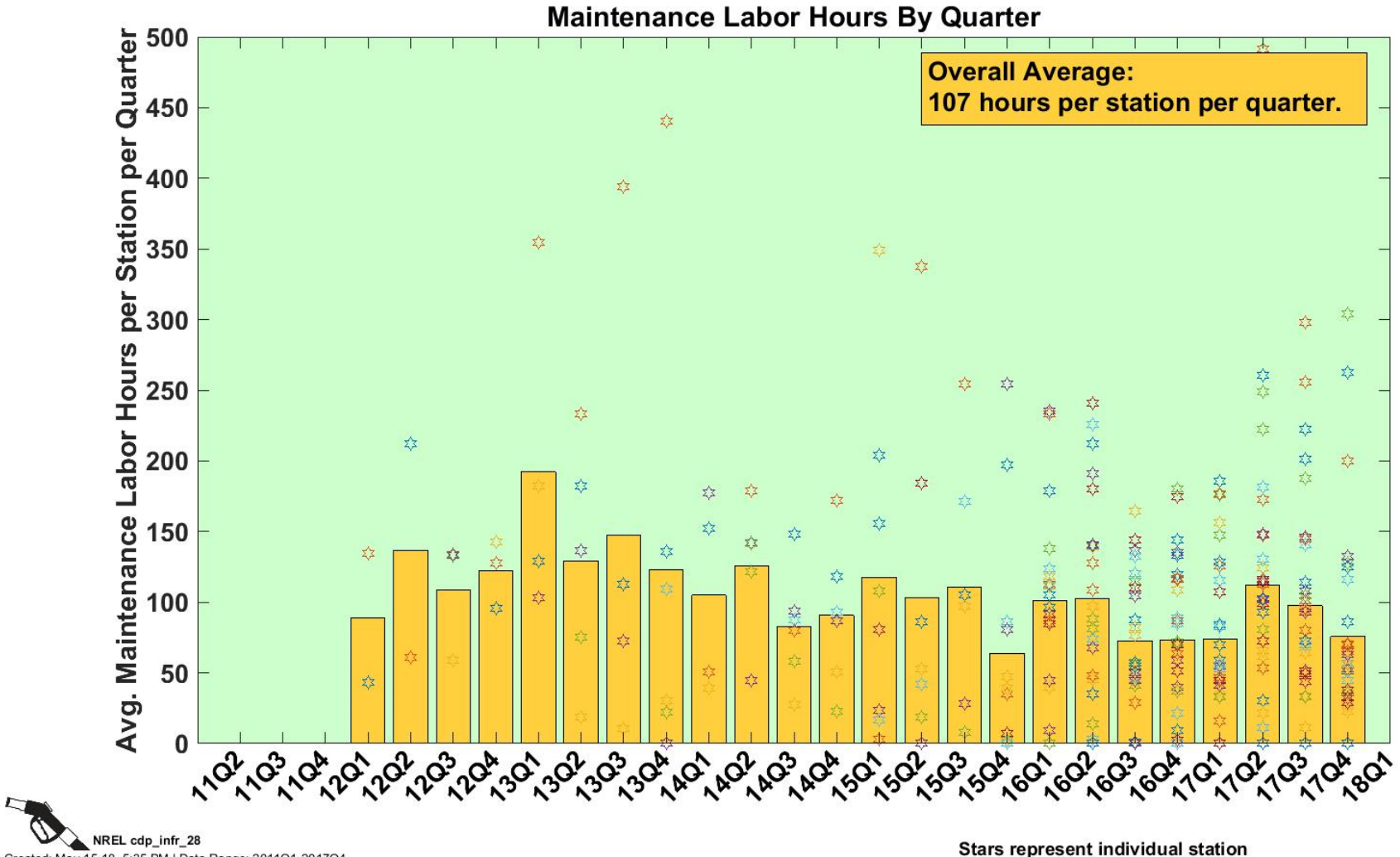
CDP-INFR-26
Compressor Monthly Maintenance



NREL cdp_infr_26
Created: May-16-18 8:16 AM | Data Range: 2011Q1-2017Q4

* 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



NREL cdp_infr_28
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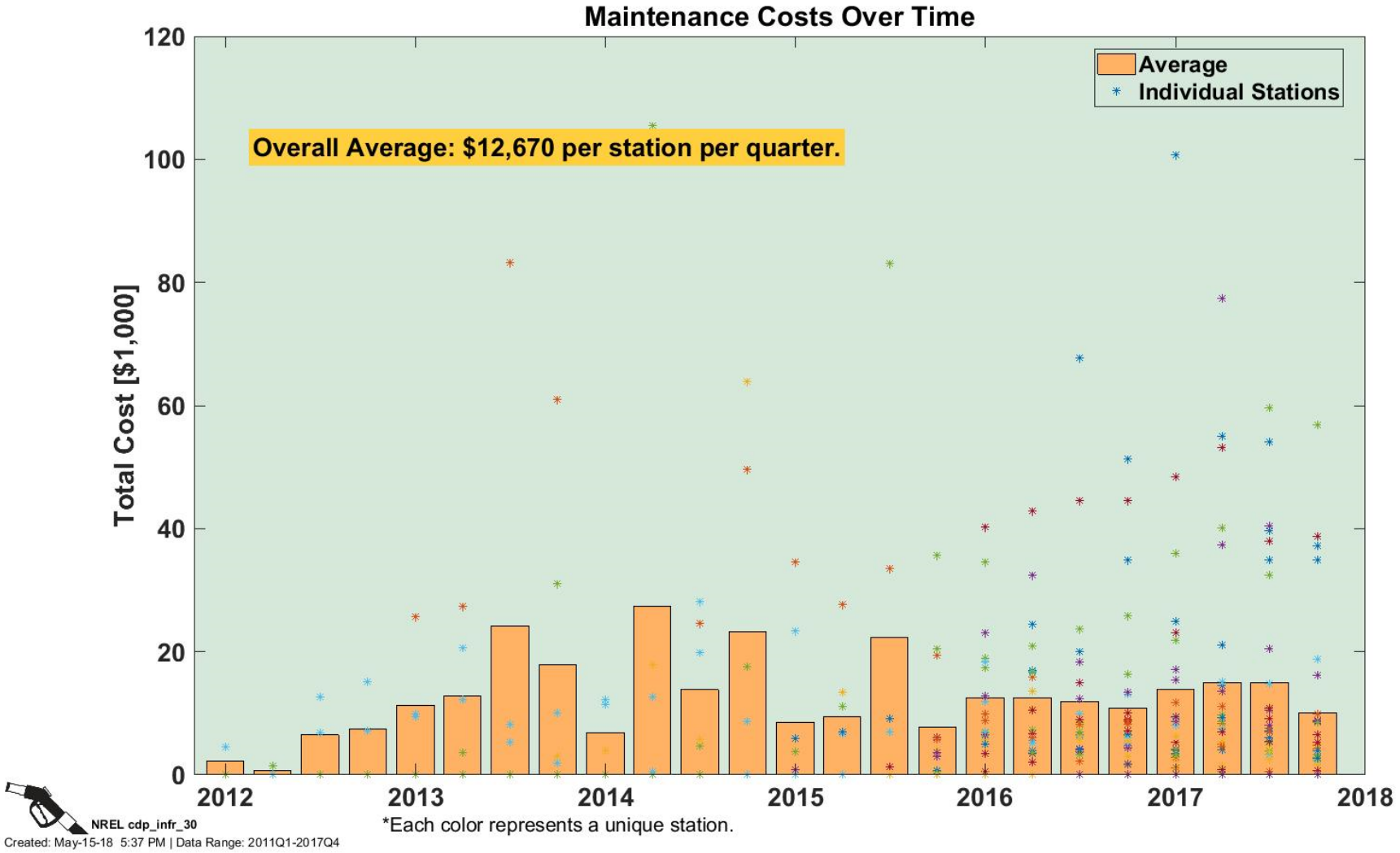
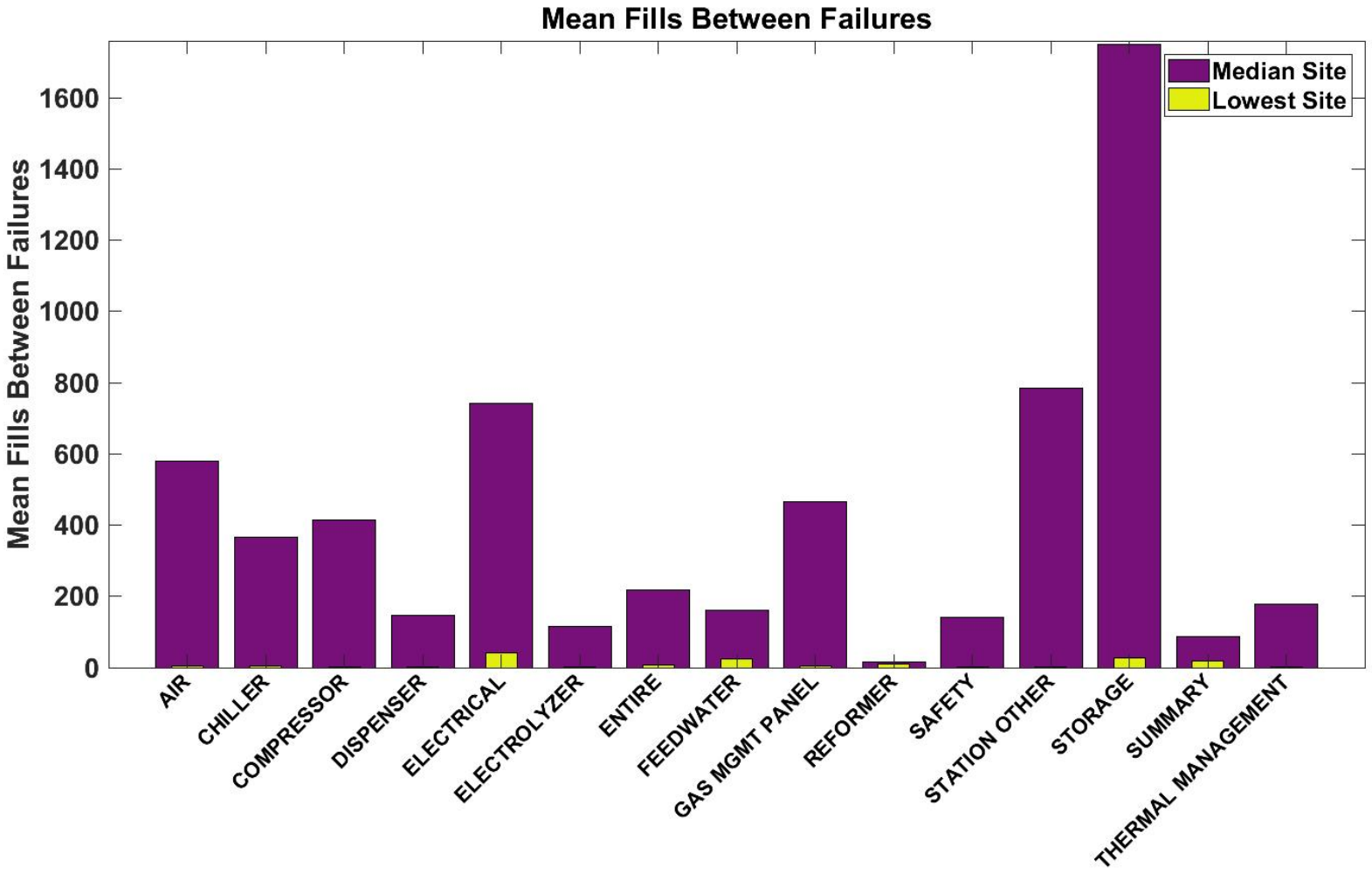
Stars represent individual station maintenance hours in a given quarter.

CDP-INFR-30
Maintenance Costs Over Time



CDP-INFR-49
Mean Fills Between Failures



NREL cdp_infr_49
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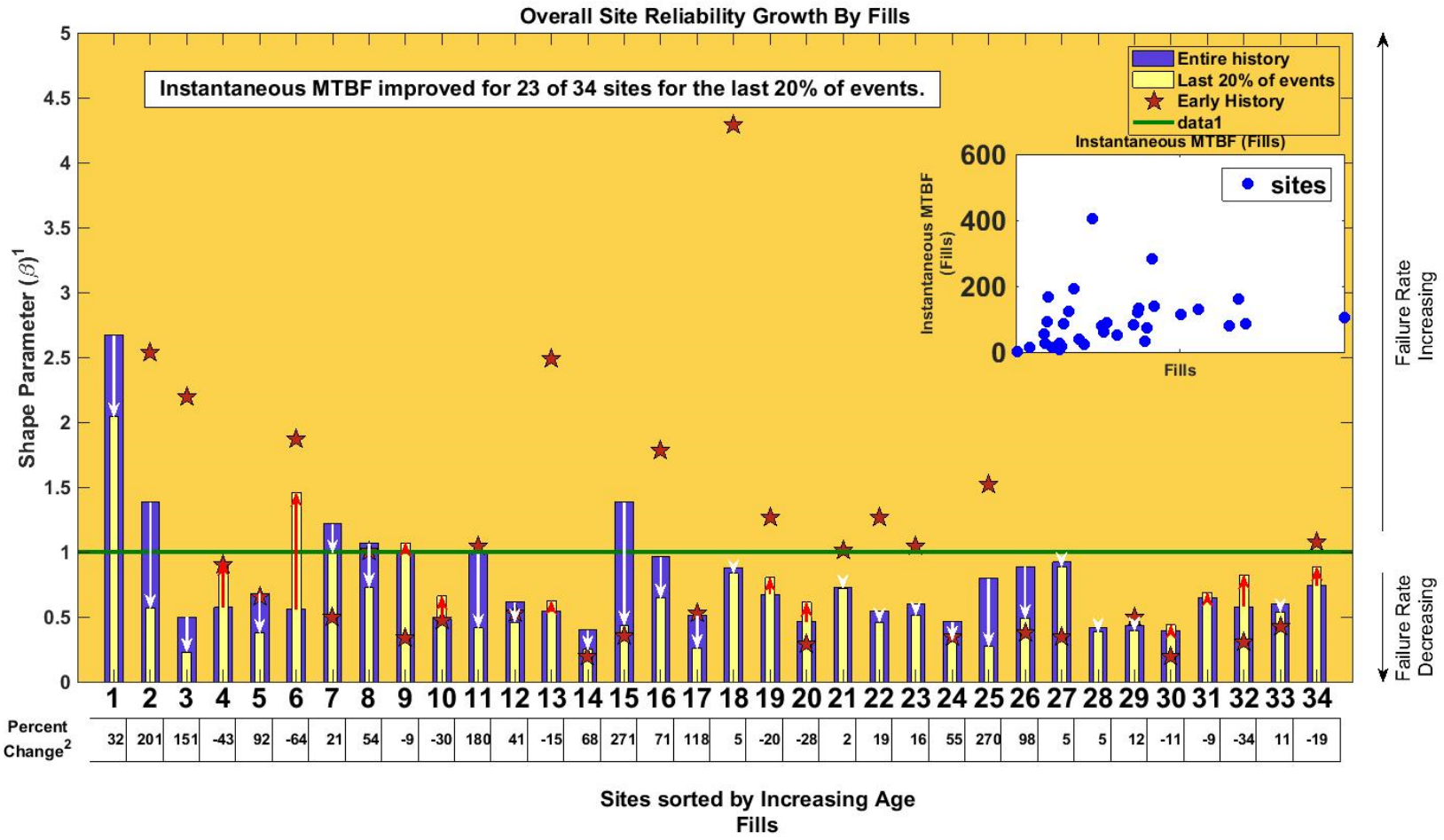
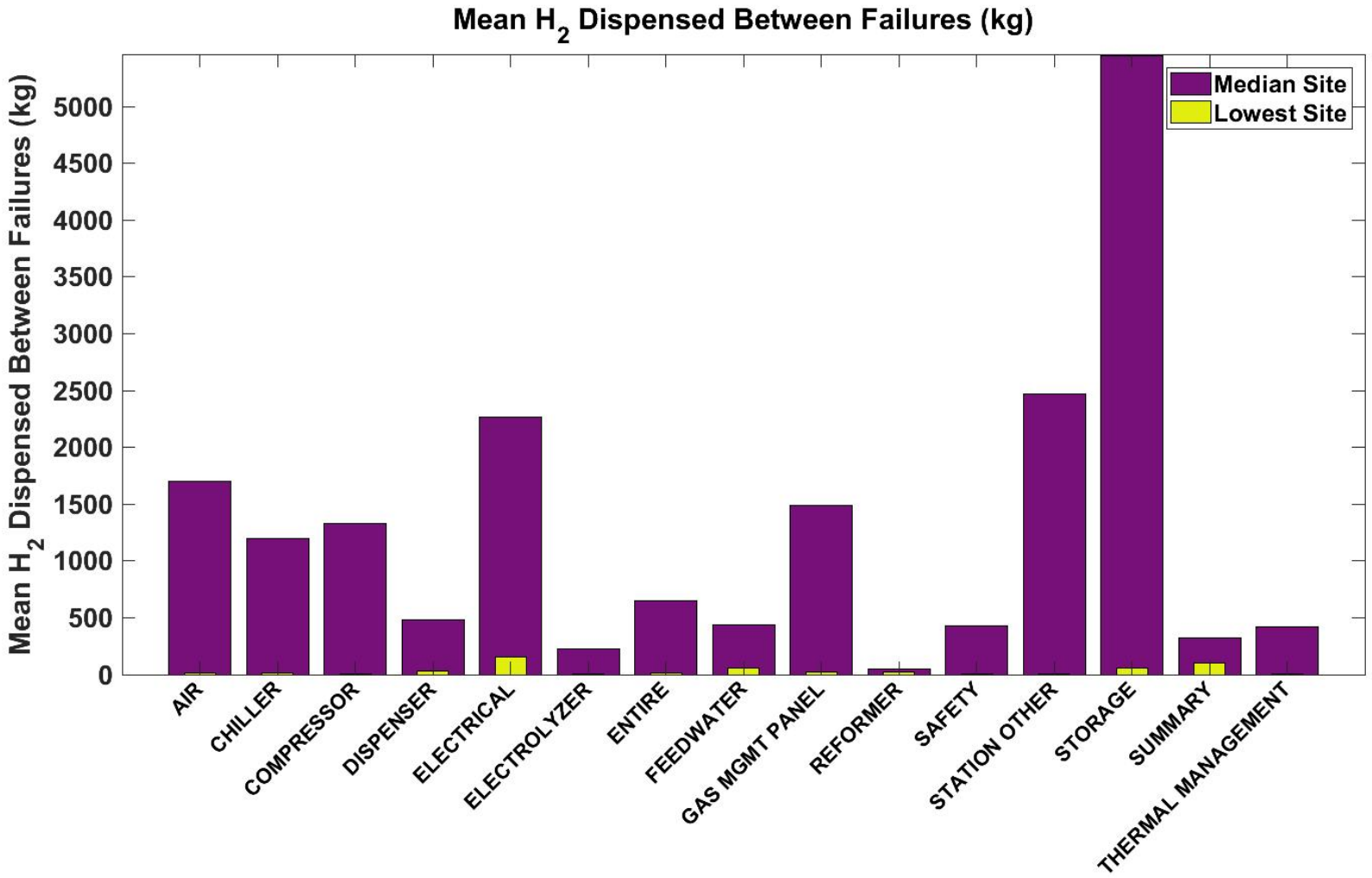
CDP-INFR-50
Reliability Growth by Fills



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

NREL cdp_infr_50
Created: May-04-18 8:34 PM | Data Range: 2011Q1-2017Q4

CDP-INFR-51
Mean Amount Dispensed Between Failures



NREL cdp_infr_51
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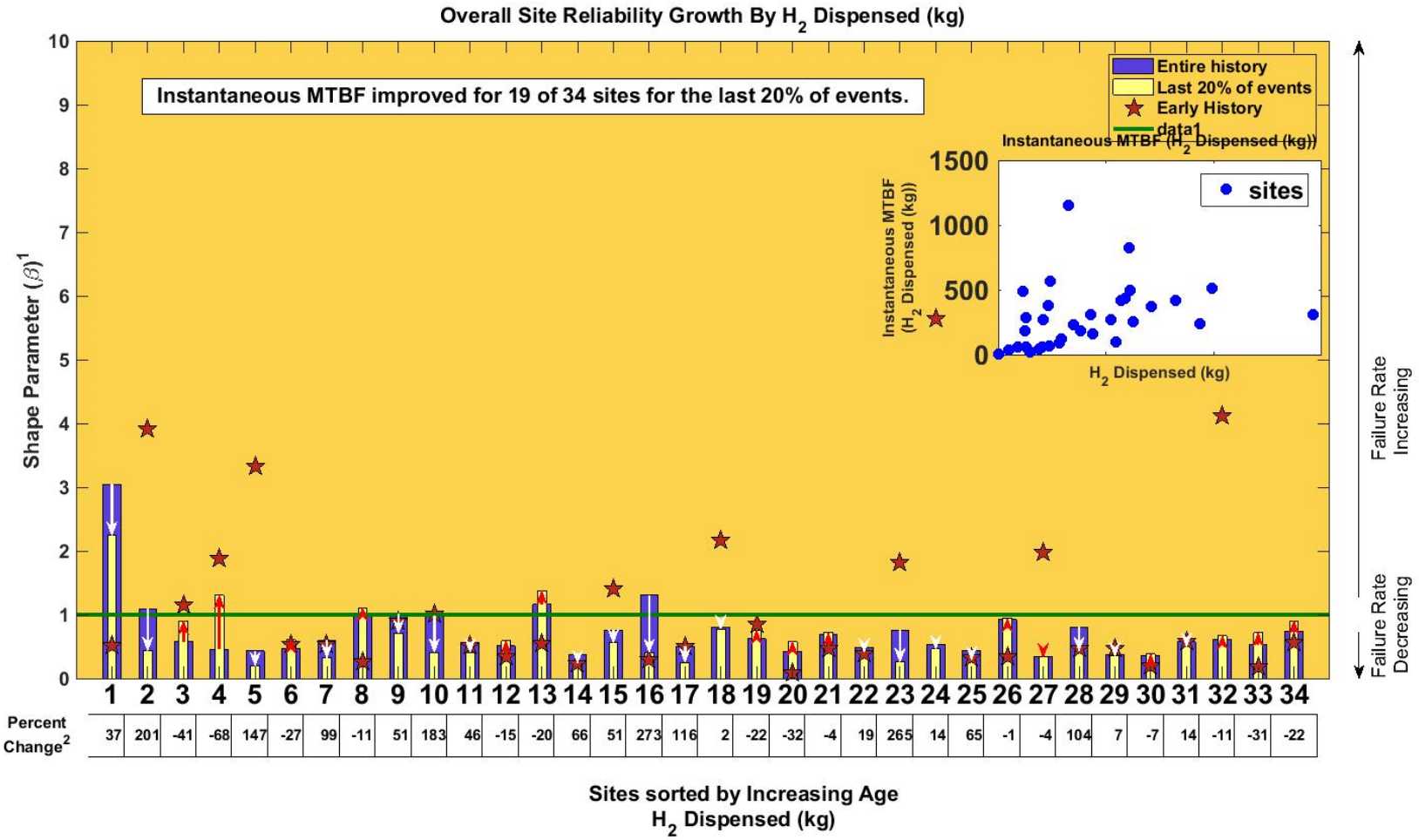
CDP-INFR-52
Reliability Growth by Amount Dispensed



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

NREL cdp_infr_52
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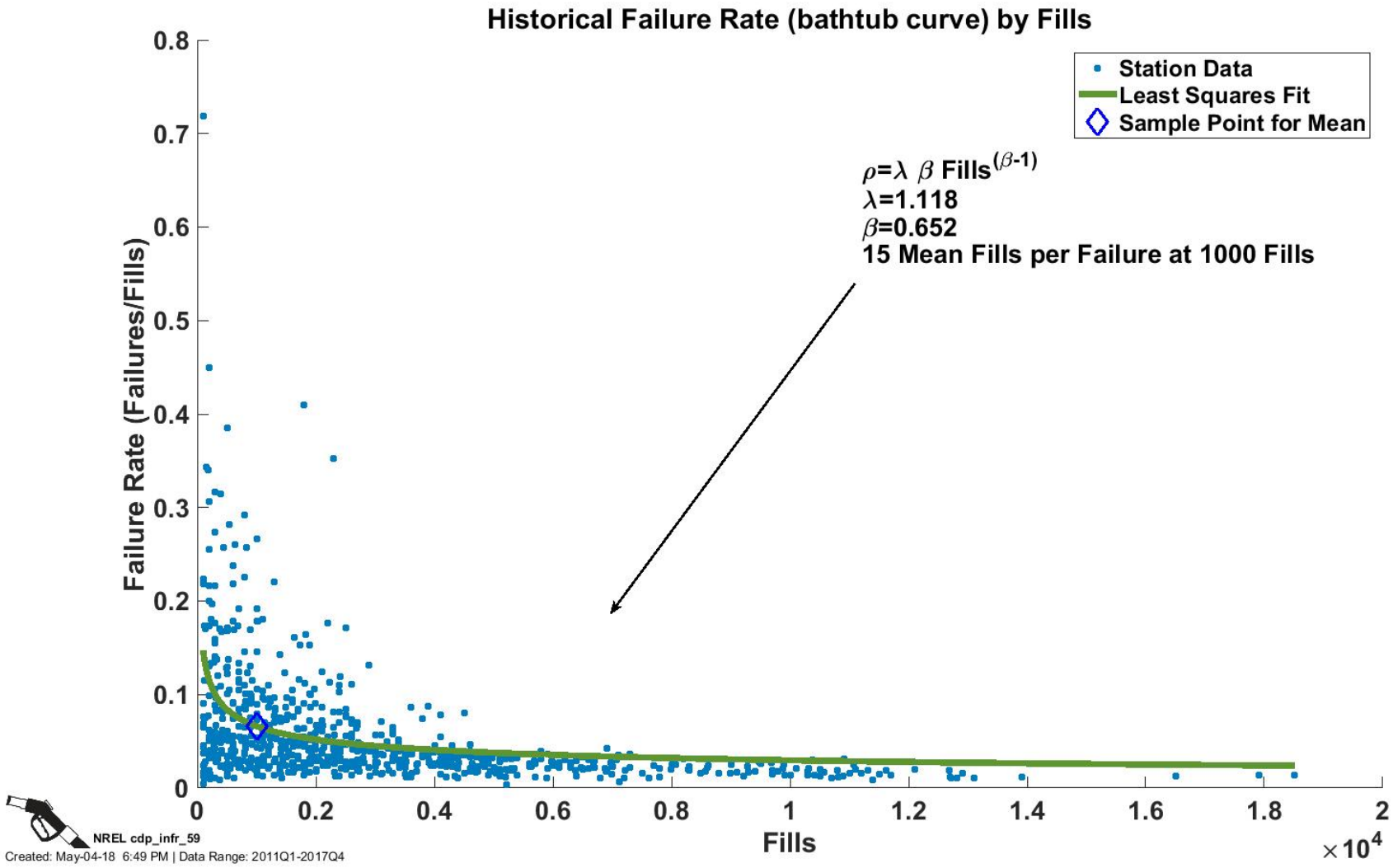
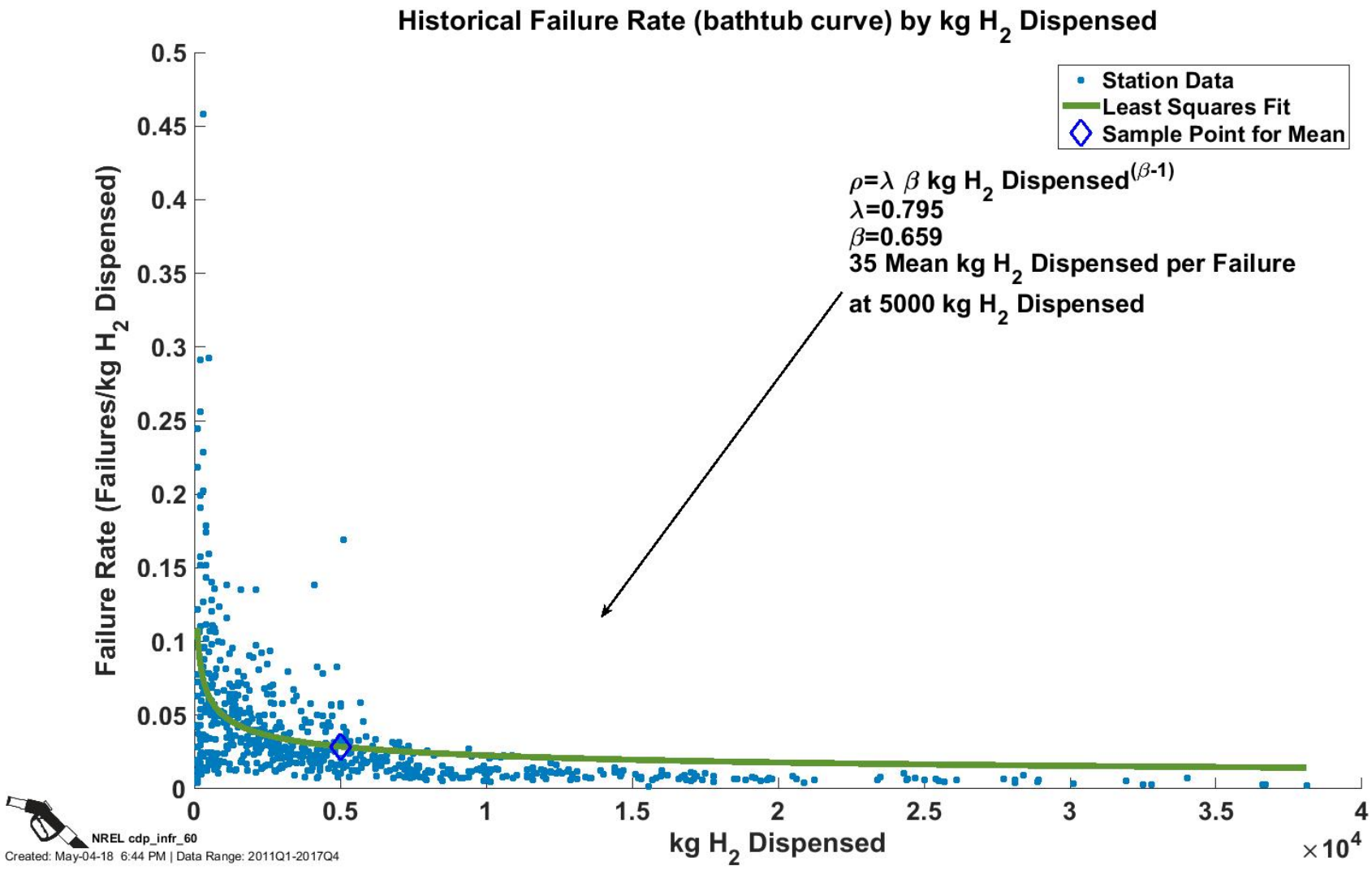
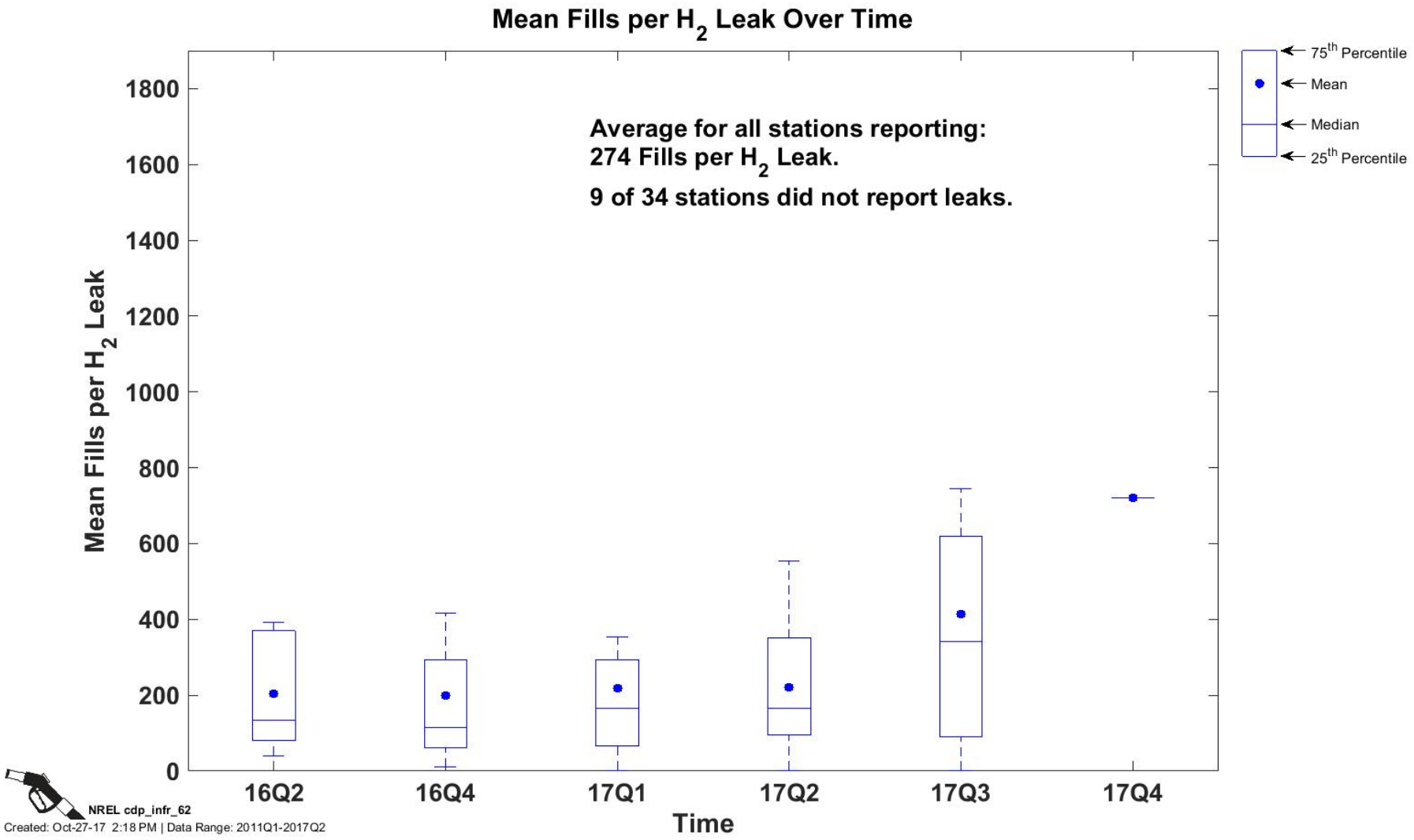
CDP-INFR-59
Historical Failure Rate by Fills



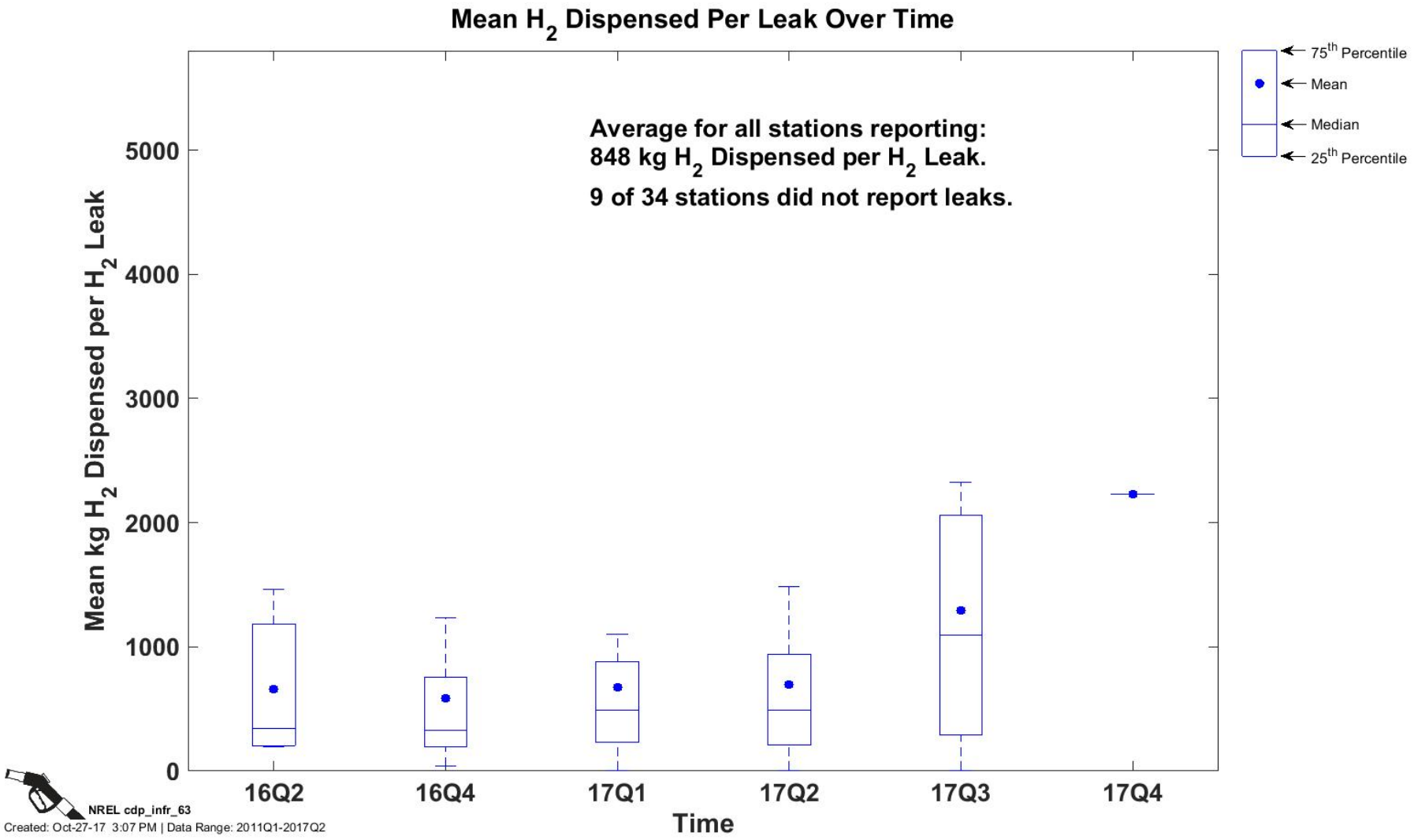
CDP-INFR-60
Historical Failure Rate by Amount Dispensed



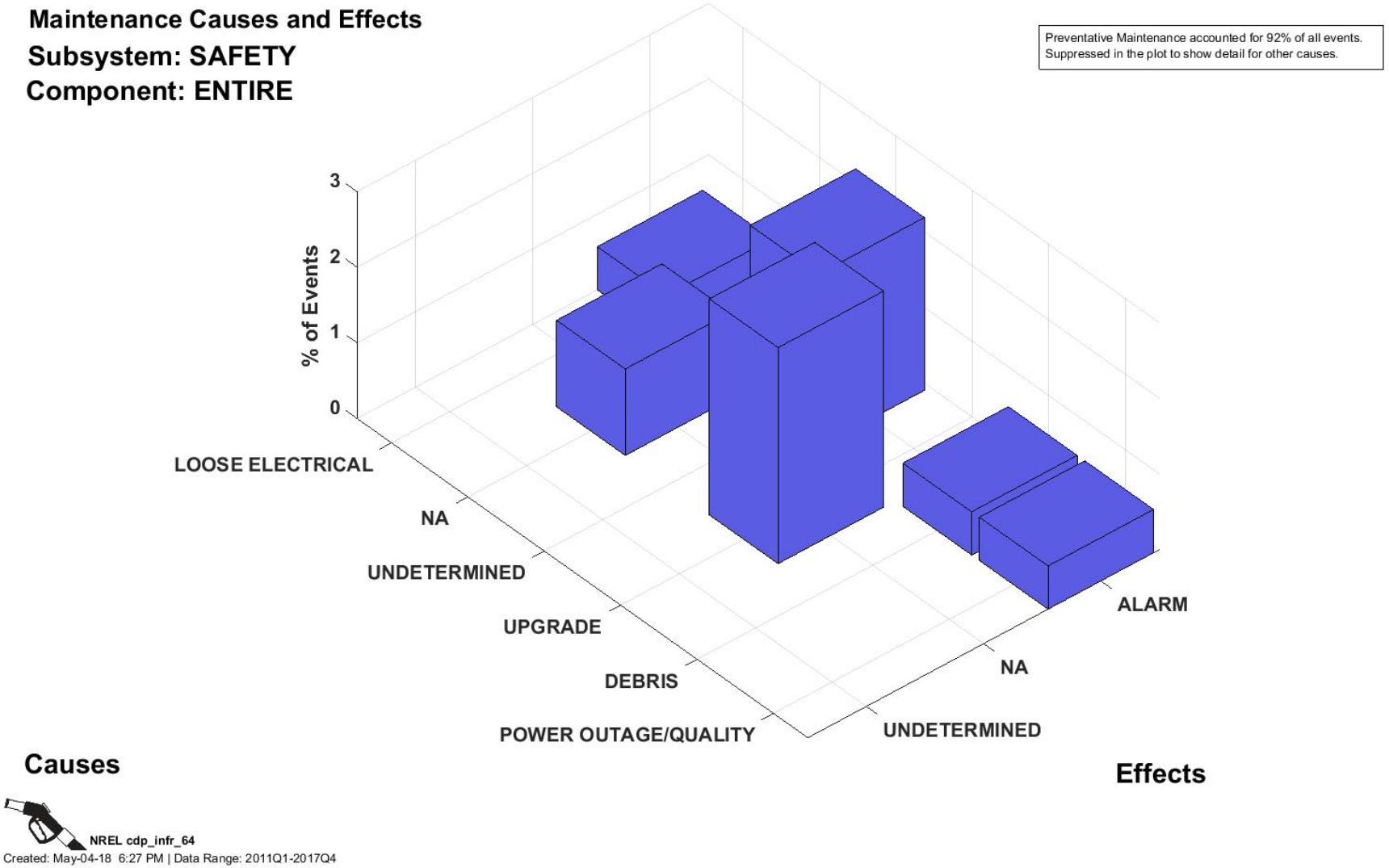
CDP-INFR-62
Mean Fills per Hydrogen Leak Over Time



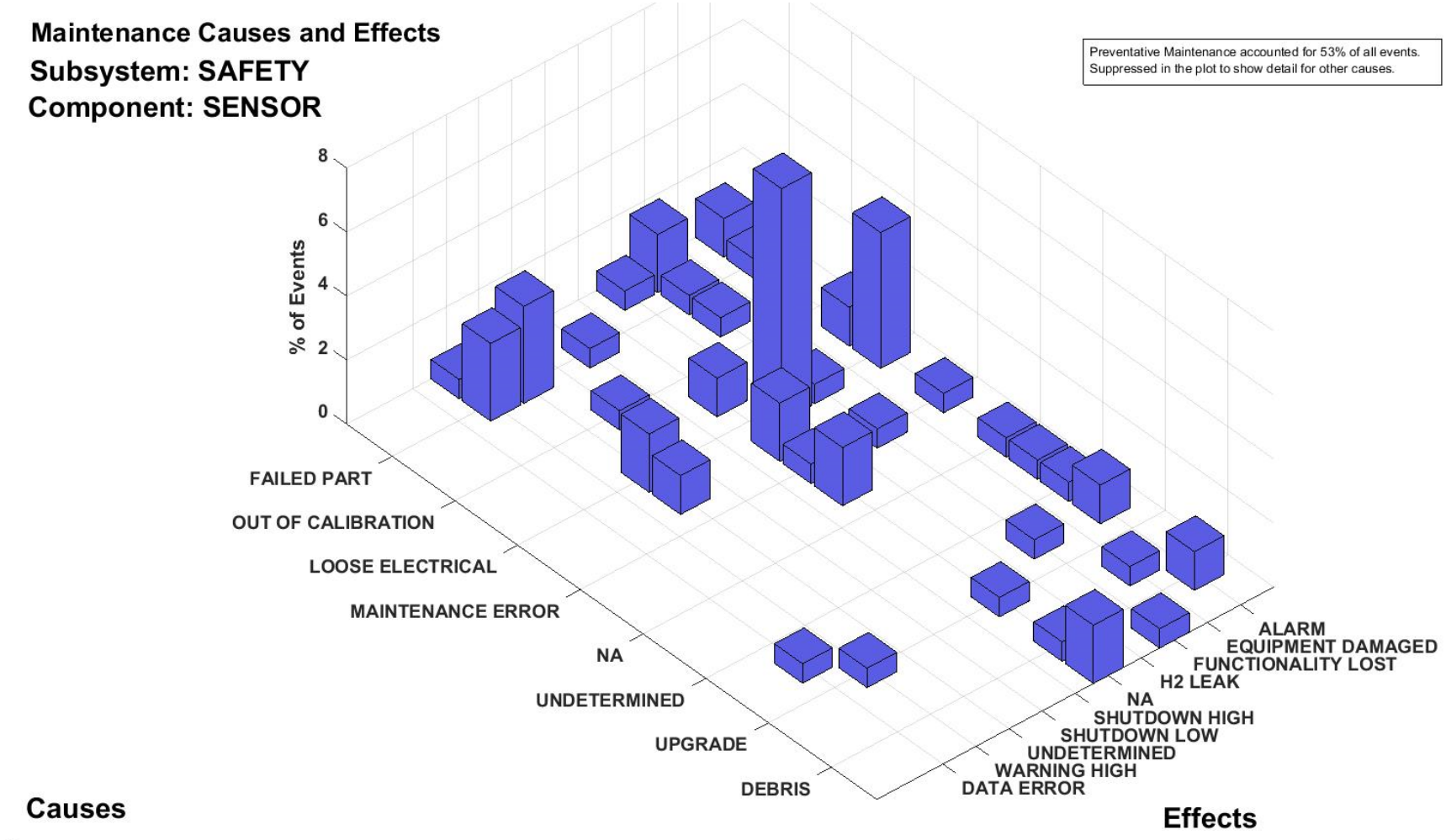
CDP-INFR-63
Mean Hydrogen Dispensed per Leak Over Time



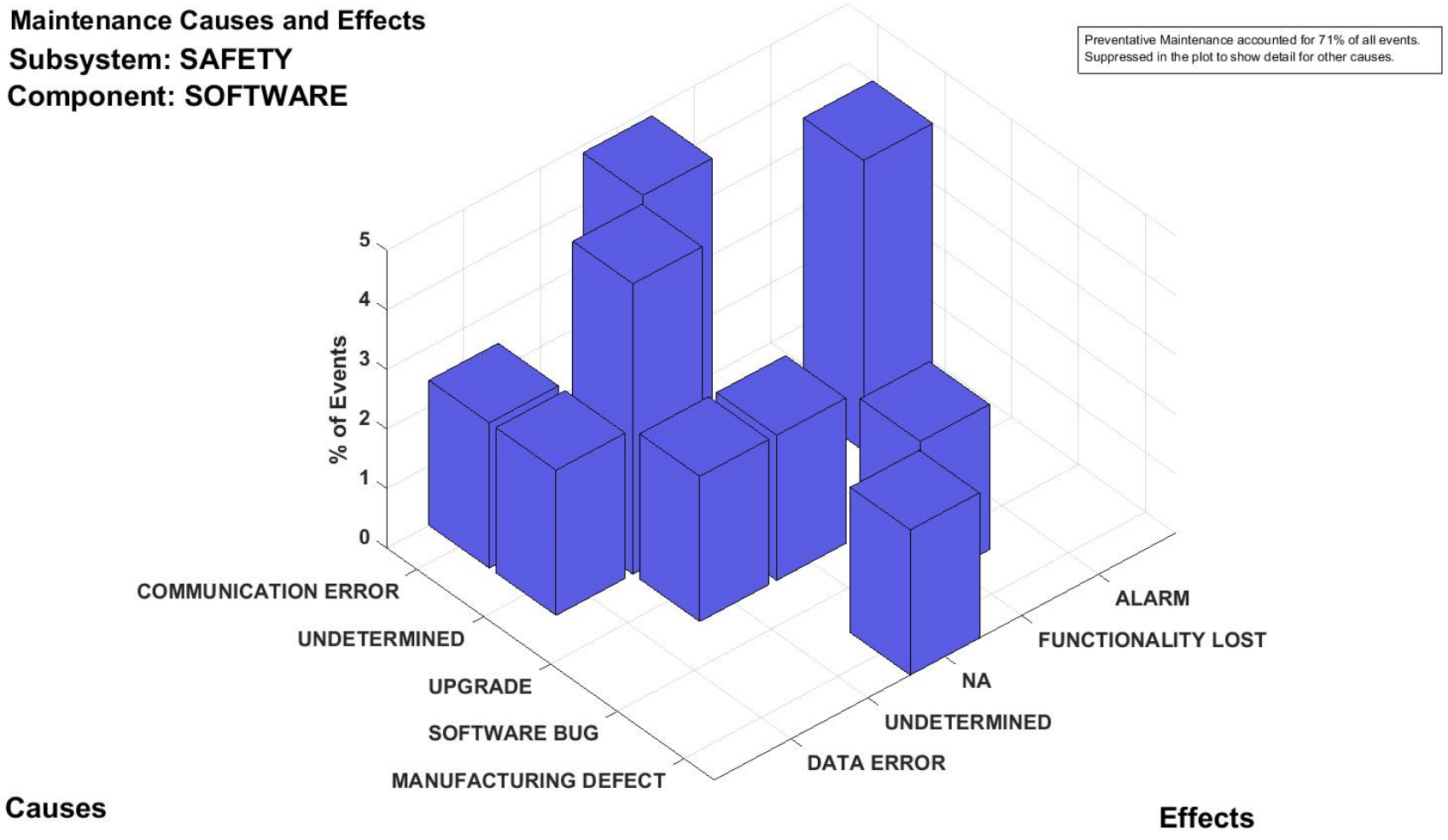
CDP-INFR-64
Maintenance Causes and Effects: Safety (Entire)



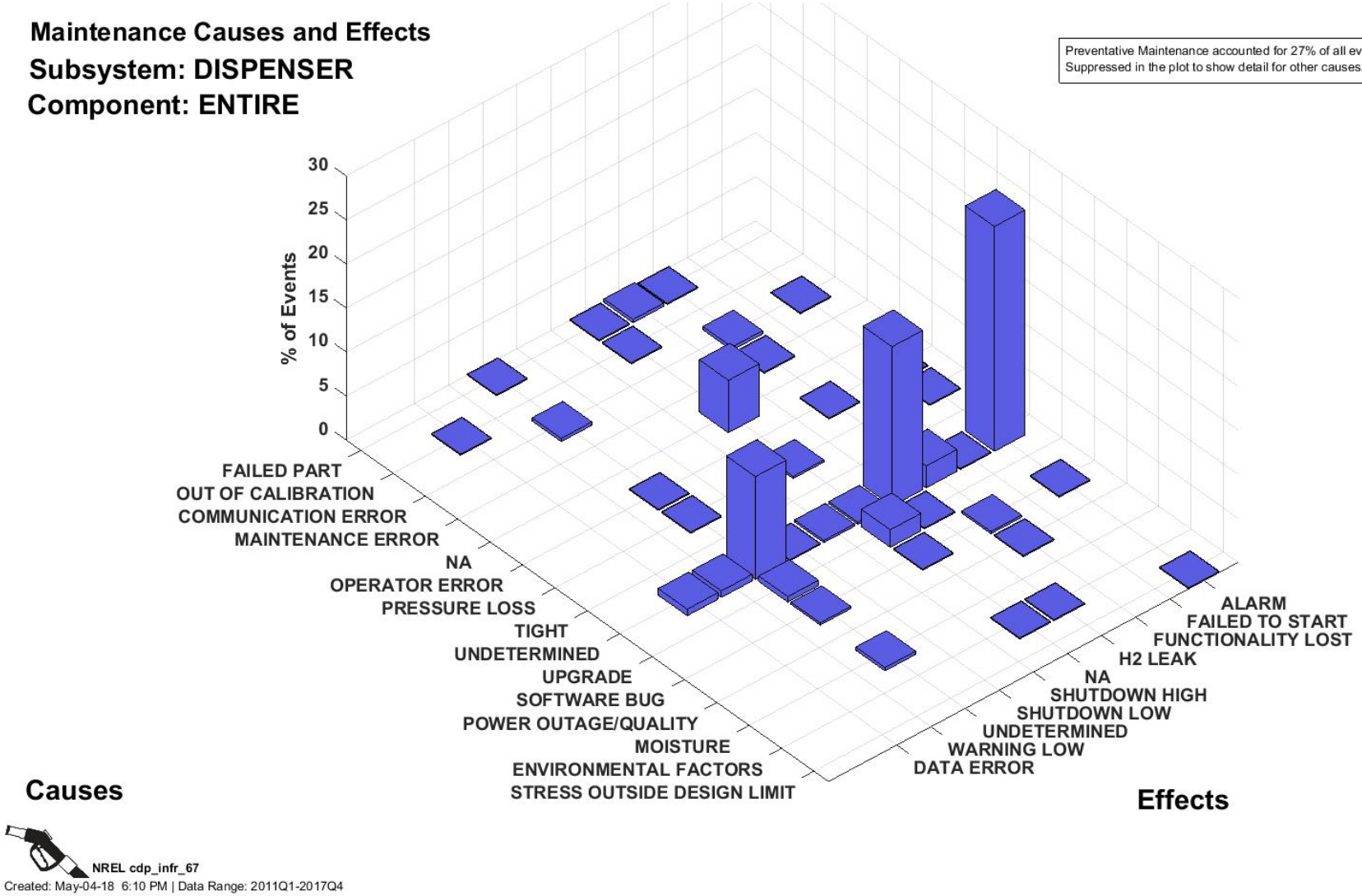
CDP-INFR-65
Maintenance Causes and Effects: Safety (Sensor)



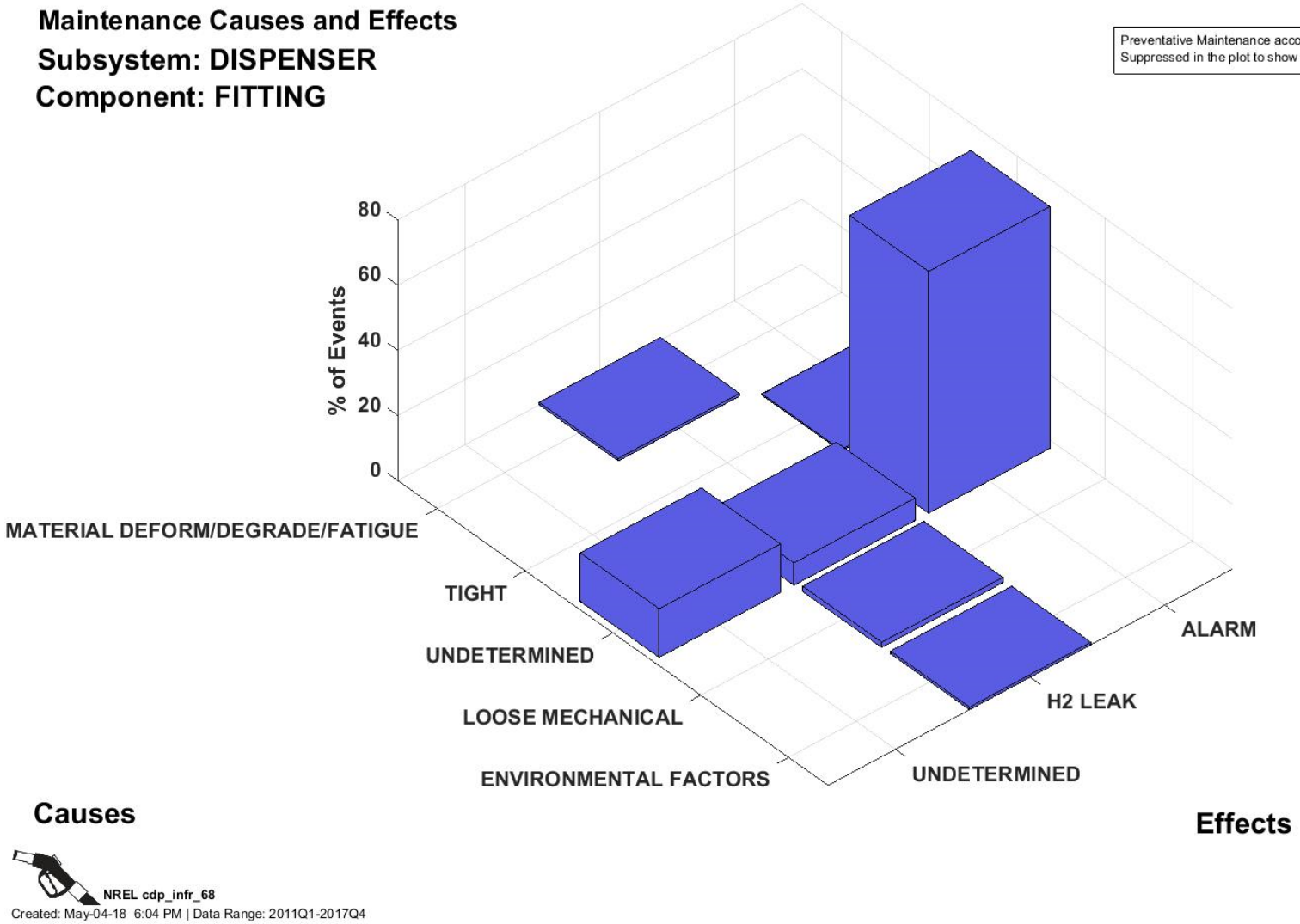
CDP-INFR-66
Maintenance Causes and Effects: Safety (Software)



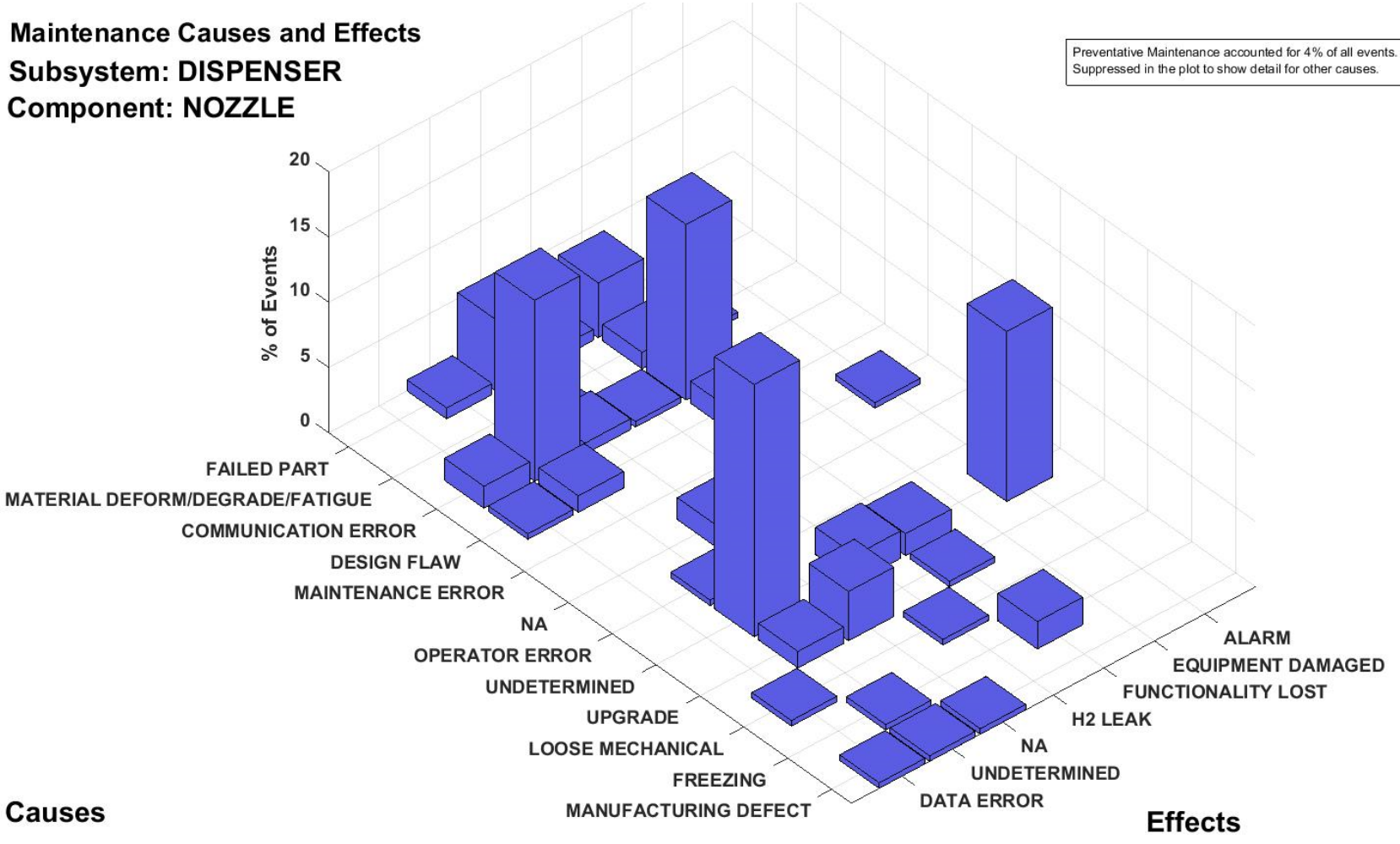
CDP-INFR-67
Maintenance Causes and Effects: Dispenser (Entire)



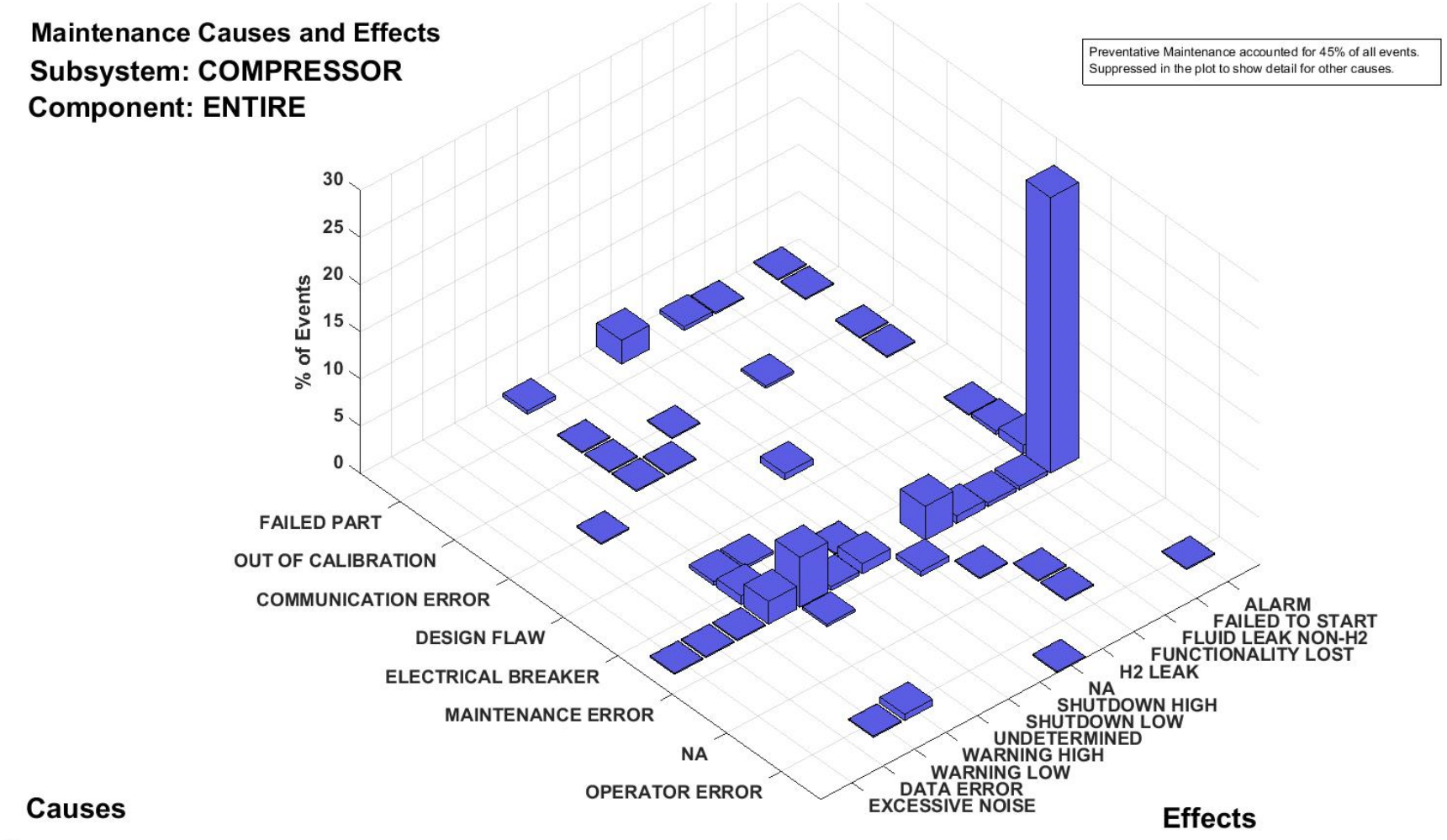
CDP-INFR-68
Maintenance Causes and Effects: Dispenser (Fitting)



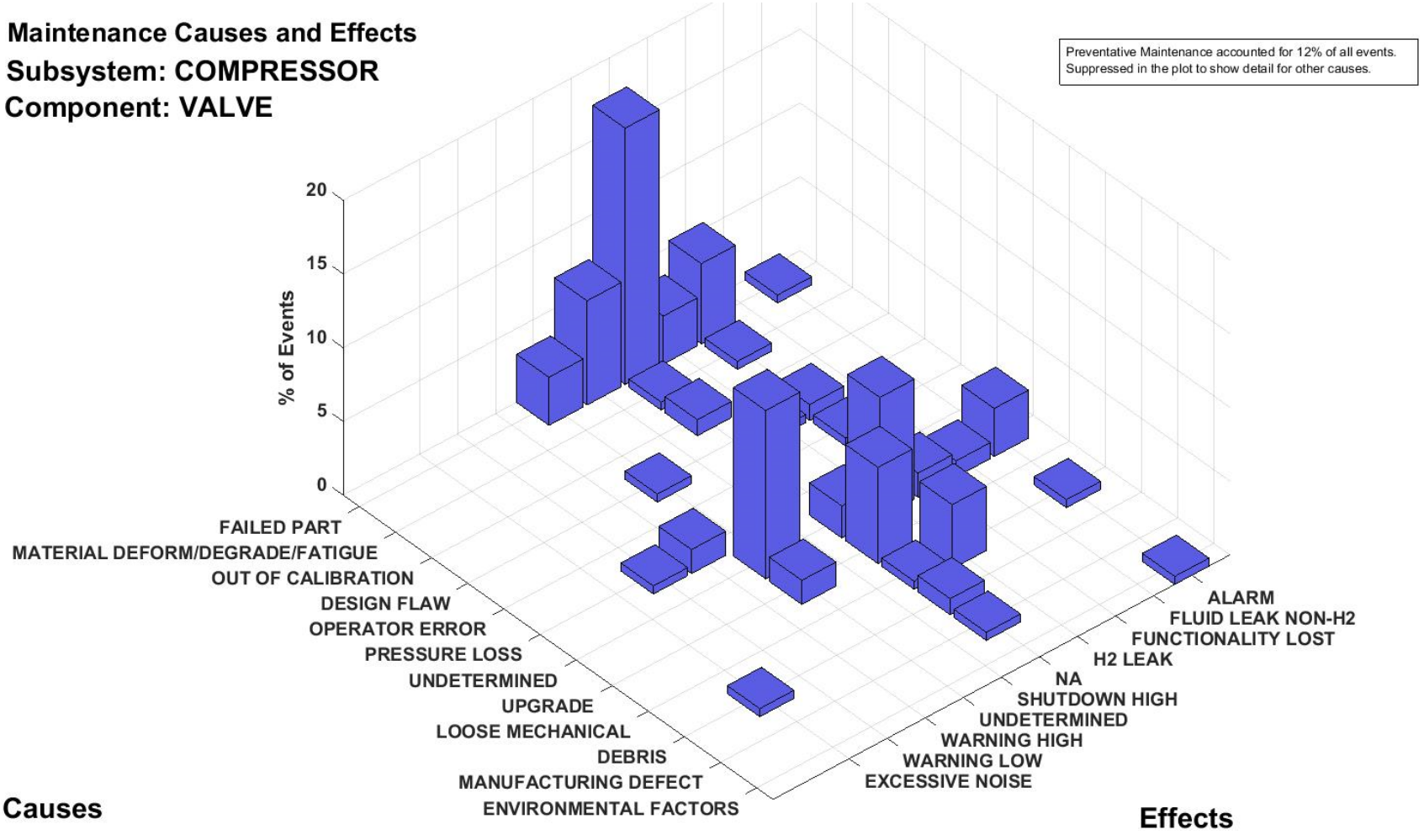
CDP-INFR-69
Maintenance Causes and Effects: Dispenser (Nozzle)



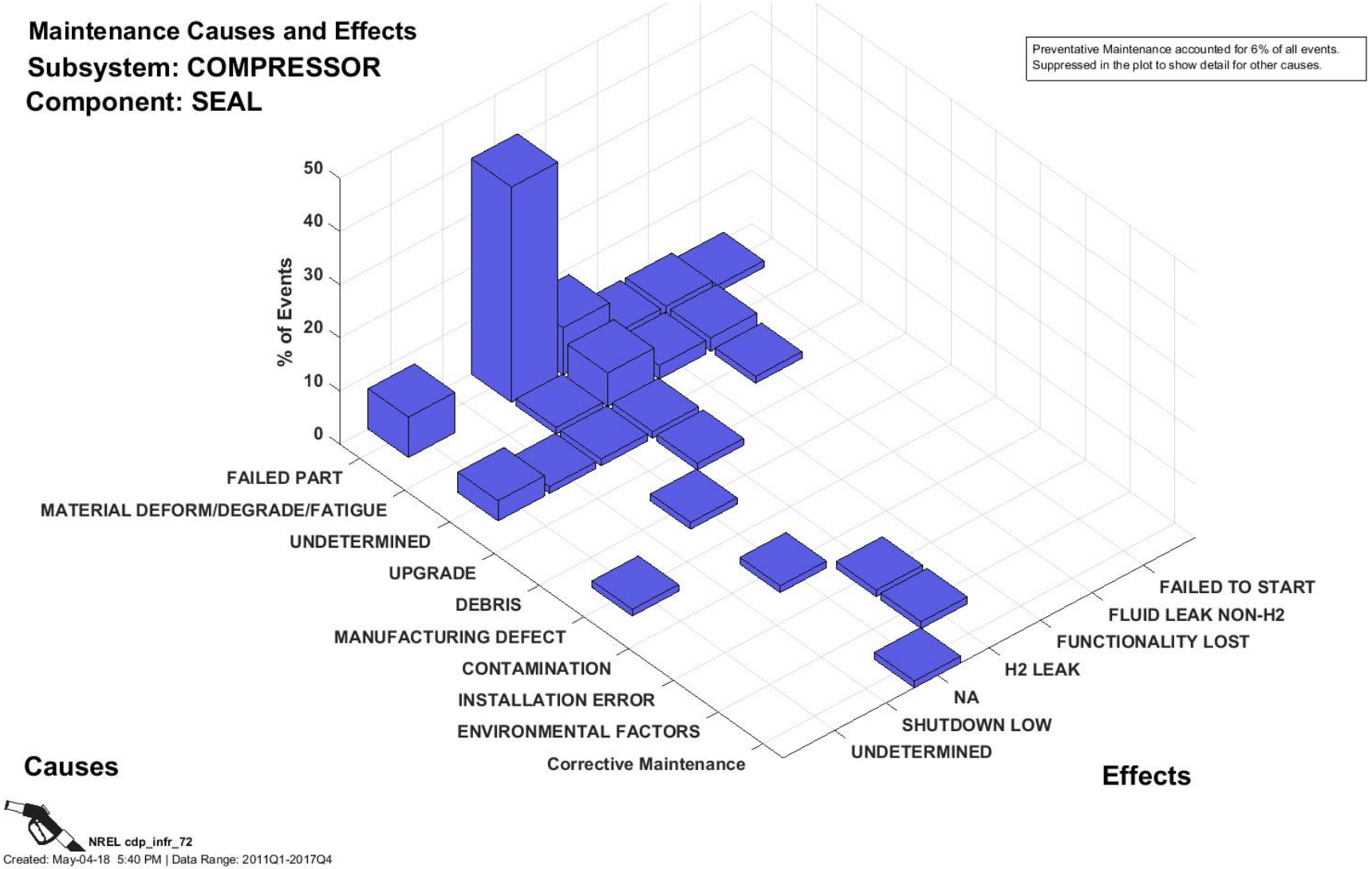
CDP-INFR-70
Maintenance Causes and Effects: Compressor (Entire)



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

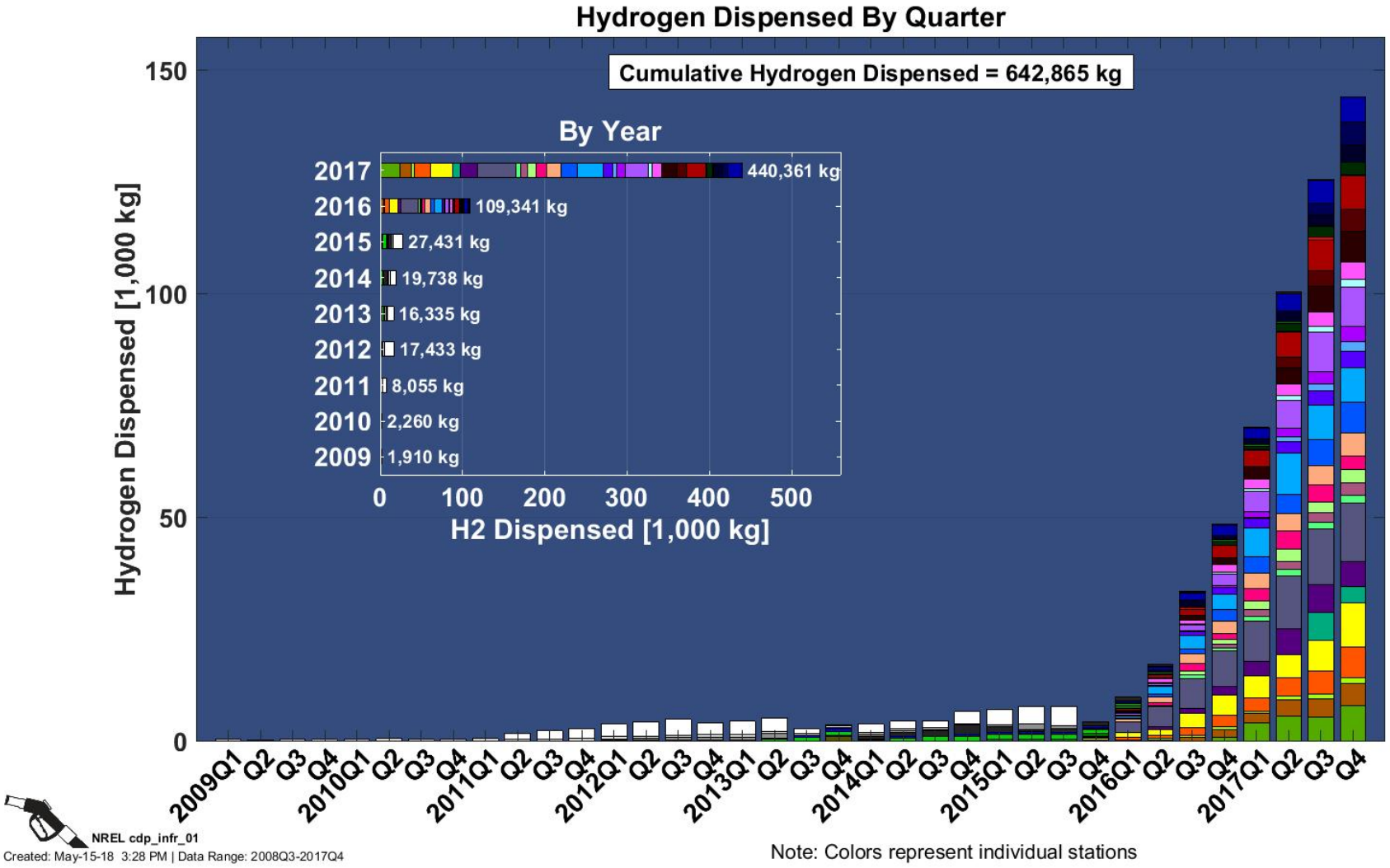


CDP-INFR-72
Maintenance Causes and Effects: Compressor (Seal)



Performance

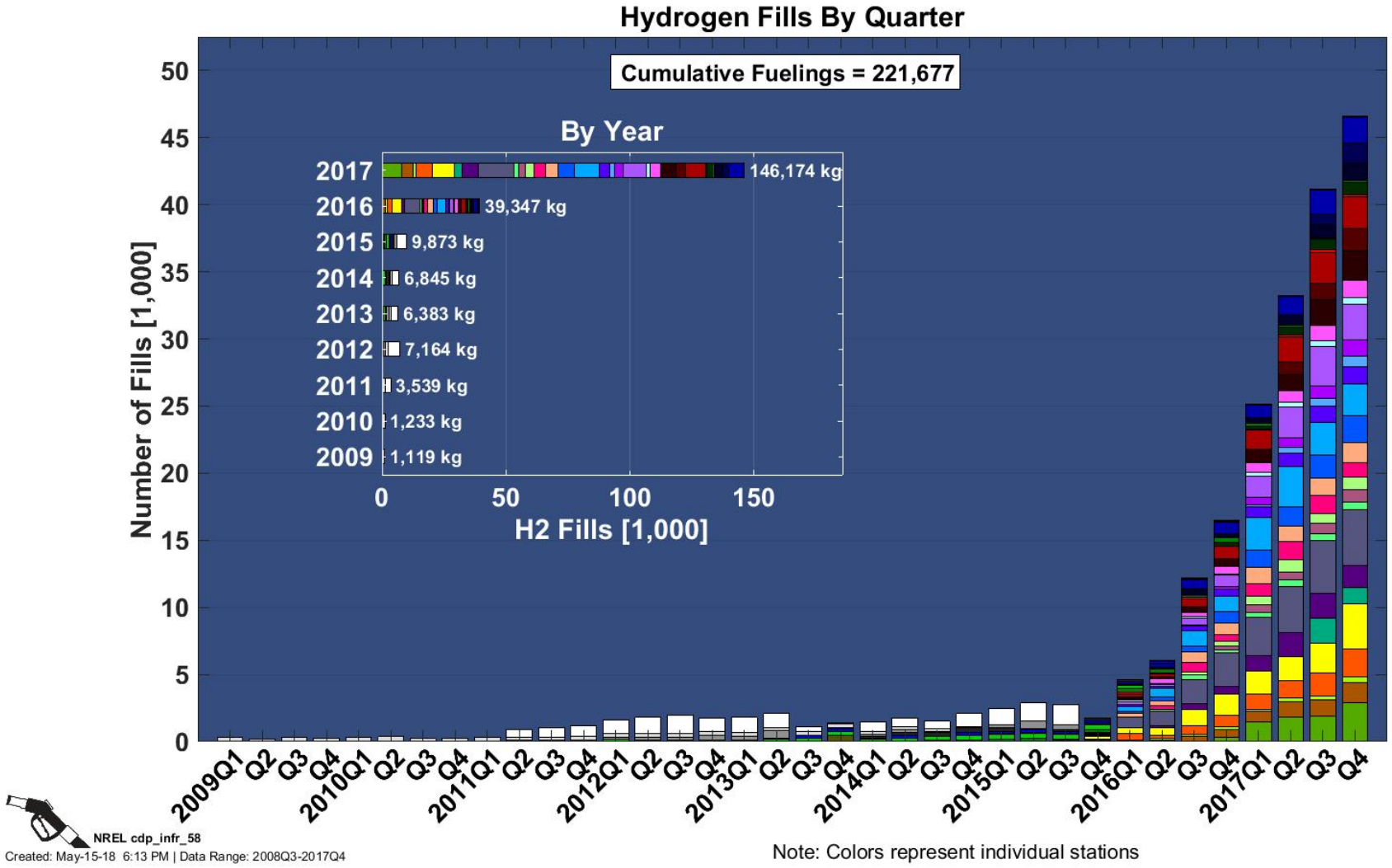
CDP-INFR-01
Hydrogen Dispensed by Quarter



NREL cdp_infr_01
Created: May-15-18 3:28 PM | Data Range: 2008Q3-2017Q4

Note: Colors represent individual stations

CDP-INFR-58
Hydrogen Fills by Quarter



NREL cdp_infr_58
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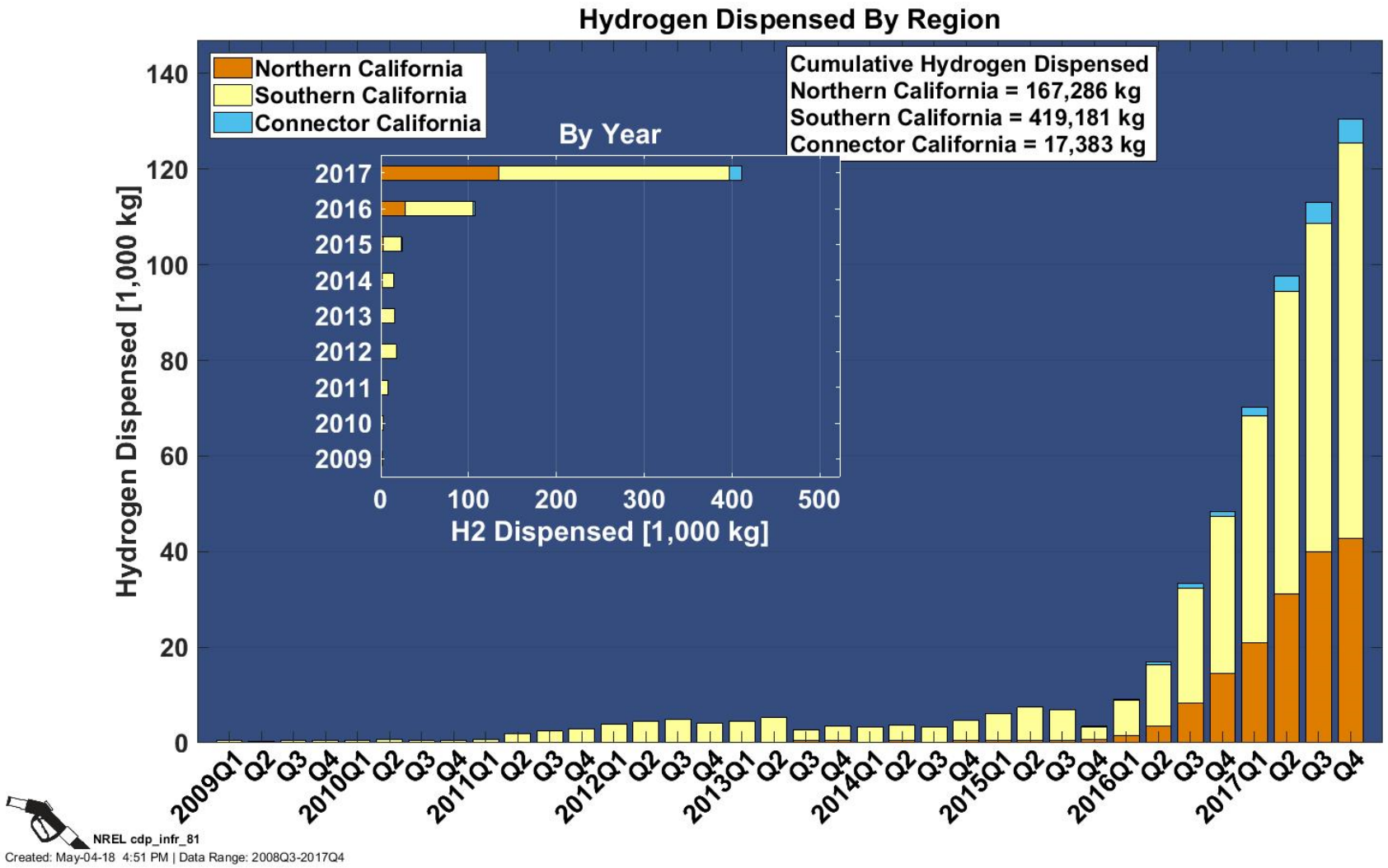
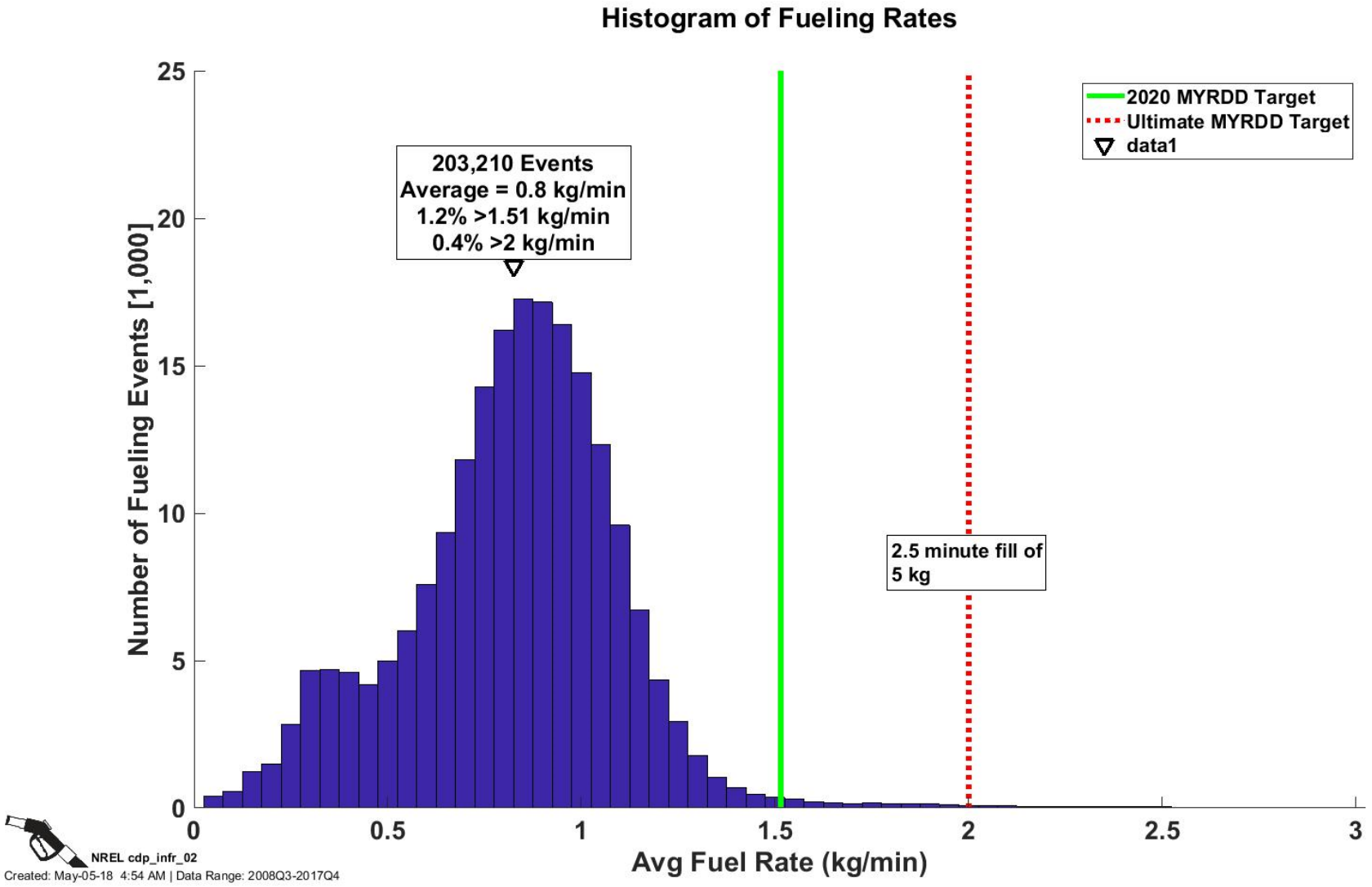
Note: Colors represent individual stations

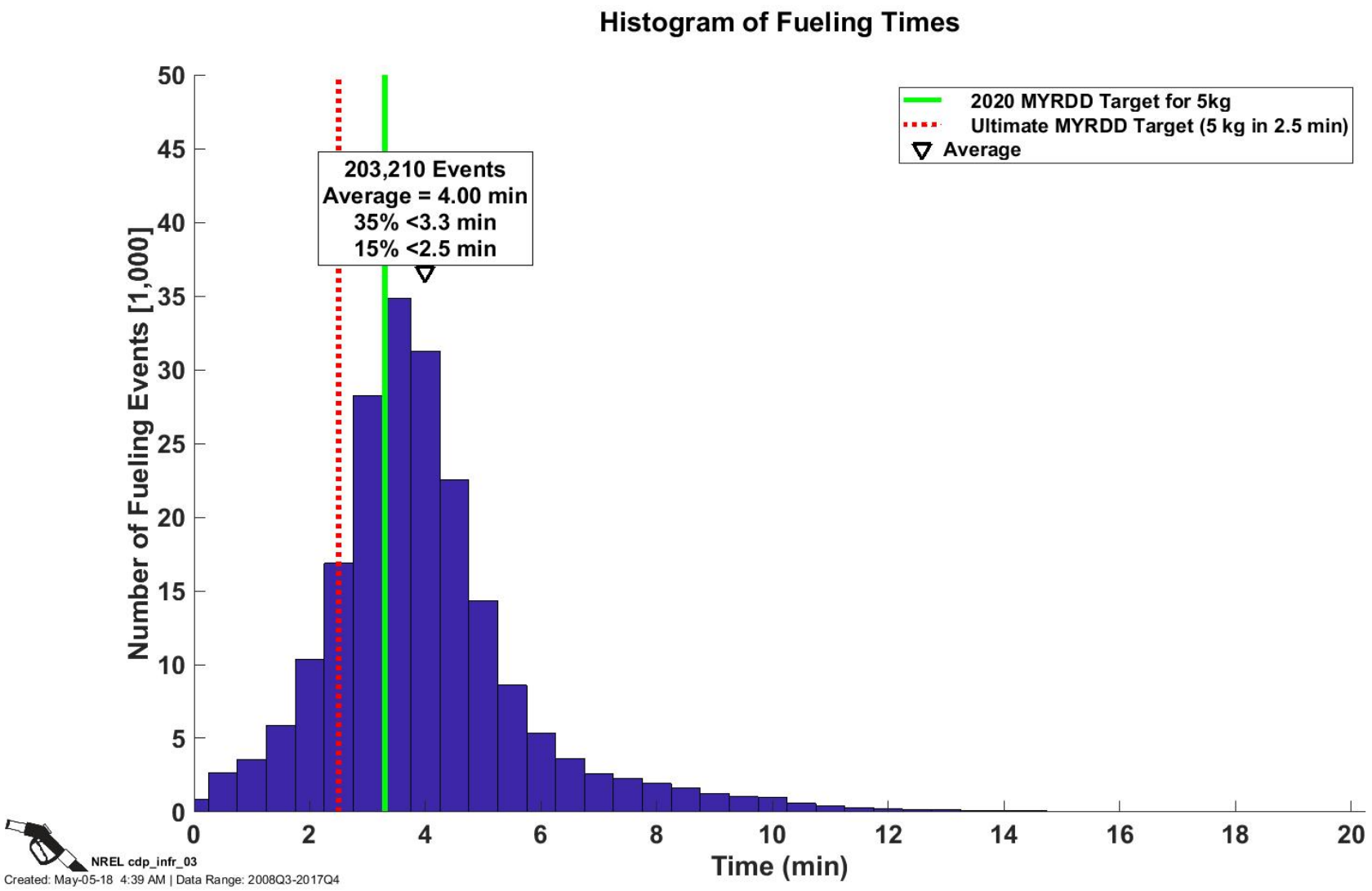
CDP-INFR-81
Hydrogen Dispensed by Region



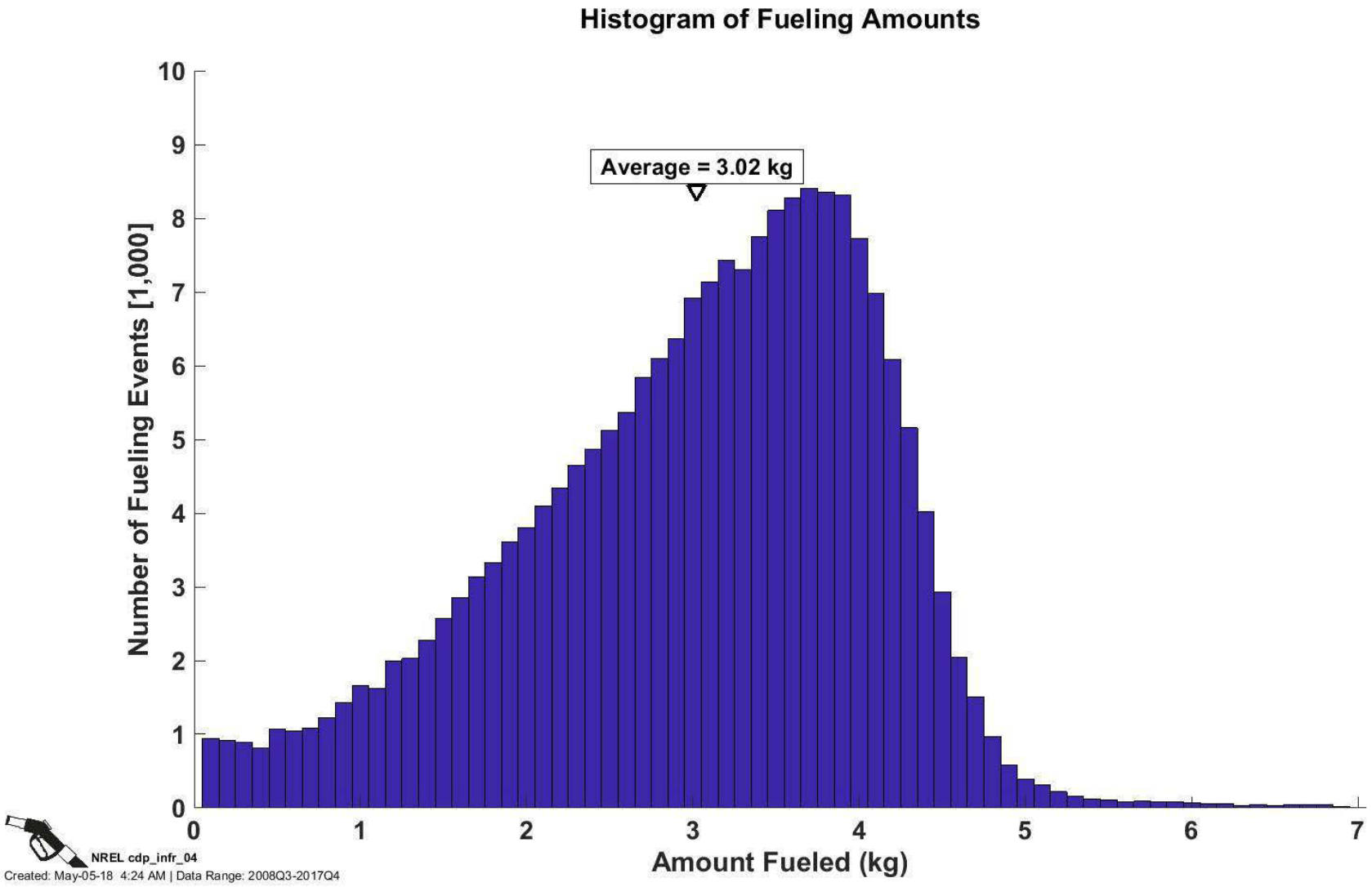
CDP-INFR-02
Histogram of Fueling Rates



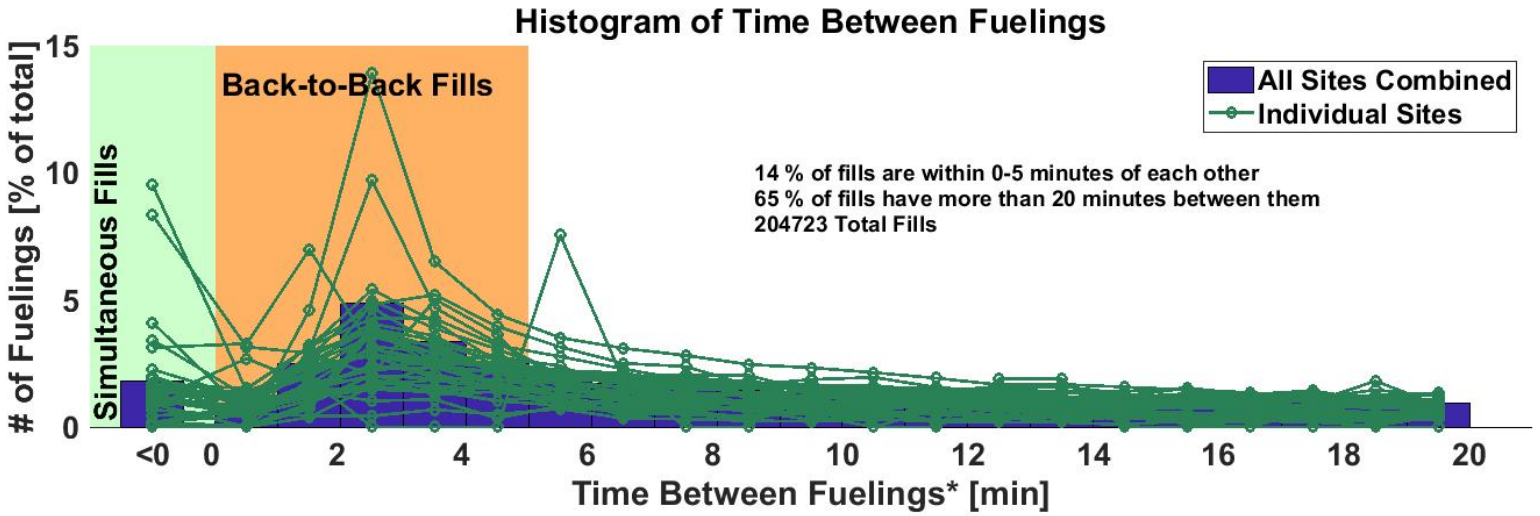
CDP-INFR-03
Histogram of Fueling Times

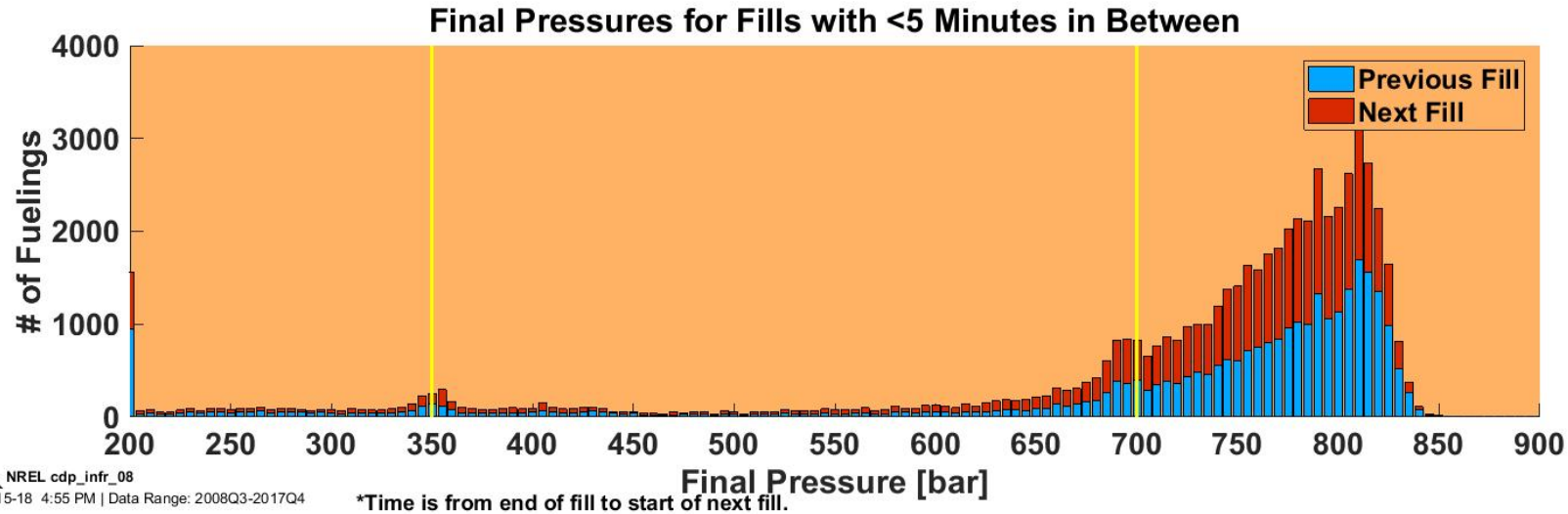


CDP-INFR-04
Histogram of Fueling Amounts



CDP-INFR-08
Time Between Fueling

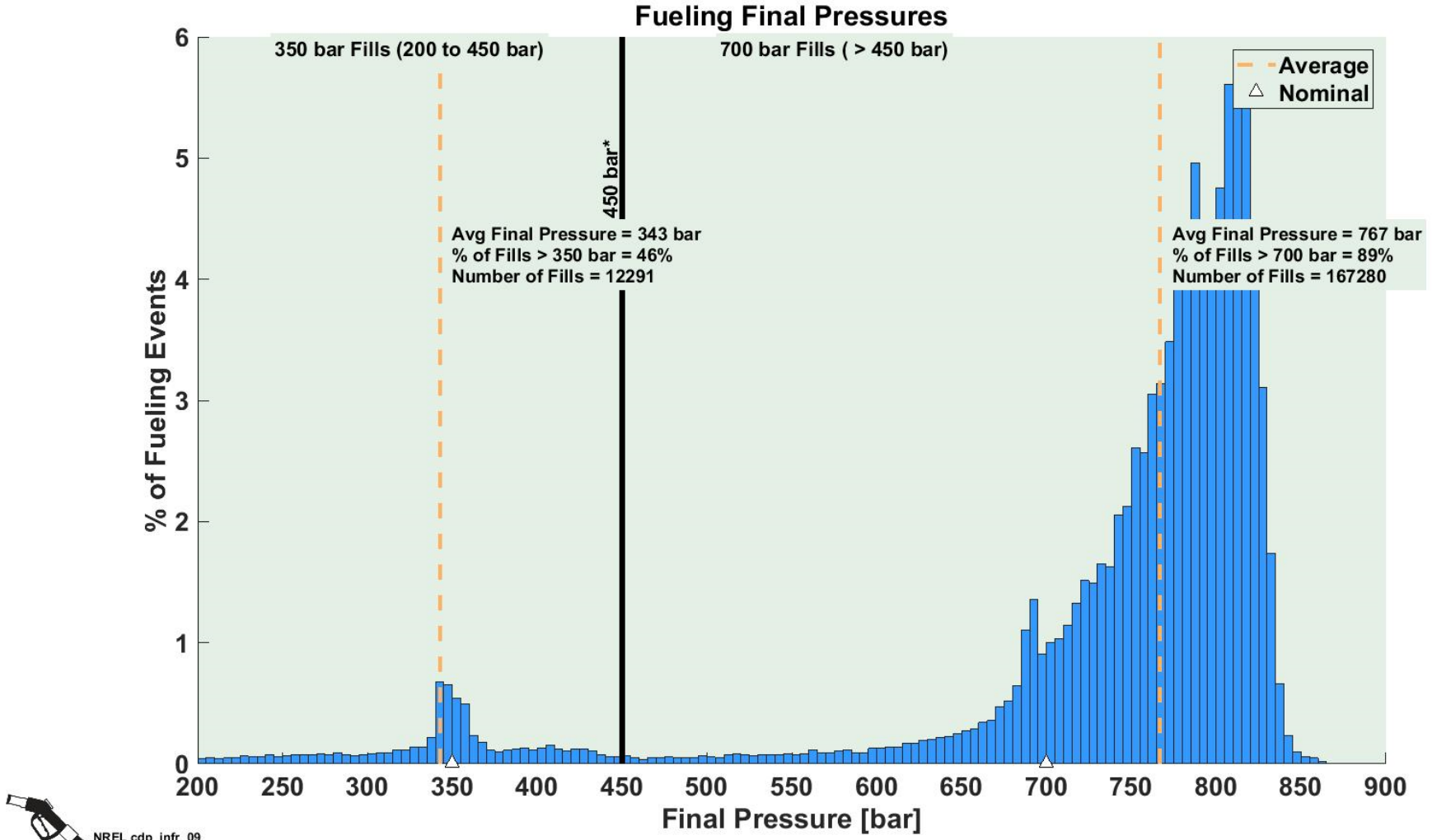




NREL cdp_infr_08
Created: May-15-18 4:55 PM | Data Range: 2008Q3-2017Q4

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

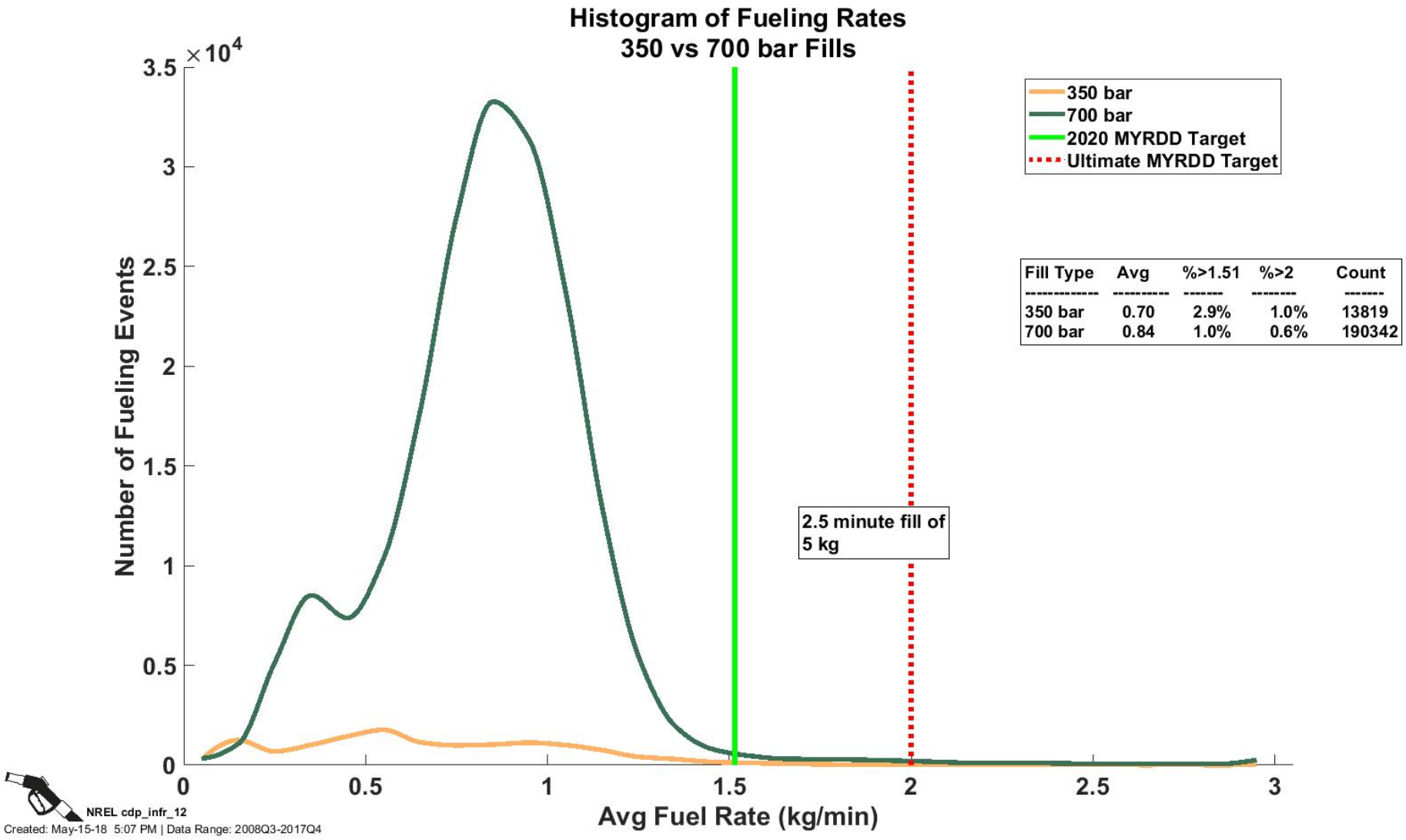
CDP-INFR-09
Fueling Final Pressures



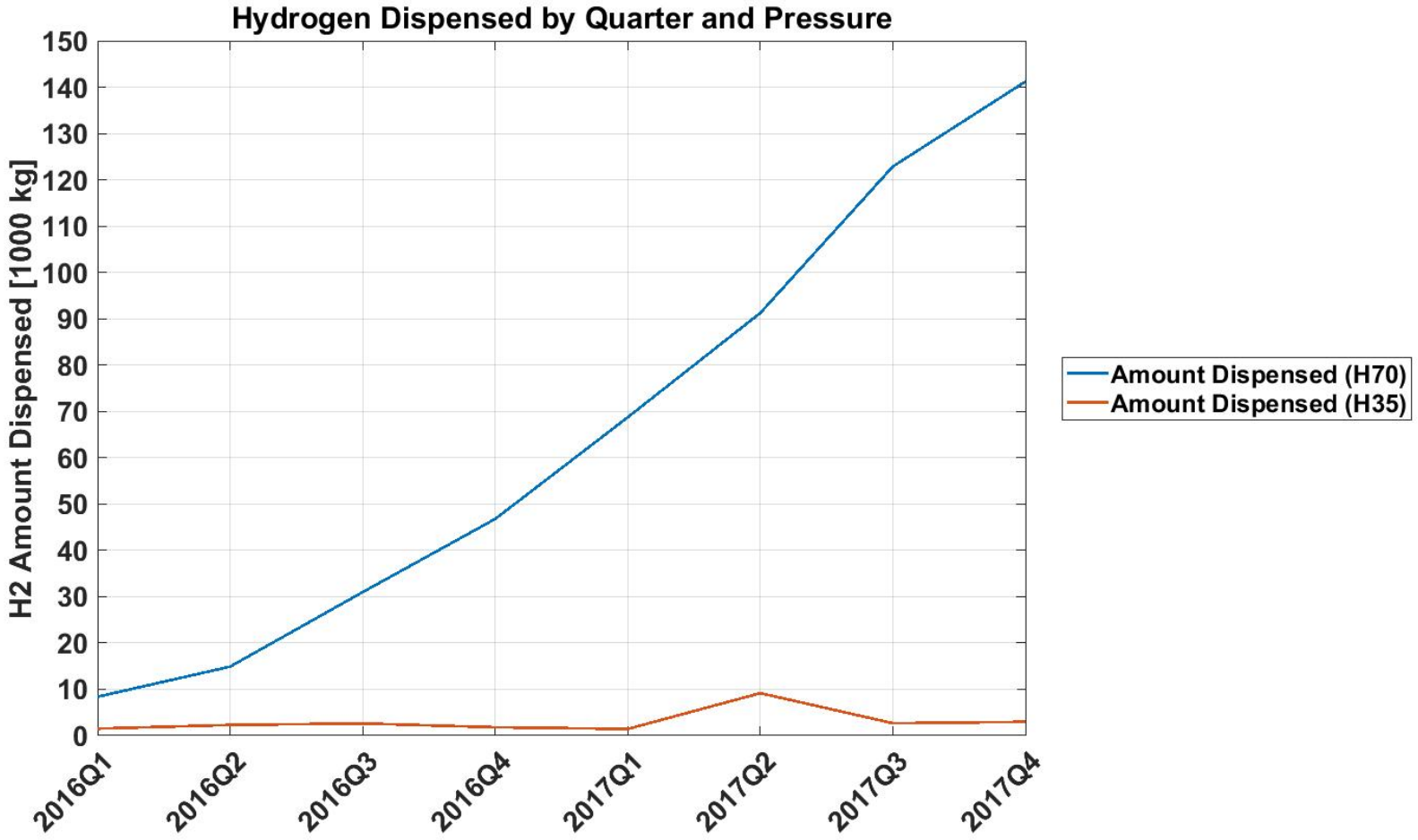
NREL cdp_infr_09
Created: May-16-18 8:36 AM | Data Range: 2008Q3-2017Q4

*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

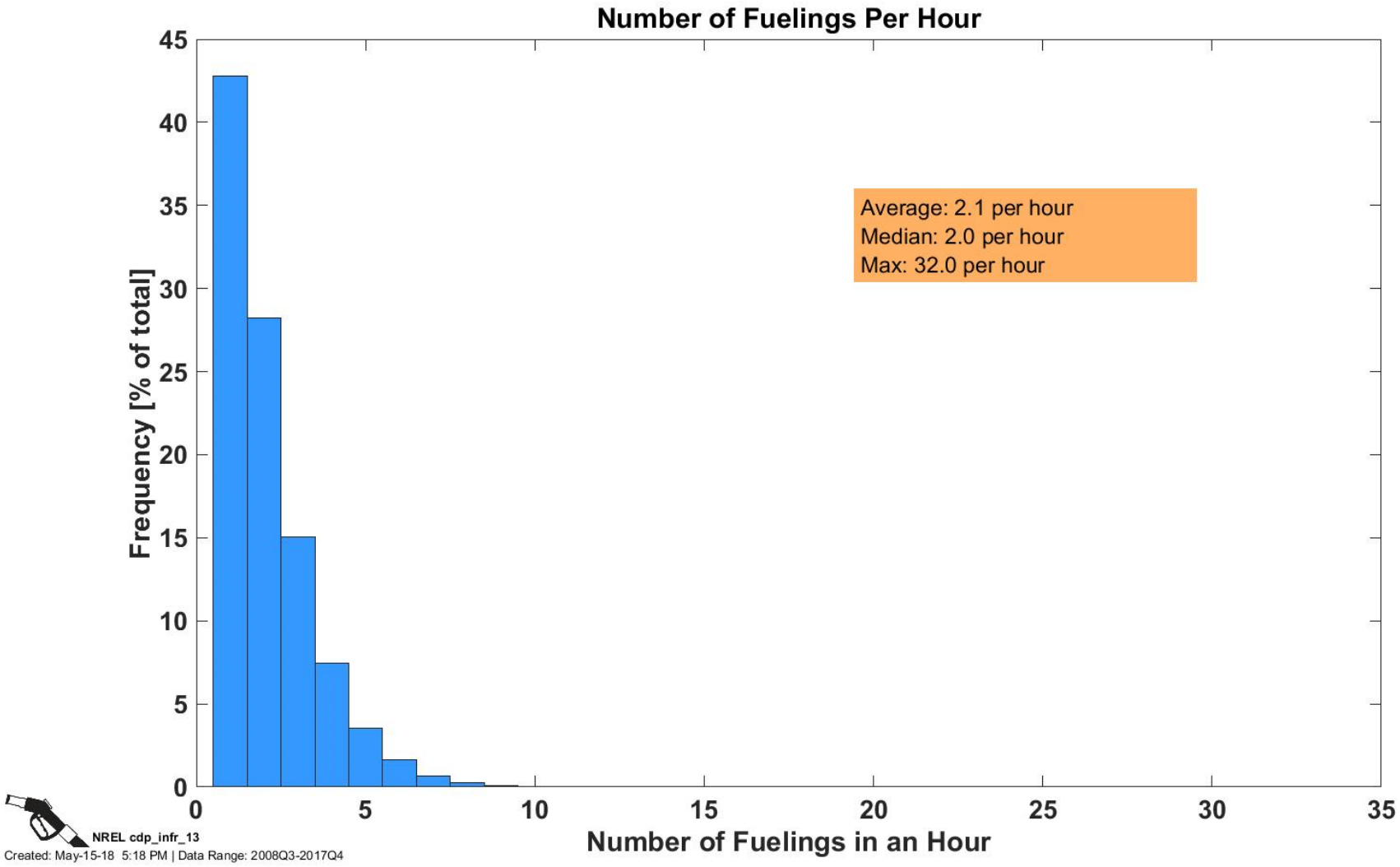


CDP-INFR-90
Hydrogen Dispensed by Quarter and Pressure

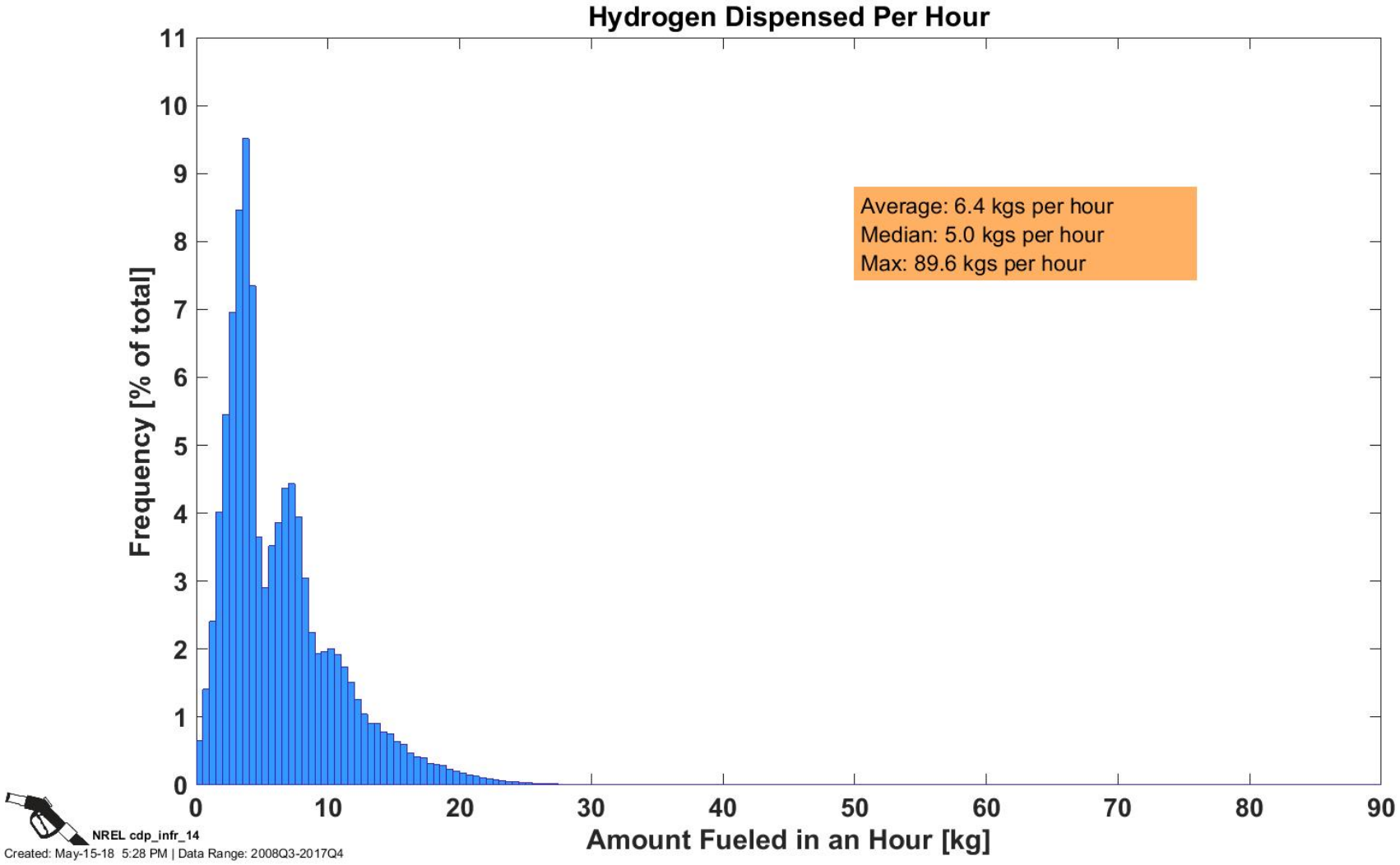


NREL cdp_infr_90
Created: May-16-18 8:50 AM | Data Range: 2008Q3-2017Q4

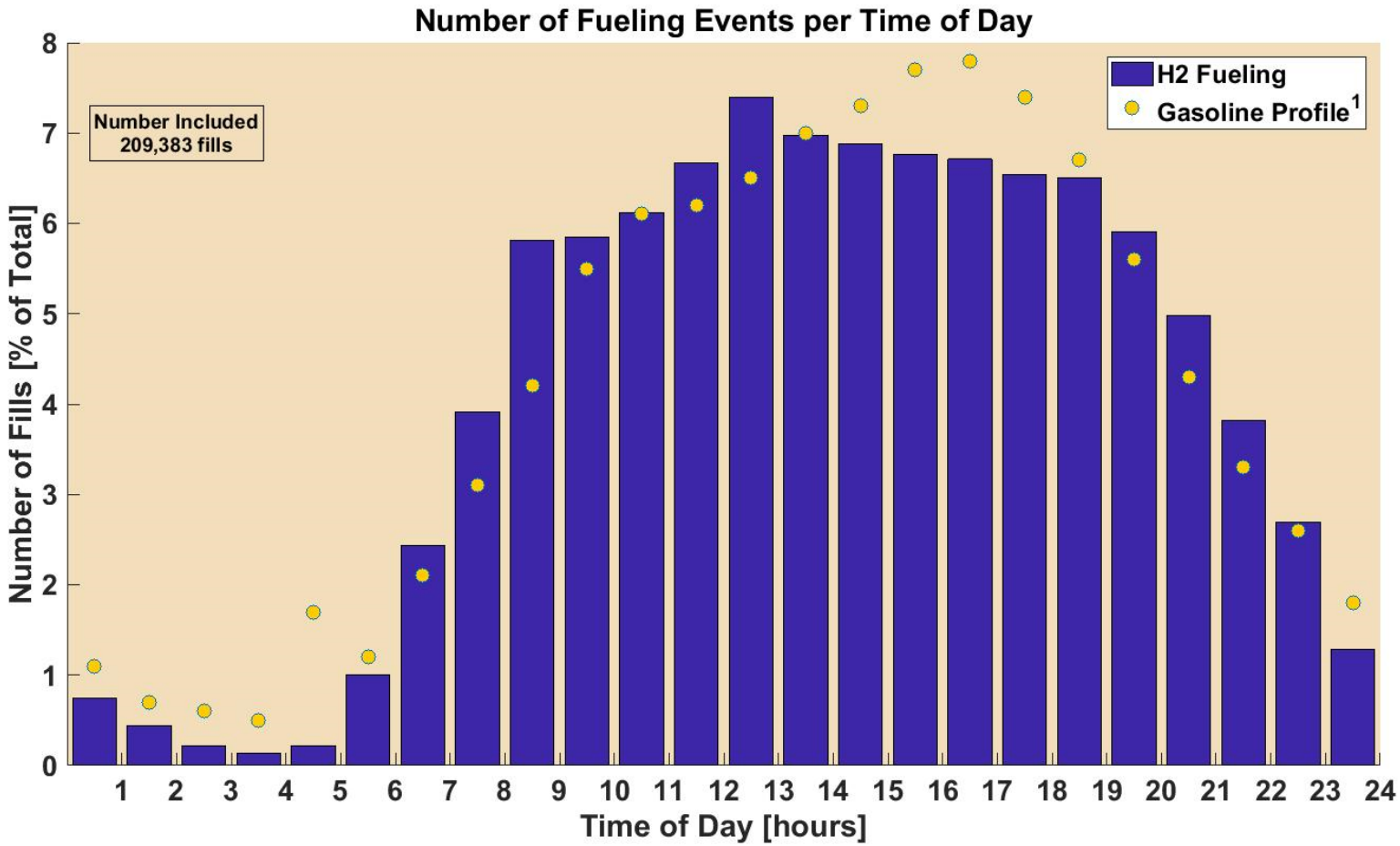
CDP-INFR-13
Number of Fueling Events per Hour



CDP-INFR-14
Hydrogen Dispensed per Hour



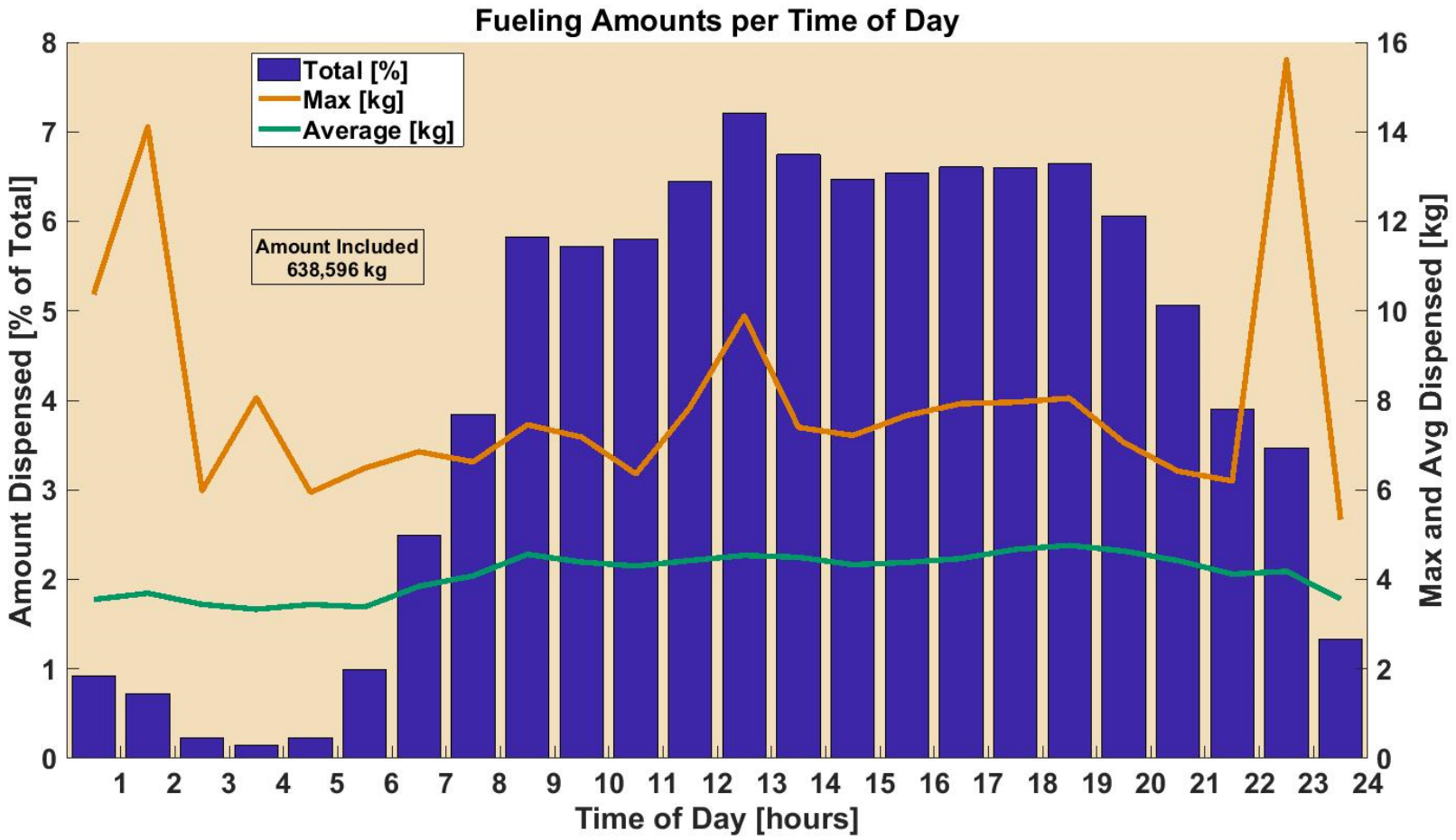
CDP-INFR-15
Number of Fills by Time of Day



NREL cdp_infr_15
Created: May-16-18 8:45 AM | Data Range: 2008Q3-2017Q4

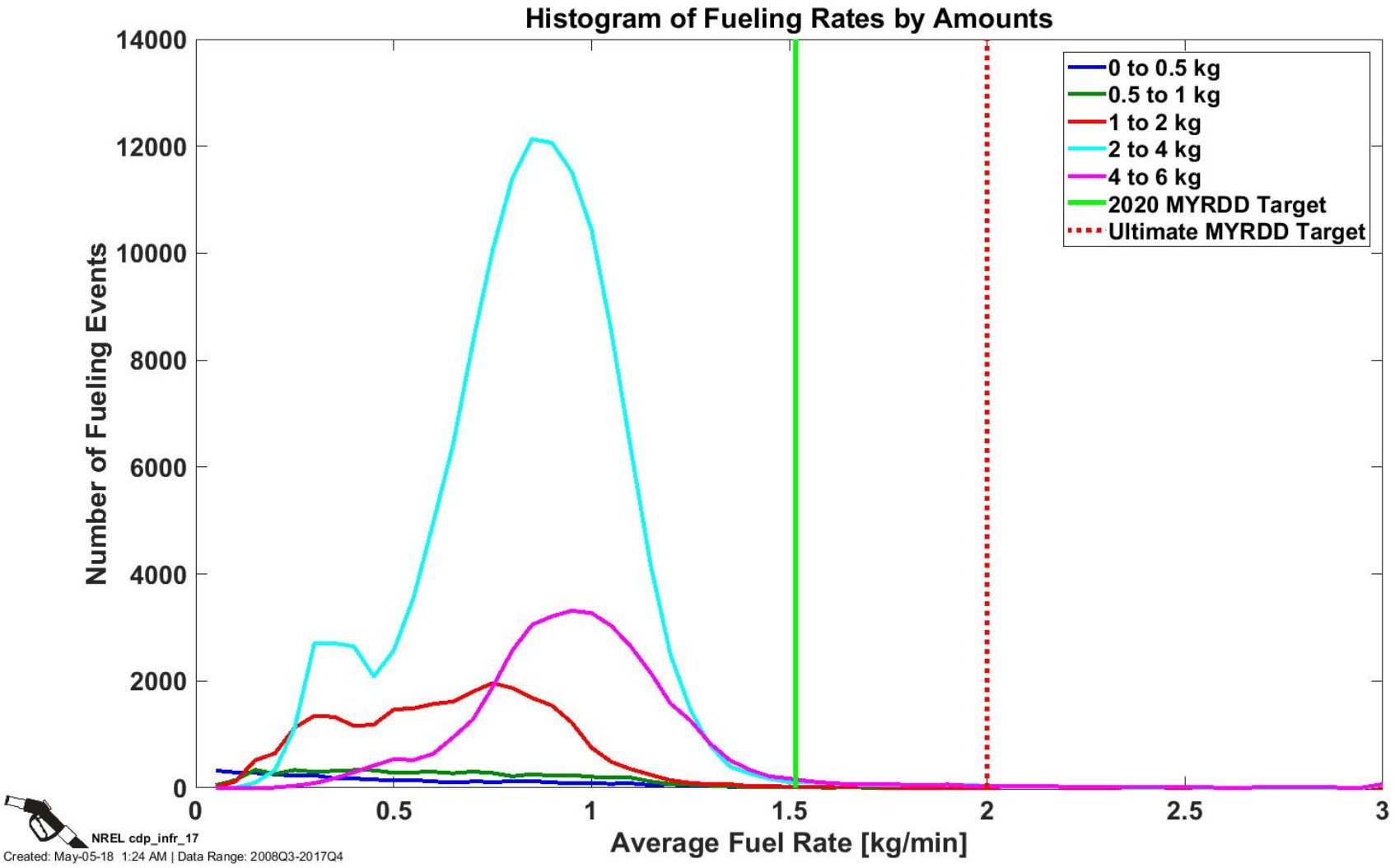
1. Friday Chevron profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.

CDP-INFR-16
Fueling Amounts per Time of Day

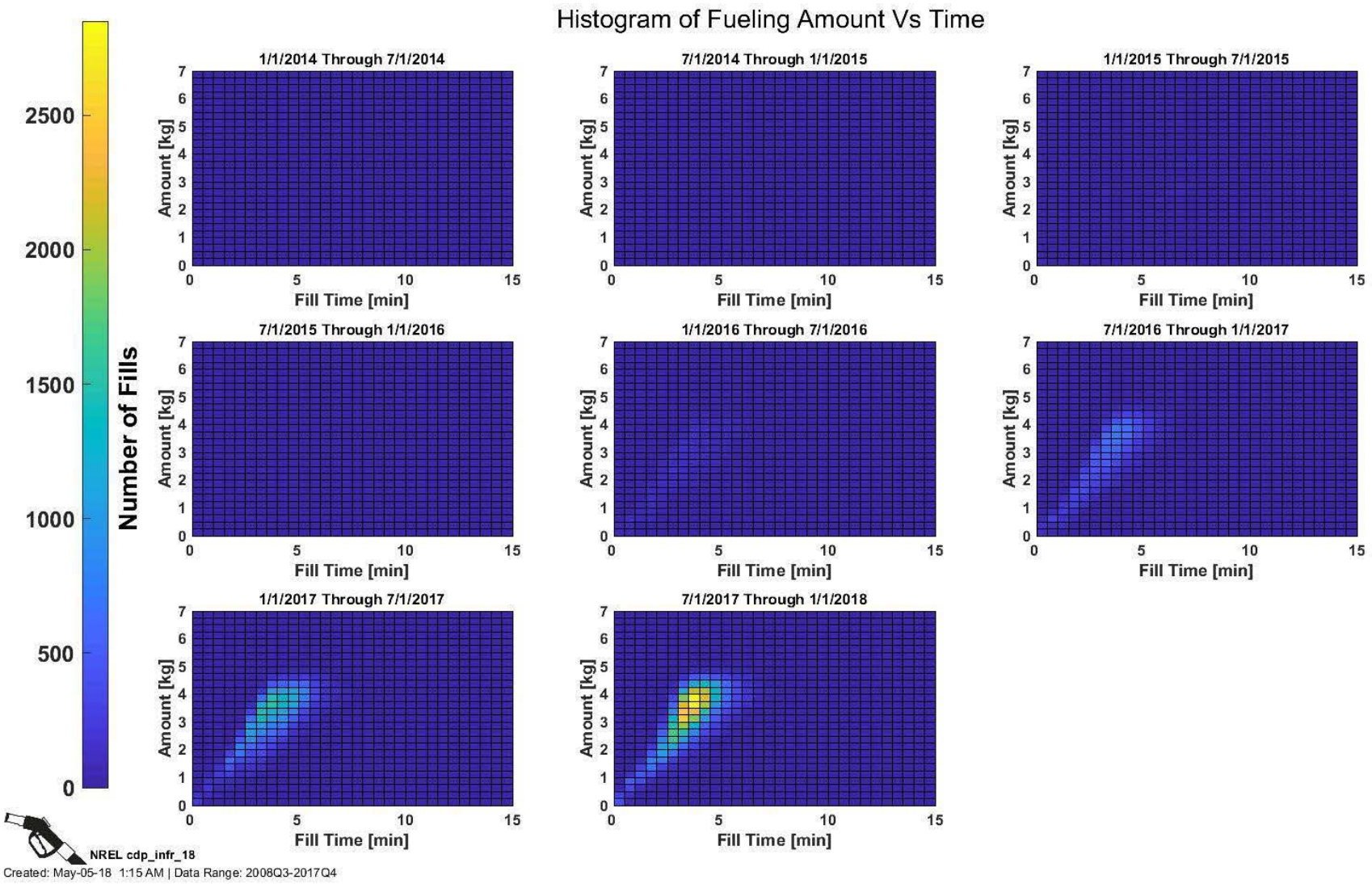


NREL cdp_infr_16
Created: May-05-18 1:38 AM | Data Range: 2008Q3-2017Q4

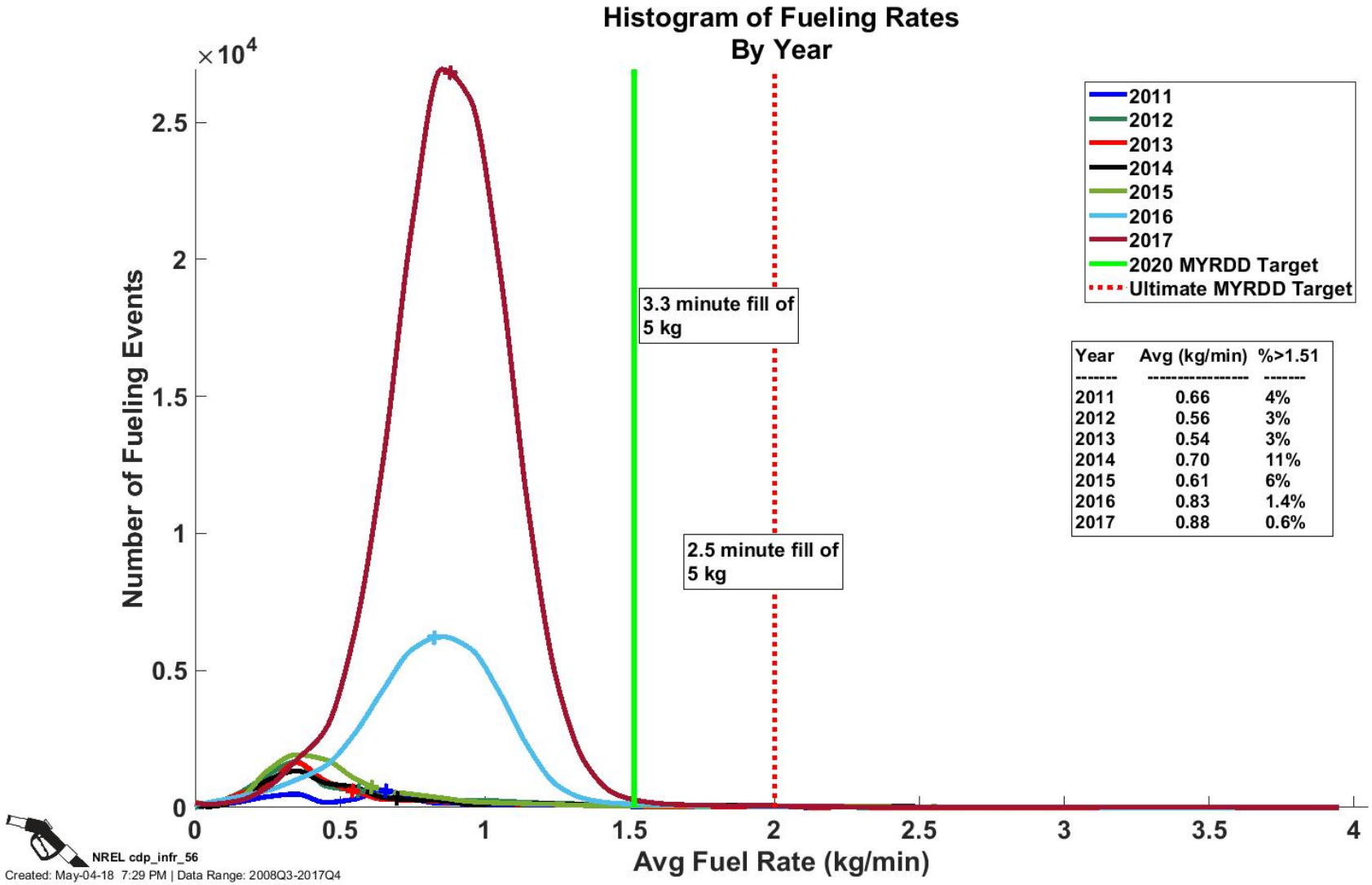
CDP-INFR-17
Fueling Rates by Amount Filled



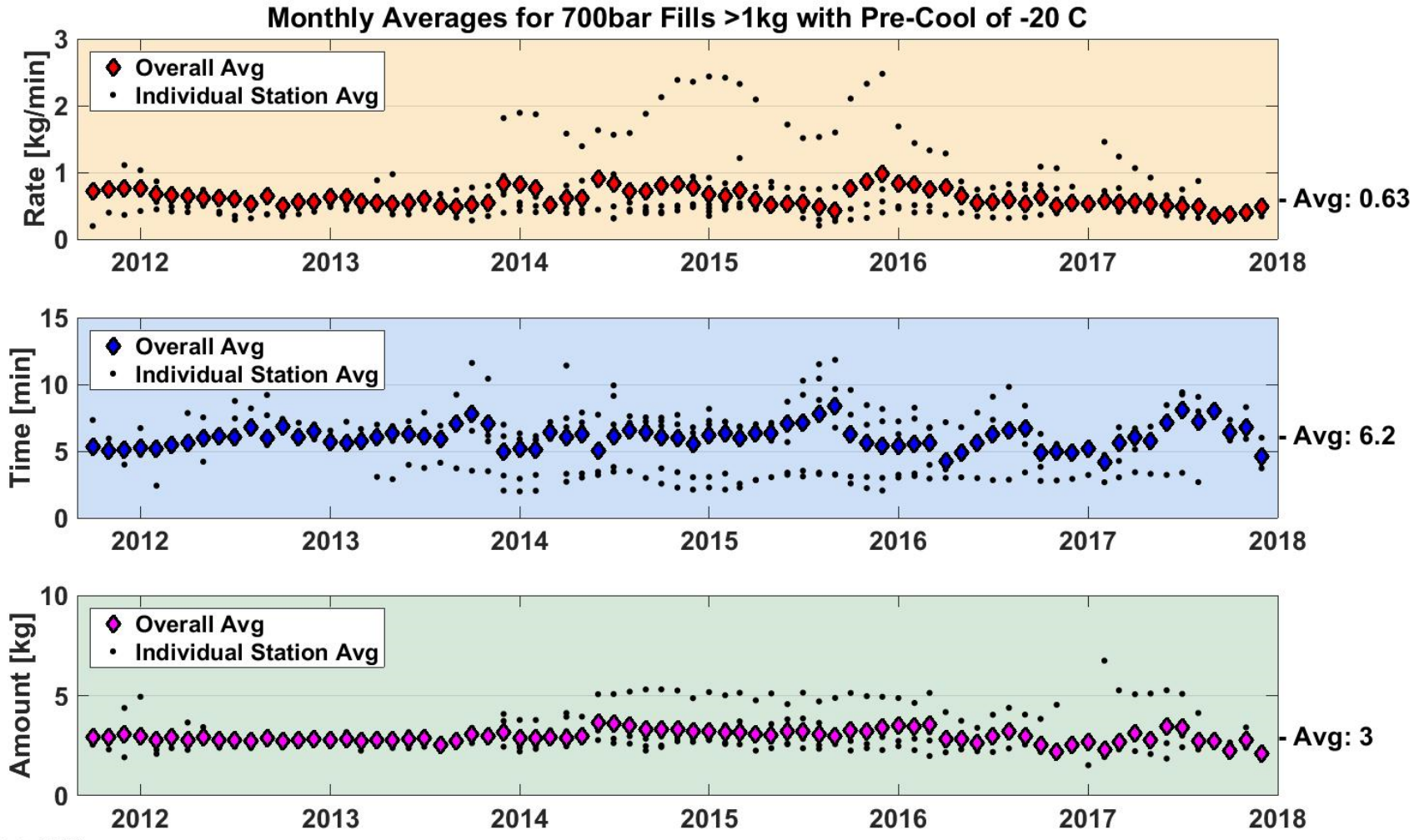
CDP-INFR-18
Fueling Amount vs. Time to Fill



CDP-INFR-56
Fueling Rates by Year

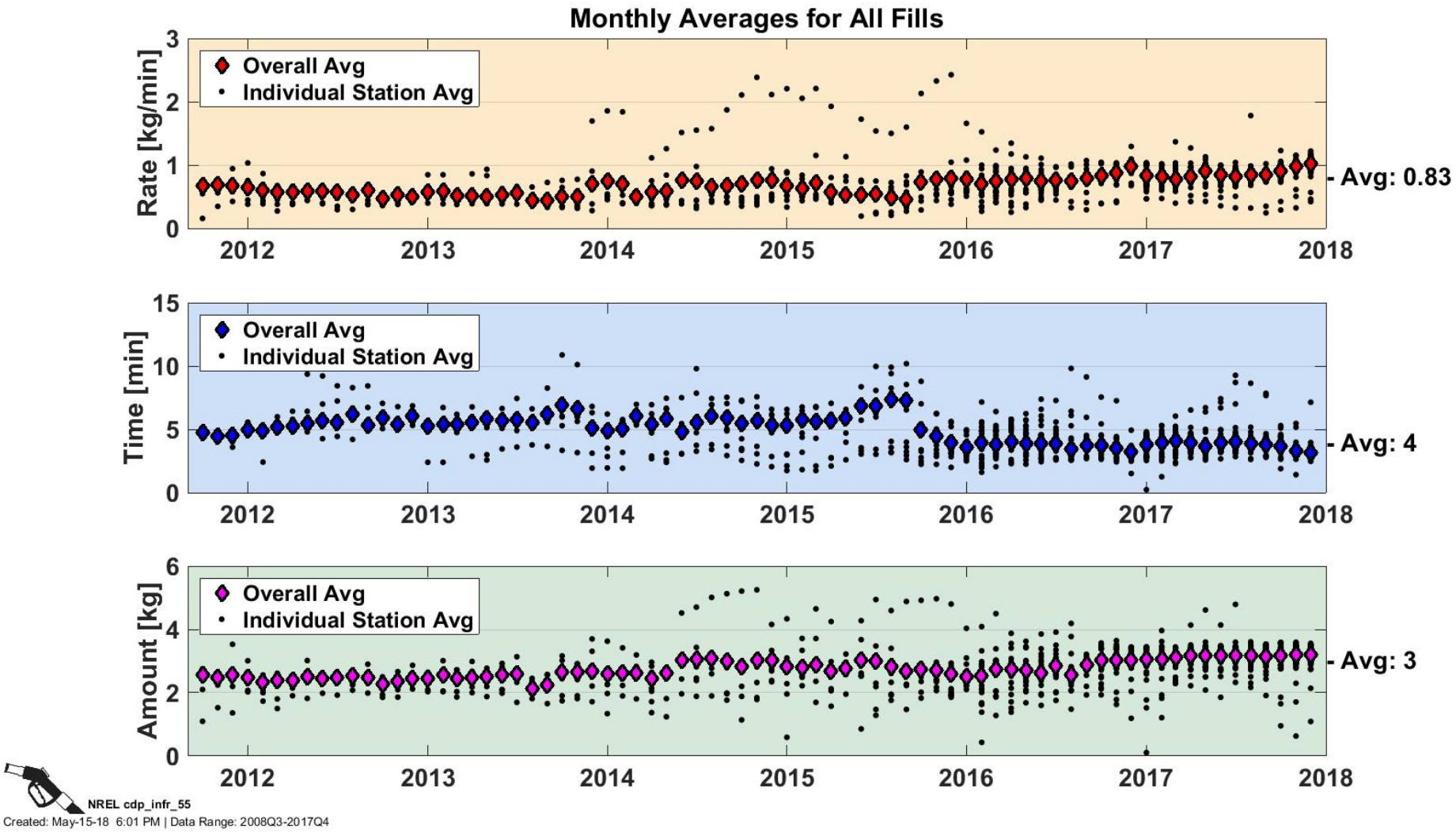


CDP-INFR-29
Monthly Averages: 700 bar Fills >1 kg with Pre-Cool of -20°C

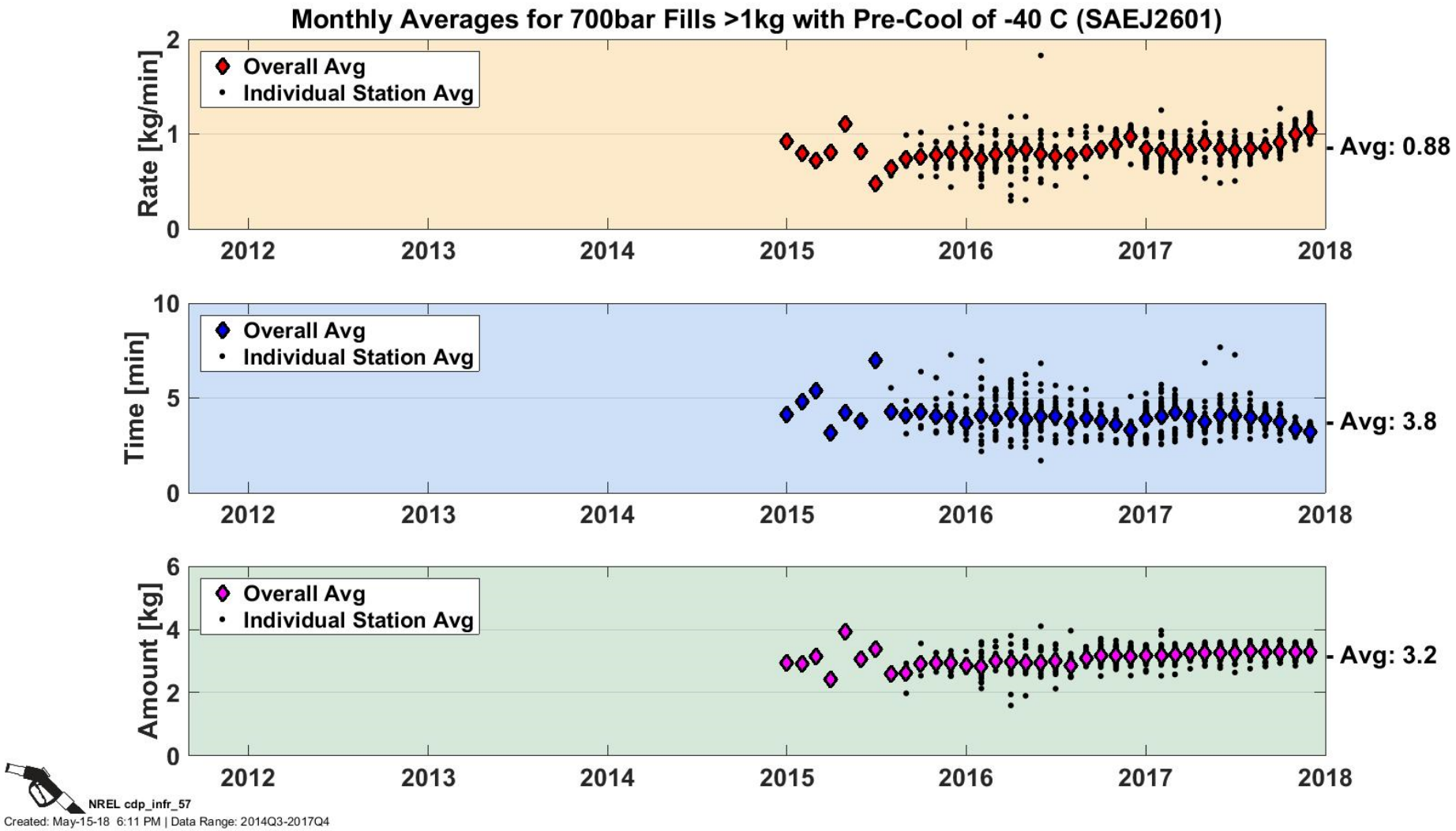


NREL cdp_infr_29
Created: May-16-18 12:36 PM | Data Range: 2011Q1-2017Q4

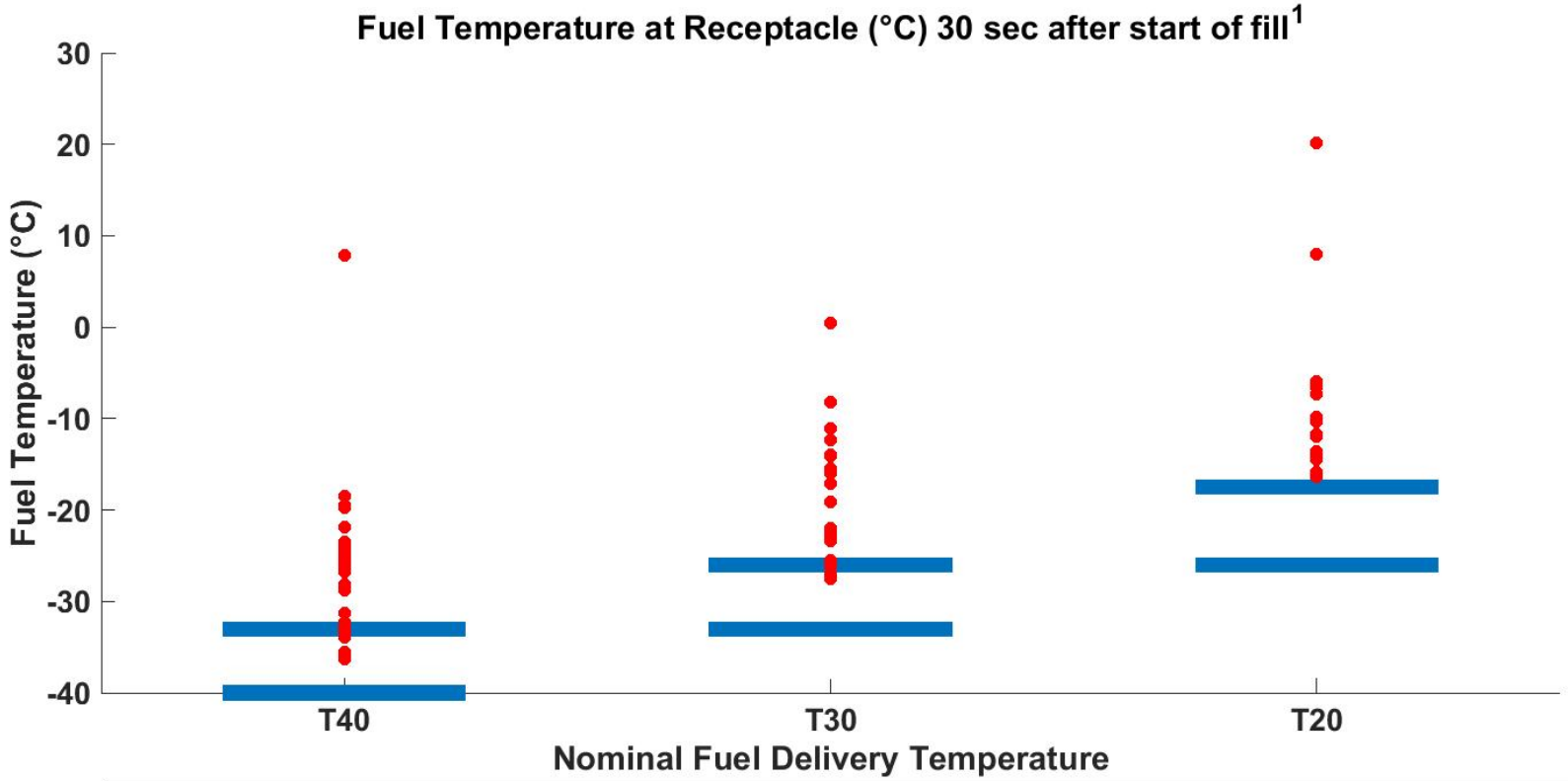
CDP-INFR-55
Monthly Averages: All Fills



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



CDP-INFR-77
Fuel Temperature at Receptacle 30 s After Start of Fill

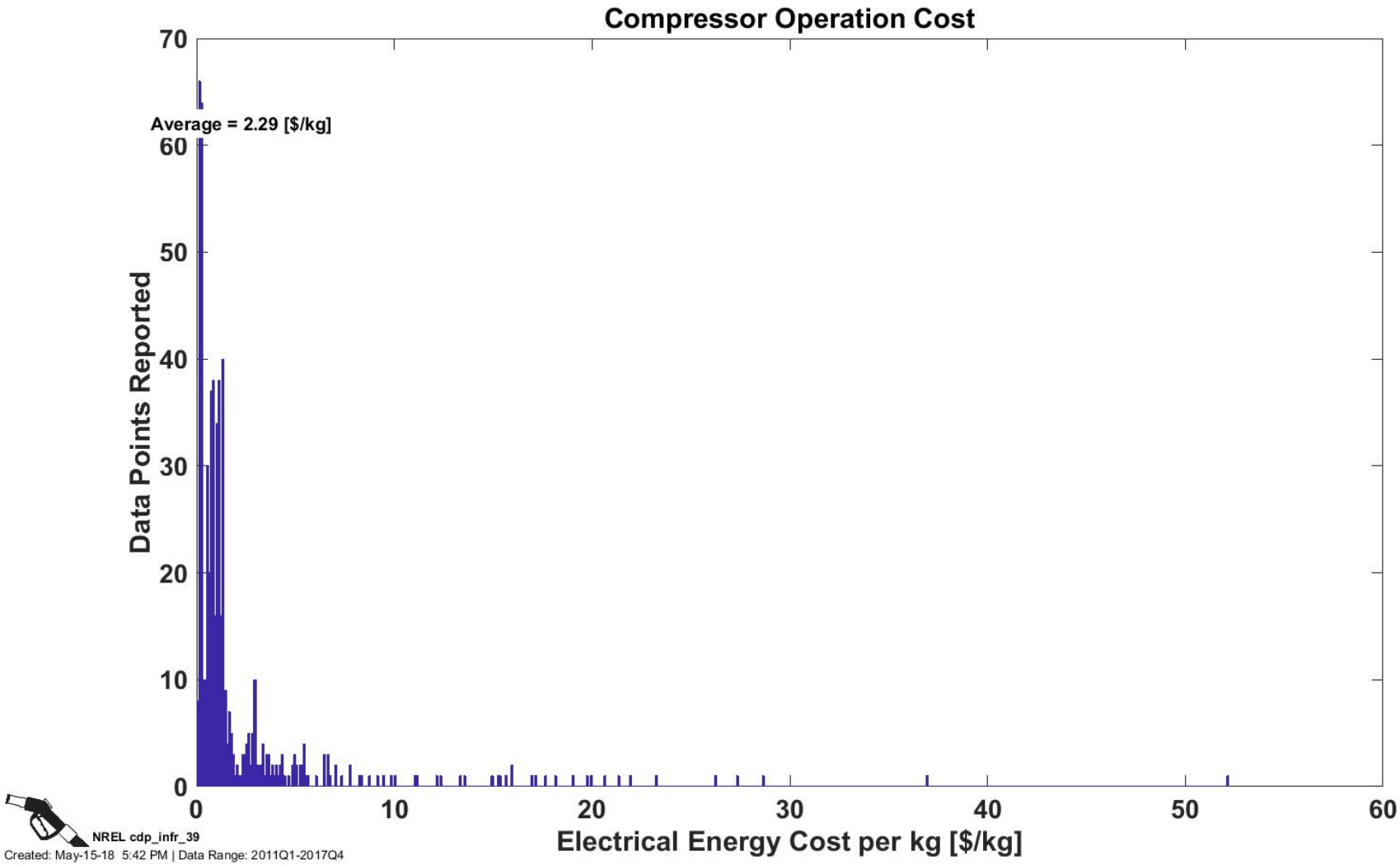


1. SAE J2601 (2014) defines fuel delivery temperature as measured near the dispenser breakaway. See paragraph 4.21. Temperature data here are from HyStEP tests measuring fuel temperature just downstream of the receptacle. SAE J2601 requires that fuel delivery temperature reach the limits shown in blue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

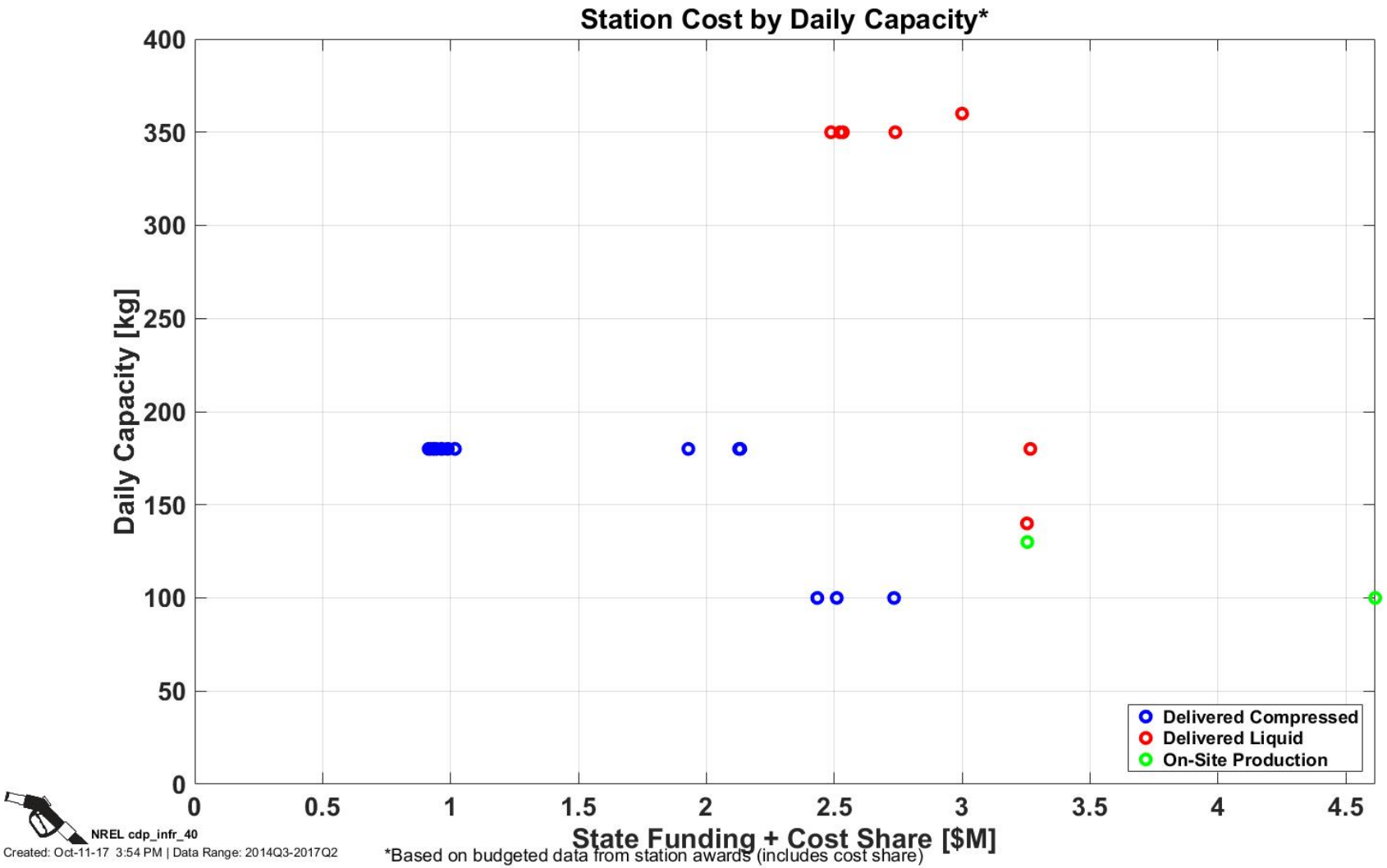
NREL cdp_infr_77
Created: Apr-27-18 4:18 PM | Data Range: 2014Q4-2017Q4

Cost

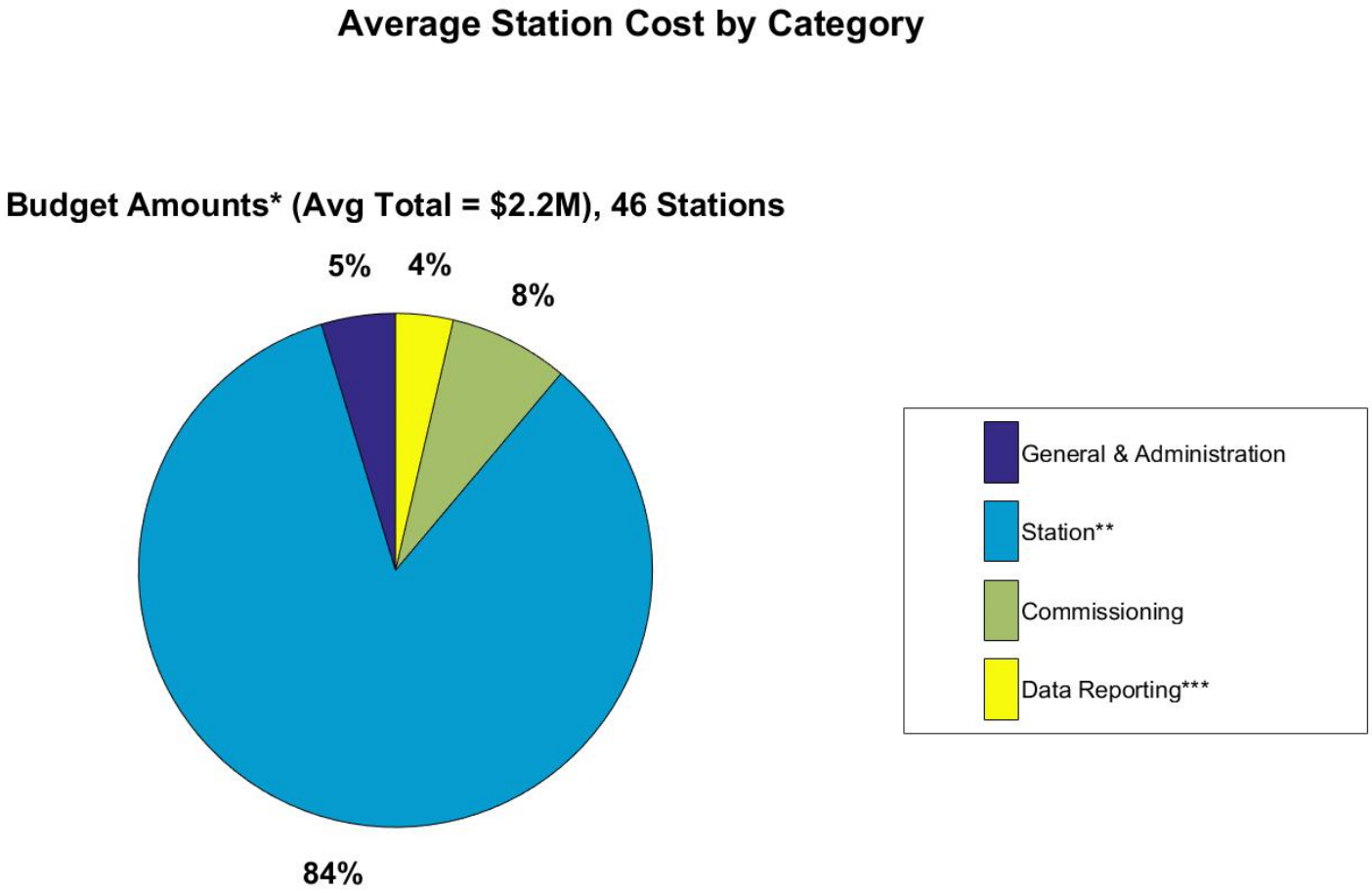
CDP-INFR-39
Compressor Operation Cost



CDP-INFR-40
Station Costs by Daily Capacity



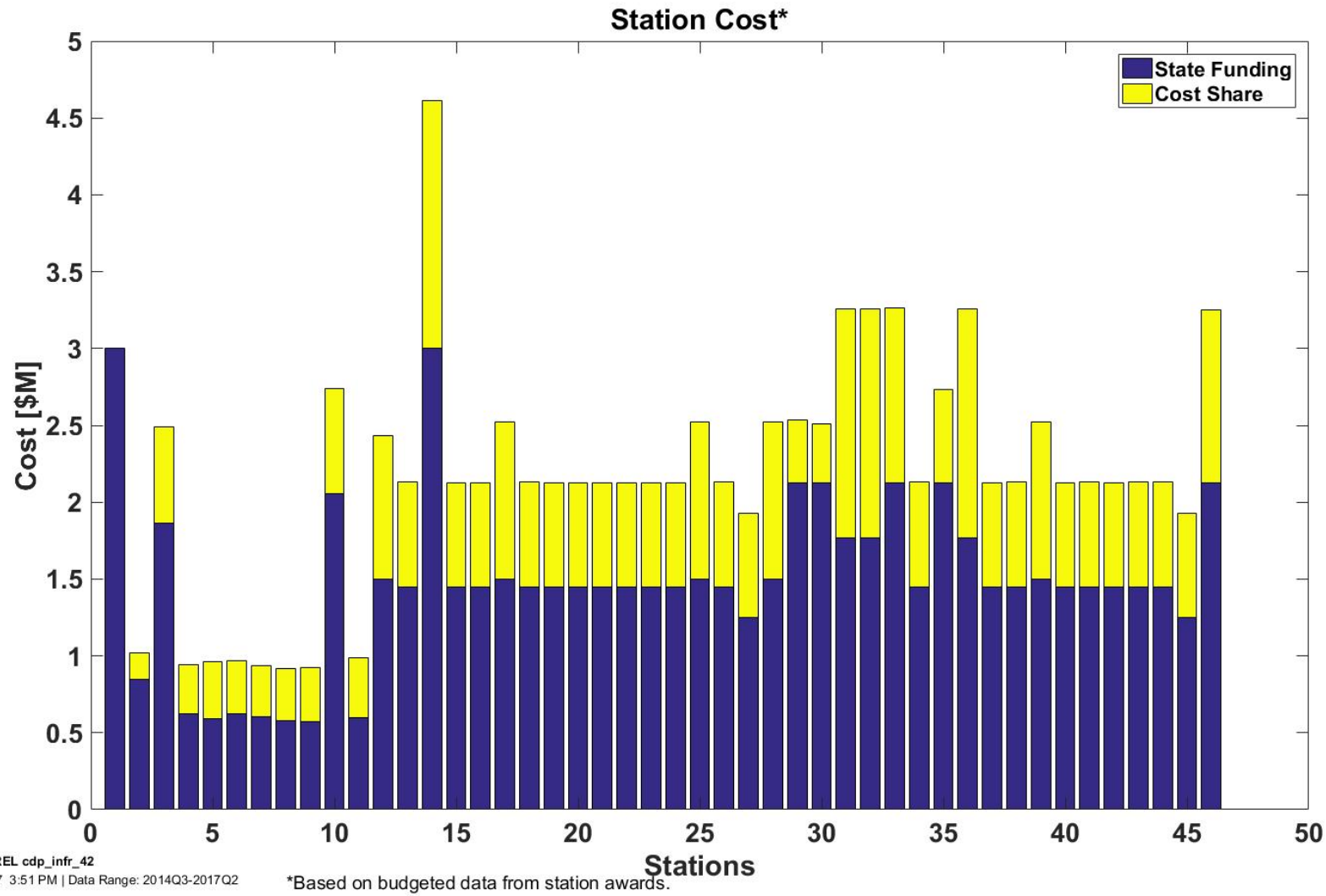
CDP-INFR-41
Average Station Cost by Category



NREL cdp_infr_41
Created: Oct-11-17 3:50 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

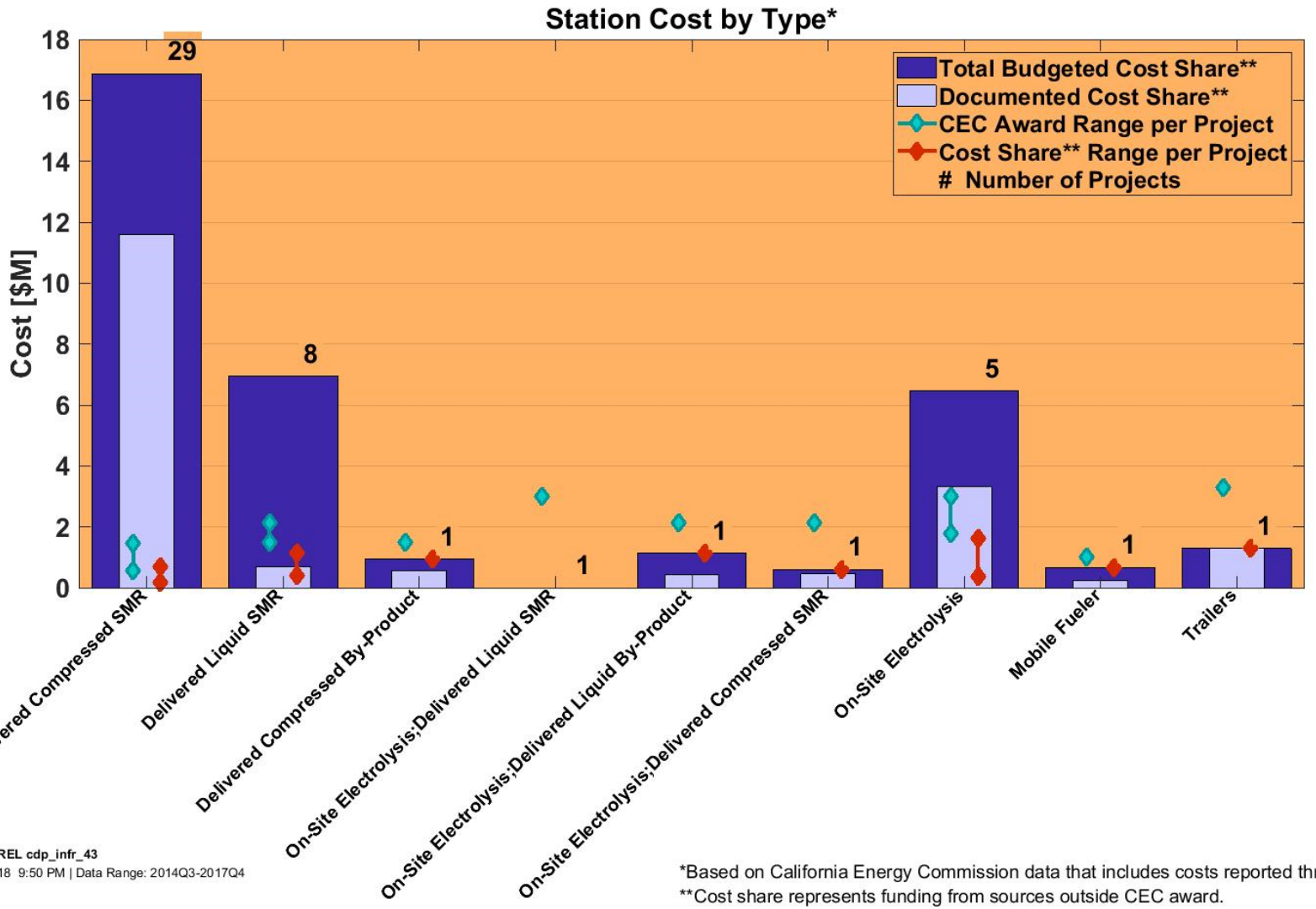
CDP-INFR-42
Station Cost



NREL cdp_infr_42
Created: Oct-11-17 3:51 PM | Data Range: 2014Q3-2017Q2

*Based on budgeted data from station awards.

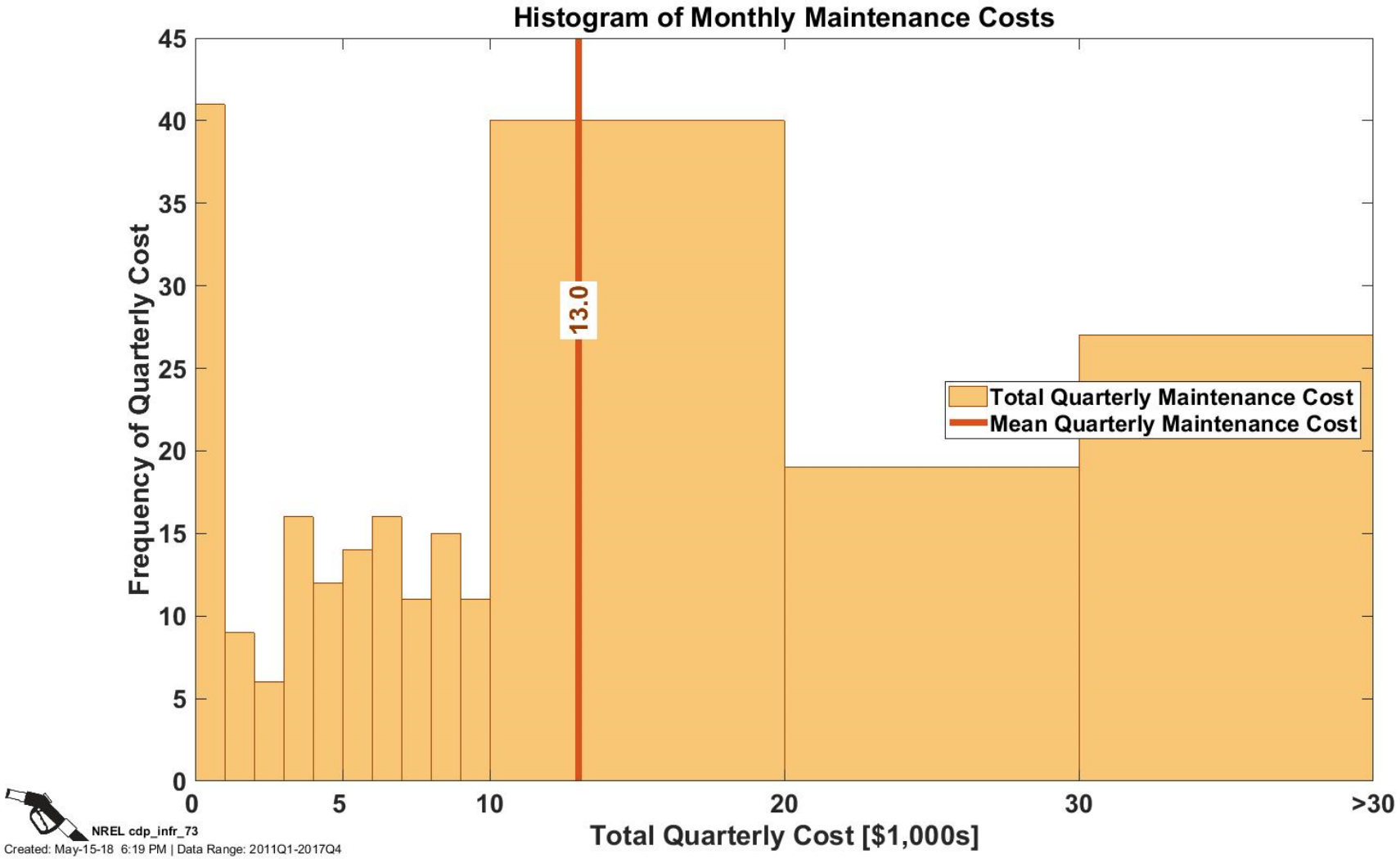
CDP-INFR-43
Station Cost by Type



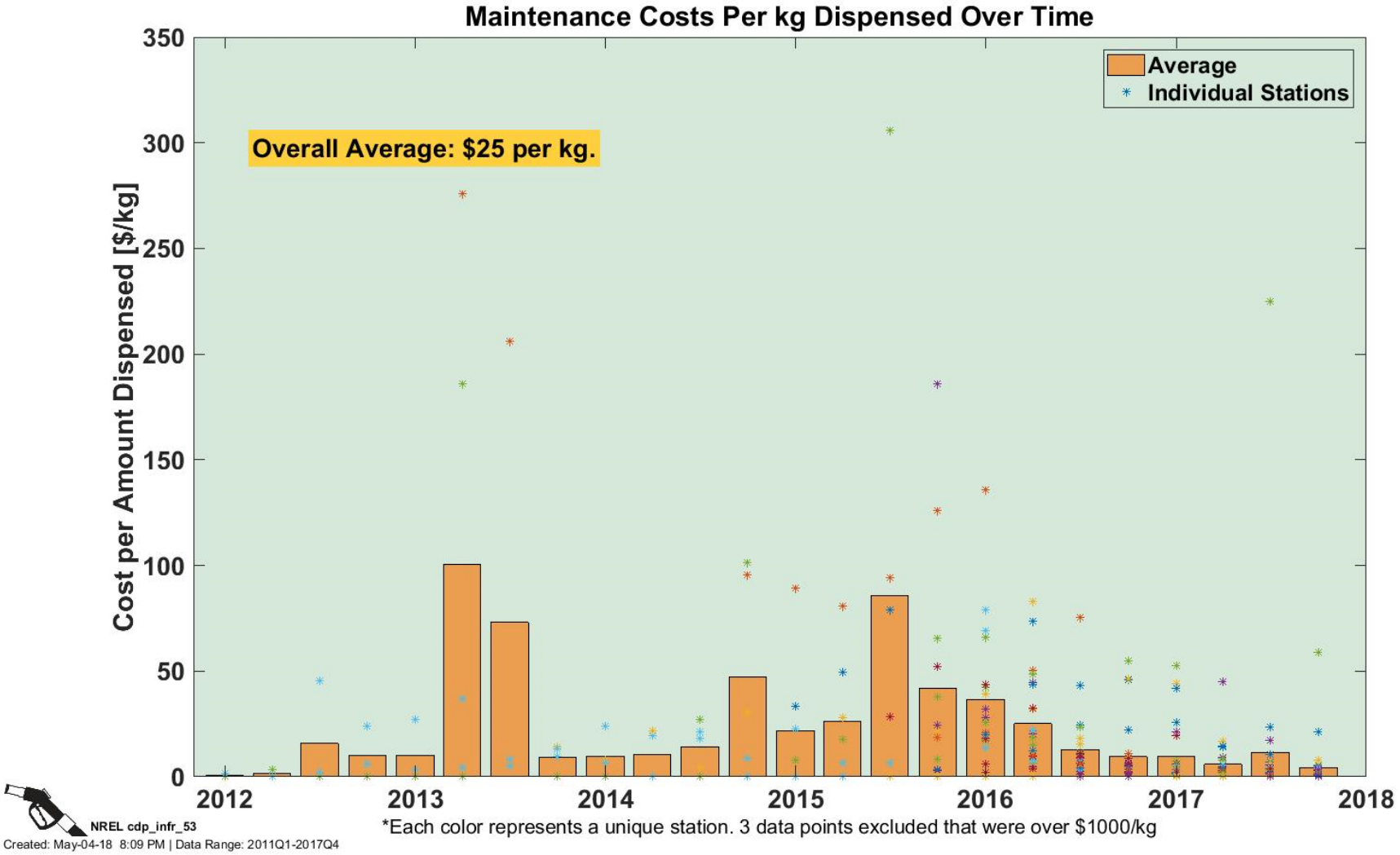
NREL cdp_infr_43
Created: May-04-18 9:50 PM | Data Range: 2014Q3-2017Q4

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

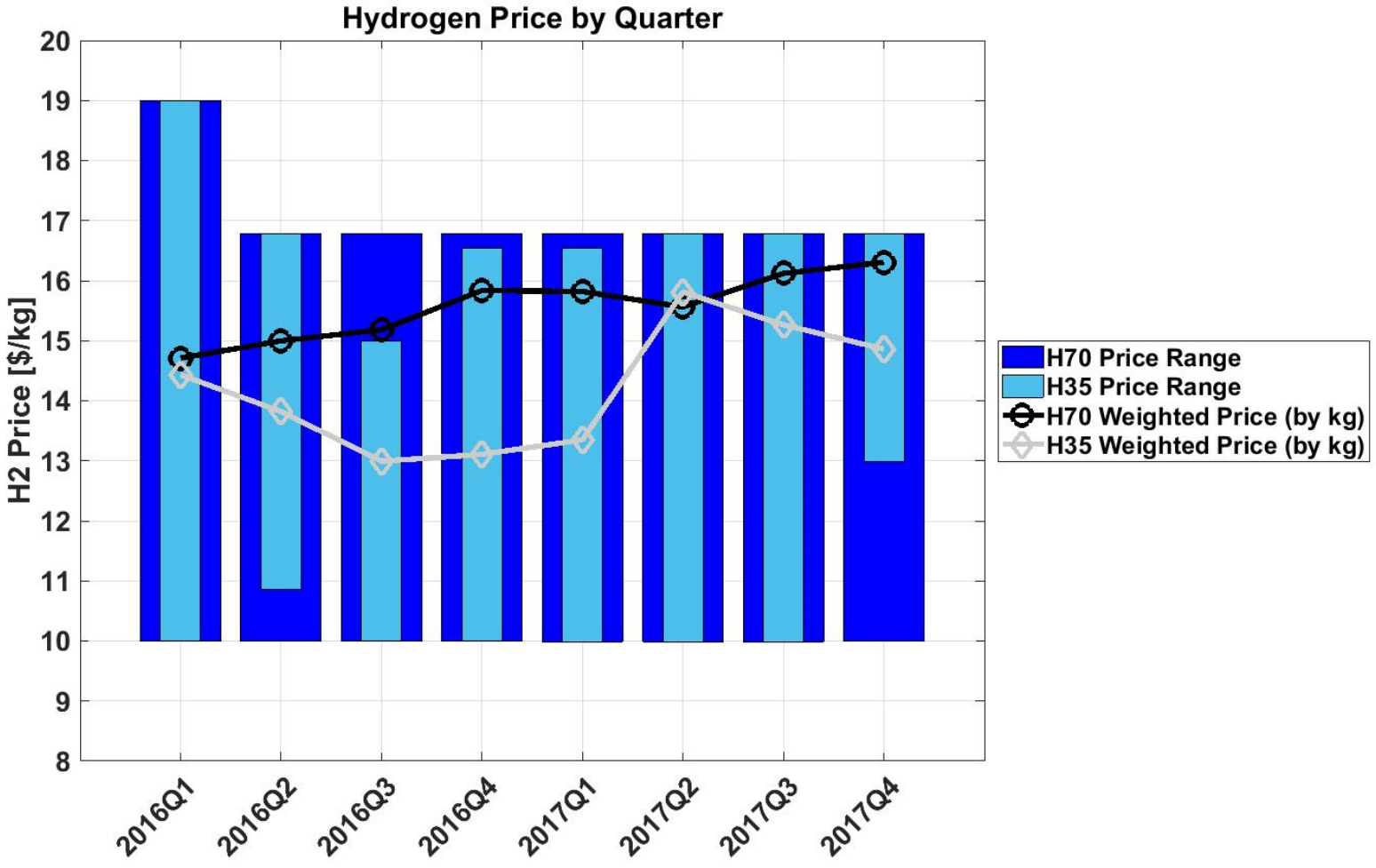
CDP-INFR-73
Monthly Maintenance Costs



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



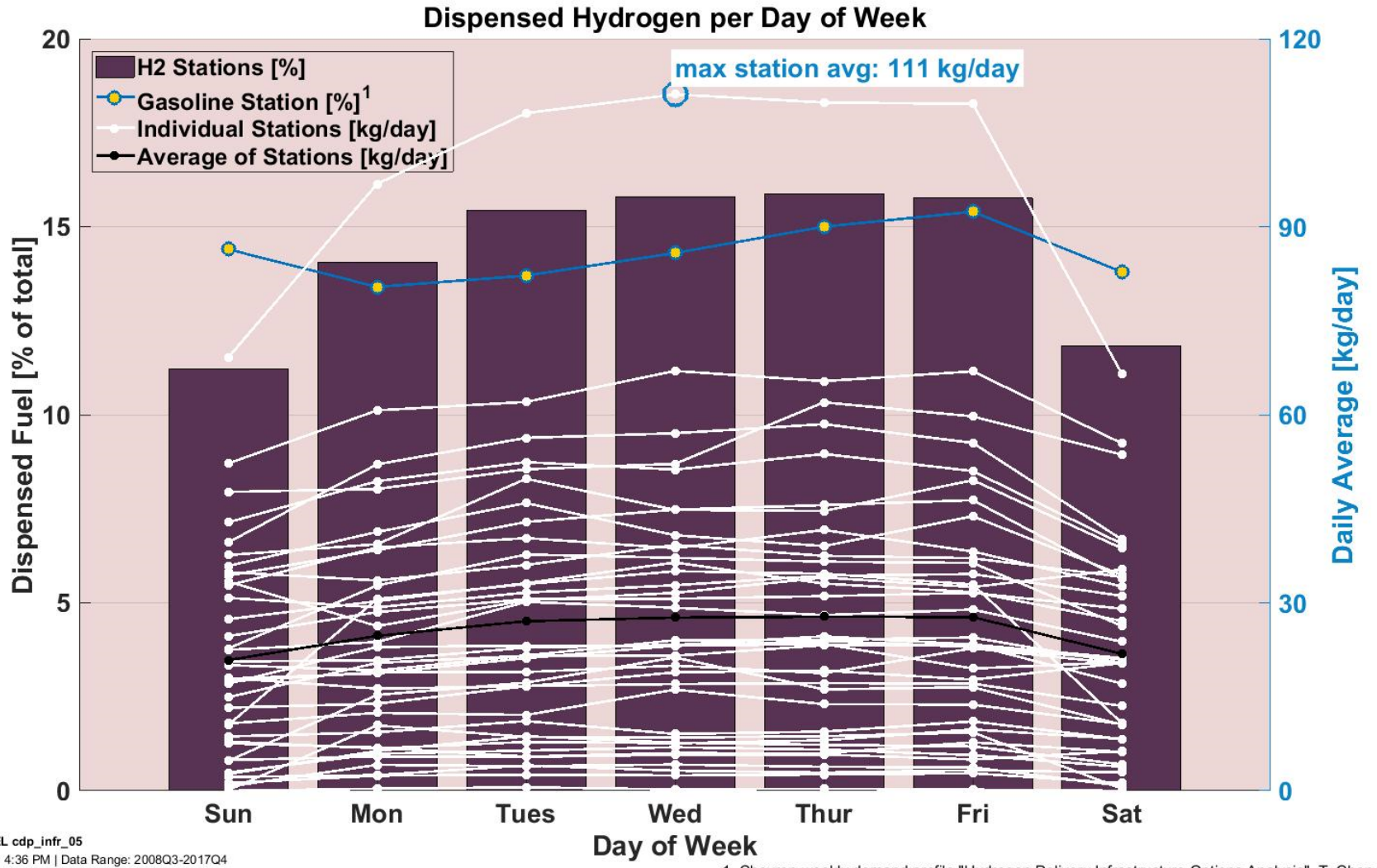
CDP-INFR-89
Hydrogen Price by Quarter



NREL cdp_infr_89
Created: May-04-18 3:49 PM | Data Range: 2008Q3-2017Q4

Utilization

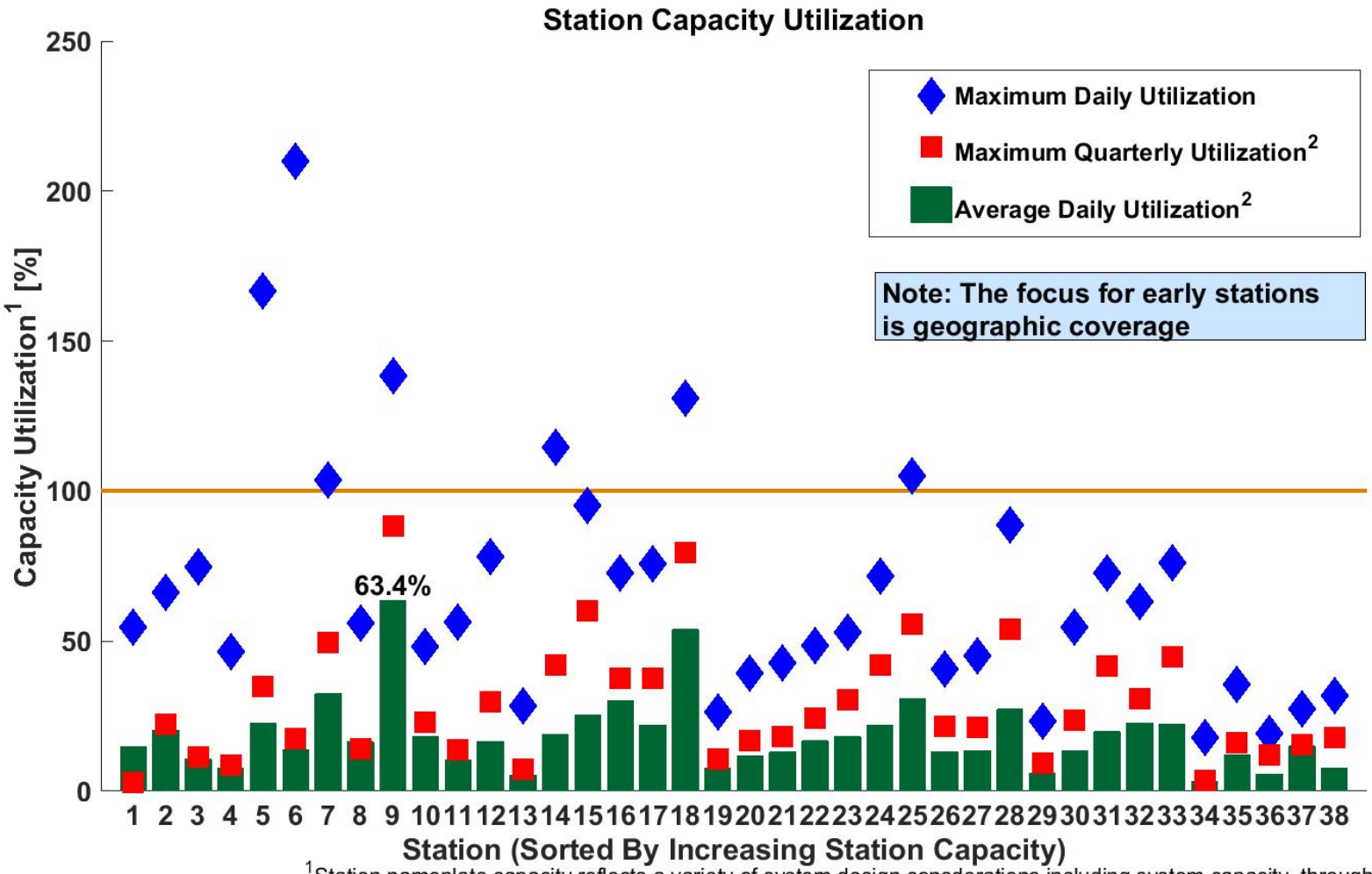
CDP-INFR-05
Dispensed Hydrogen per Day of Week



NREL cdp_infr_05
Created: May-15-18 4:36 PM | Data Range: 2008Q3-2017Q4

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

CDP-INFR-06
Station Capacity Utilization

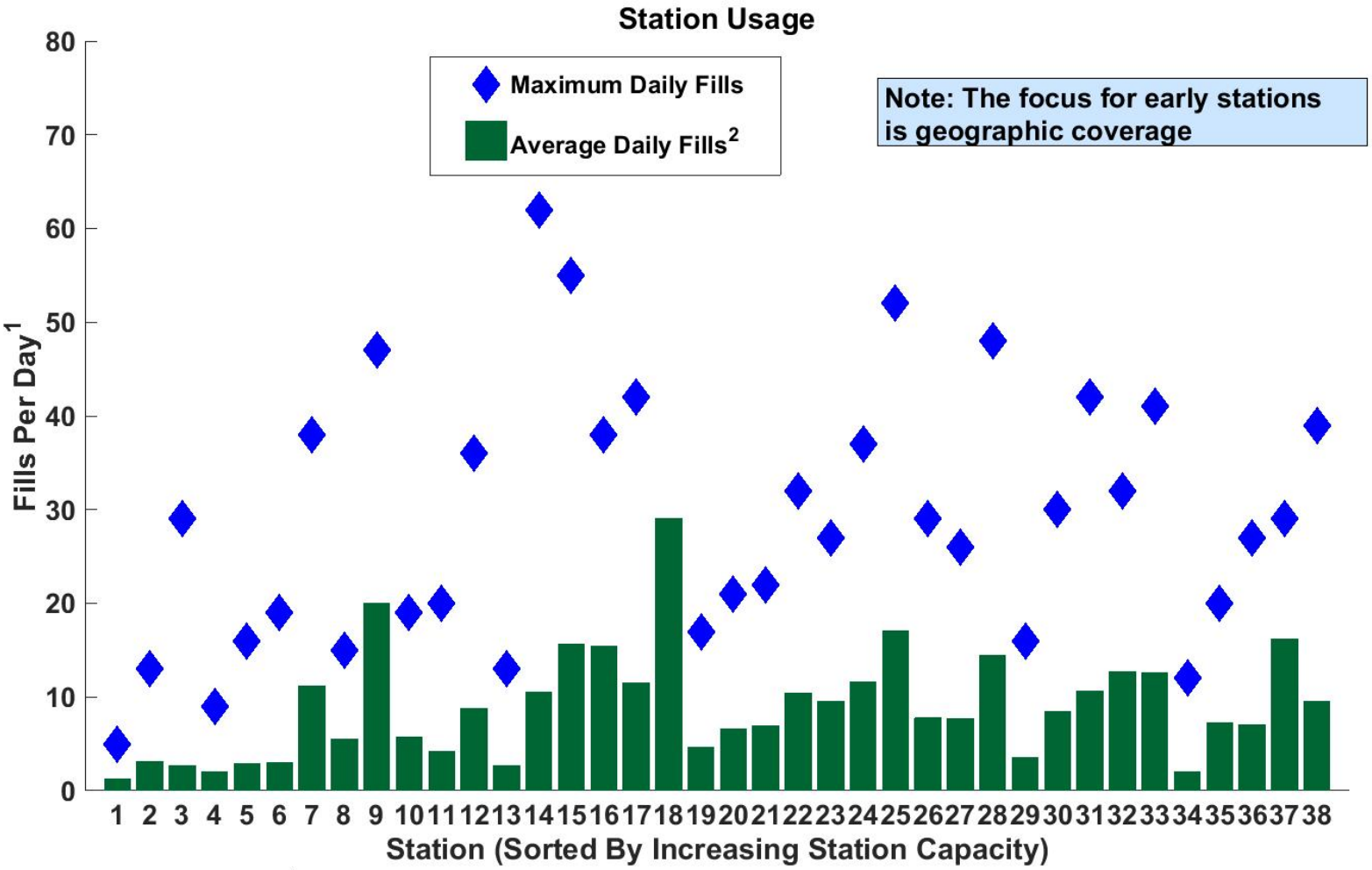


NREL cdp_infr_06
Created: May-15-18 4:42 PM | Data Range: 2008Q3-2017Q4

[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

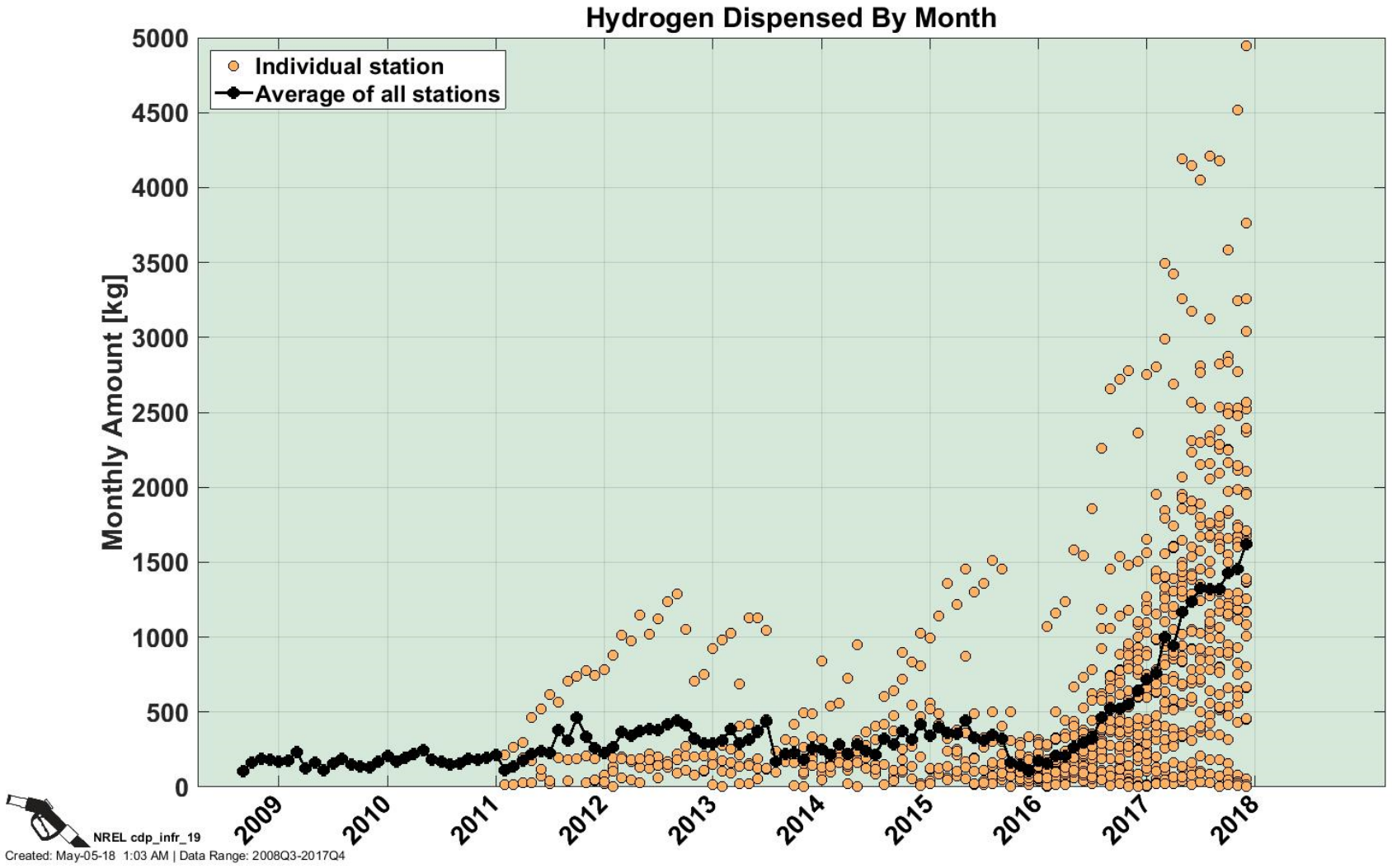


NREL cdp_infr_07
Created: May-15-18 4:47 PM | Data Range: 2008Q3-2017Q4

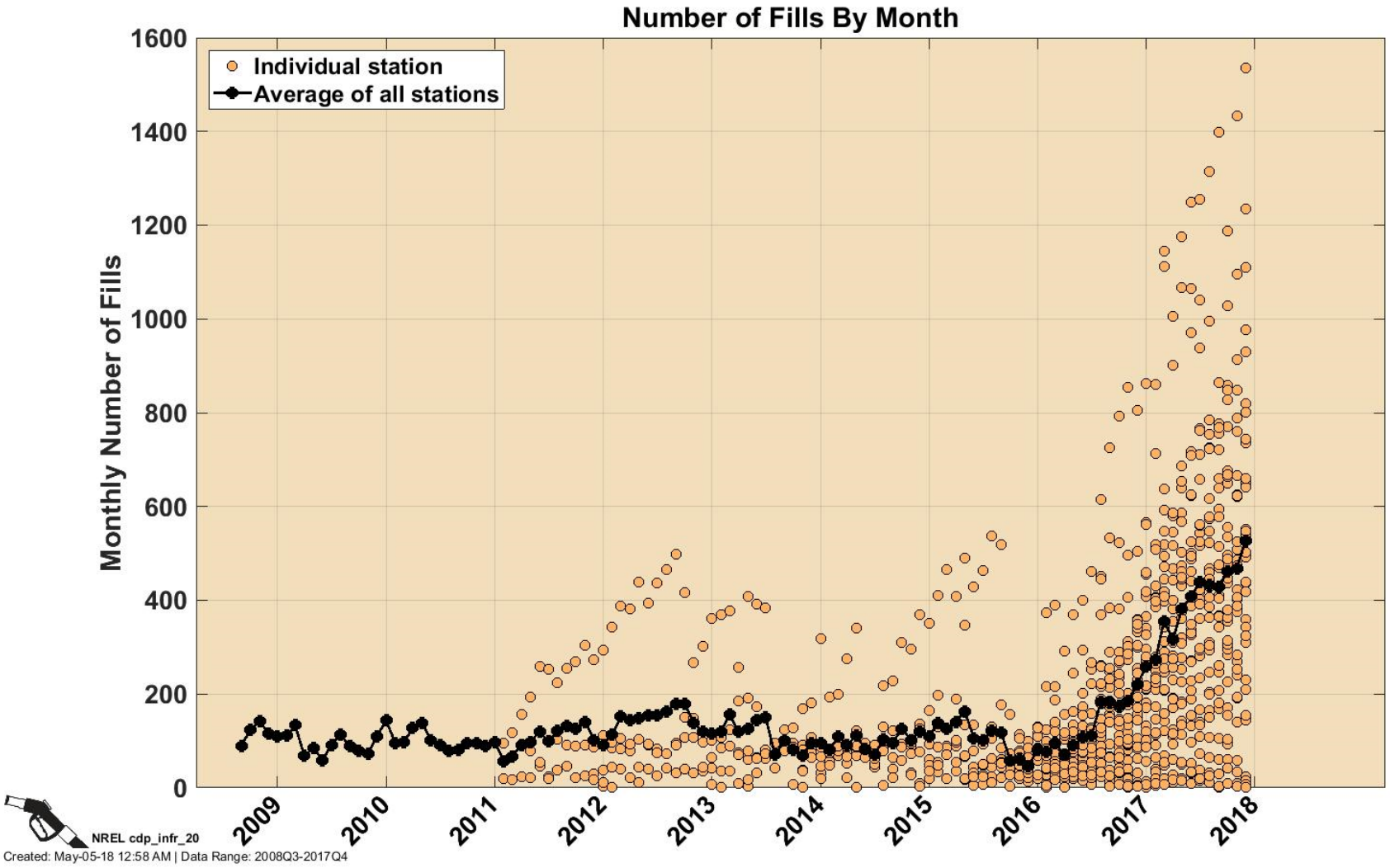
[1]Excludes hydrogen fills of < 0.5 kg

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

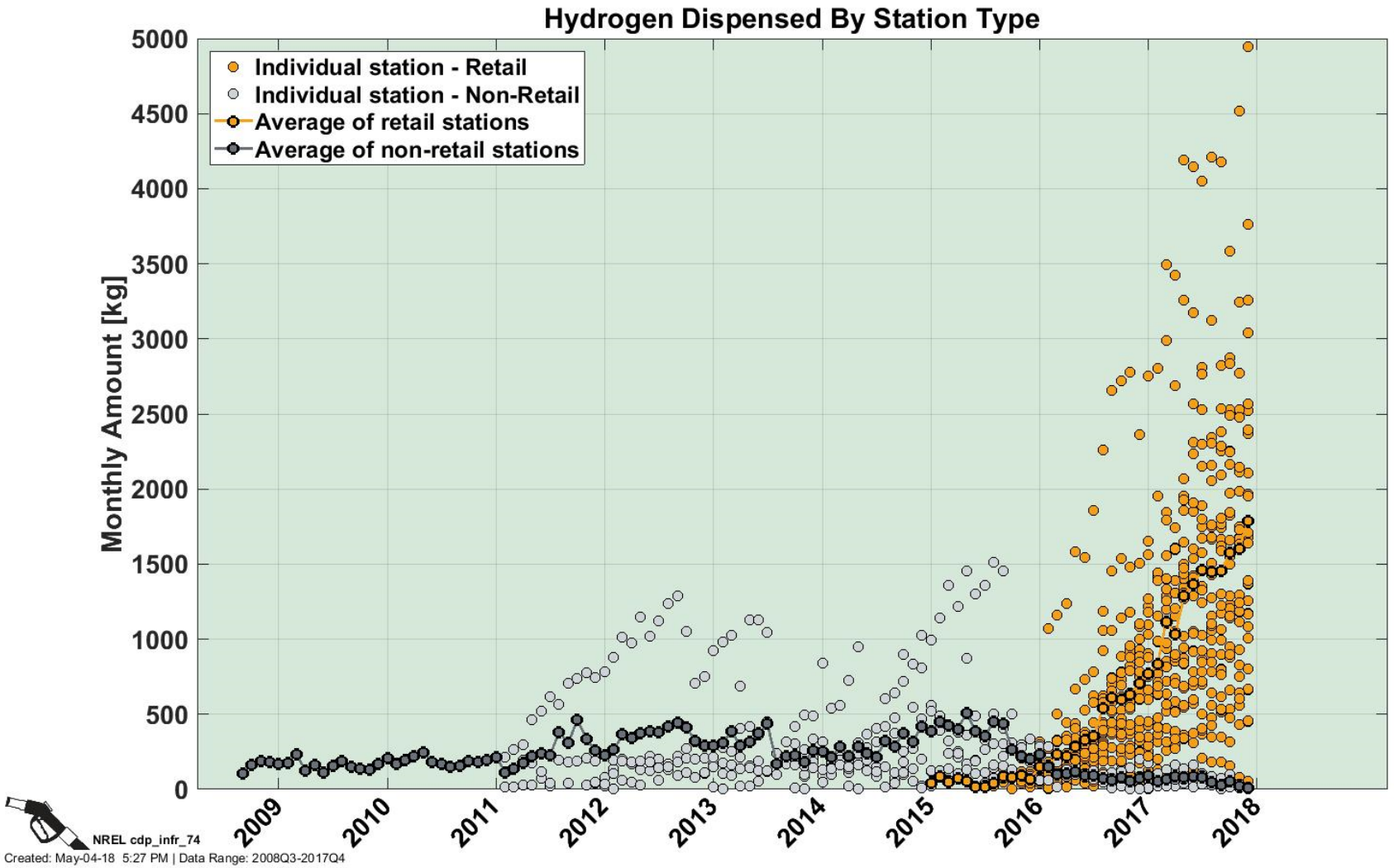
CDP-INFR-19
Hydrogen Dispensed by Month



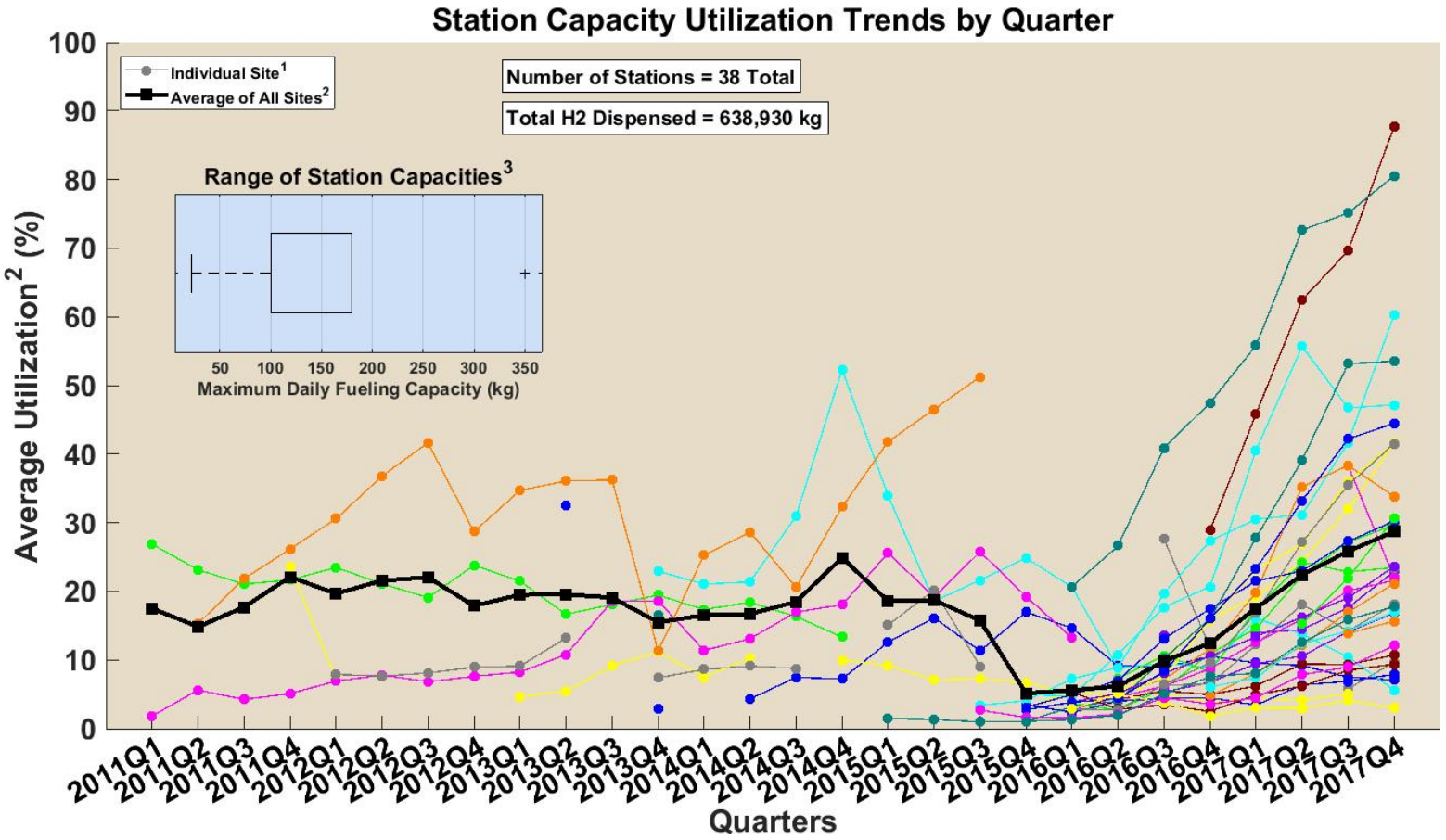
CDP-INFR-20
Number of Fills by Month



CDP-INFR-74
Hydrogen Dispensed by Station Type



CDP-INFR-44
Station Capacity Utilization Trends by Quarter



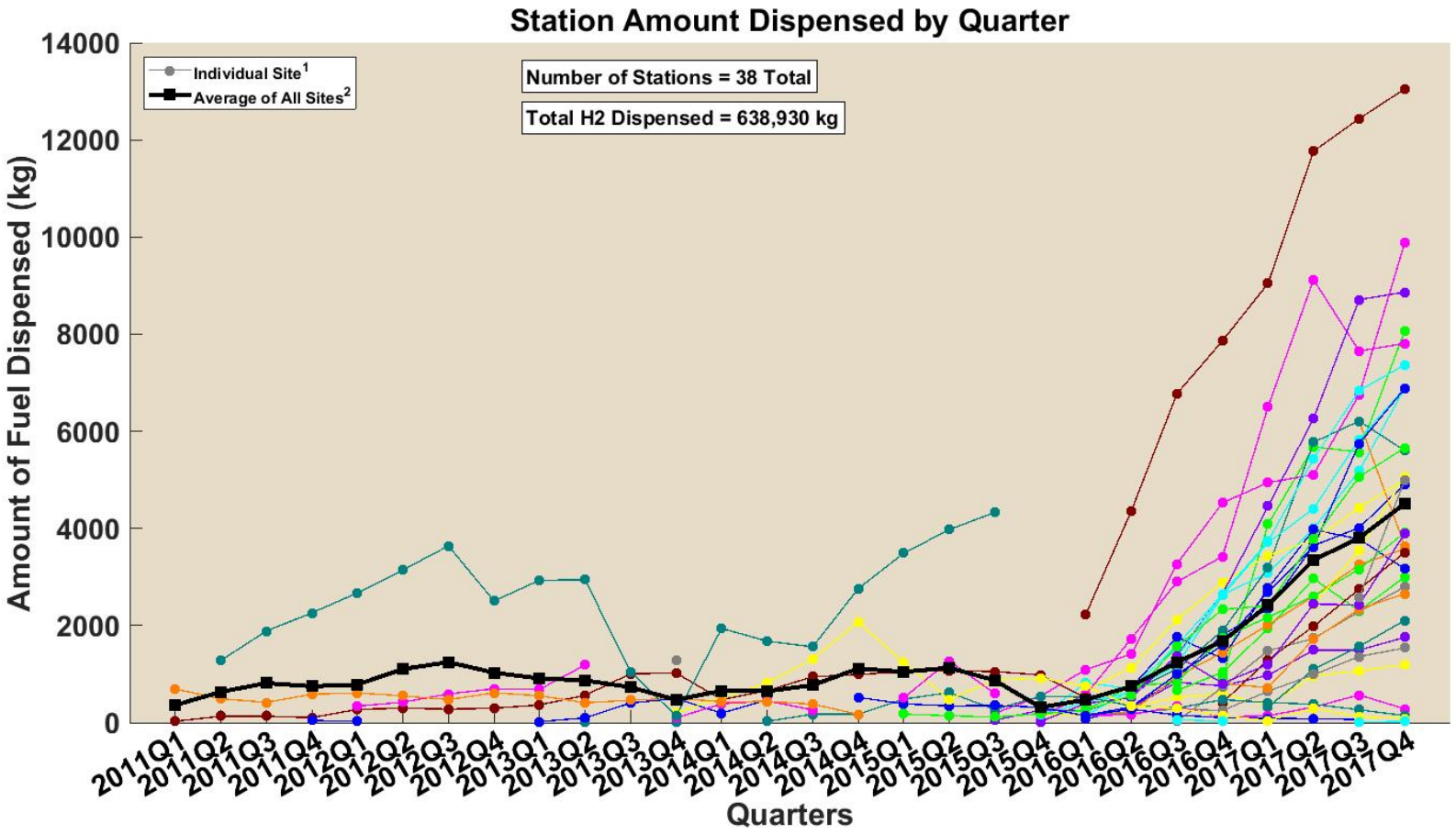
[1] Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

[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 cdp_infr_44
Created: May-07-18 11:36 AM | Data Range: 2008Q3-2017Q4

CDP-INFR-45
Station Amount Dispensed by Quarter

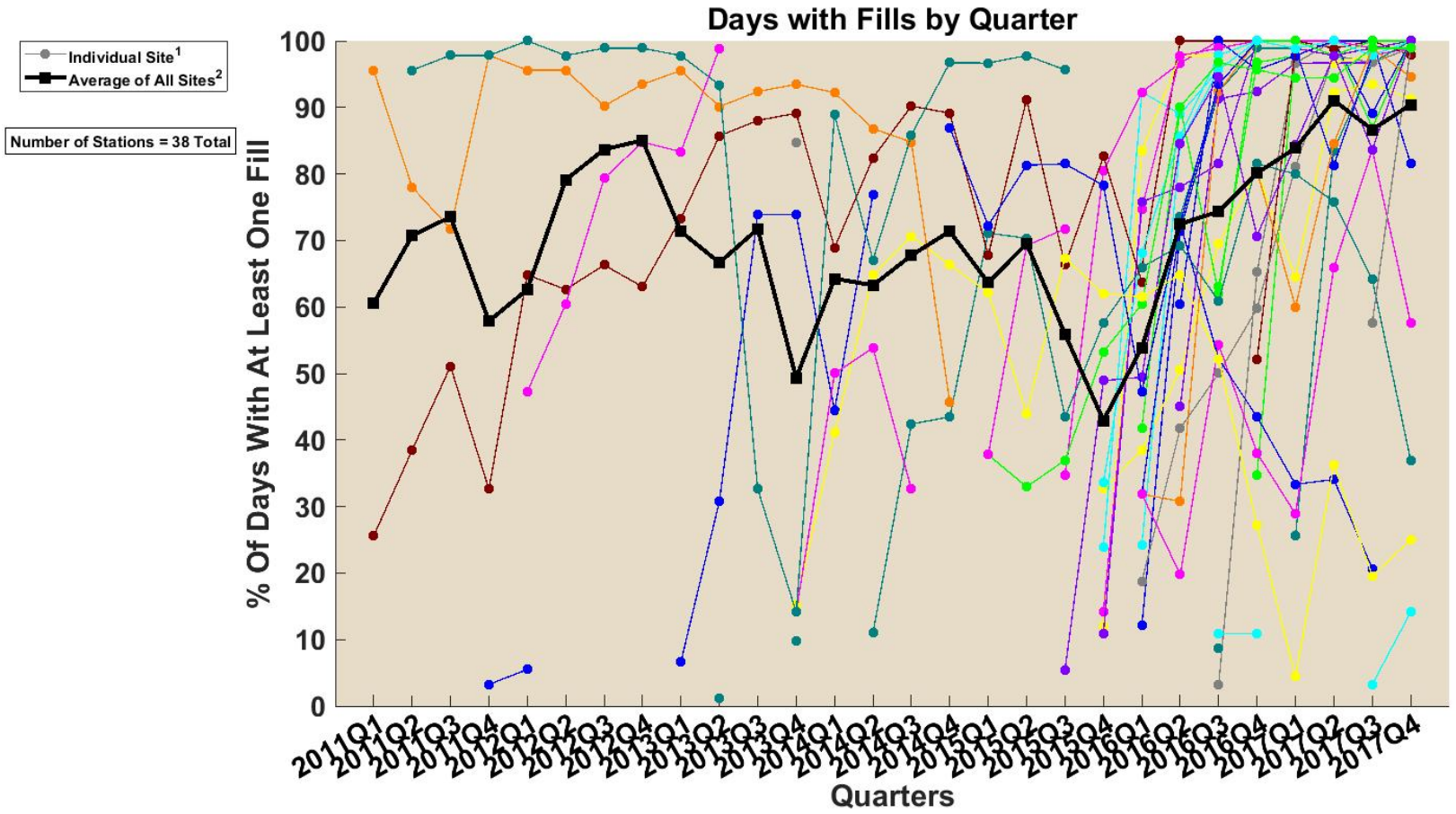


[1] Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

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

NREL cdp_infr_45
Created: May-15-18 5:45 PM | Data Range: 2008Q3-2017Q4

CDP-INFR-46
Days with Fills by Quarter

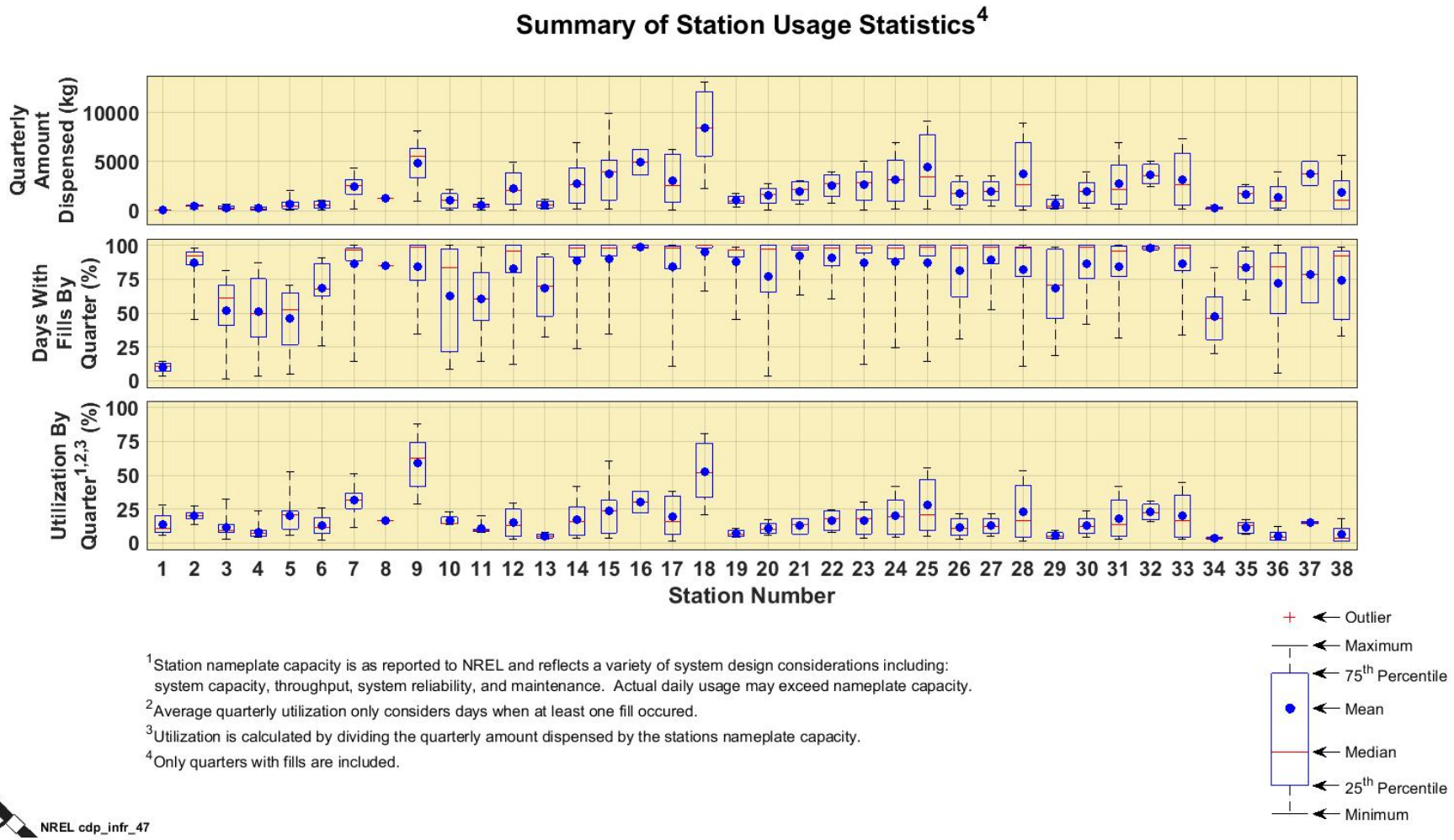


[1] Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station had no fills or was missing data. Each station is represented by a unique color.

[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 cdp_infr_46
Created: May-15-18 5:49 PM | Data Range: 2008Q3-2017Q4

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.

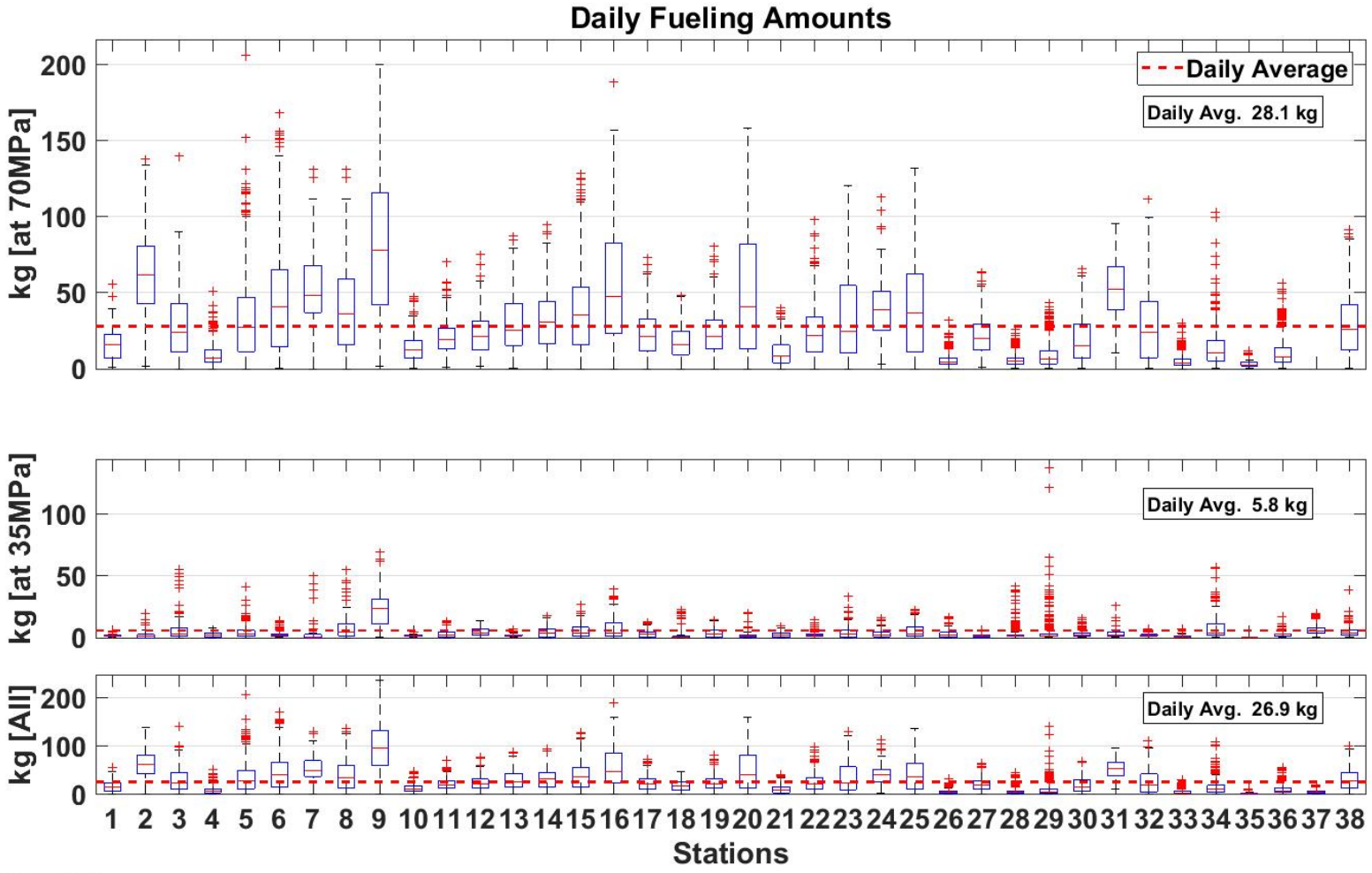
[2]Average quarterly utilization only considers days when at least one fill occured.

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

[4]Only quarters with fills are included.

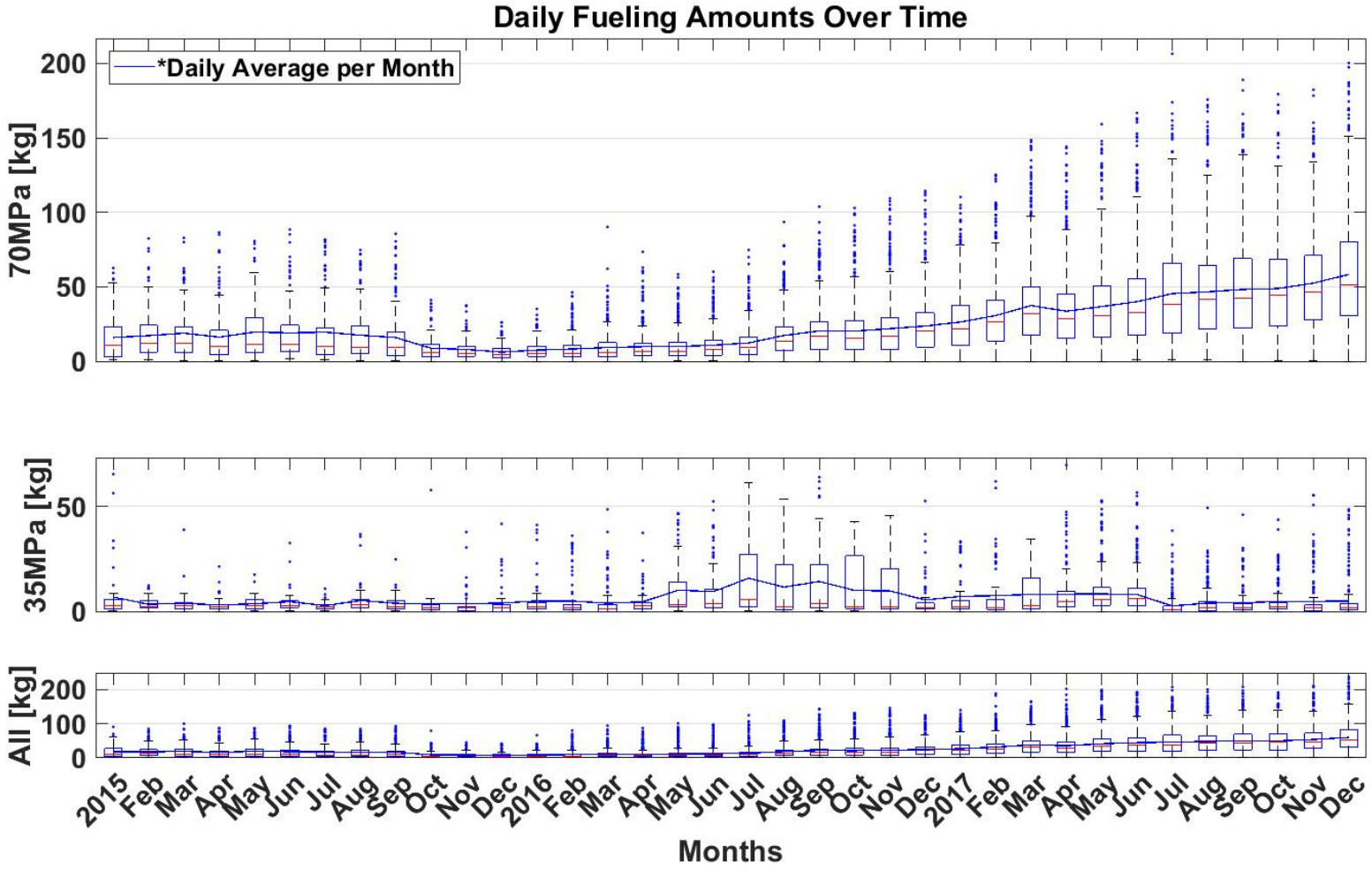
NREL cdp_infr_47
Created: May-04-18 9:01 PM | Data Range: 2008Q3-2017Q4

CDP-INFR-80
Daily Fueling Amounts by Station



NREL cdp_infr_80
Created: May-04-18 4:56 PM | Data Range: 2008Q3-2017Q4

CDP-INFR-82
Daily Fueling Amounts by Month

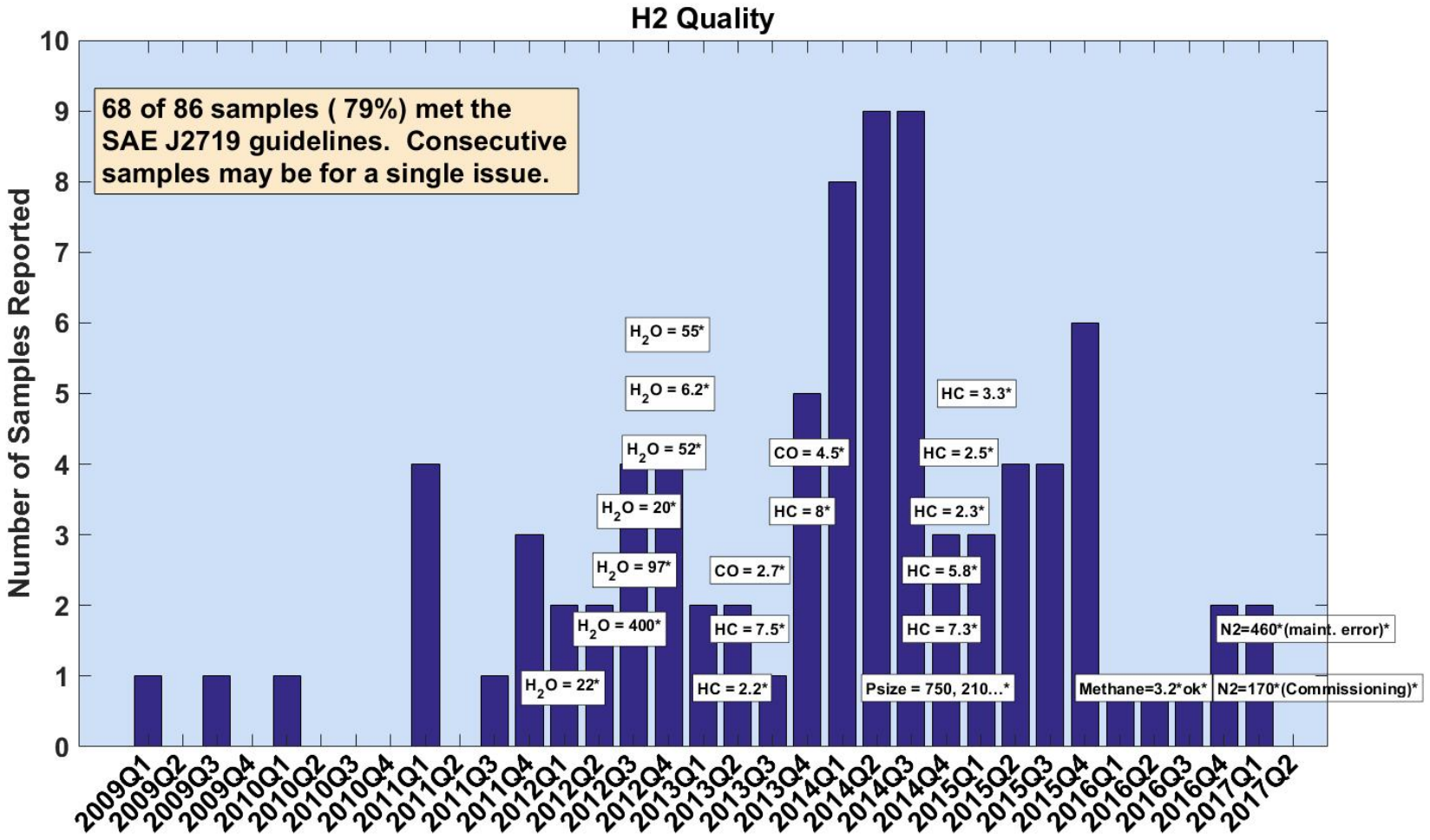


NREL cdp_infr_82
Created: May-04-18 4:35 PM | Data Range: 2008Q3-2017Q4

*Daily average only includes days with fills.

Hydrogen Quality

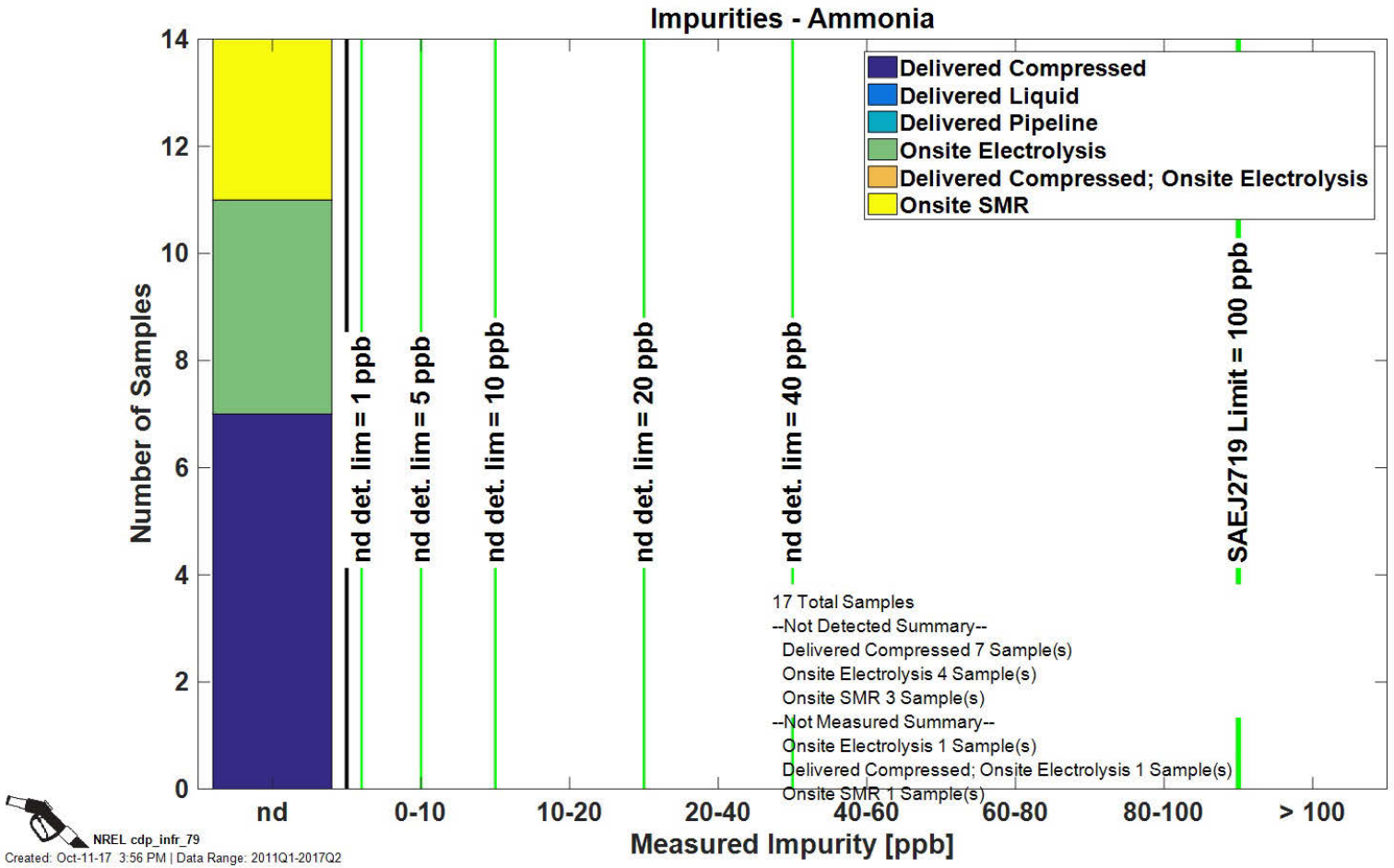
CDP-INFR-25
Hydrogen Quality



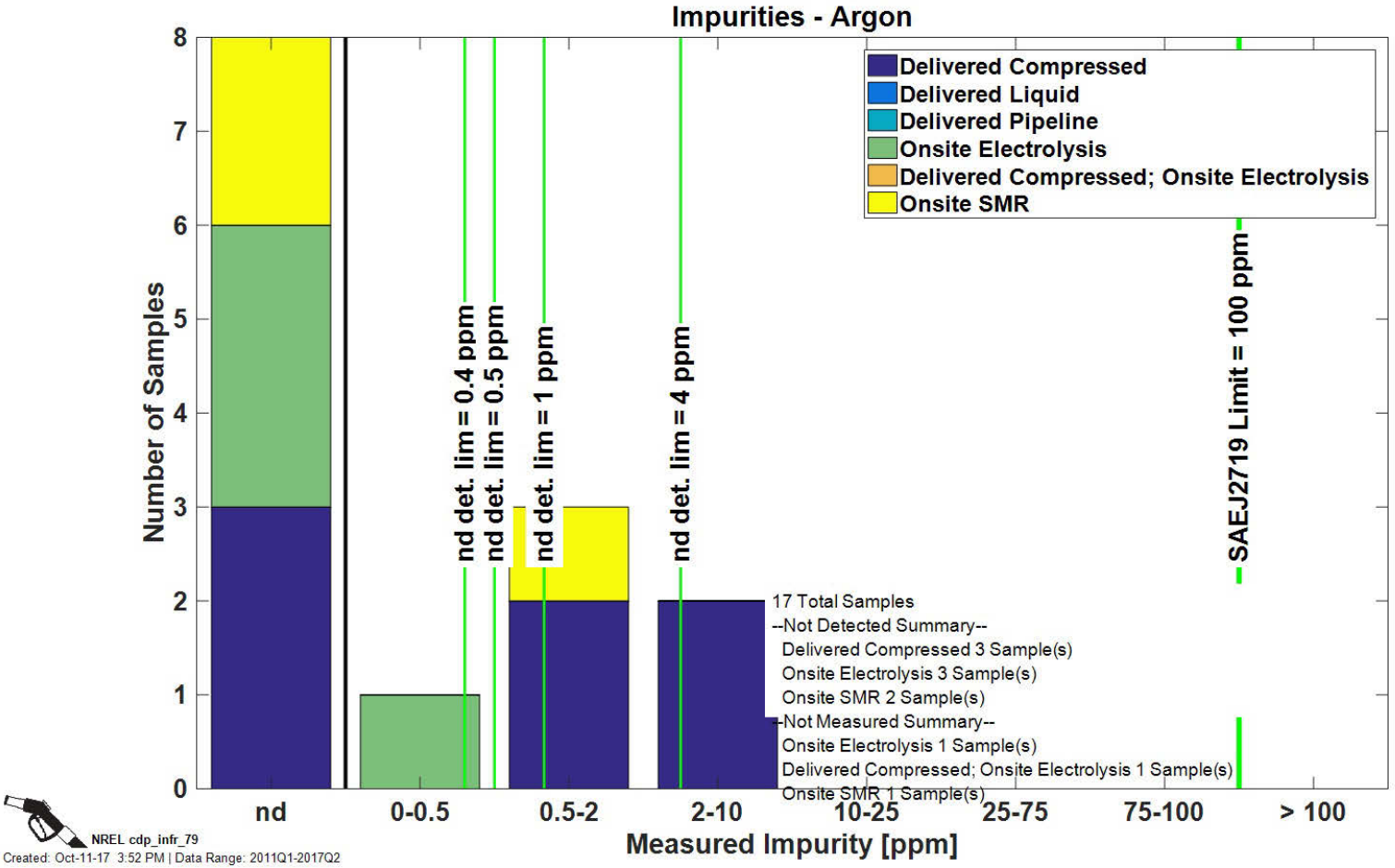
NREL cdp_infr_25
Created: Oct-11-17 3:52 PM | Data Range: 2008Q3-2017Q2

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

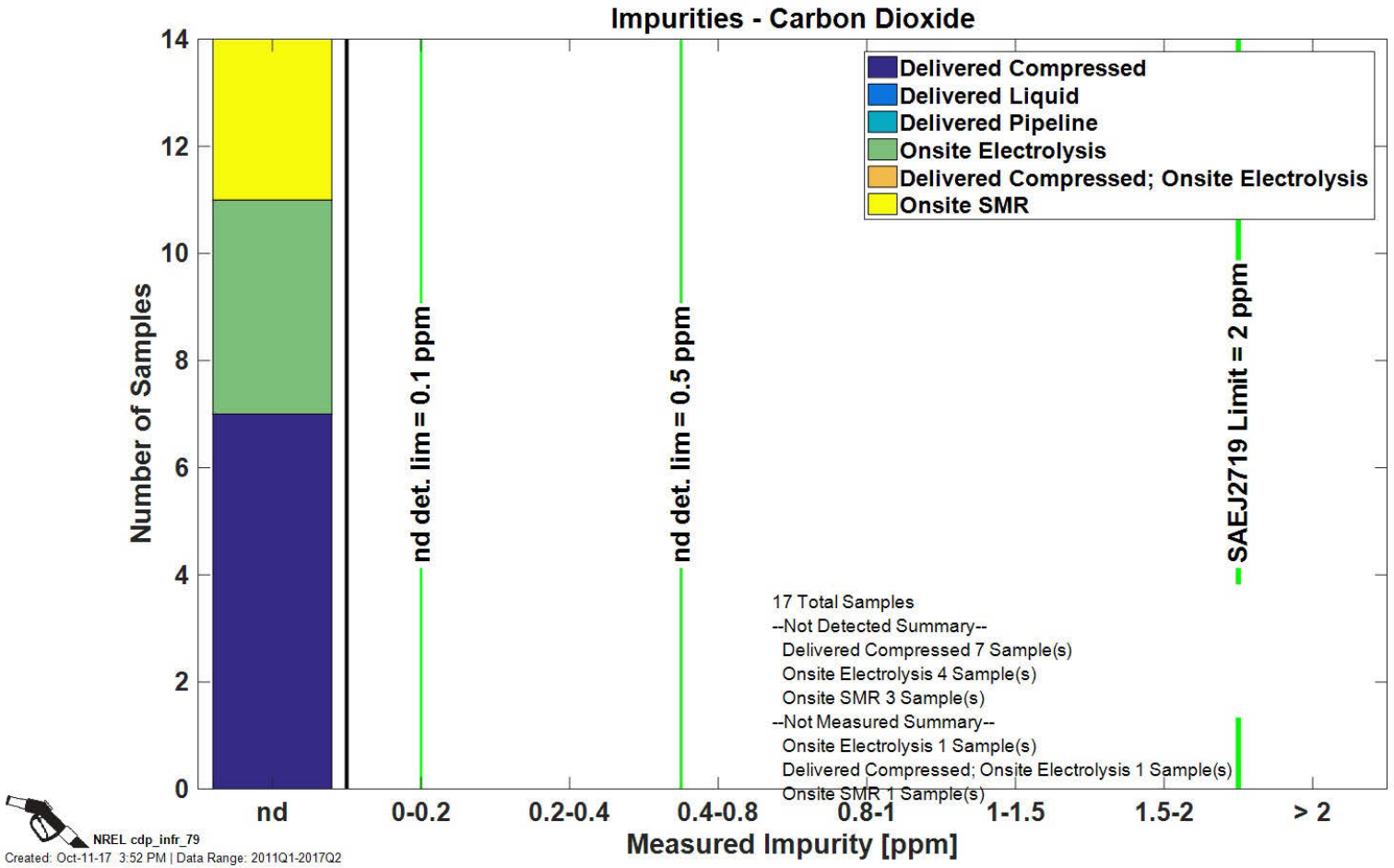
CDP-INFR-79
Impurities—Ammonia



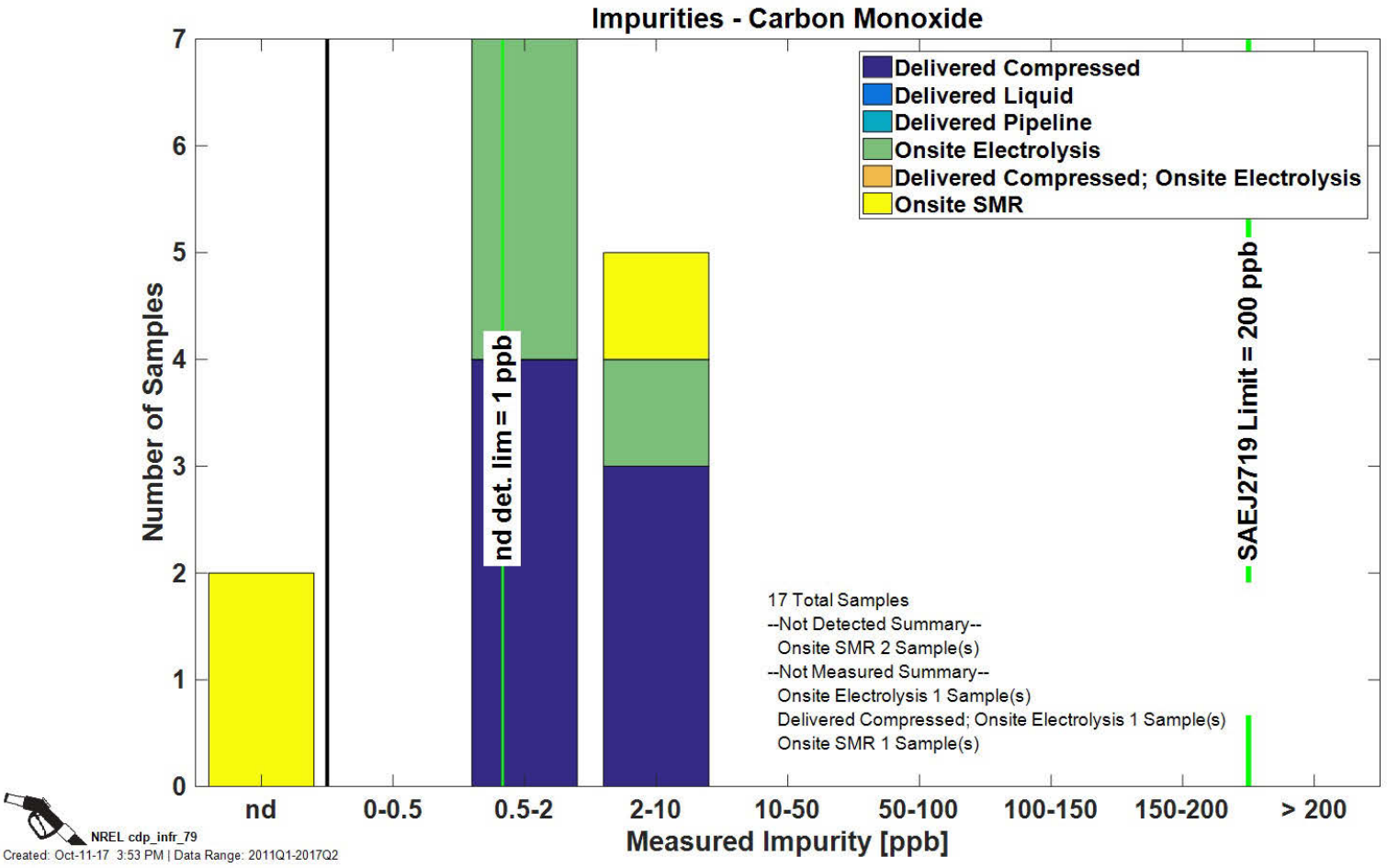
CDP-INFR-79
Impurities—Argon



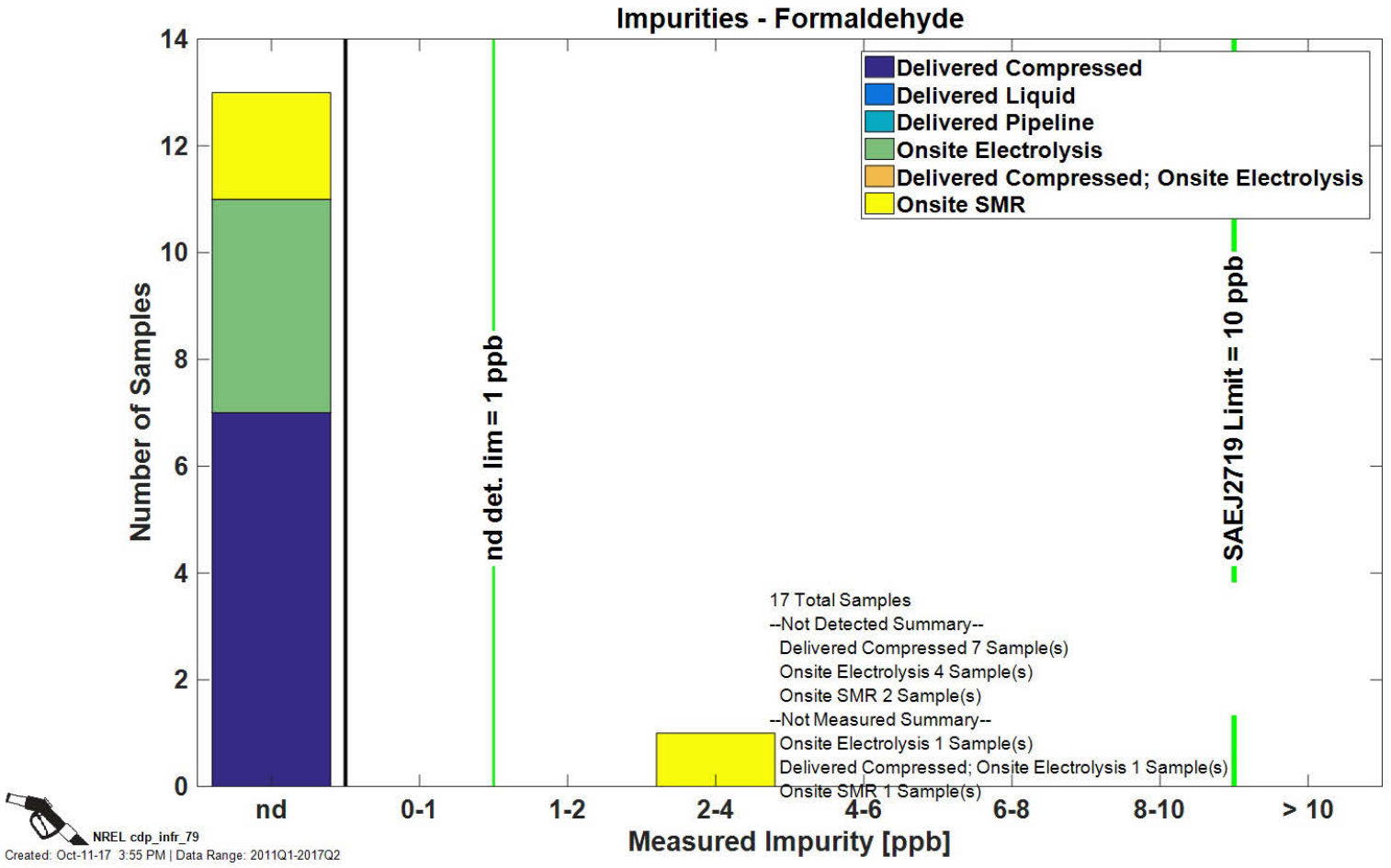
CDP-INFR-79
Impurities—Carbon Dioxide



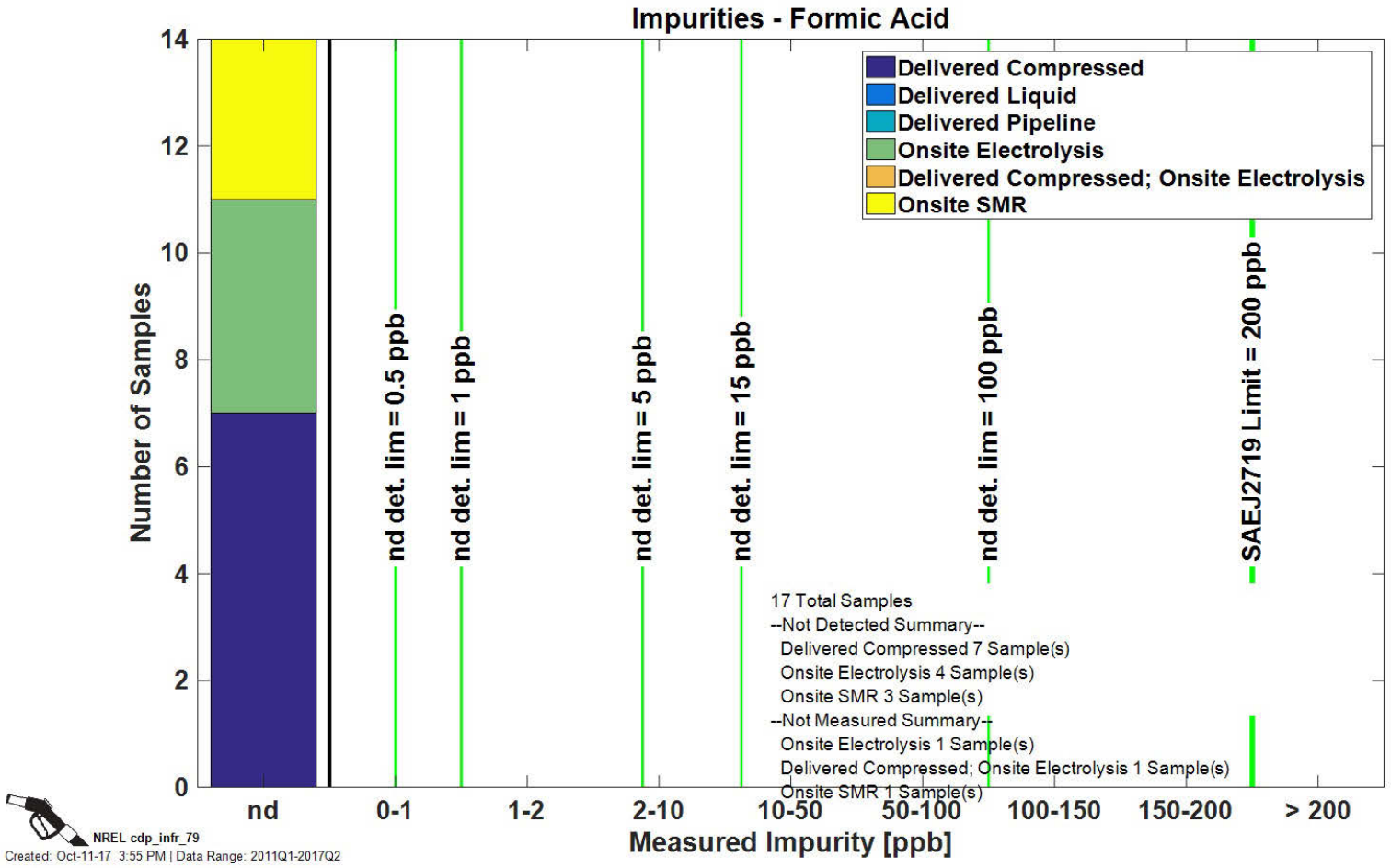
CDP-INFR-79
Impurities—Carbon Monoxide



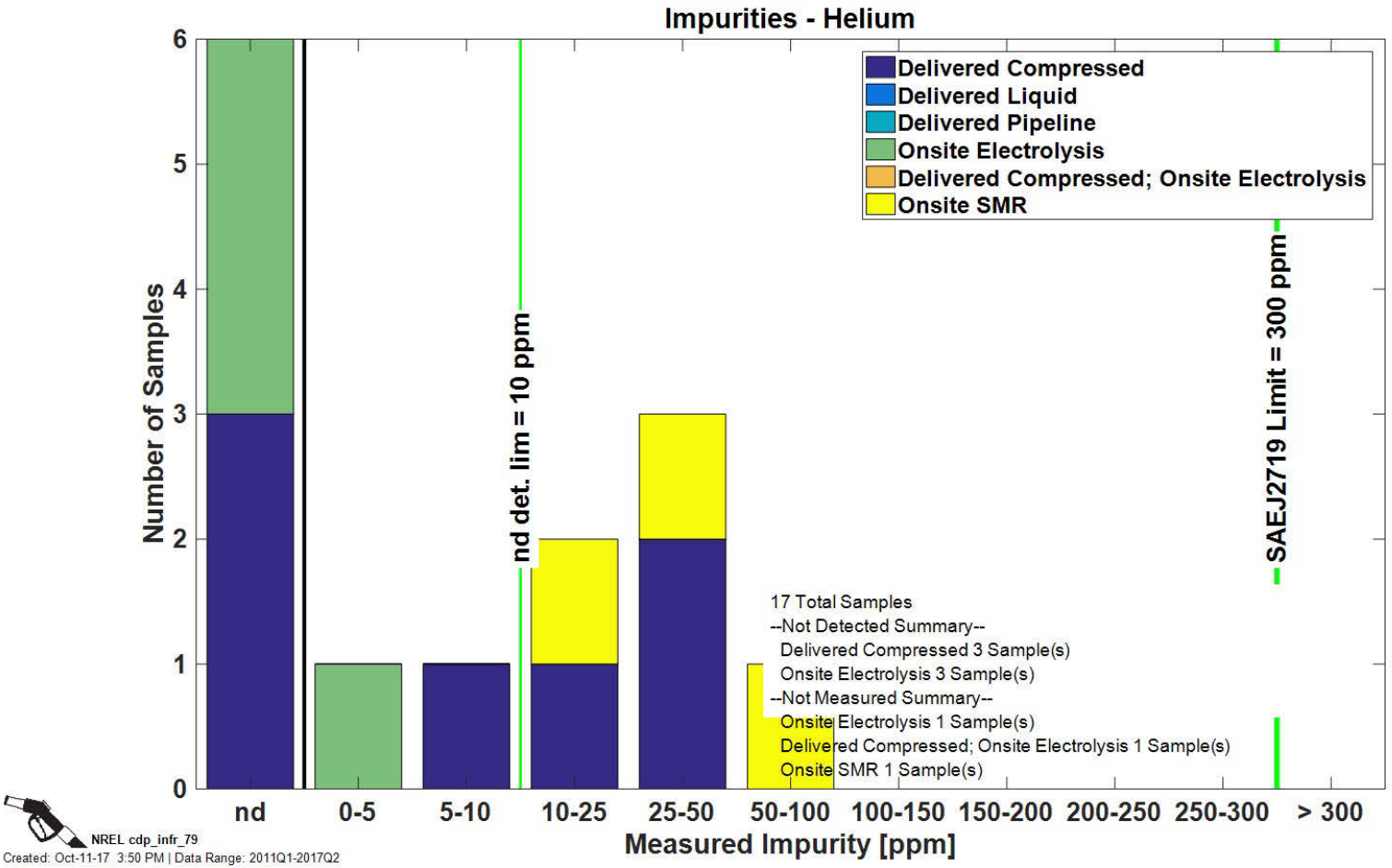
CDP-INFR-79
Impurities—Formaldehyde



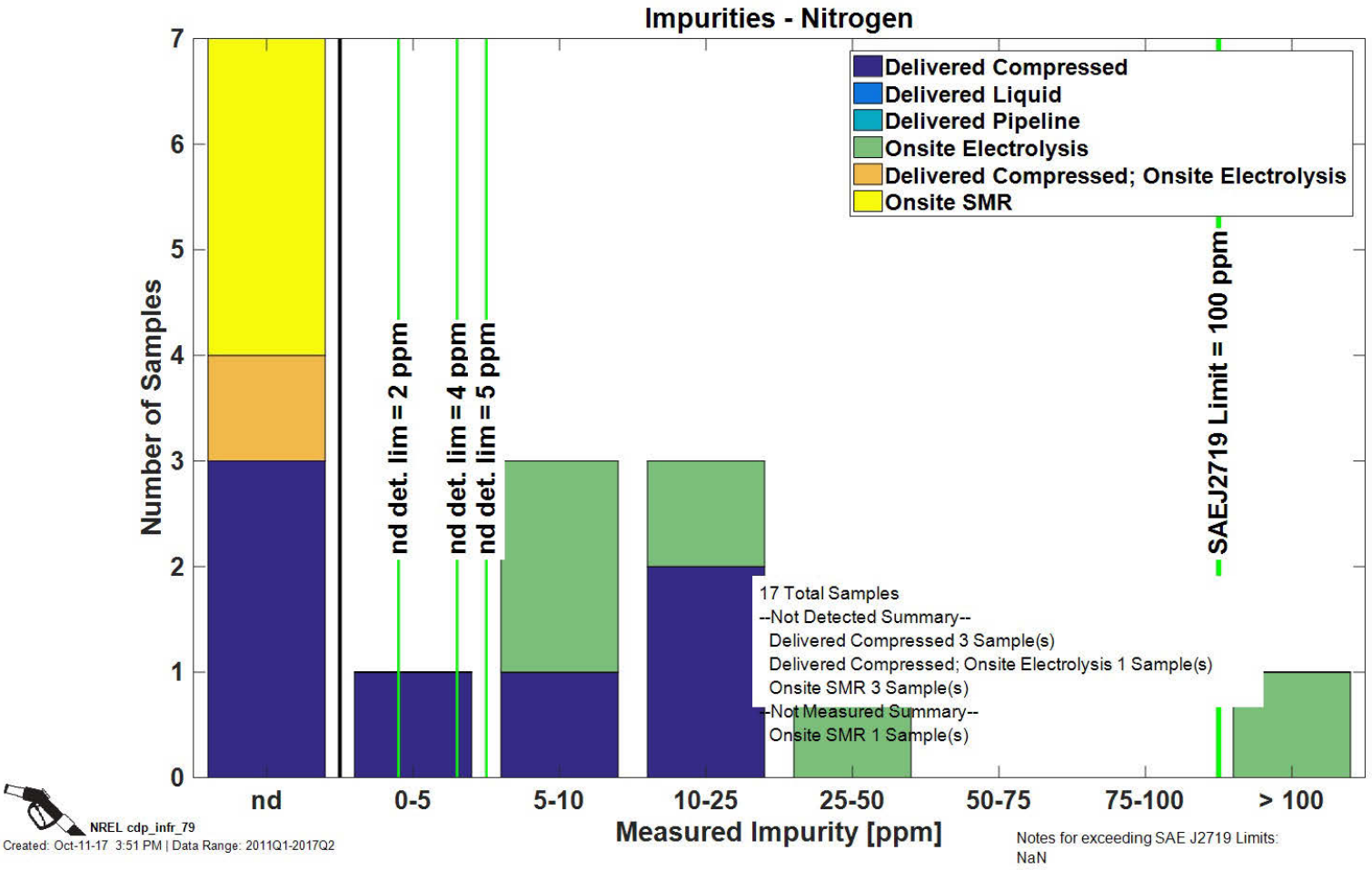
CDP-INFR-79
Impurities—Formic Acid



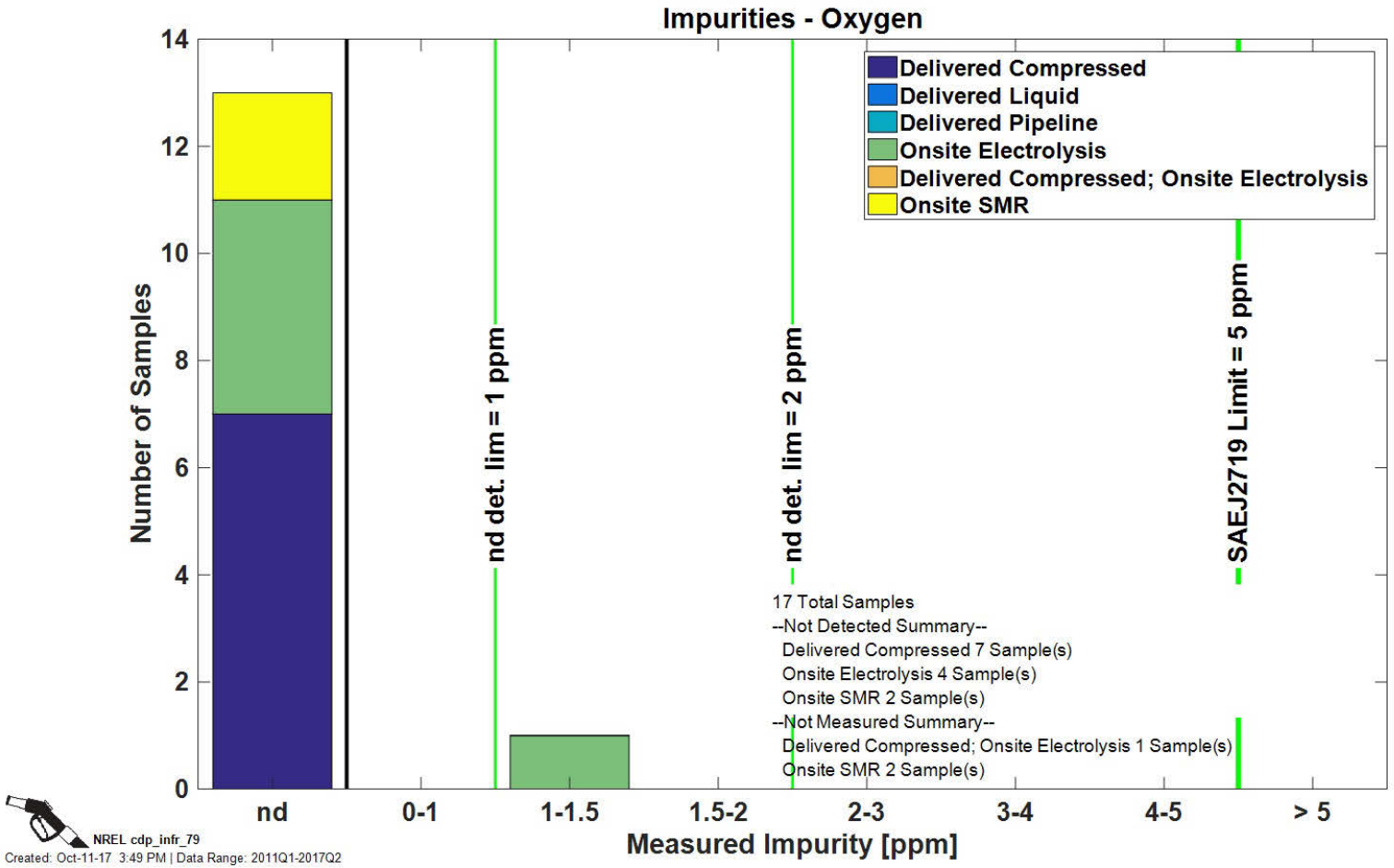
CDP-INFR-79
Impurities—Helium



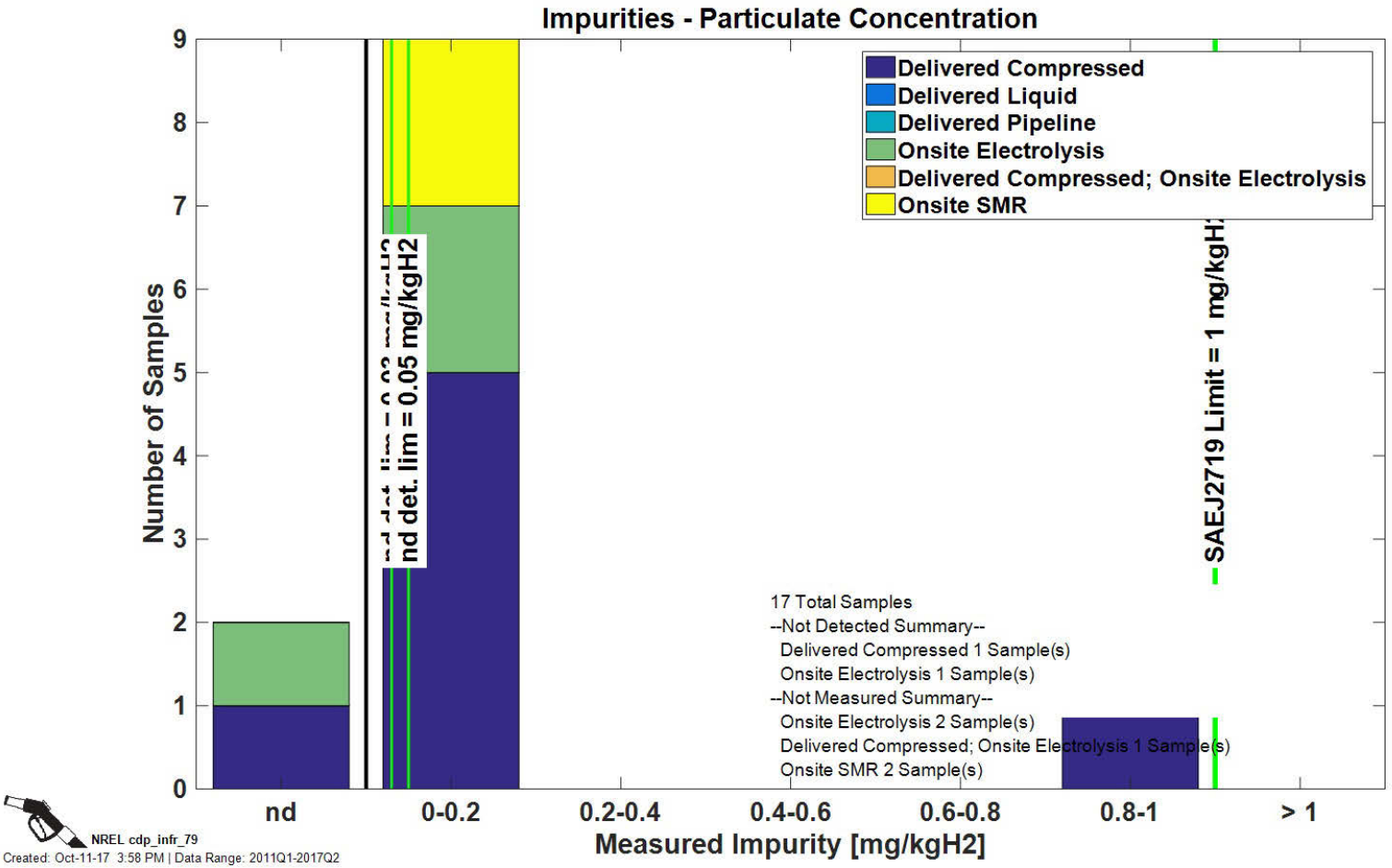
CDP-INFR-79
Impurities—Nitrogen



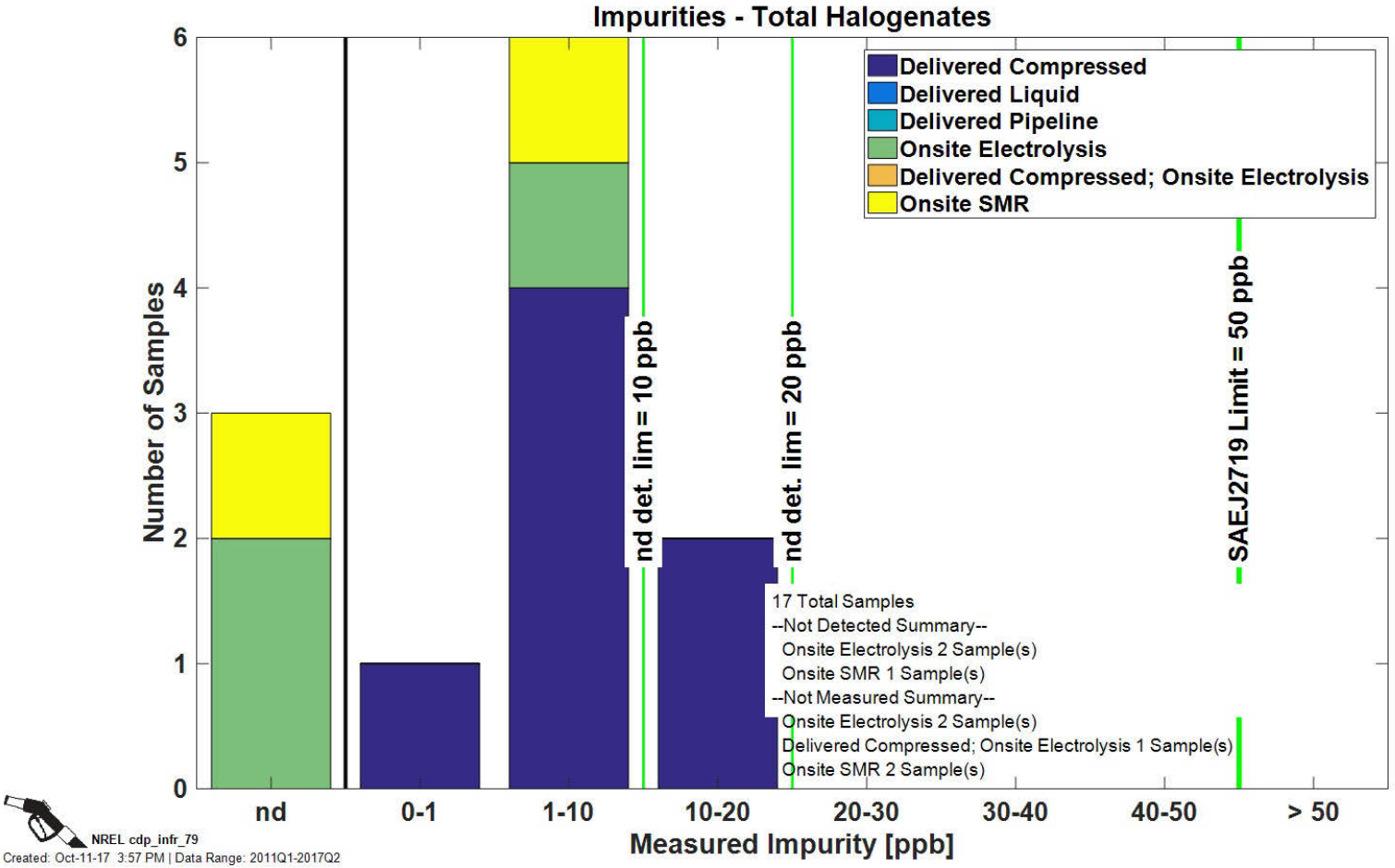
CDP-INFR-79
Impurities—Oxygen



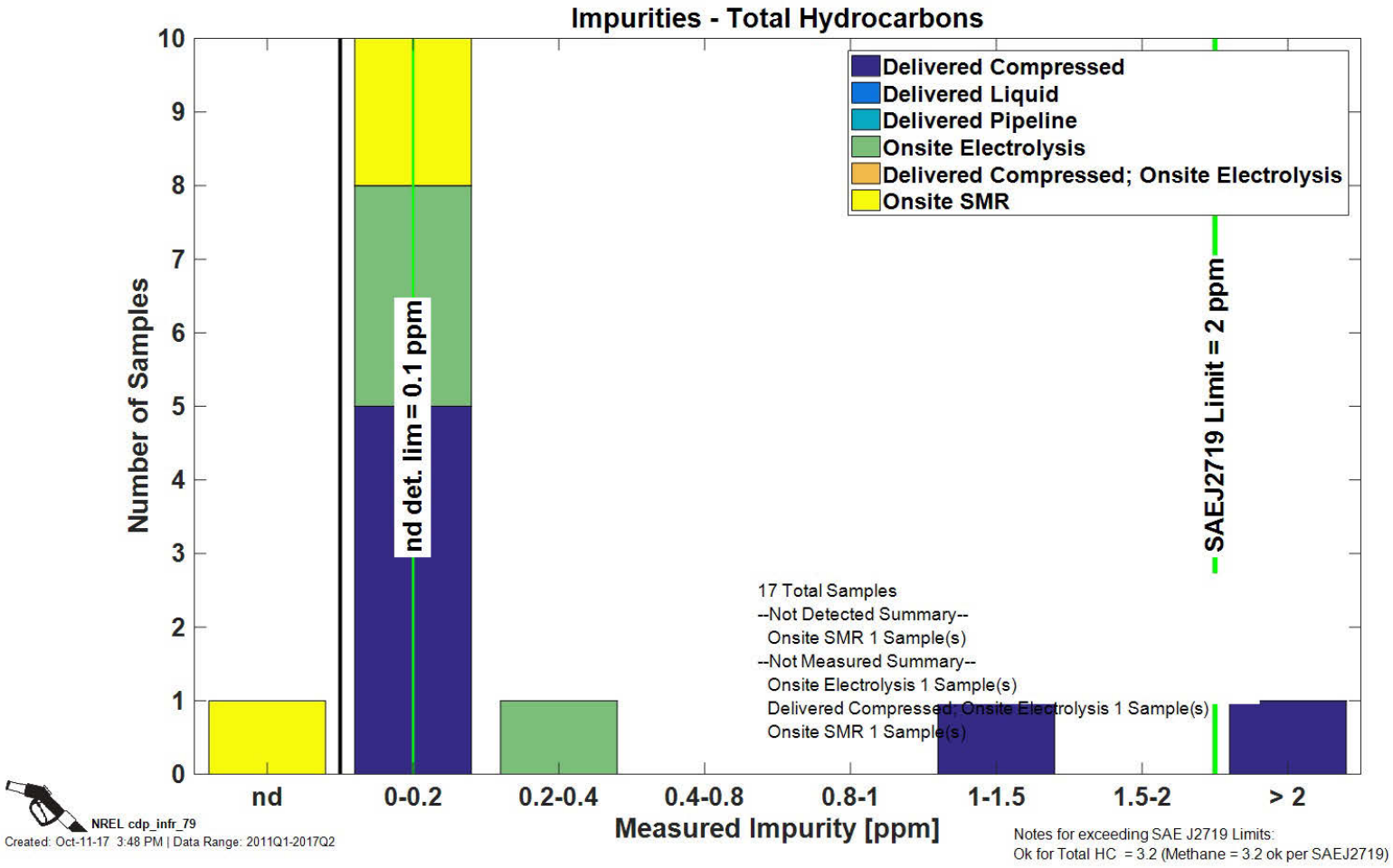
CDP-INFR-79
Impurities—Particulate Concentration



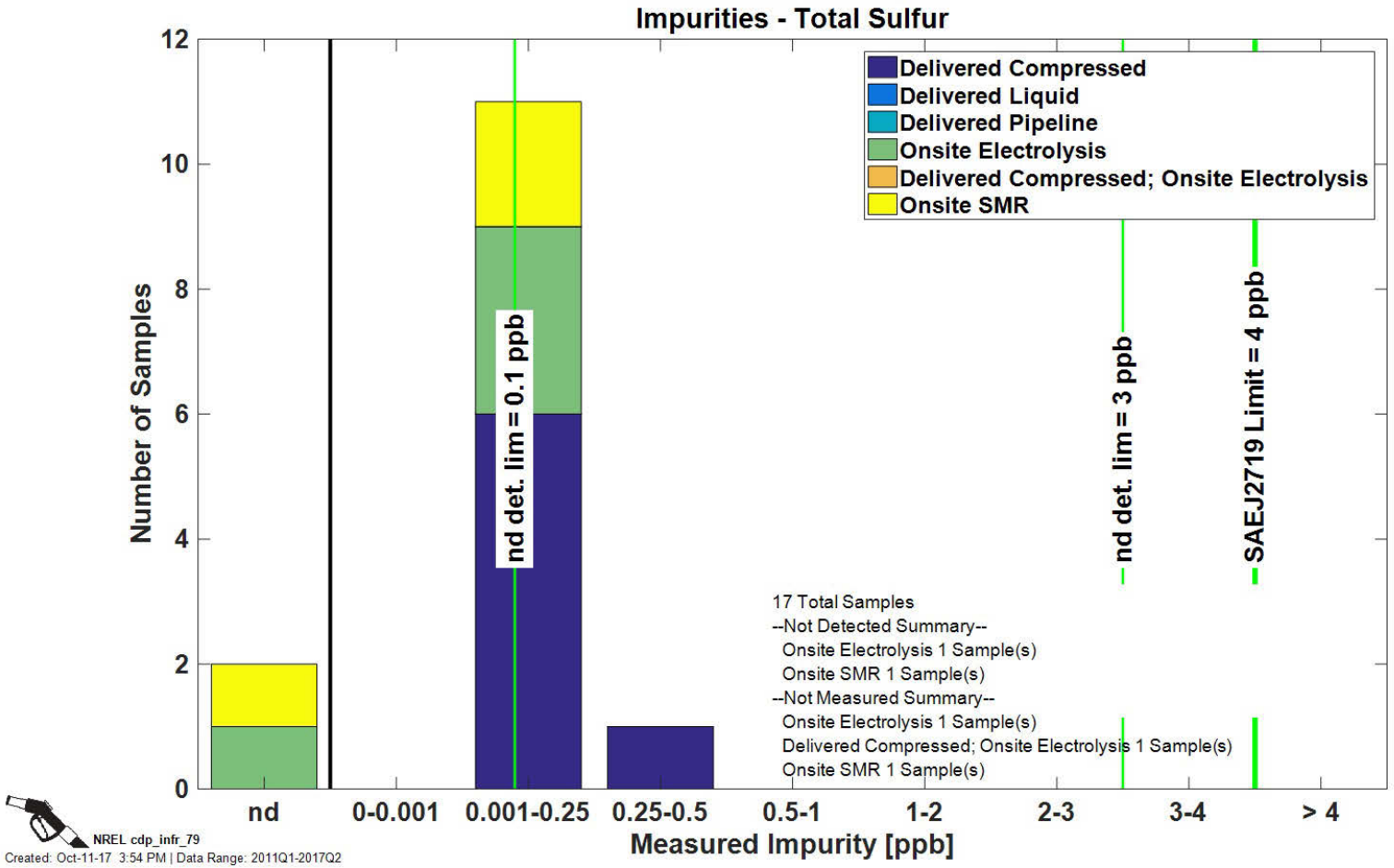
CDP-INFR-79
Impurities—Total Halogenates



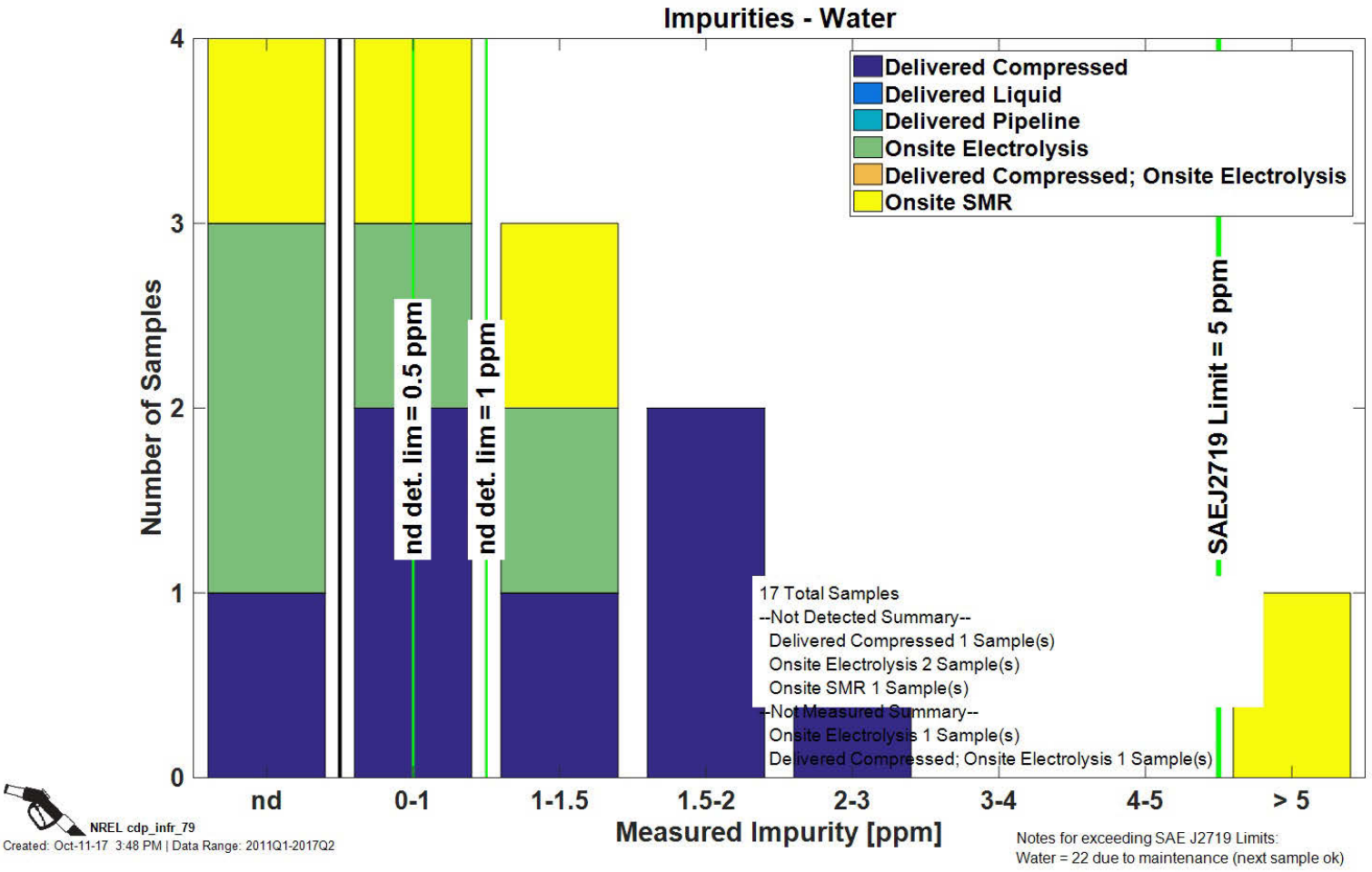
CDP-INFR-79
Impurities—Total Hydrocarbons



CDP-INFR-79
Impurities—Total Sulfur

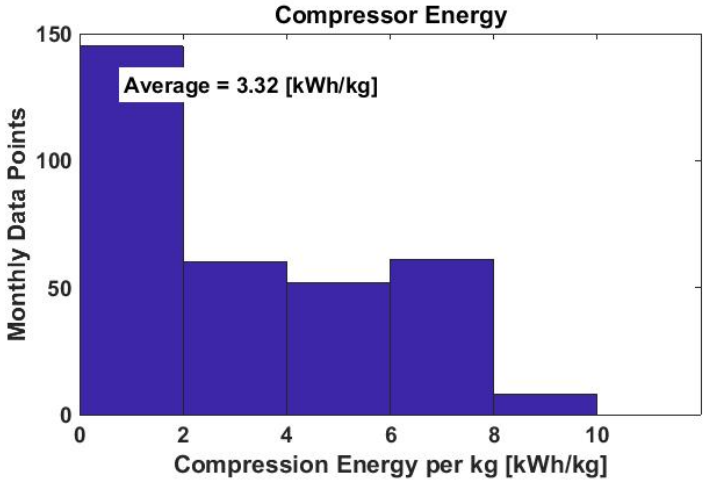


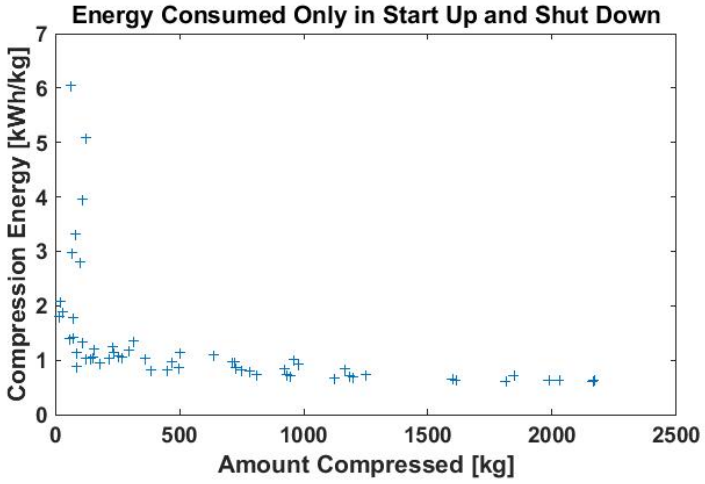
CDP-INFR-79
Impurities—Water

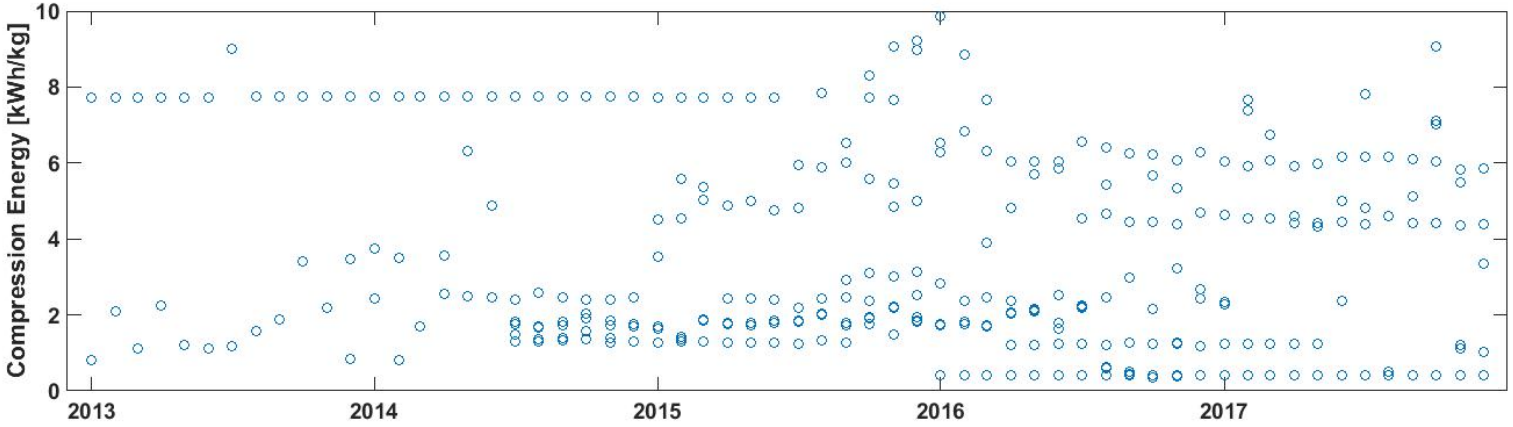


Component Energy

CDP-INFR-35
Compressor Energy







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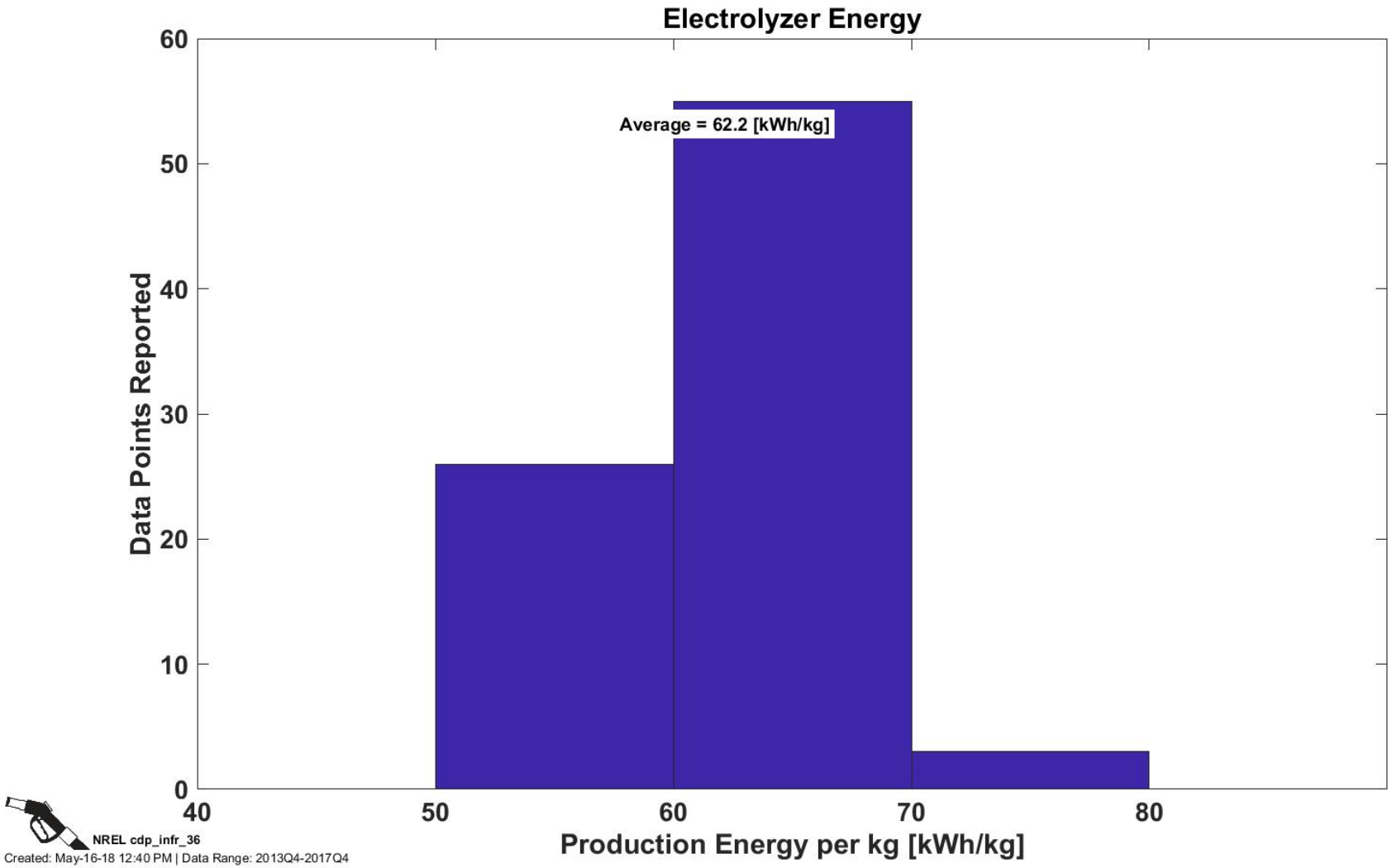
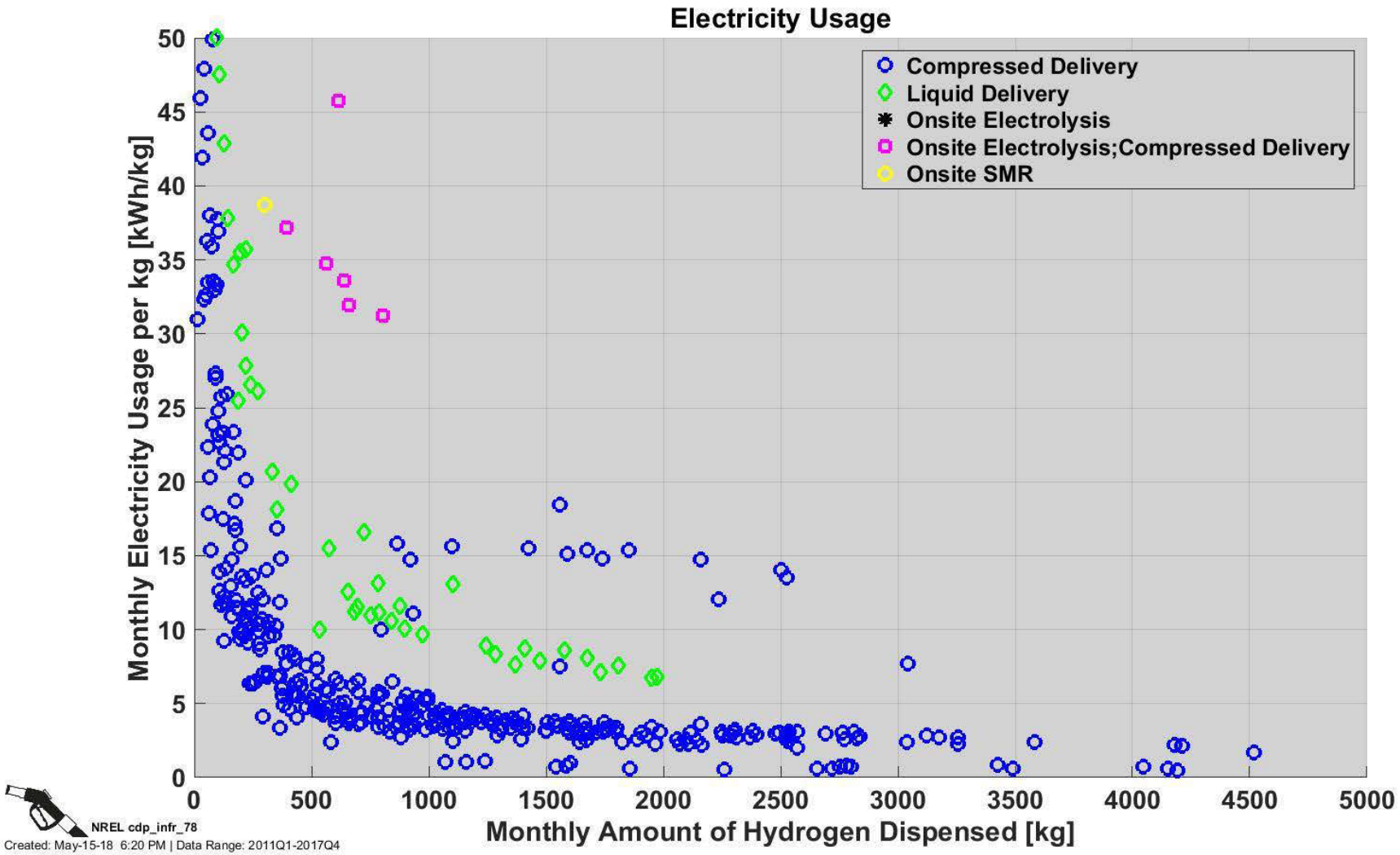
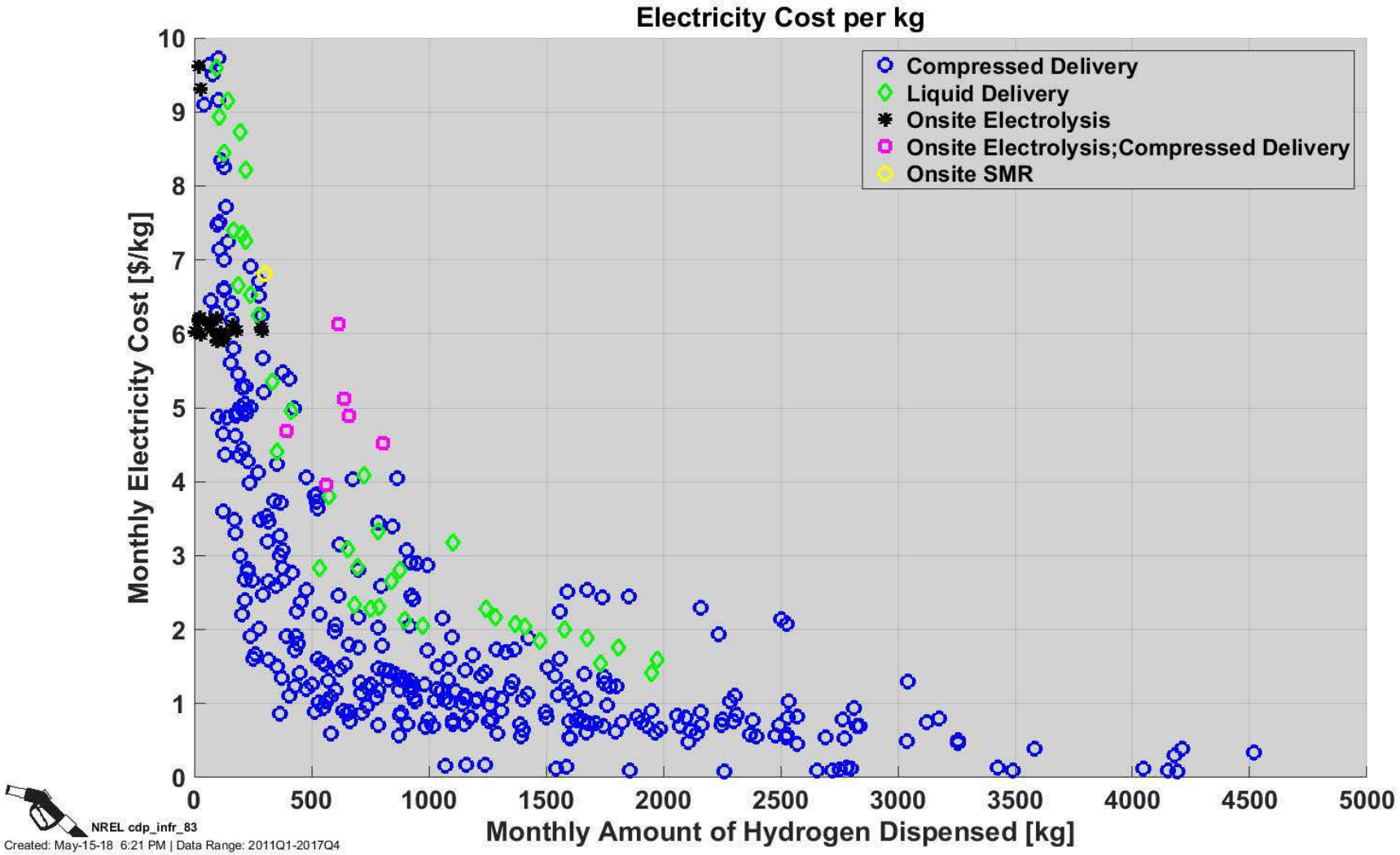
CDP-INFR-36
Electrolyzer Energy



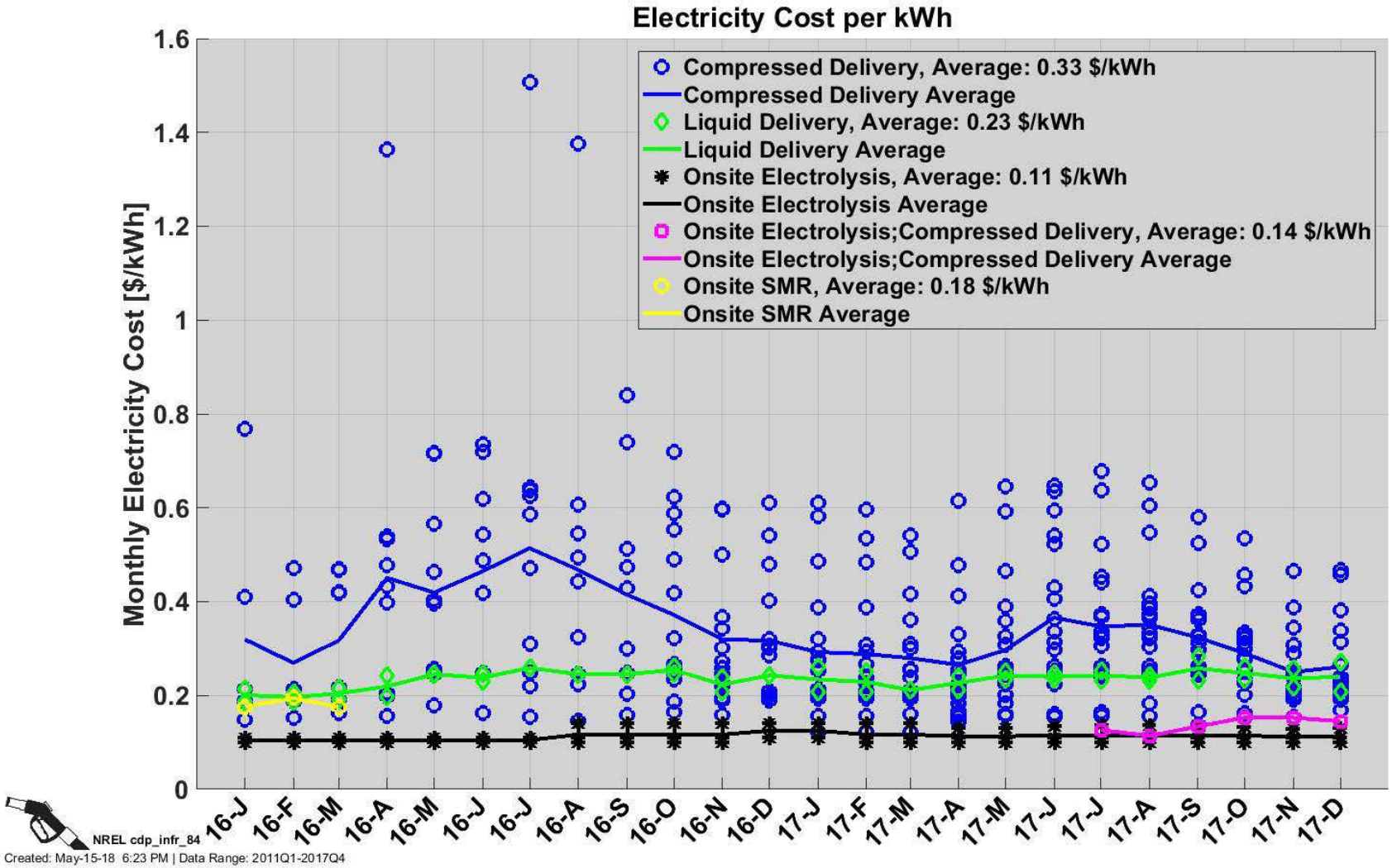
CDP-INFR-78
Station Energy per kg Dispensed



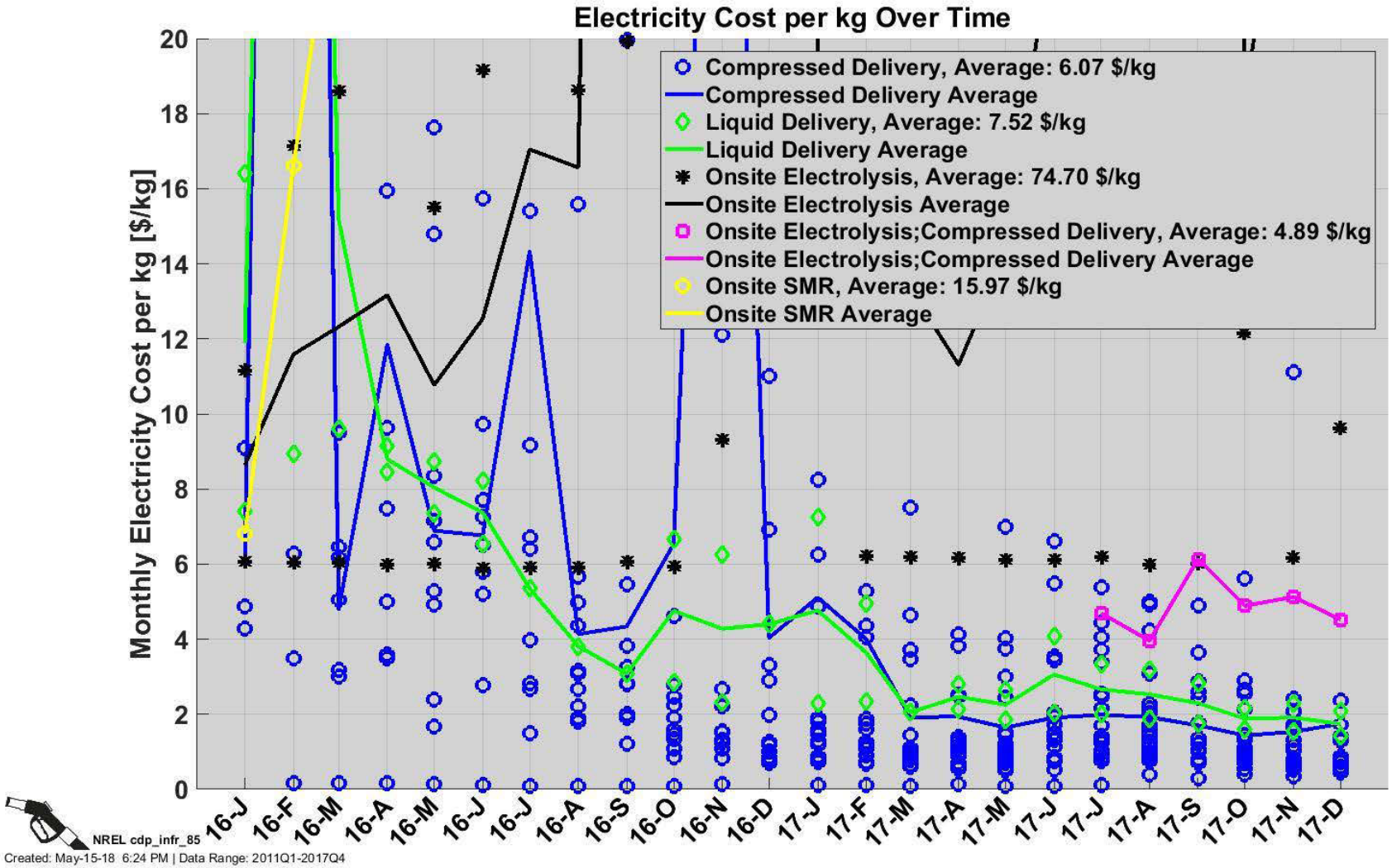
CDP-INFR-83
Station Energy Cost per kg Dispensed



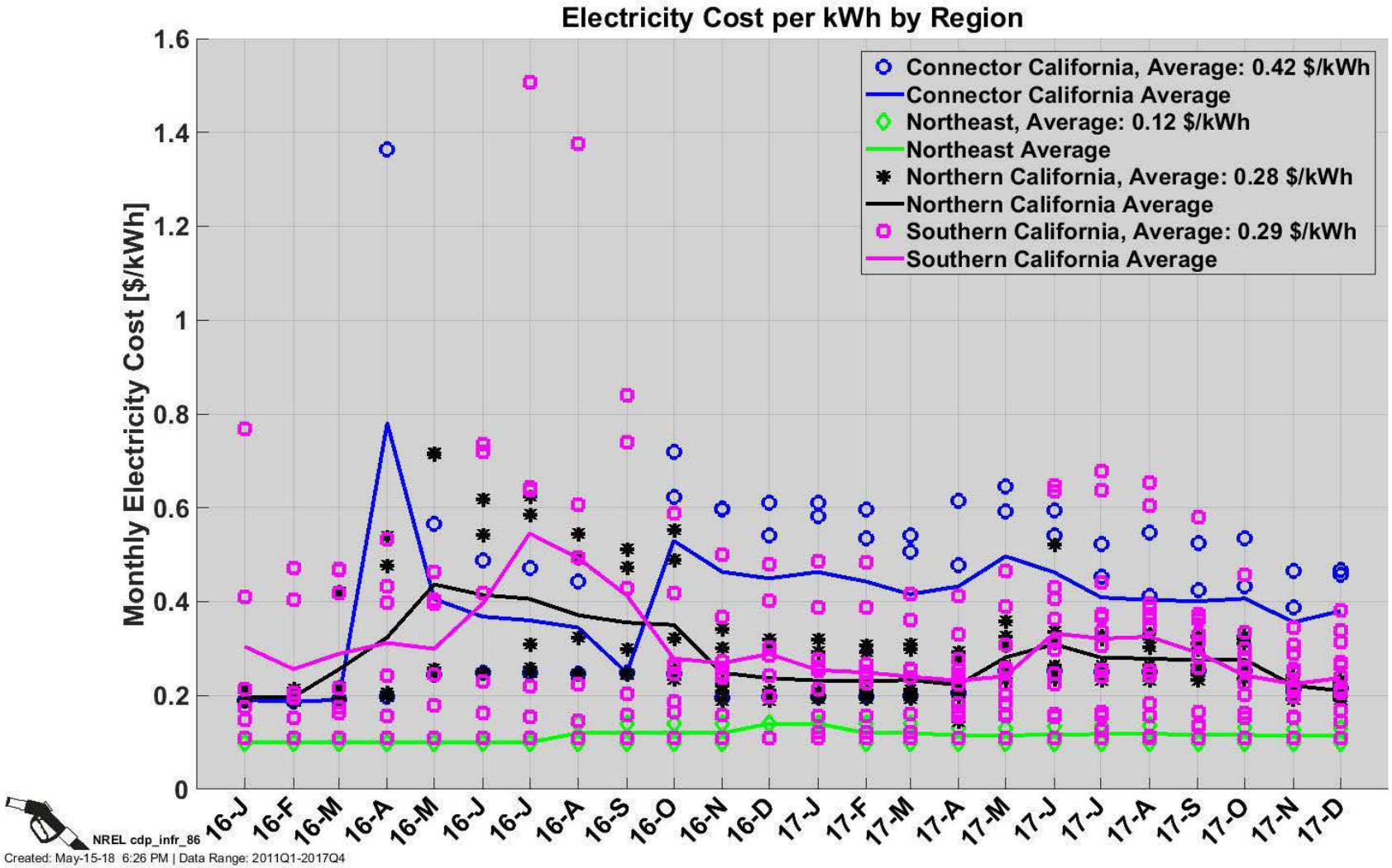
CDP-INFR-84
Station Electricity Cost per kWh



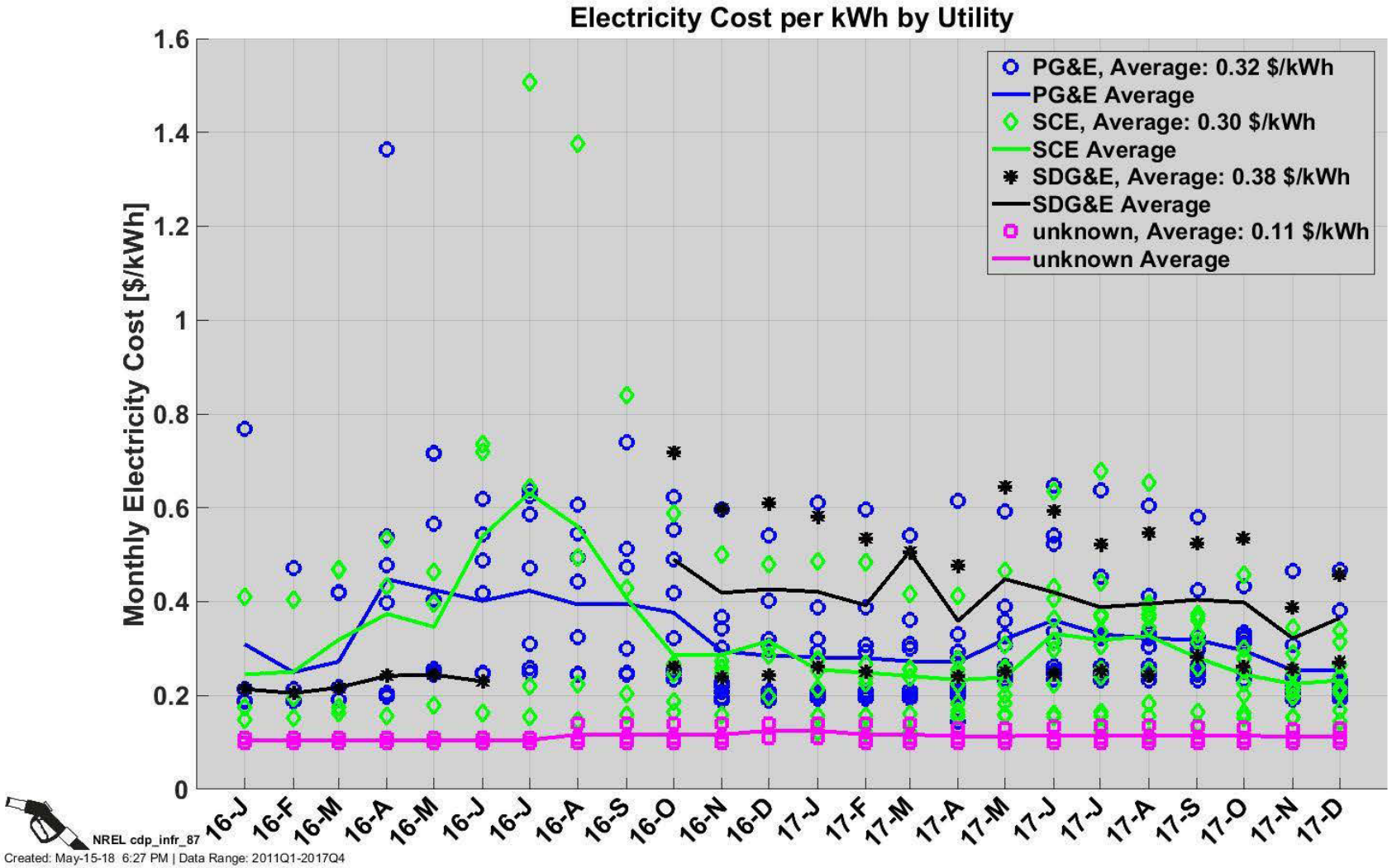
CDP-INFR-85
Station Electricity Cost per kg Over Time



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



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



Thank You

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