



Next Generation Hydrogen Station Composite Data Products: **Retail Stations**

Winter 2020: Data through Quarter 4 of 2020

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December 7, 2021

NREL/PR-5700-81661

Hydrogen Station Project Partners



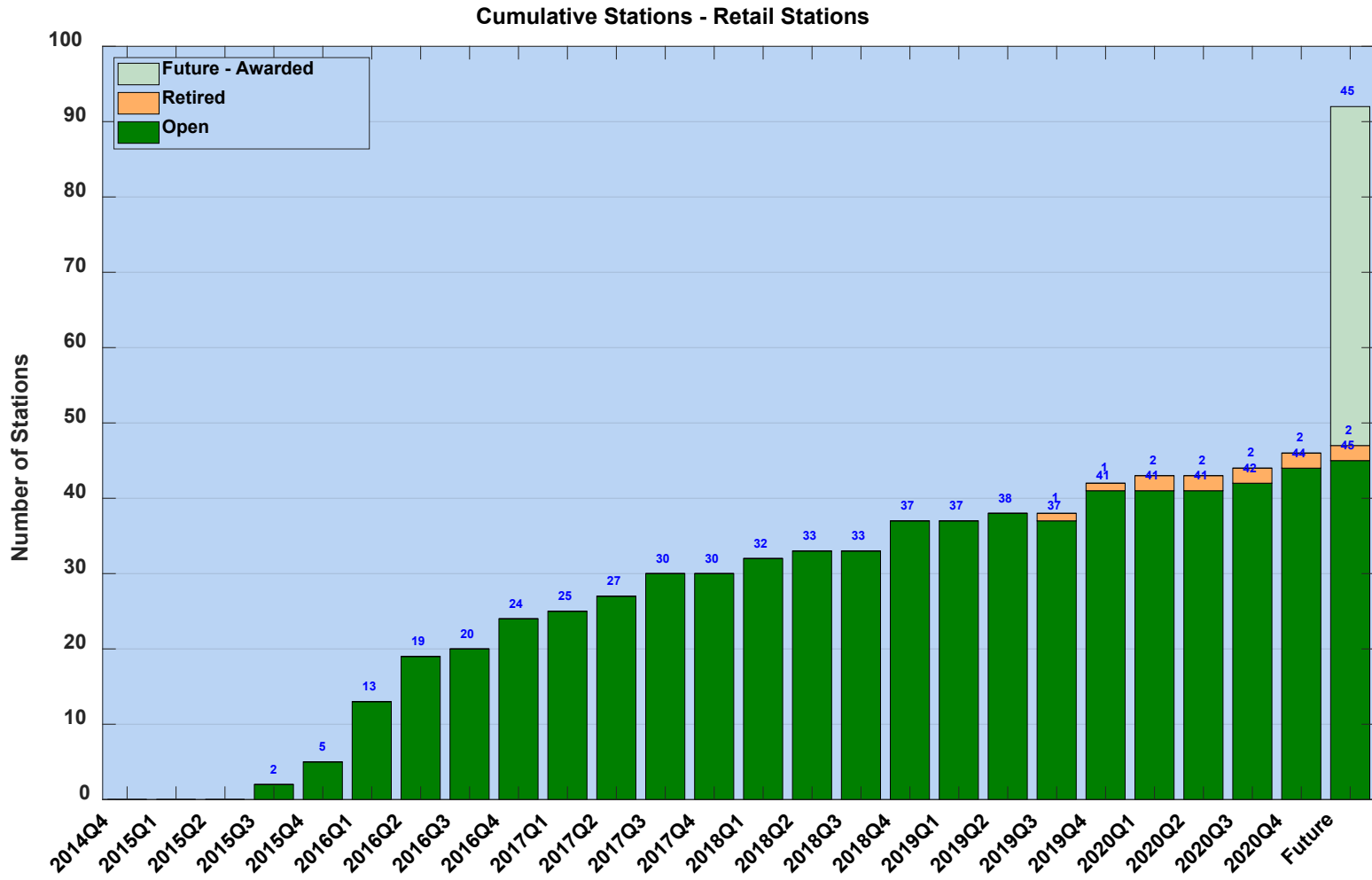
- Air Liquide
- Air Products
- California Air Resources Board
- California Energy Commission
- California State University Los Angeles
- Equilon
- FirstElement Fuel
- Gas Technology Institute
- ITM Power
- Iwatani
- Linde
- H2 Frontier
- Messer
- Proton OnSite
- Shell
- IPHE and HySUT



Analysis Categories



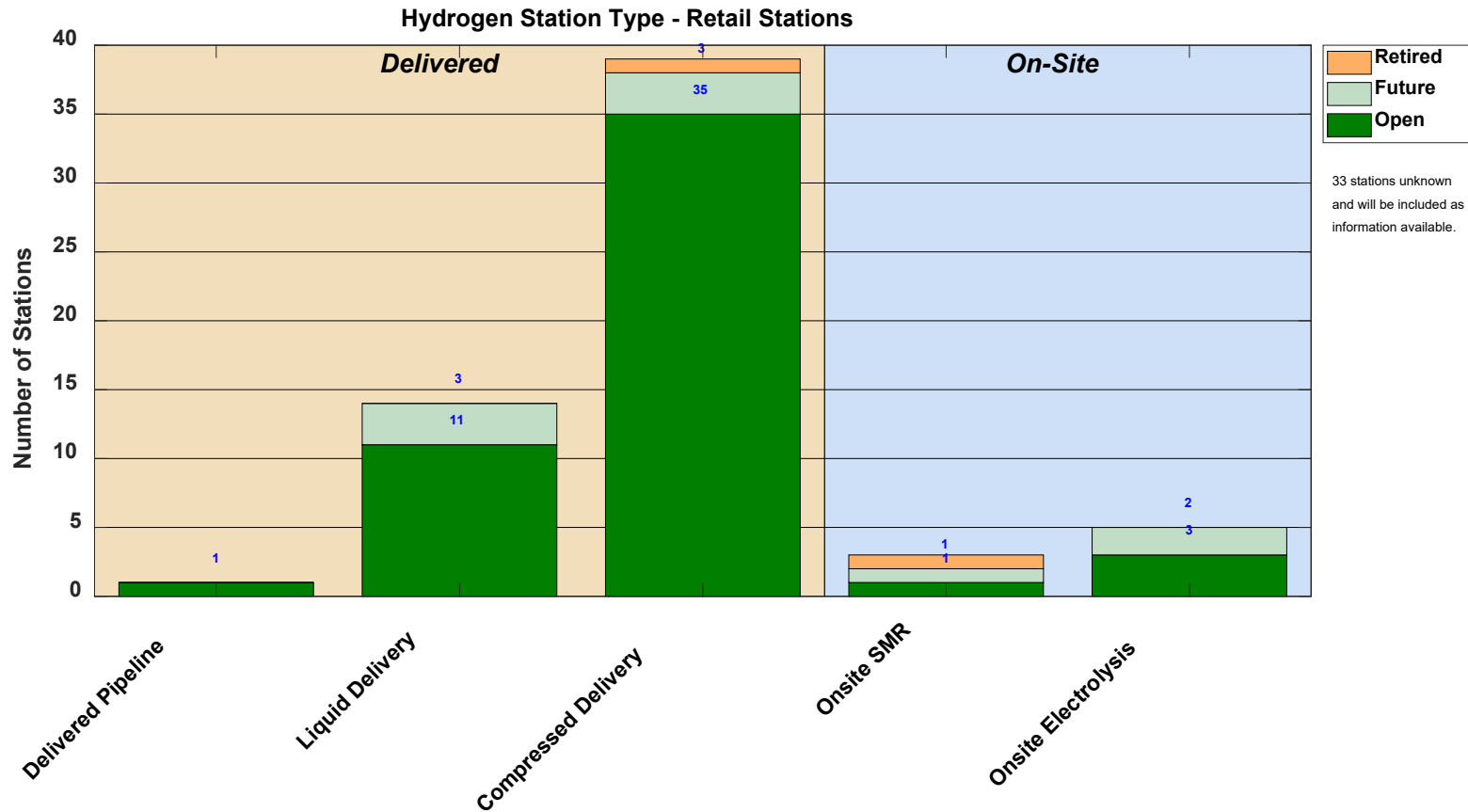
Deployment



NREL cdpRETAIL_infr_10

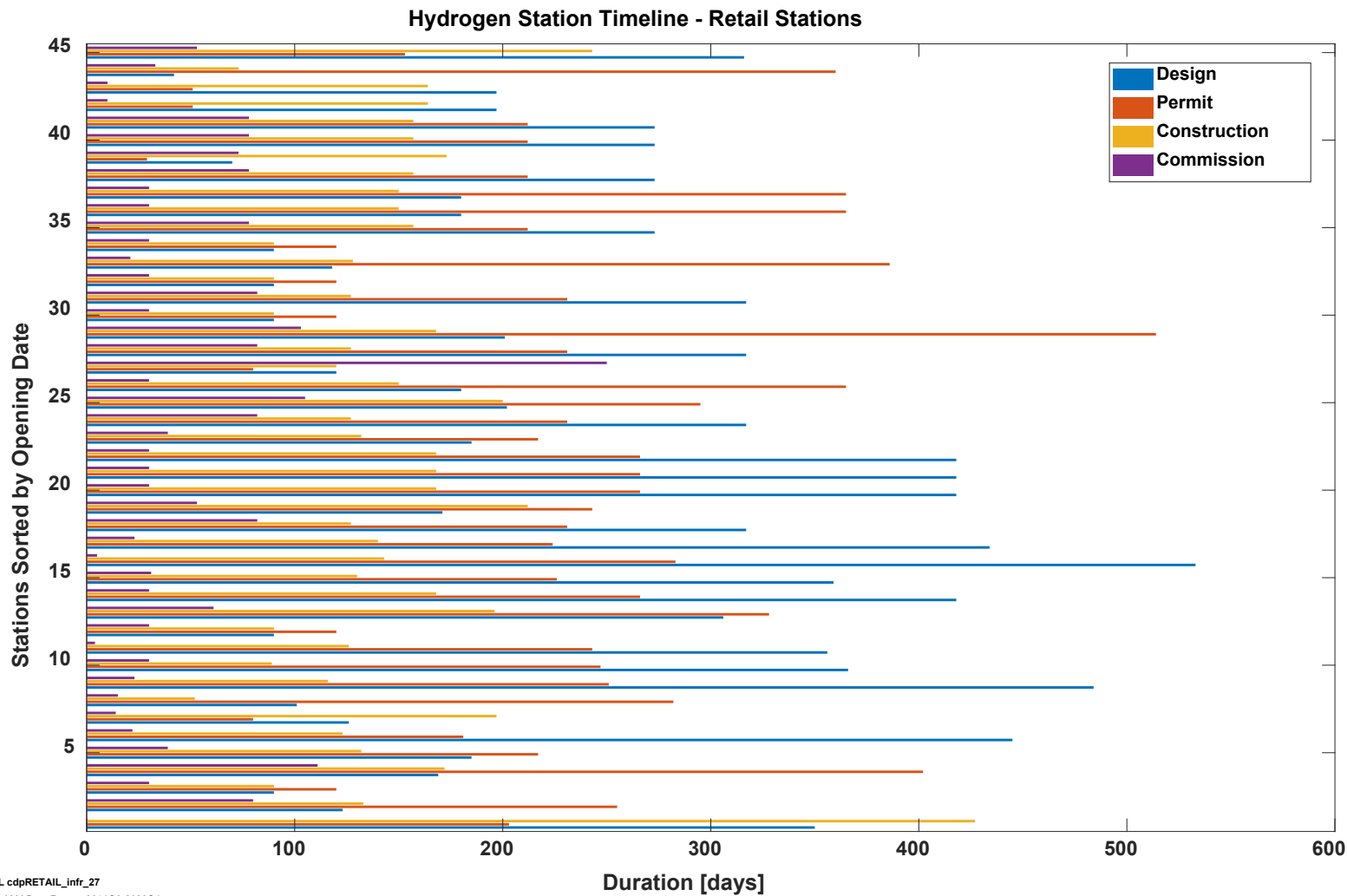
Created: Dec-07-21 11:47 AM | Data Range: 2014Q3-2020Q4

Hydrogen Stations by Type

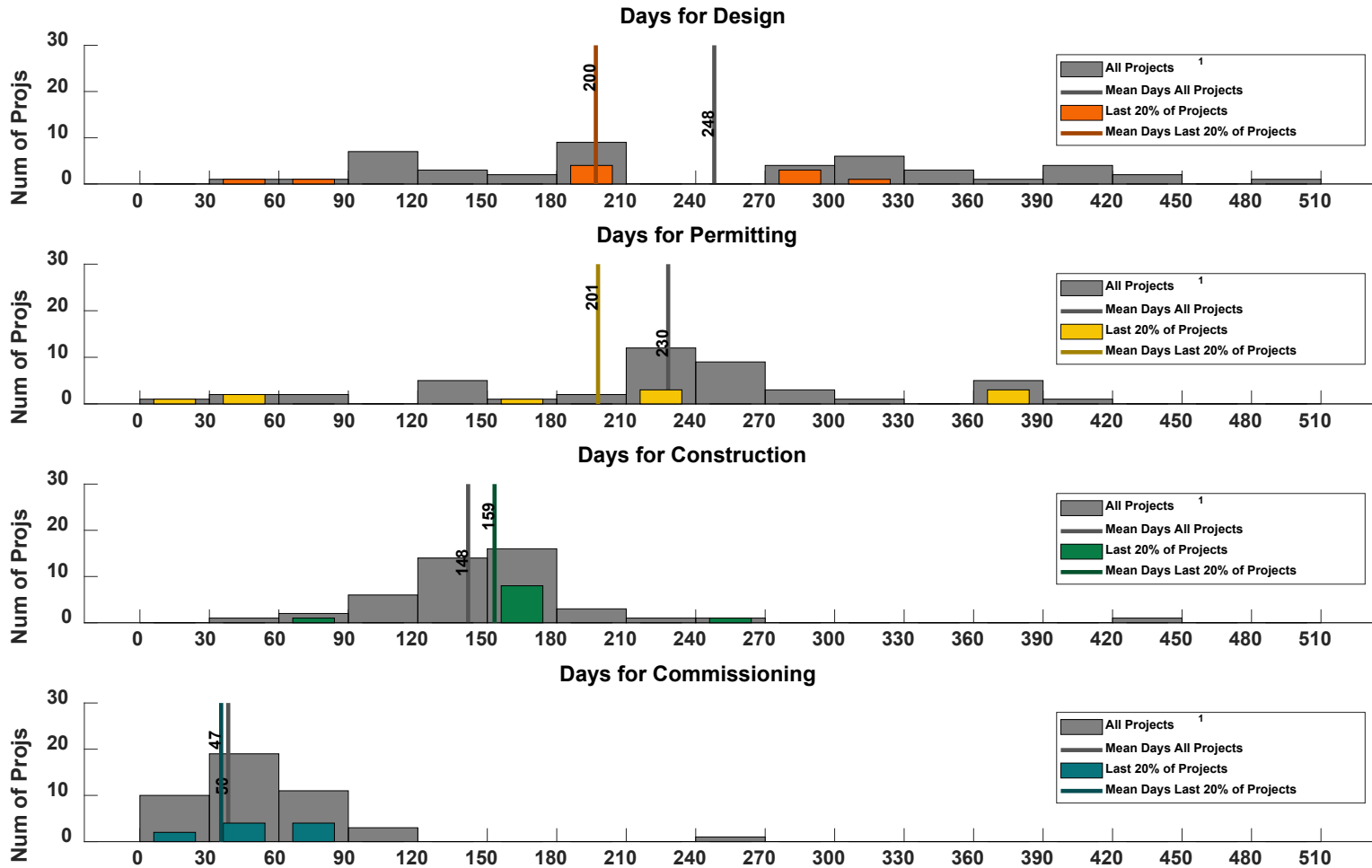


NREL cdpRETAIL_infr_11

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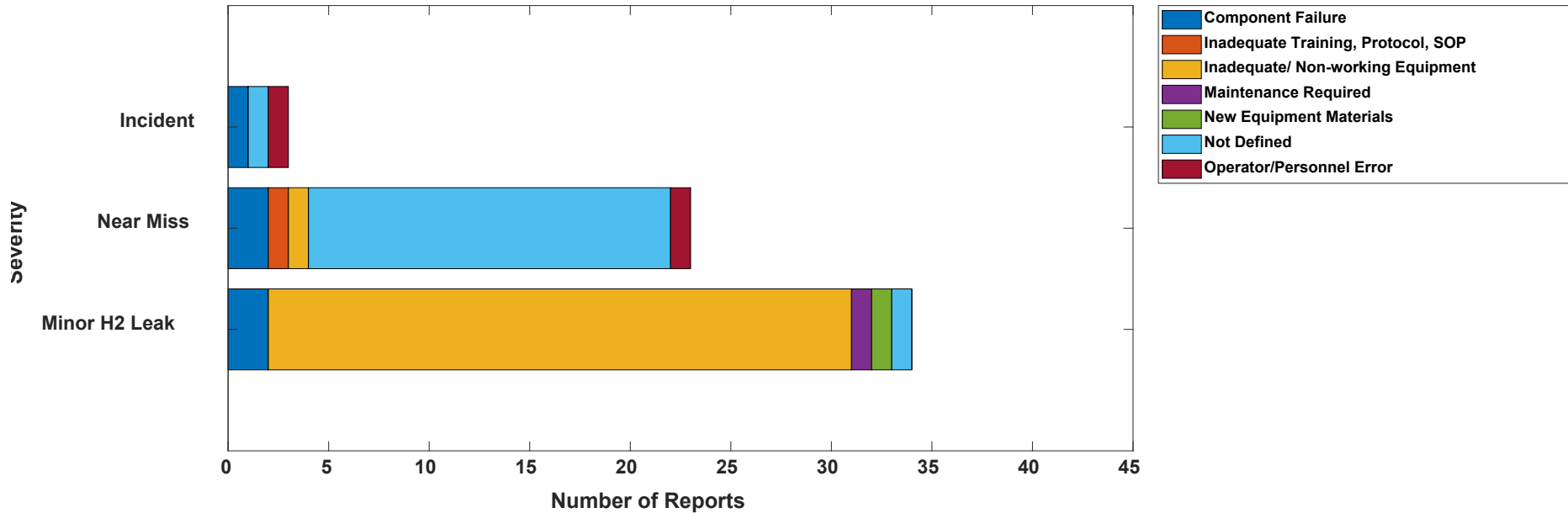


Hydrogen Station Timeline Trend - Retail Stations



Safety

Safety Reports Primary Factors - 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:

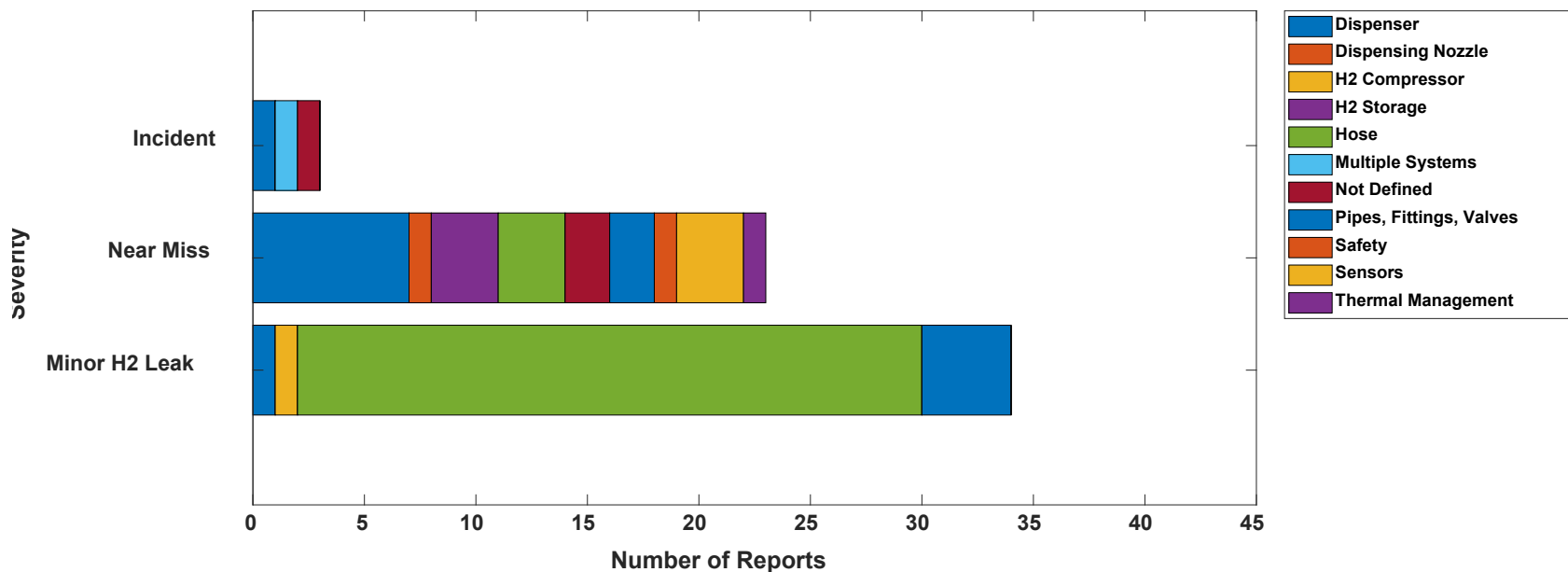
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdpRETAIL_infr_31

Created: Nov-16-21 1:49 PM | Data Range: 2014Q3-2020Q4

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:

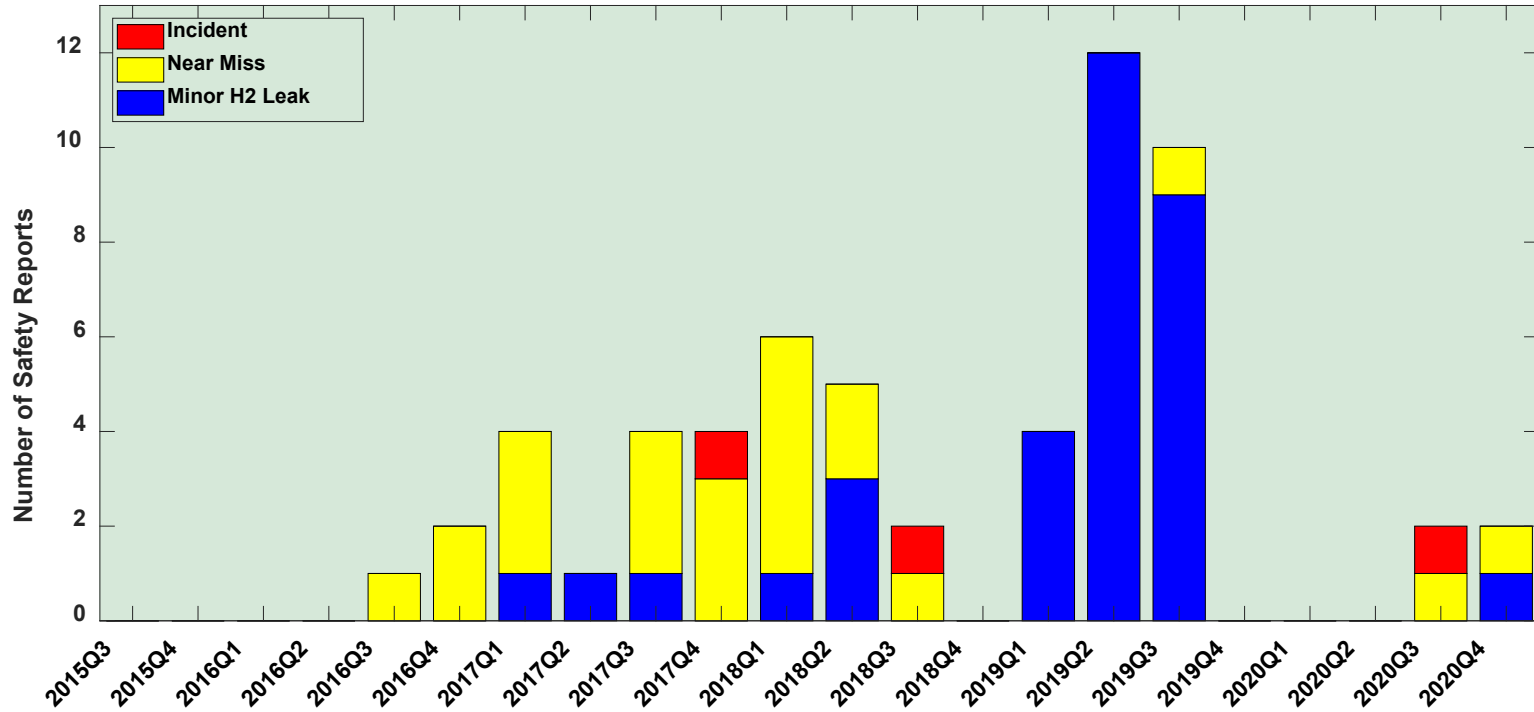
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdpRETAIL_infr_32

Created: Nov-16-21 1:51 PM | Data Range: 2014Q3-2020Q4

Safety Reports By Quarter - 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:

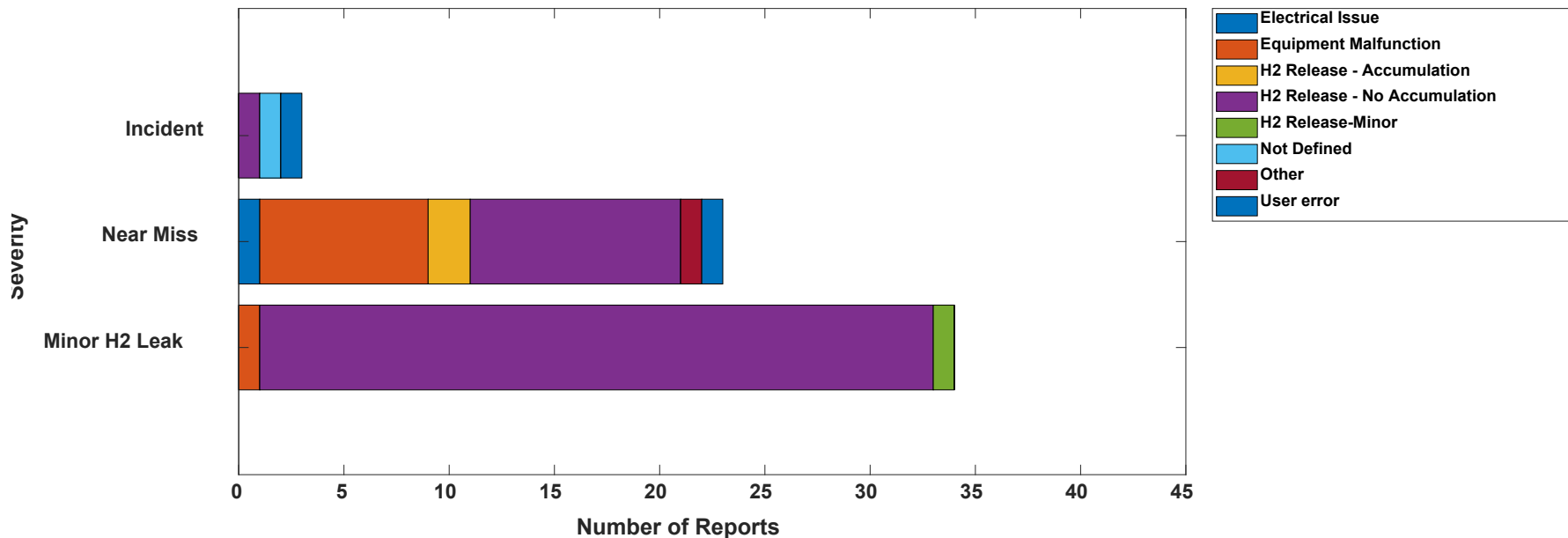
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdpRETAIL_infr_33

Created: Nov-16-21 1:52 PM | Data Range: 2014Q3-2020Q4

Safety Reports By Event Description - 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:

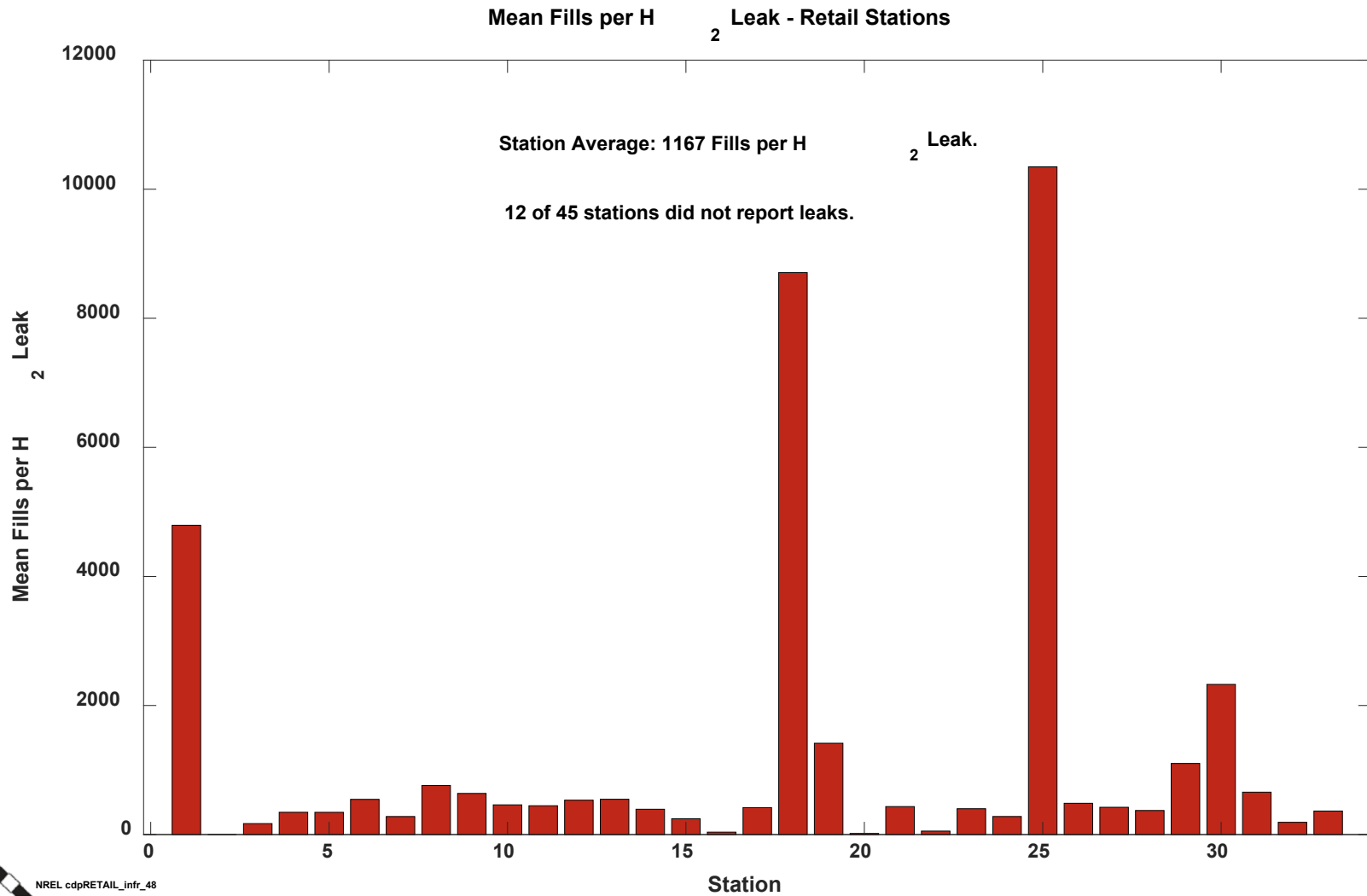
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite




NREL cdpRETAIL_infr_34

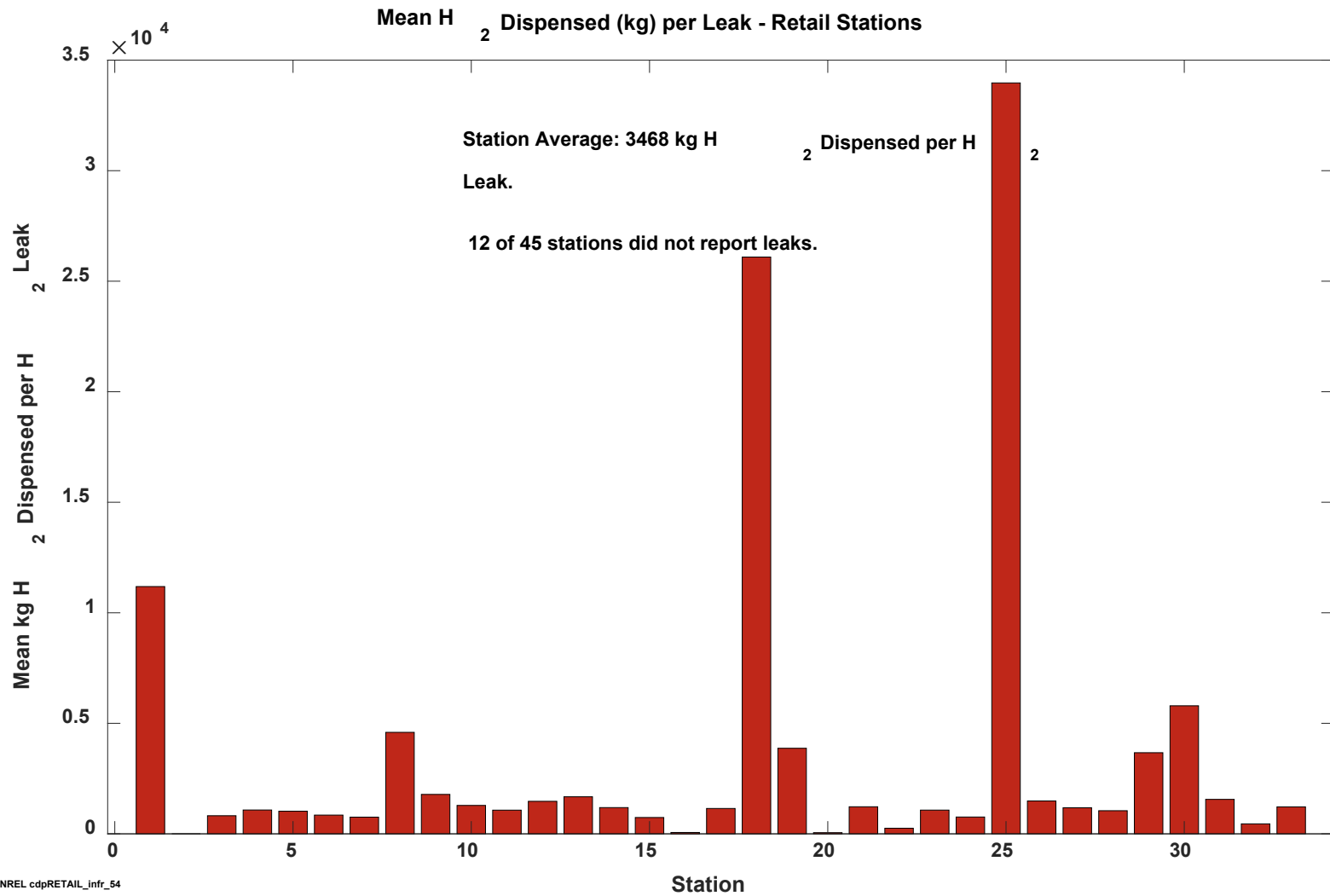
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Mean Fills per Hydrogen Leak



 NREL cdpRETAIL_infr_48
Created: Sep-15-21 5:58 PM | Data Range: 2014Q3-2020Q4

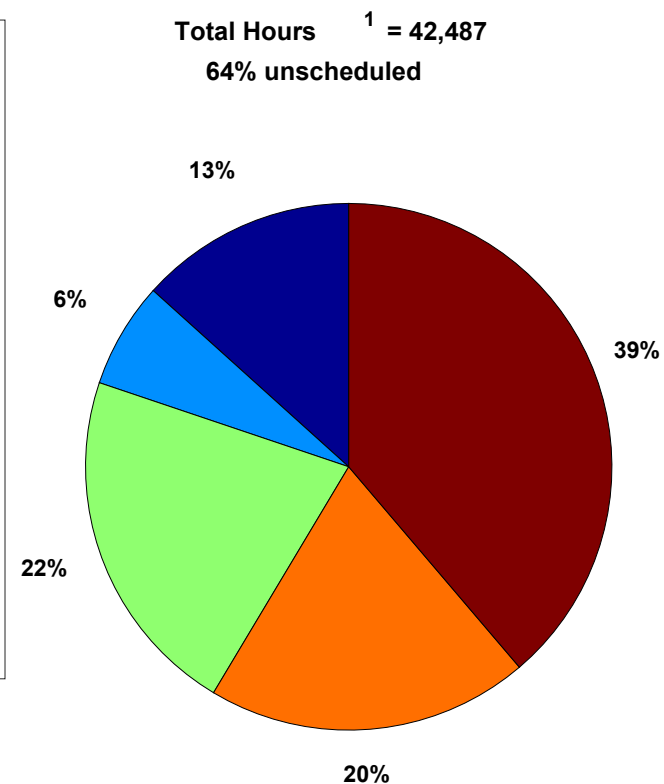
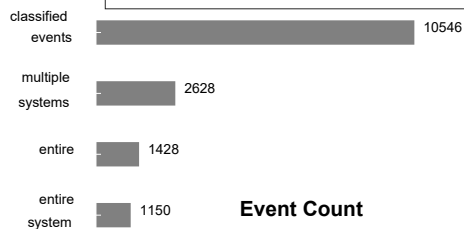
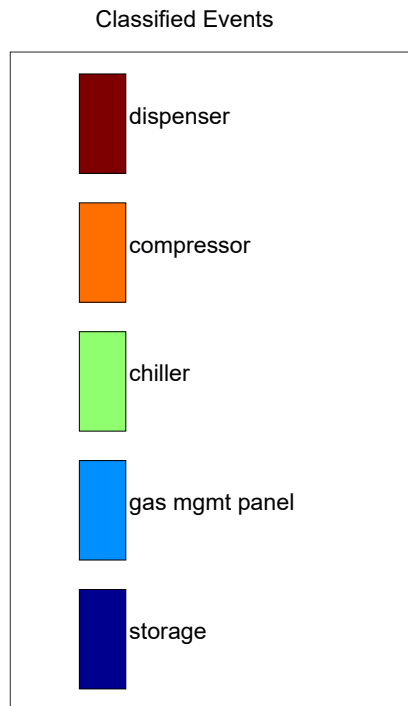
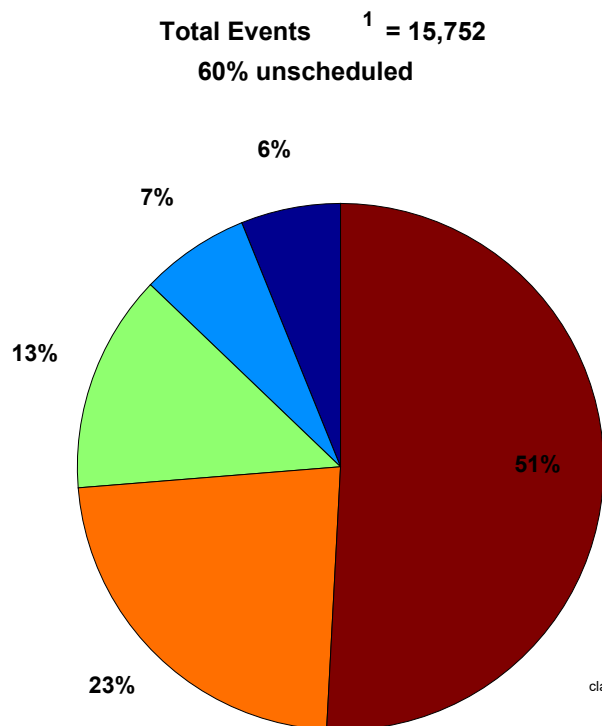
Mean Hydrogen Dispensed per Hydrogen Leak



Maintenance and Reliability

Maintenance by Known Equipment Type - Retail Stations

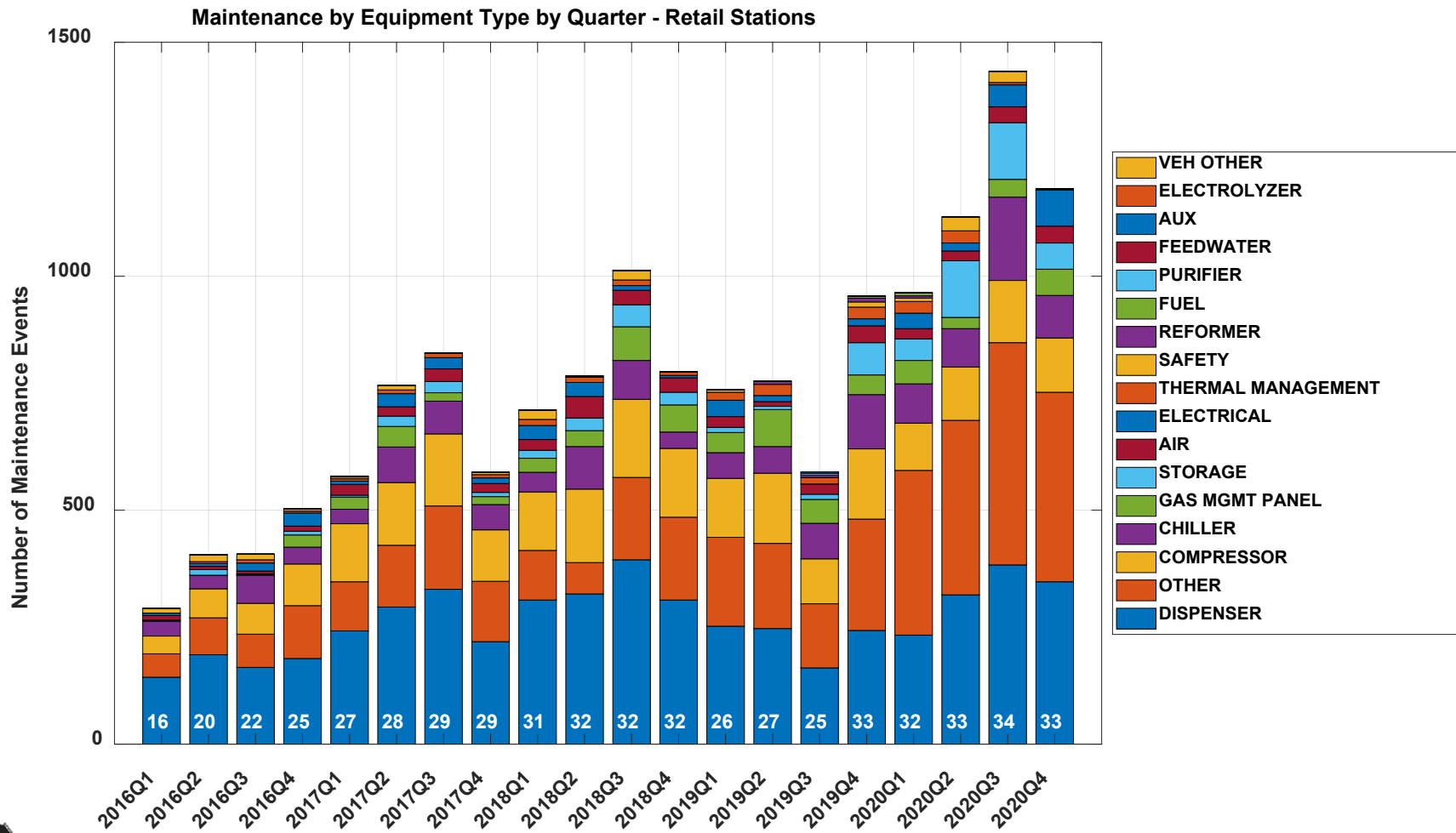
2



MISC includes the following failure modes: entire, veh other, air, aux, electrolyzer, feedwater, purifier, fuel, reformer, safety, thermal management, electrical, air, other

1. Total includes classified events (plotted) and unclassified events.
2. Maintenance events with unknown equipment type excluded from plot.

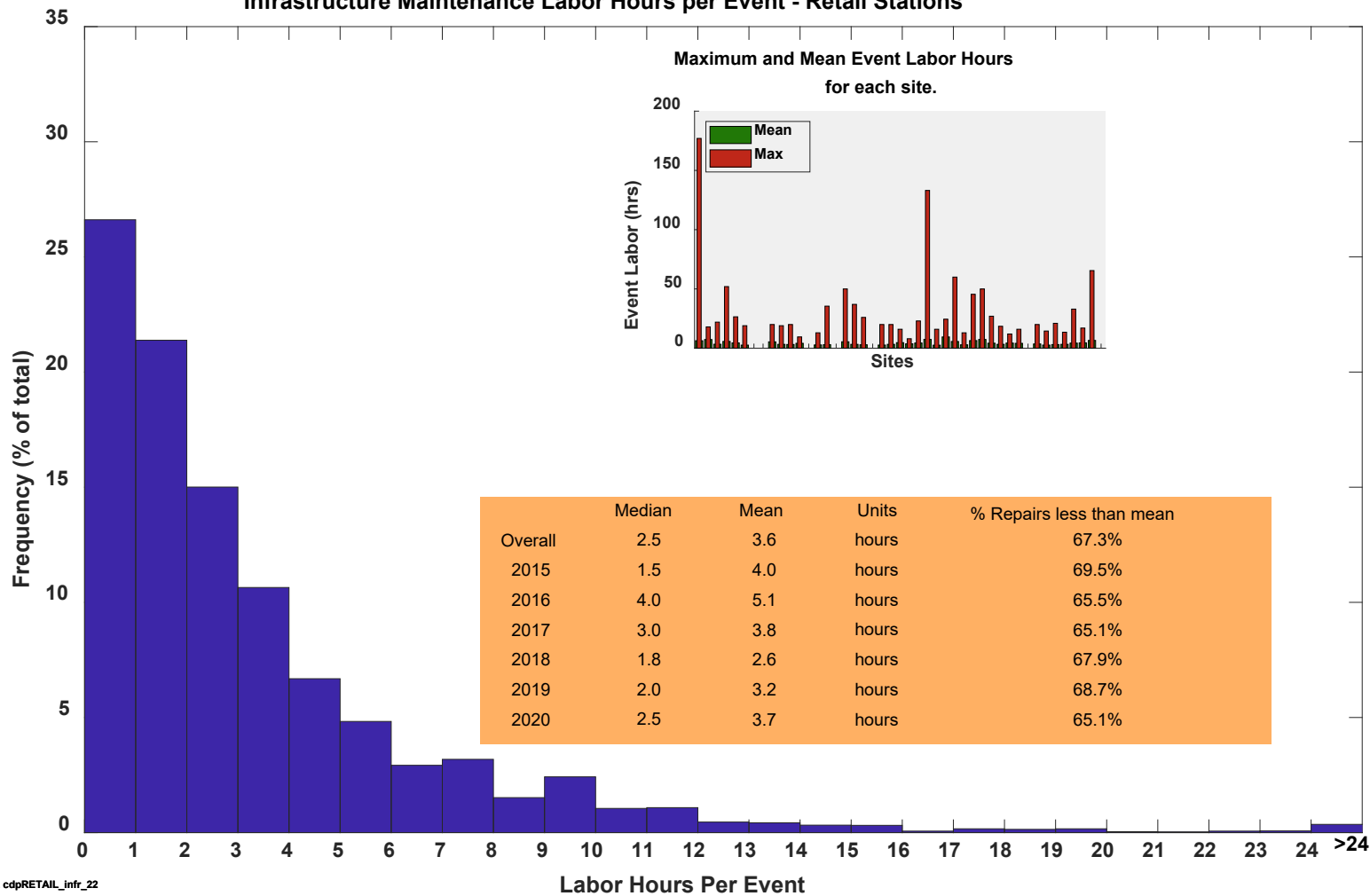
Maintenance by Equipment Type by Quarter



NREL cdpRETAIL_infr_94
 Created: Sep-16-21 12:05 PM | Data Range: 2014Q3-2020Q4

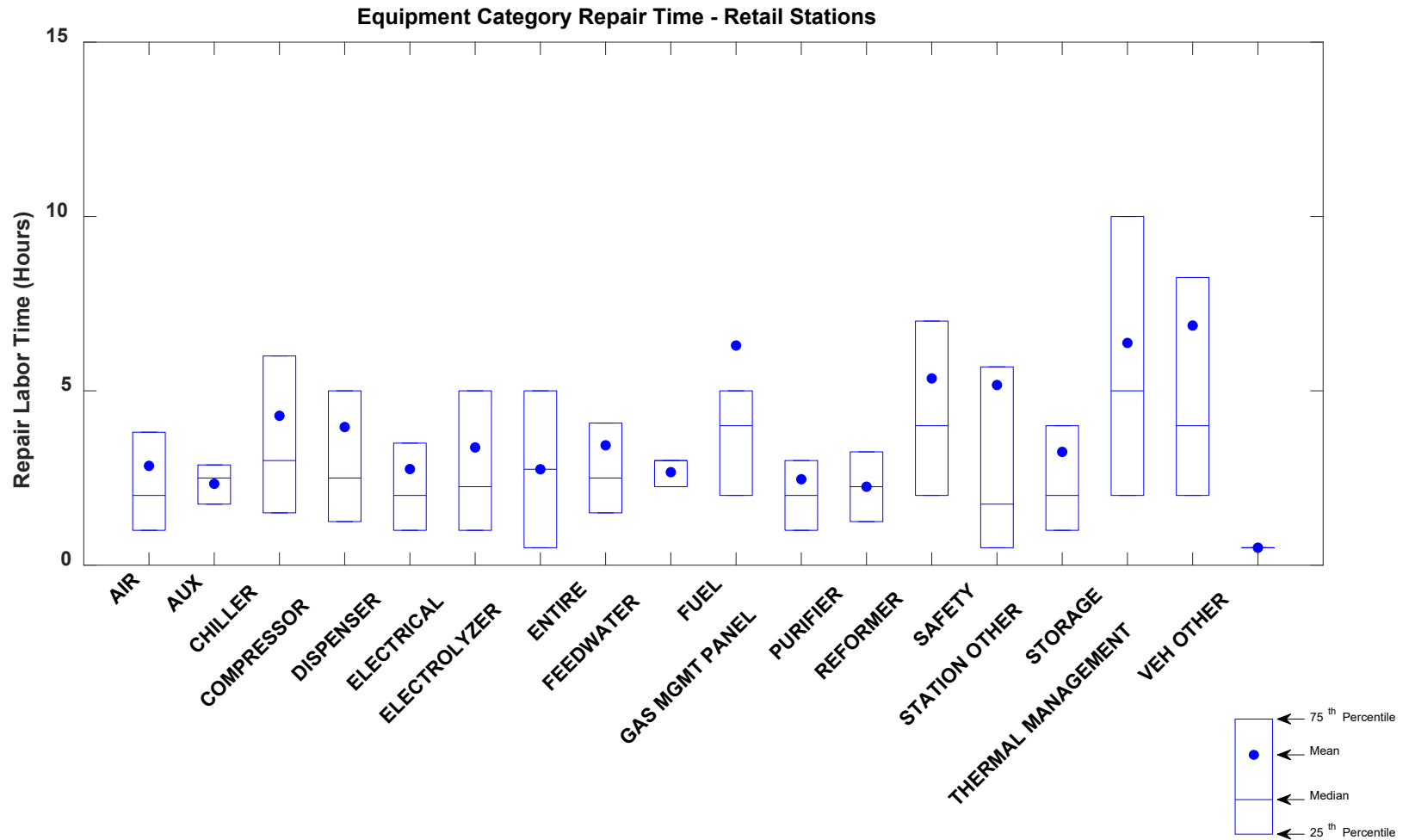
Number at bottom of bars is number of stations reporting for that quarter.
 "OTHER" includes items for which equipment type could not be determined from the data.

Infrastructure Maintenance Labor Hours per Event - Retail Stations



NREL cdpRETAIL_infr_22

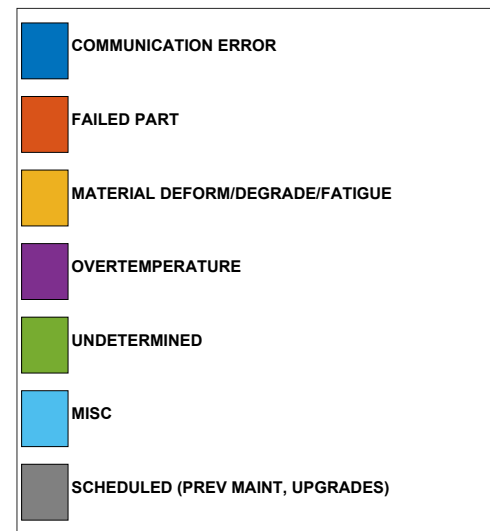
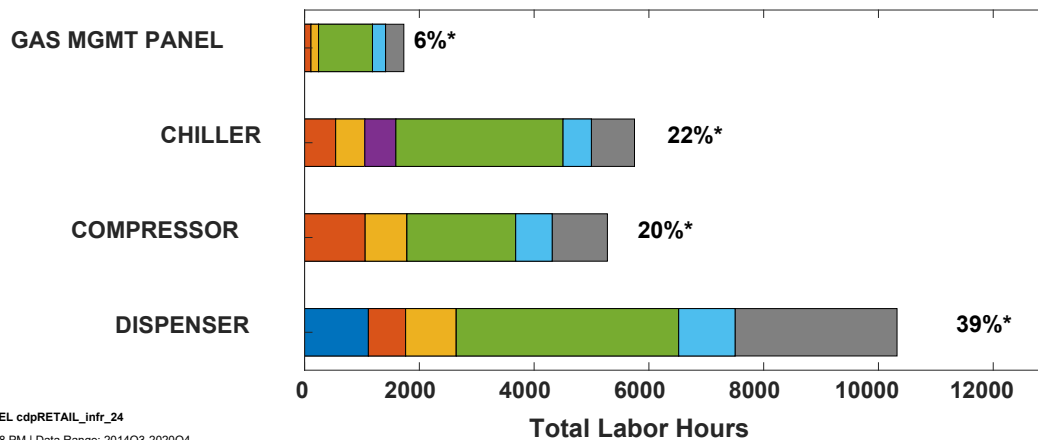
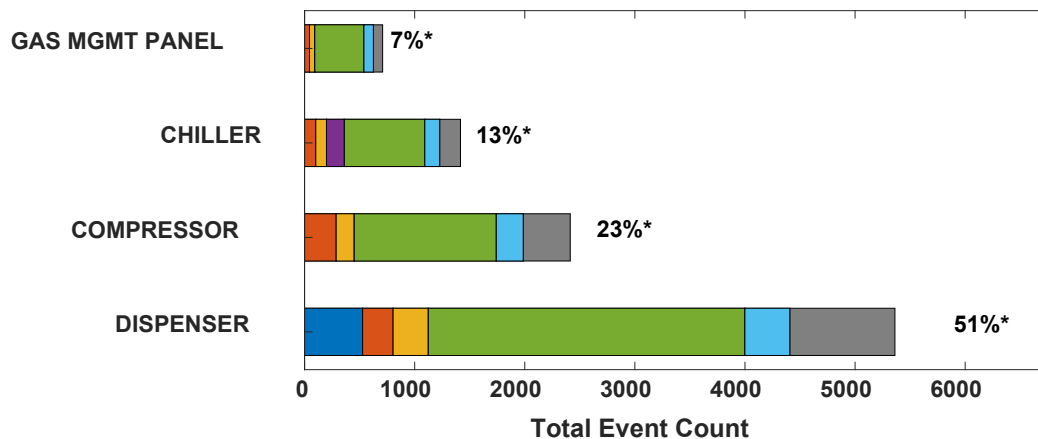
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NREL cdpRETAIL_infr_23

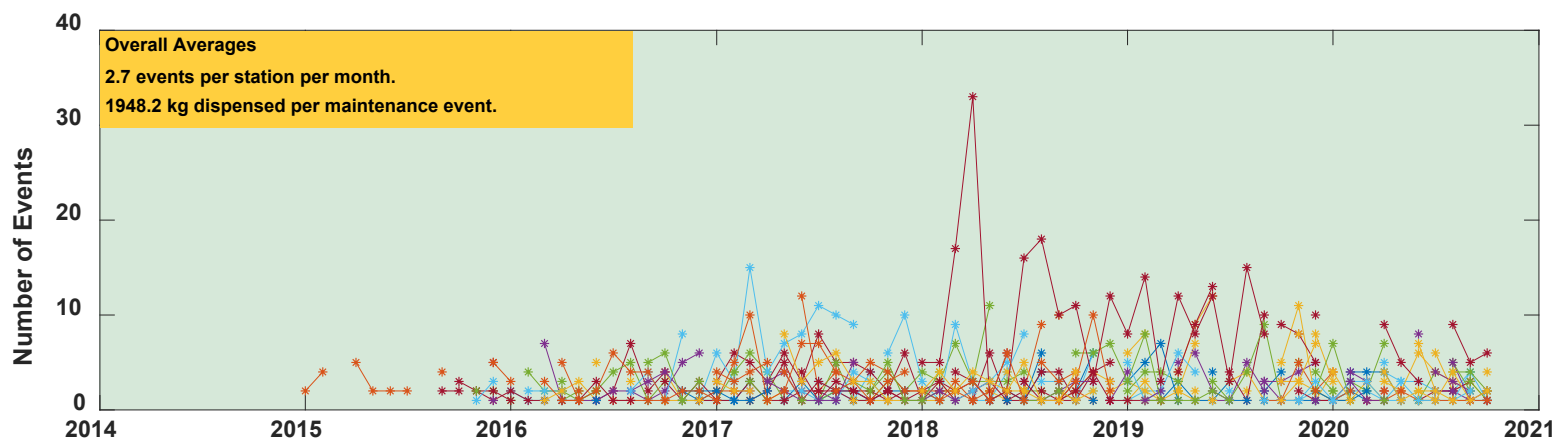
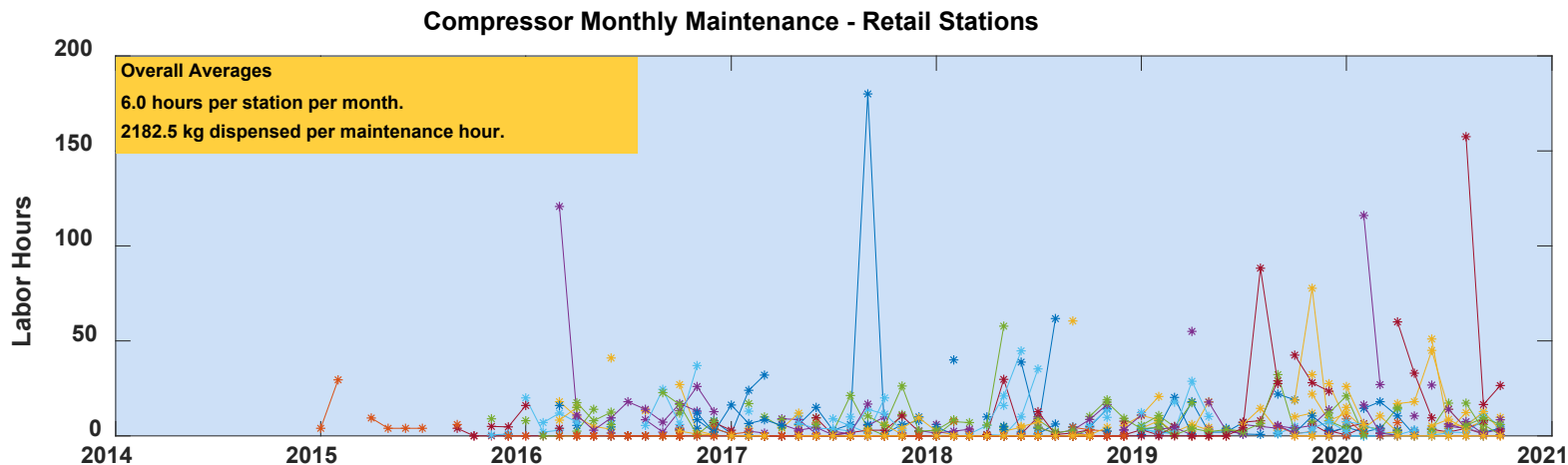
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Failure Modes for Top Equipment Categories - Retail Stations



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

* Percentage of total events or hours.

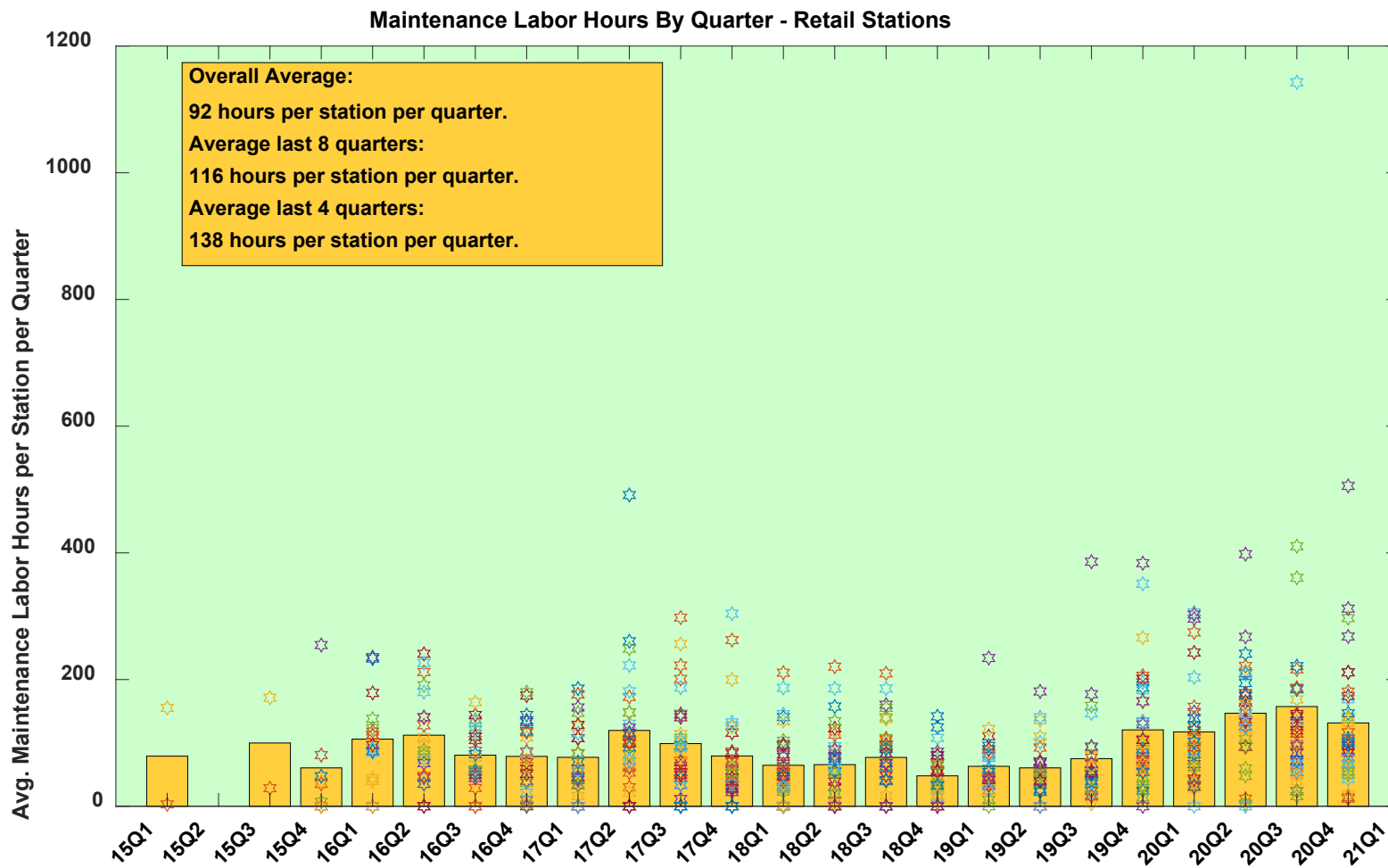


NREL cdpRETAIL_infr_26

Created: Oct-12-21 1:49 PM | Data Range: 2014Q3-2020Q4

* 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 Quarter

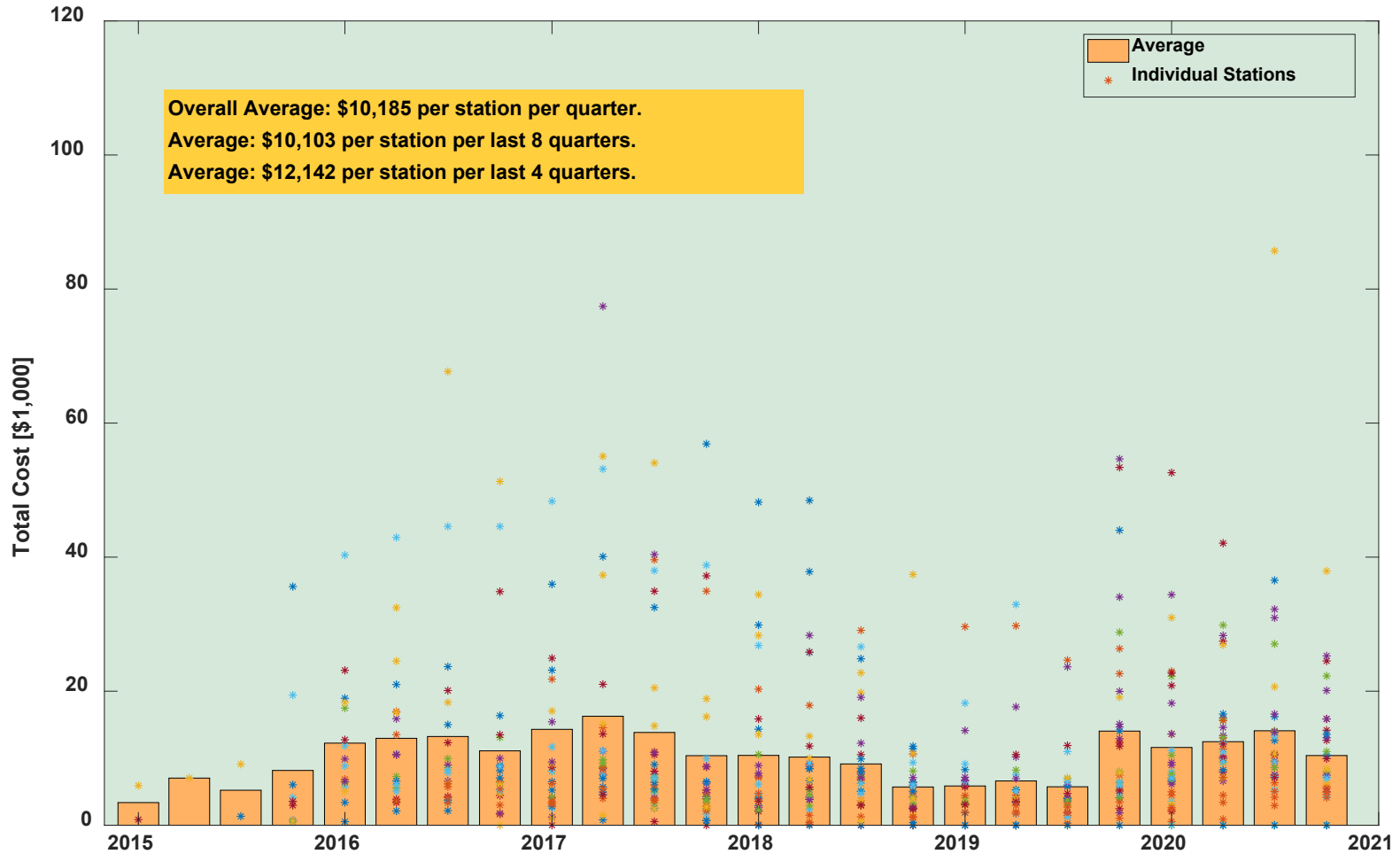


NREL cdpRETAIL_infr_28

Created: Sep-23-21 11:03 AM | Data Range: 2014Q3-2020Q4

Stars represent individual station maintenance hours in a given quarter.

Maintenance Costs Over Time - Retail Stations



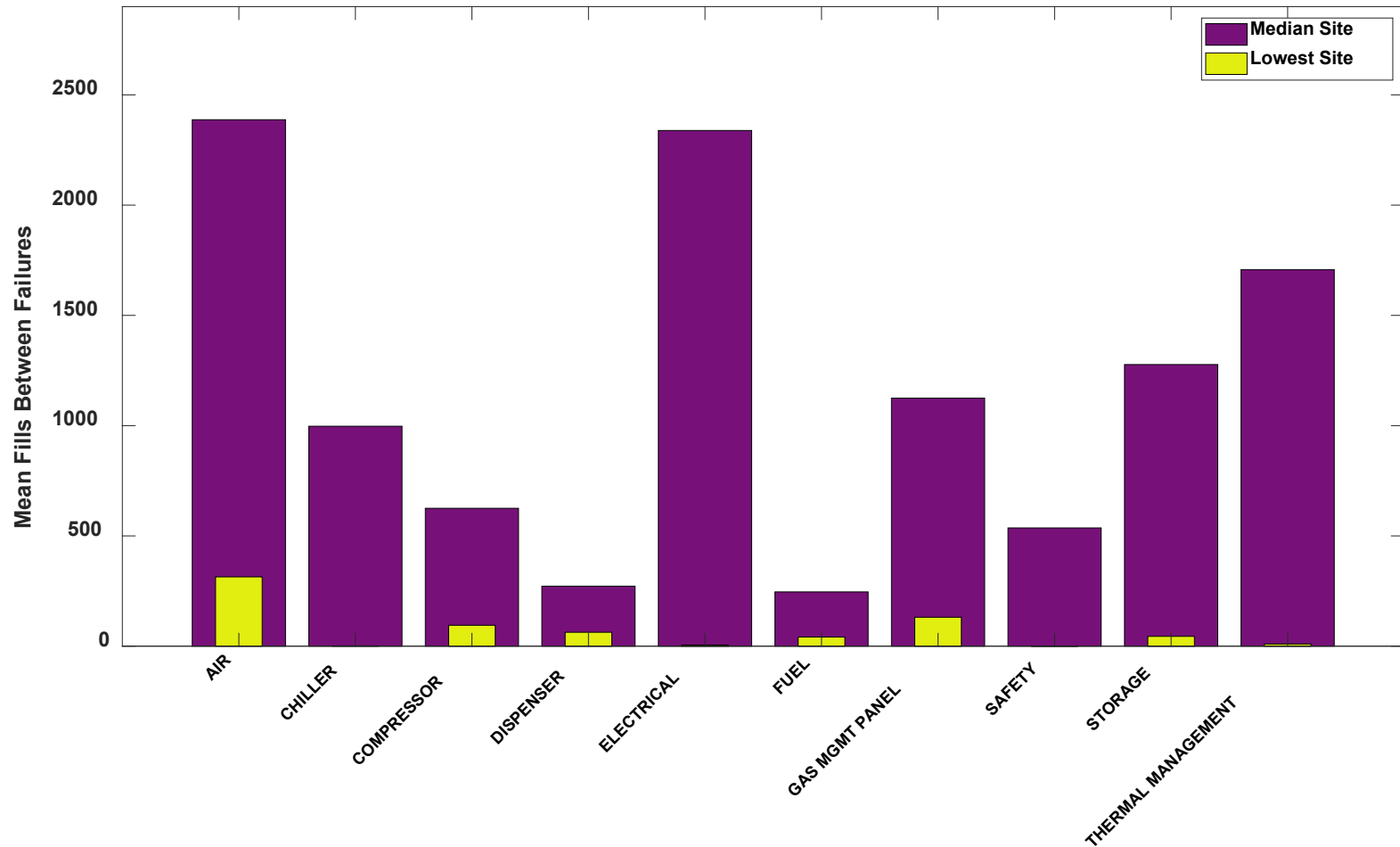
*Each color represents a unique station.



NREL cdpRETAIL_infr_30

Created: Sep-08-21 4:19 PM | Data Range: 2014Q3-2020Q4

Mean Fills Between Failures - Retail Stations

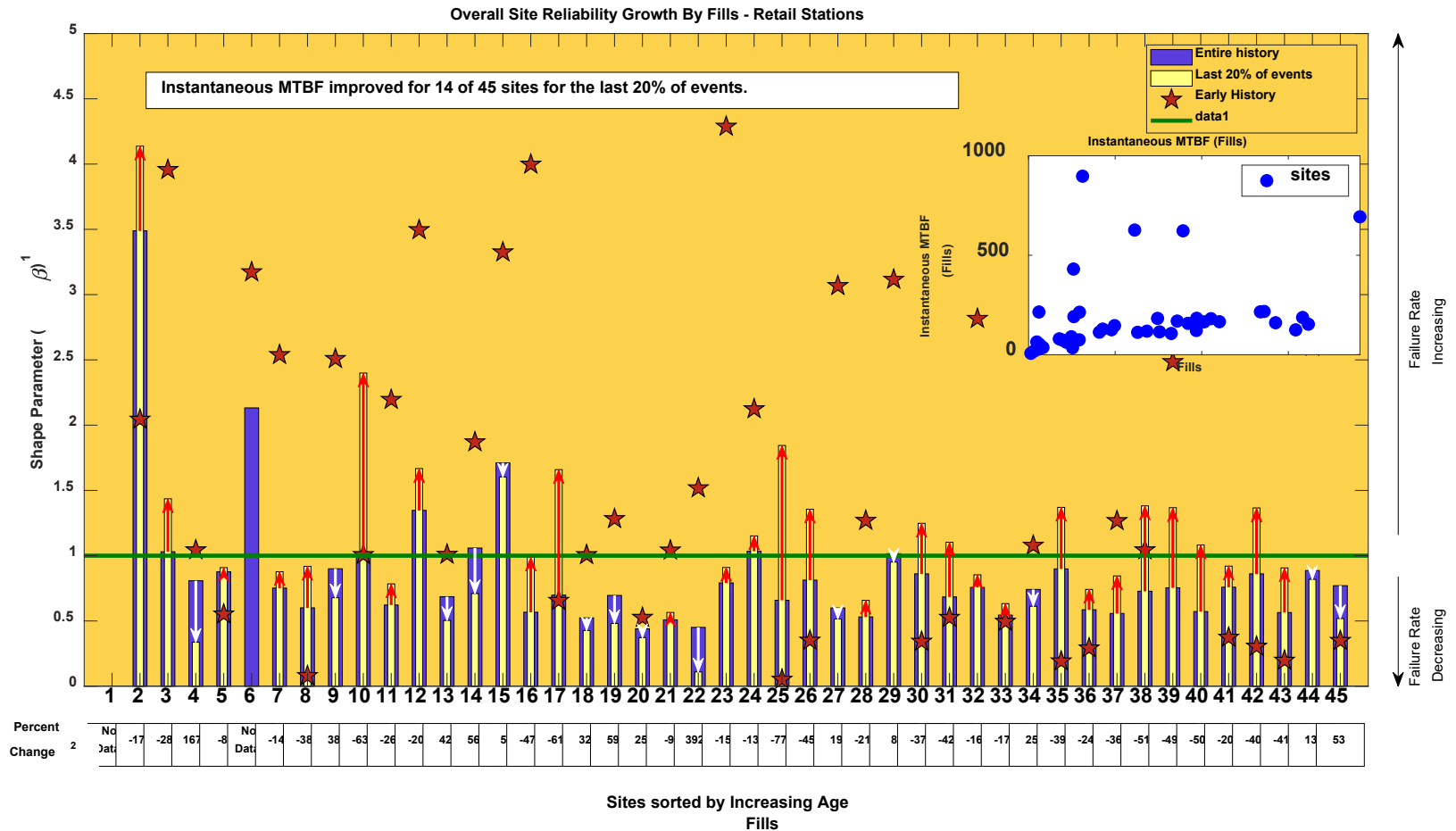


NREL cdpRETAIL_infr_49

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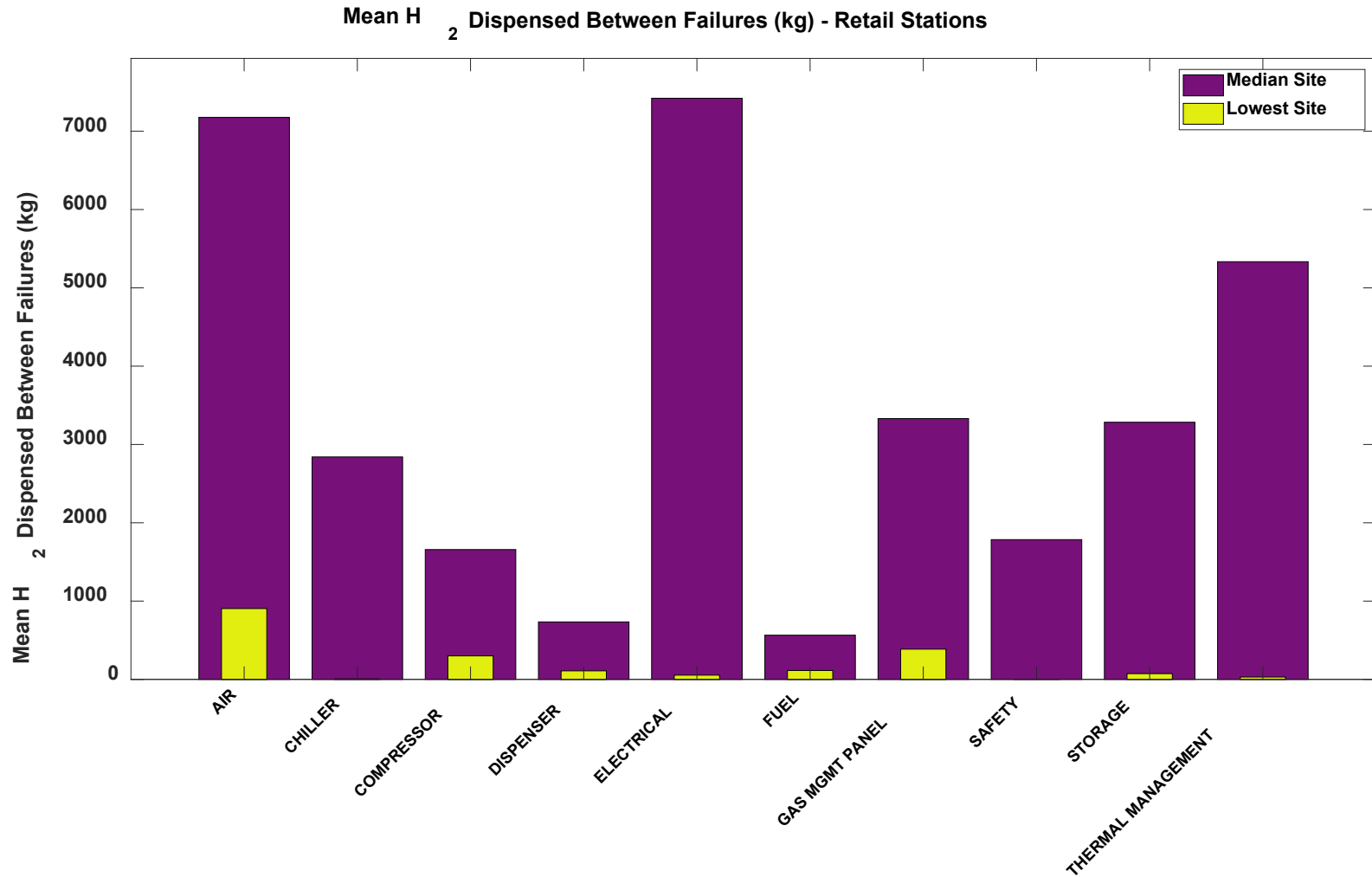
CDP-INFR-50

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

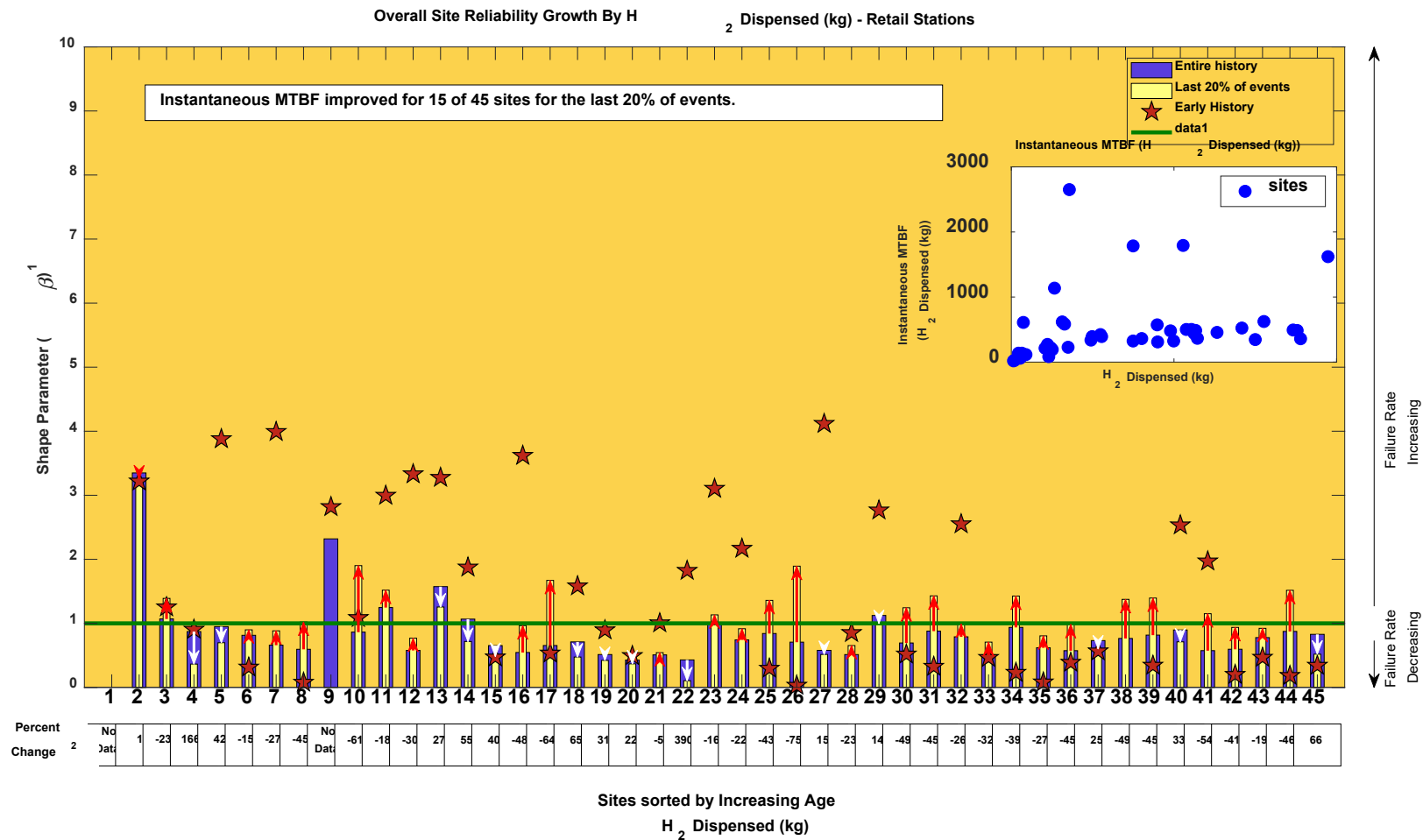
Mean Amount Dispensed Between Failures



NREL cdpRETAIL_infr_51

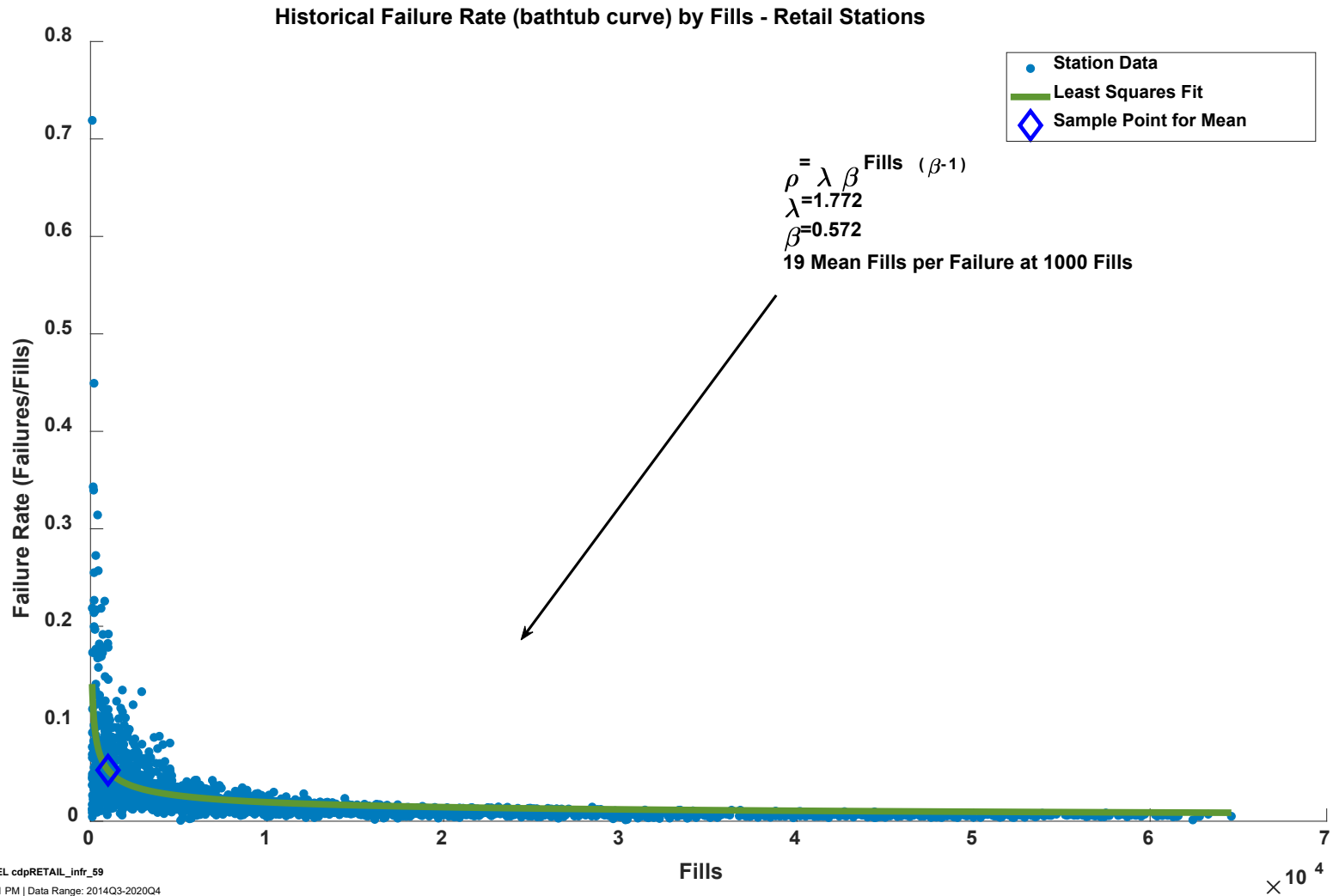
Created: Sep-15-21 5:28 PM | Data Range: 2014Q3-2020Q4

Reliability Growth by Amount Dispensed

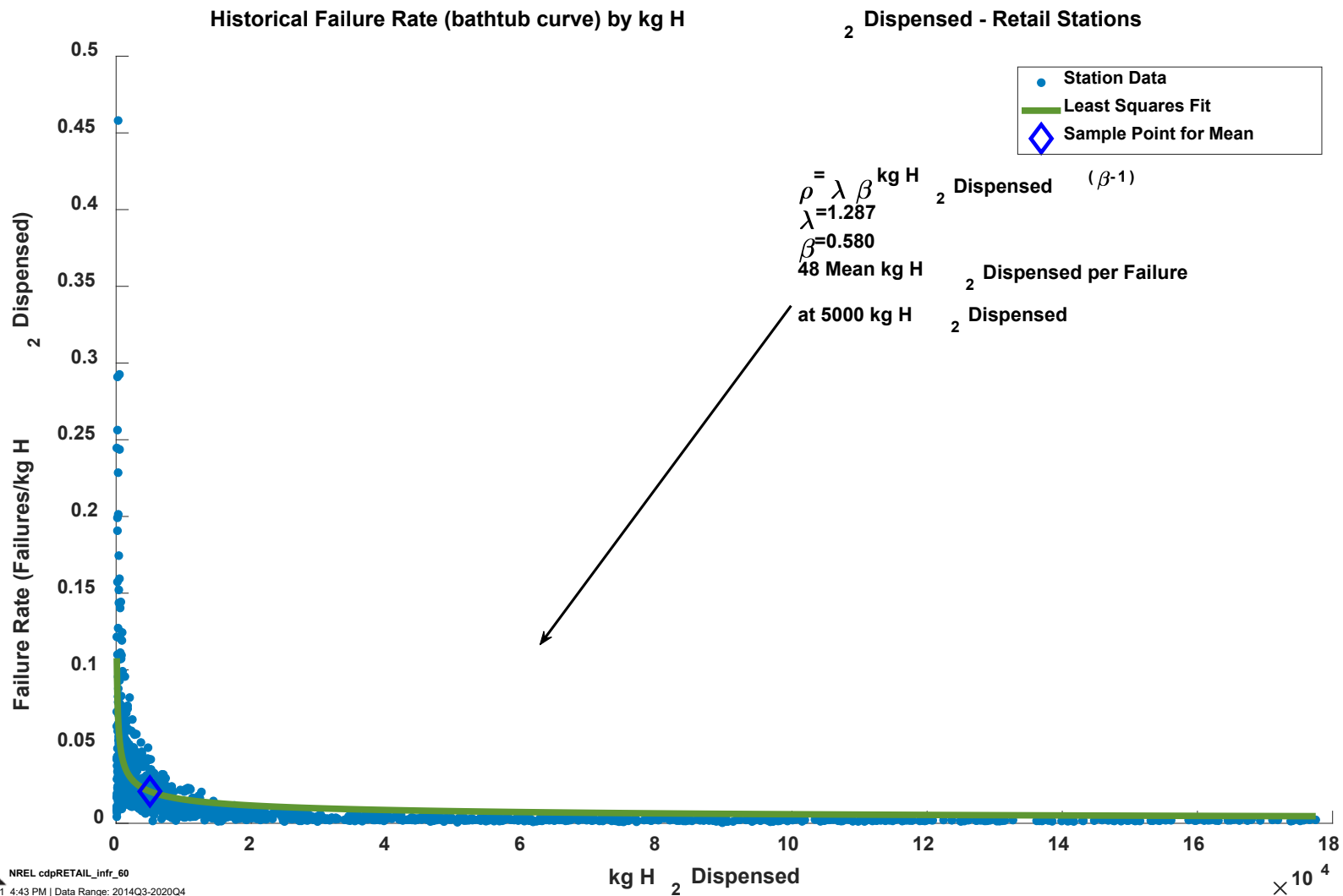



1. IEC 61164:2004(E), Reliability Growth - Statistical Test and Evaluation Methods, IEC. 2004.

2. % change in instantaneous mean H₂ Dispensed (kg) between failures



Historical Failure Rate by Amount Dispensed



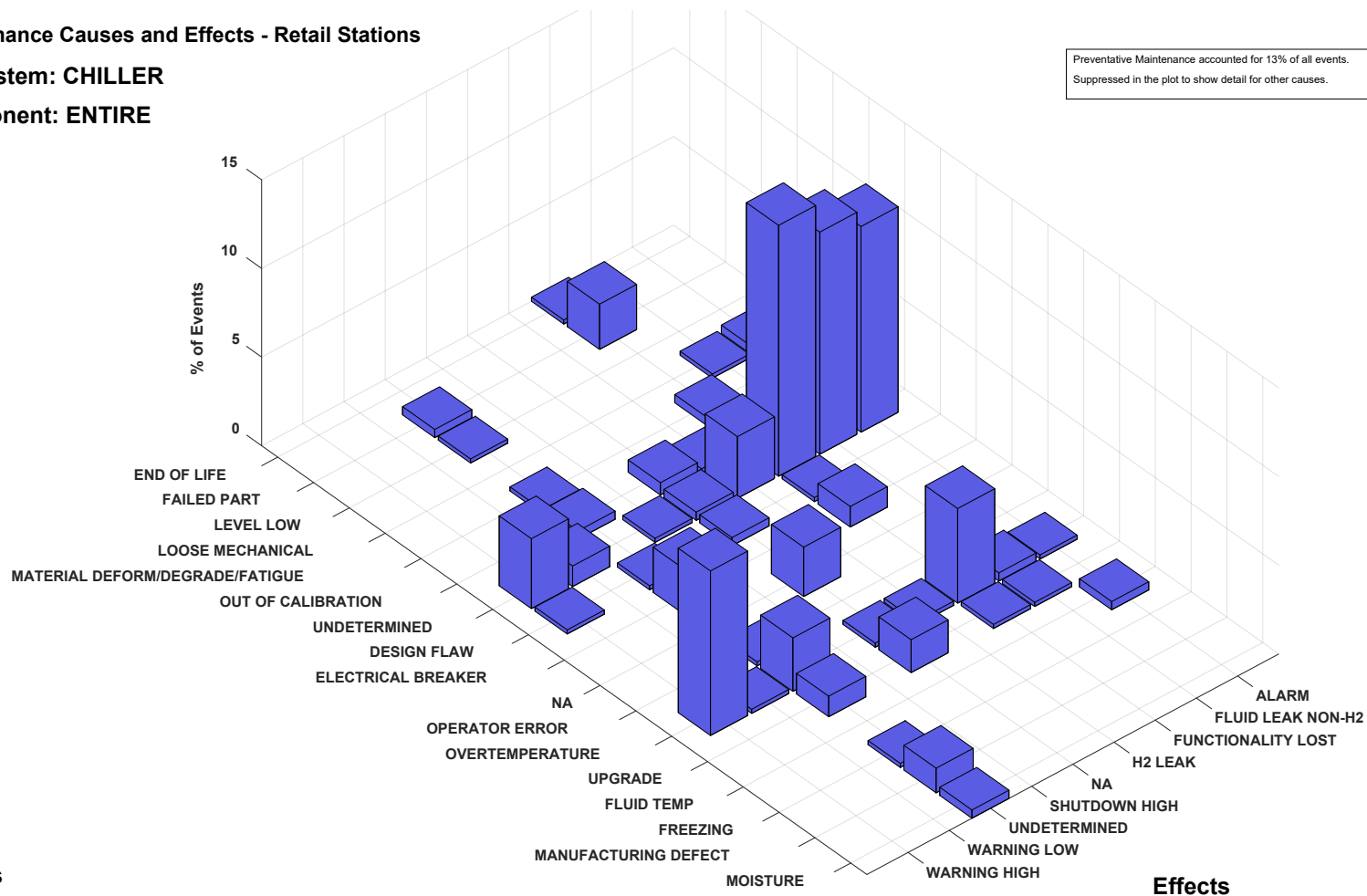

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Maintenance Causes and Effects - Retail Stations

Subsystem: CHILLER

Component: ENTIRE

Preventative Maintenance accounted for 13% of all events.
 Suppressed in the plot to show detail for other causes.



Causes

Effects



NREL cdpRETAIL_infr_64

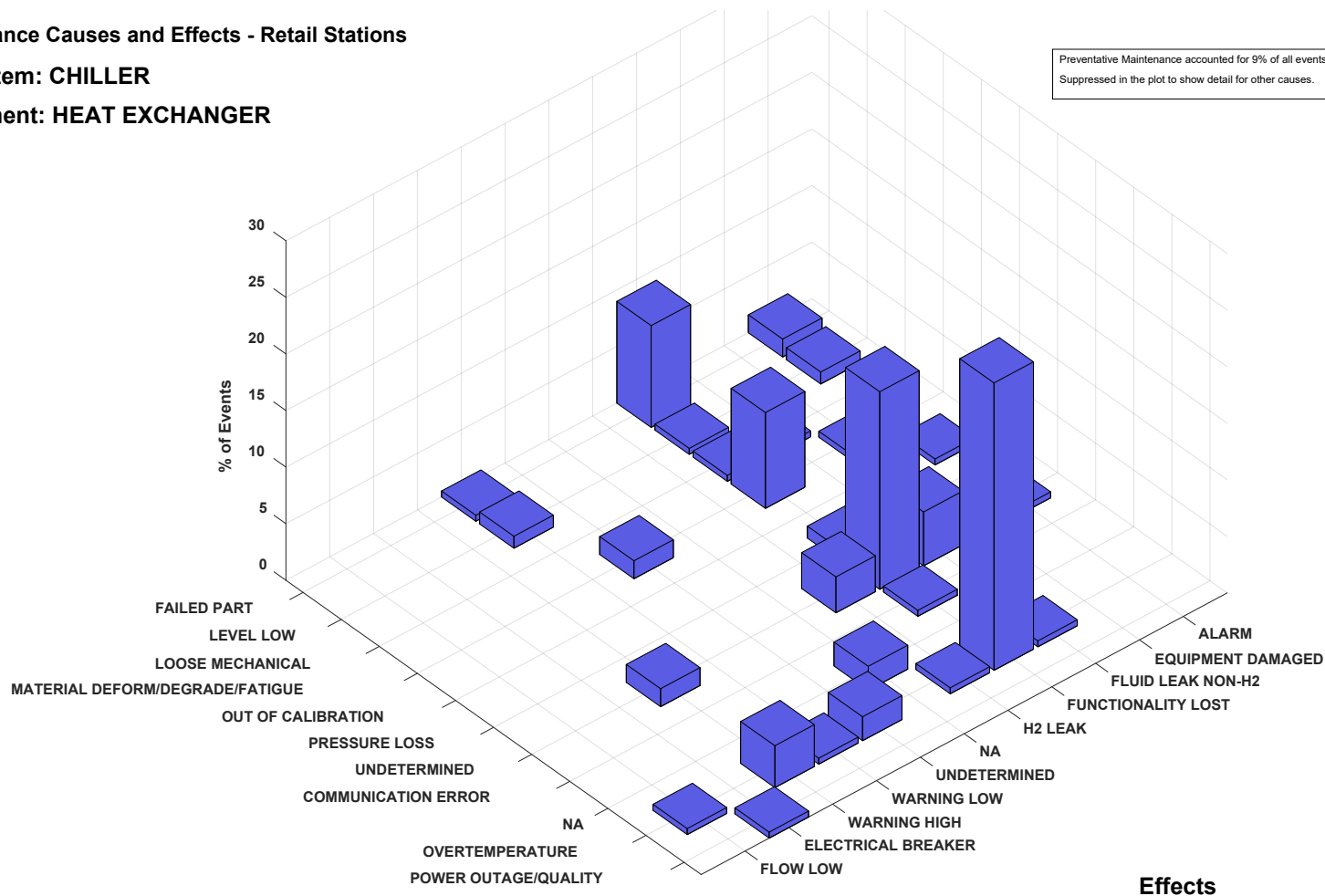
Created: Sep-15-21 4:22 PM | Data Range: 2014Q3-2020Q4

Maintenance Causes and Effects - Retail Stations

Subsystem: CHILLER

Component: HEAT EXCHANGER

Preventative Maintenance accounted for 9% of all events.
Suppressed in the plot to show detail for other causes.



Causes

Effects



NREL cdpRETAIL_infr_65

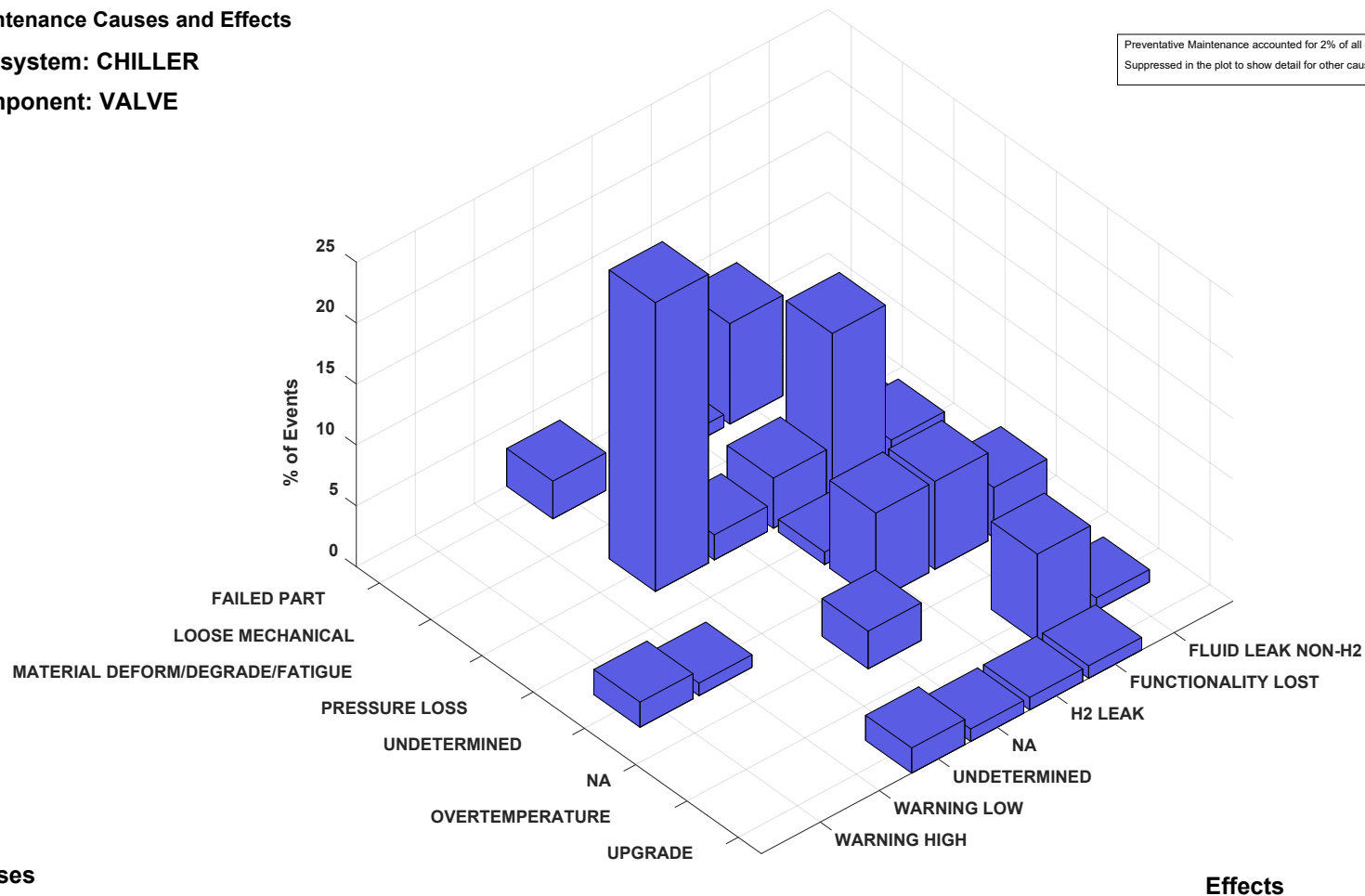
Created: Sep-15-21 4:16 PM | Data Range: 2014Q3-2020Q4

Maintenance Causes and Effects

Subsystem: CHILLER

Component: VALVE

Preventative Maintenance accounted for 2% of all events.
Suppressed in the plot to show detail for other causes.



Causes

Effects



NREL cdpRETAIL_infr_66

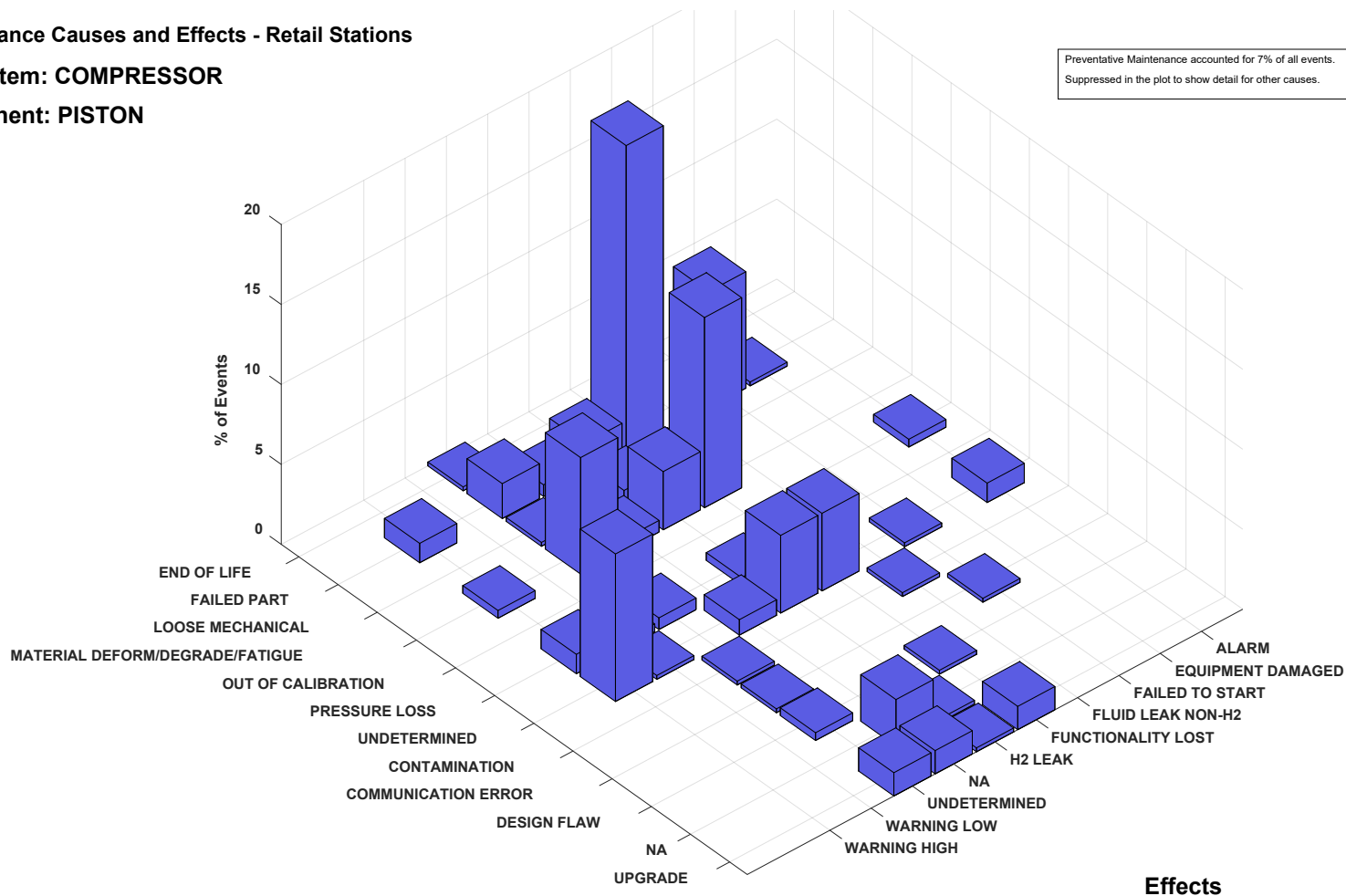
Created: Sep-15-21 4:11 PM | Data Range: 2014Q3-2020Q4

Maintenance Causes and Effects - Retail Stations

Subsystem: COMPRESSOR

Component: PISTON

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



Causes

Effects



NREL cdpRETAIL_infr_71

Created: Sep-15-21 3:37 PM | Data Range: 2014Q3-2020Q4

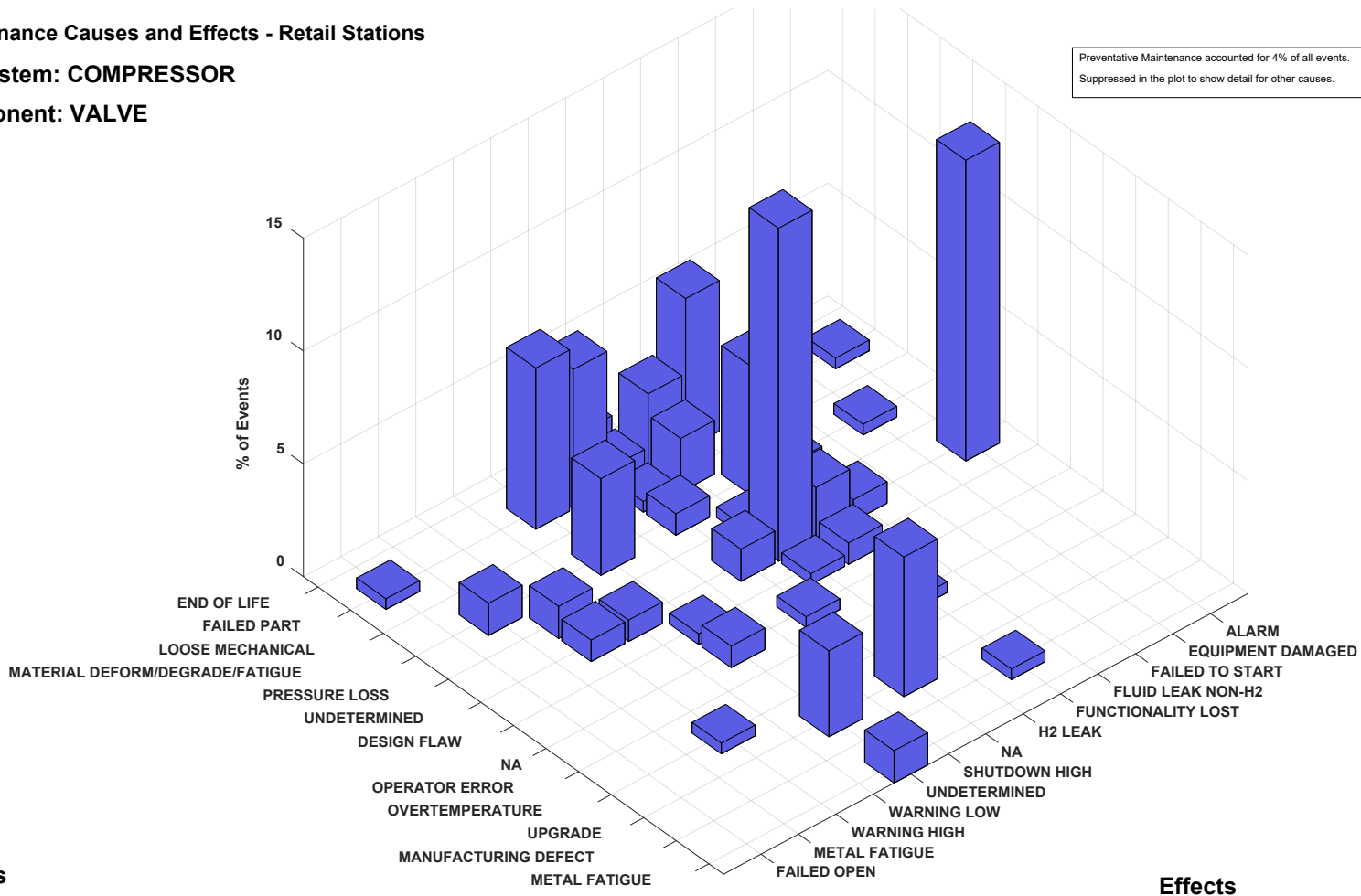
Maintenance Causes and Effects: Compressor (Valve)

Maintenance Causes and Effects - Retail Stations

Subsystem: COMPRESSOR

Component: VALVE

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



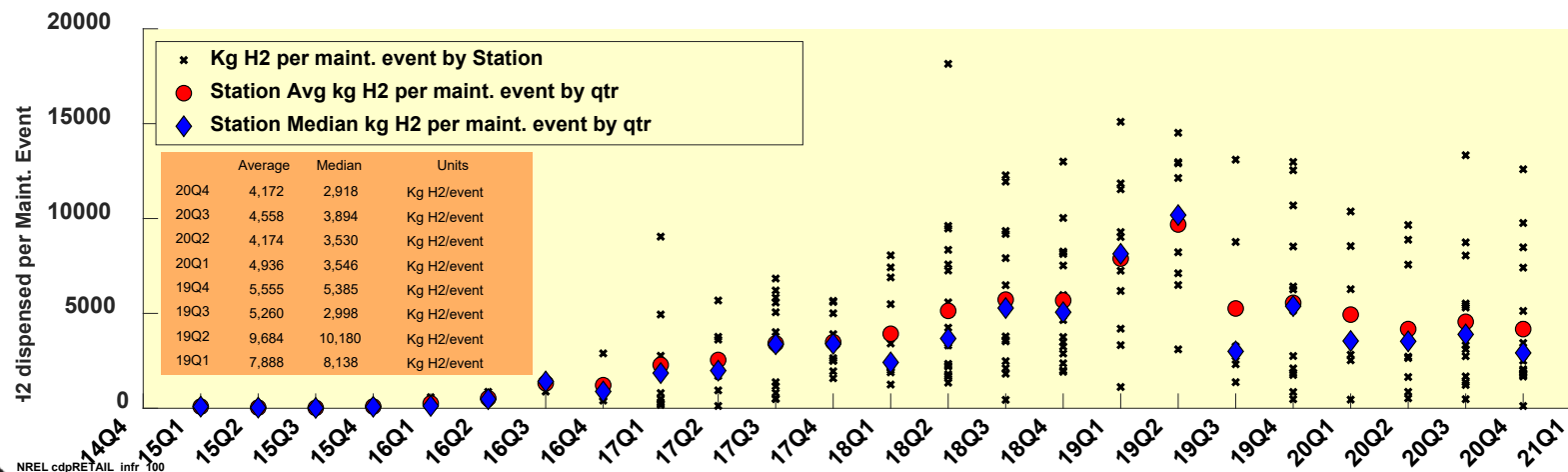
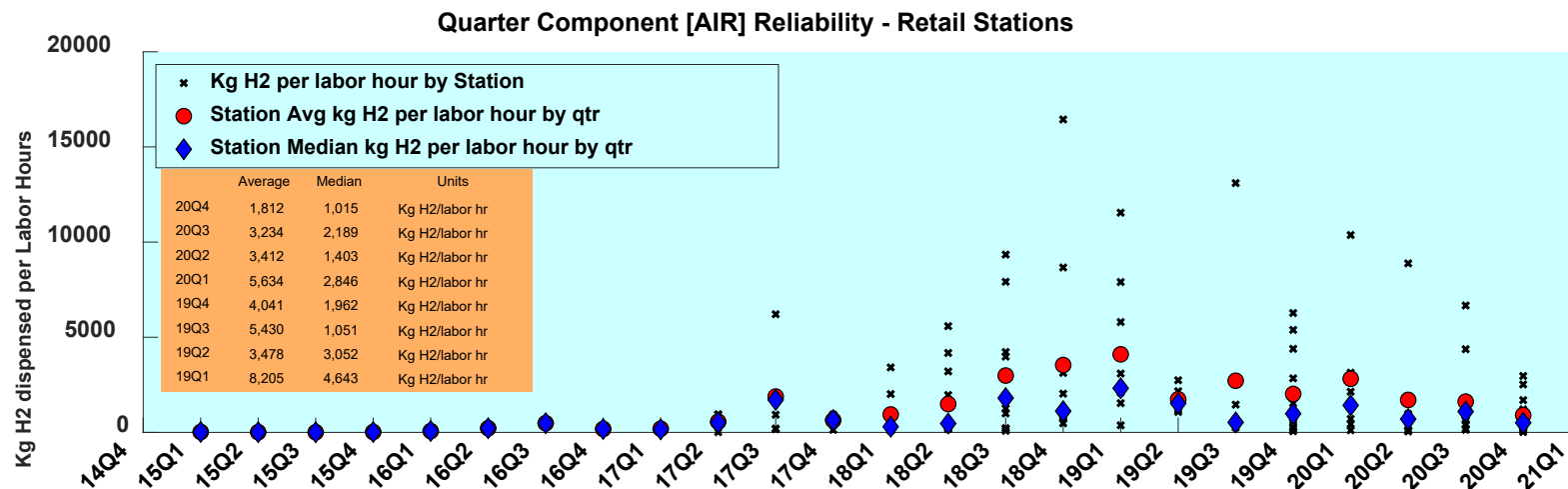
Causes

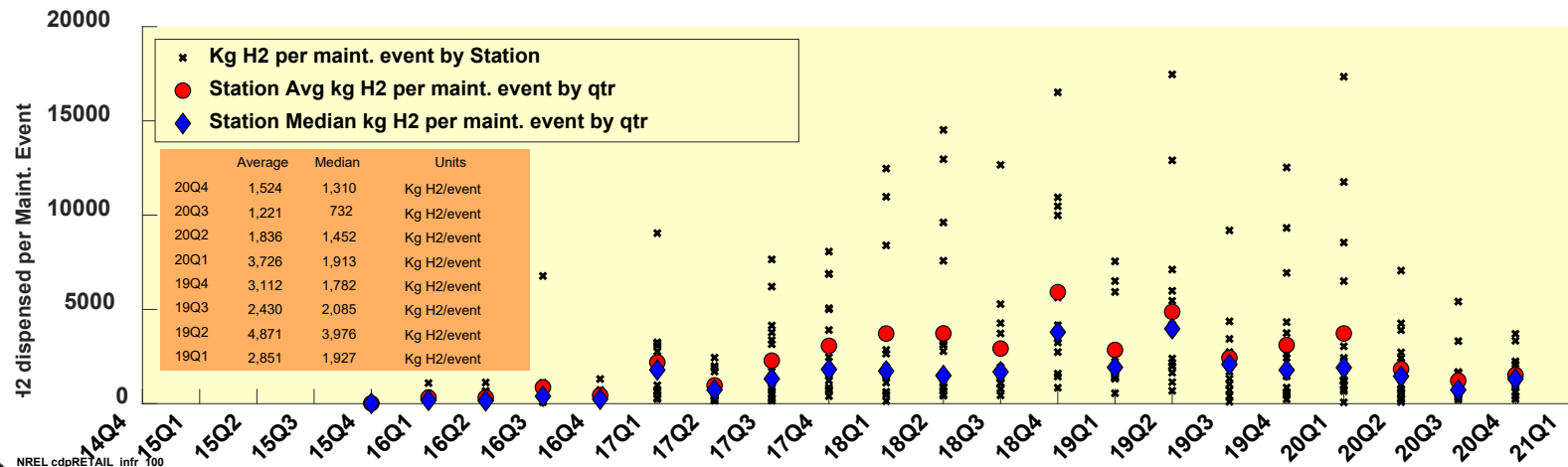
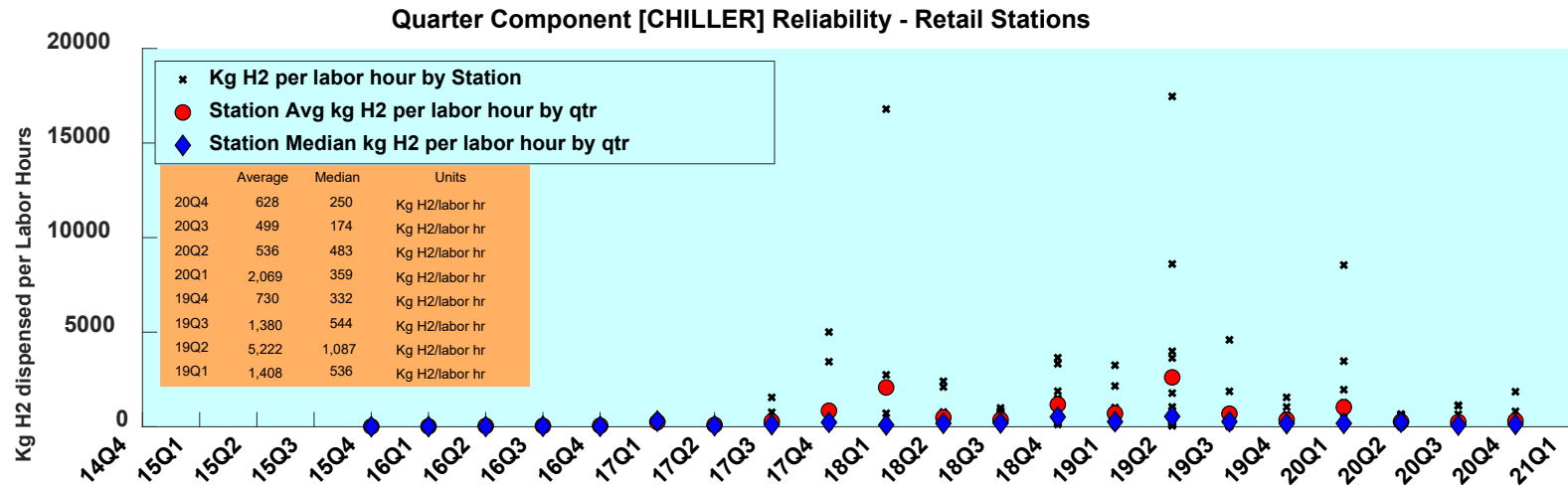
Effects



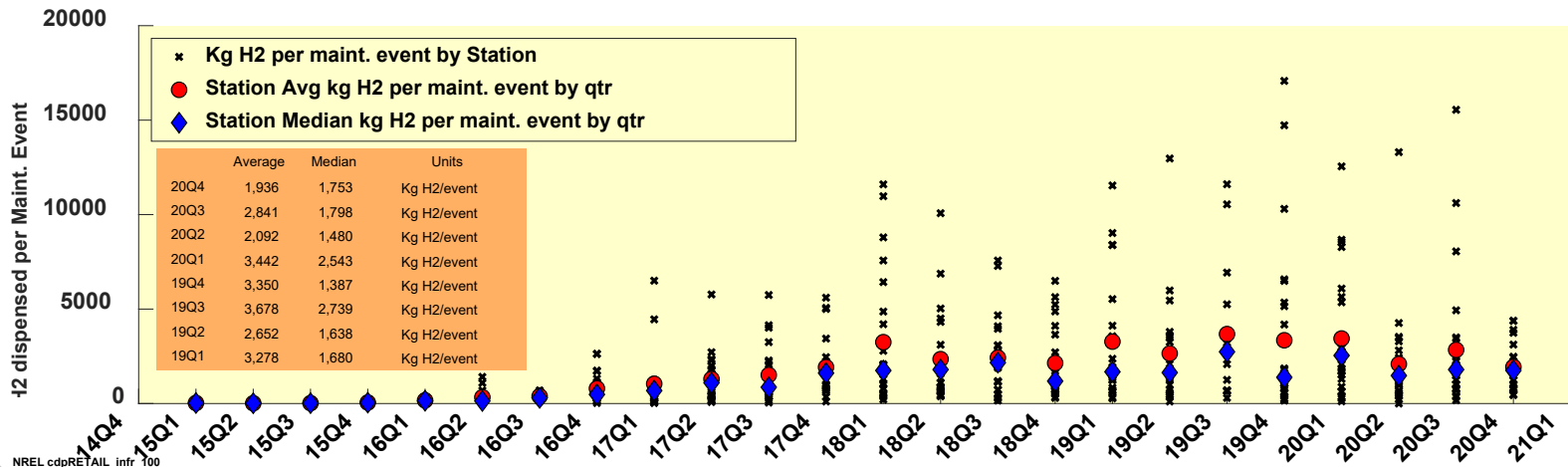
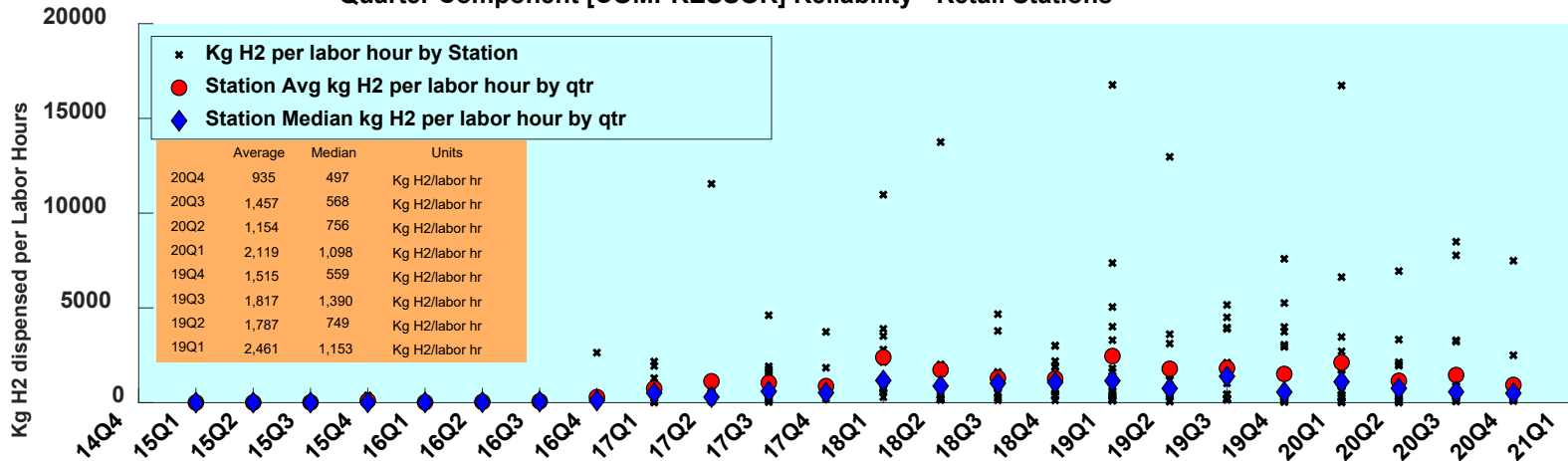
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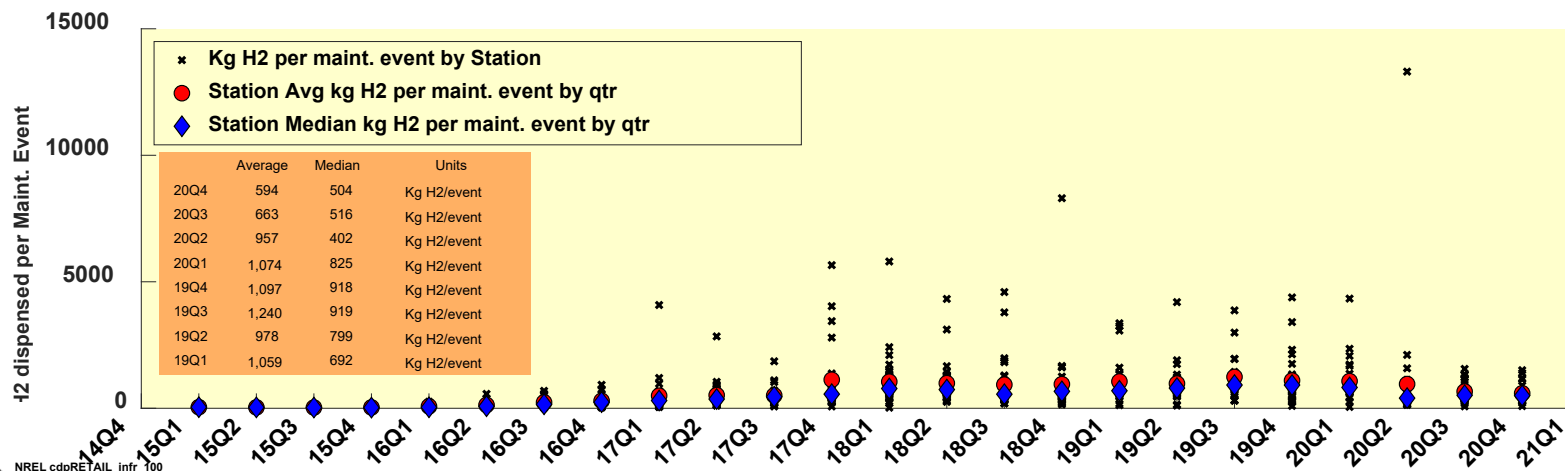
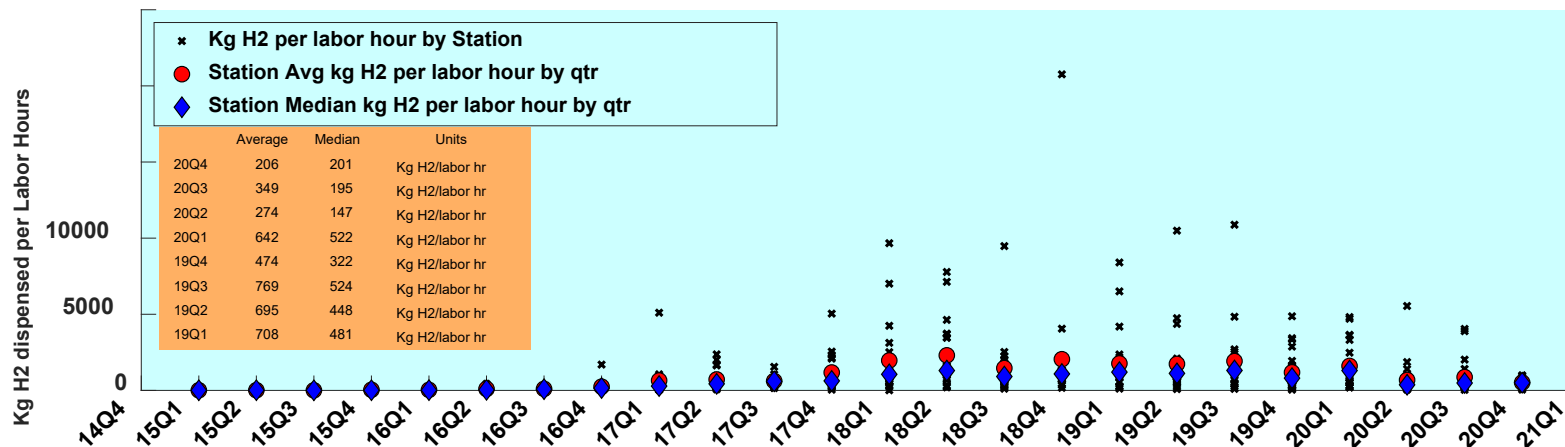




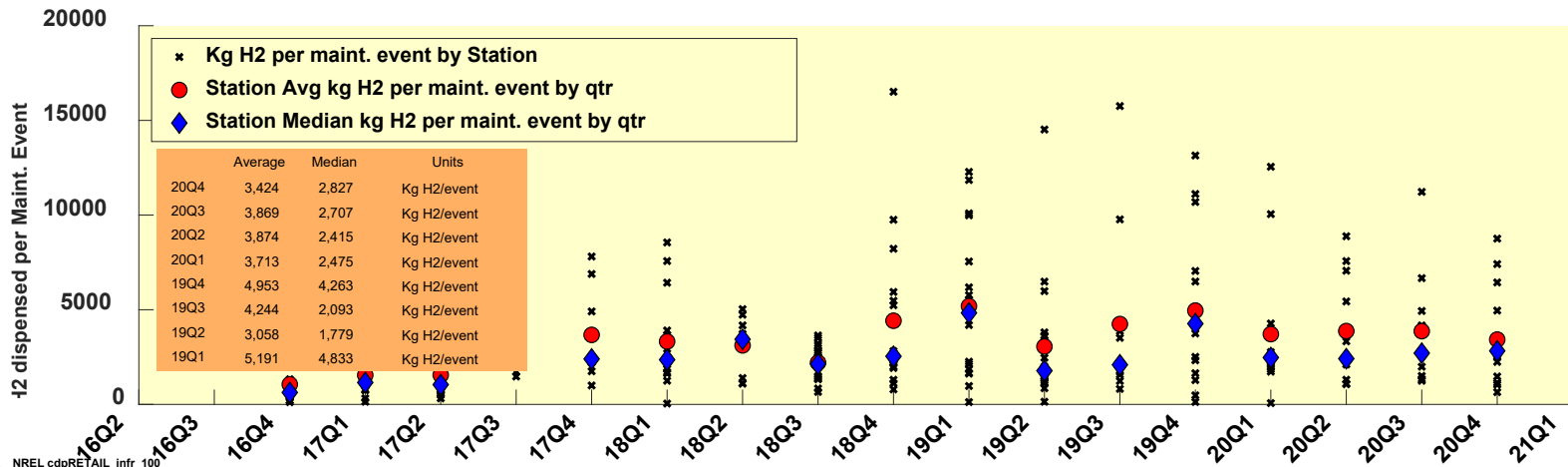
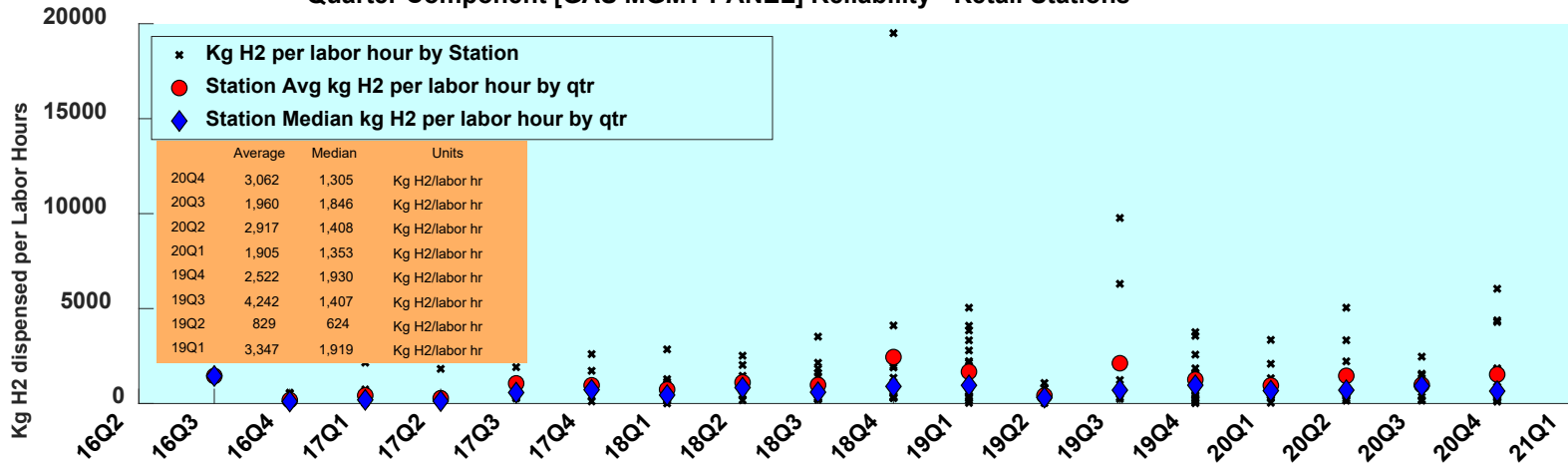
Quarter Component [COMPRESSOR] Reliability - Retail Stations



Quarter Component [DISPENSER] Reliability - Retail Stations

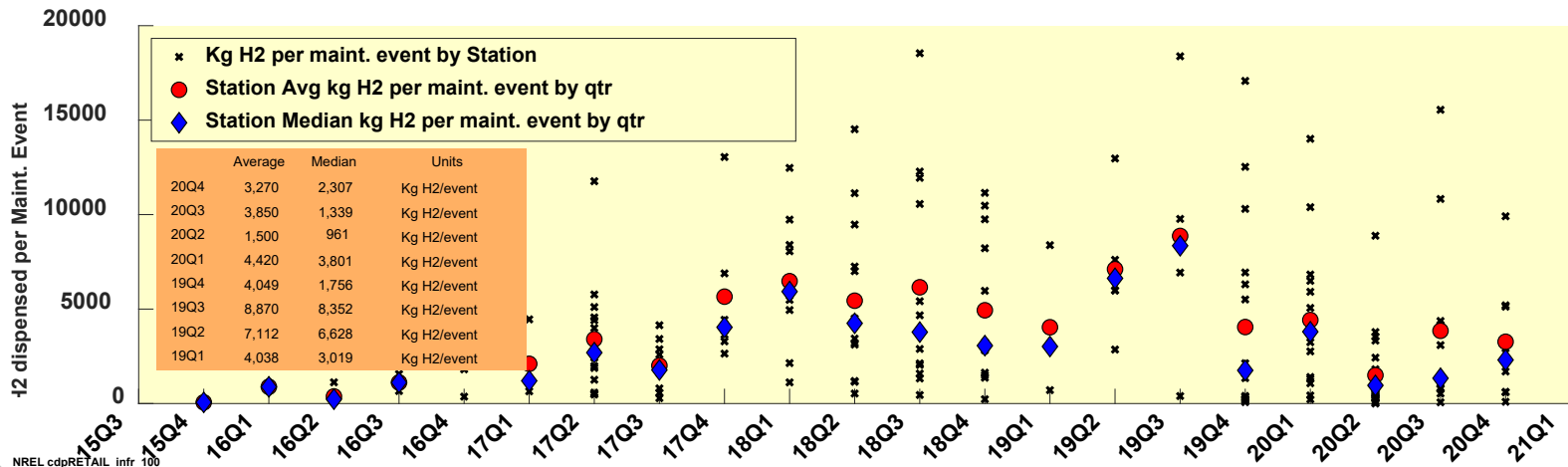
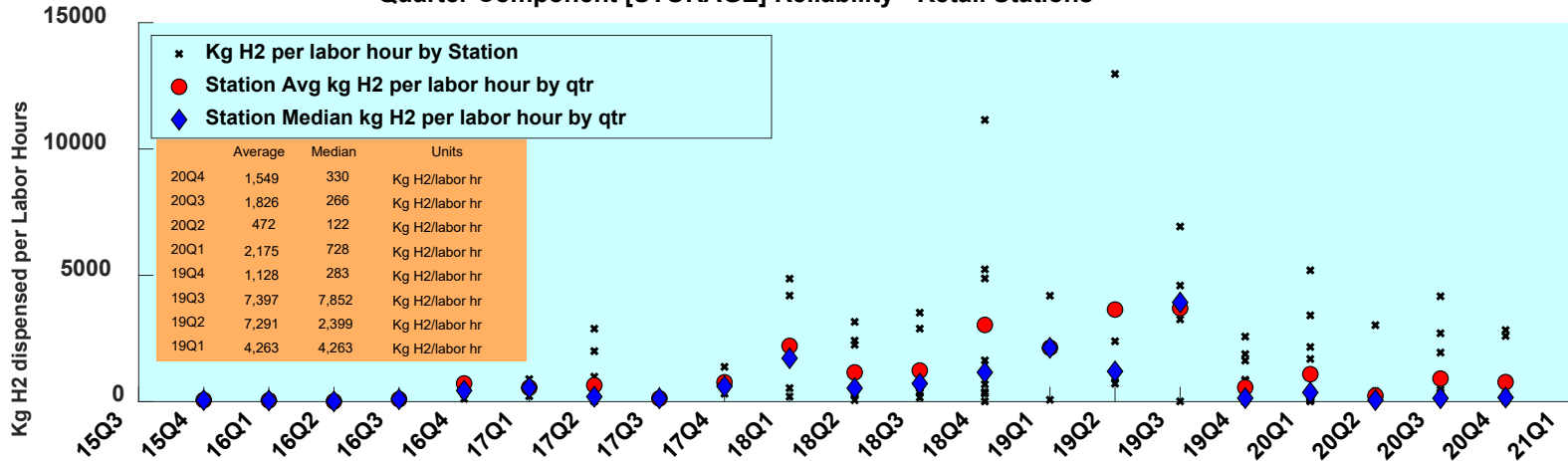


Quarter Component [GAS MGMT PANEL] Reliability - Retail Stations



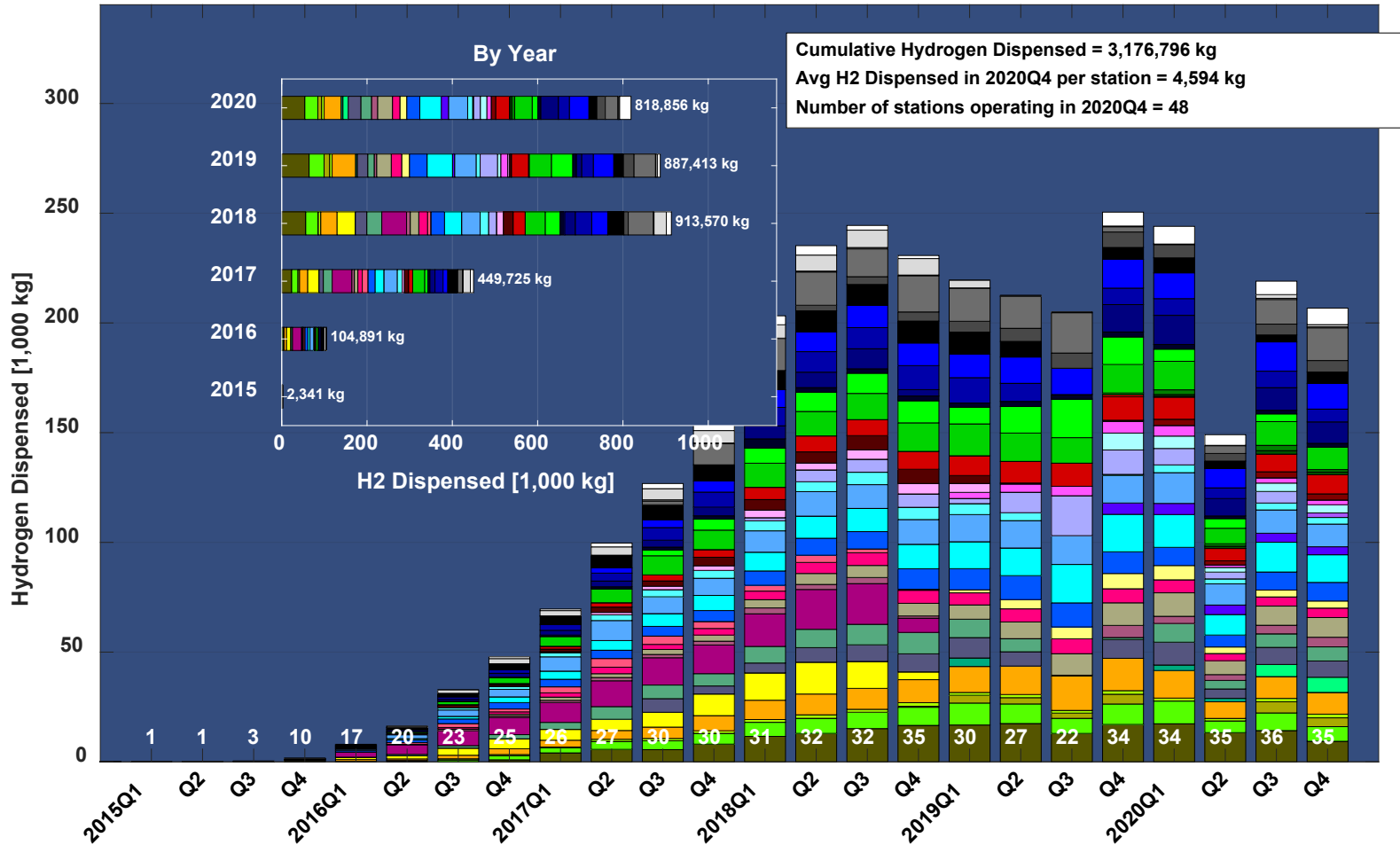
Quarter Component [STORAGE] Reliability – Retail Stations

Quarter Component [STORAGE] Reliability - Retail Stations



Performance

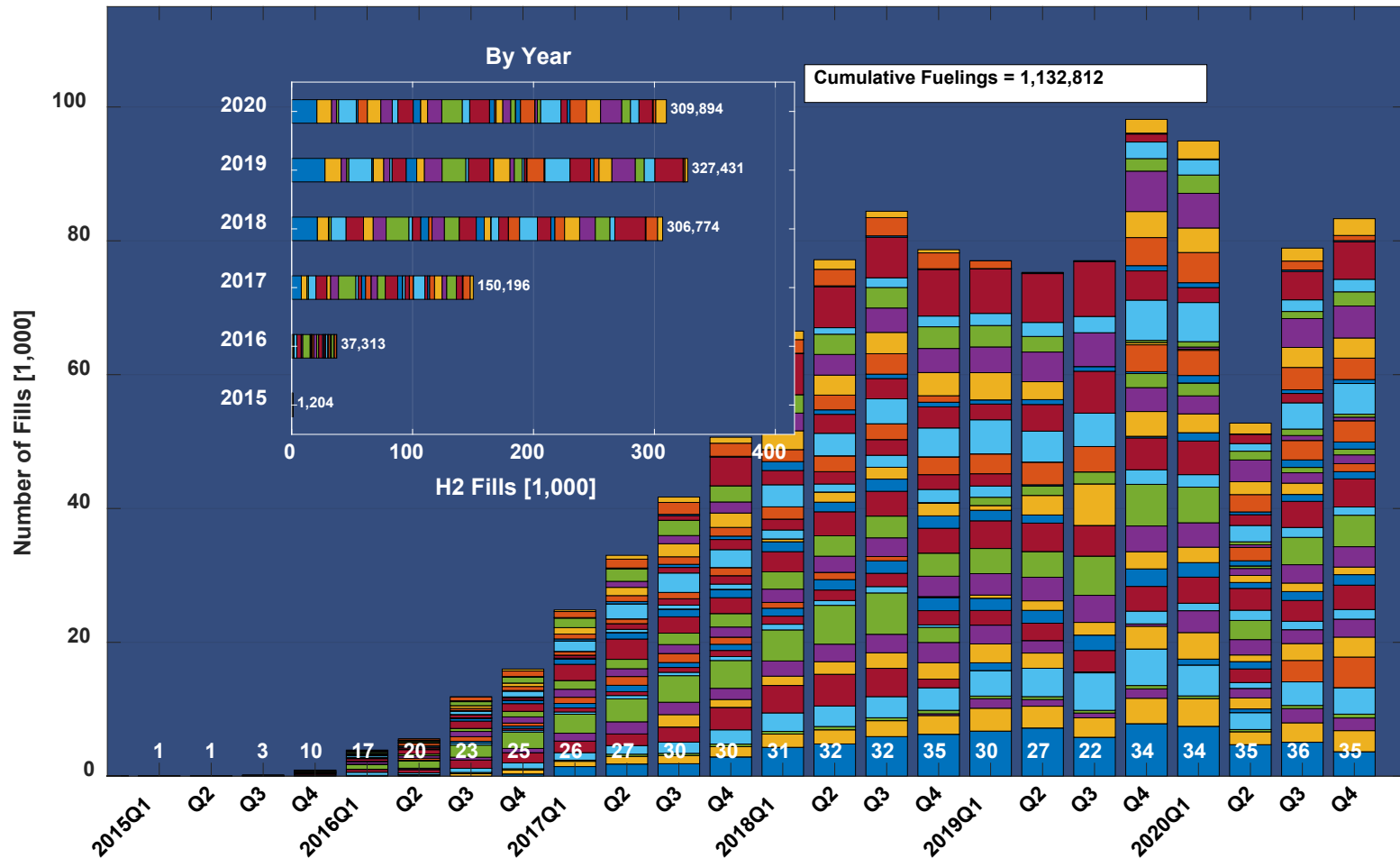
Hydrogen Dispensed By Quarter - Retail Stations



NREL cdpRETAIL_infr_01

Created: Aug-19-21 11:20 AM | Data Range: 2014Q3-2020Q4

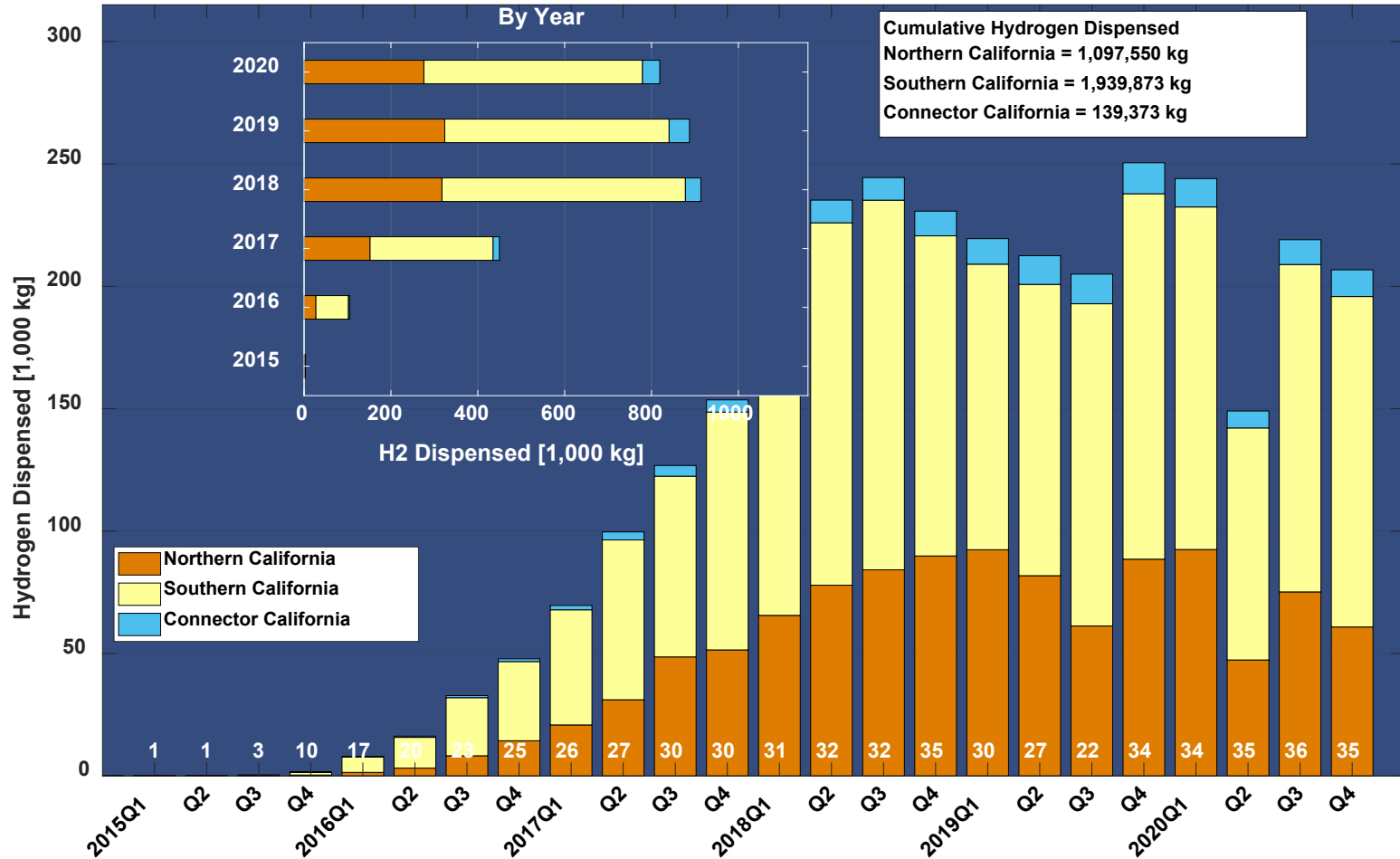
Hydrogen Fills By Quarter - Retail Stations



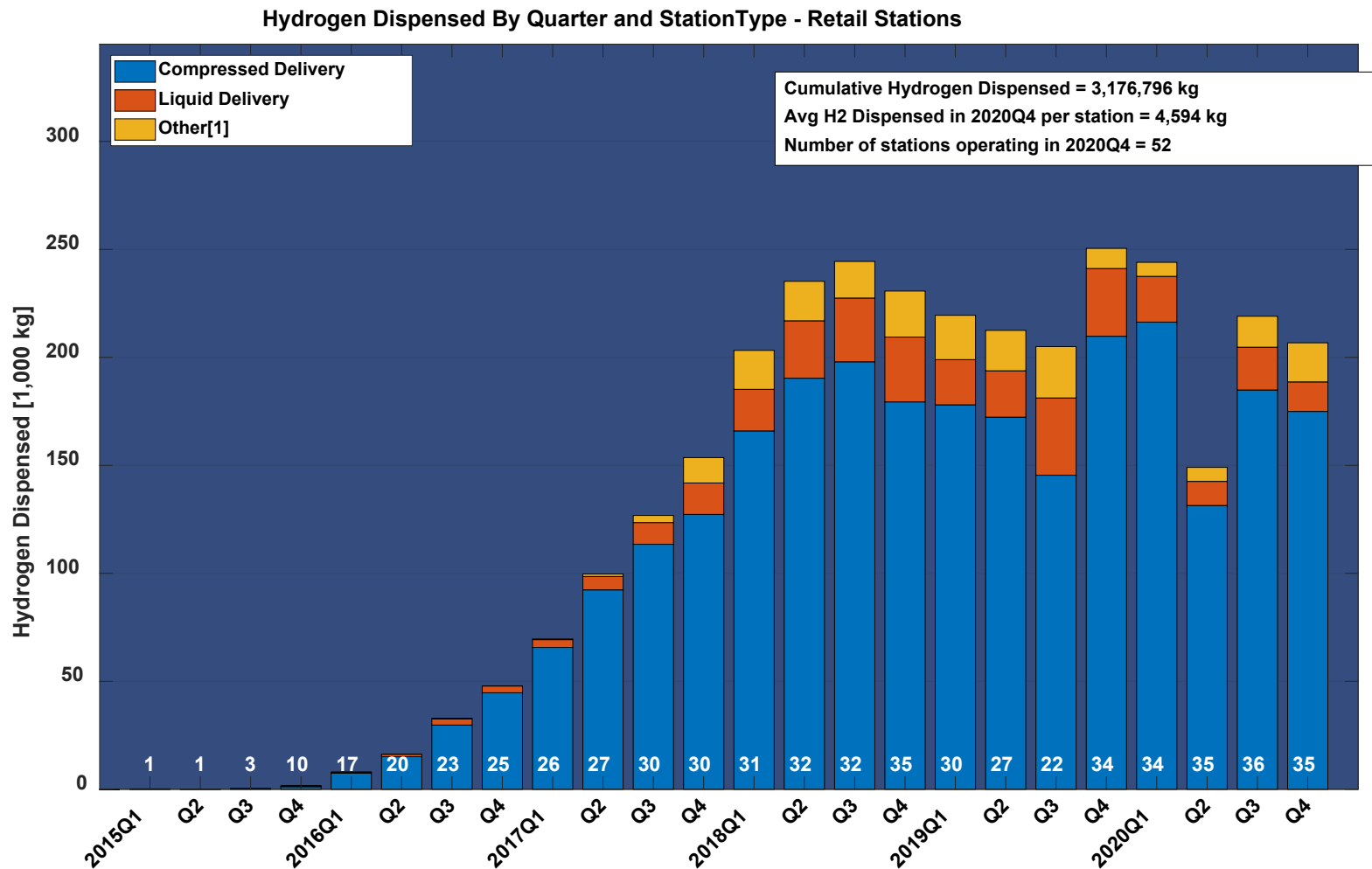
Note: Colors represent individual stations. Stations reporting data count is number at bottom of bar.

H2 Dispensed by Region

Hydrogen Dispensed By Region - Retail Stations



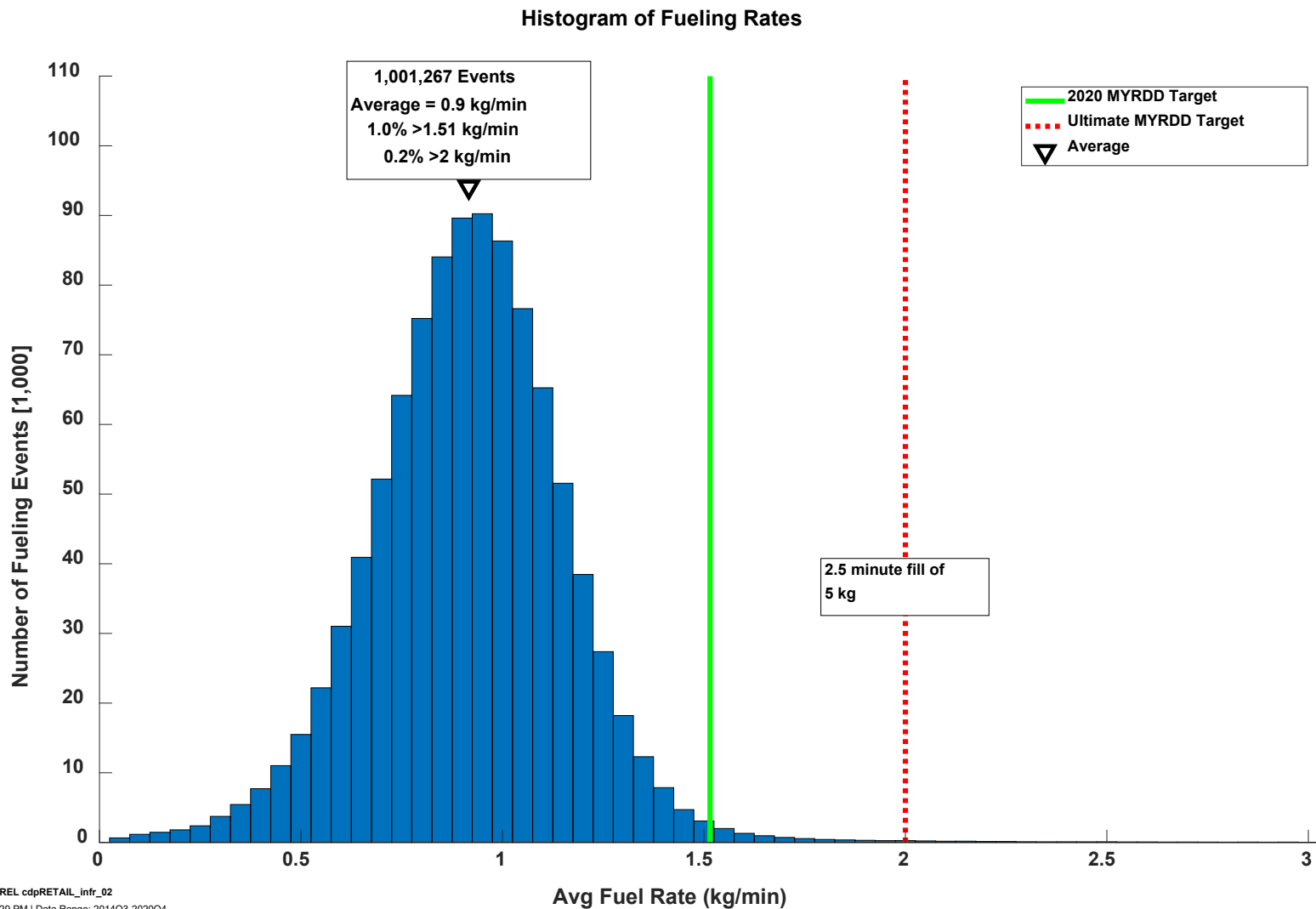
Note: Station count is number at bottom of bar.



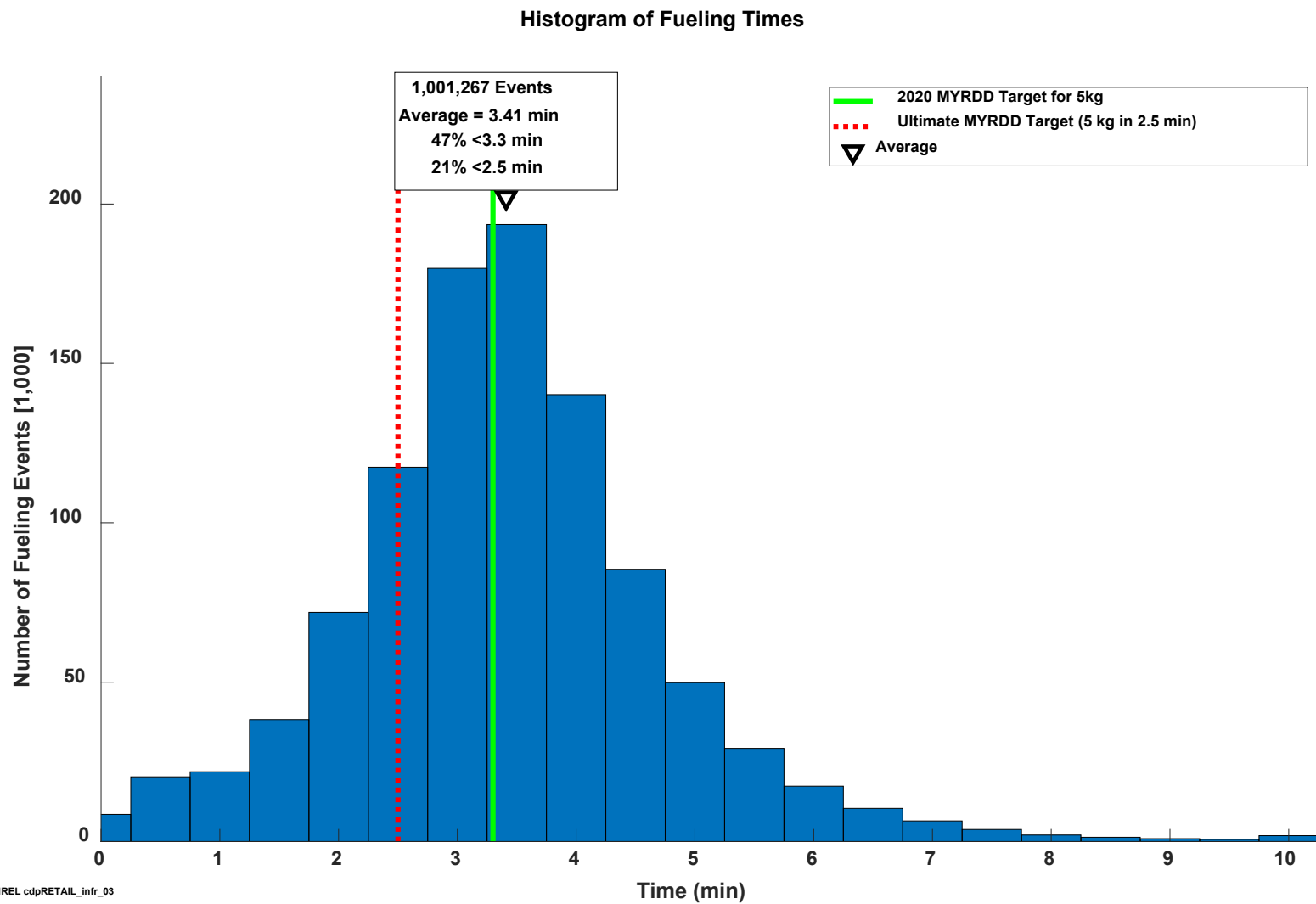
Note: Stations reporting data count is number at bottom of bar.

[1] Other includes pipeline and stations with multiple hydrogen sources.

Histogram of Fueling Rates



Histogram of Fueling Times

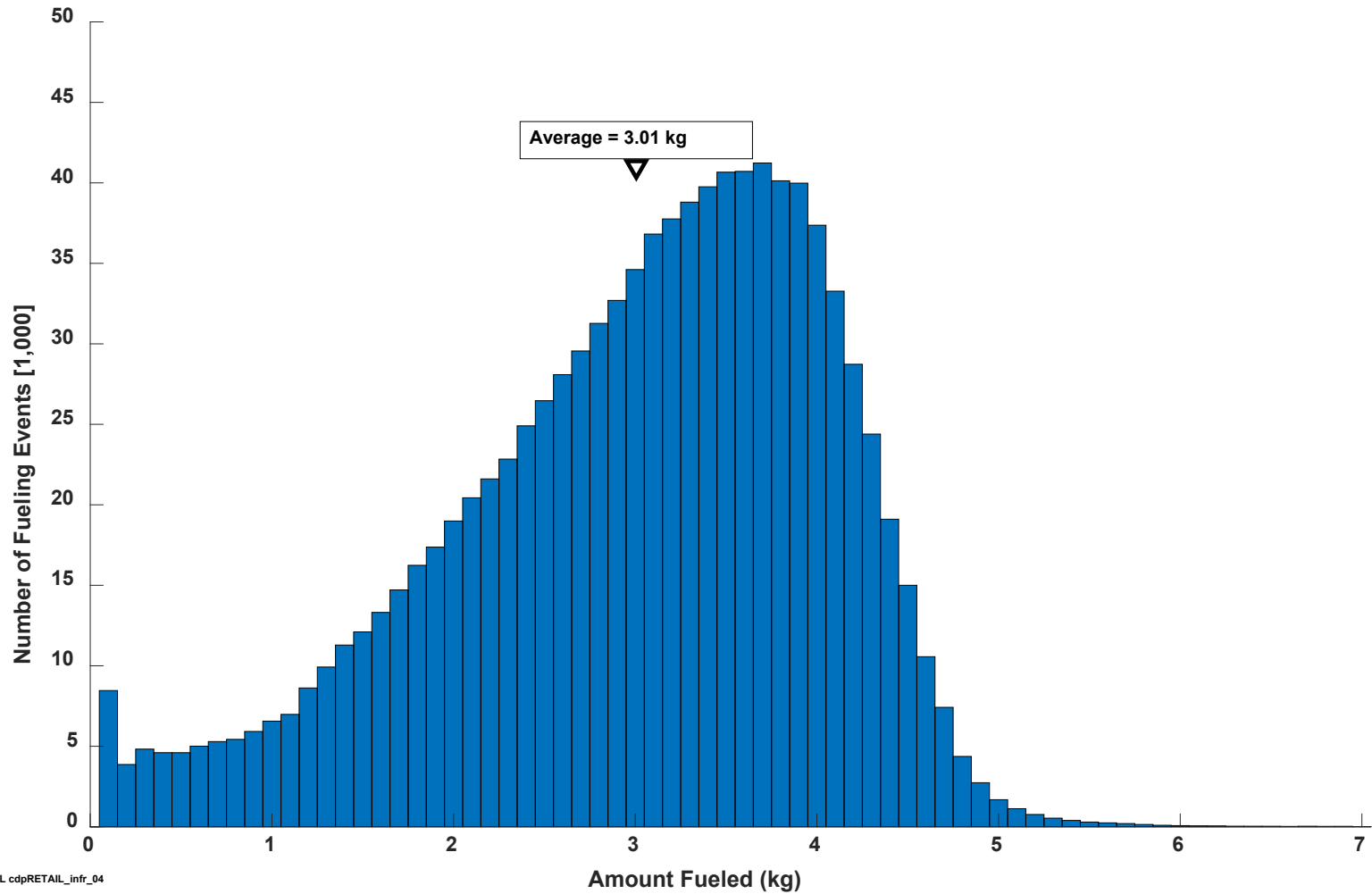



NREL cdpRETAIL_infr_03

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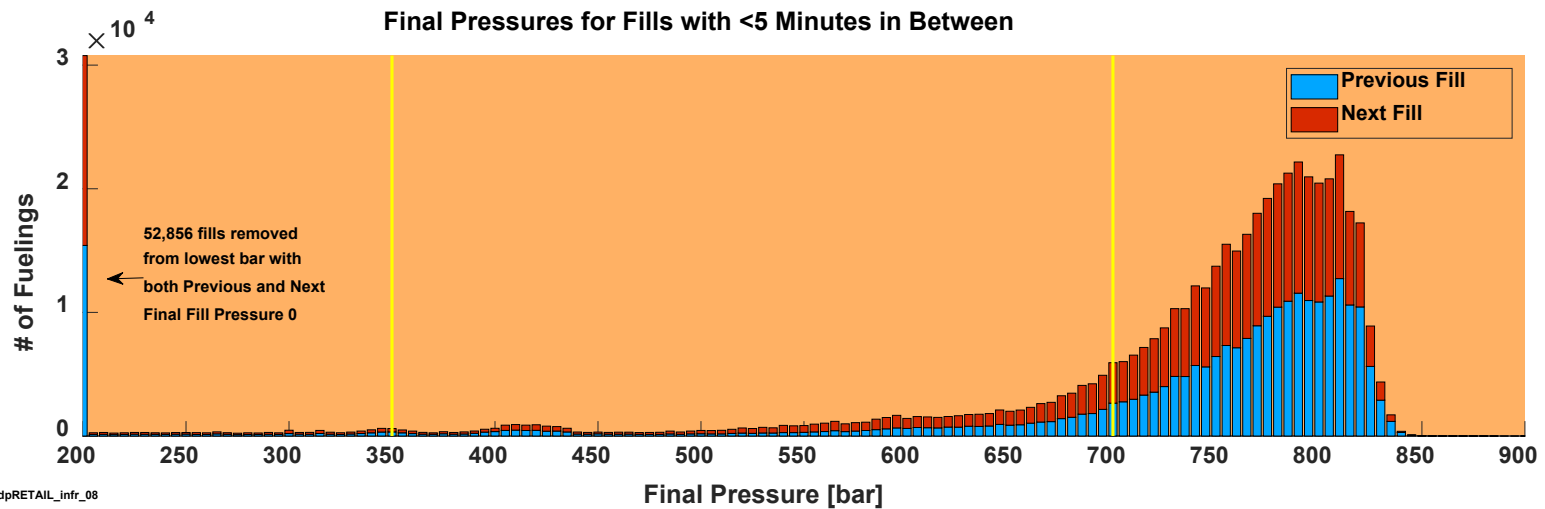
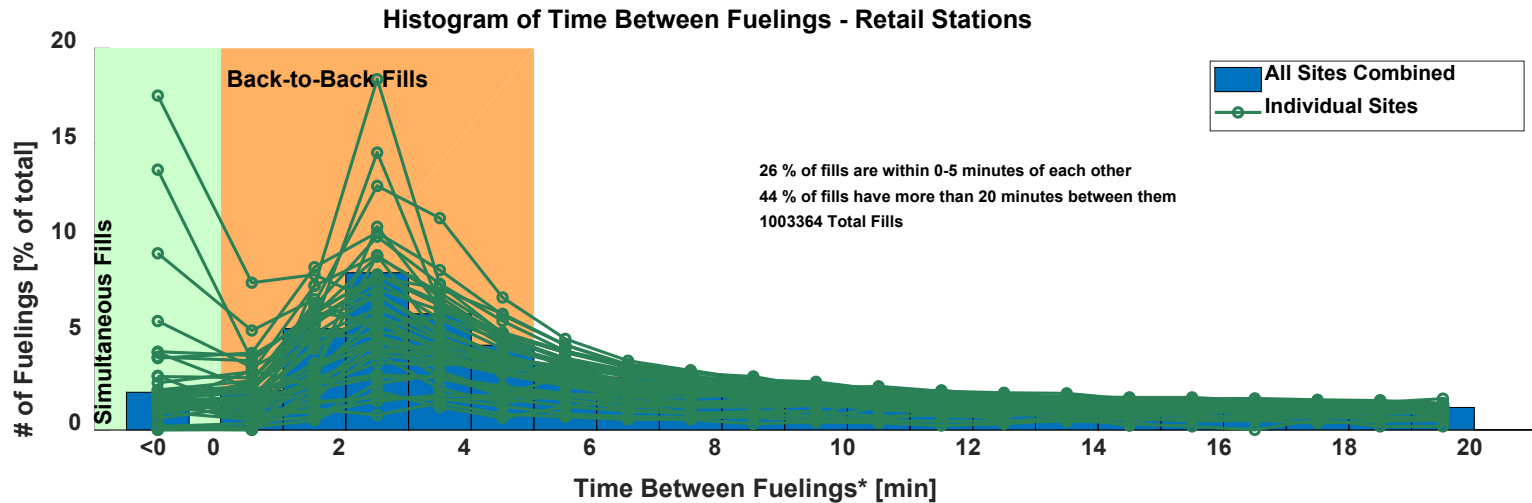
Histogram of Fueling Amounts

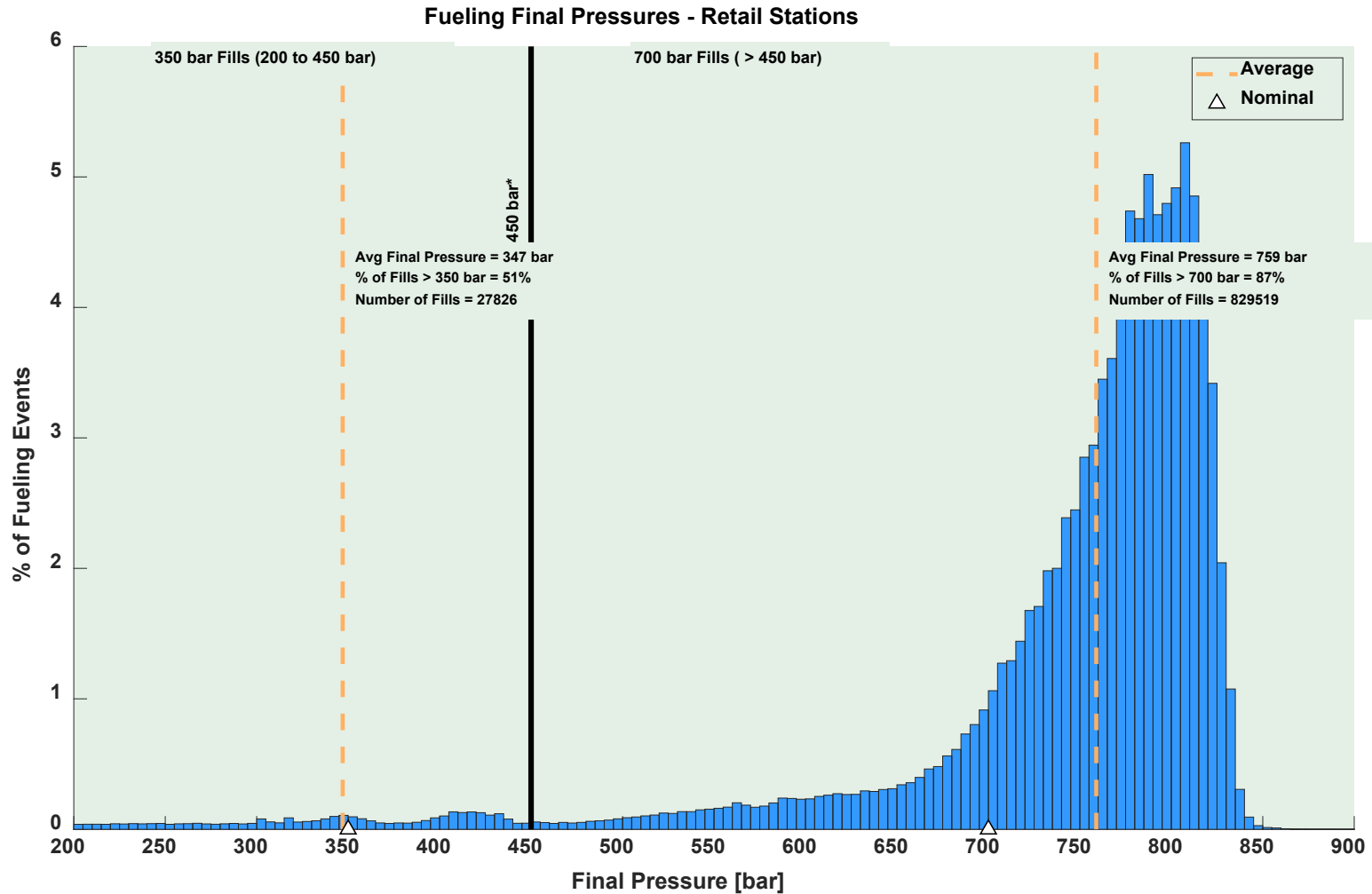
Histogram of Fueling Amounts



 NREL cdpRETAIL_infr_04
Created: Aug-05-21 2:44 PM | Data Range: 2014Q3-2020Q4

Time Between Fueling

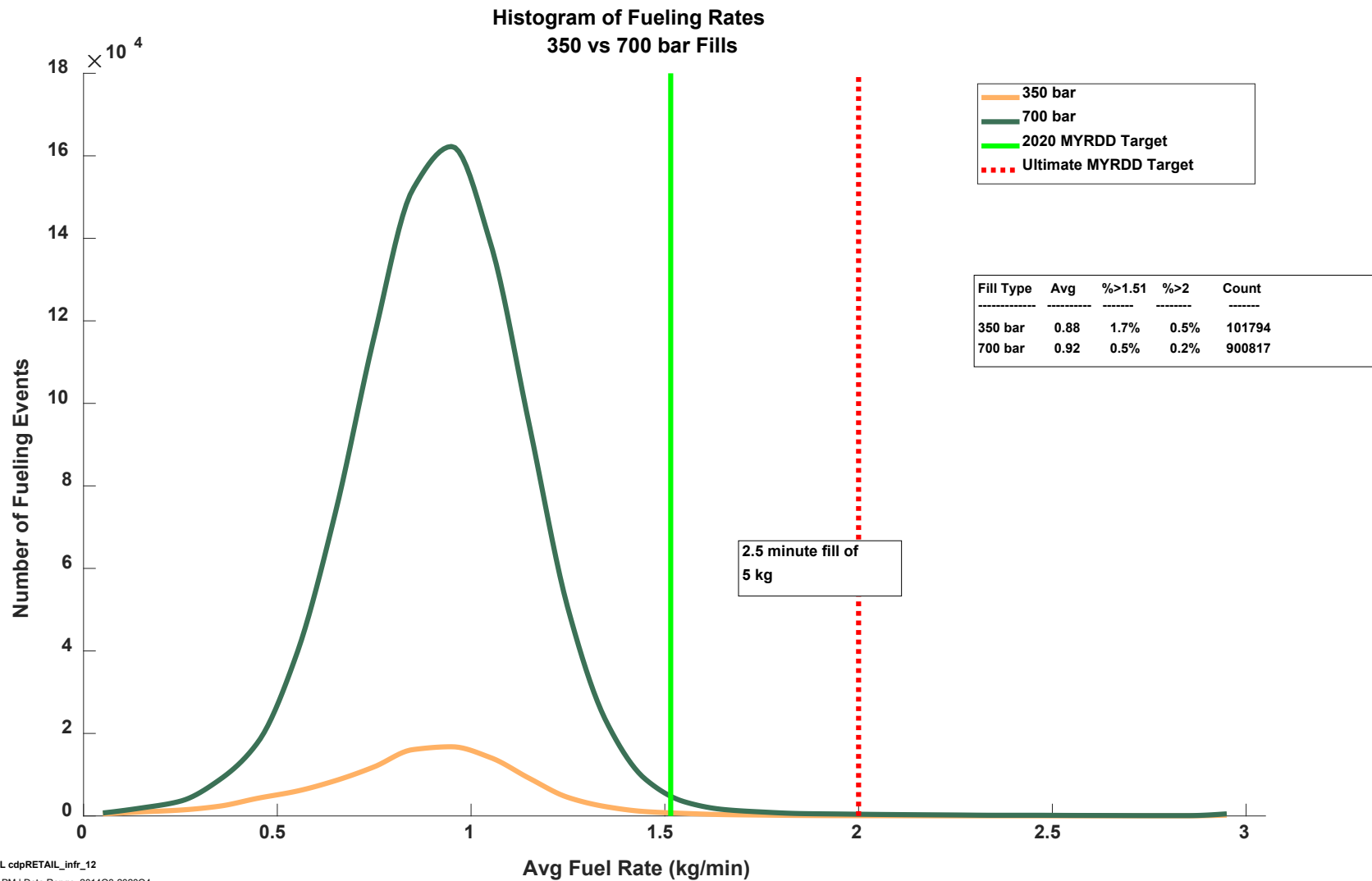




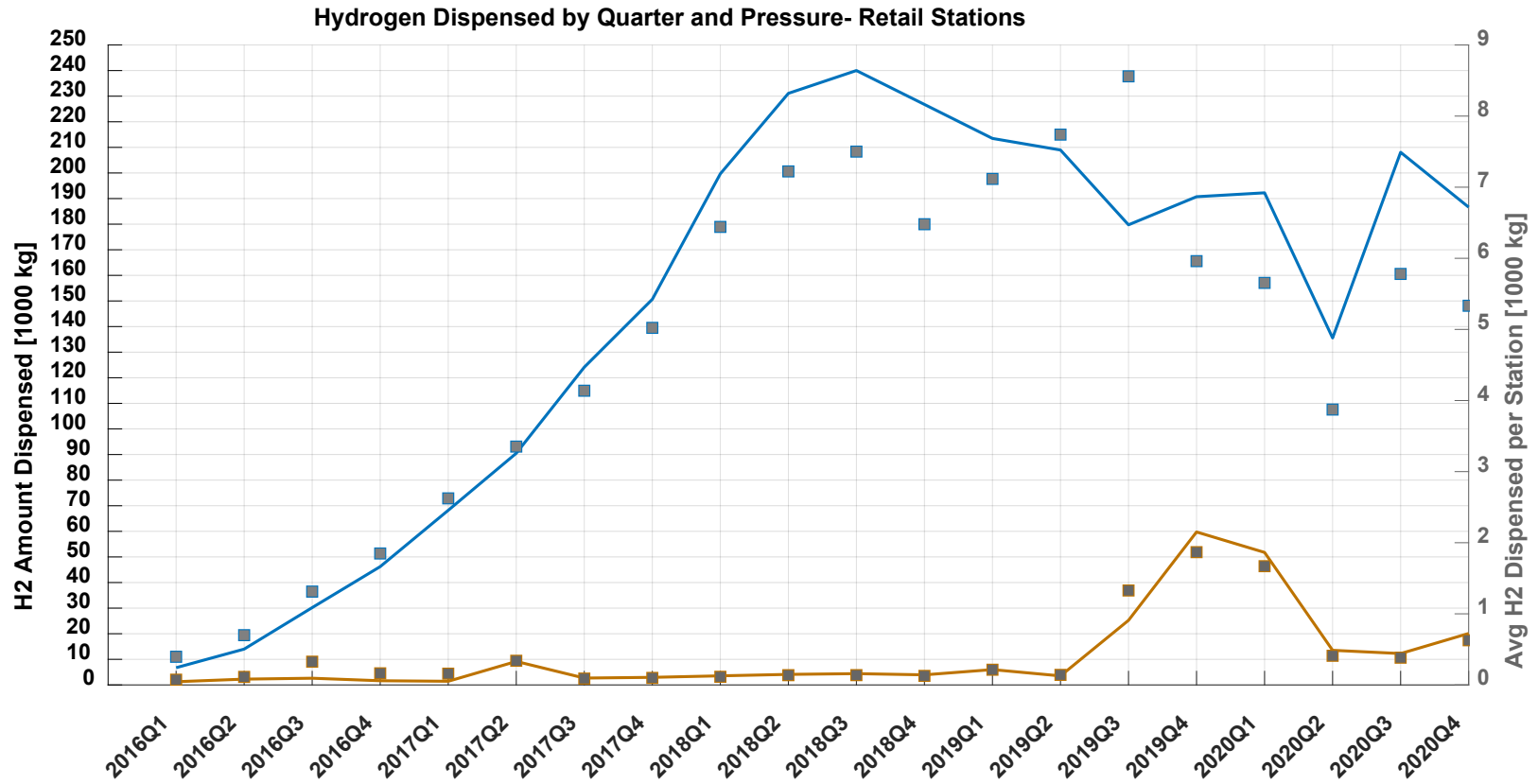
NREL cdpRETAIL_infr_09

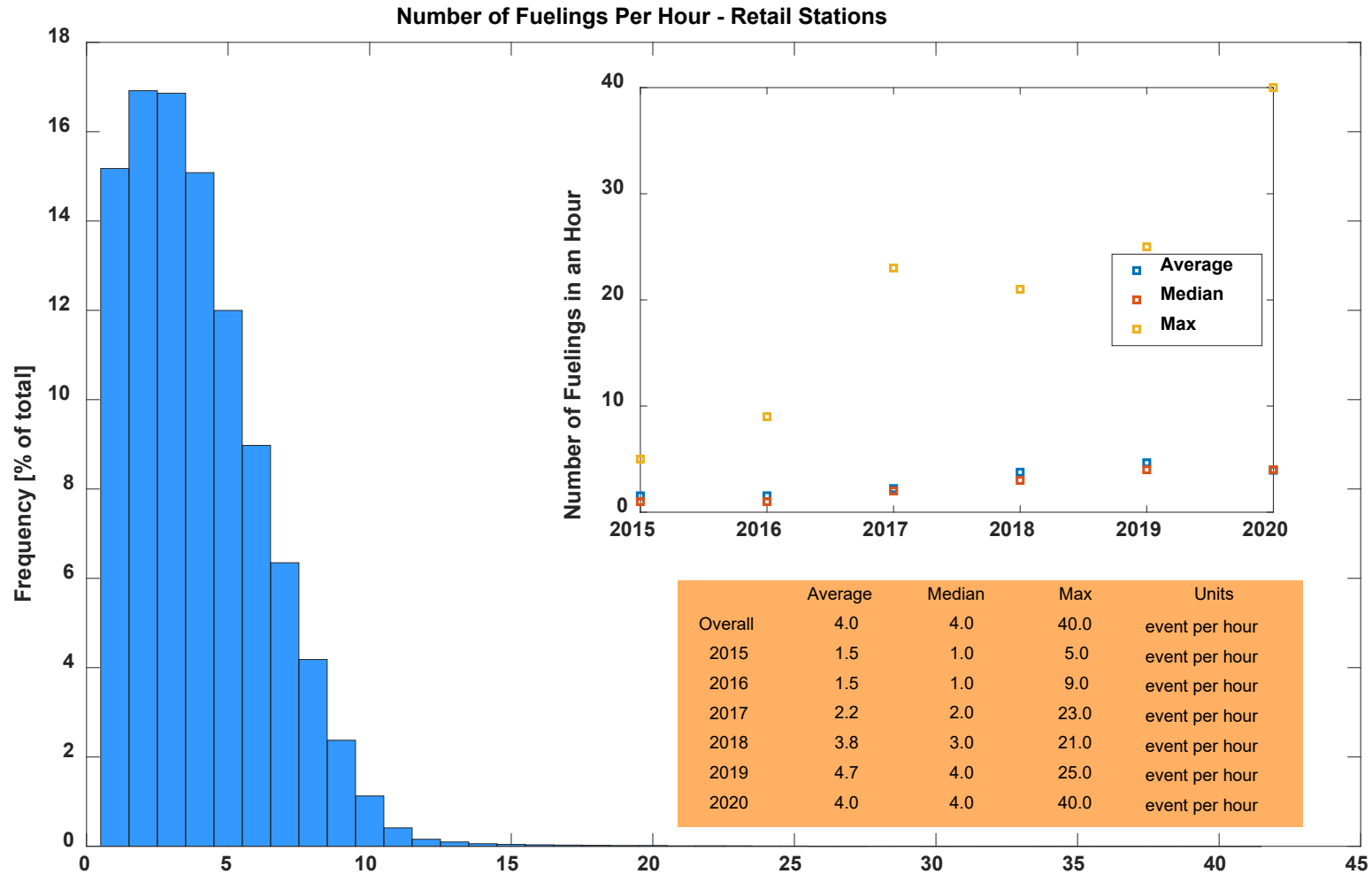
Created: Aug-05-21 8:54 AM | Data Range: 2014Q3-2020Q4

*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.



Hydrogen Dispensed by Quarter and Pressure

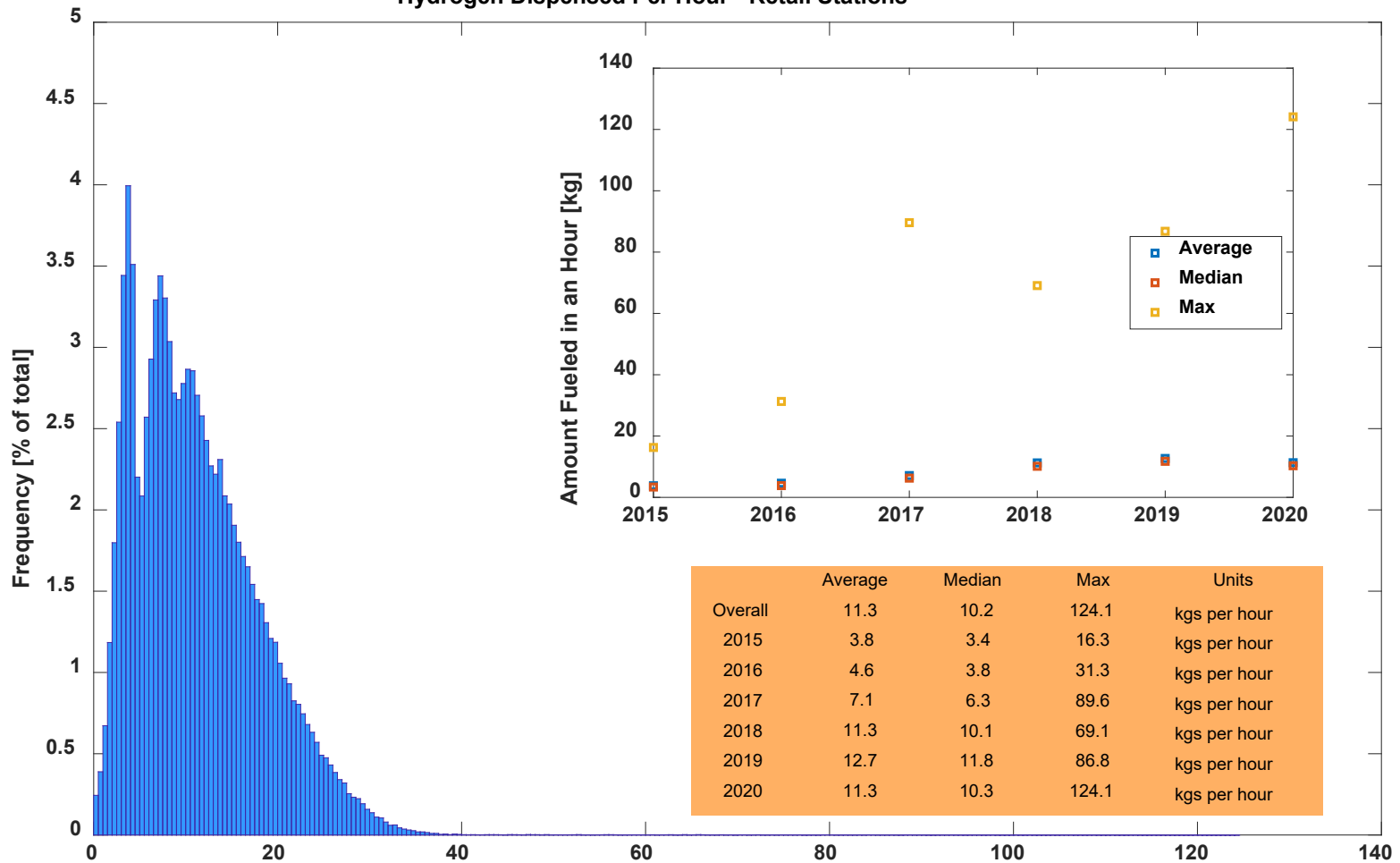


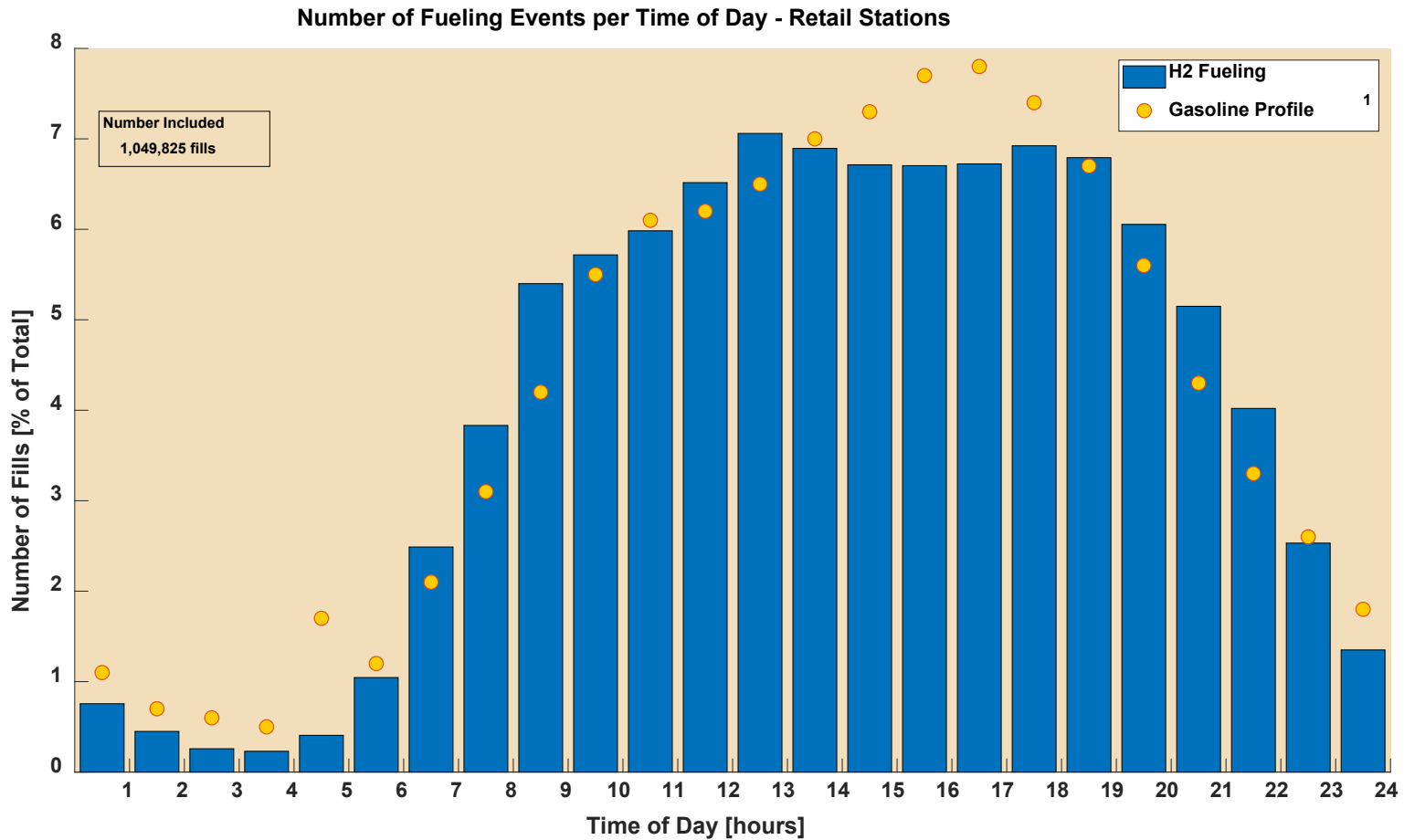


NREL cdpRETAIL_infr_13

Created: Aug-26-21 12:27 PM | Data Range: 2014Q3-2020Q4

Hydrogen Dispensed Per Hour - Retail Stations

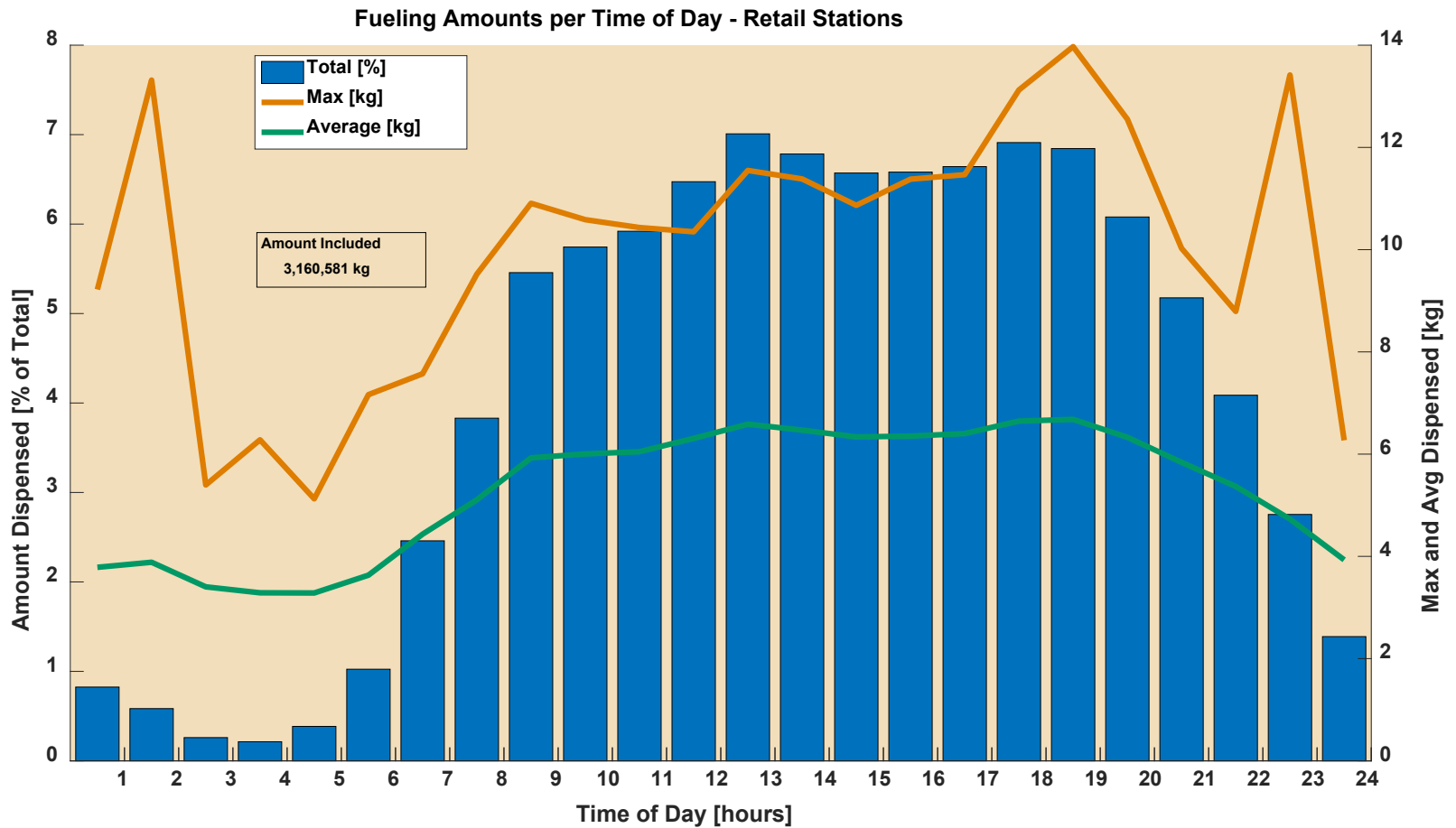




NREL cdpRETAIL_infr_15

Created: Aug-04-21 2:13 PM | Data Range: 2014Q3-2020Q4

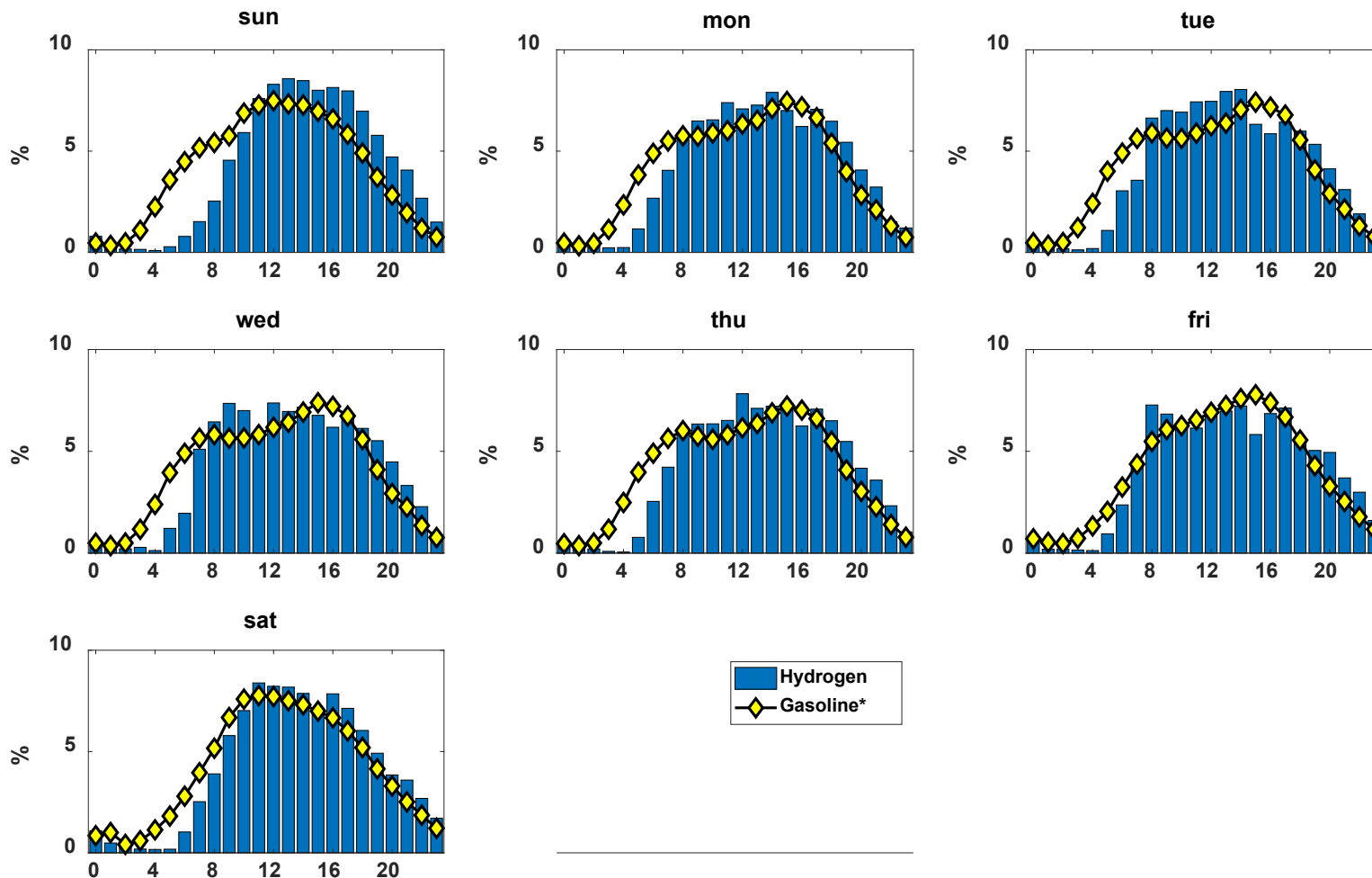
1. Friday Chevron profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.



CDP-INFR-88a Connector/Destination Stations

Fueling Profile by Day and Hour

Fueling Amounts by Day and Hour - Retail Stations - Connector/Destination California



NREL cdpRETAIL_infr_88a

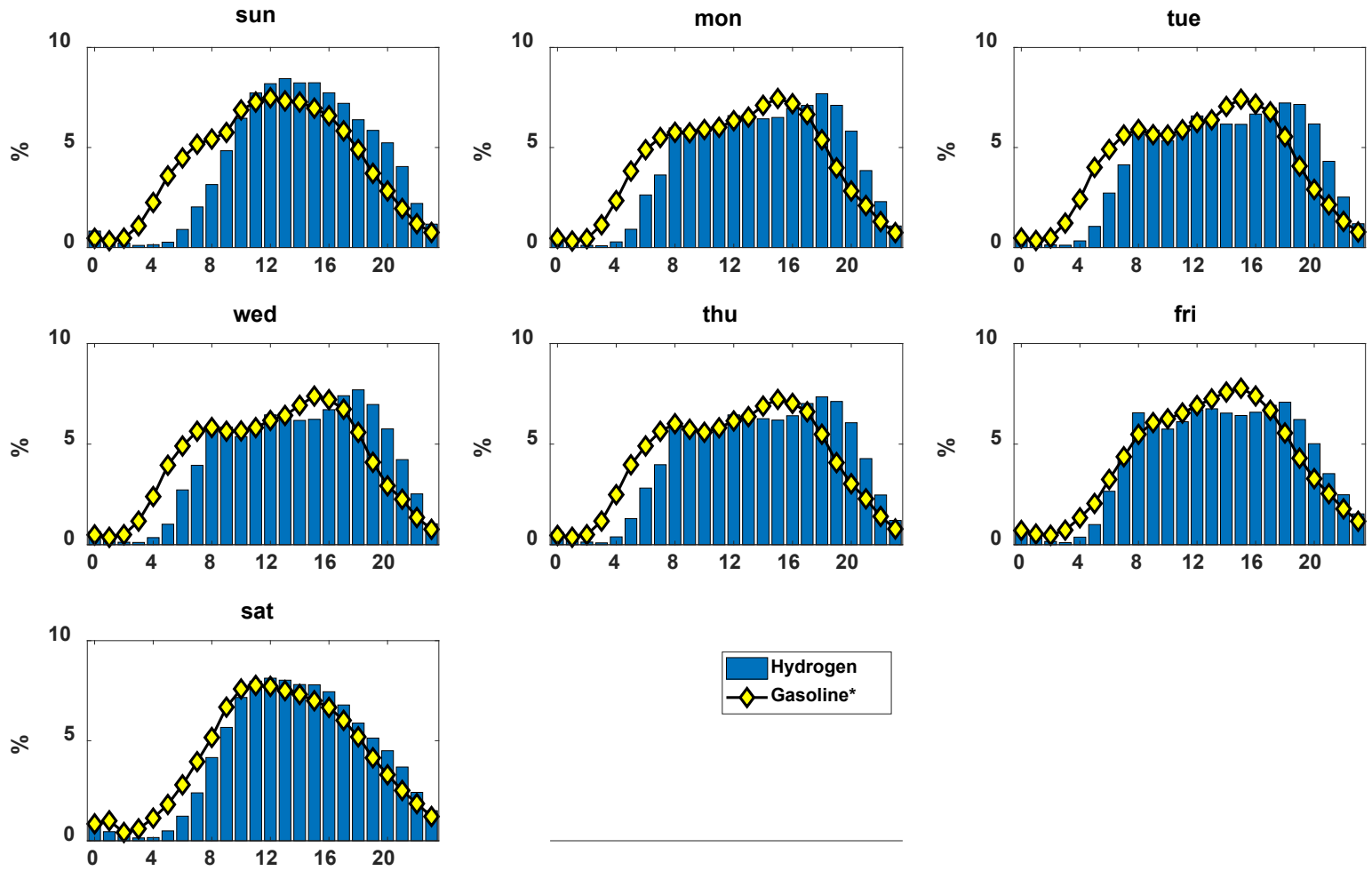
Created: Oct-21-21 3:09 PM | Data Range: 2014Q3-2020Q4

*Chevron gasoline profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.

CDP-INFR-88b Northern California

Fueling Profile by Day and Hour

Fueling Amounts by Day and Hour - Retail Stations - Northern California



NREL cdpRETAIL_infr_88b

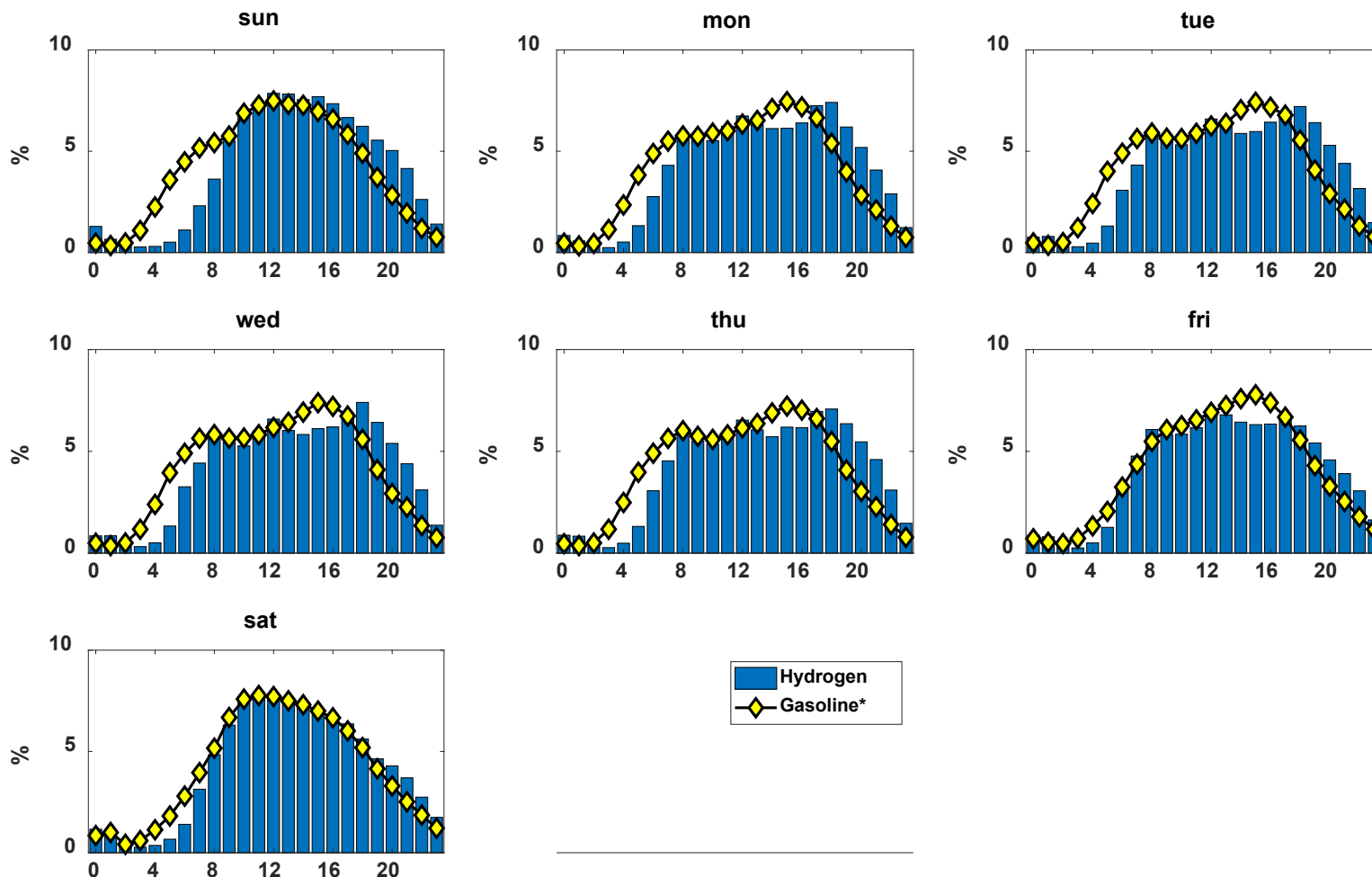
Created: Oct-21-21 3:09 PM | Data Range: 2014Q3-2020Q4


*Chevron gasoline profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.

CDP-INFR-88c Southern California

Fueling Profile by Day and Hour

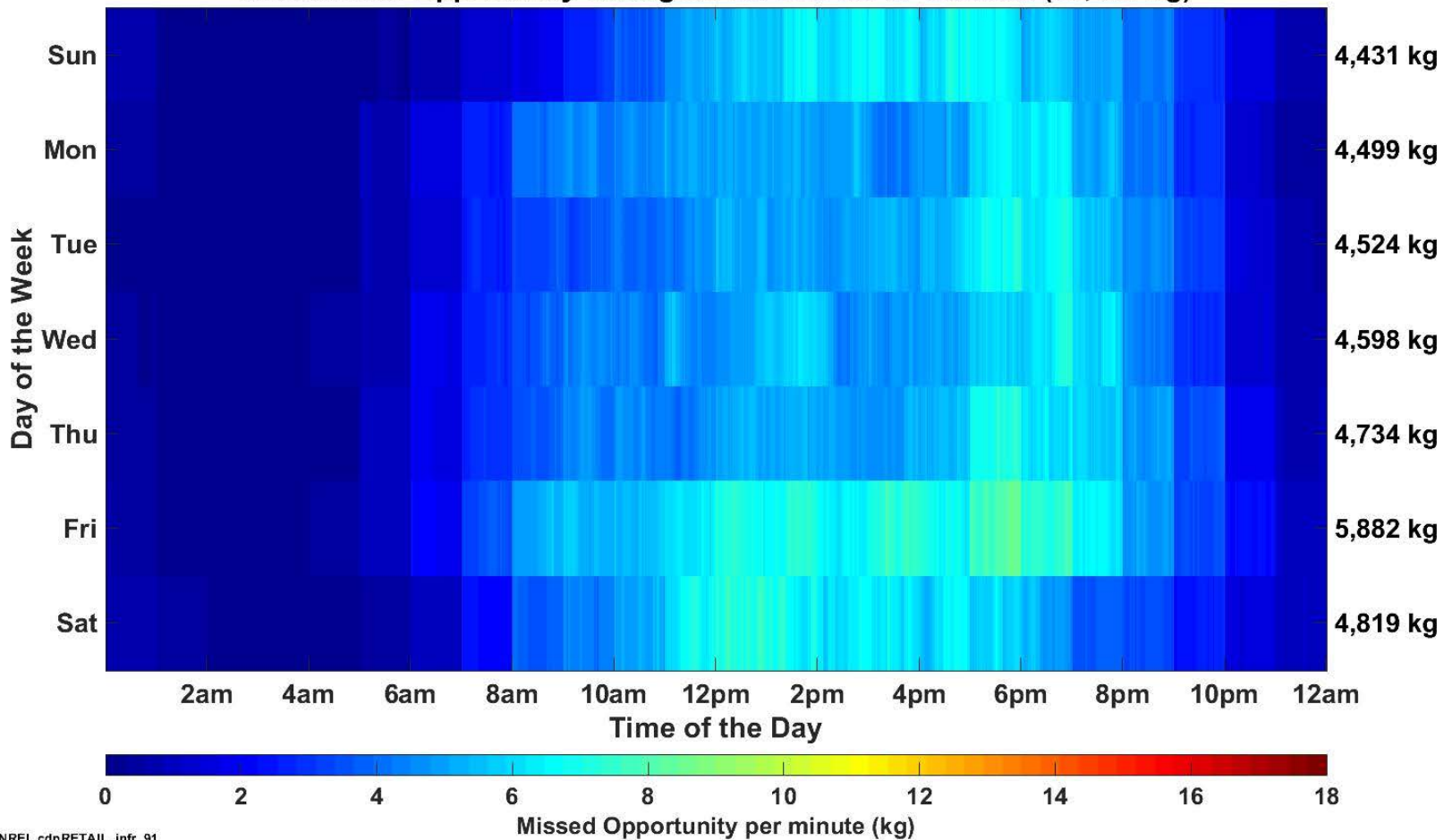
Fueling Amounts by Day and Hour - Retail Stations - Southern California



 NREL cdpRETAIL_infr_88c
Created: Oct-21-21 3:09 PM | Data Range: 2014Q3-2020Q4

*Chevron gasoline profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.

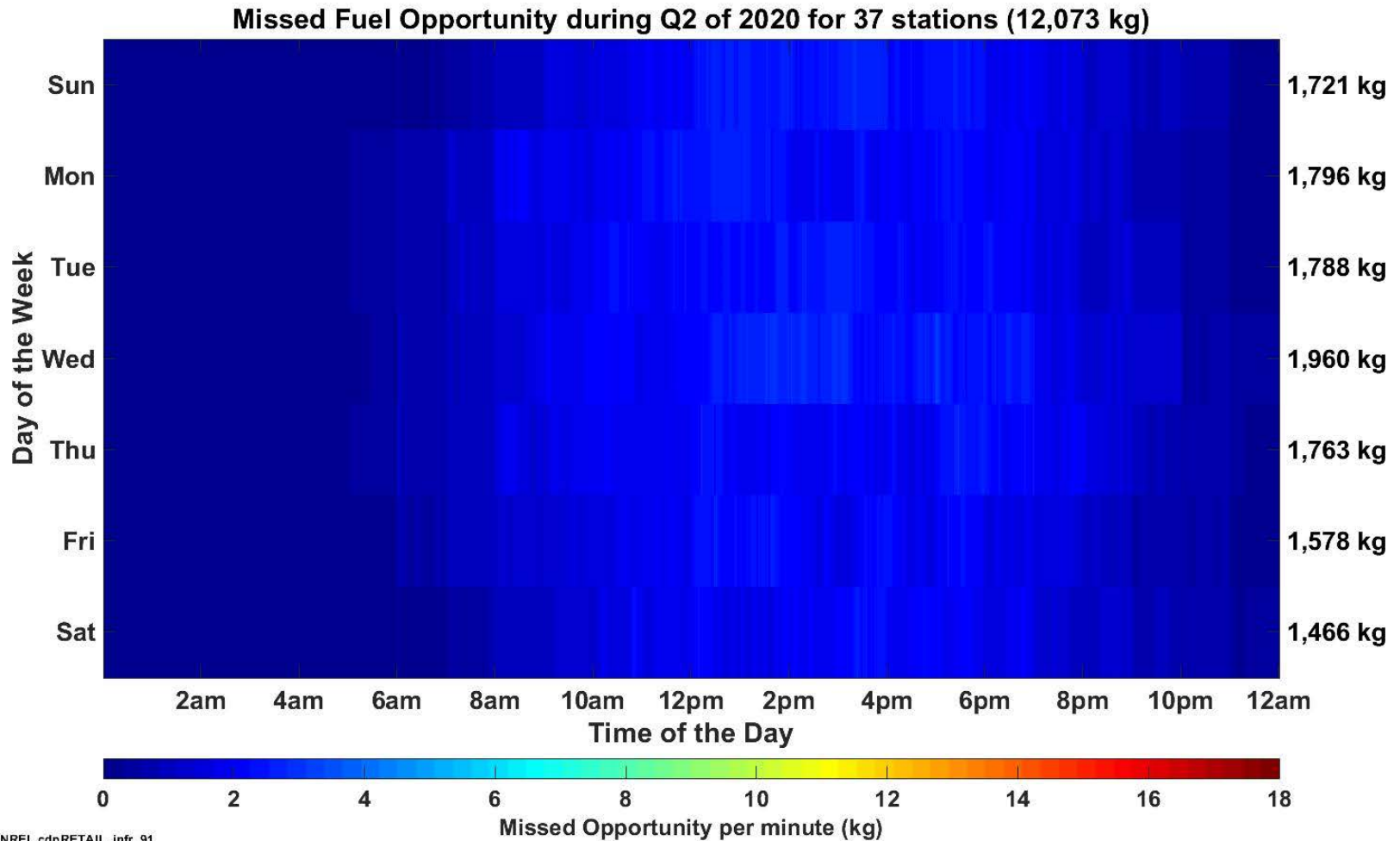
Missed Fuel Opportunity during Q1 of 2020 for 37 stations (33,487 kg)



NREL cdpRETAIL_infr_91

Created: Sep-16-21 2:38 PM | Data Range: 2013Q4-2020Q4

*The minute fill profile was taken as an average from an hourly total.

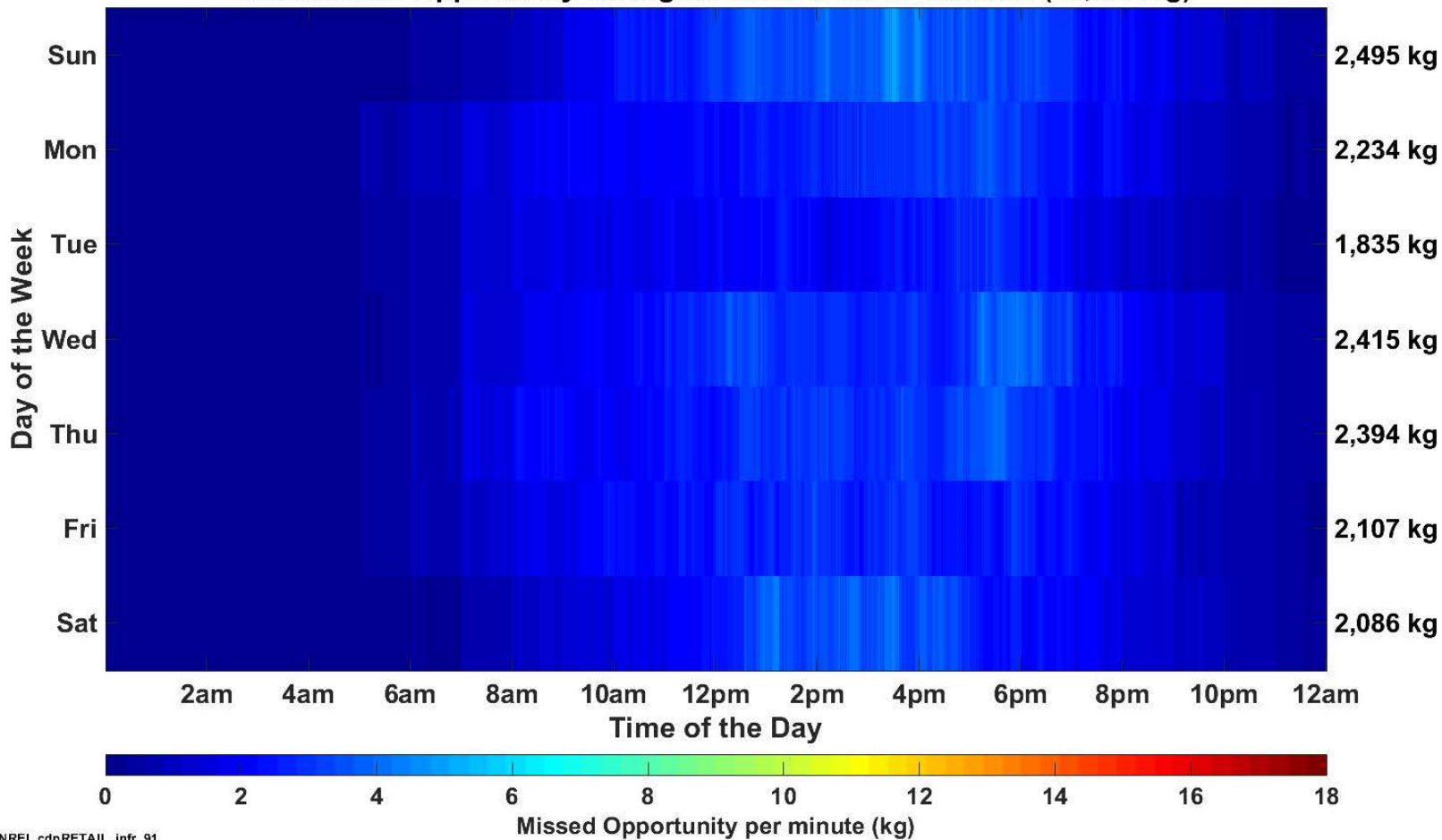


NREL cdpRETAIL_infr_91

Created: Sep-16-21 2:51 PM | Data Range: 2013Q4-2020Q4

*The minute fill profile was taken as an average from an hourly total.

Missed Fuel Opportunity during Q3 of 2020 for 37 stations (15,566 kg)

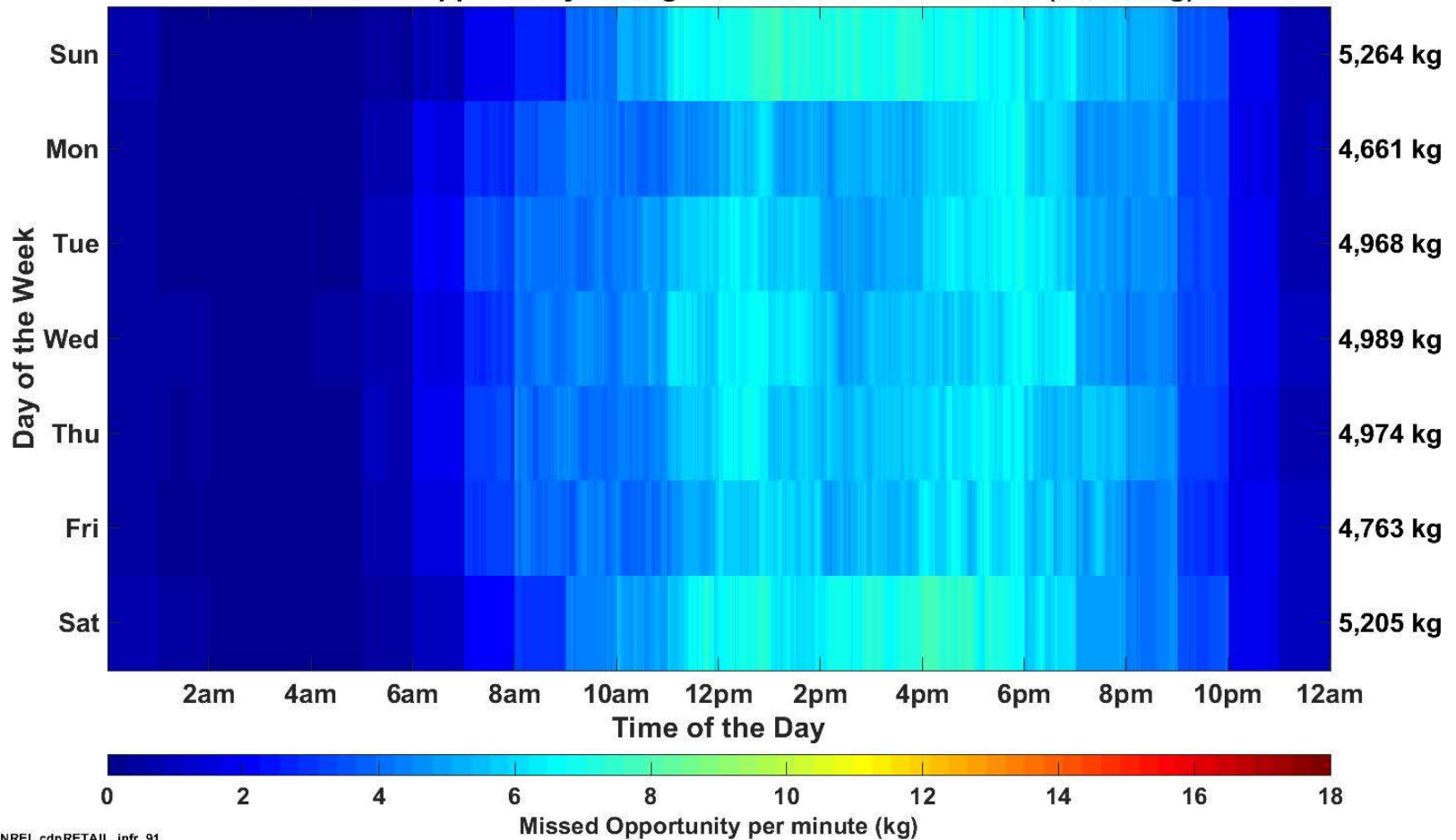


NREL cdpRETAIL_infr_91

Created: Sep-16-21 3:04 PM | Data Range: 2013Q4-2020Q4

*The minute fill profile was taken as an average from an hourly total.

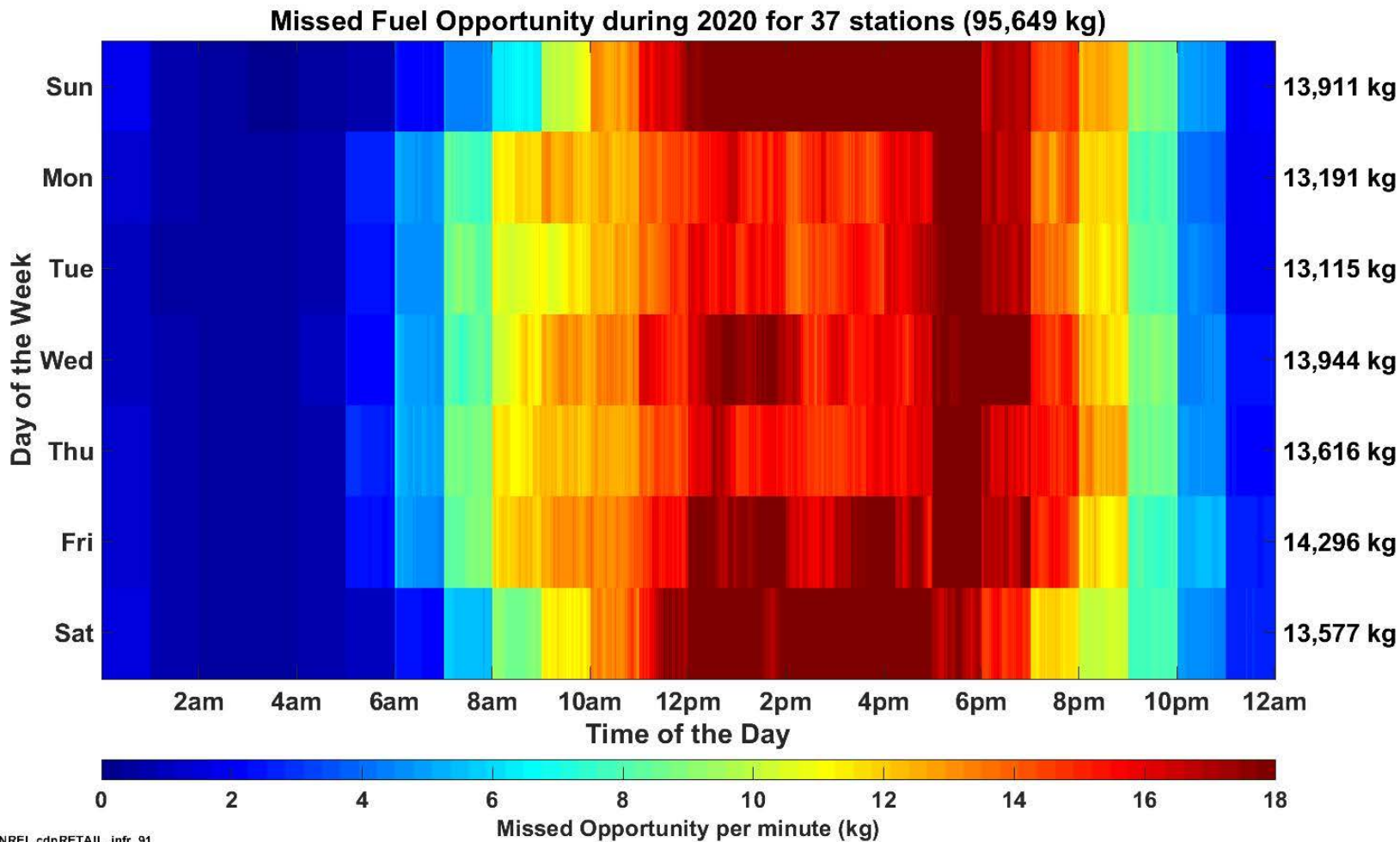
Missed Fuel Opportunity during Q4 of 2020 for 37 stations (34,823 kg)



NREL cdpRETAIL_infr_91

Created: Sep-16-21 3:18 PM | Data Range: 2013Q4-2020Q4

*The minute fill profile was taken as an average from an hourly total.

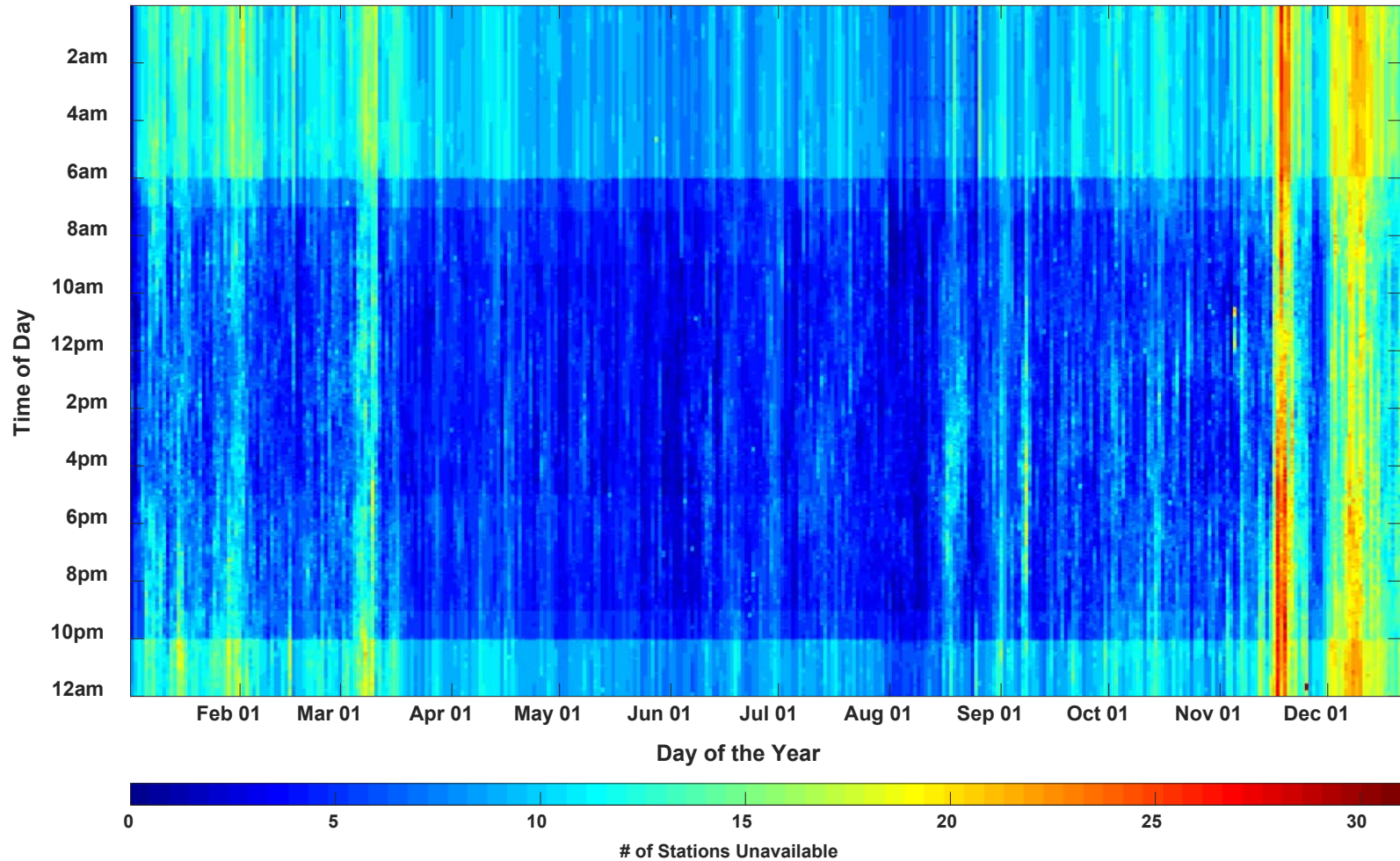


NREL cdpRETAIL_infr_91

Created: Sep-16-21 3:31 PM | Data Range: 2013Q4-2020Q4

*The minute fill profile was taken as an average from an hourly total.

2020 Station Unavailability for 43 stations

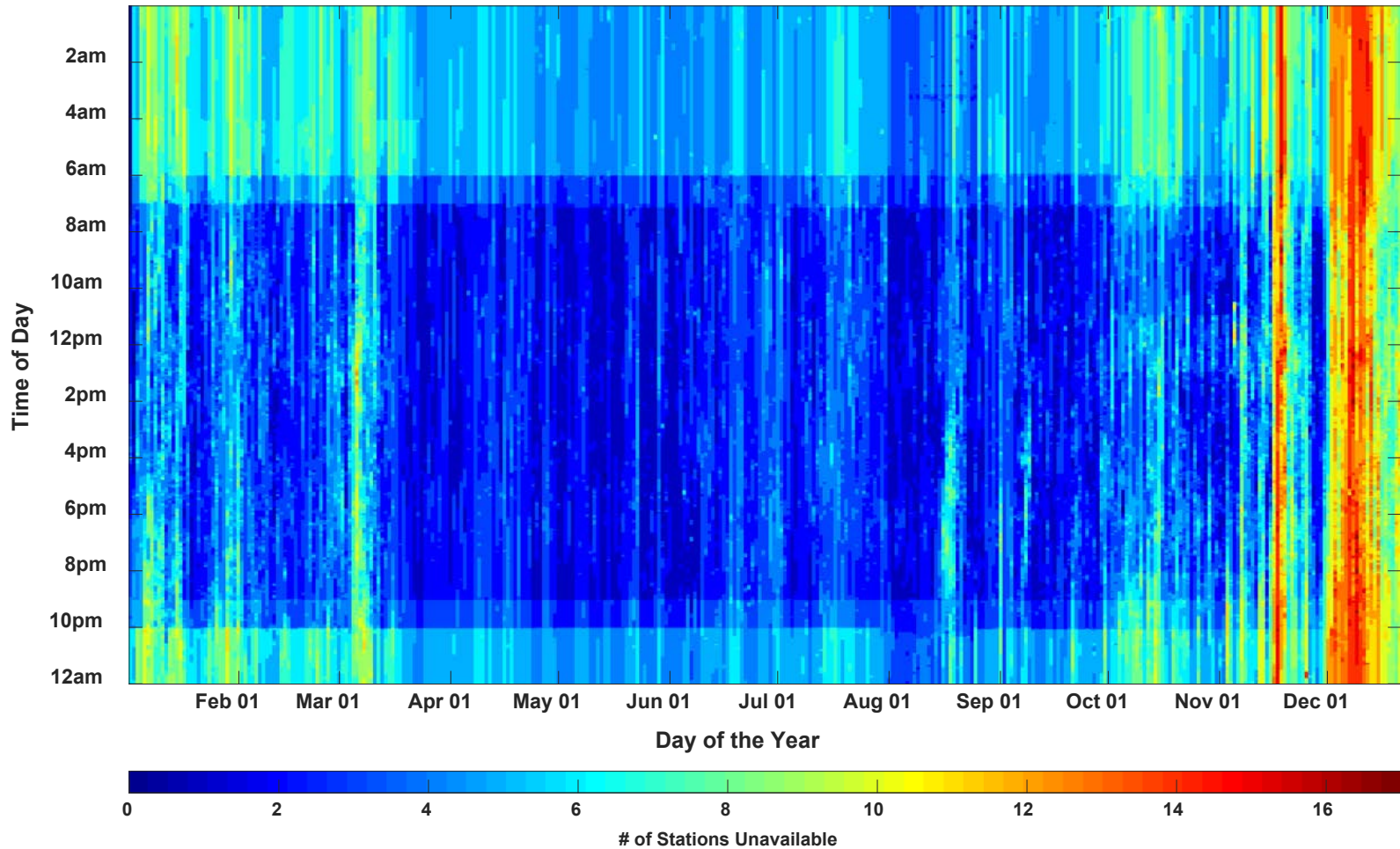


NREL cdpRETAIL_infr_93

Created: Sep-16-21 12:03 PM | Data Range: 2012Q1-2020Q4

* y-axis resolution - minutes | x-axis resolution - days

2020 Station Unavailability for 19 stations
Northern California



NREL cdpRETAIL_infr_95

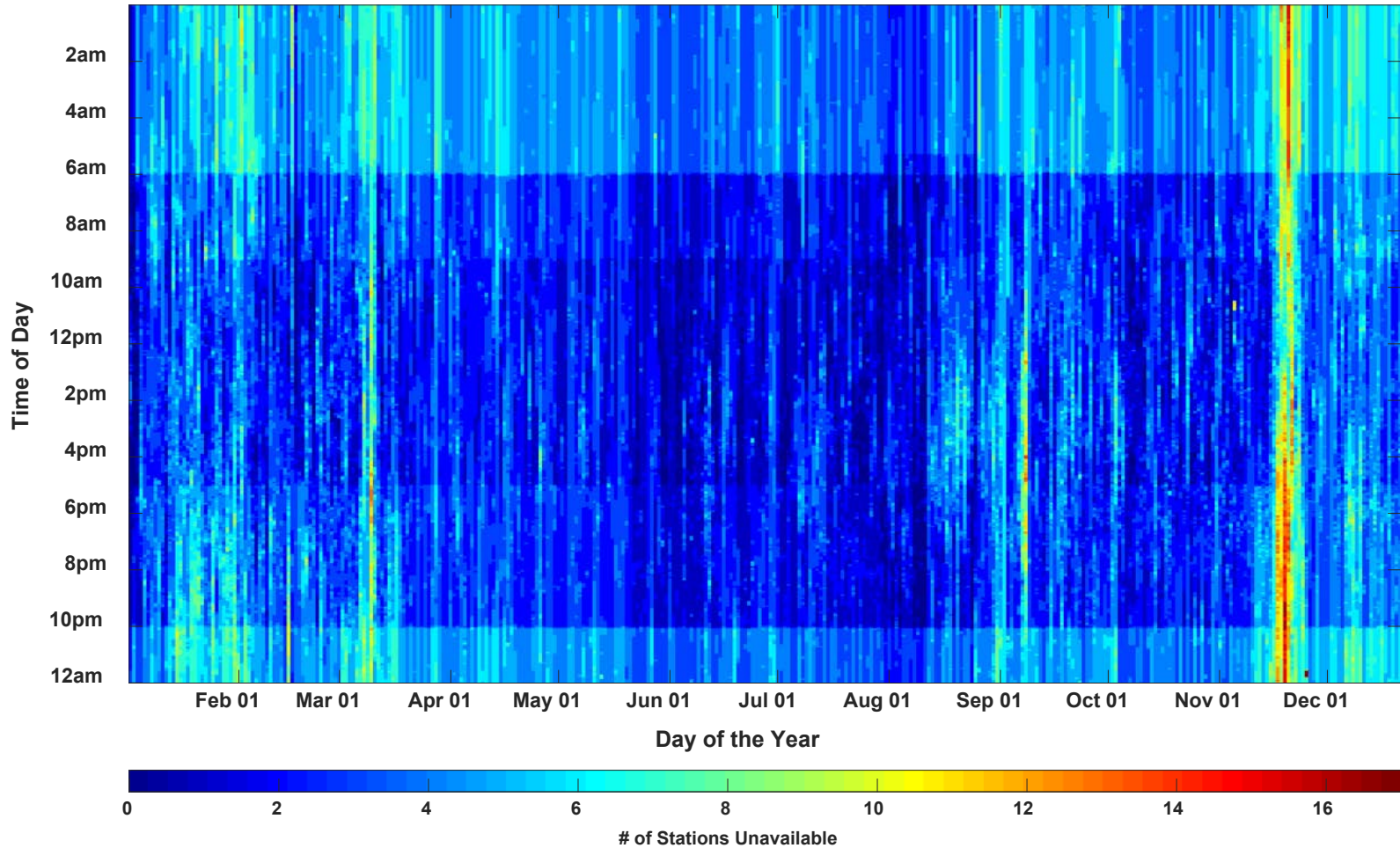
Created: Sep-16-21 12:49 PM | Data Range: 2012Q1-2020Q4


* y-axis resolution - minutes | x-axis resolution - days

CDP-INFR-95

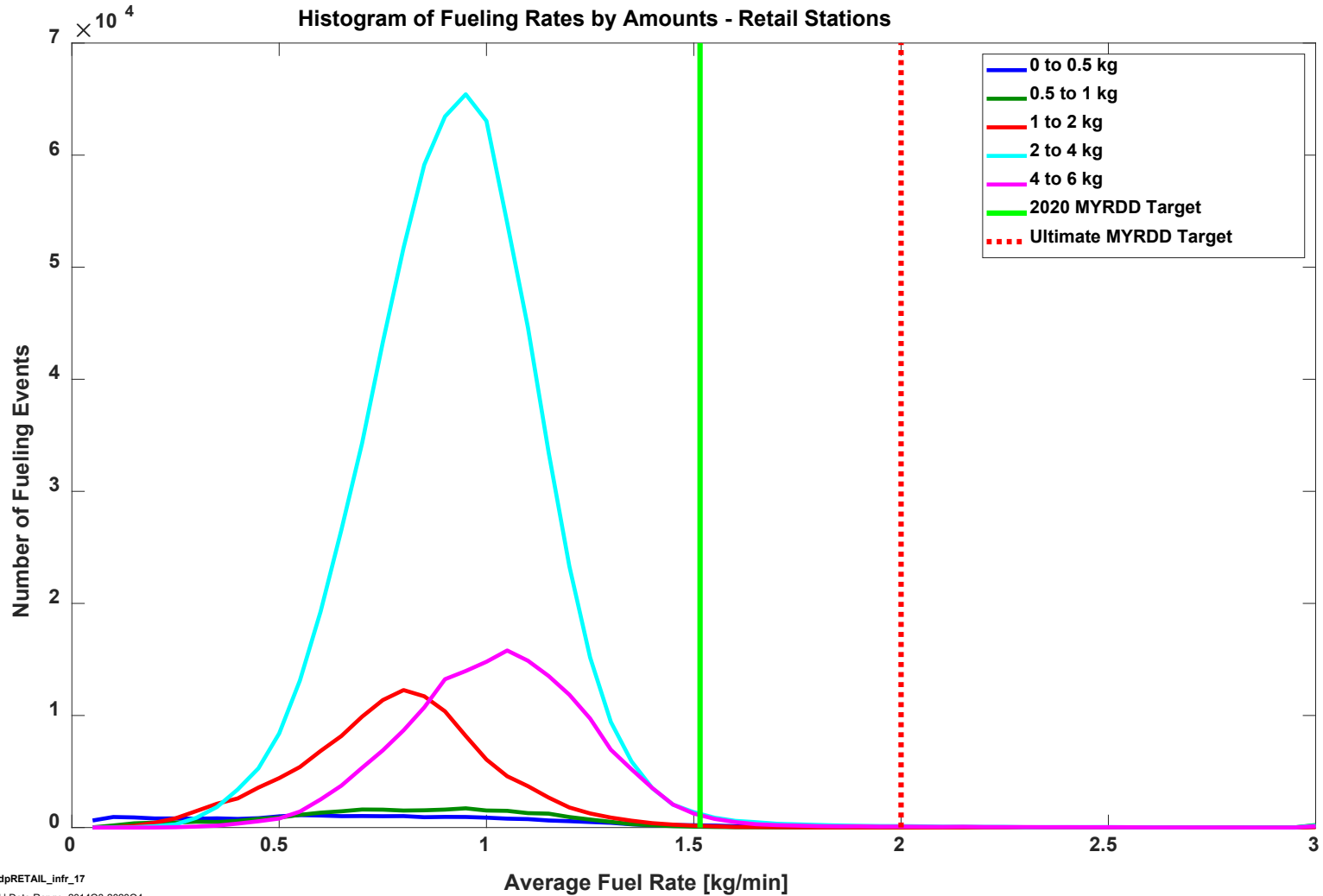
Station Unavailability


2020 Station Unavailability for 24 stations
Southern California



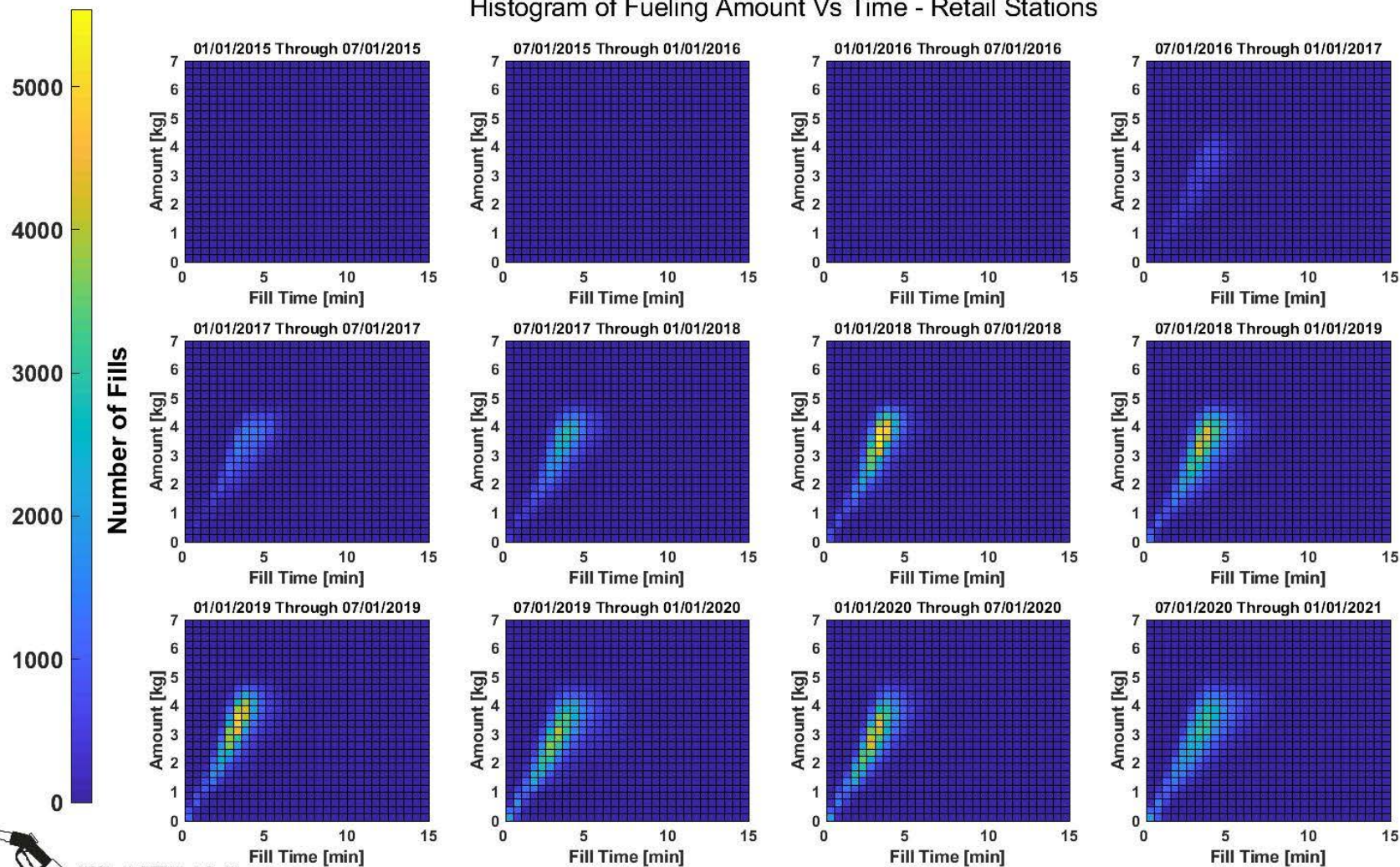
 NREL cdpRETAIL_infr_95
Created: Sep-16-21 12:49 PM | Data Range: 2012Q1-2020Q4

* y-axis resolution - minutes | x-axis resolution - days



 NREL cdpRETAIL_infr_17
Created: Aug-04-21 1:05 PM | Data Range: 2014Q3-2020Q4

Histogram of Fueling Amount Vs Time - Retail Stations

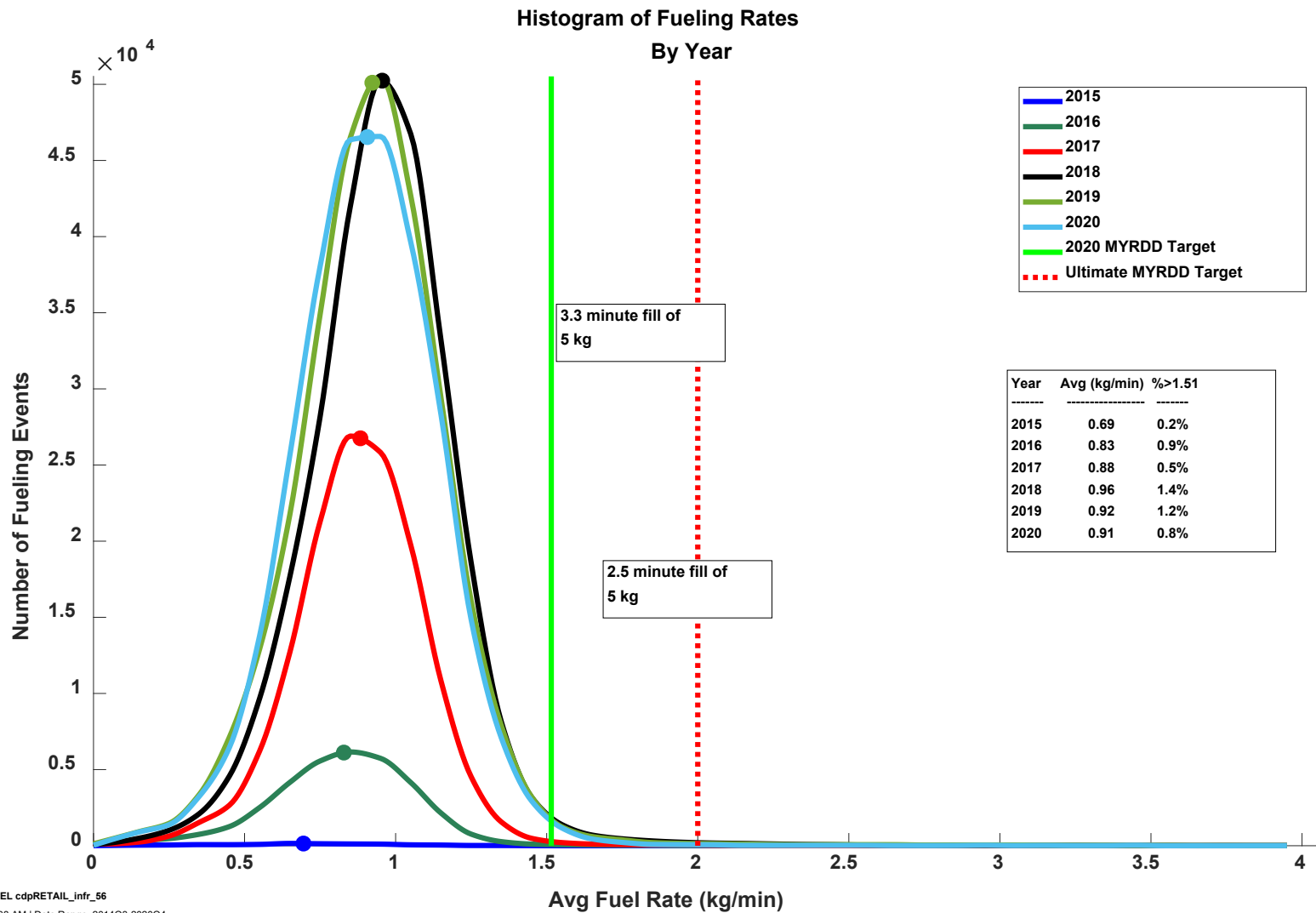


NREL cdpRETAIL_infr_18

Created: Aug-26-21 4:15 PM | Data Range: 2014Q3-2020Q4

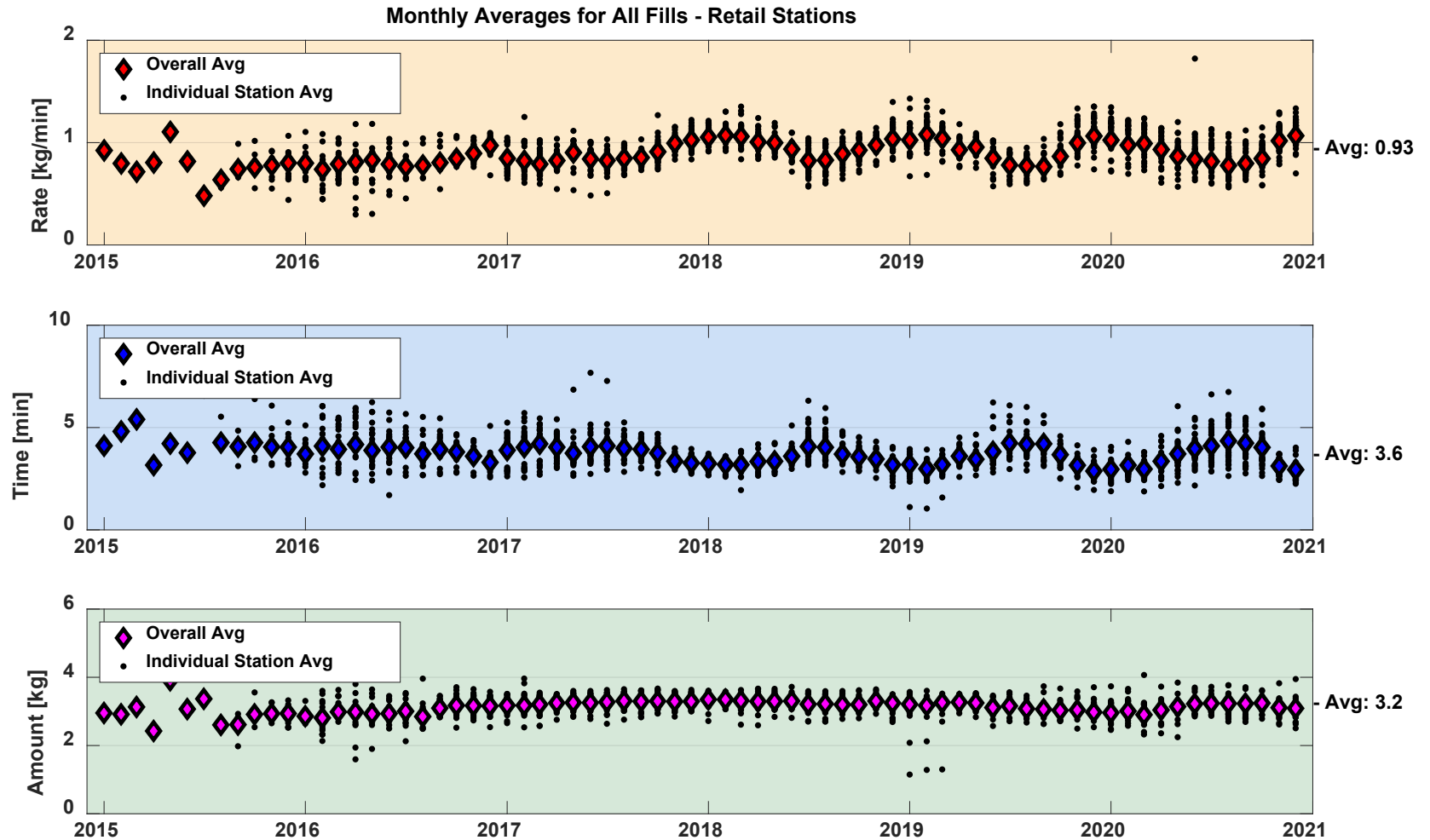
CDP-INFR-56

Fueling Rates by Year



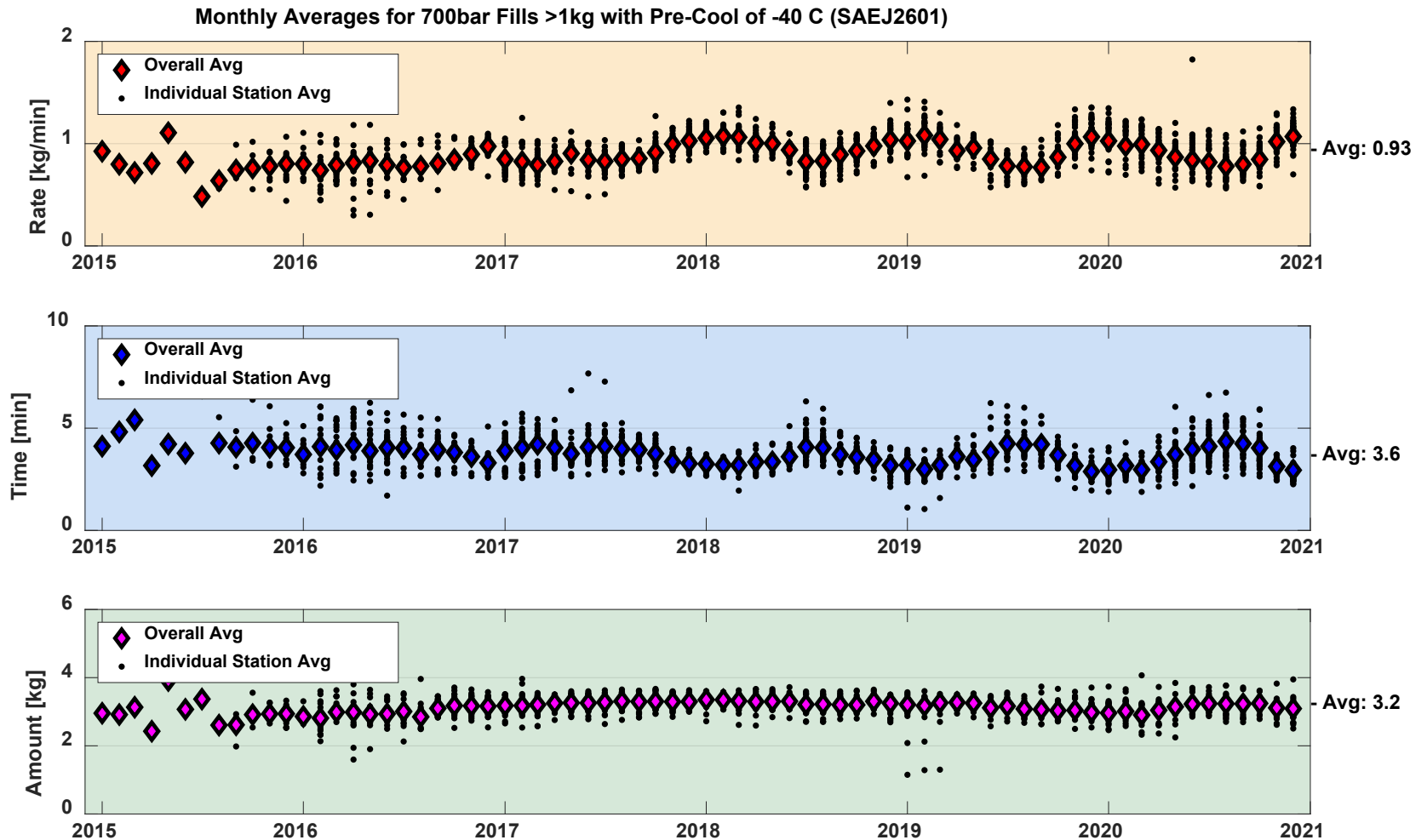
NREL cdpRETAIL_infr_56
Created: Sep-08-21 10:08 AM | Data Range: 2014Q3-2020Q4

Monthly Averages: All Fills



CDP-INFR-57

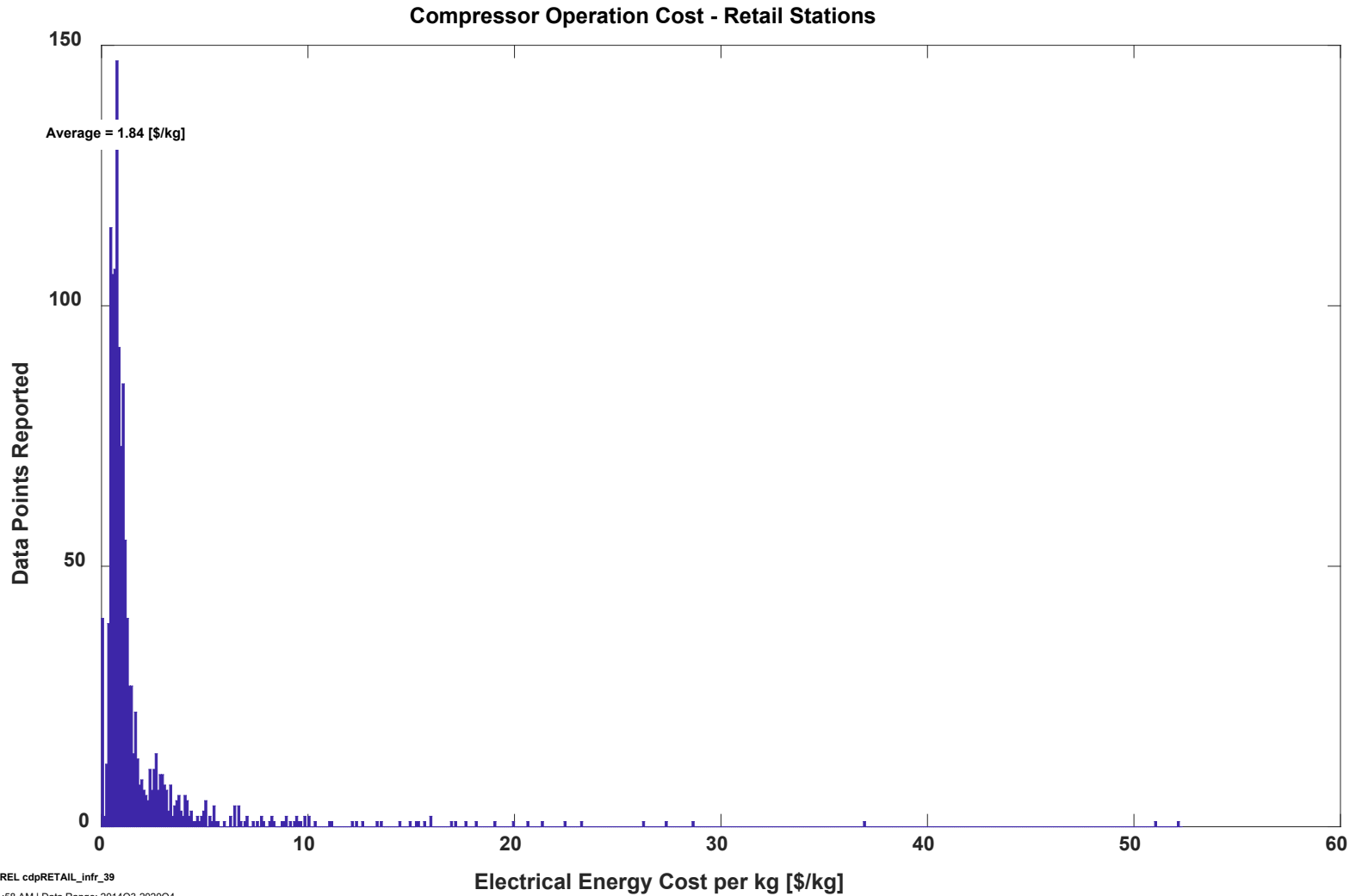
Monthly Averages: 700 bar Fills >1 kg with Pre-Cool of -40°C

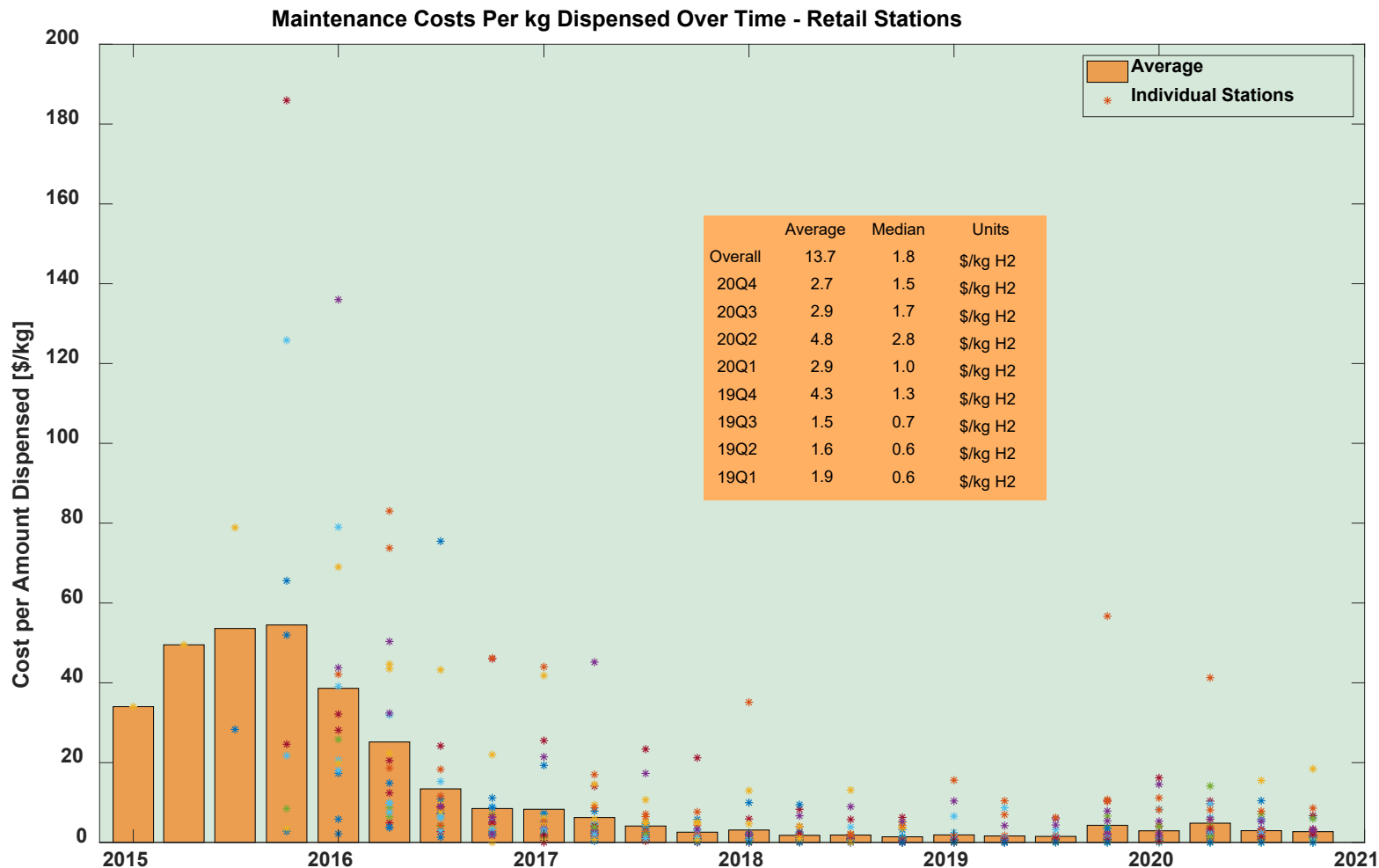


NREL cdpRETAIL_infr_57

Created: Aug-05-21 2:42 PM | Data Range: 2014Q3-2020Q4

Cost



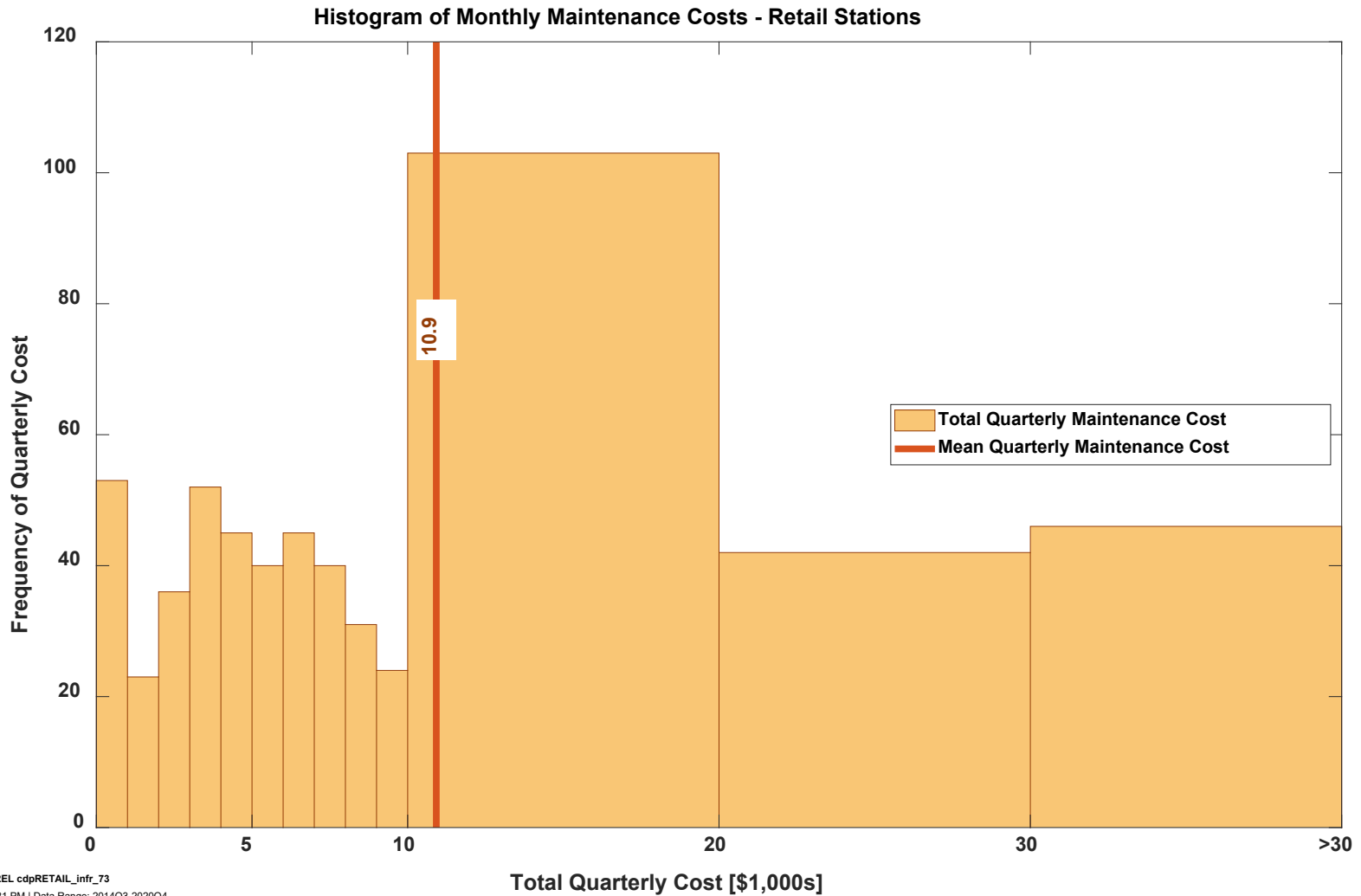


NREL cdpRETAIL_infr_53

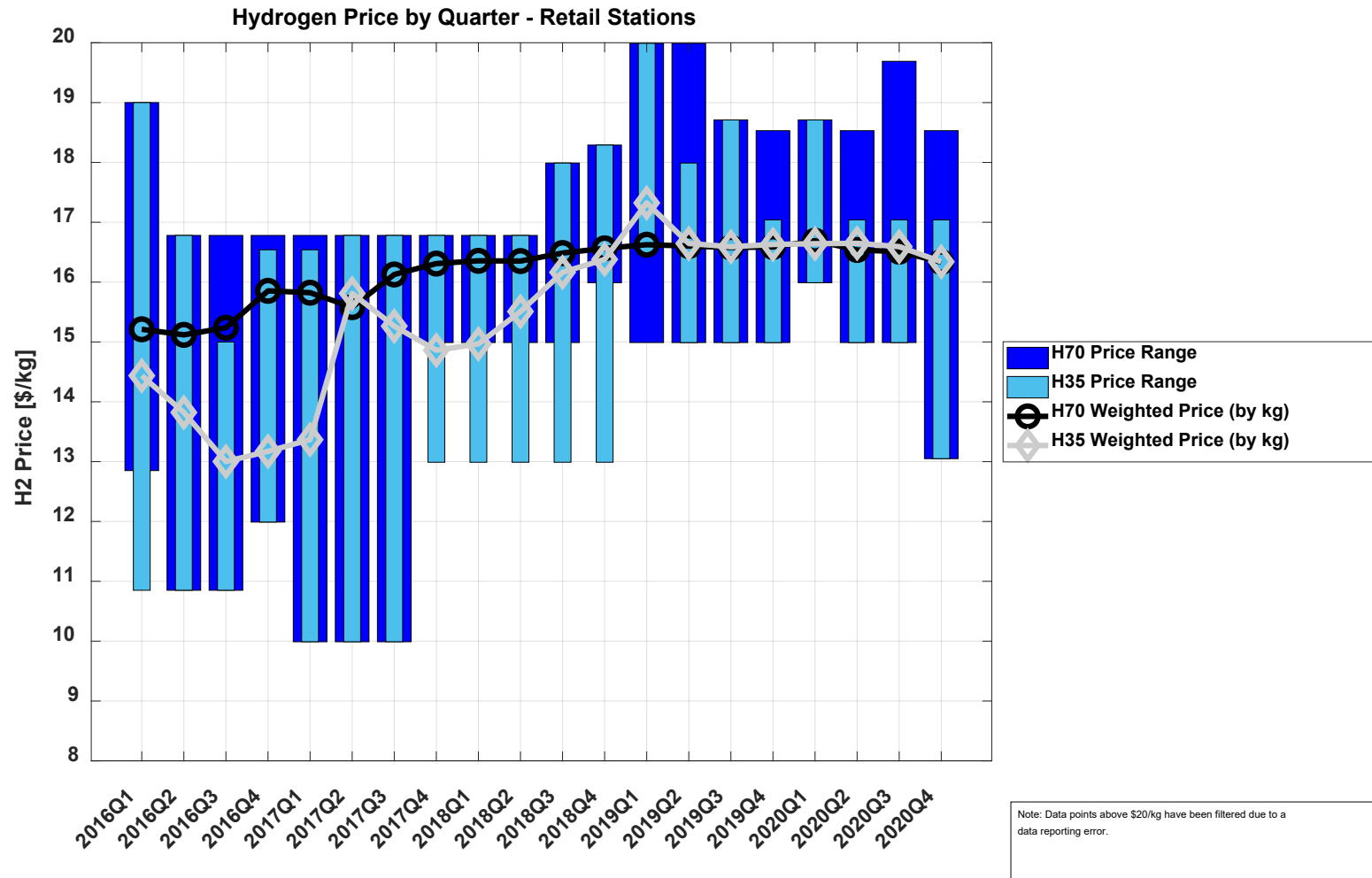
Created: Oct-26-21 10:53 AM | Data Range: 2014Q3-2020Q4

*Each color represents a unique station. 1 data points excluded that were over \$1000/kg

Histogram of Monthly Maintenance Costs

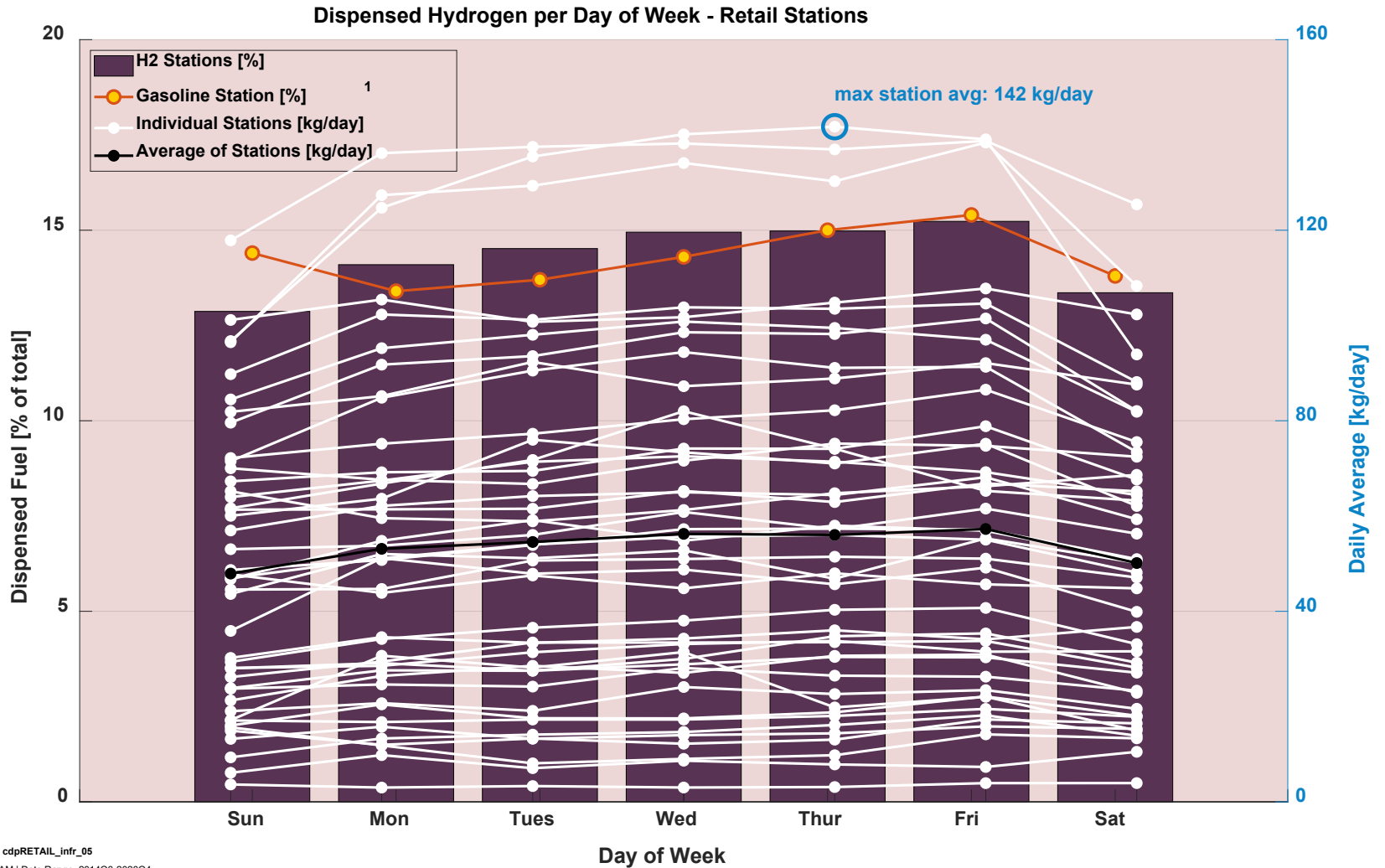


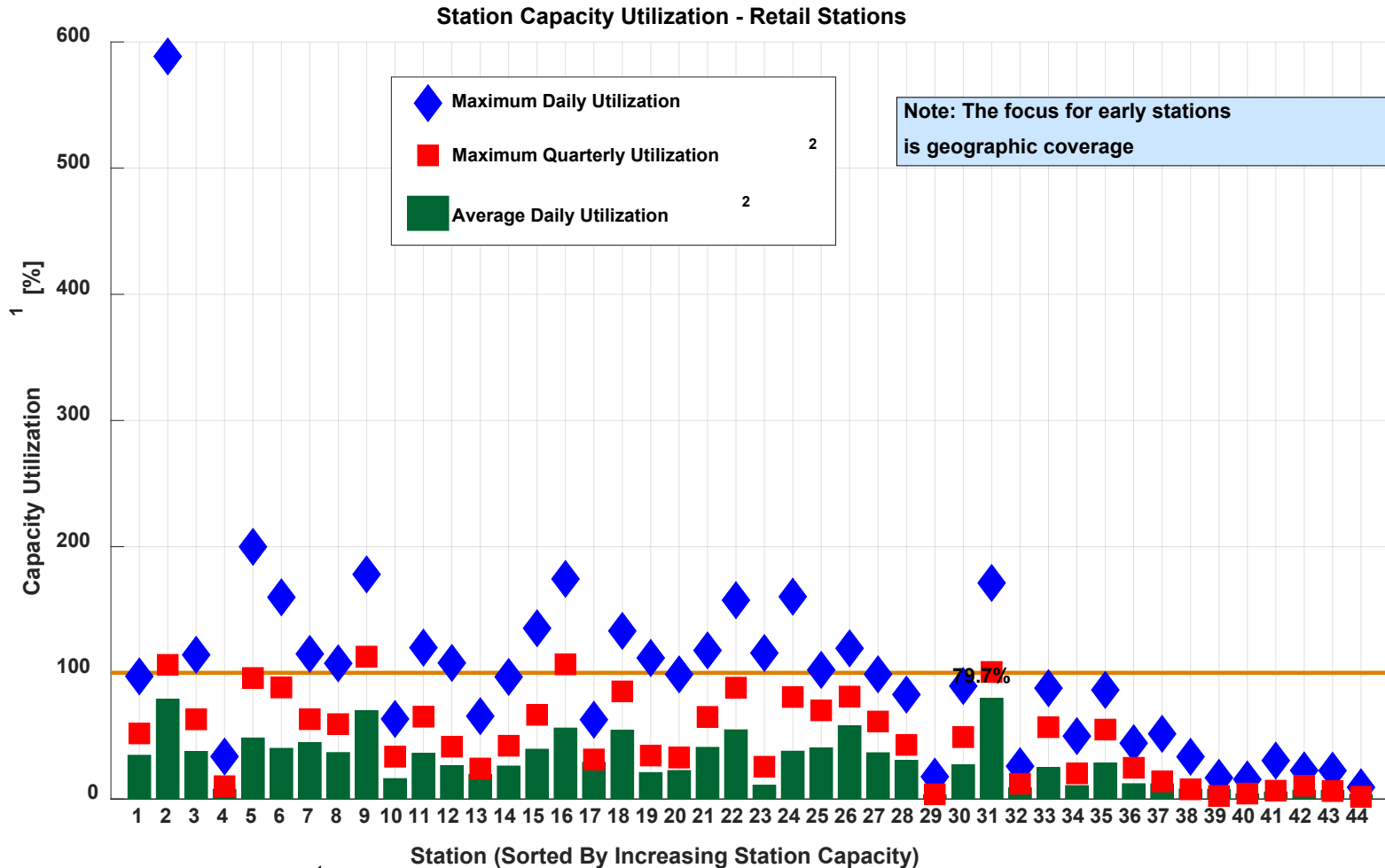
Hydrogen Price by Quarter



Utilization

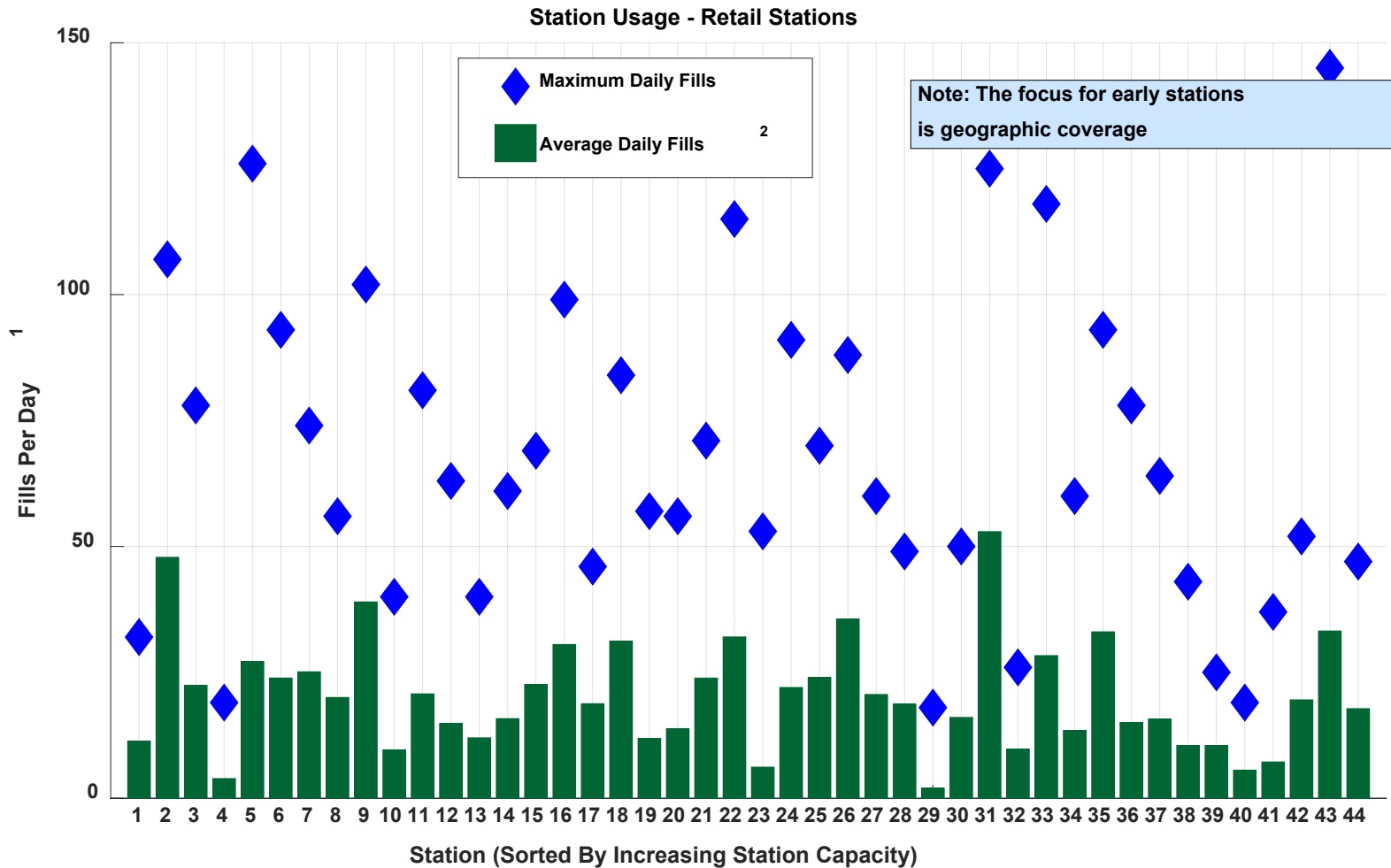
Dispensed Hydrogen per Day of Week



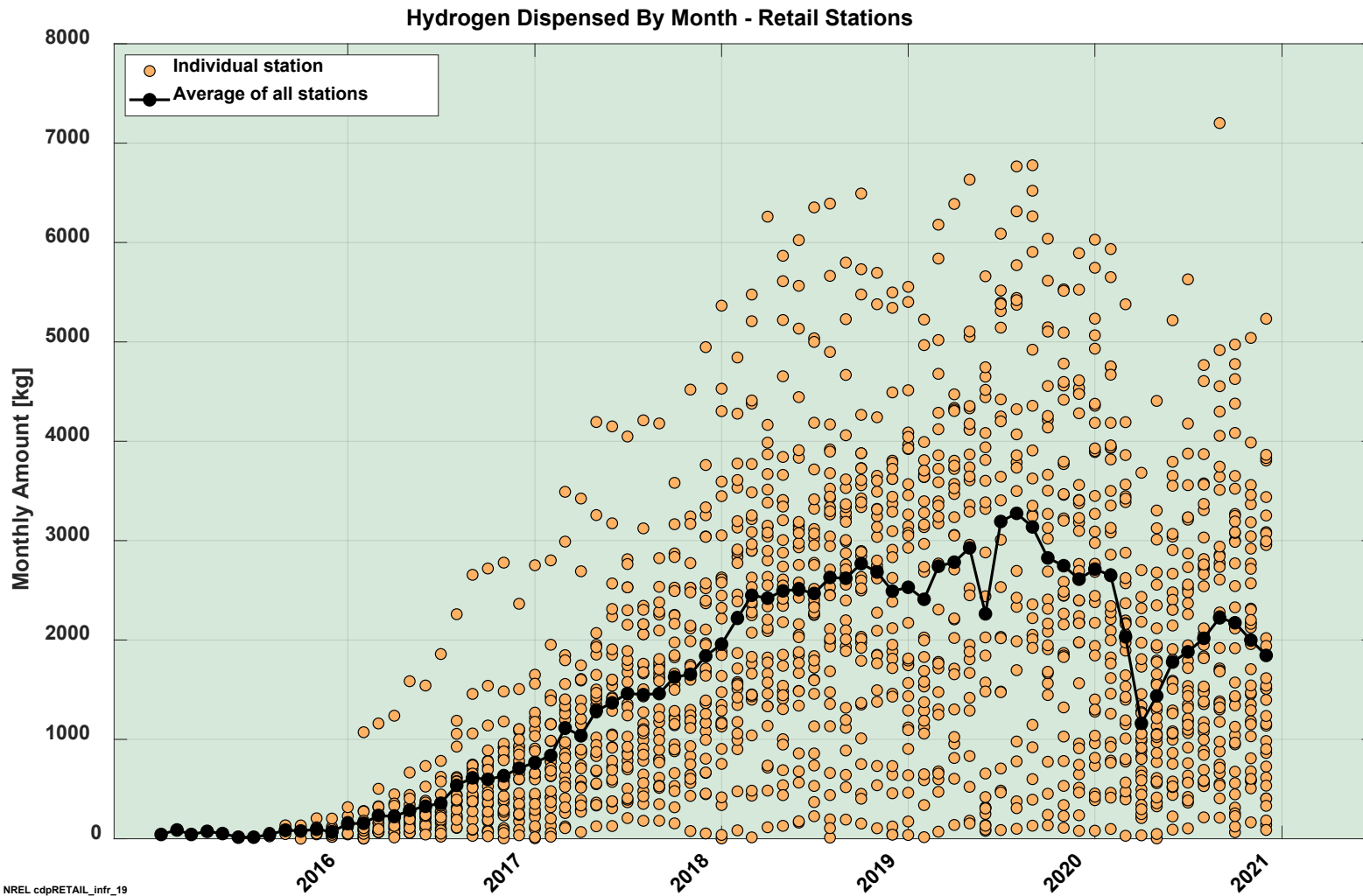


CDP-INFR-07

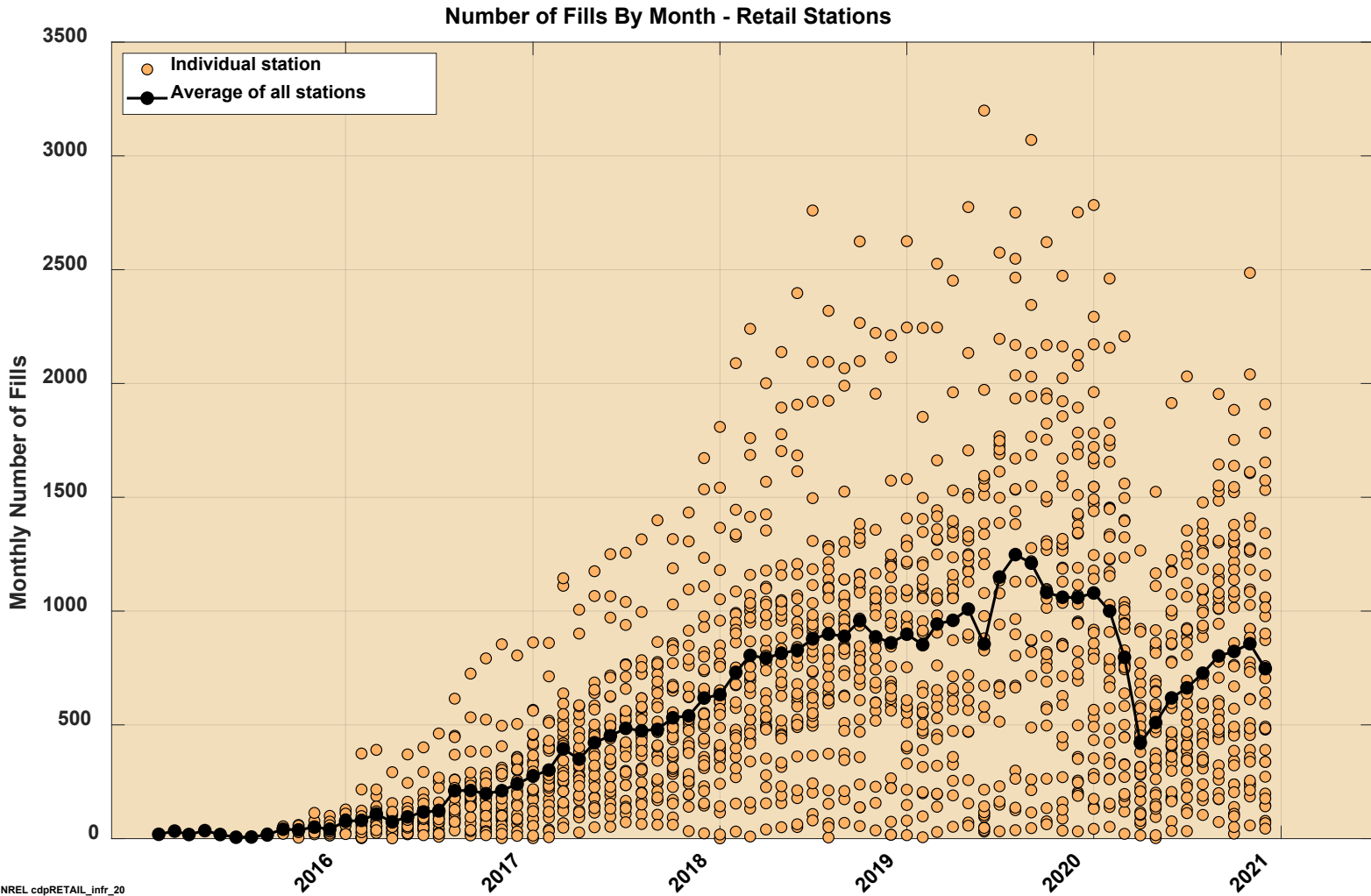
Station Usage



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

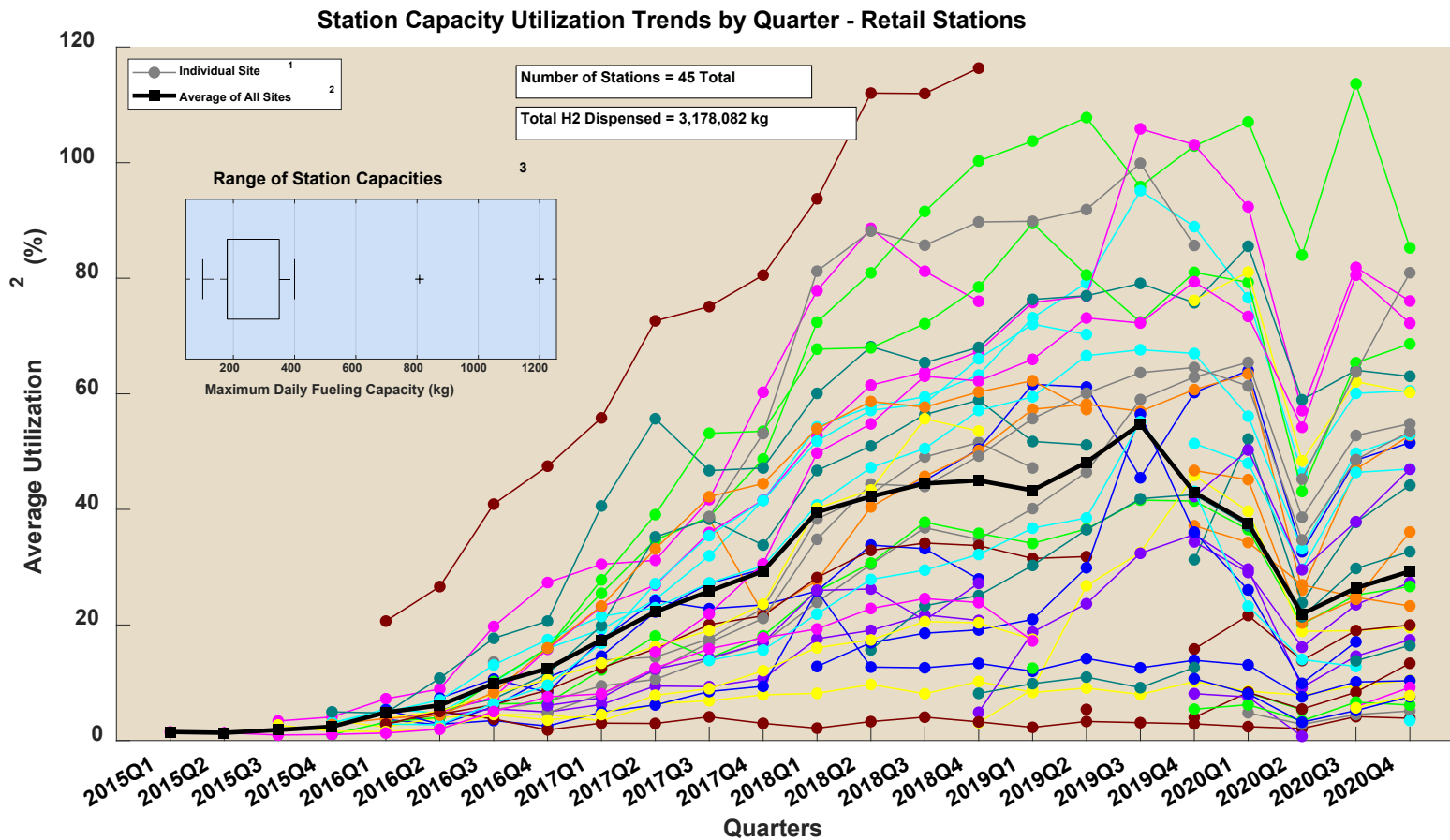


NREL cdpRETAIL_infr_19
Created: Dec-07-21 11:19 AM | Data Range: 2014Q3-2020Q4



NREL cdpRETAIL_infr_20

Created: Dec-07-21 11:10 AM | Data Range: 2014Q3-2020Q4



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.

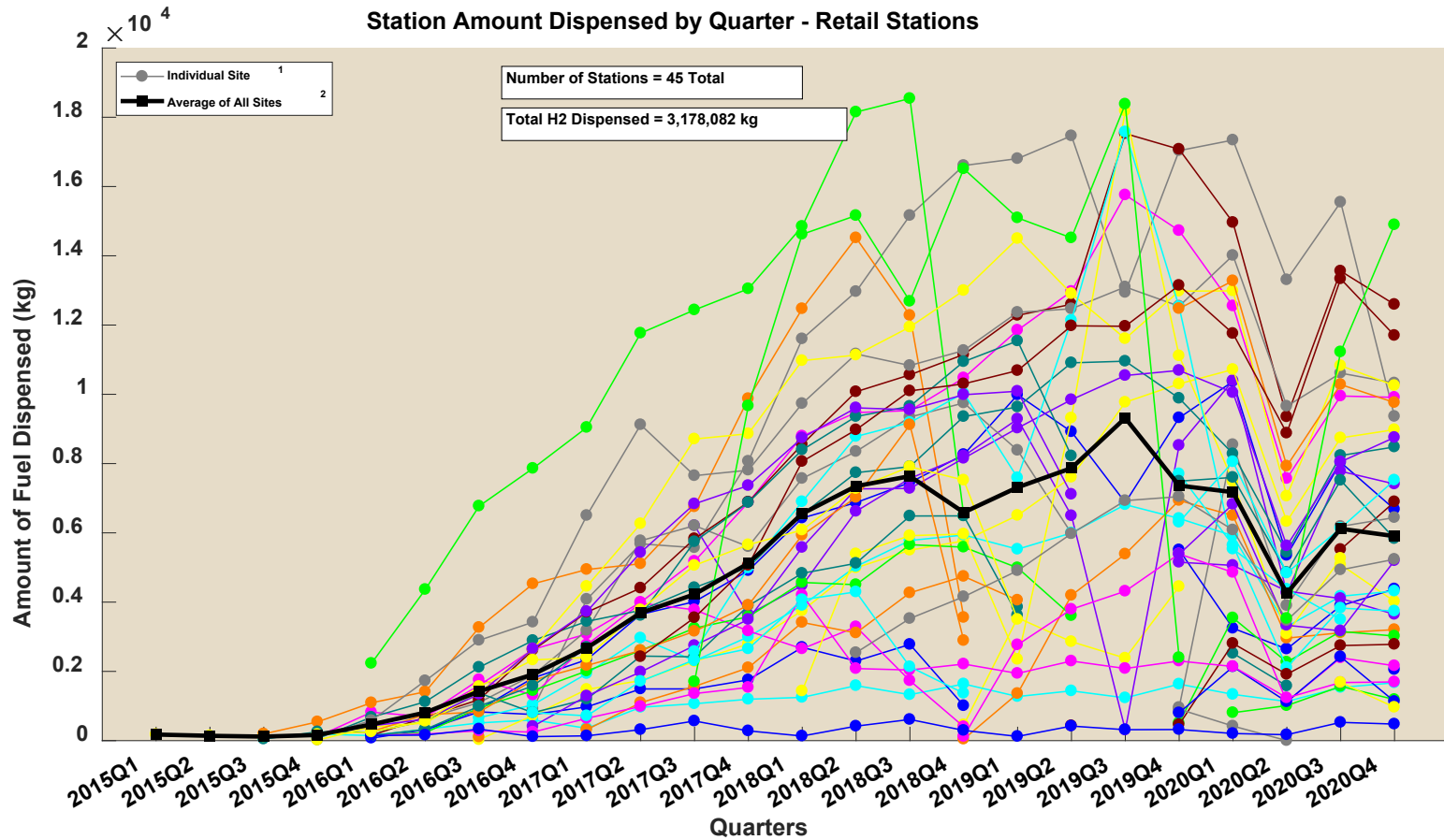
² Average quarterly utilization only considers quarters when at least one fill occurred.

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.



CDP-INFR-45

Station Amount Dispensed by Quarter



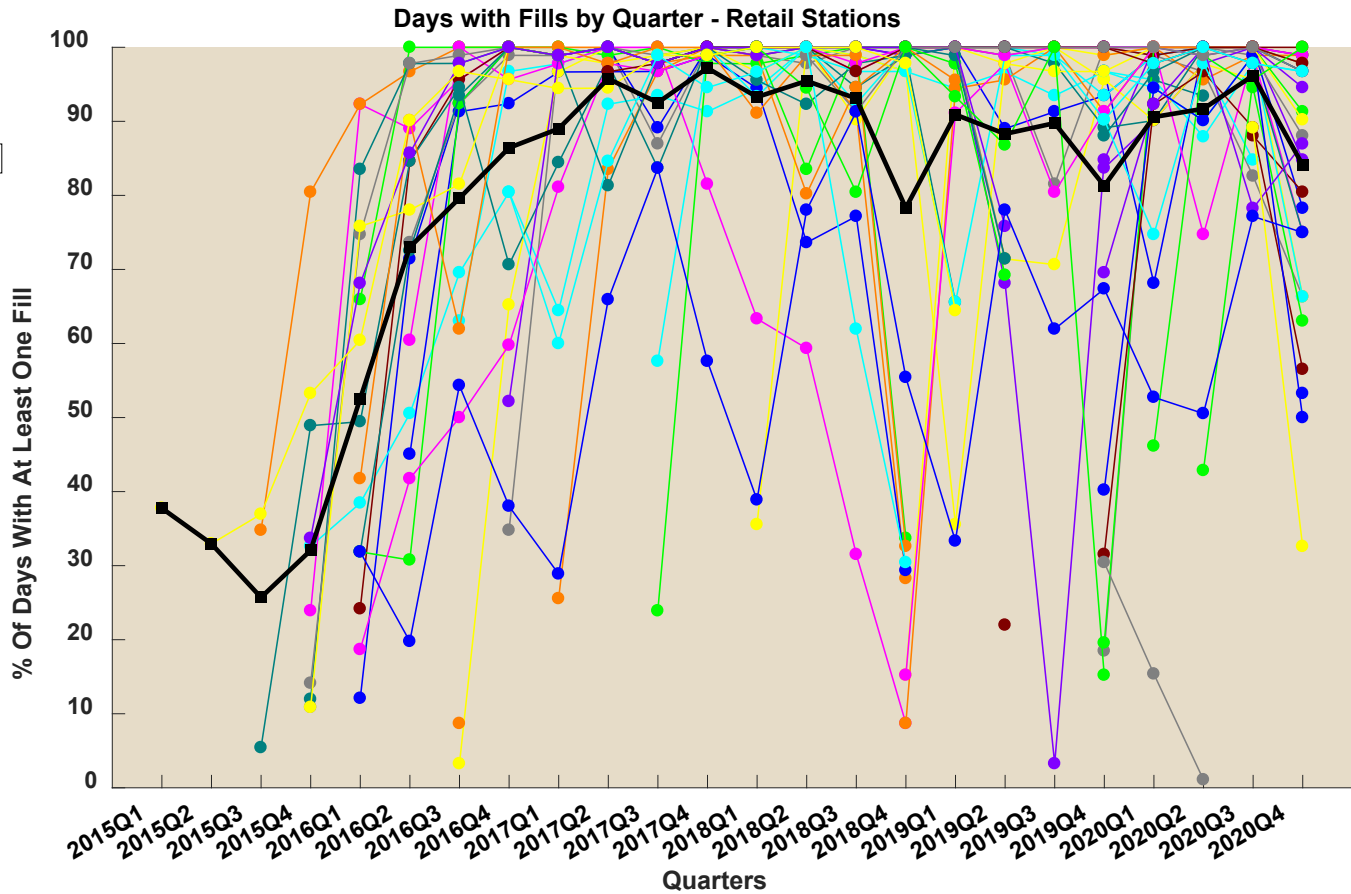
¹ Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

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



NREL cdpRETAIL_infr_45

Created: Aug-05-21 5:38 PM | Data Range: 2014Q3-2020Q4



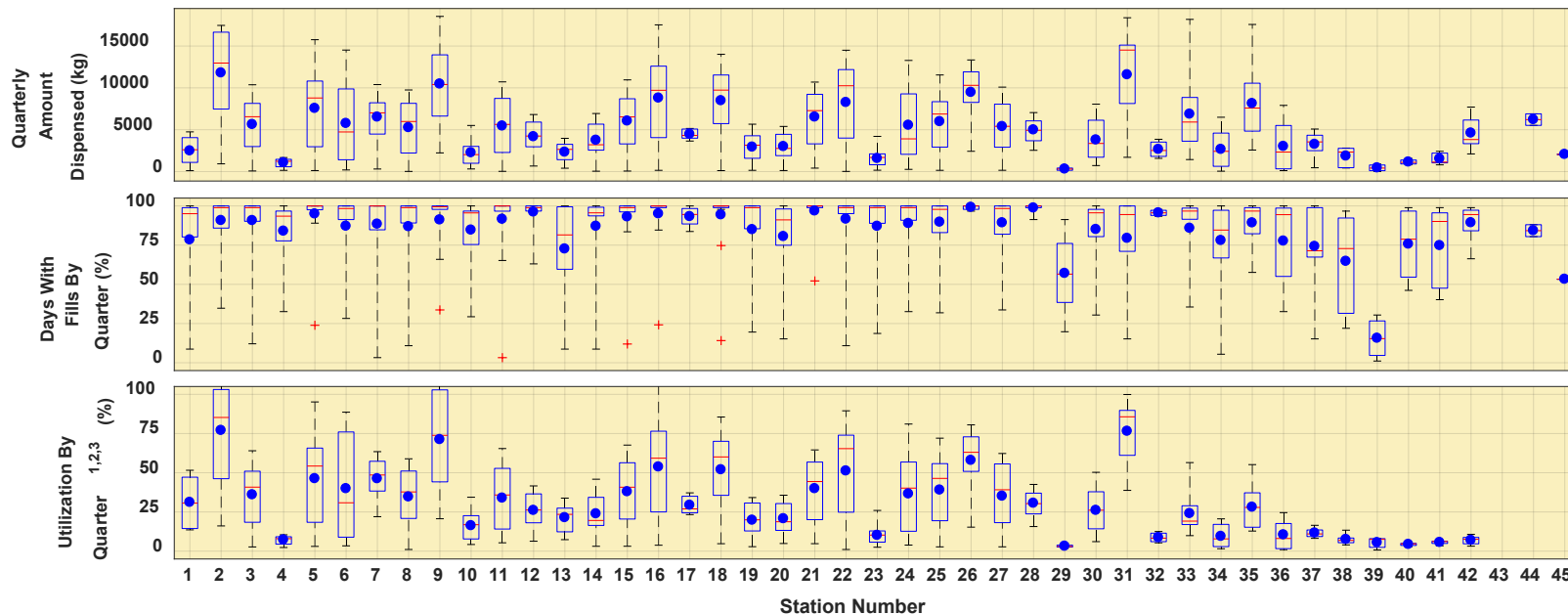
¹ Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station had no fills or was missing data. Each station is represented by a unique color.

² The average percent of days with fills only considers quarters in which at least one fill occurred. Stations with no filling 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.

days
equal weight

Summary of Station Usage Statistics - Retail Stations

4

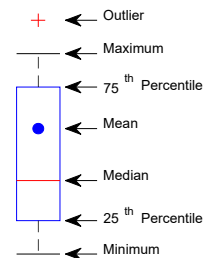


¹ Station nameplate capacity is as reported to NREL and reflects a variety of system design considerations including: system capacity, throughput, system reliability, and maintenance. Actual daily usage may exceed nameplate capacity.

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

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

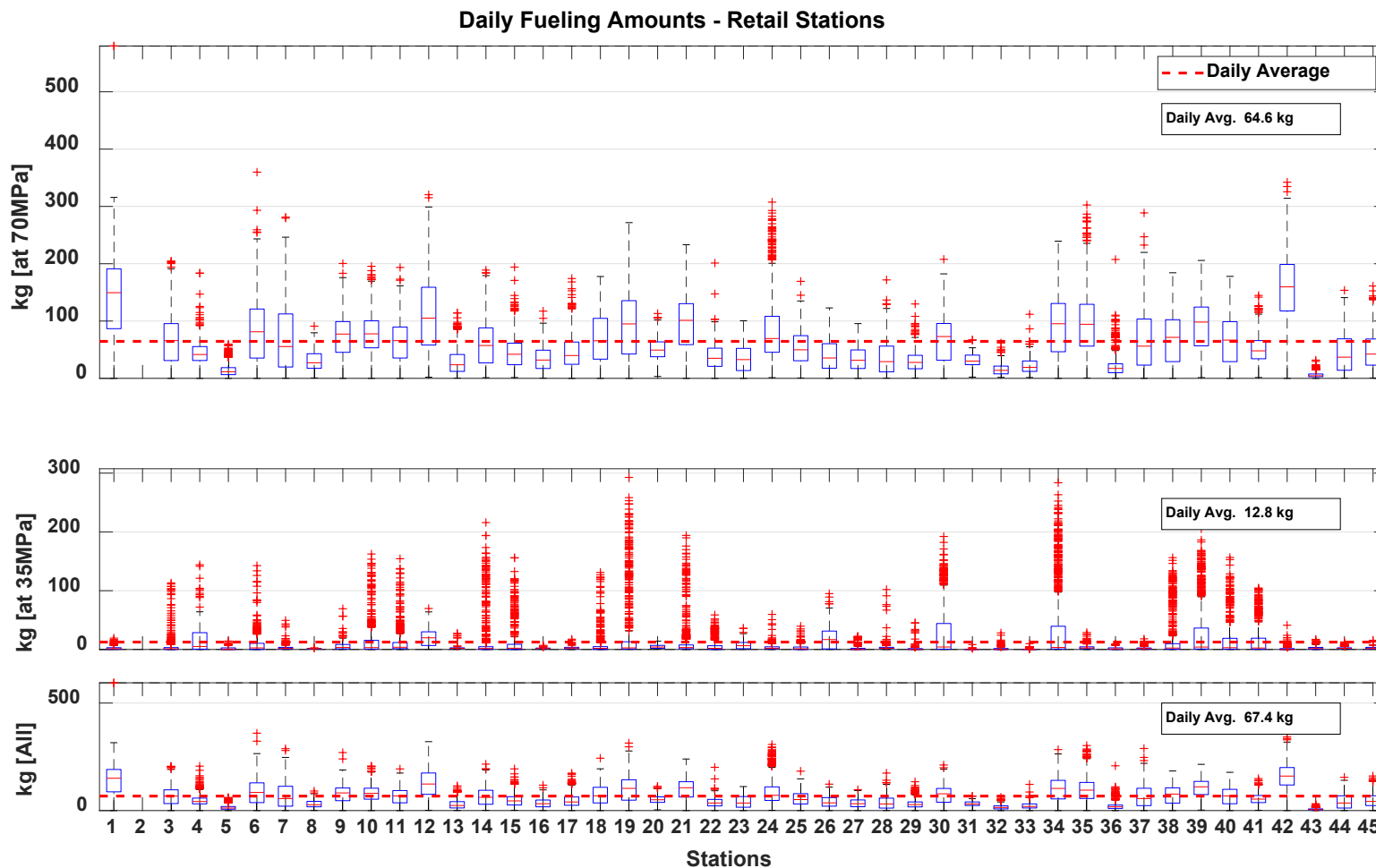
⁴ Only quarters with fills are included.



NREL cdpRETAIL_infr_47

Created: Aug-05-21 4:51 PM | Data Range: 2014Q3-2020Q4

Daily Fueling Amounts by Station

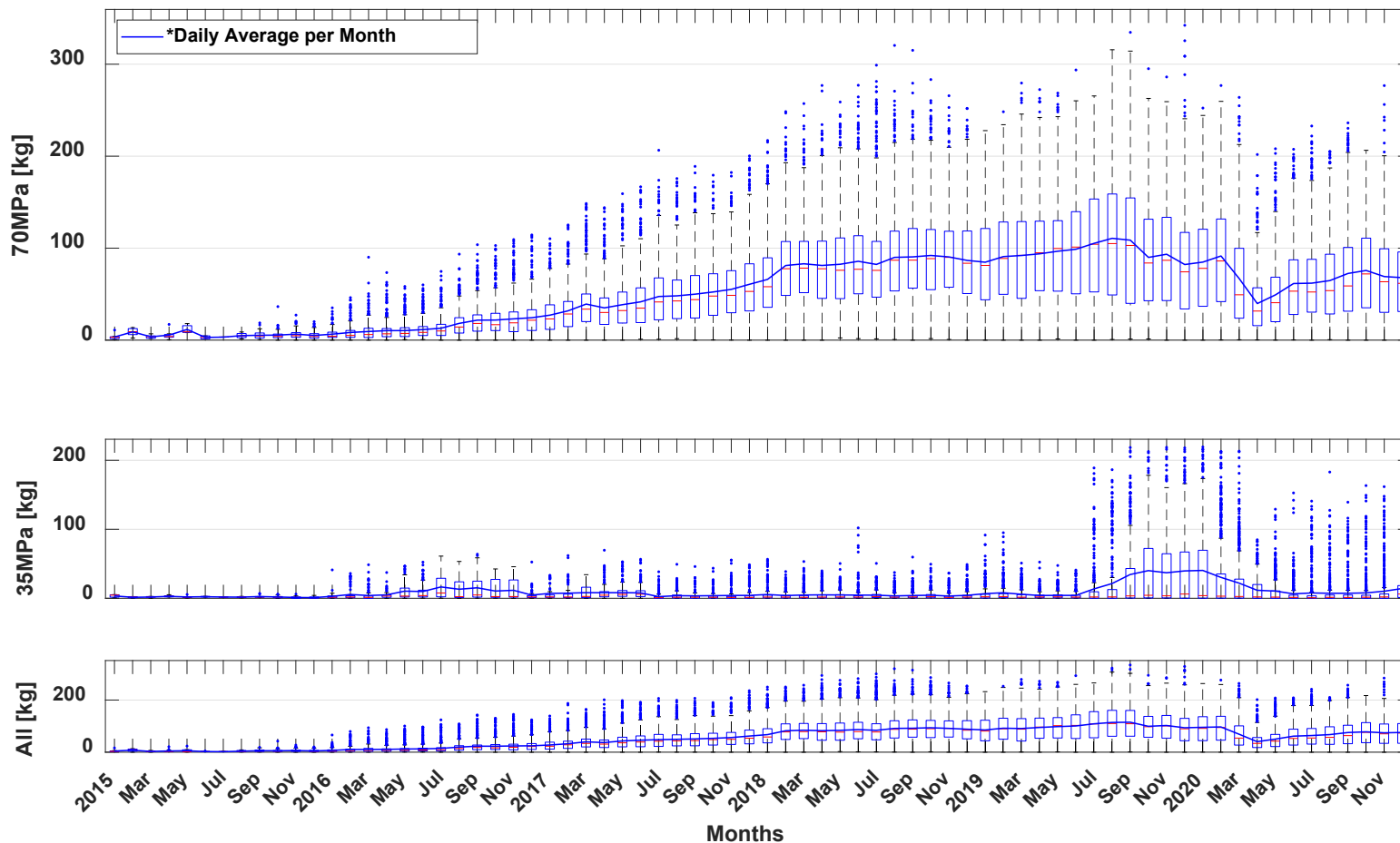


NREL cdpRETAIL_infr_80

Created: Nov-11-21 2:10 PM | Data Range: 2014Q3-2020Q4

Note: Some outliers clipped.

Daily Fueling Amounts Over Time - Retail Stations

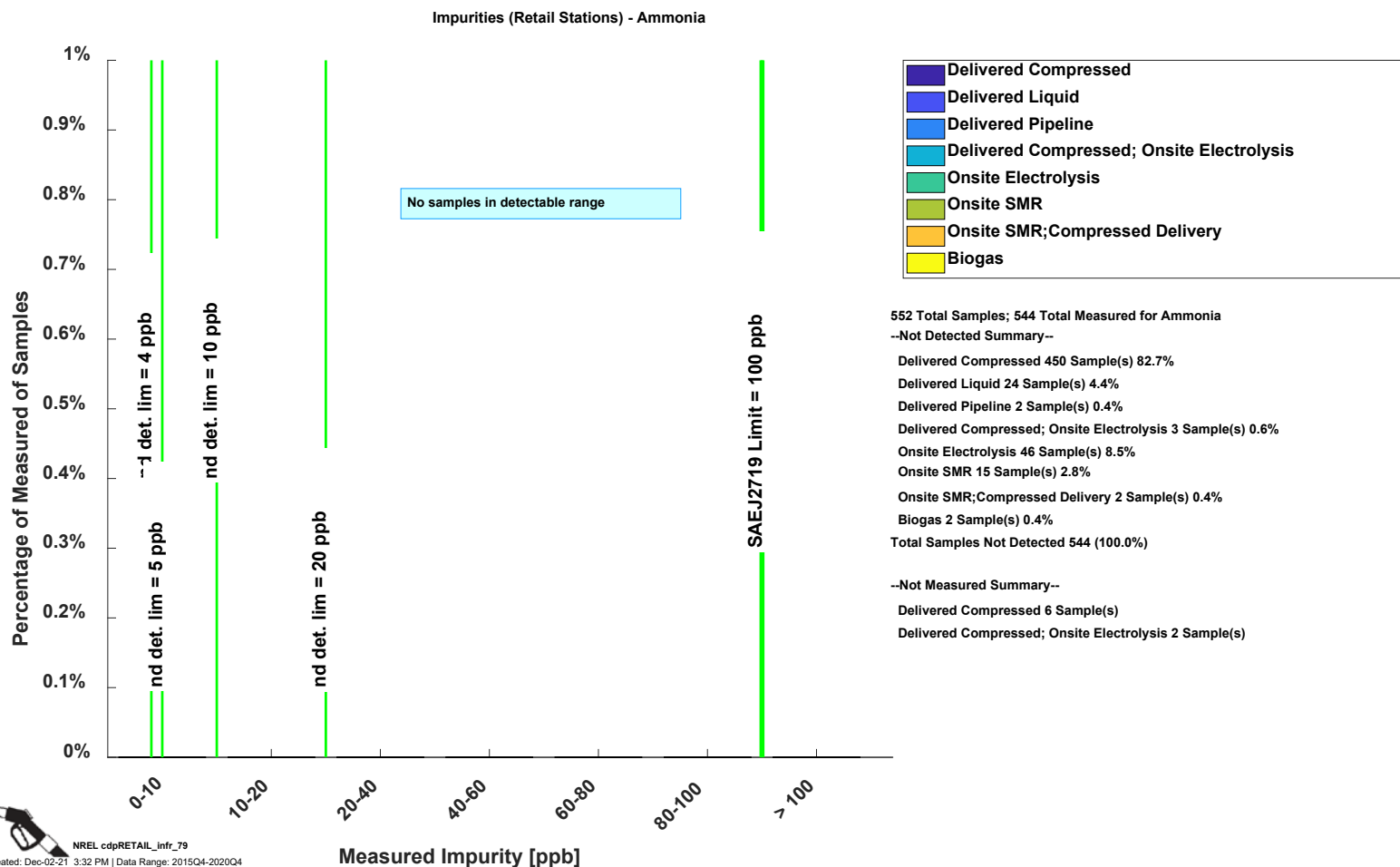


NREL cdpRETAIL_infr_82

Created: Sep-08-21 2:00 PM | Data Range: 2014Q3-2020Q4

*Daily average only includes days with fills. Outliers more than 3 standard deviations are not shown.

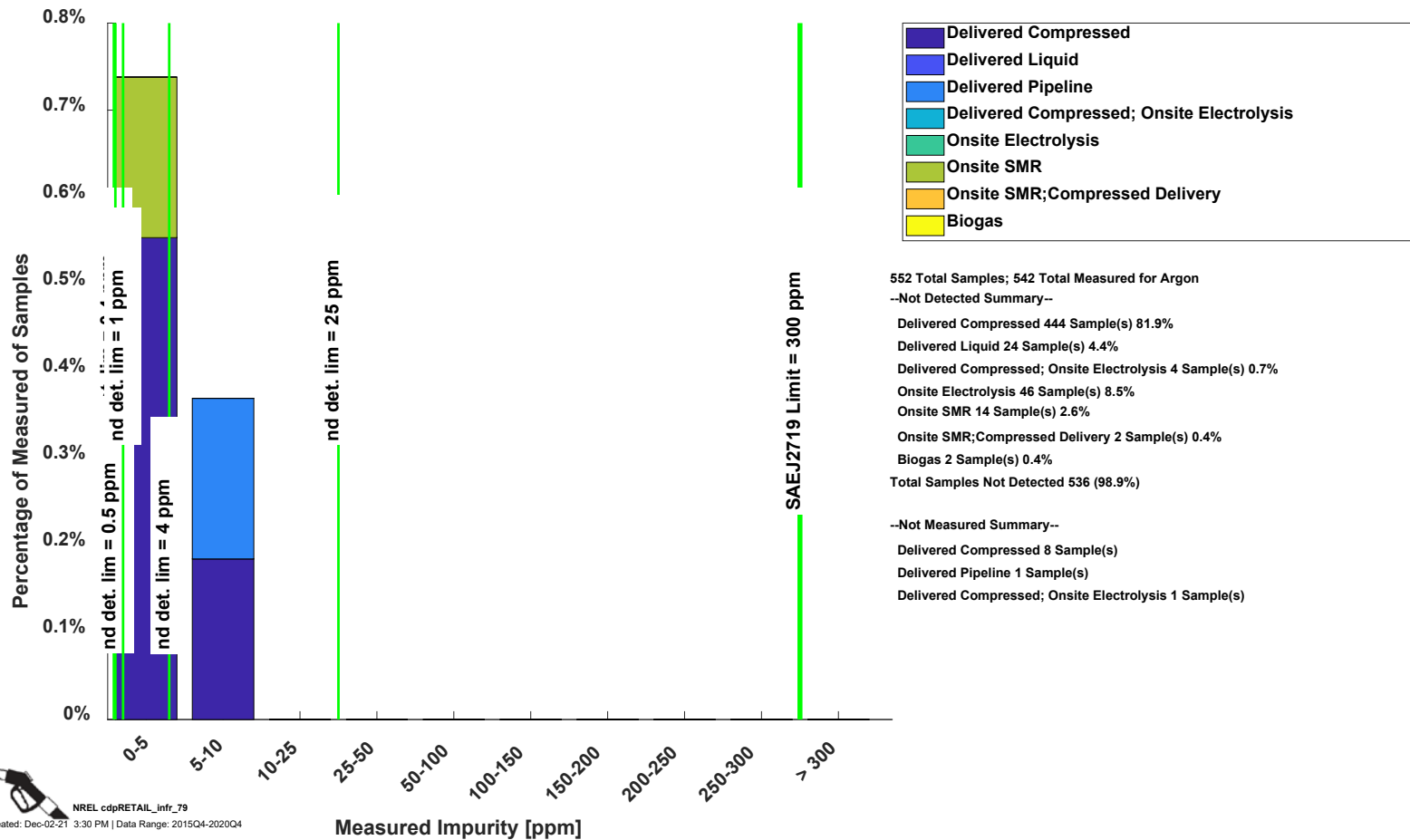
Hydrogen Quality



CDP-INFR-79

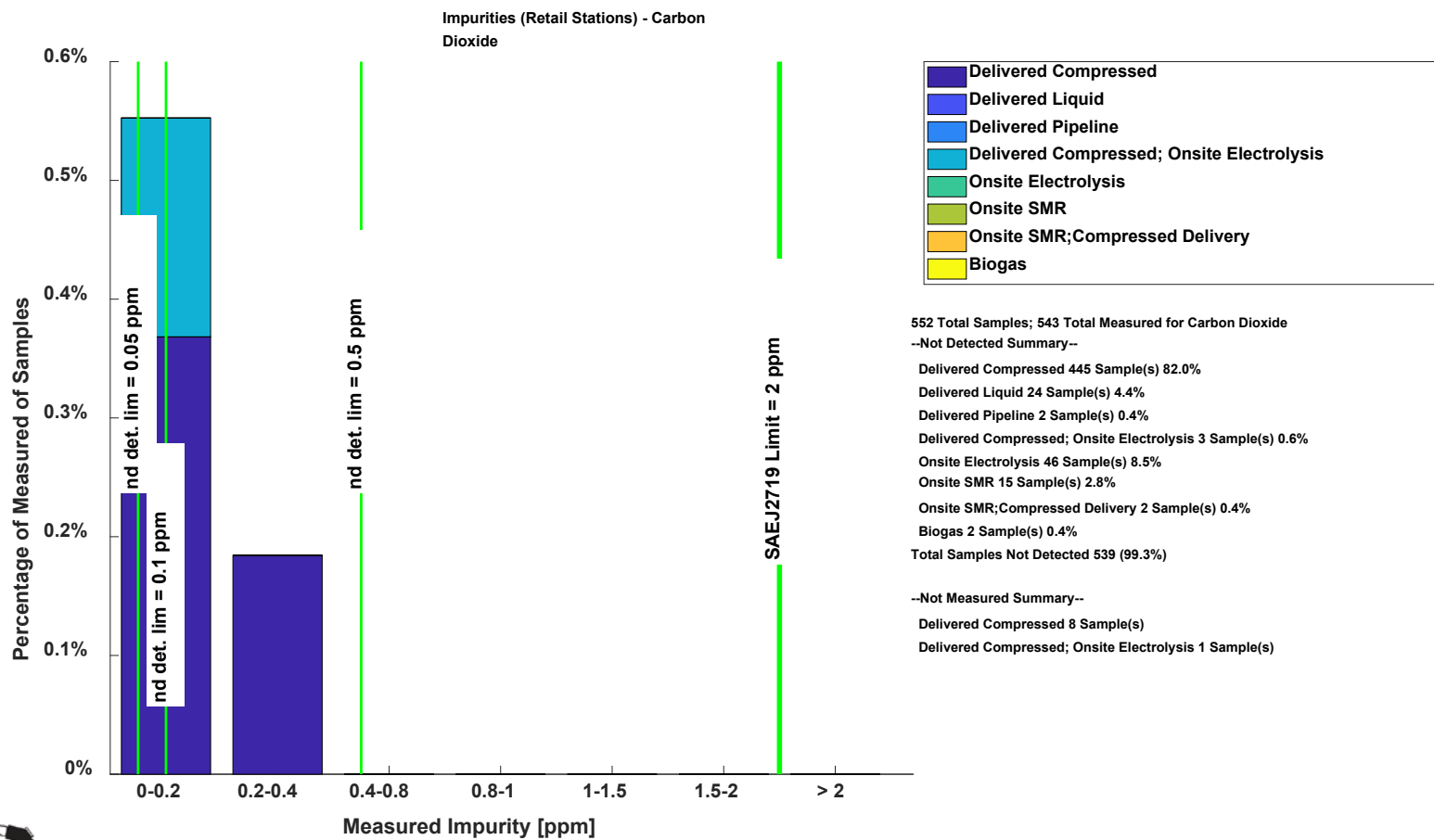
Impurities—Argon

Impurities (Retail Stations) - Argon



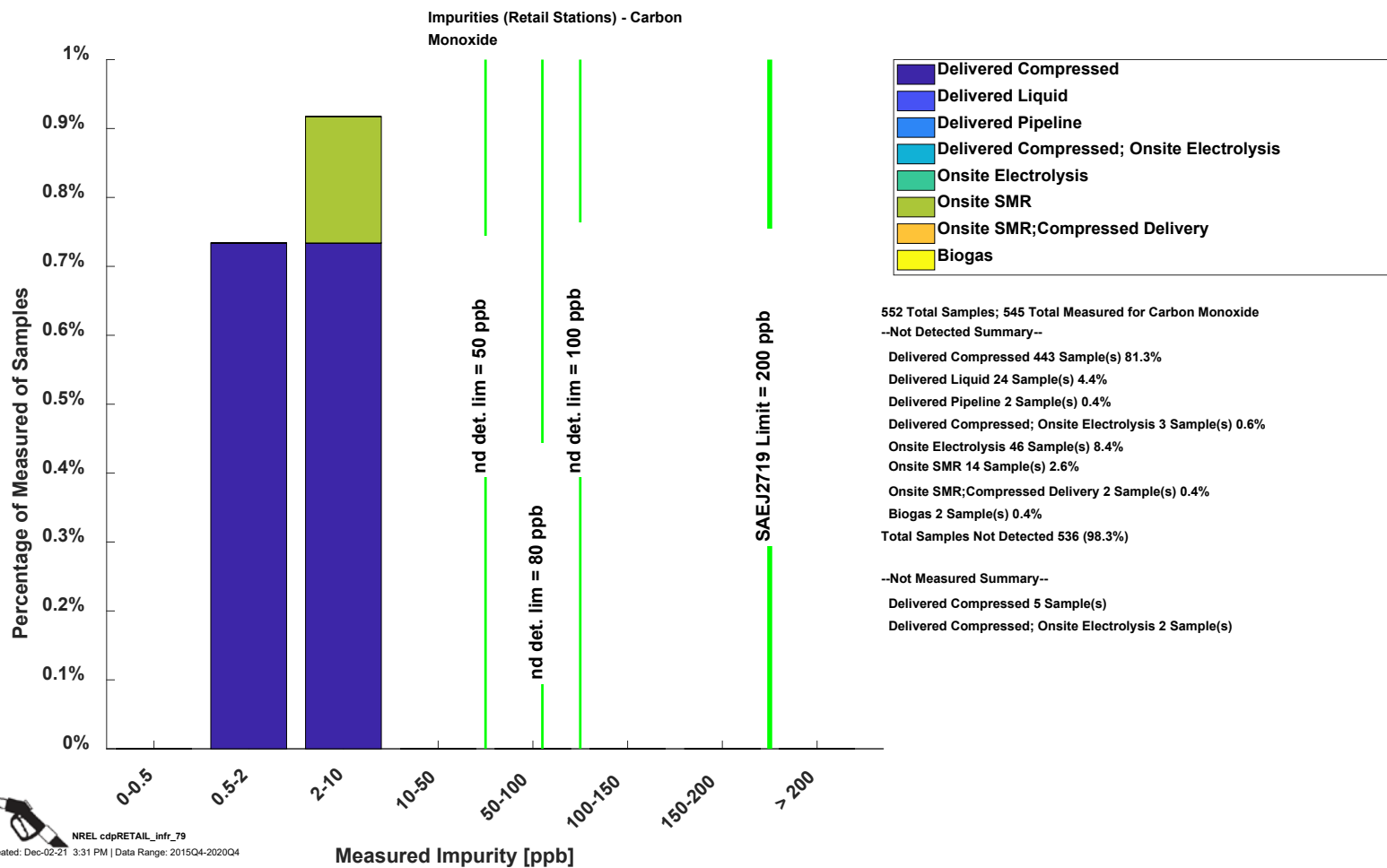
NREL cdpRETAIL_infr_79

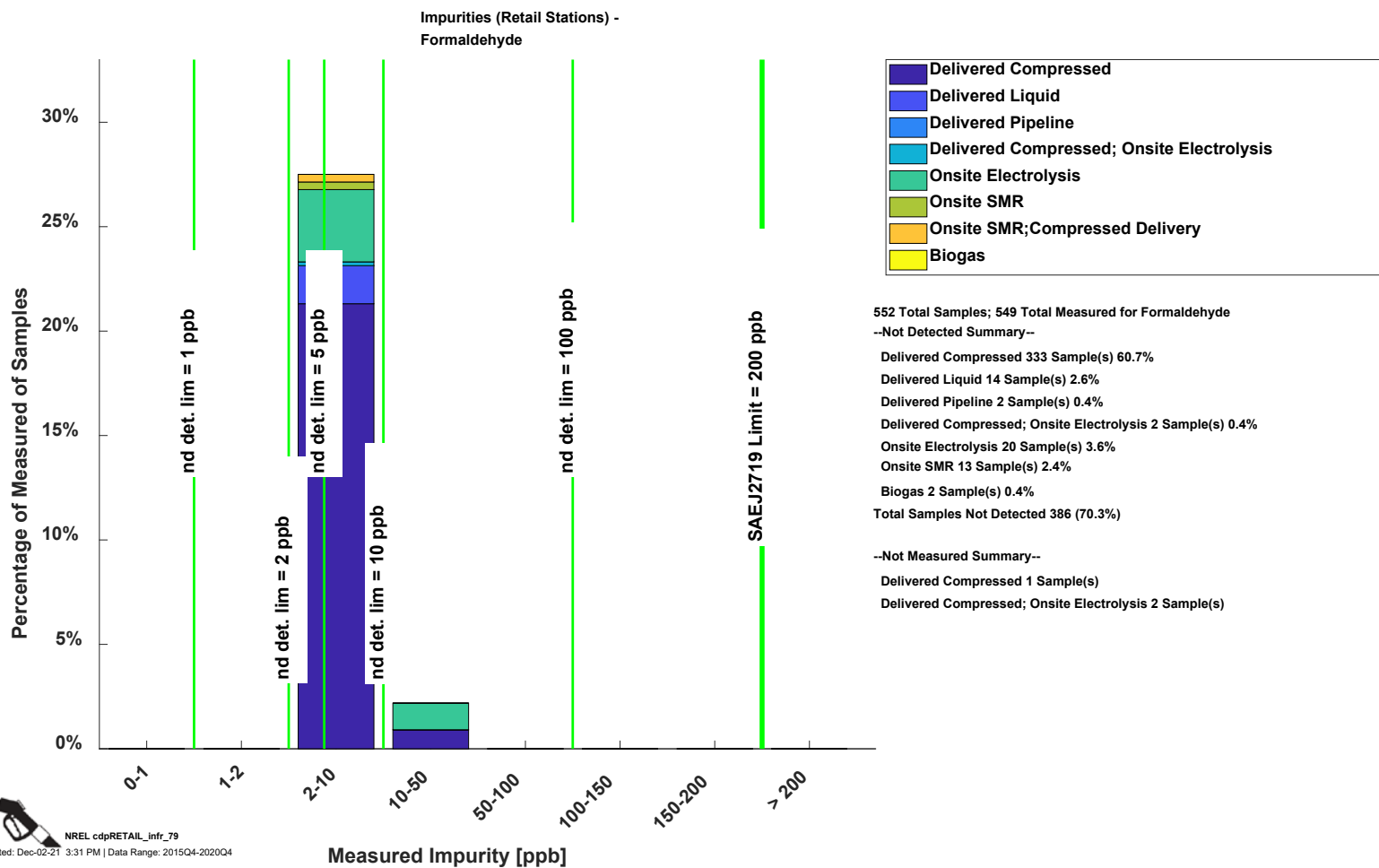
Created: Dec-02-21 3:30 PM | Data Range: 2015Q4-2020Q4



NREL cdpRETAIL_infr_79

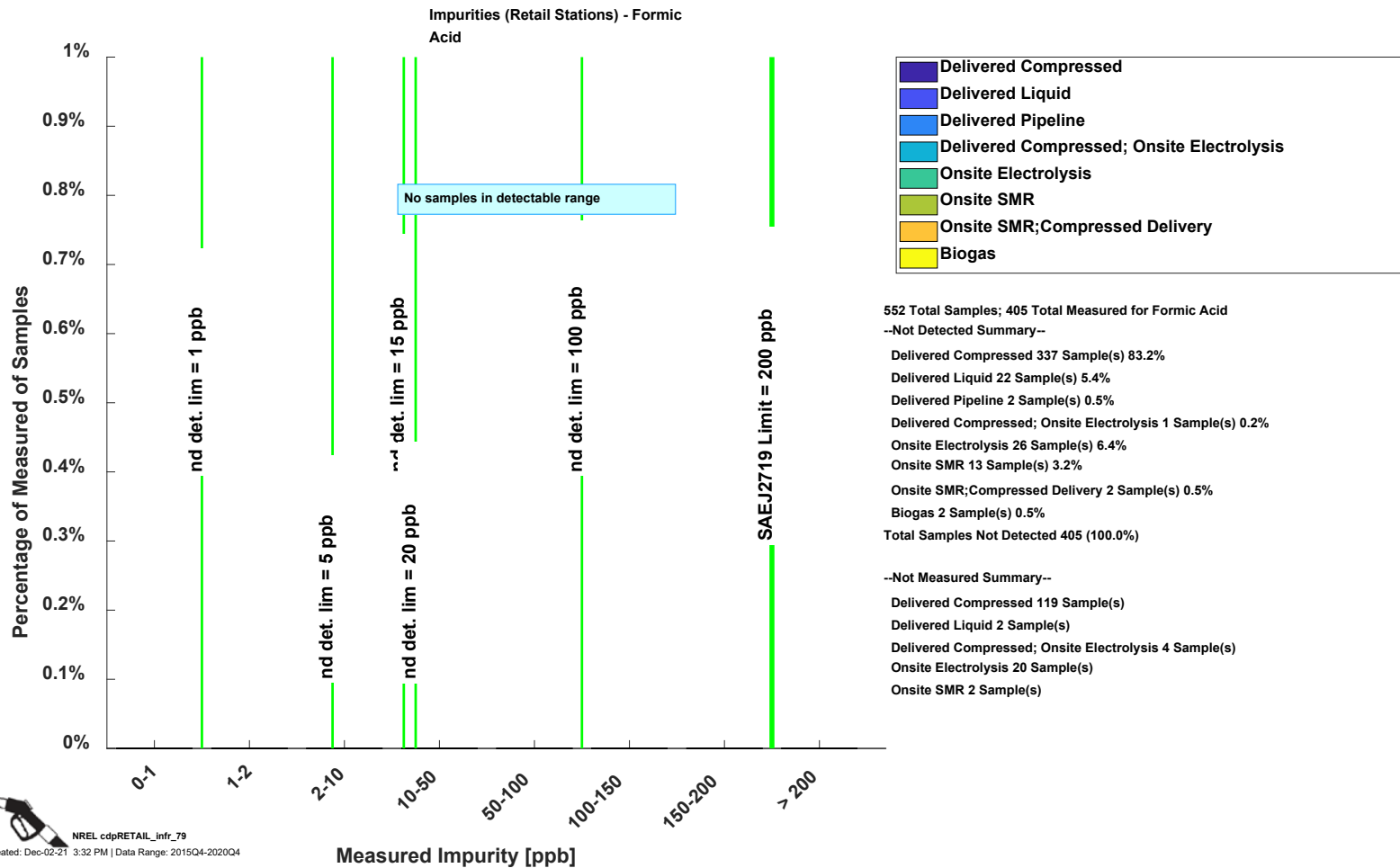
Created: Dec-02-21 3:31 PM | Data Range: 2015Q4-2020Q4





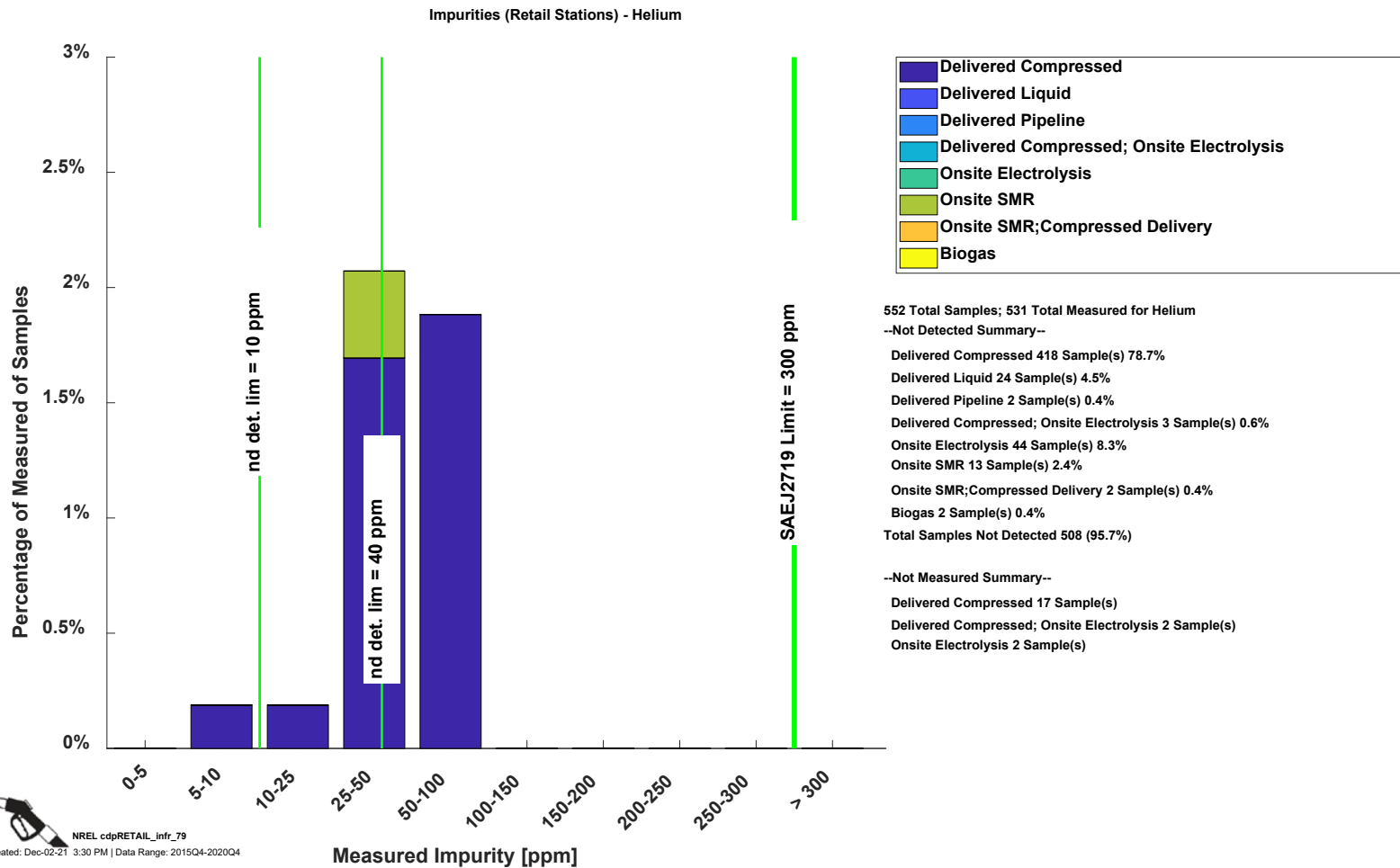
NREL cdpRETAIL_infr_79

Created: Dec-02-21 3:31 PM | Data Range: 2015Q4-2020Q4

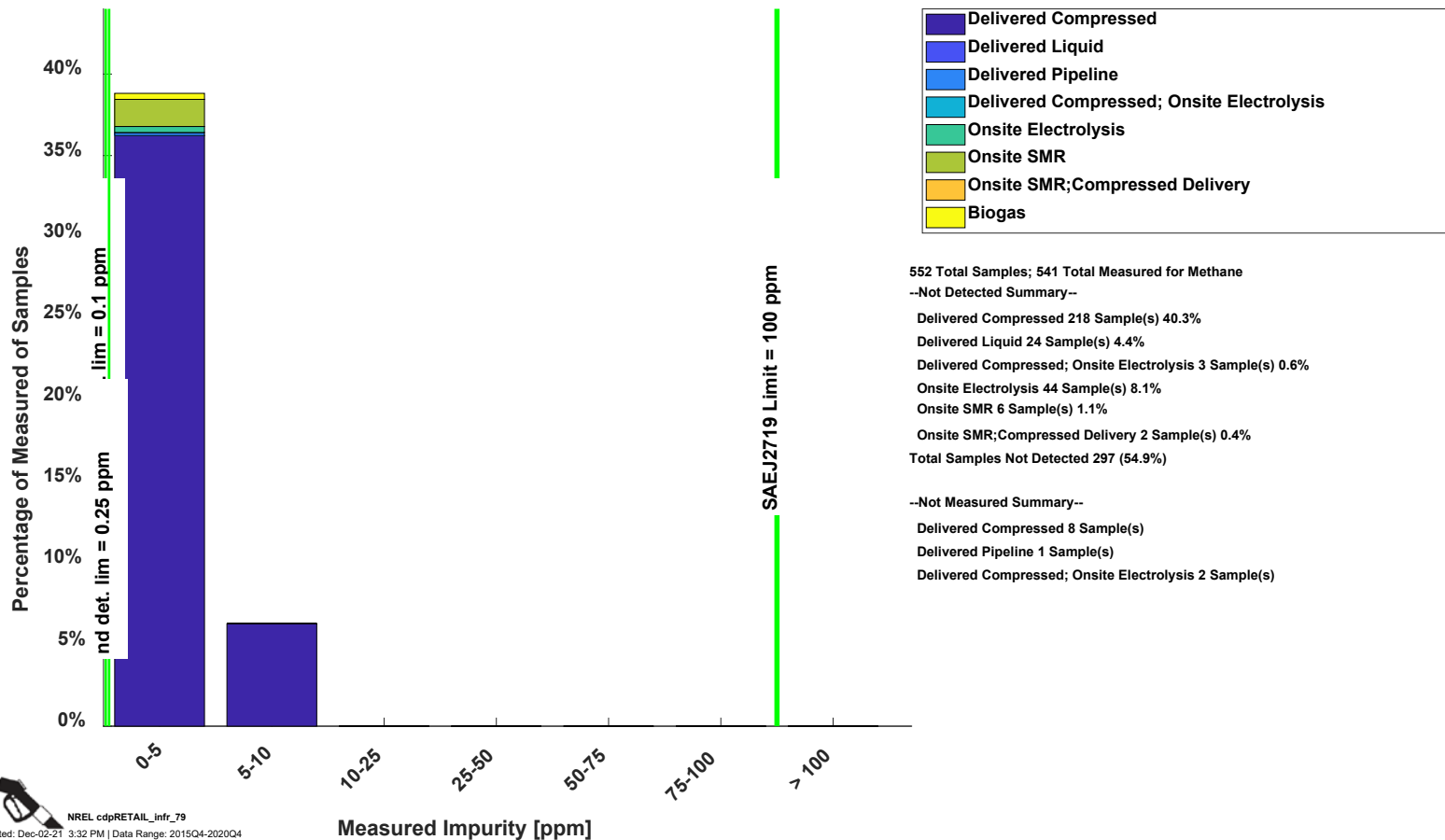


NREL cdpRETAIL_infr_79

Created: Dec-02-21 3:32 PM | Data Range: 2015Q4-2020Q4

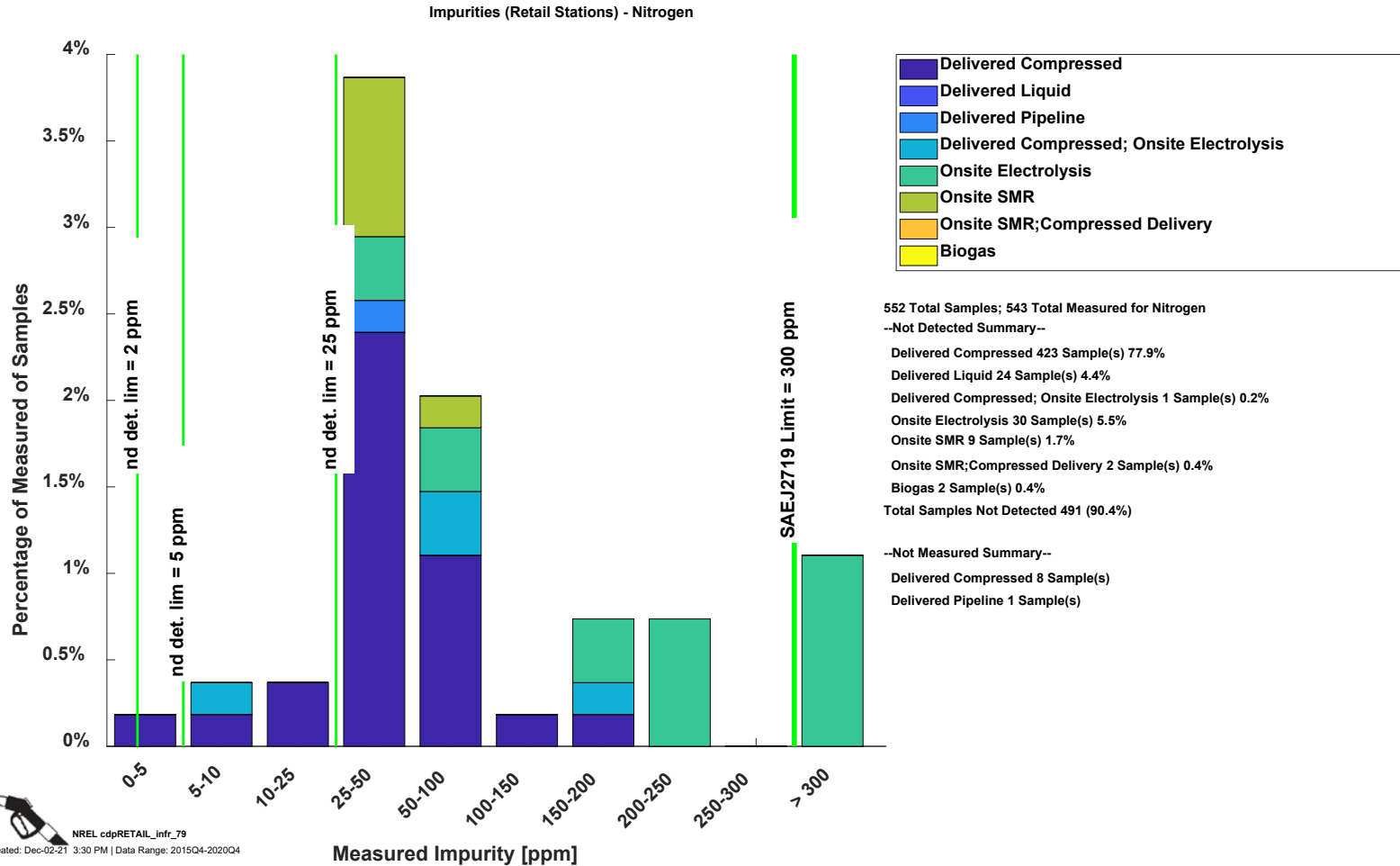


Impurities (Retail Stations) - Methane



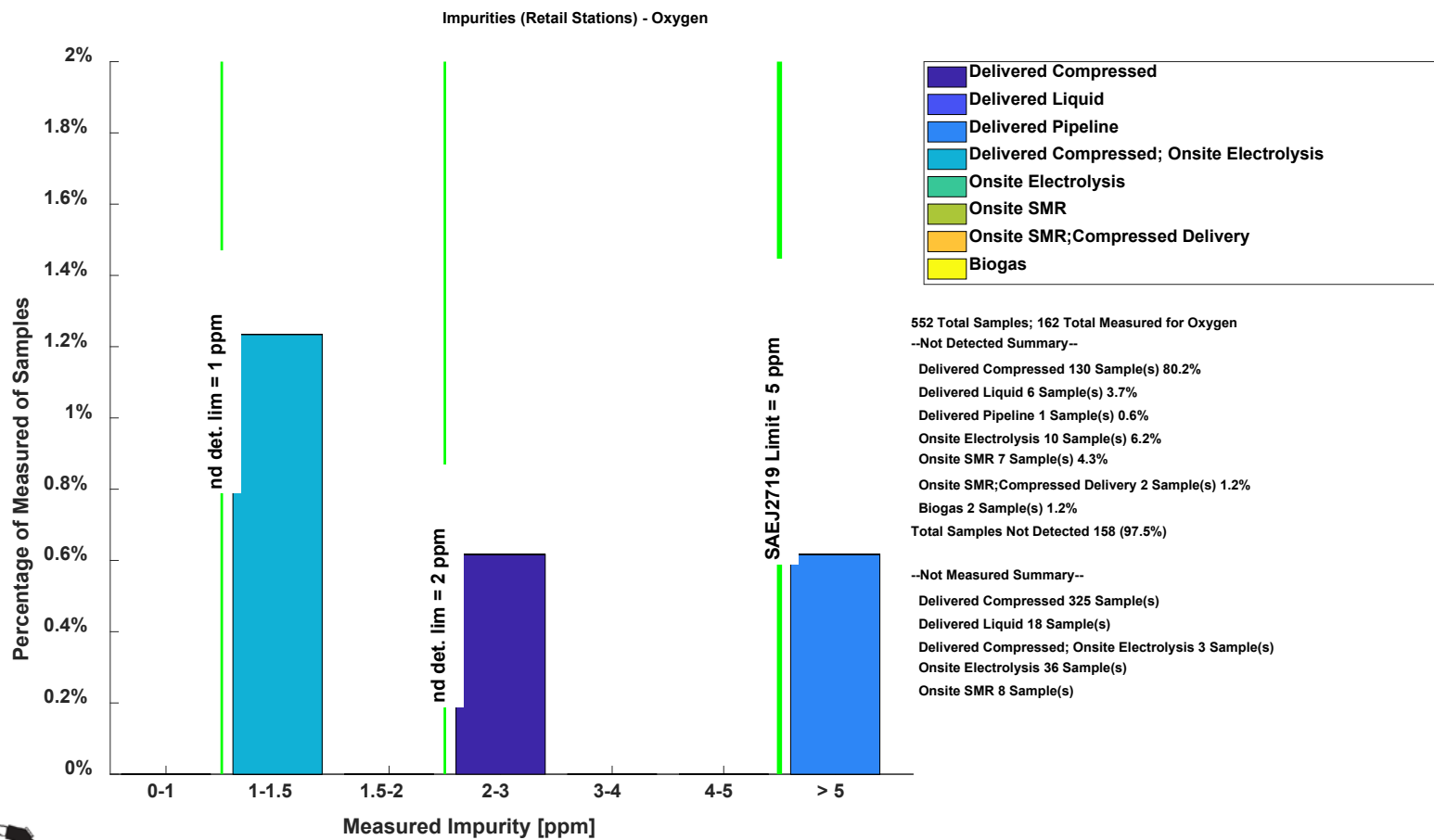
NREL cdpRETAIL_infr_79

Created: Dec-02-21 3:32 PM | Data Range: 2015Q4-2020Q4



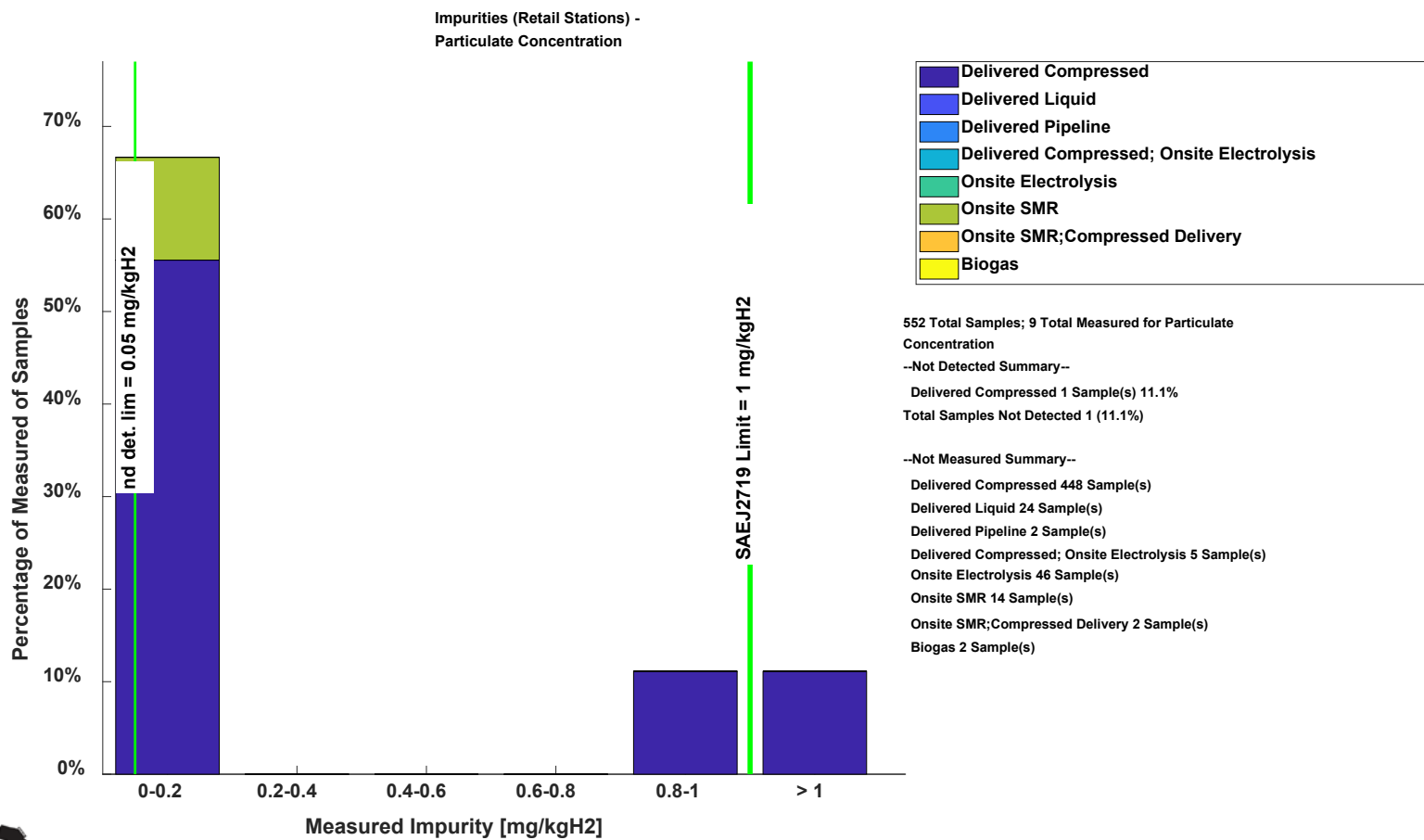
CDP-INFR-79

Impurities—Oxygen



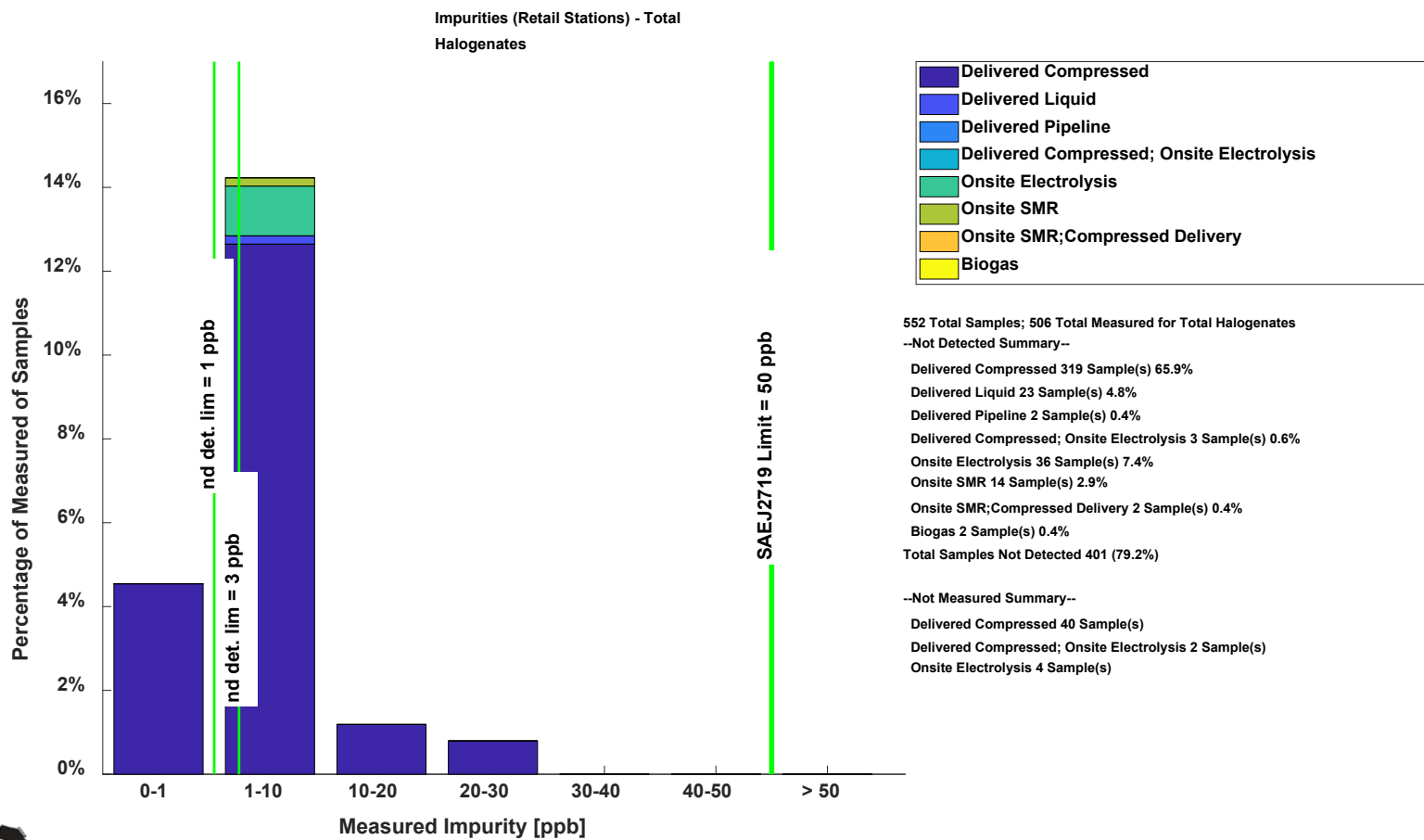
NREL cdpRETAIL_infr_79

Created: Dec-02-21 3:29 PM | Data Range: 2015Q4-2020Q4



NREL cdpRETAIL_infr_79

Created: Dec-02-21 3:32 PM | Data Range: 2015Q4-2020Q4



552 Total Samples; 506 Total Measured for Total Halogenates

--Not Detected Summary--

- Delivered Compressed 319 Sample(s) 65.9%
- Delivered Liquid 23 Sample(s) 4.8%
- Delivered Pipeline 2 Sample(s) 0.4%
- Delivered Compressed; Onsite Electrolysis 3 Sample(s) 0.6%
- Onsite Electrolysis 36 Sample(s) 7.4%
- Onsite SMR 14 Sample(s) 2.9%
- Onsite SMR; Compressed Delivery 2 Sample(s) 0.4%
- Biogas 2 Sample(s) 0.4%
- Total Samples Not Detected 401 (79.2%)

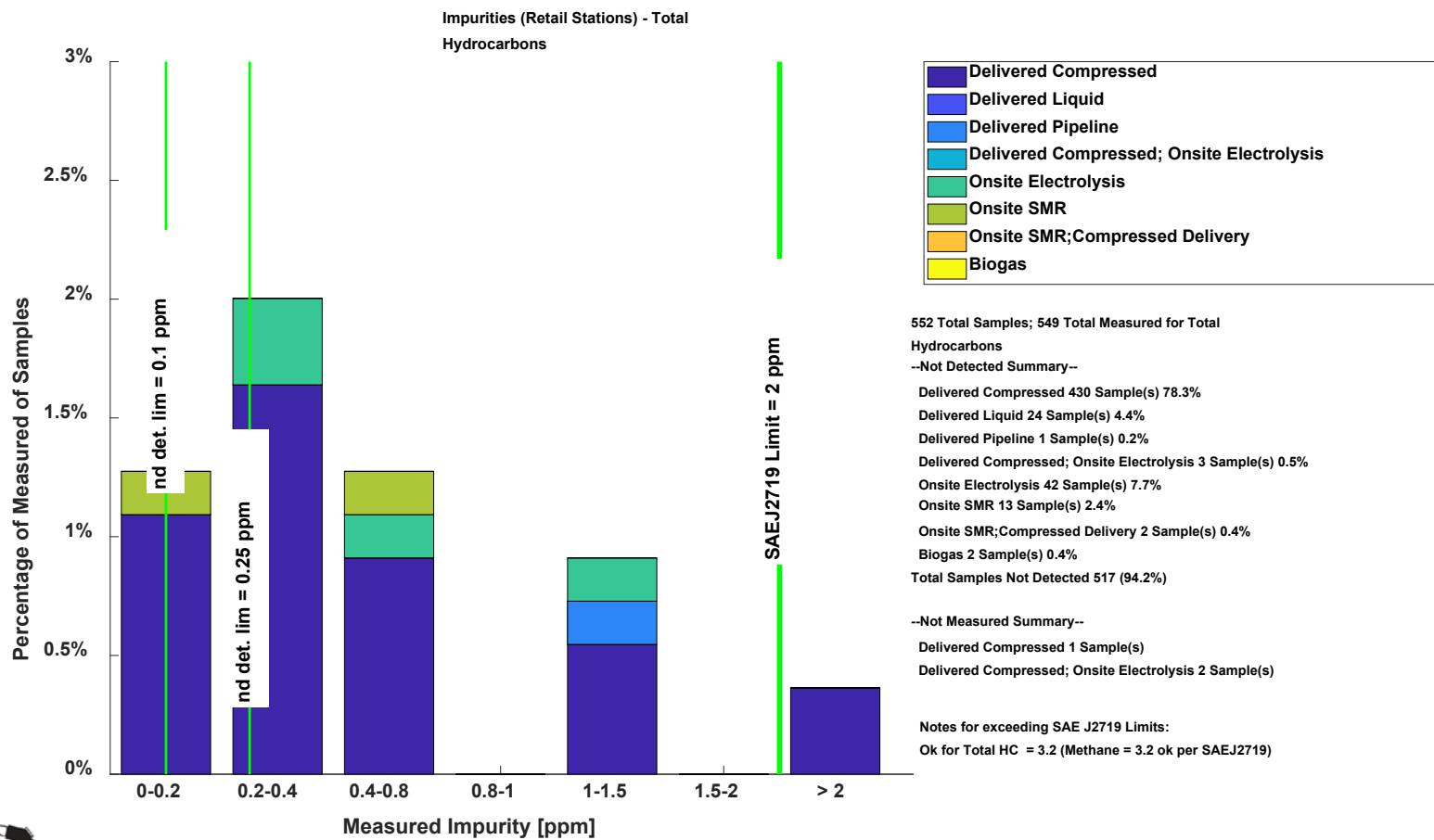
--Not Measured Summary--

- Delivered Compressed 40 Sample(s)
- Delivered Compressed; Onsite Electrolysis 2 Sample(s)
- Onsite Electrolysis 4 Sample(s)



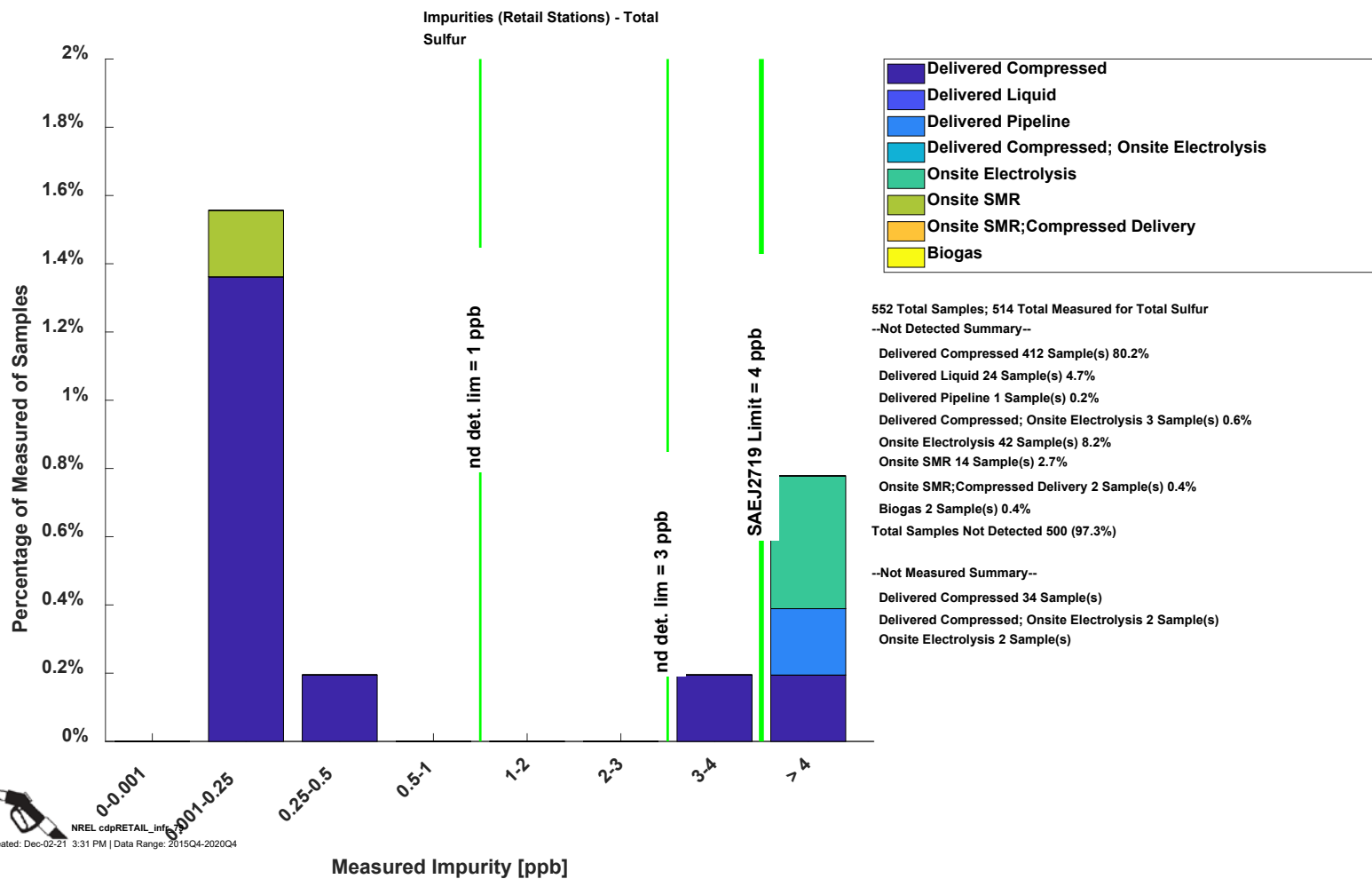
NREL cdpRETAIL_infr_79

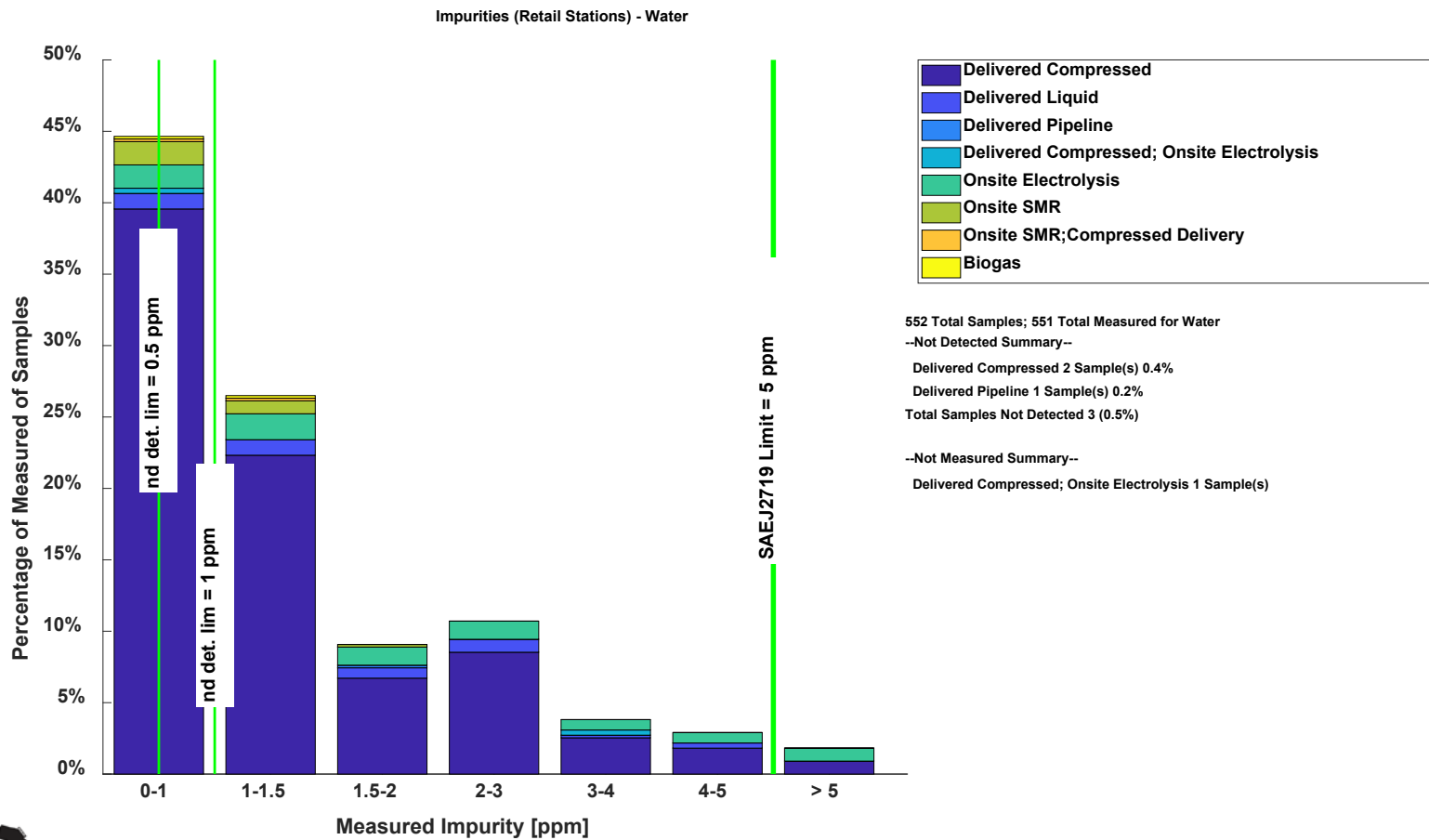
Created: Dec-02-21 3:32 PM | Data Range: 2015Q4-2020Q4



NREL cdpRETAIL_infr_79

Created: Dec-02-21 3:29 PM | Data Range: 2015Q4-2020Q4





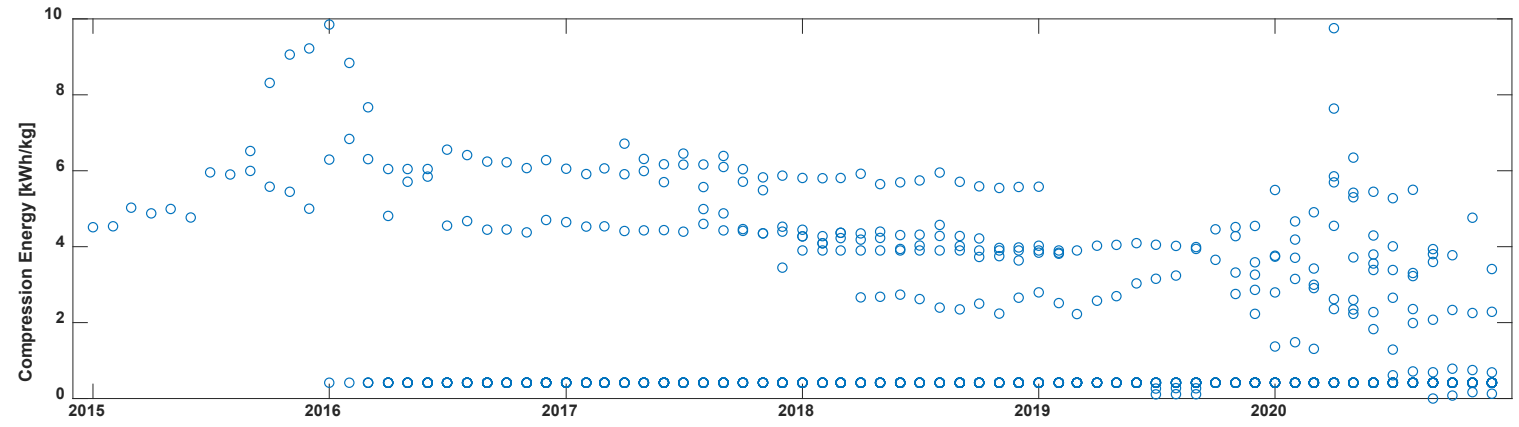
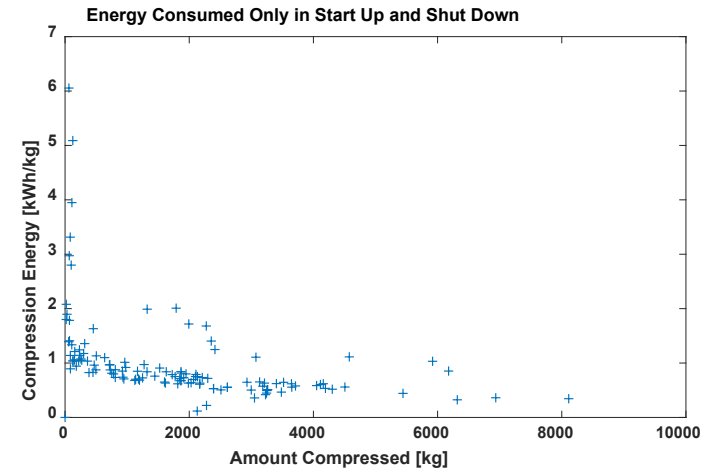
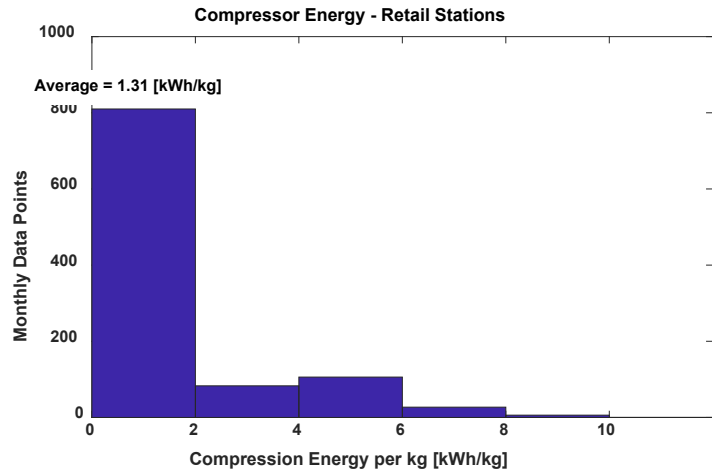
NREL cdpRETAIL_infr_79

Created: Dec-02-21 3:29 PM | Data Range: 2015Q4-2020Q4

Component Energy

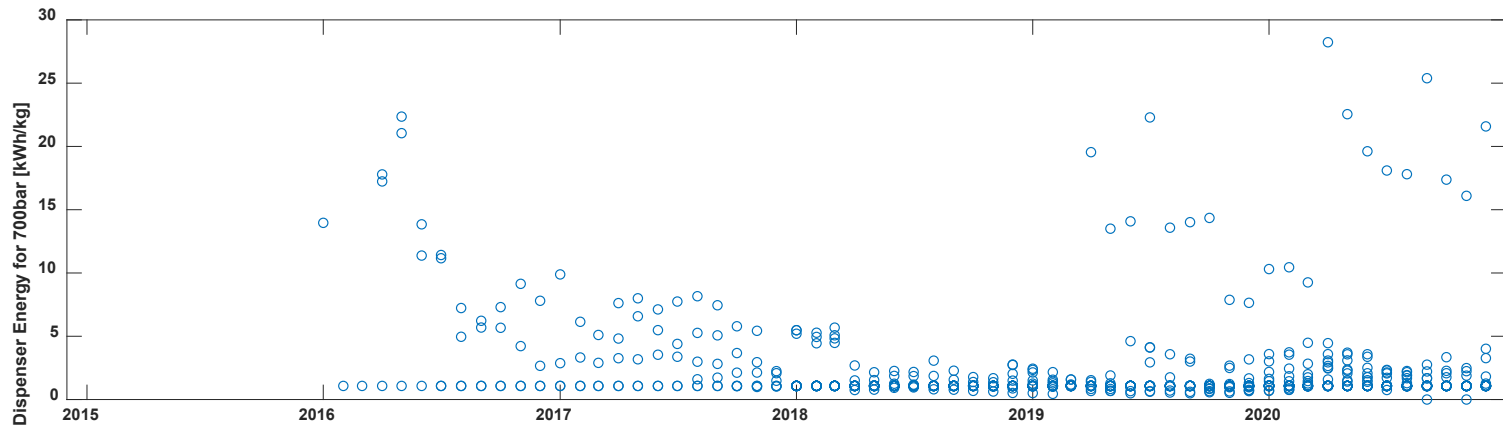
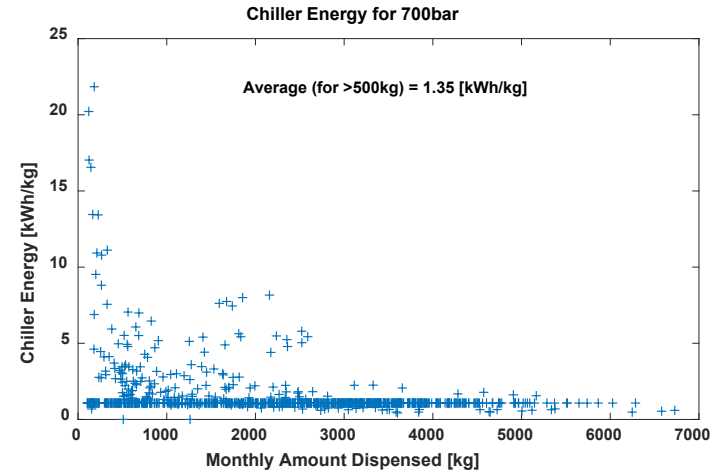
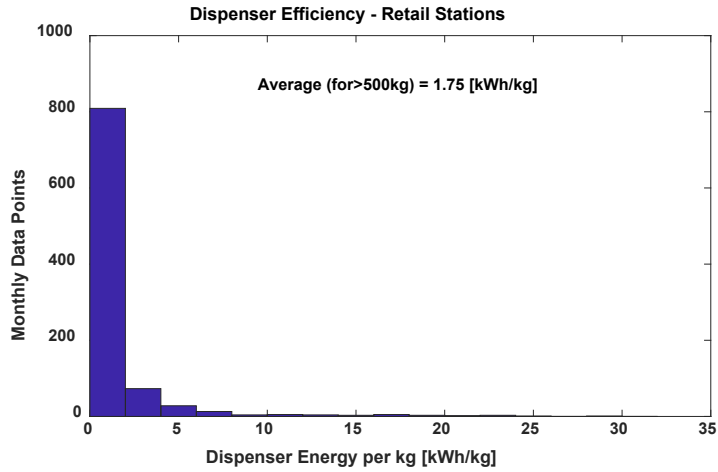
CDP-INFR-35

Compressor Energy



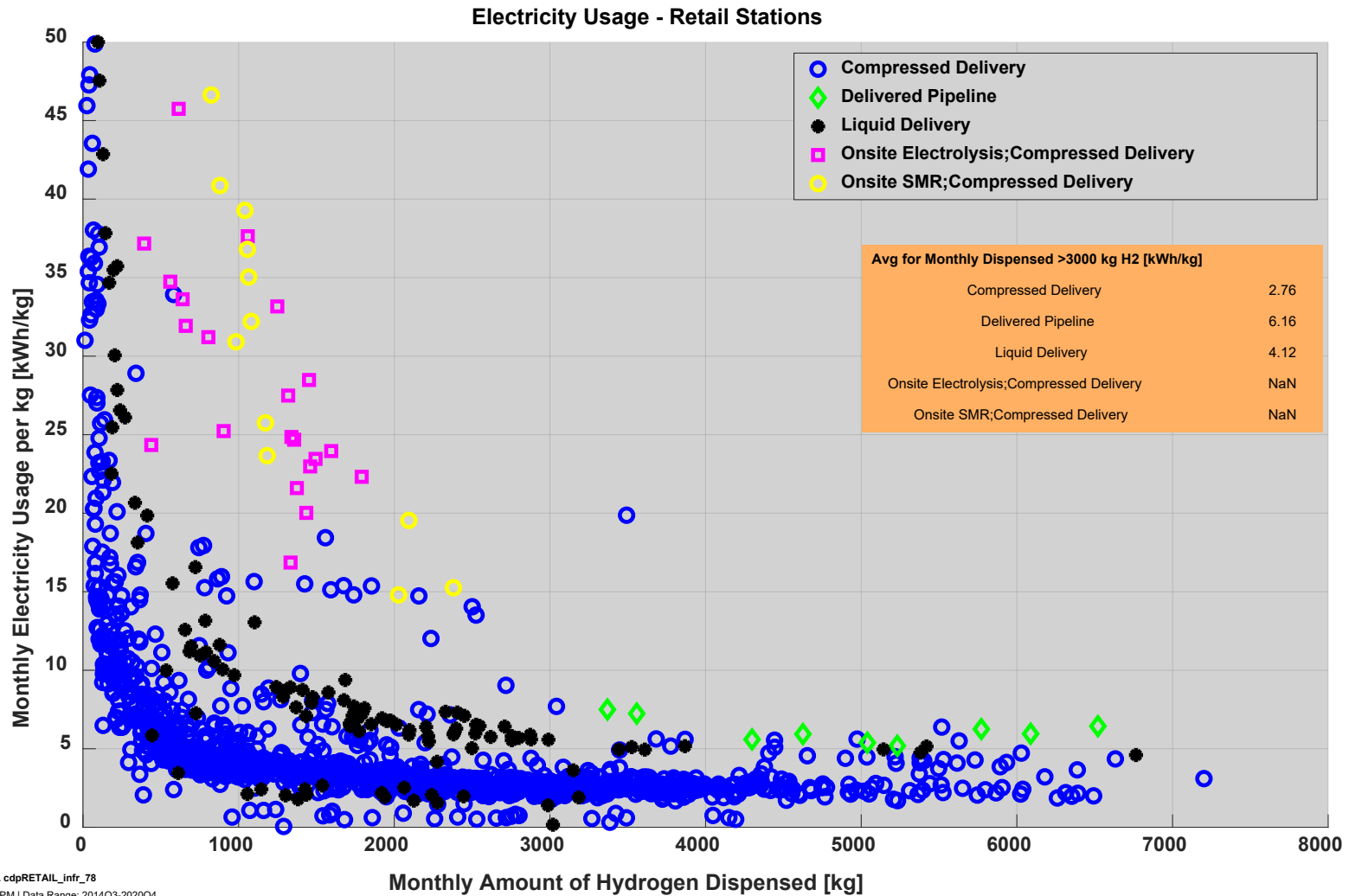
CDP-INFR-92

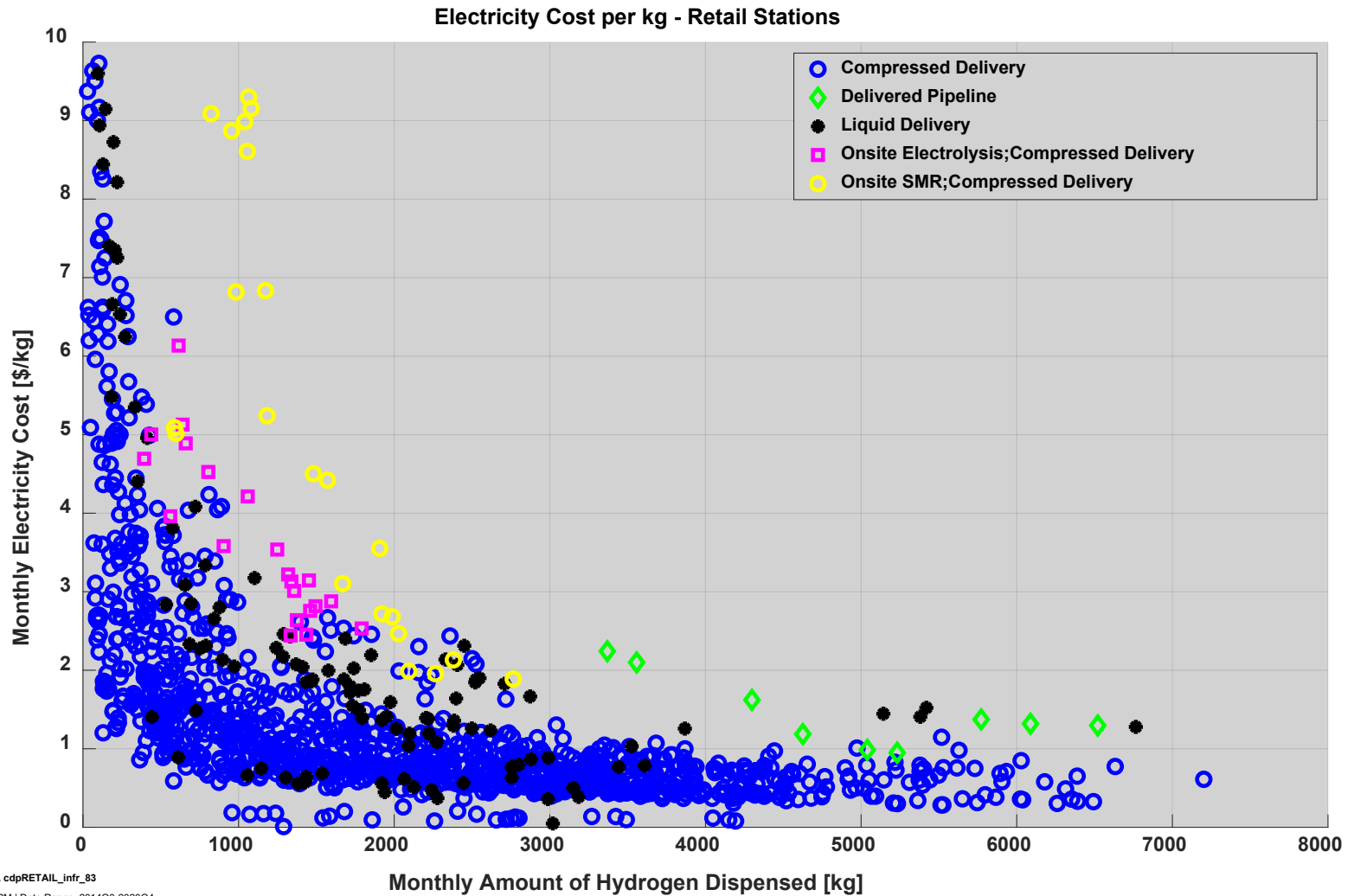
Dispenser Energy



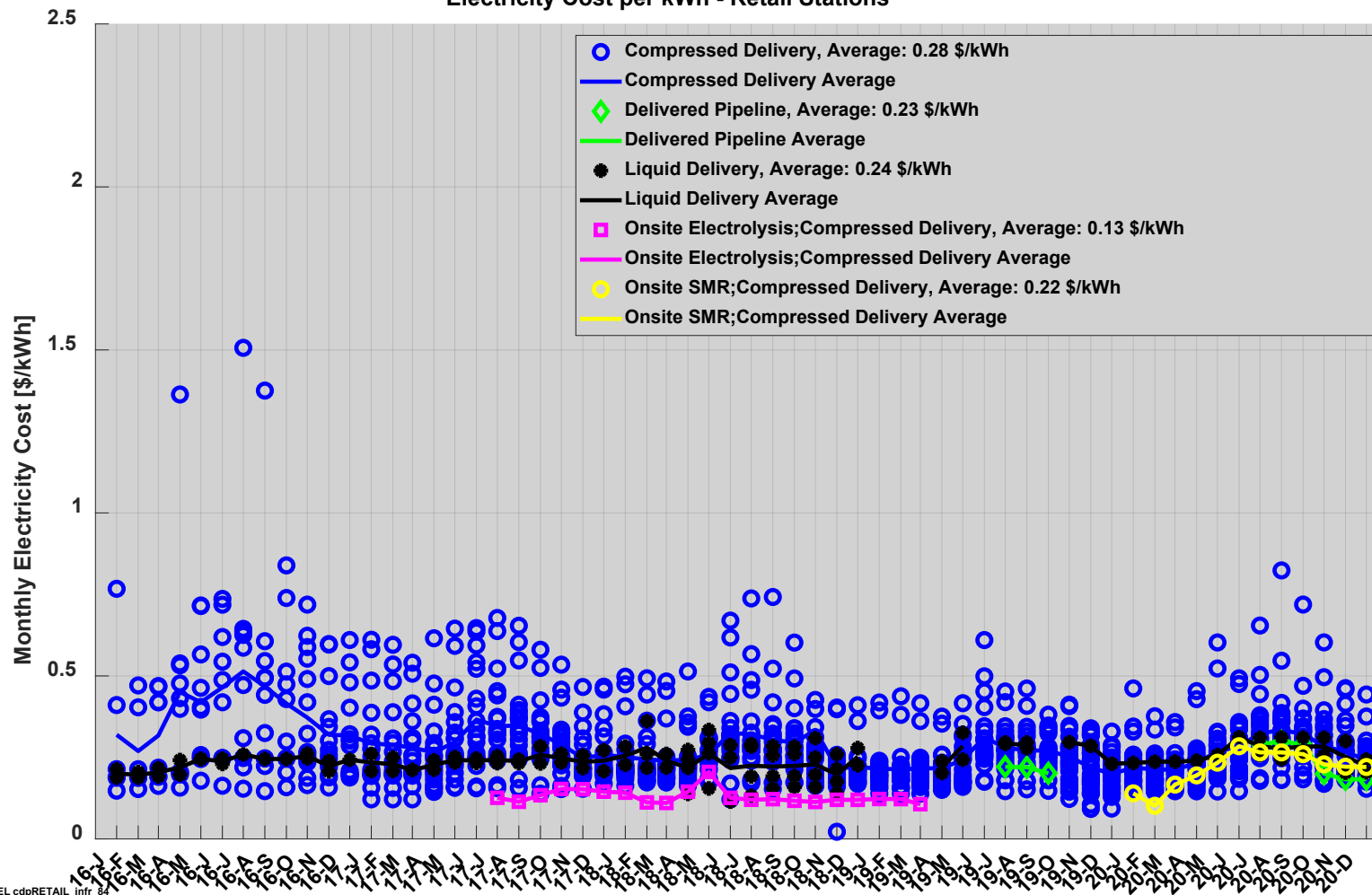
NREL cdpRETAIL_infr_92

Created: Sep-16-21 11:14 AM | Data Range: 2014Q3-2020Q4





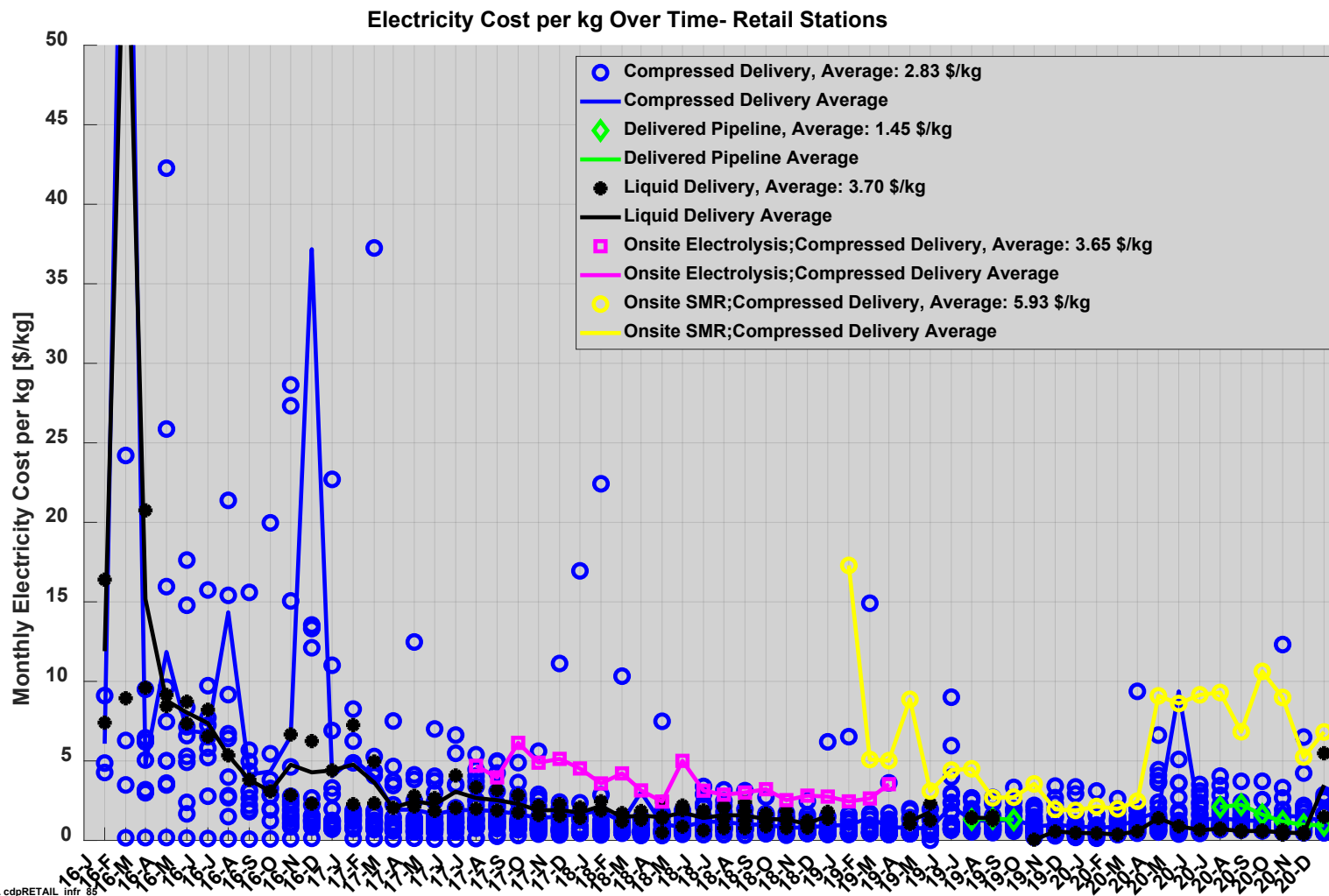
Electricity Cost per kWh - Retail Stations



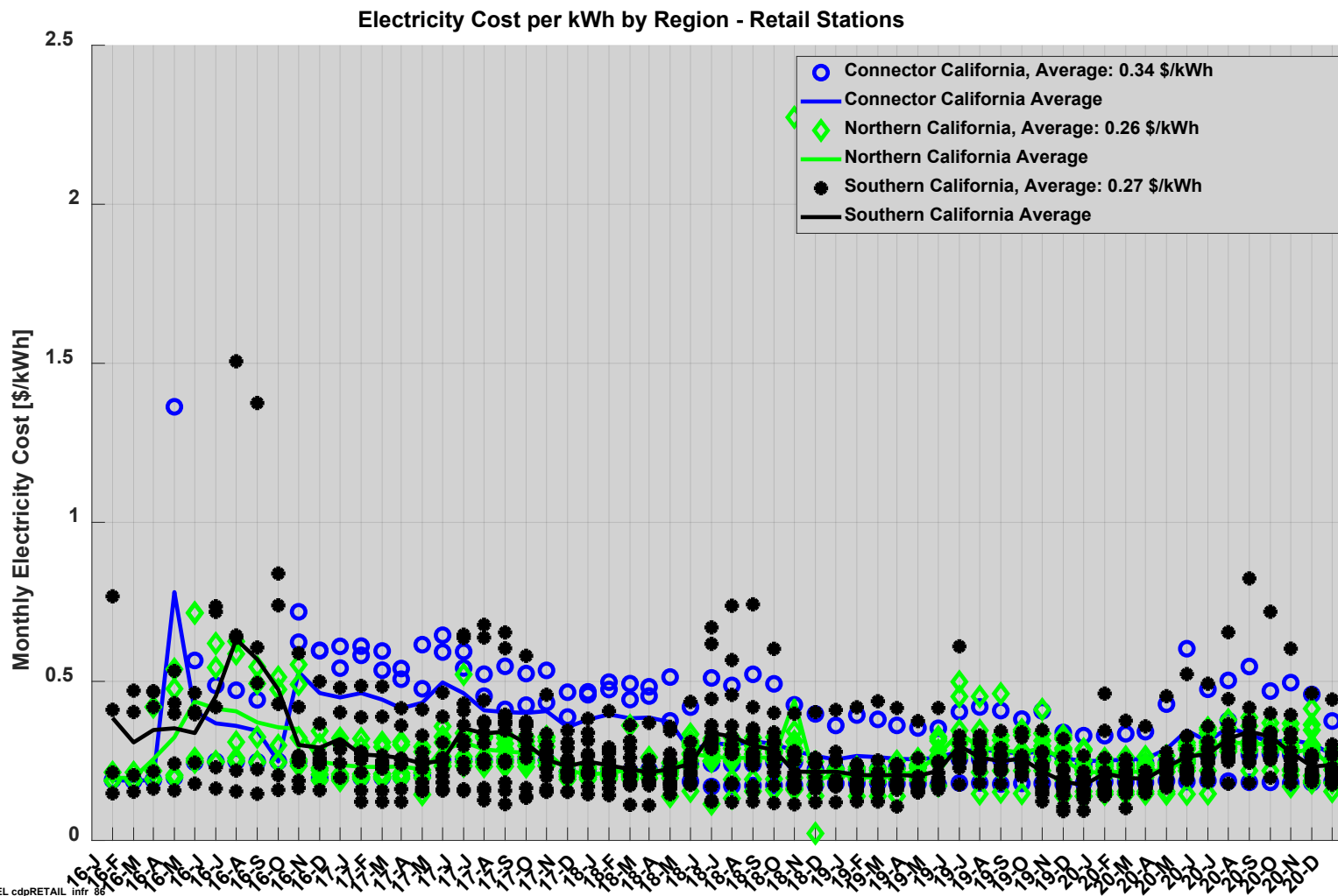
NREL cdpRETAIL_infr_84

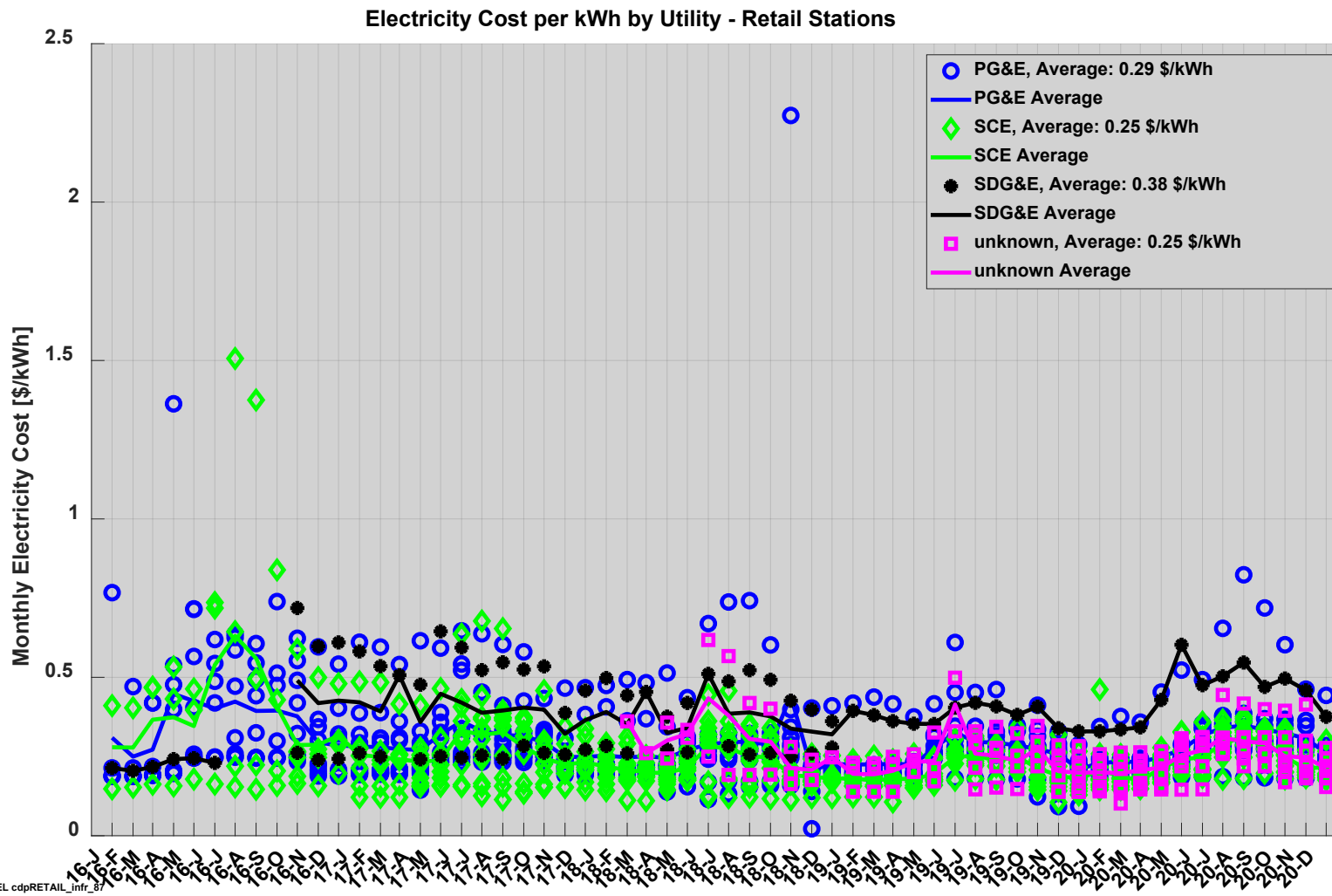
Created: Sep-08-21 2:35 PM | Data Range: 2014Q3-2020Q4

*Some data has been filtered due to station reporting errors.



Station Electricity Cost per kWh by Region





*Some data has been filtered due to station reporting errors.