



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

Summer 2021: Data through Quarter 2 of 2021

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May 20, 2022

NREL/PR-5400-83036

Hydrogen Station Project Partners



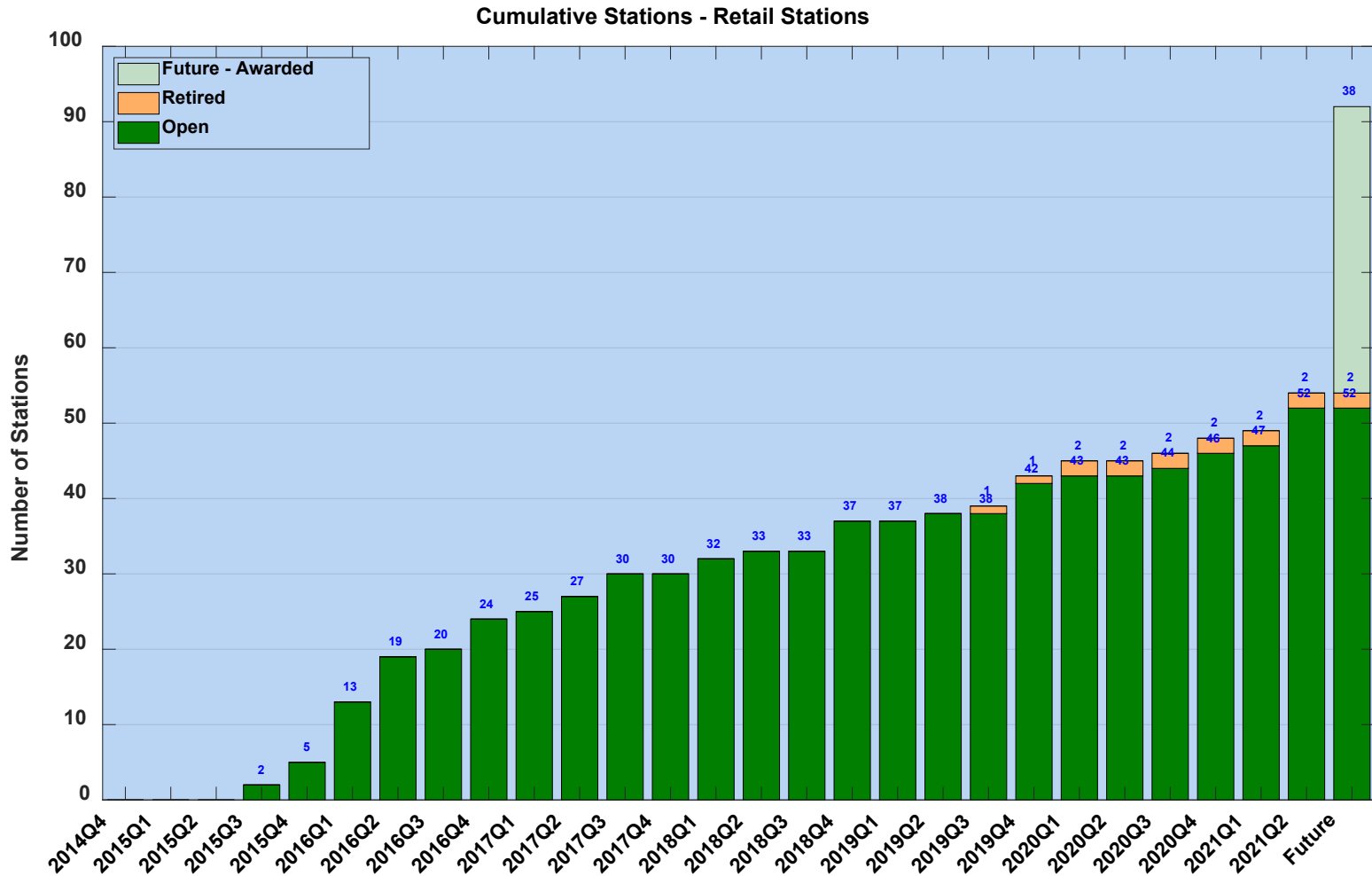
- Air Liquide
- Air Products
- California Air Resources Board
- California Energy Commission
- California State University Los Angeles
- Equilon
- FirstElement Fuel
- Gas Technology Institute
- ITM Power
- Iwatani
- Linde
- H2 Frontier
- Messer
- Proton OnSite
- Shell
- IPHE and HySUT



Analysis Categories



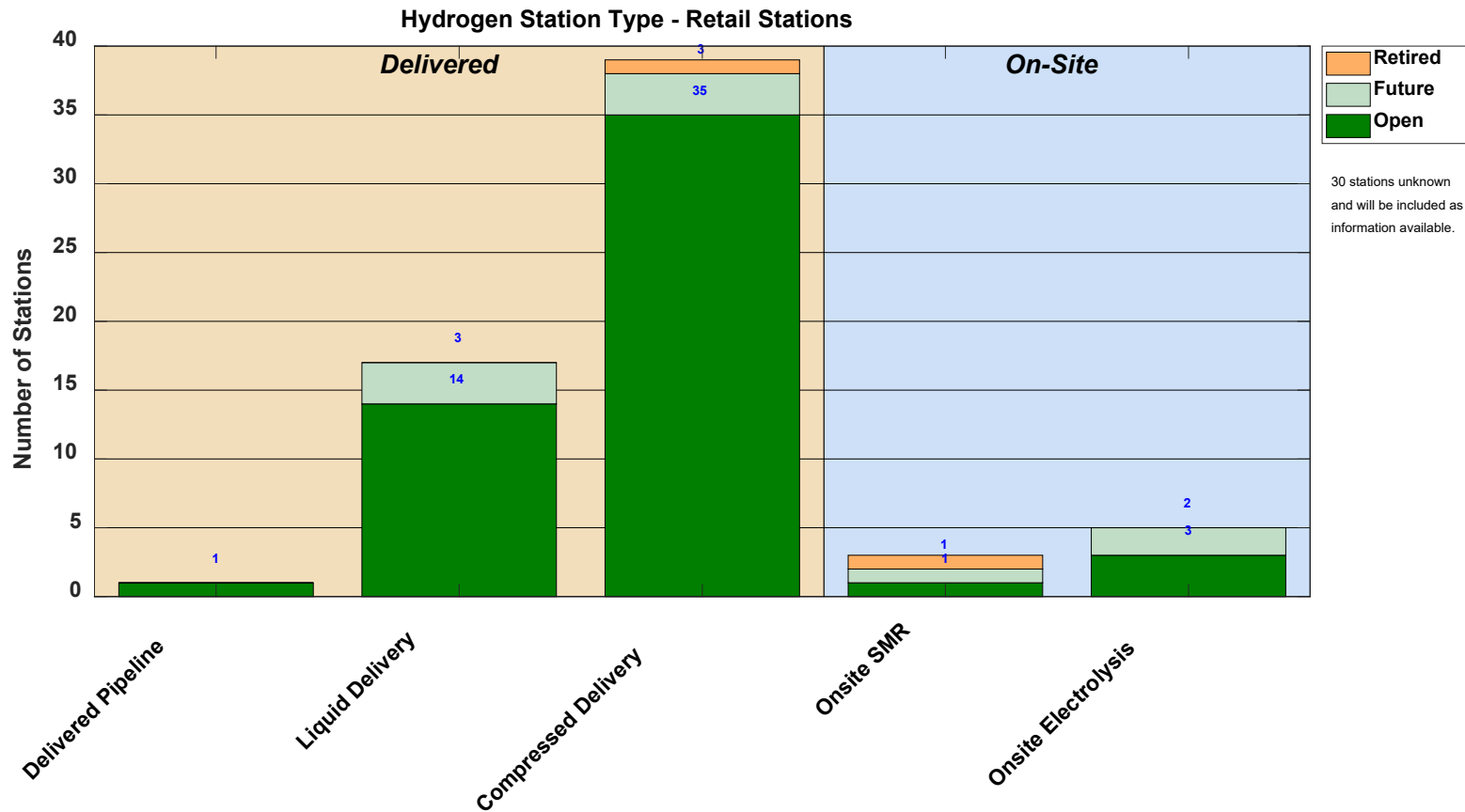
Deployment

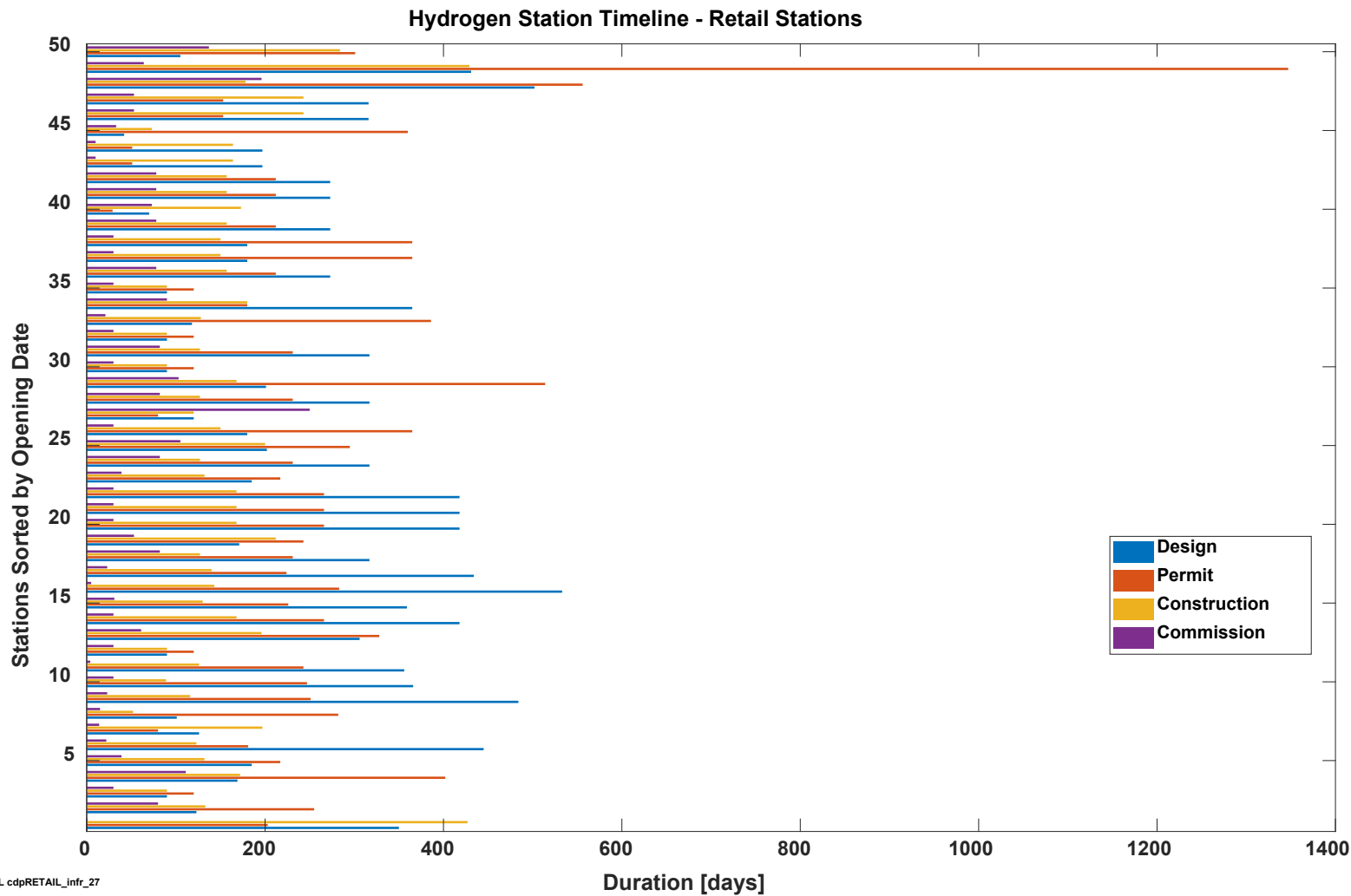


NREL cdpRETAIL_infr_10

Created: May-03-22 12:50 PM | Data Range: 2014Q3-2021Q2

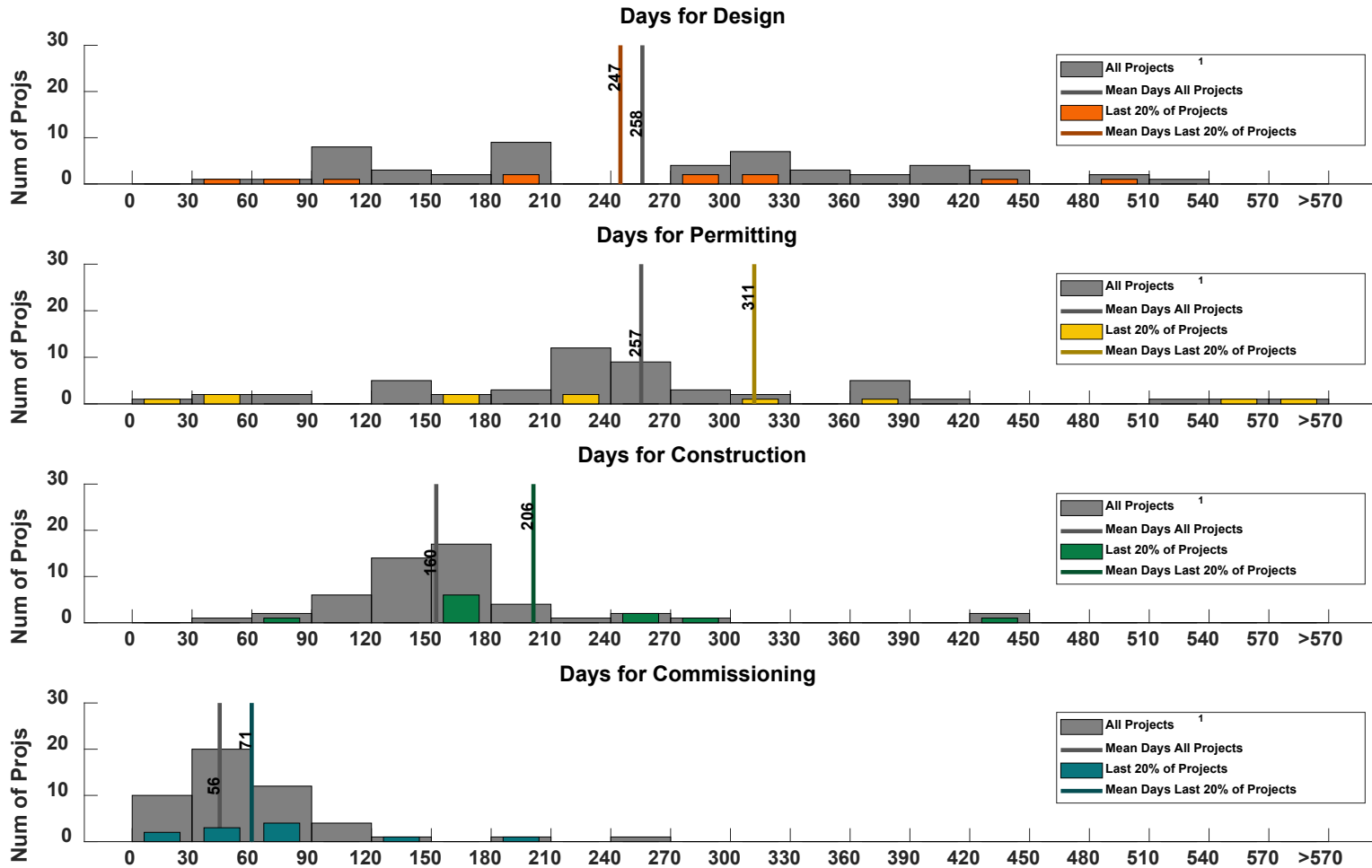
Hydrogen Stations by Type





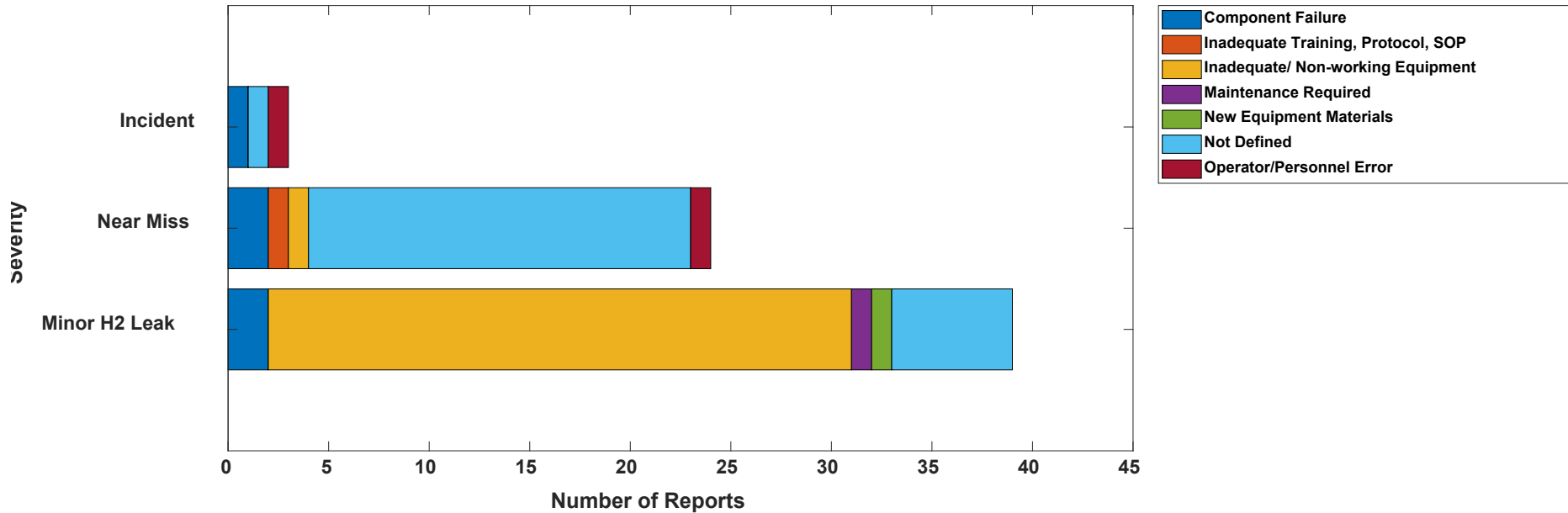
Hydrogen Station Timeline Trend - Retail Stations

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:

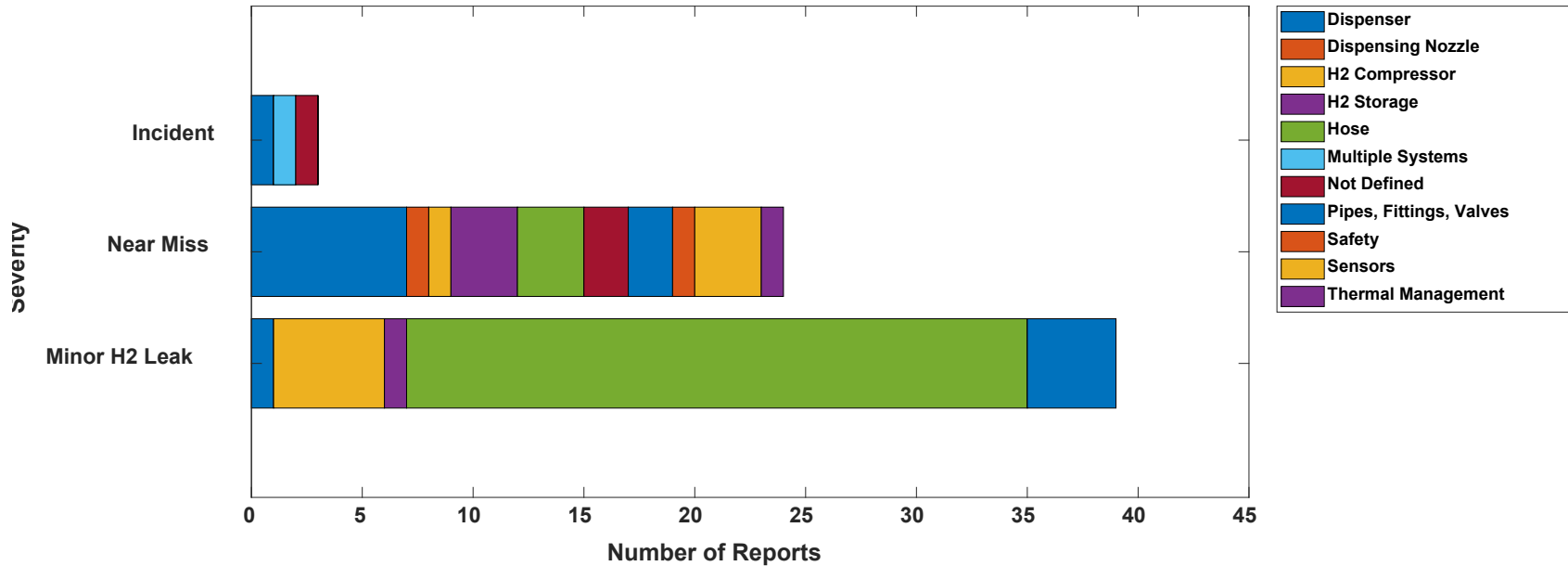
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdpRETAIL_infr_31

Created: Mar-29-22 3:09 PM | Data Range: 2014Q3-2021Q2

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:

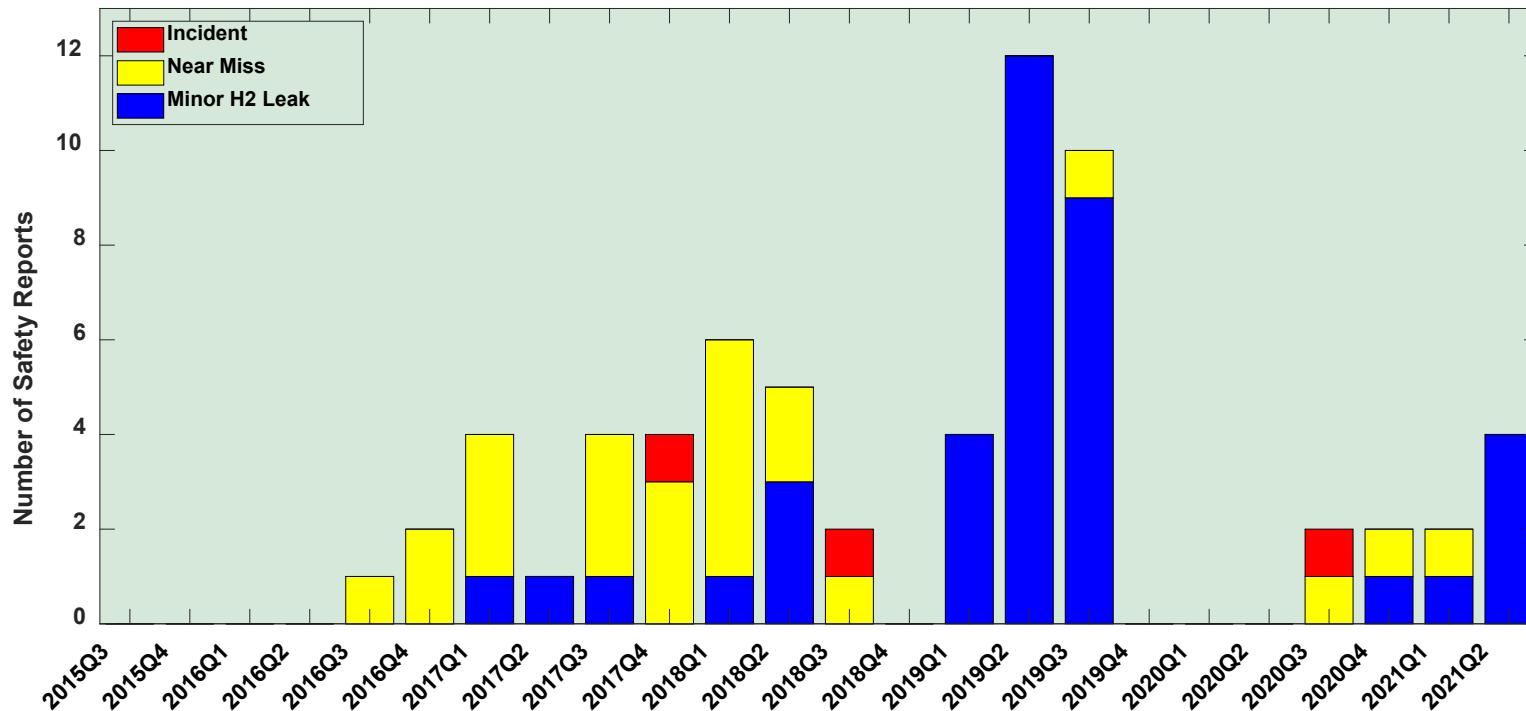
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdpRETAIL_infr_32

Created: Mar-29-22 3:10 PM | Data Range: 2014Q3-2021Q2

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:

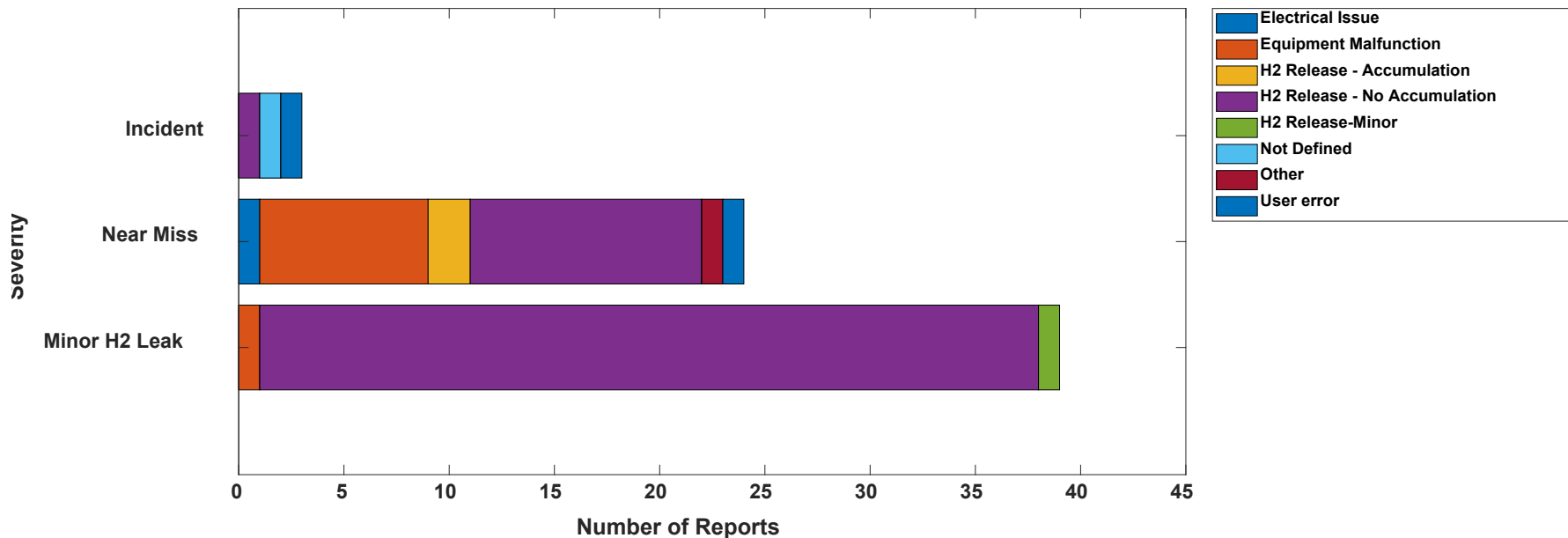
- an event that under slightly different circumstances could have become an incident
- any hydrogen release sufficient to sustain a flame if ignited

A Minor H2 Leak is:

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



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:

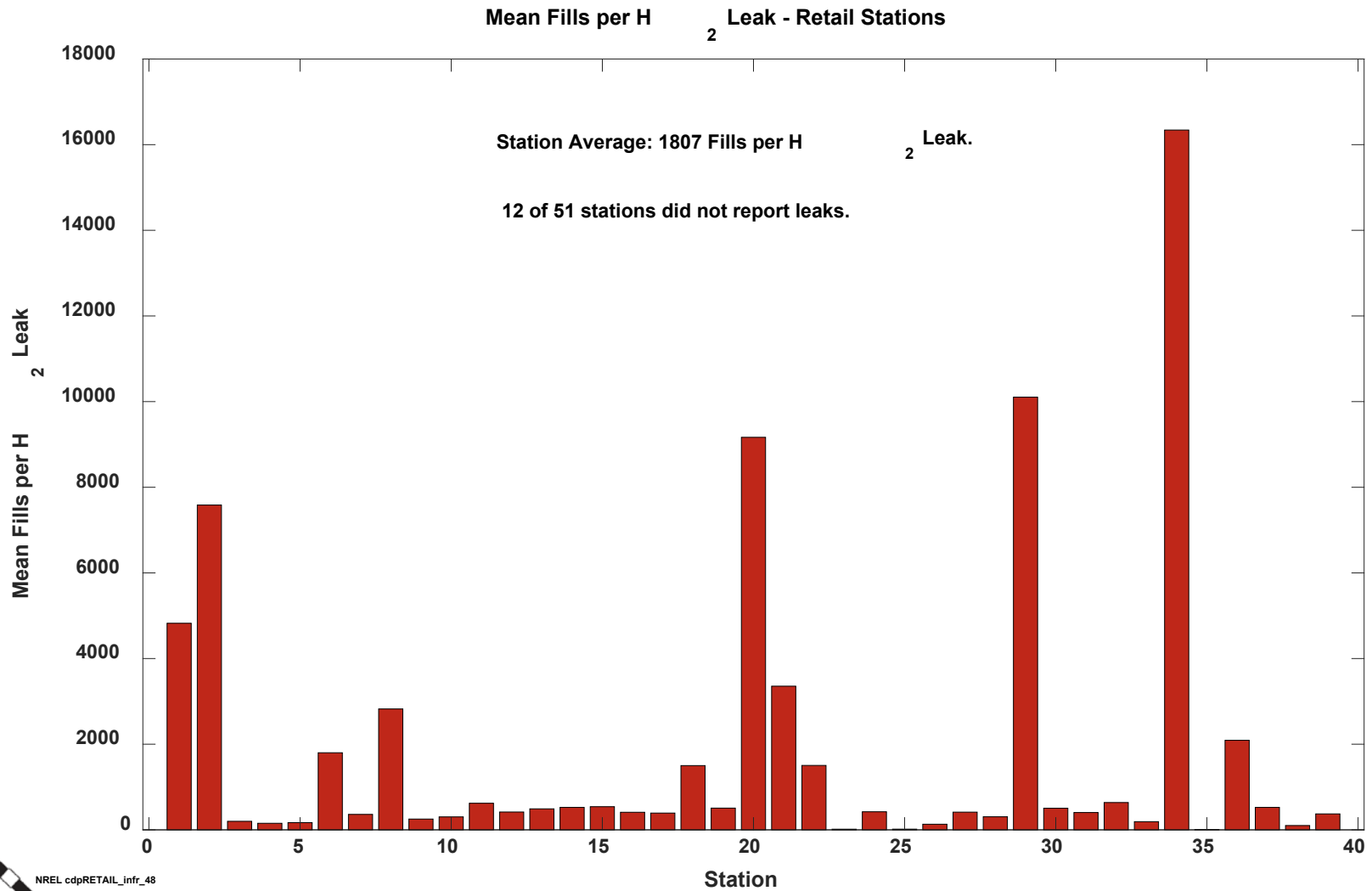
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdpRETAIL_infr_34

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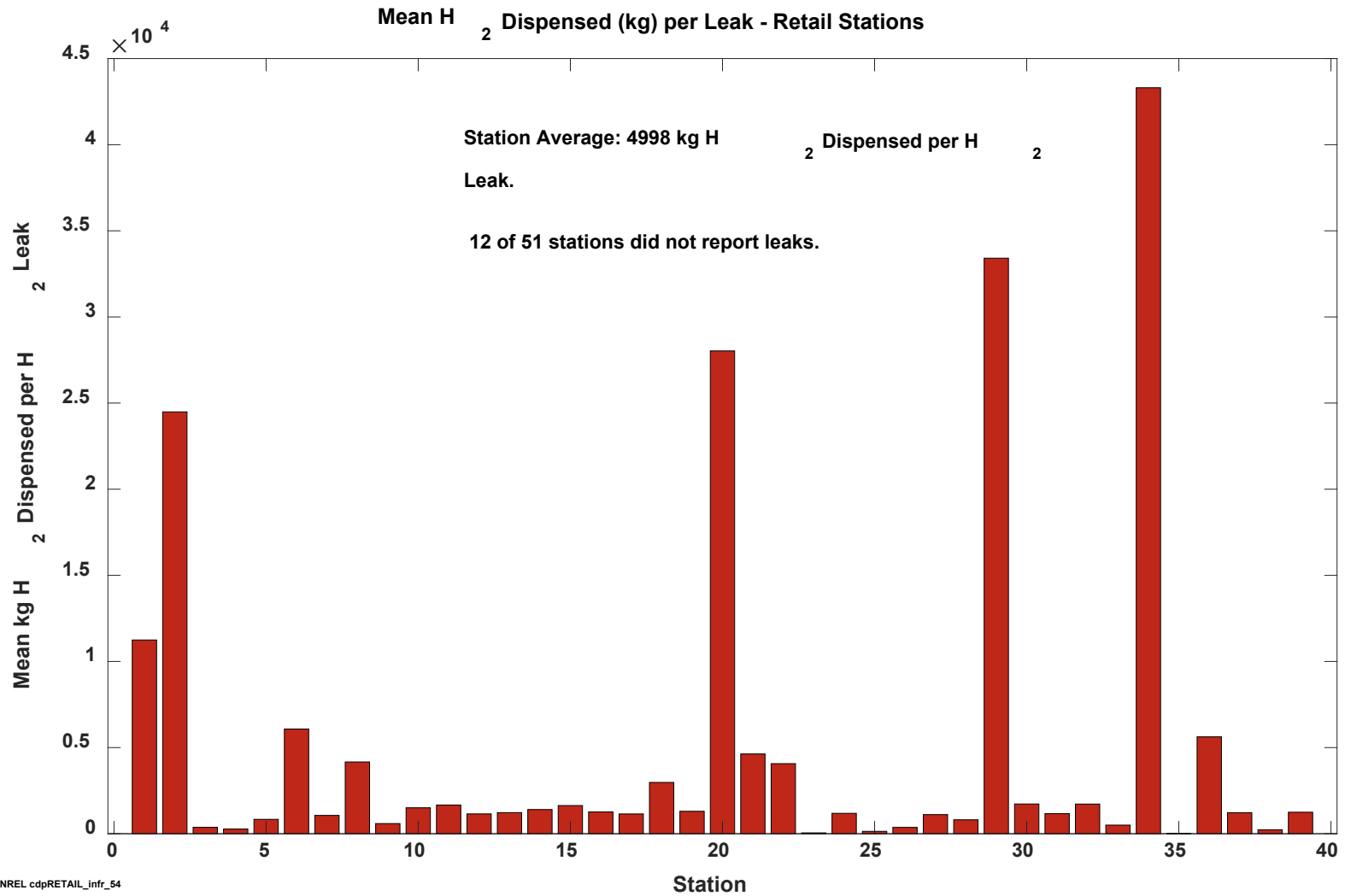
Mean Fills per Hydrogen Leak




NREL cdpRETAIL_infr_48

Created: Apr-14-22 10:14 AM | Data Range: 2014Q3-2021Q2

Mean Hydrogen Dispensed per Hydrogen Leak

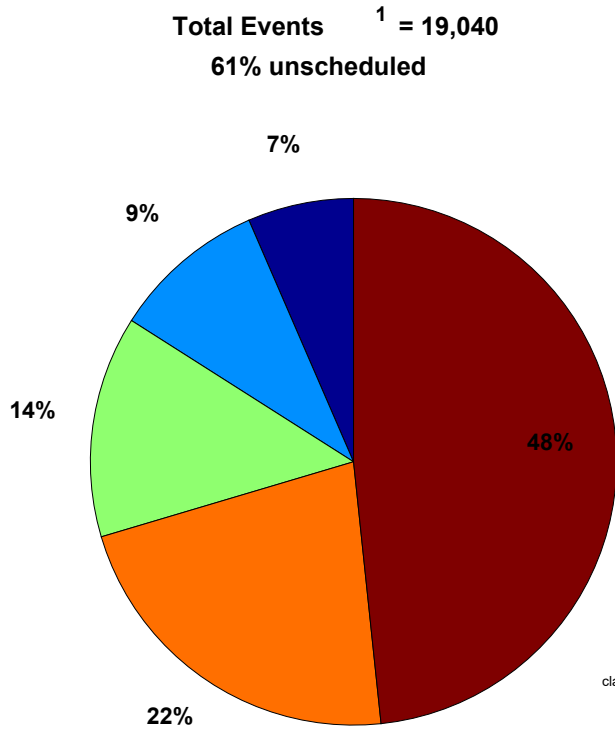


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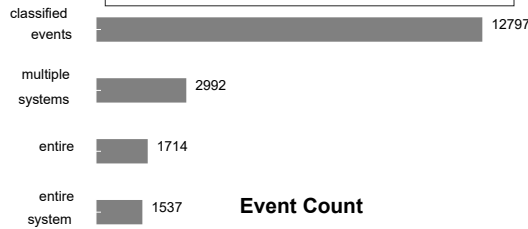
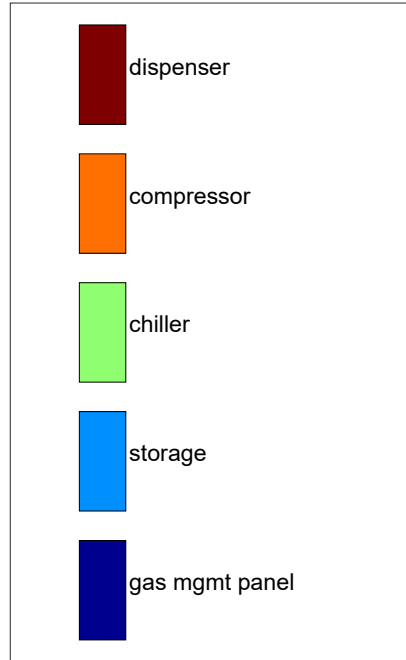
Maintenance and Reliability

Maintenance by Known Equipment Type - Retail Stations

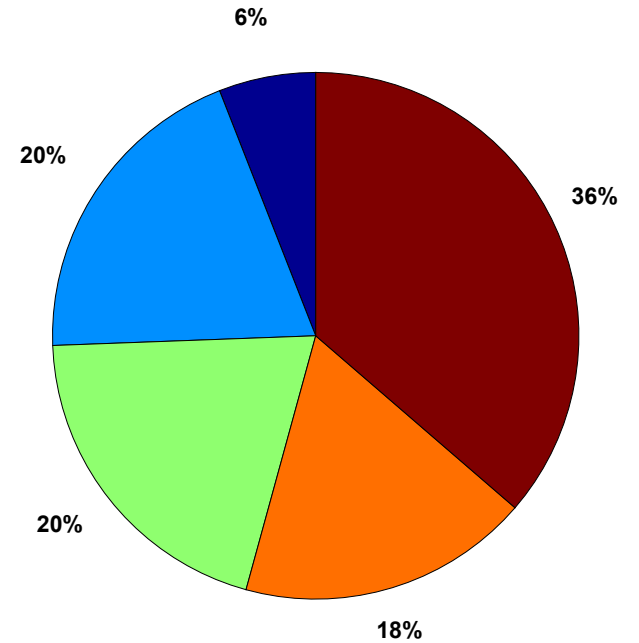
2



Classified Events



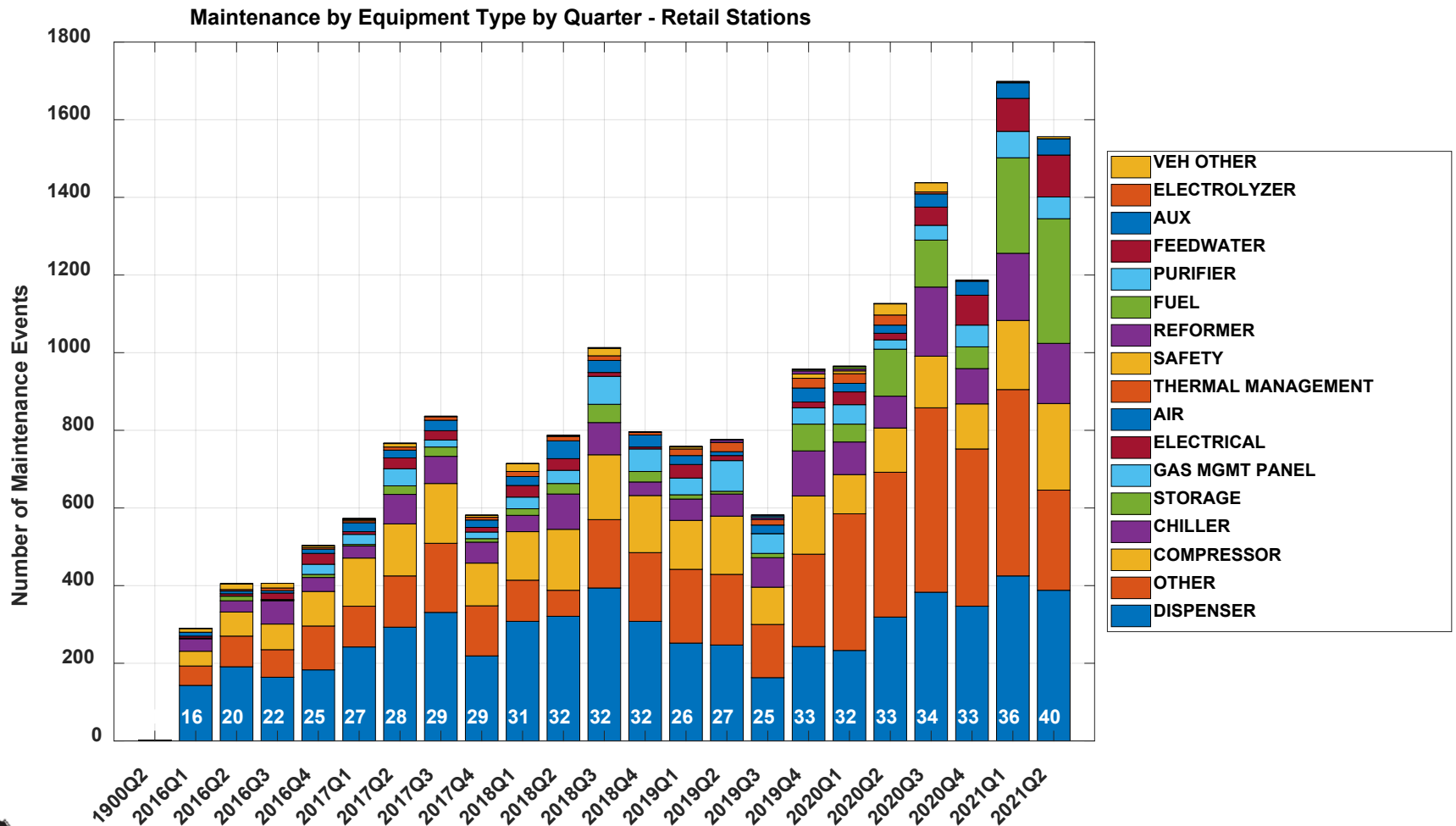
Total Hours ¹ = 51,960
64% unscheduled



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

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

Maintenance by Equipment Type by Quarter

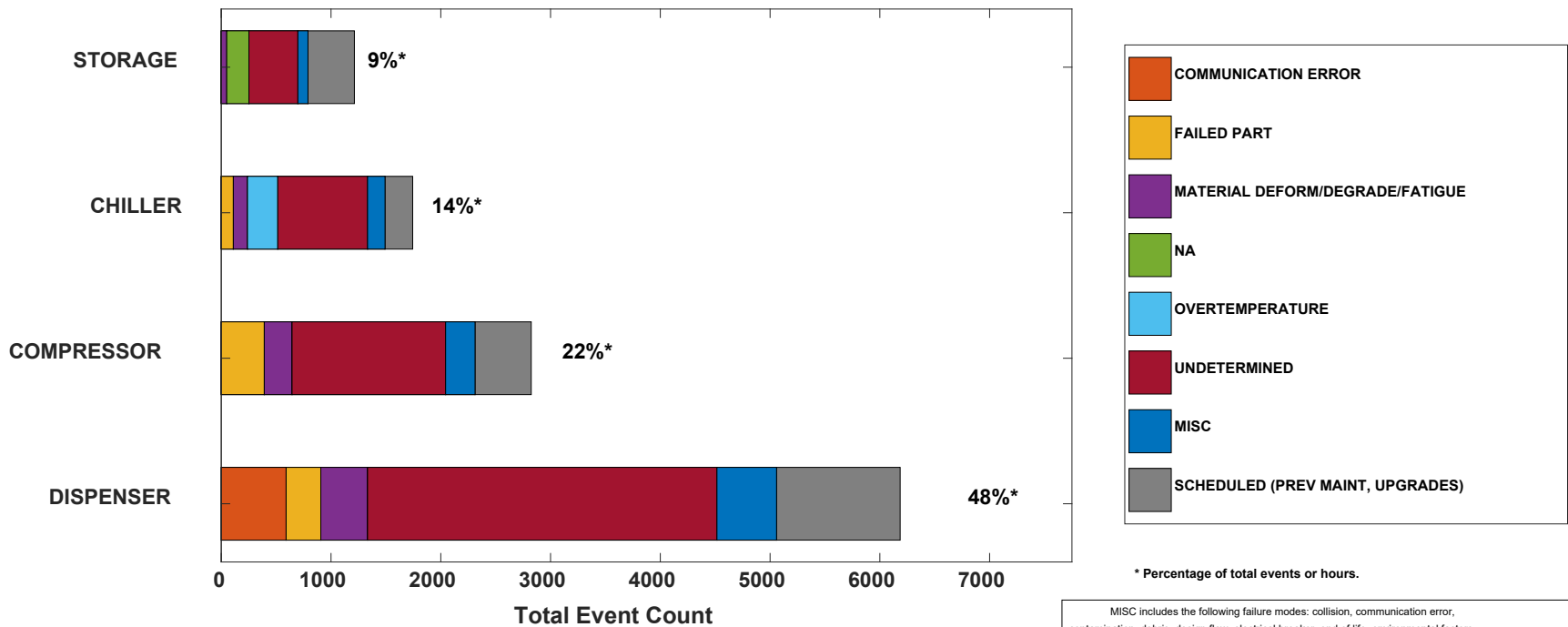


NREL cdpRETAIL_infr_94
 Created: Mar-28-22 5:21 PM | Data Range: 2014Q3-2021Q2

Number at bottom of bars is number of stations reporting for that quarter.

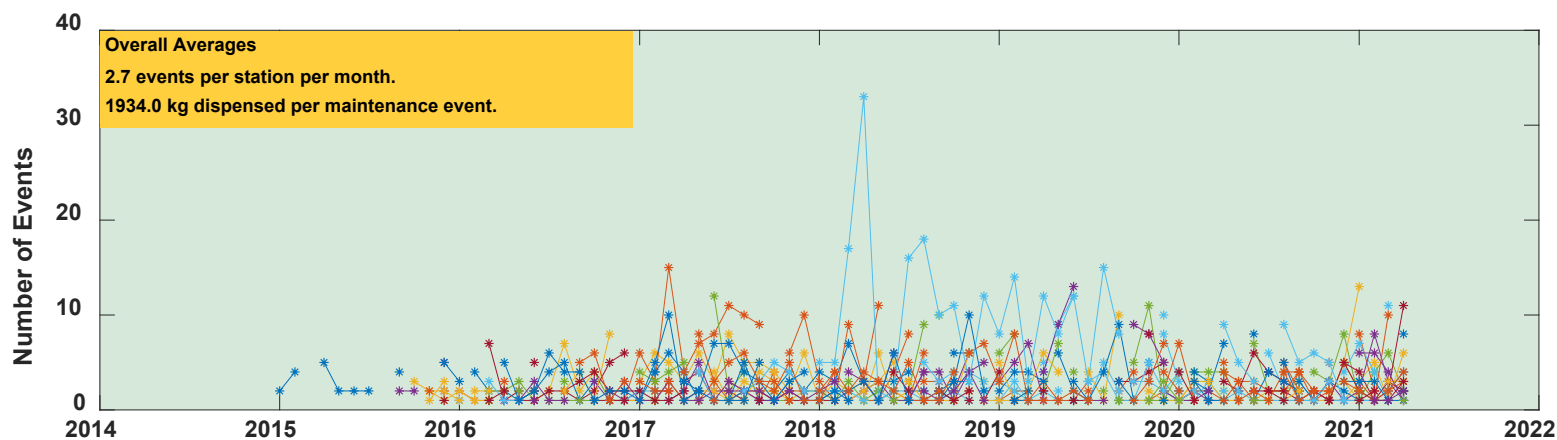
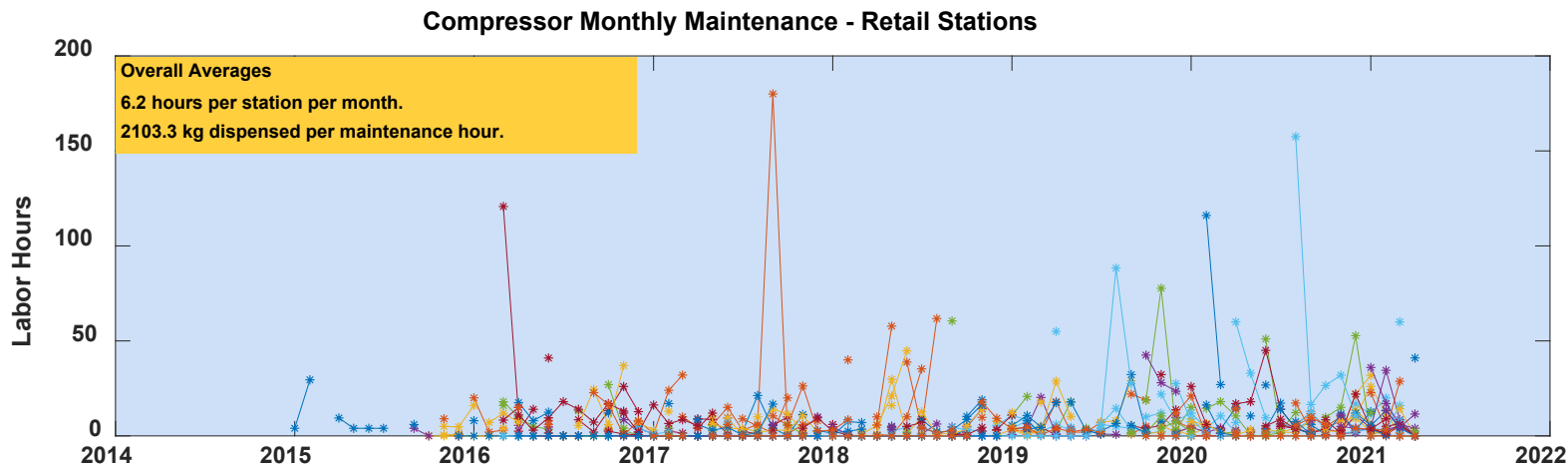
"OTHER" includes items for which equipment type could not be determined from the data.

Failure Modes for Top Equipment Categories - Retail Stations



NREL cdpRETAIL_infr_24

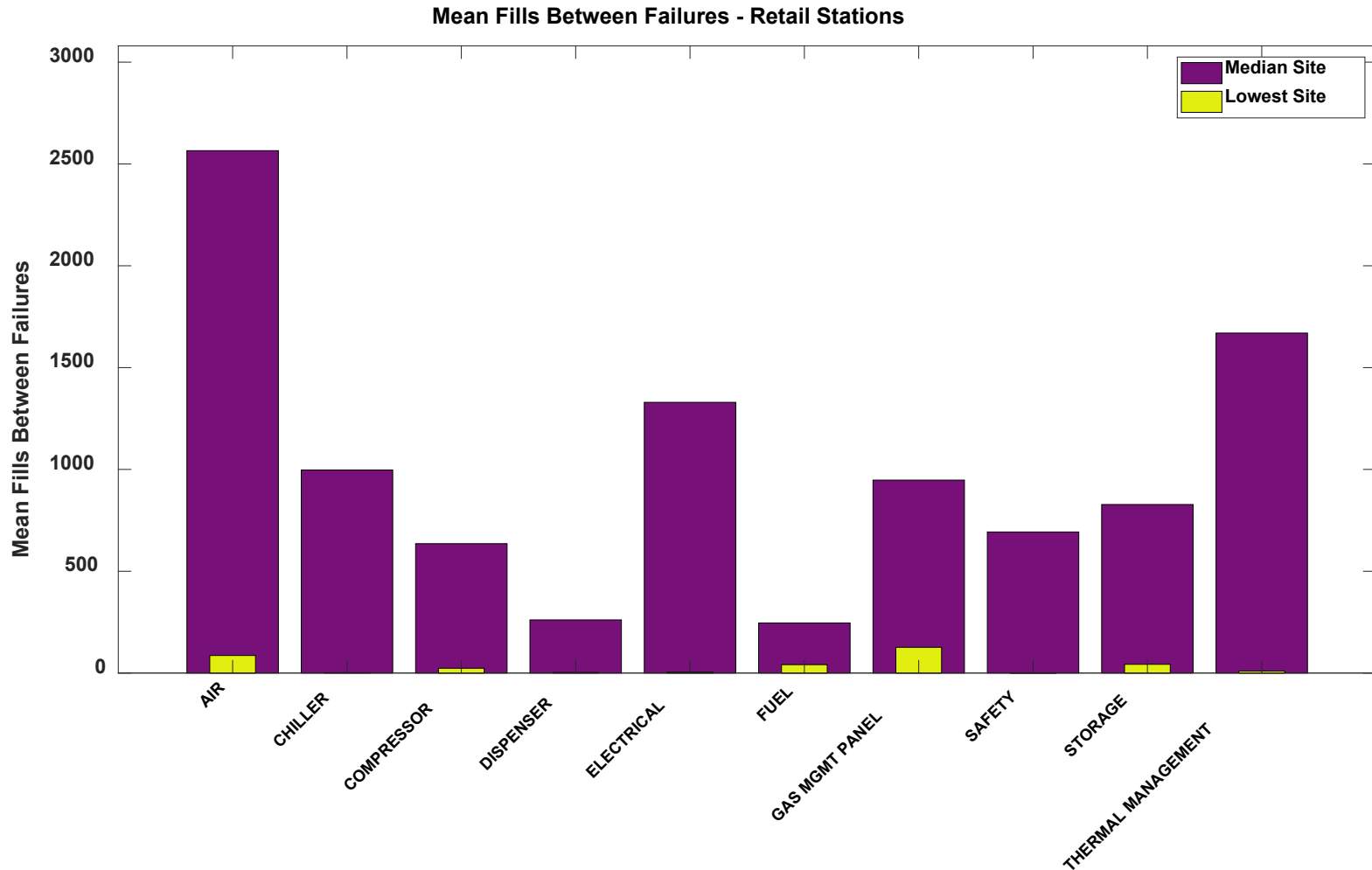
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NREL cdpRETAIL_infr_26

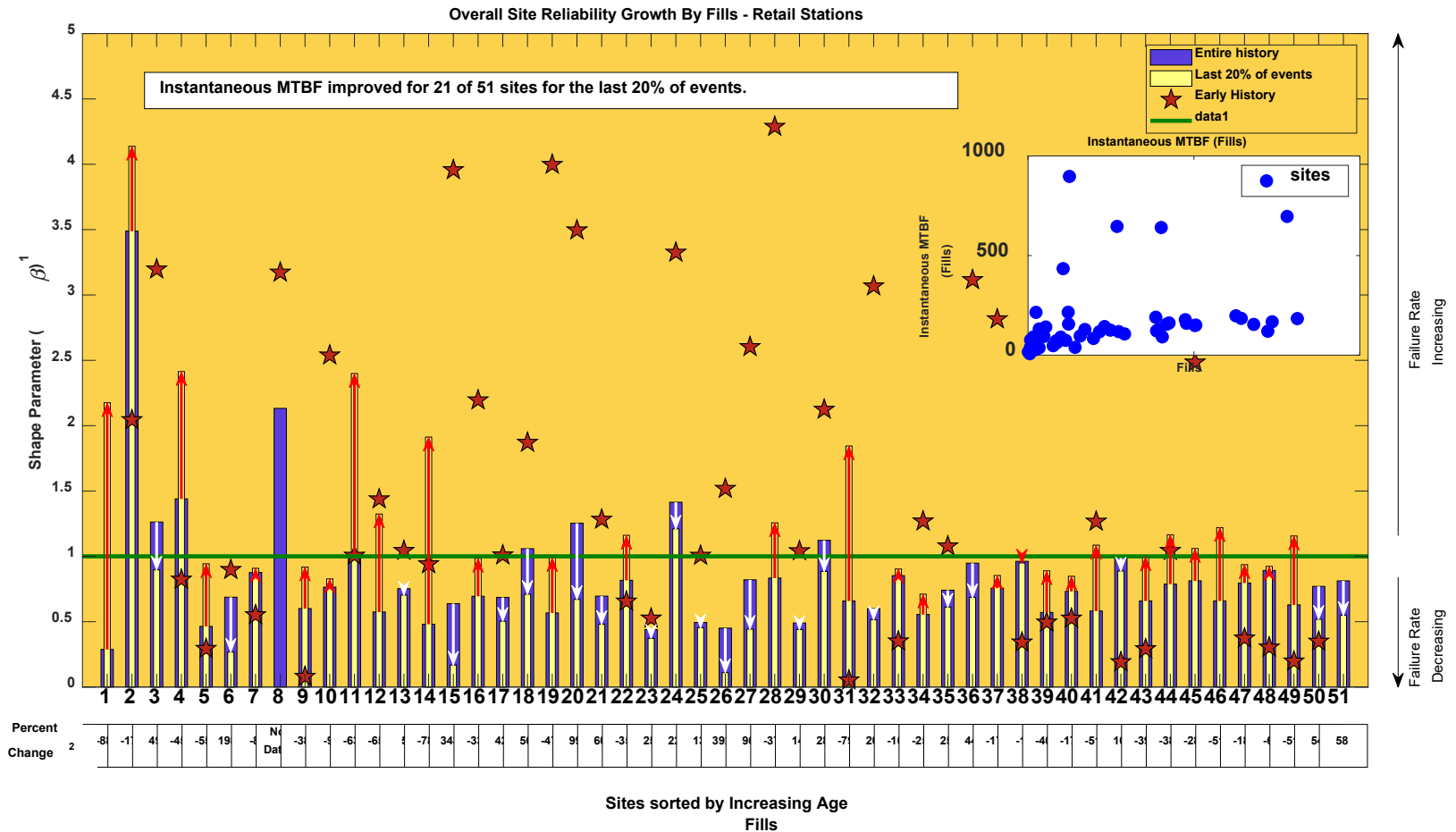
Created: Mar-29-22 2:44 PM | Data Range: 2014Q3-2021Q2

* 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.



NREL cdpRETAIL_infr_49

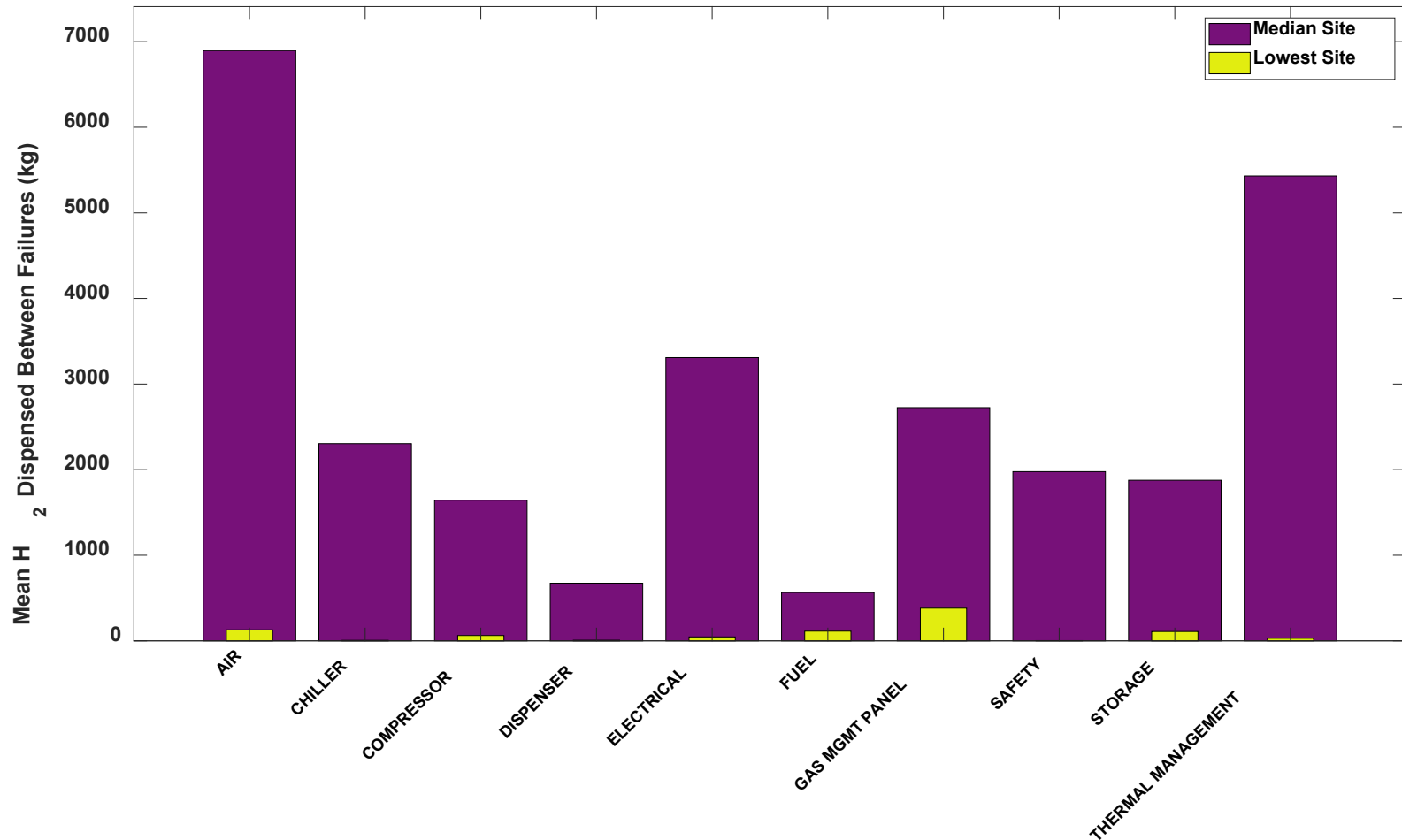
Created: Apr-14-22 10:07 AM | Data Range: 2014Q3-2021Q2



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

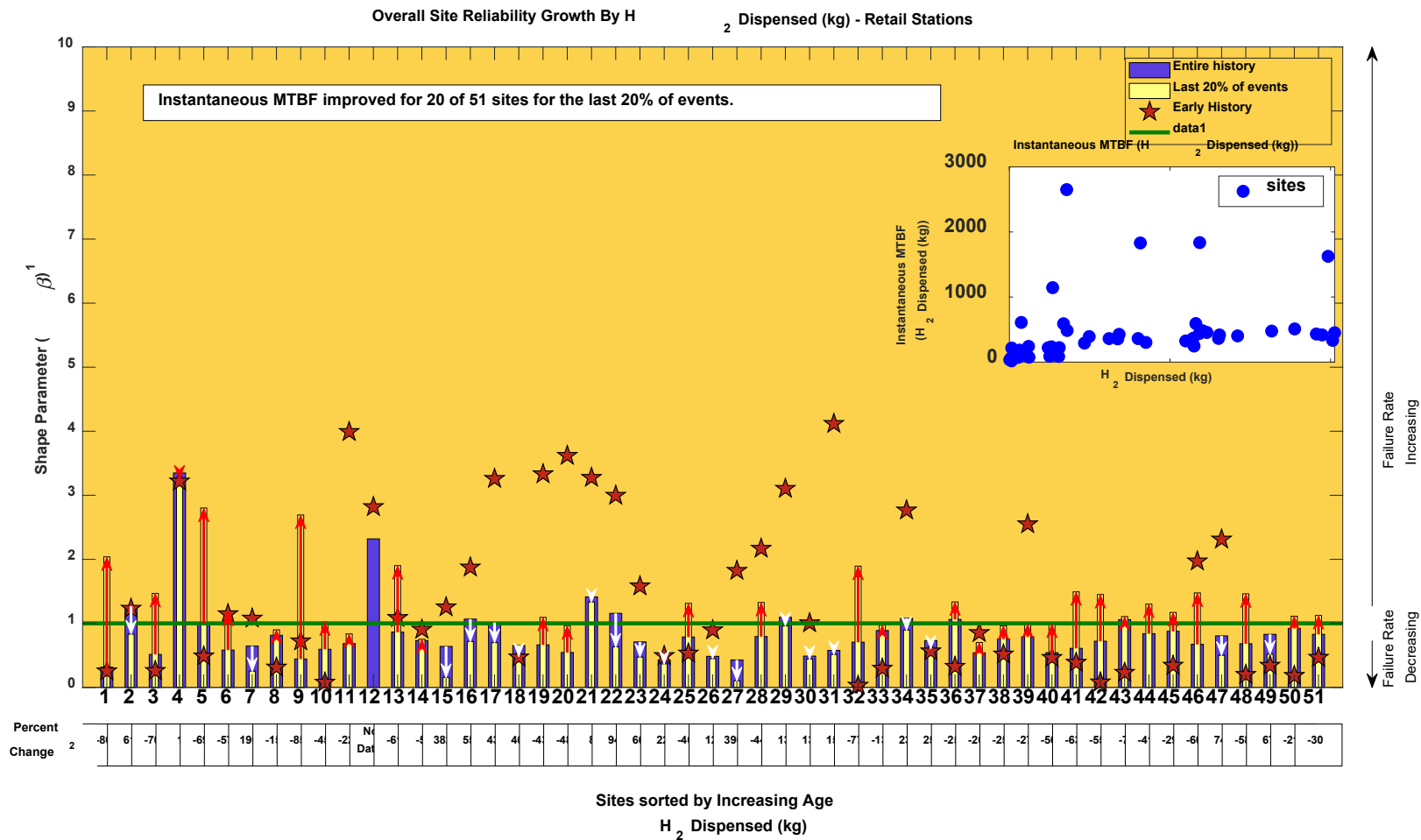
Mean Amount Dispensed Between Failures

Mean H₂ Dispensed Between Failures (kg) - Retail Stations



NREL cdpRETAIL_infr_51

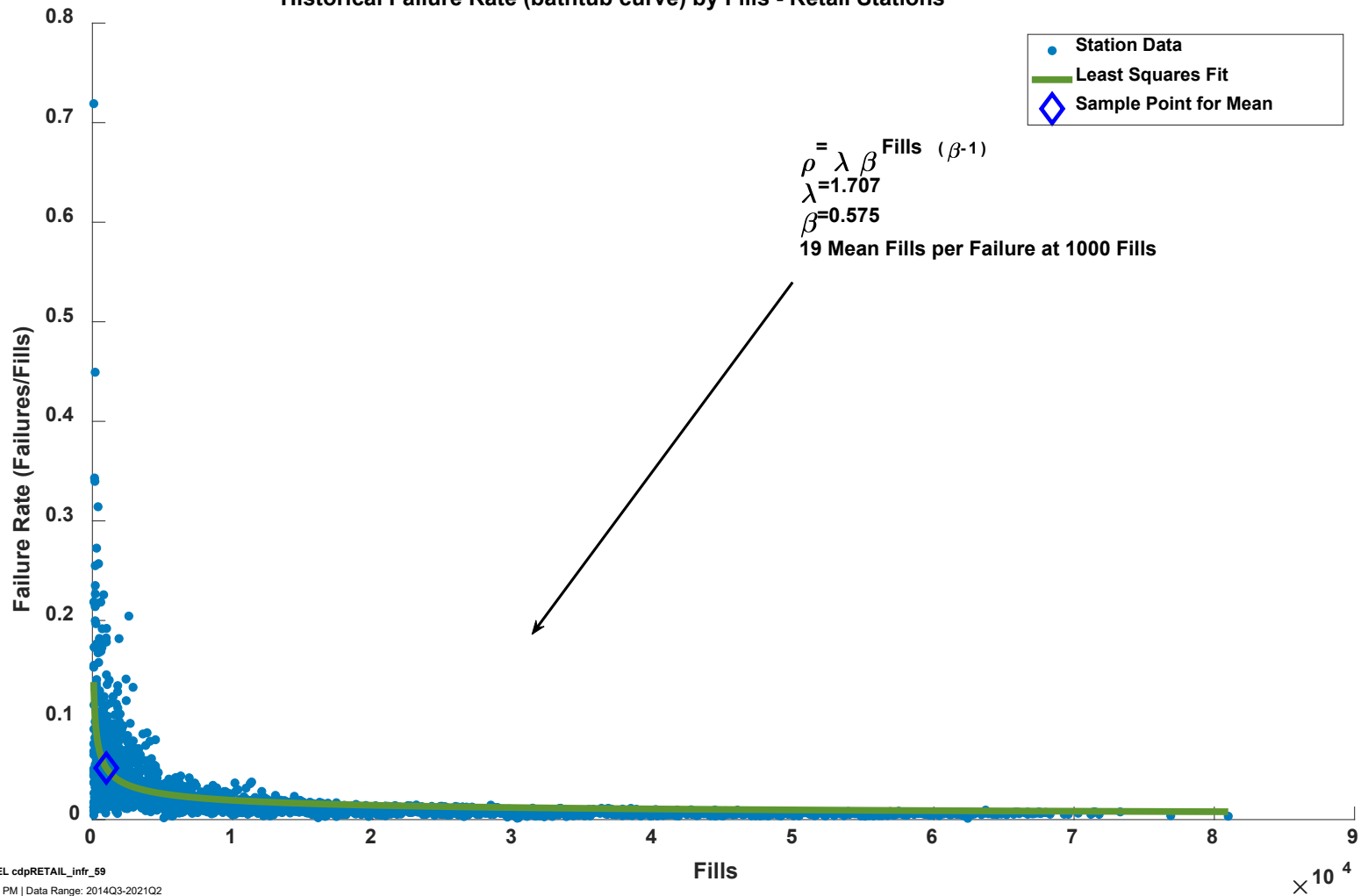
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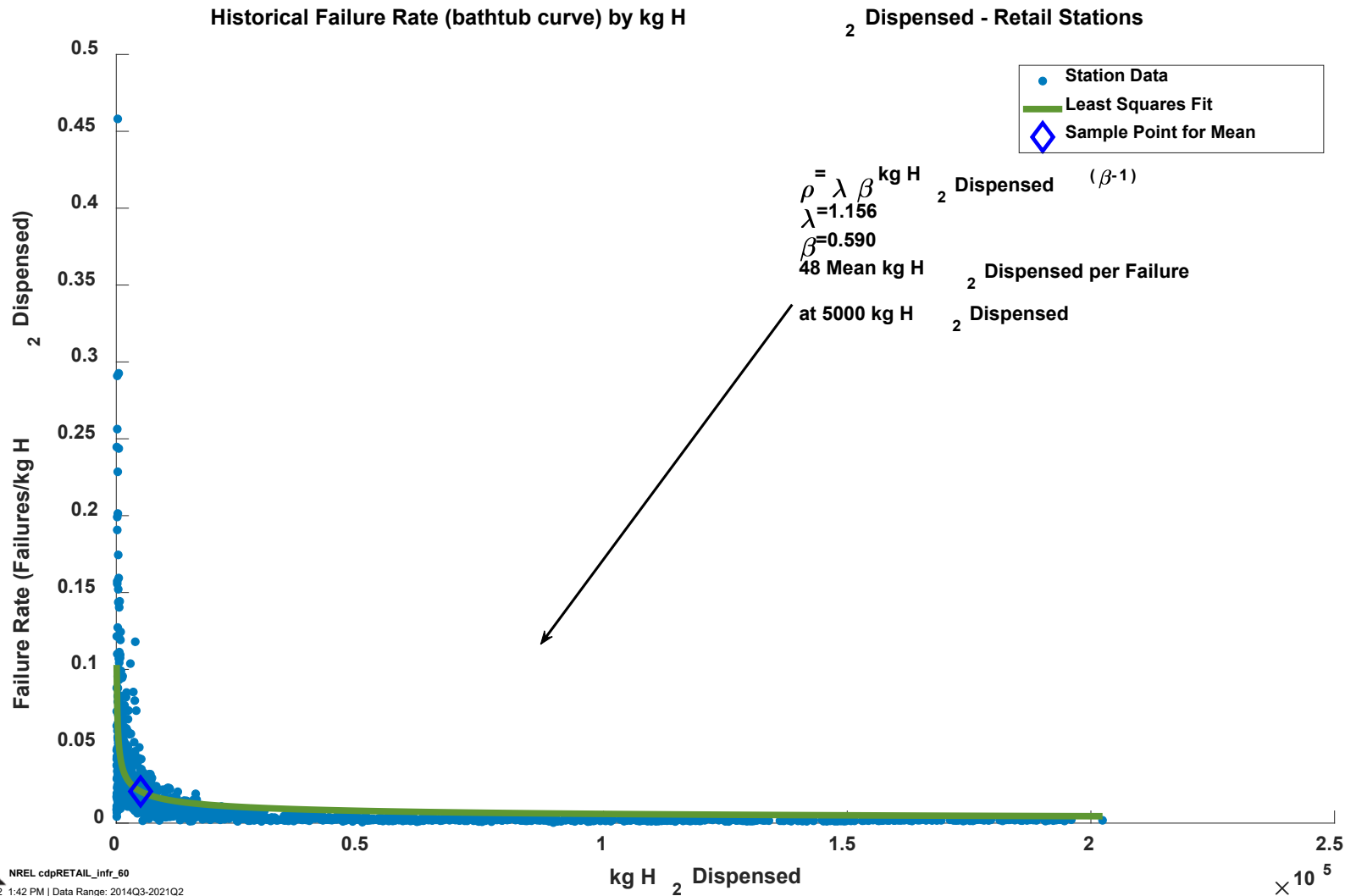
1. IEC 61164:2004(E), Reliability Growth - Statistical Test and Evaluation Methods, IEC. 2004.

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

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



Historical Failure Rate by Amount Dispensed

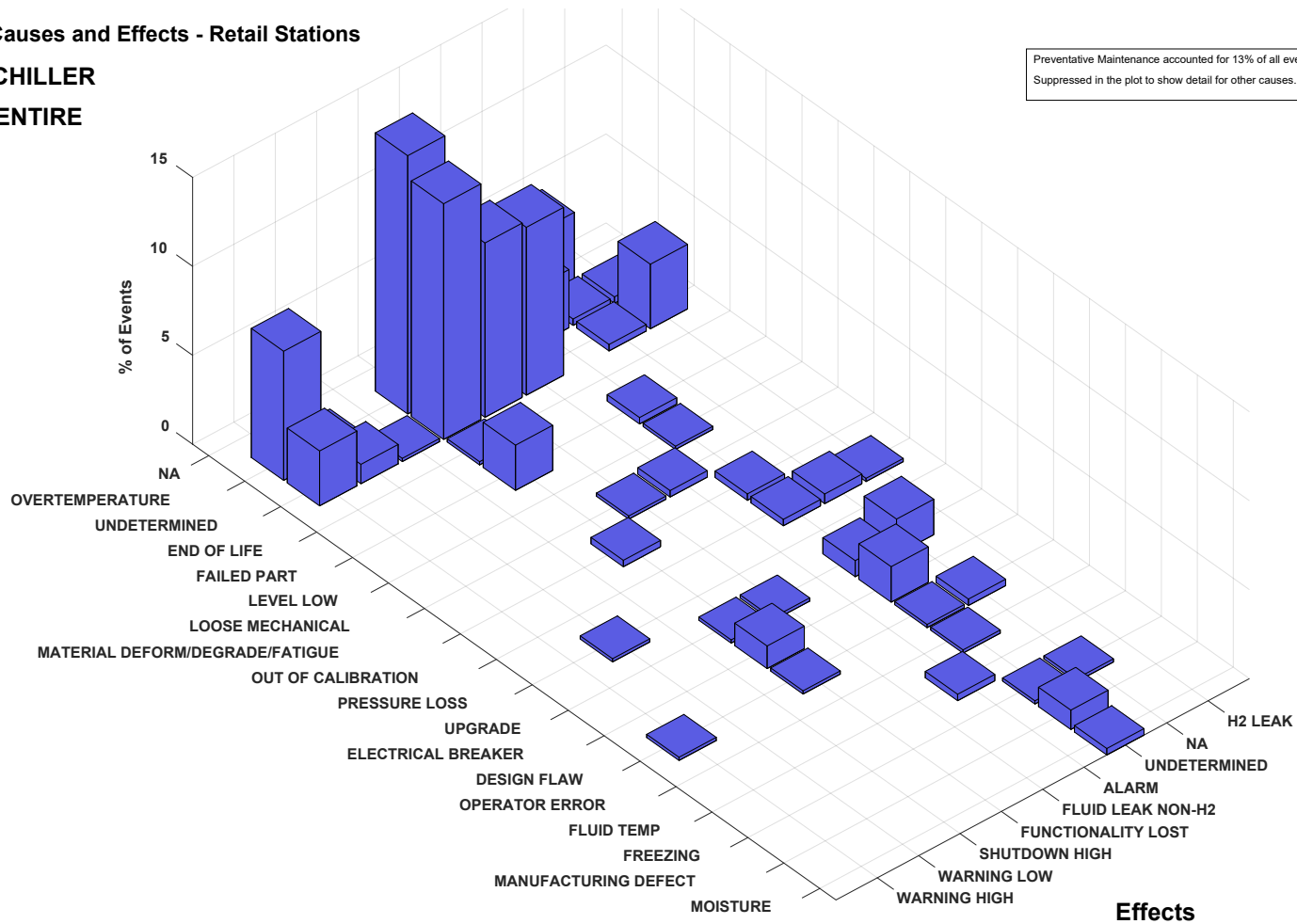


Maintenance Causes and Effects - Retail Stations

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: Apr-14-22 1:36 PM | Data Range: 2014Q3-2021Q2

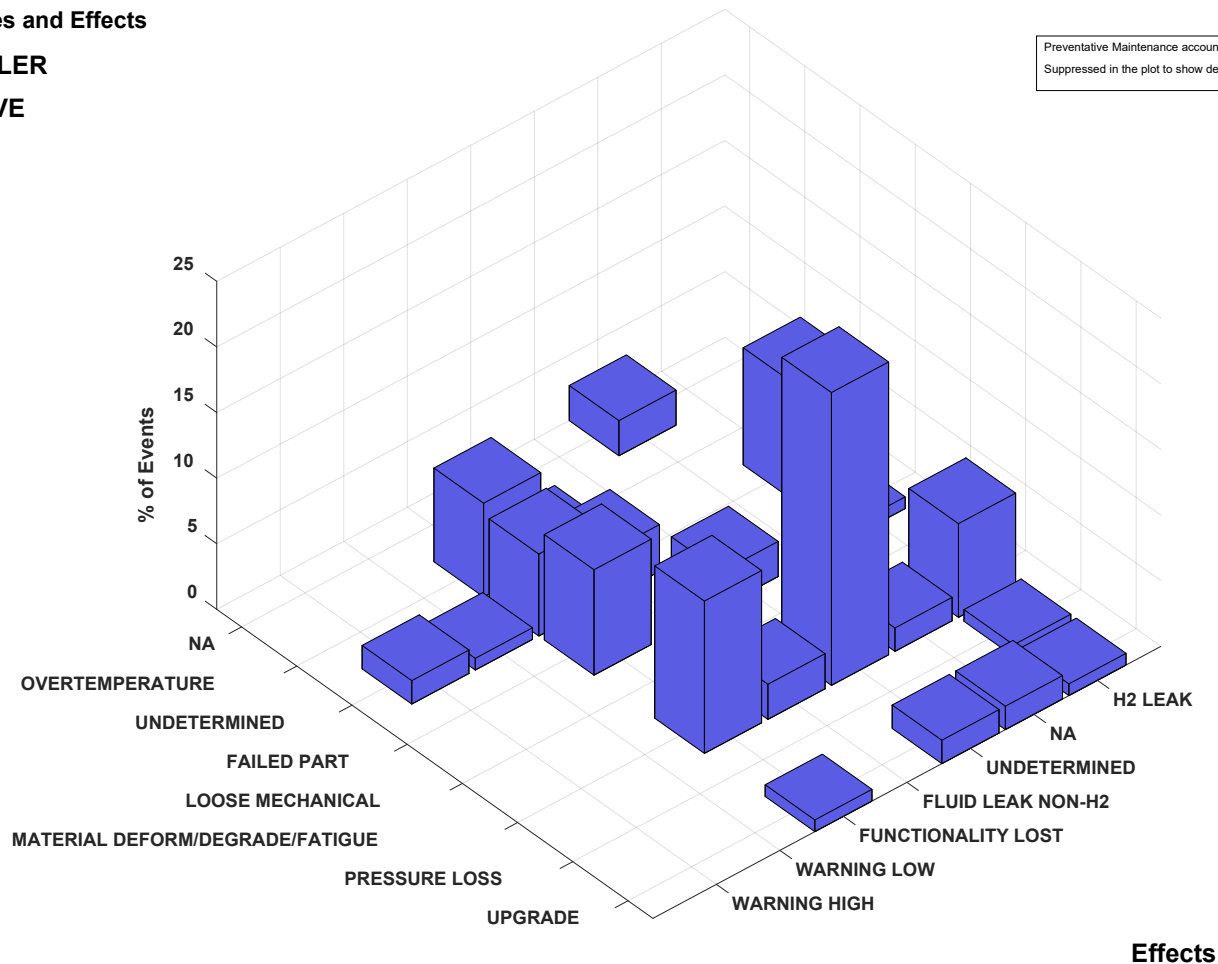
Maintenance Causes and Effects: Chiller (Refrigerant)

Maintenance Causes and Effects

Subsystem: CHILLER

Component: VALVE

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



Causes

Effects



NREL cdpRETAIL_infr_66

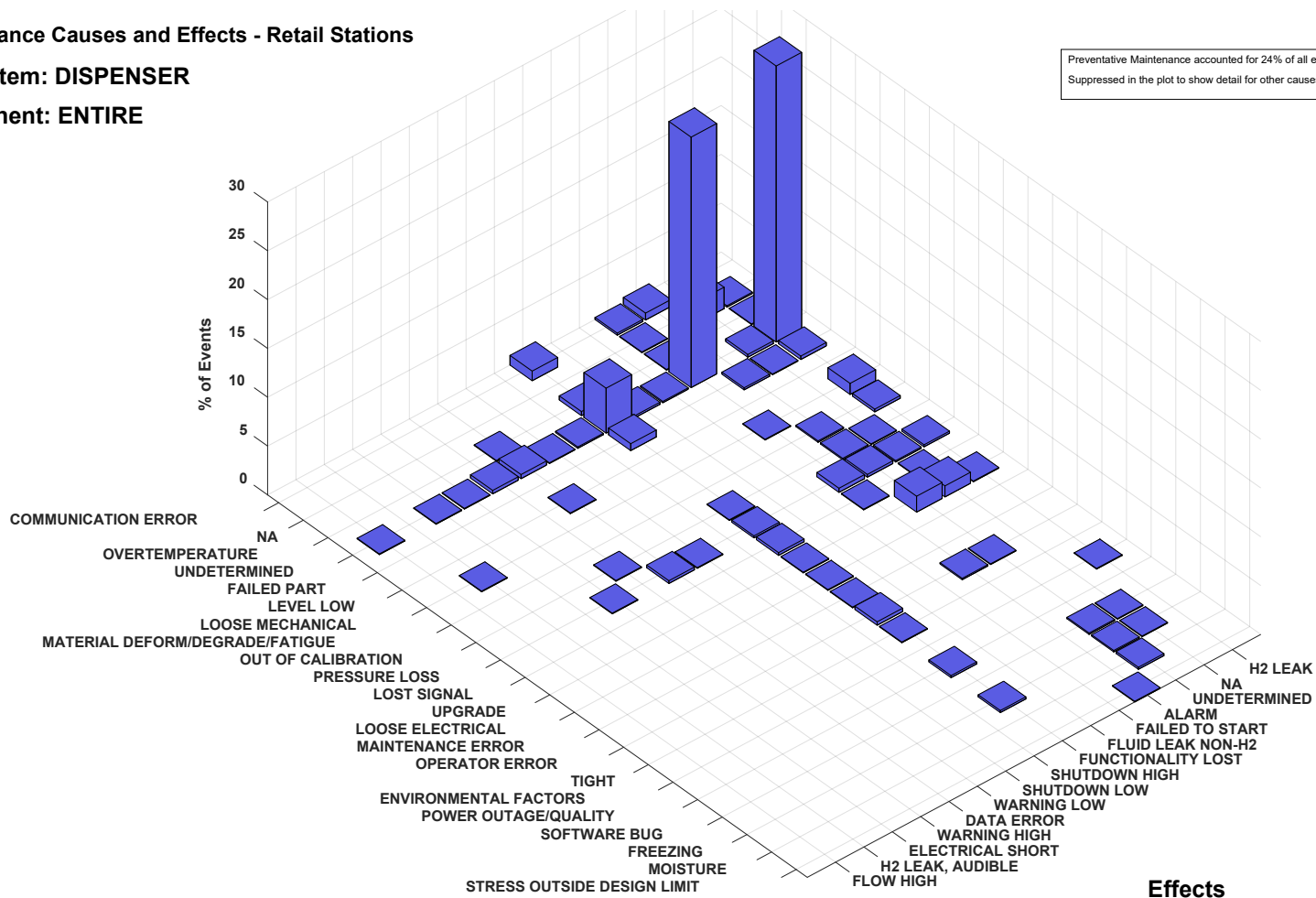
Created: Apr-14-22 1:24 PM | Data Range: 2014Q3-2021Q2

Maintenance Causes and Effects - Retail Stations

Subsystem: DISPENSER

Component: ENTIRE

Preventative Maintenance accounted for 24% of all events.
Suppressed in the plot to show detail for other causes.



Causes

Effects



NREL cdpRETAIL_infr_67

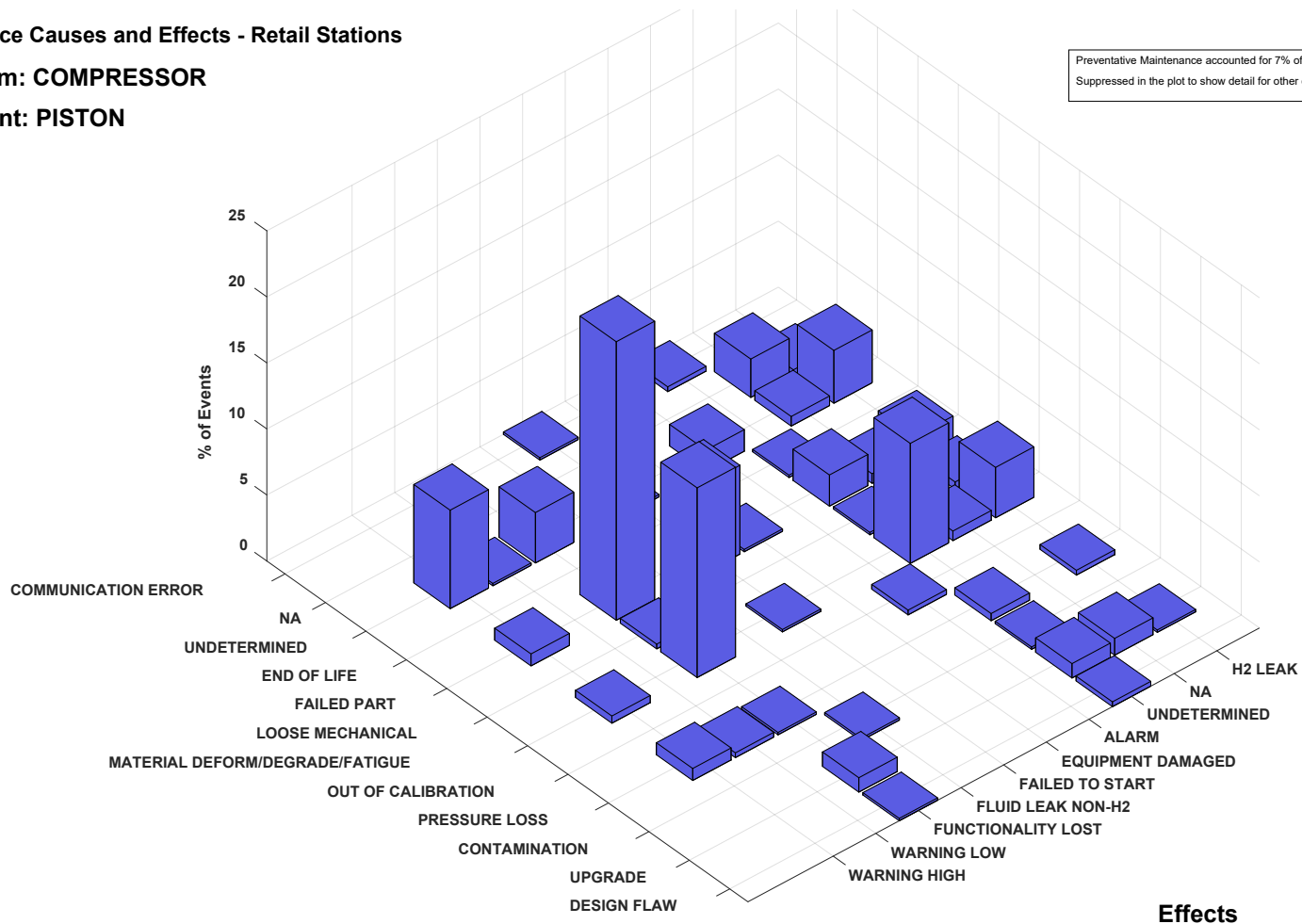
Created: Apr-14-22 1:17 PM | Data Range: 2014Q3-2021Q2

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

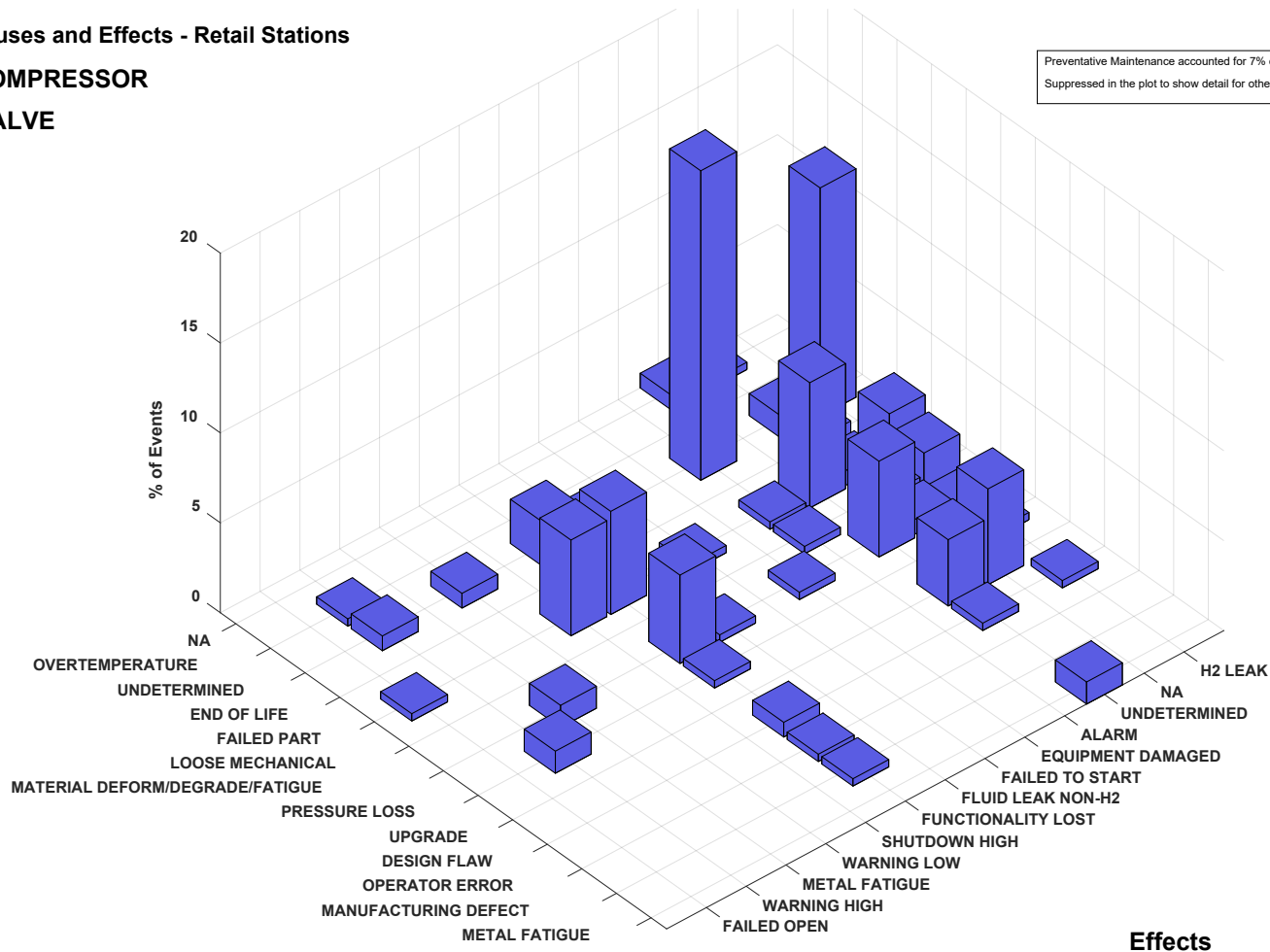
Created: Apr-14-22 12:51 PM | Data Range: 2014Q3-2021Q2

Maintenance Causes and Effects: Compressor (Valve)

Maintenance Causes and Effects - Retail Stations

Subsystem: COMPRESSOR

Component: VALVE



Causes

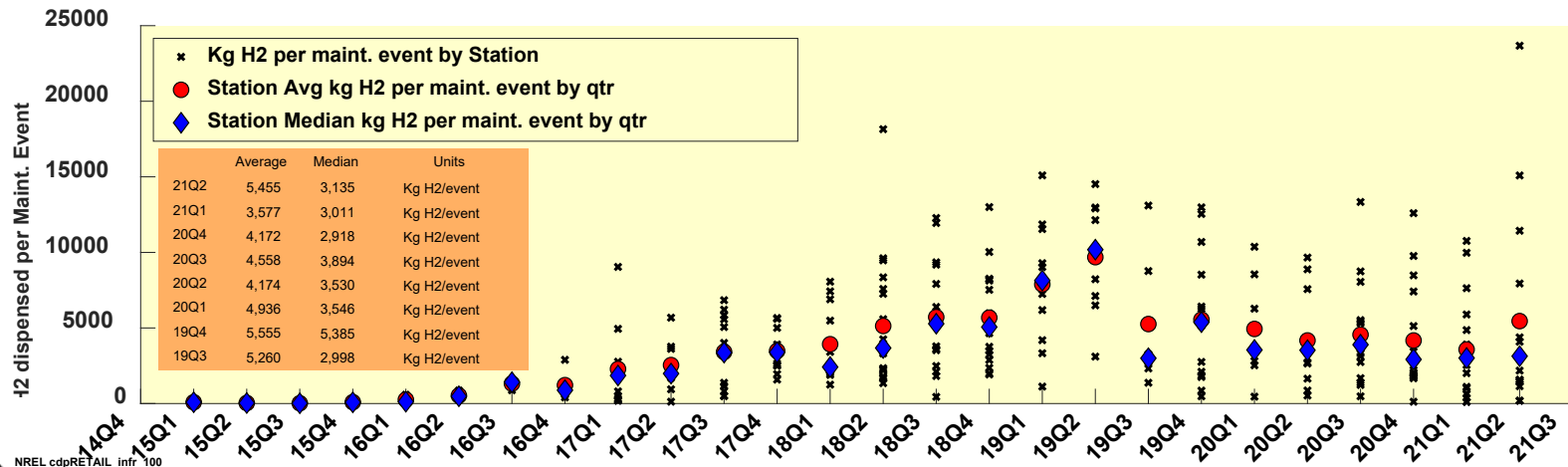
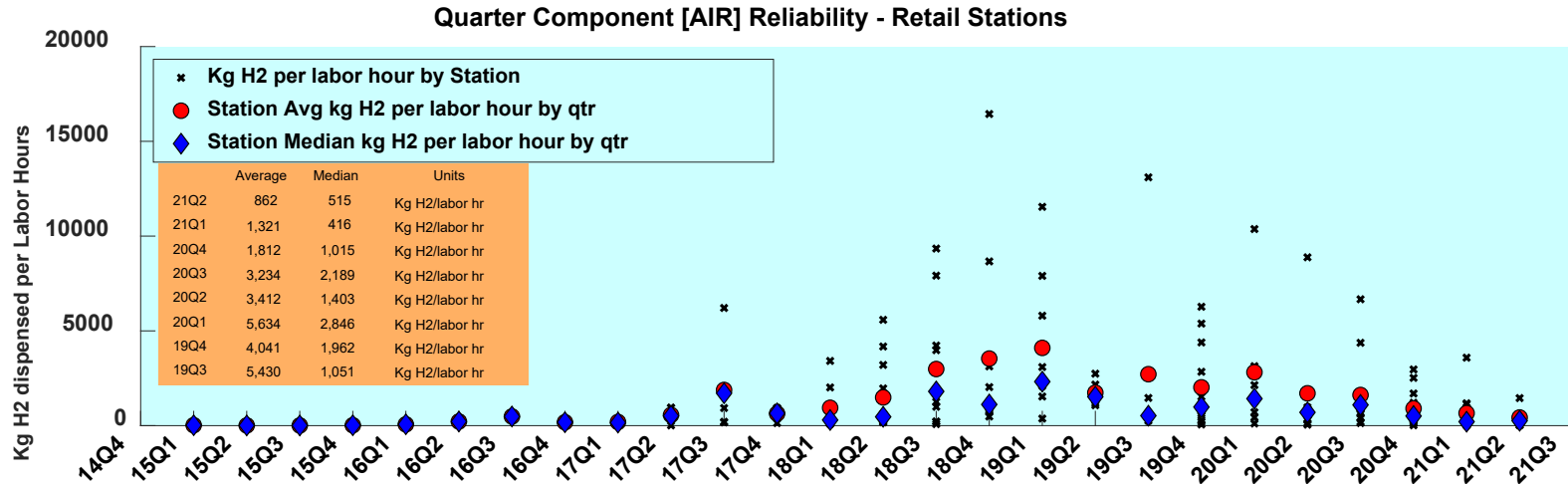
Effects



NREL cdpRETAIL_infr_72

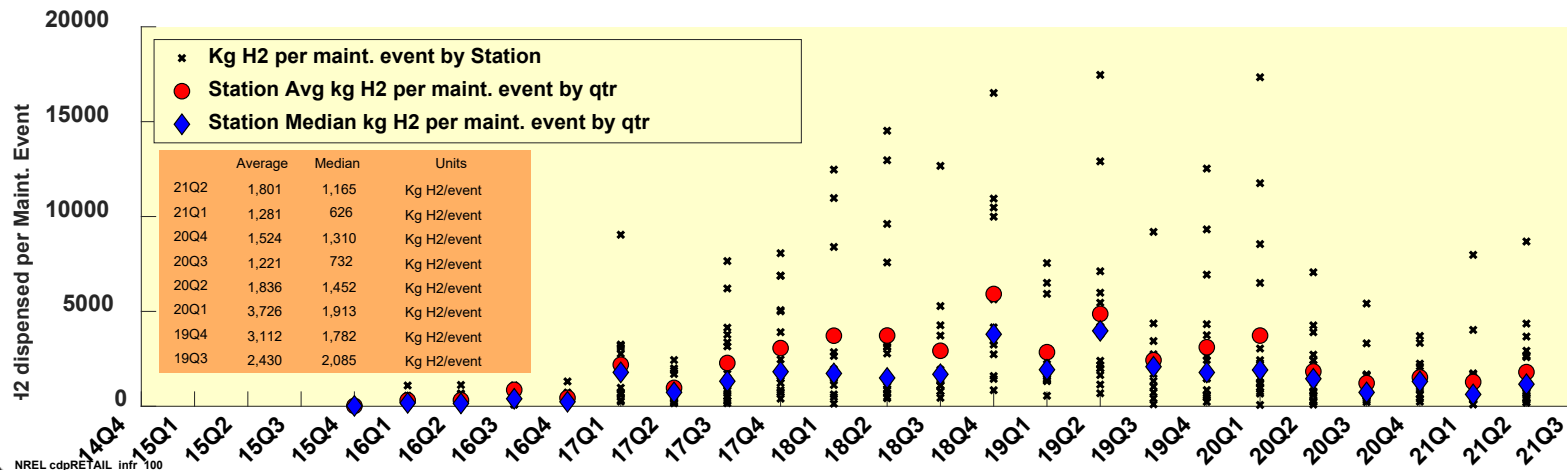
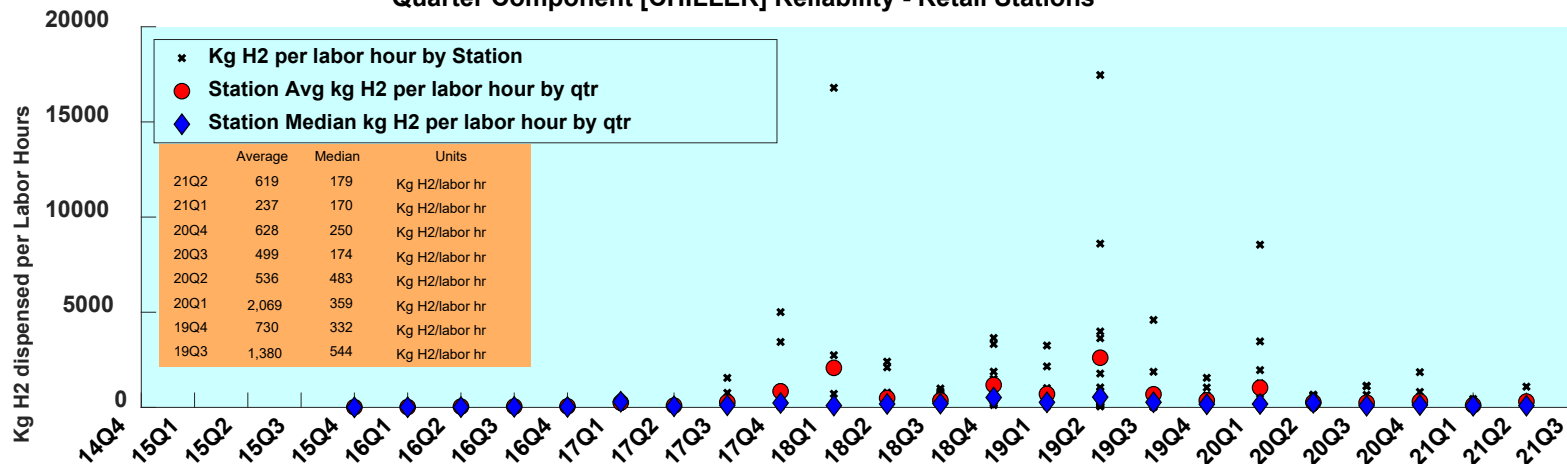
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Quarter Component [AIR] Reliability – Retail Stations

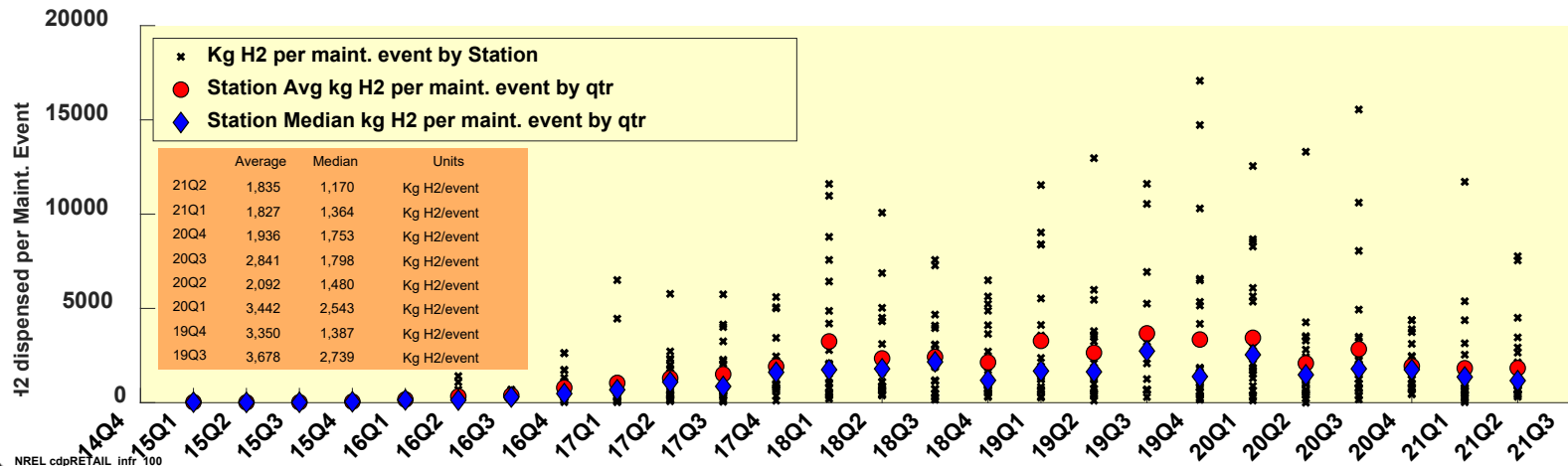
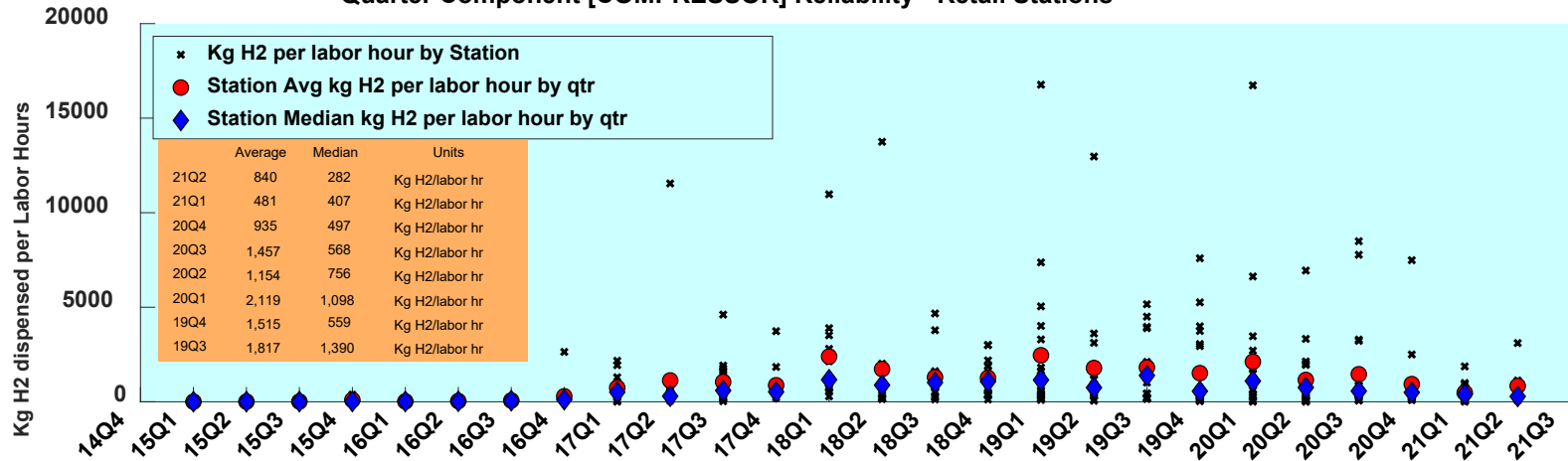


Quarter Component [CHILLER] Reliability – Retail Stations

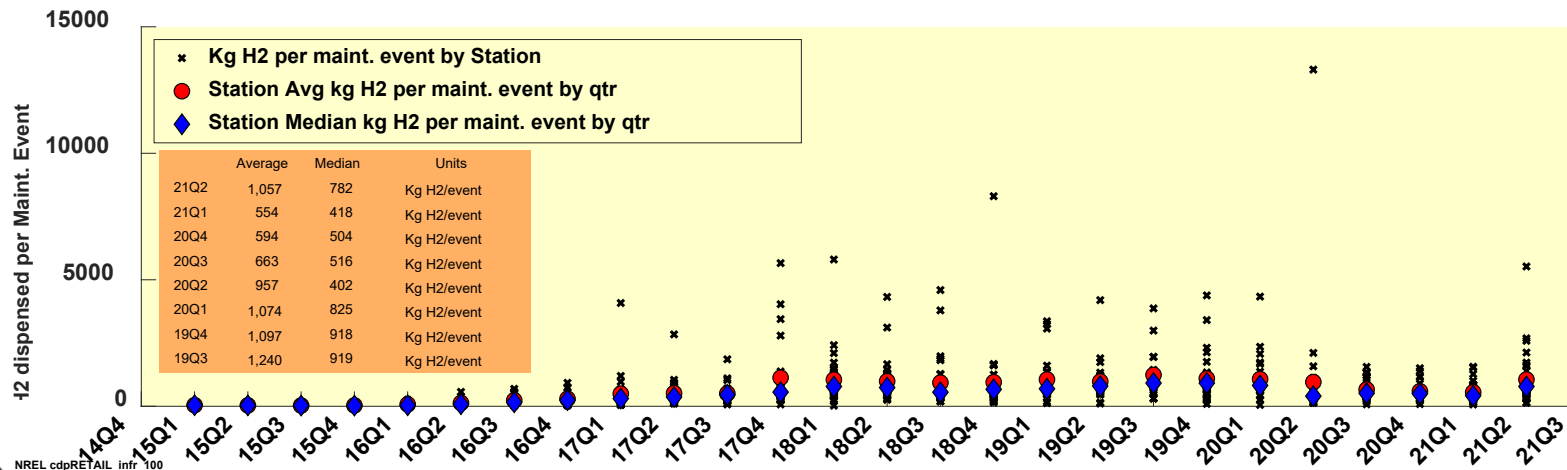
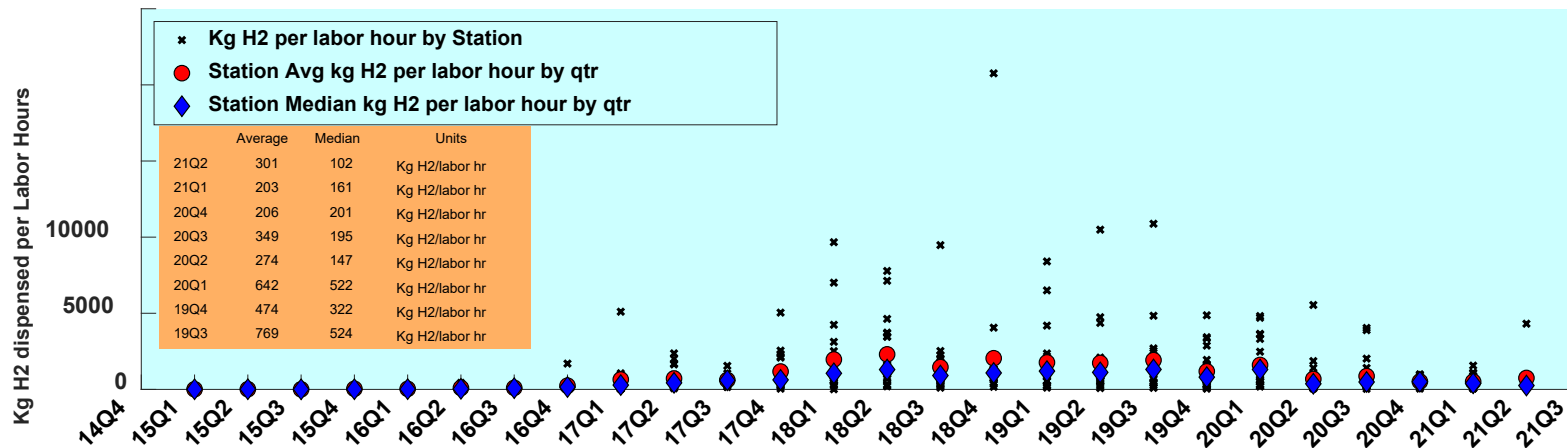
Quarter Component [CHILLER] Reliability - Retail Stations



Quarter Component [COMPRESSOR] Reliability - Retail Stations



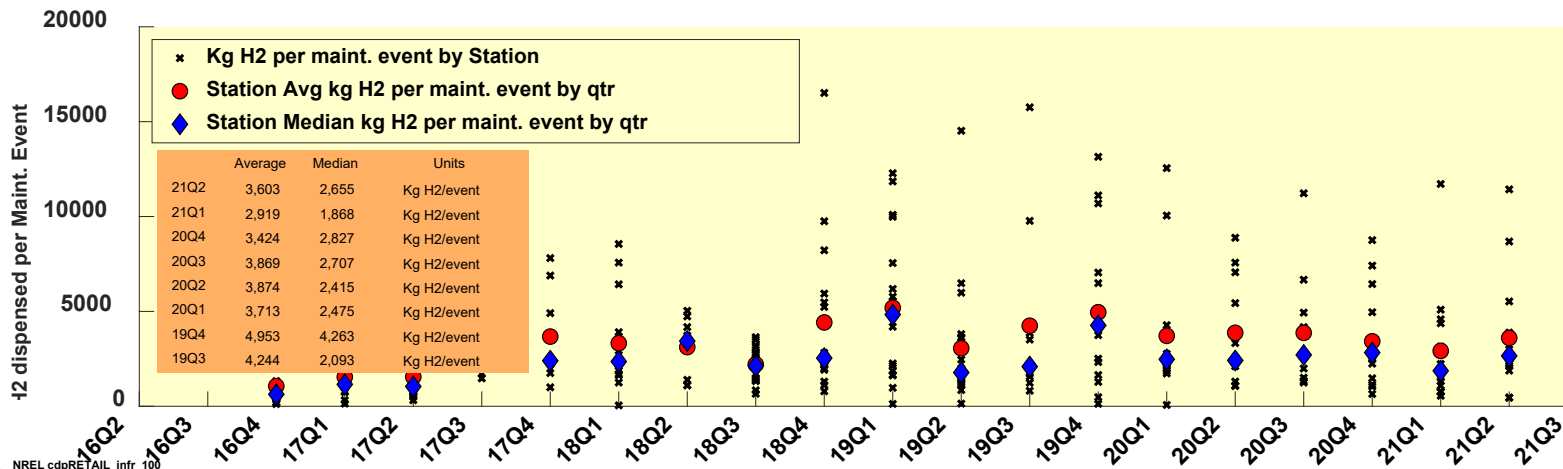
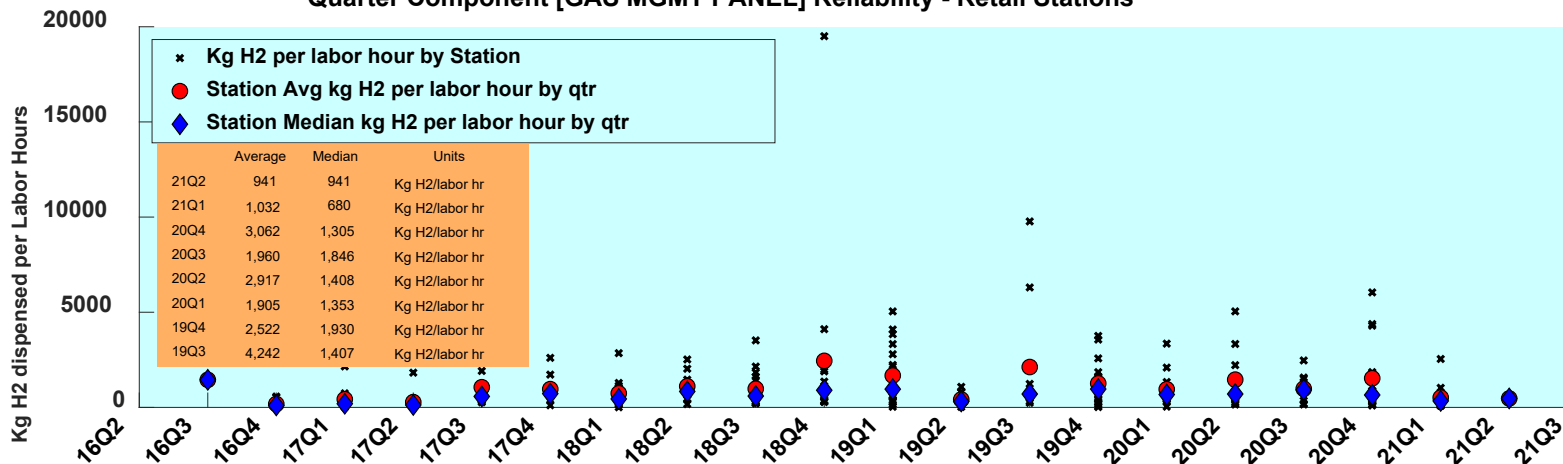
Quarter Component [DISPENSER] Reliability - Retail Stations



NREL cdpRETAIL_infr_100

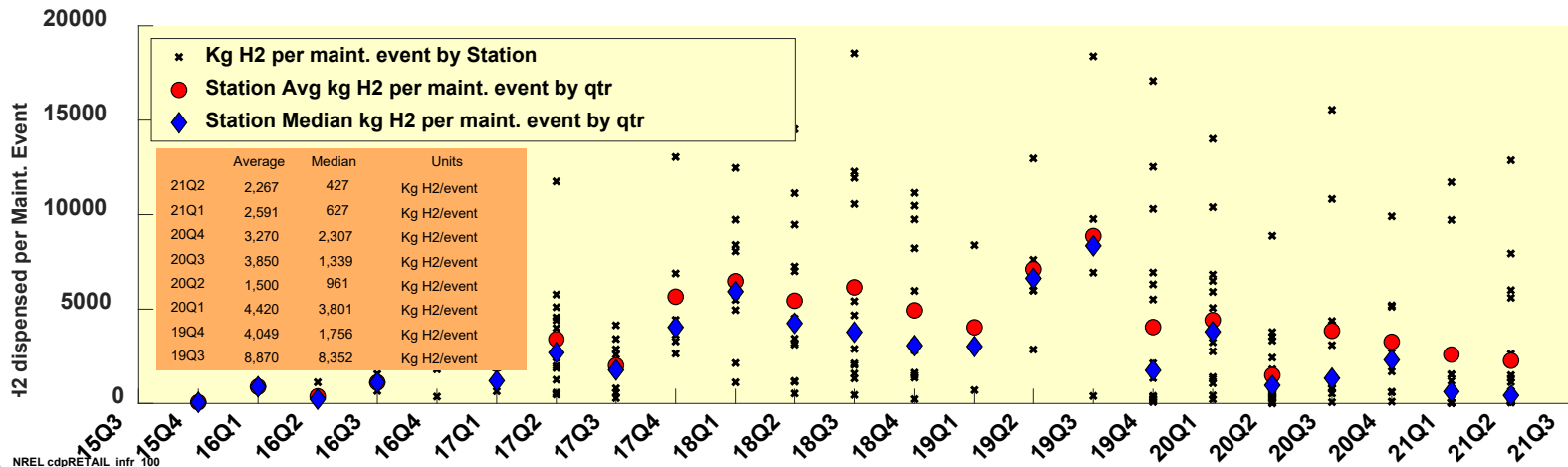
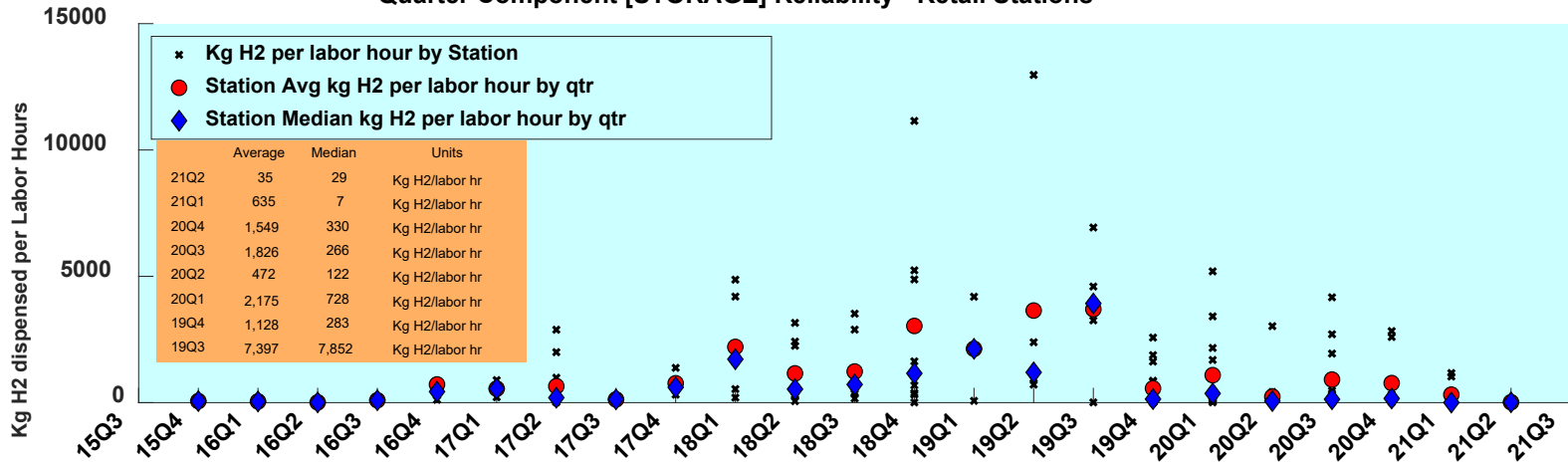
Created: Apr-20-22 3:44 PM | Data Range: 2014Q3-2021Q2

Quarter Component [GAS MGMT PANEL] Reliability - Retail Stations



Quarter Component [STORAGE] Reliability – Retail Stations

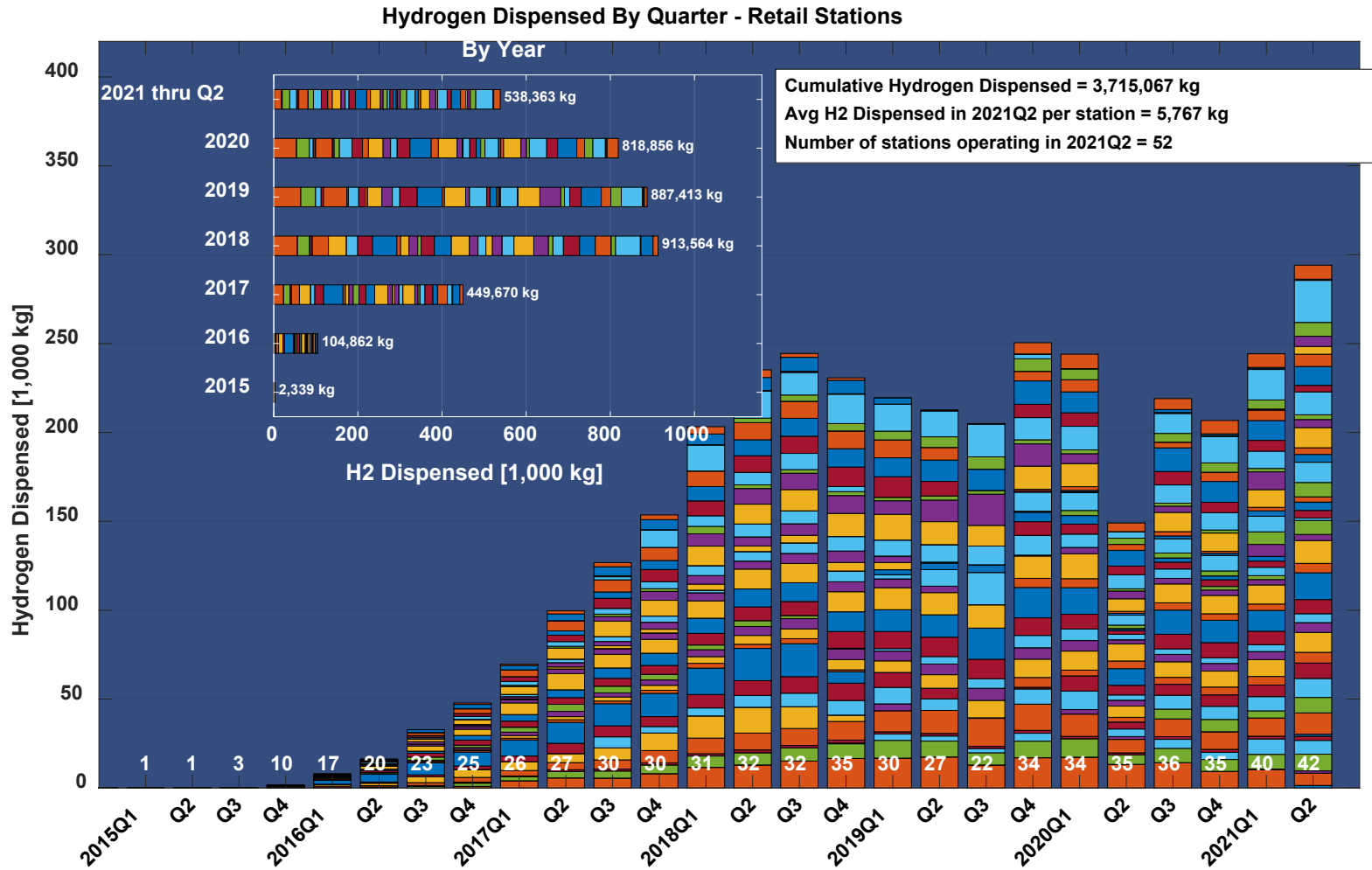
Quarter Component [STORAGE] Reliability - Retail Stations



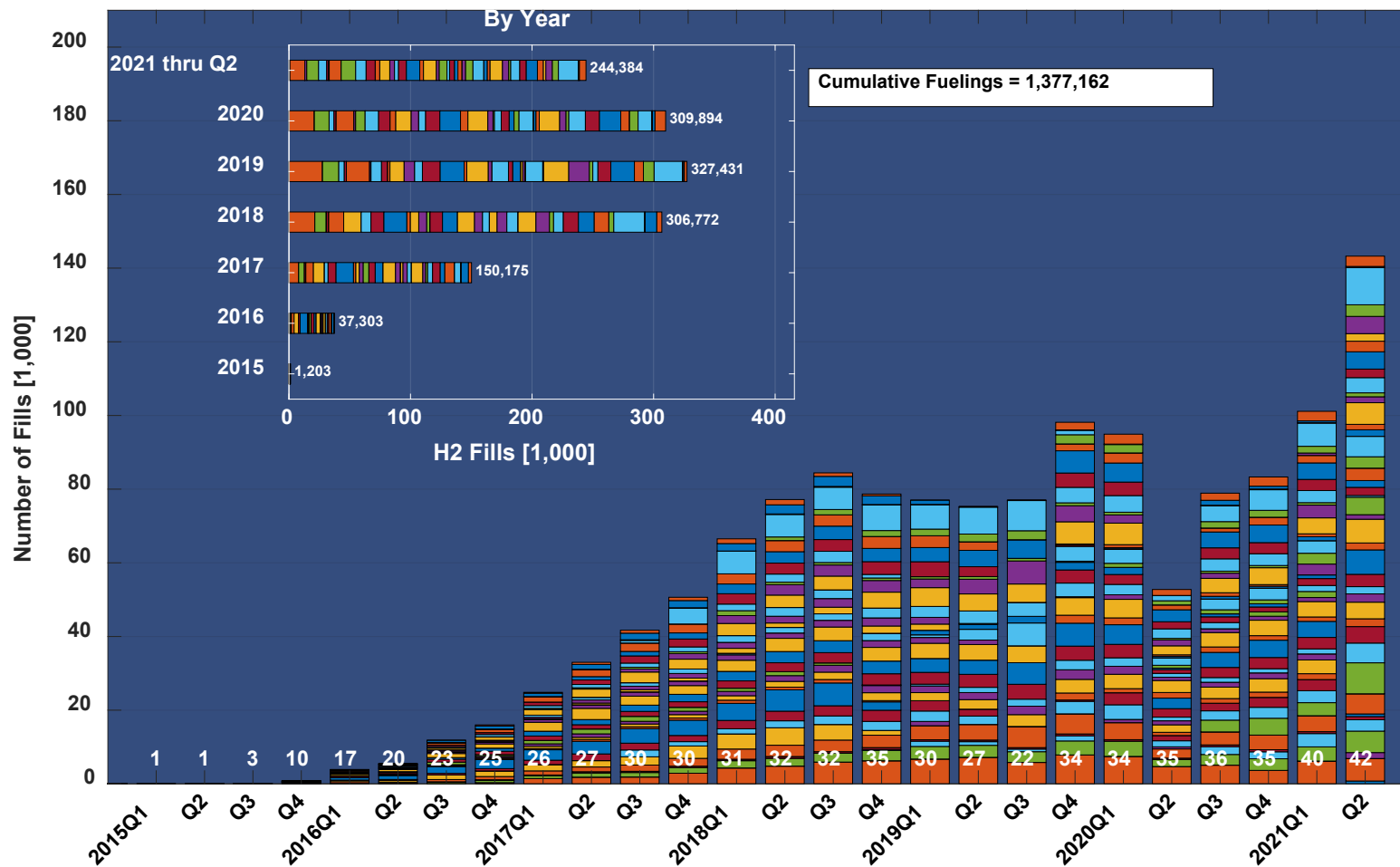
NREL cdpRETAIL_infr_100

Created: Apr-20-22 3:59 PM | Data Range: 2014Q3-2021Q2

Performance



Hydrogen Fills By Quarter - Retail Stations

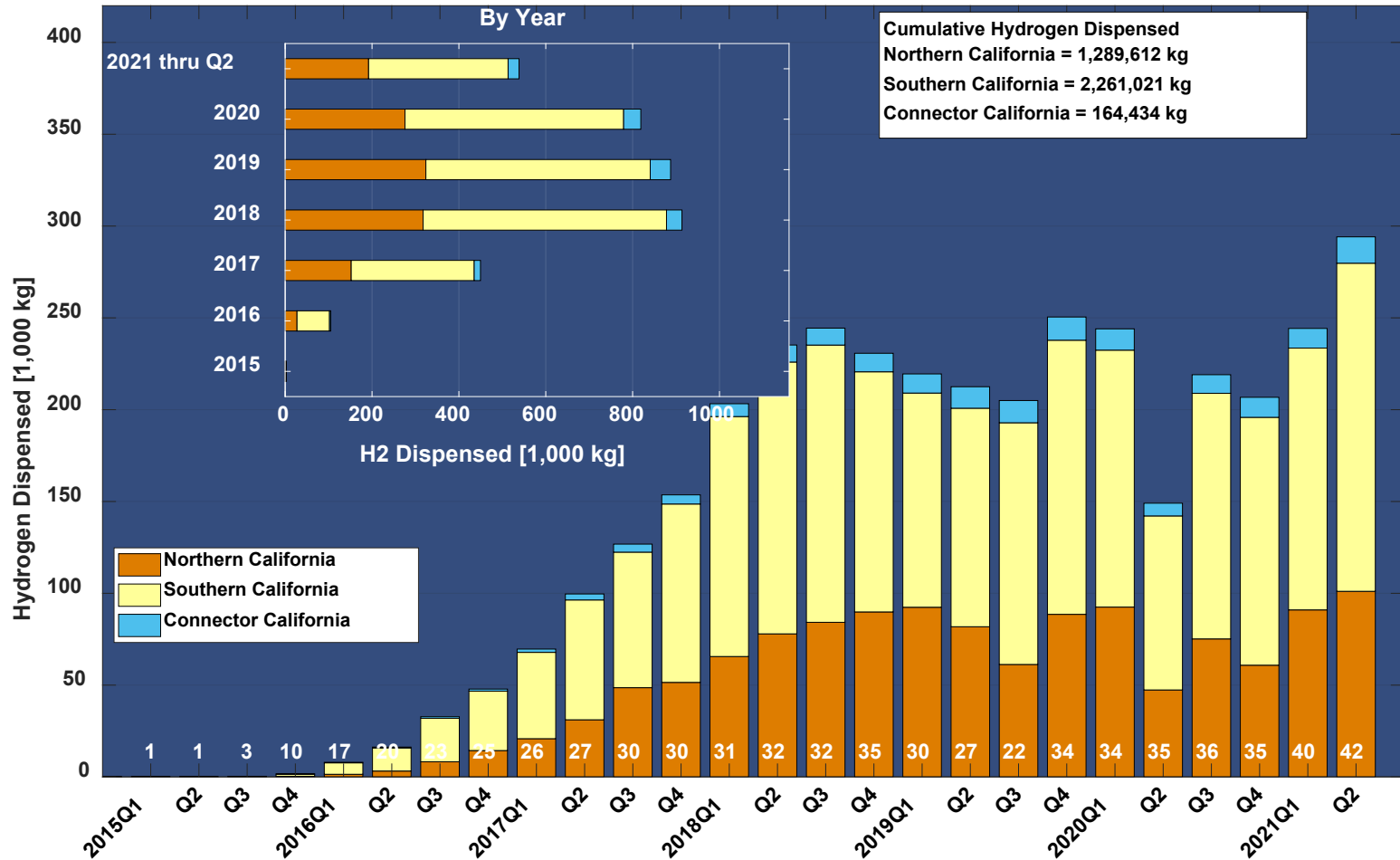


NREL cdpRETAIL_infr_58

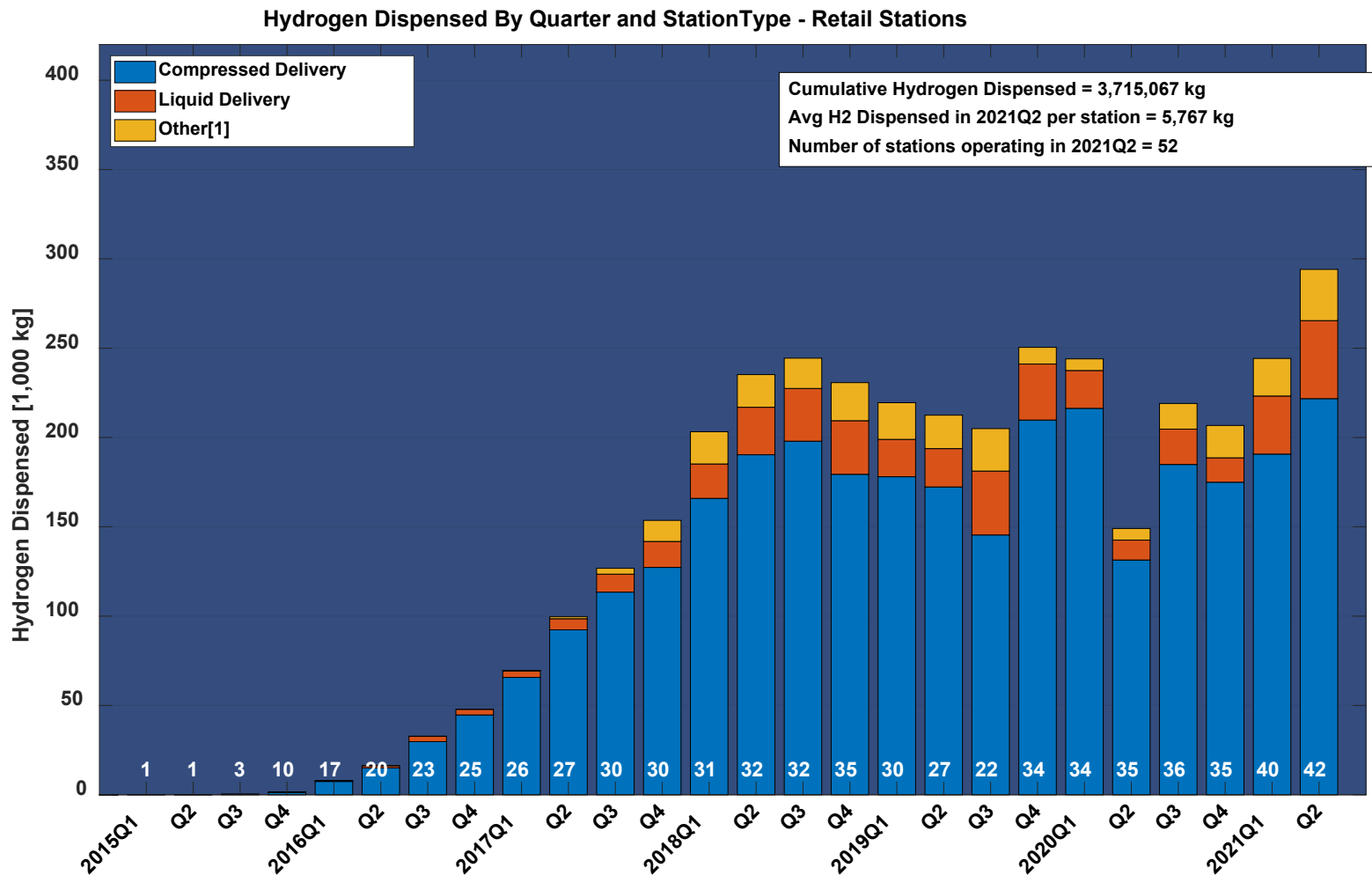
Created: Apr-28-22 3:38 PM | Data Range: 2014Q3-2021Q2

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

Hydrogen Dispensed By Region - Retail Stations



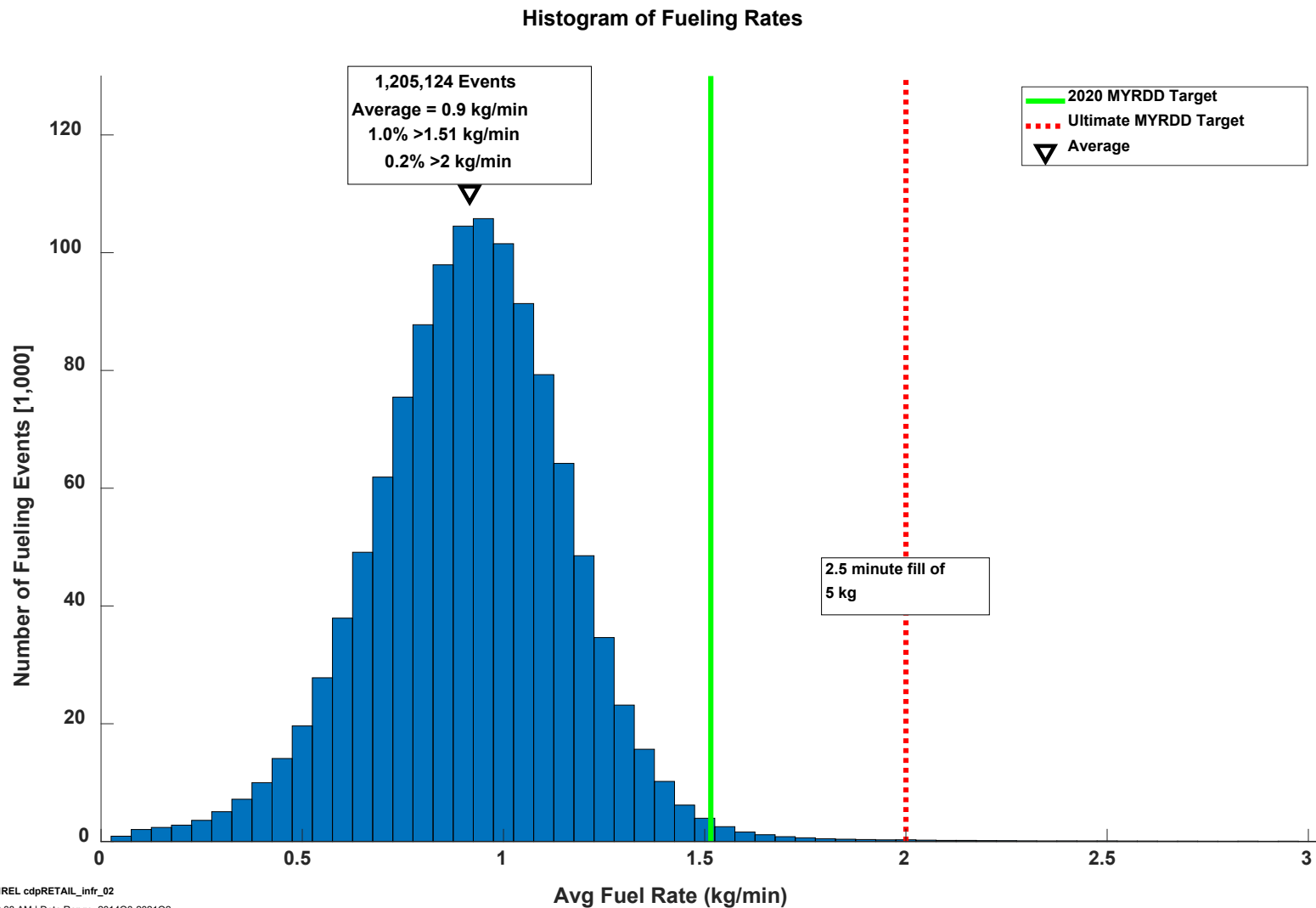
Note: Station count is number at bottom of bar.



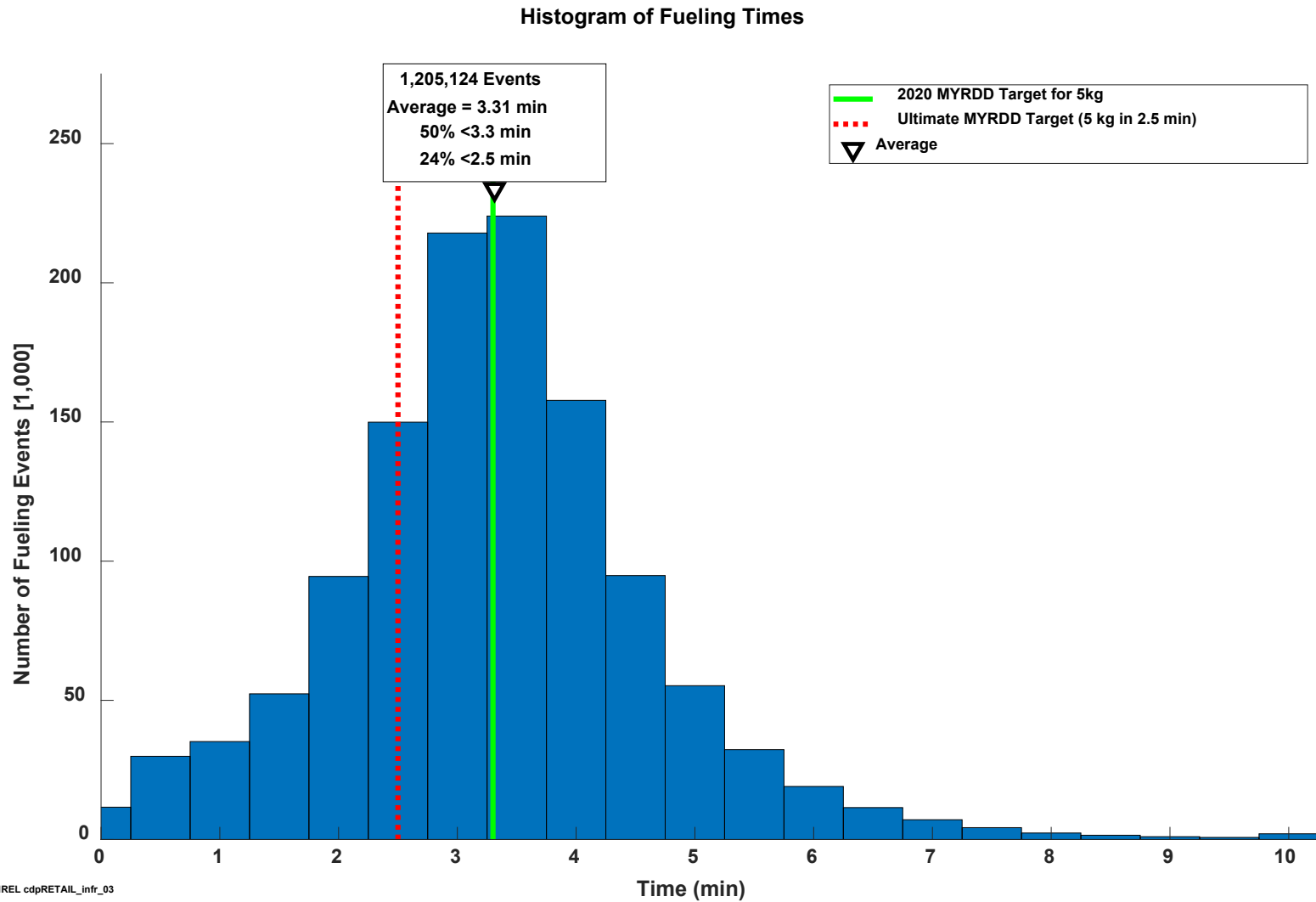
Note: Stations reporting data count is number at bottom of bar.

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

Histogram of Fueling Rates



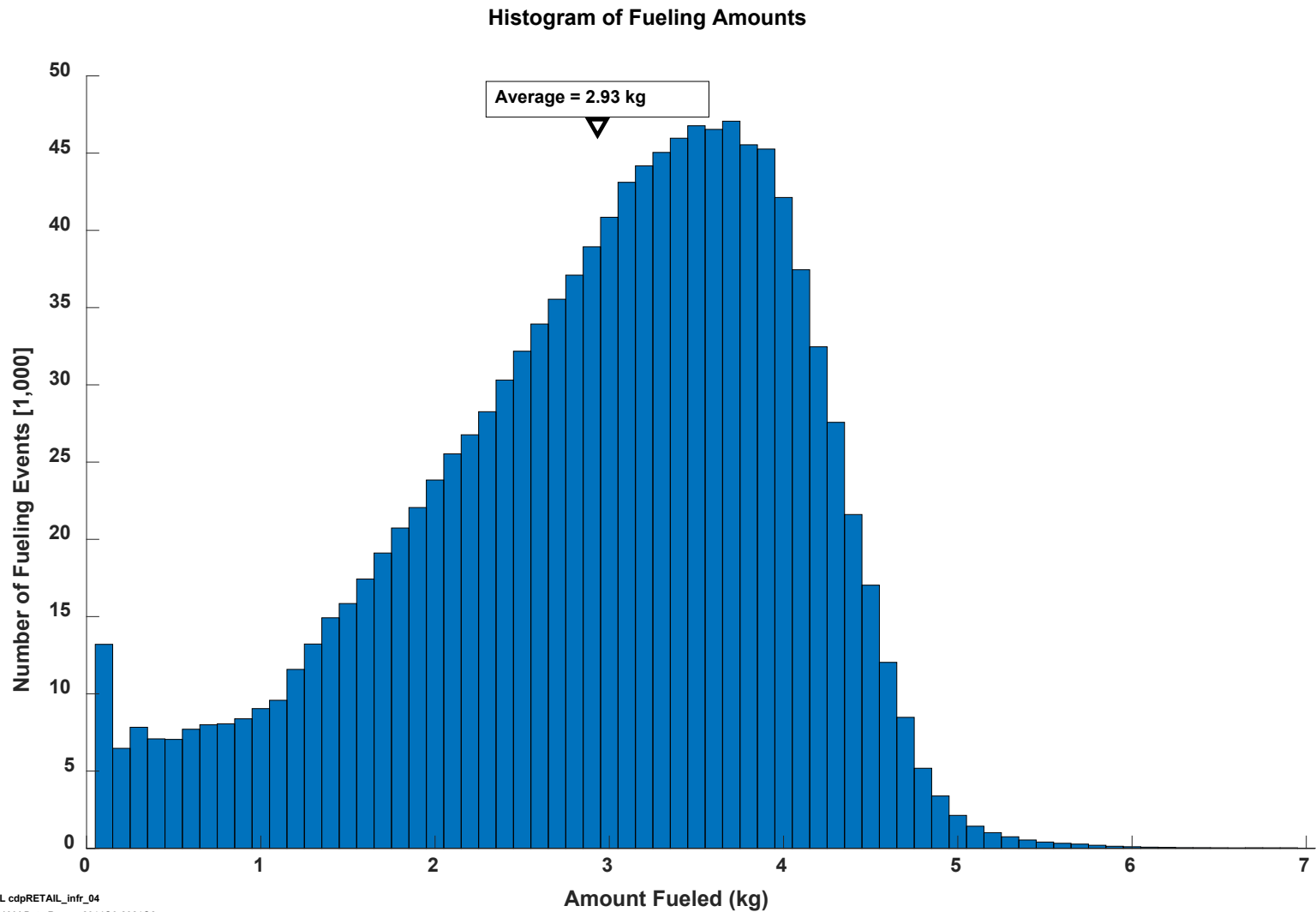
Histogram of Fueling Times

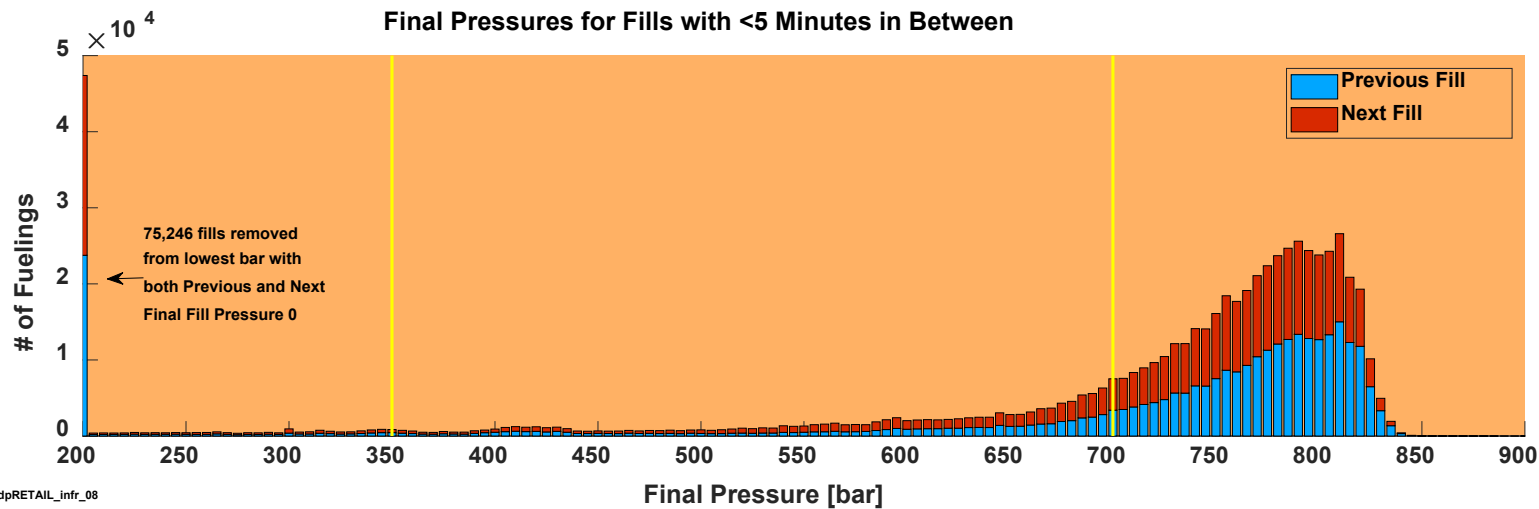
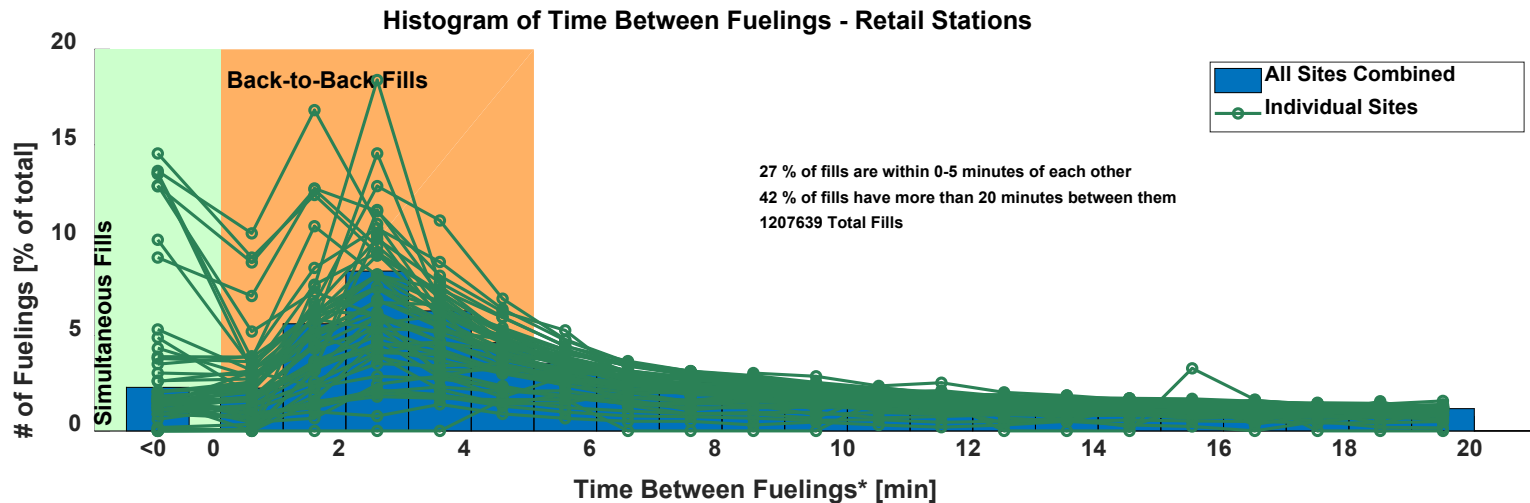


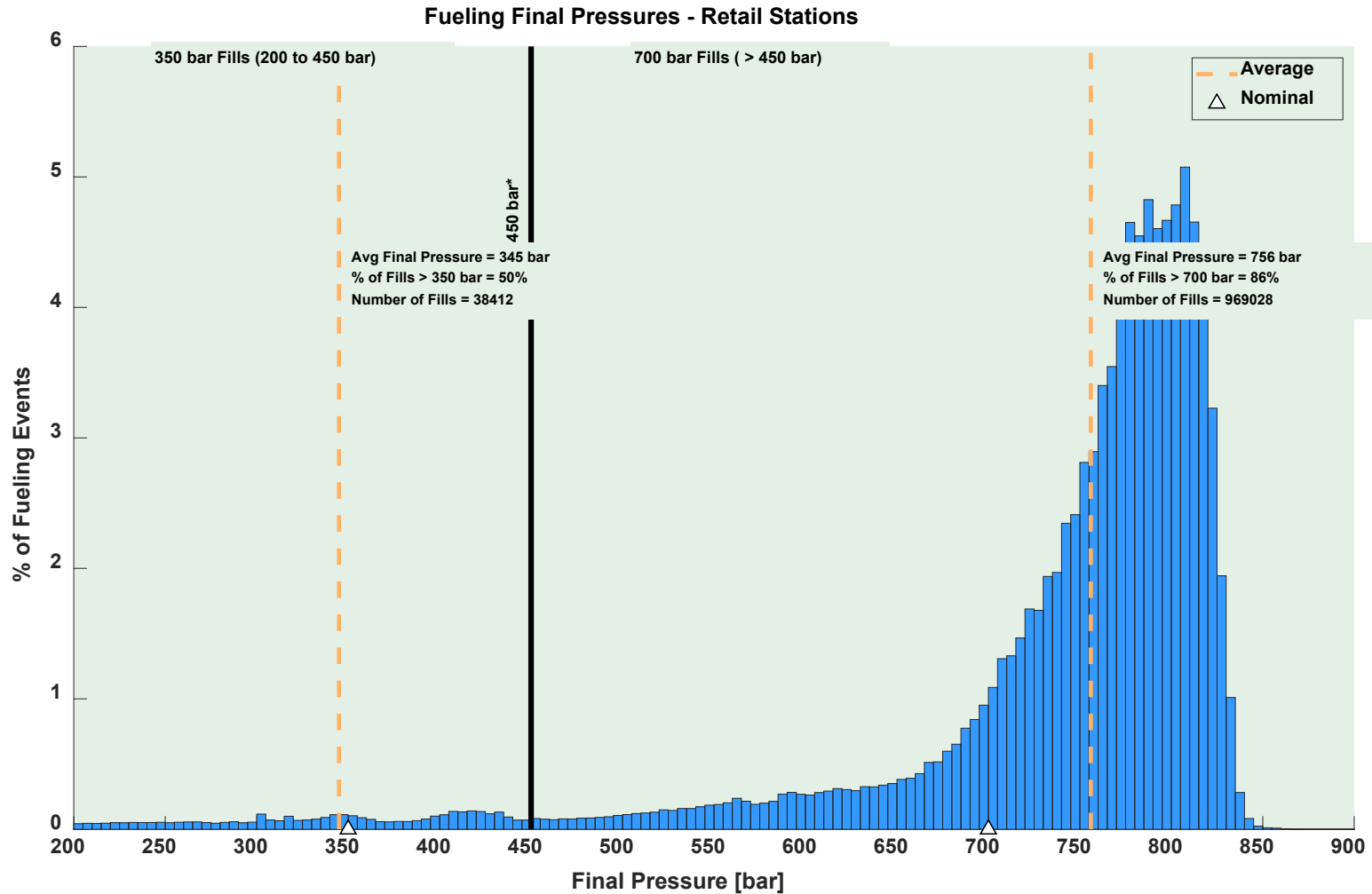
NREL cdpRETAIL_infr_03

Created: Apr-29-22 11:20 AM | Data Range: 2014Q3-2021Q2

Histogram of Fueling Amounts



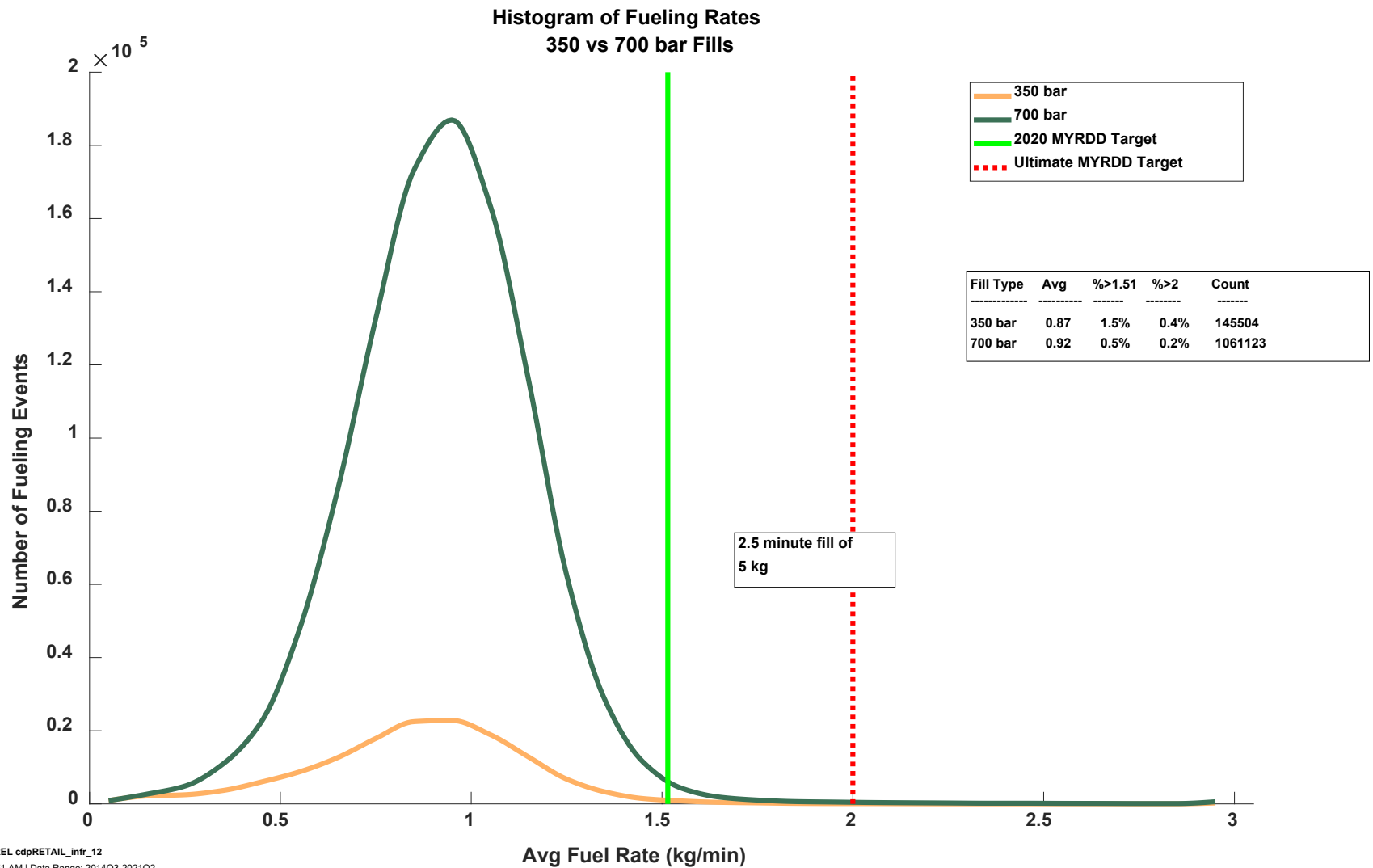




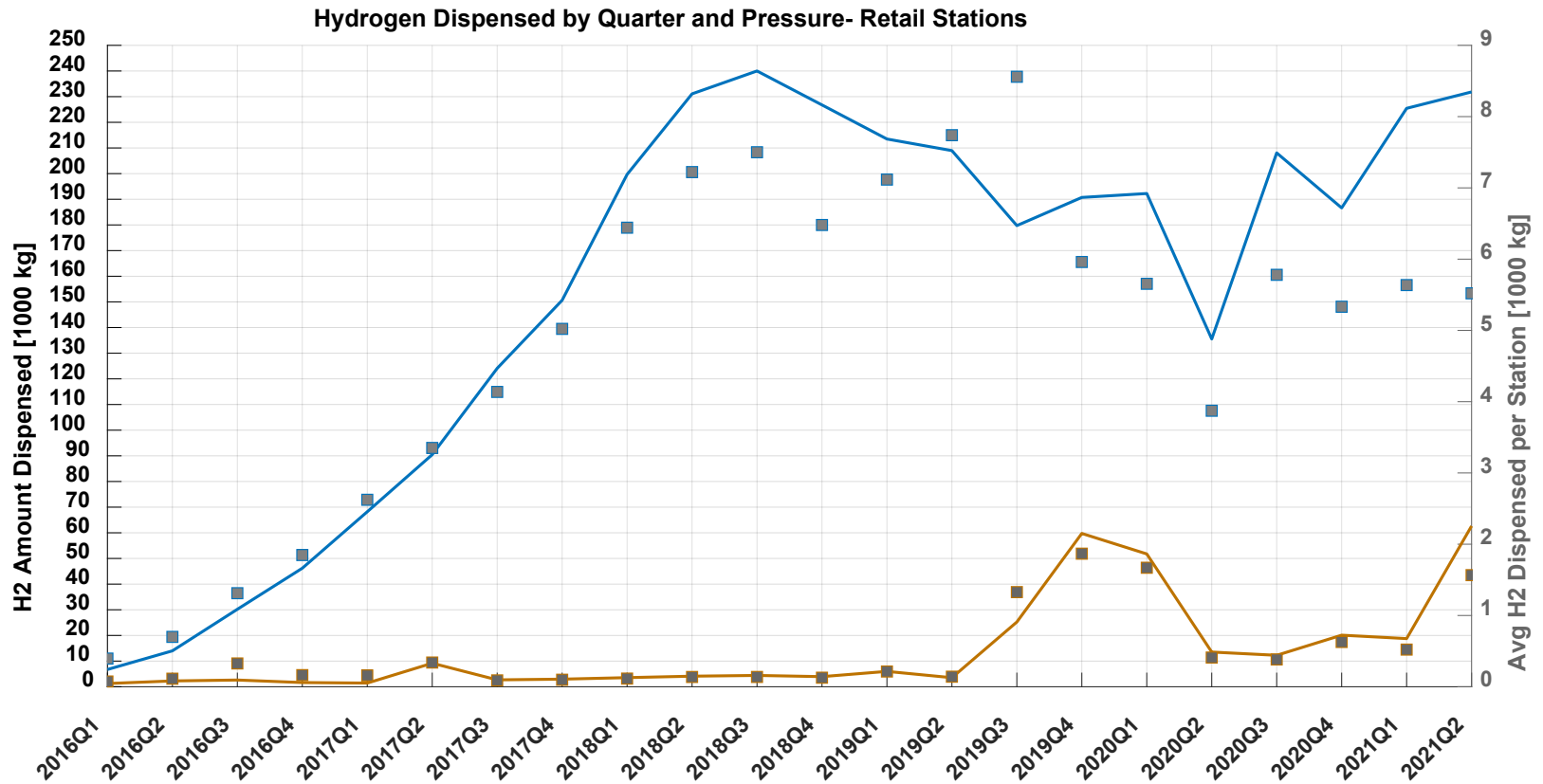
NREL cdpRETAIL_infr_09

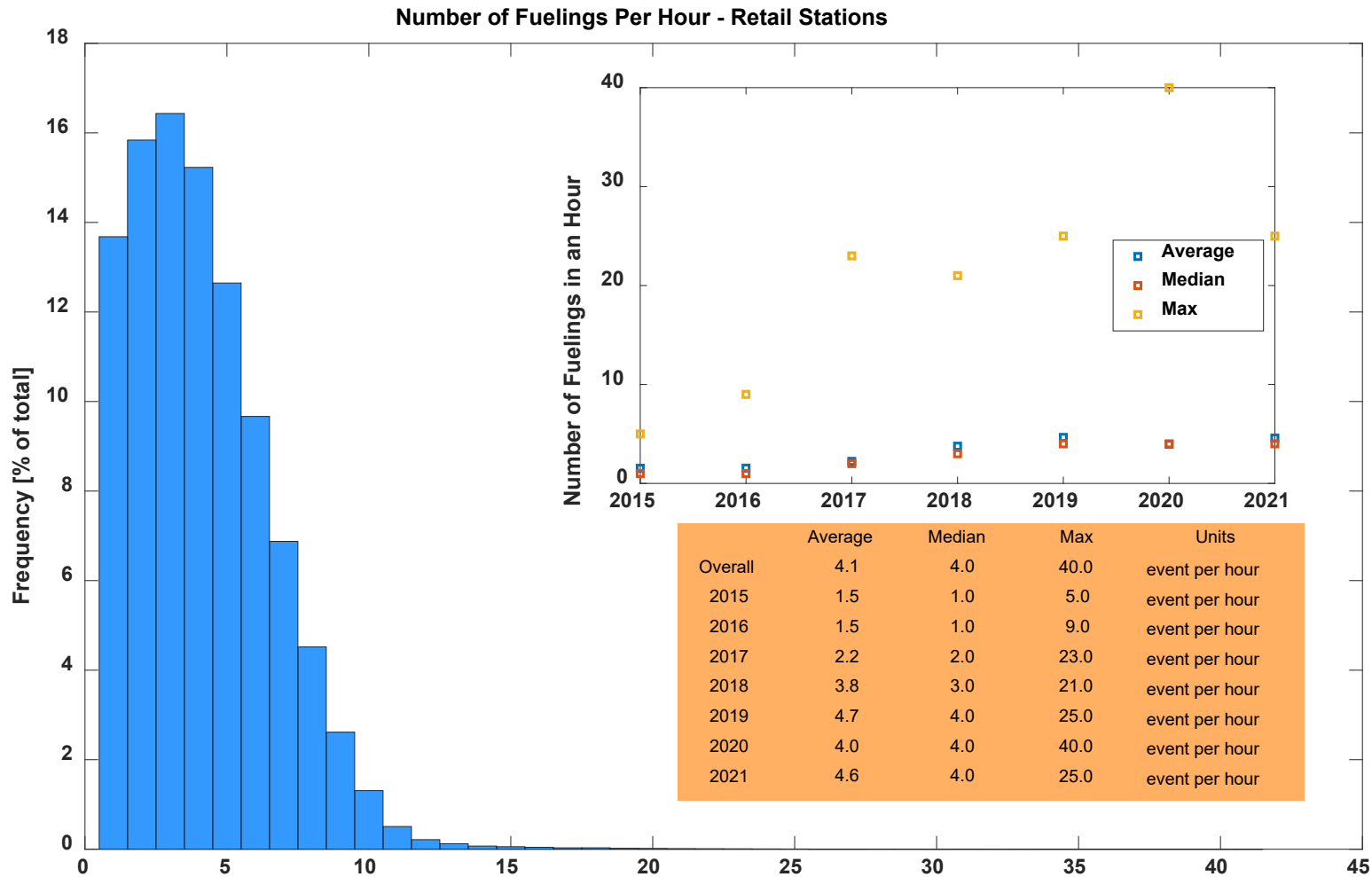
Created: Mar-09-22 2:47 AM | Data Range: 2014Q3-2021Q2

*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

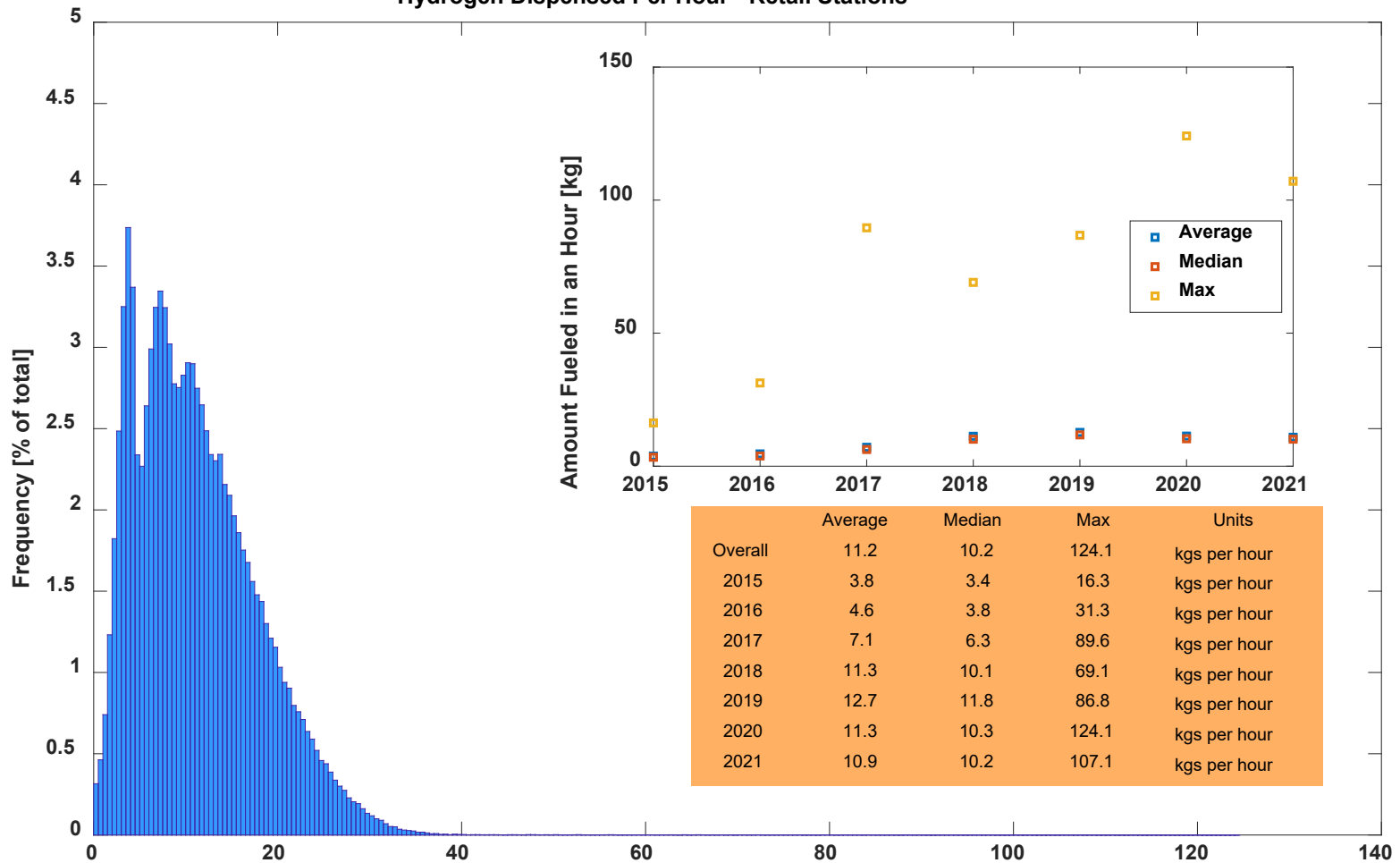




NREL cdpRETAIL_infr_13

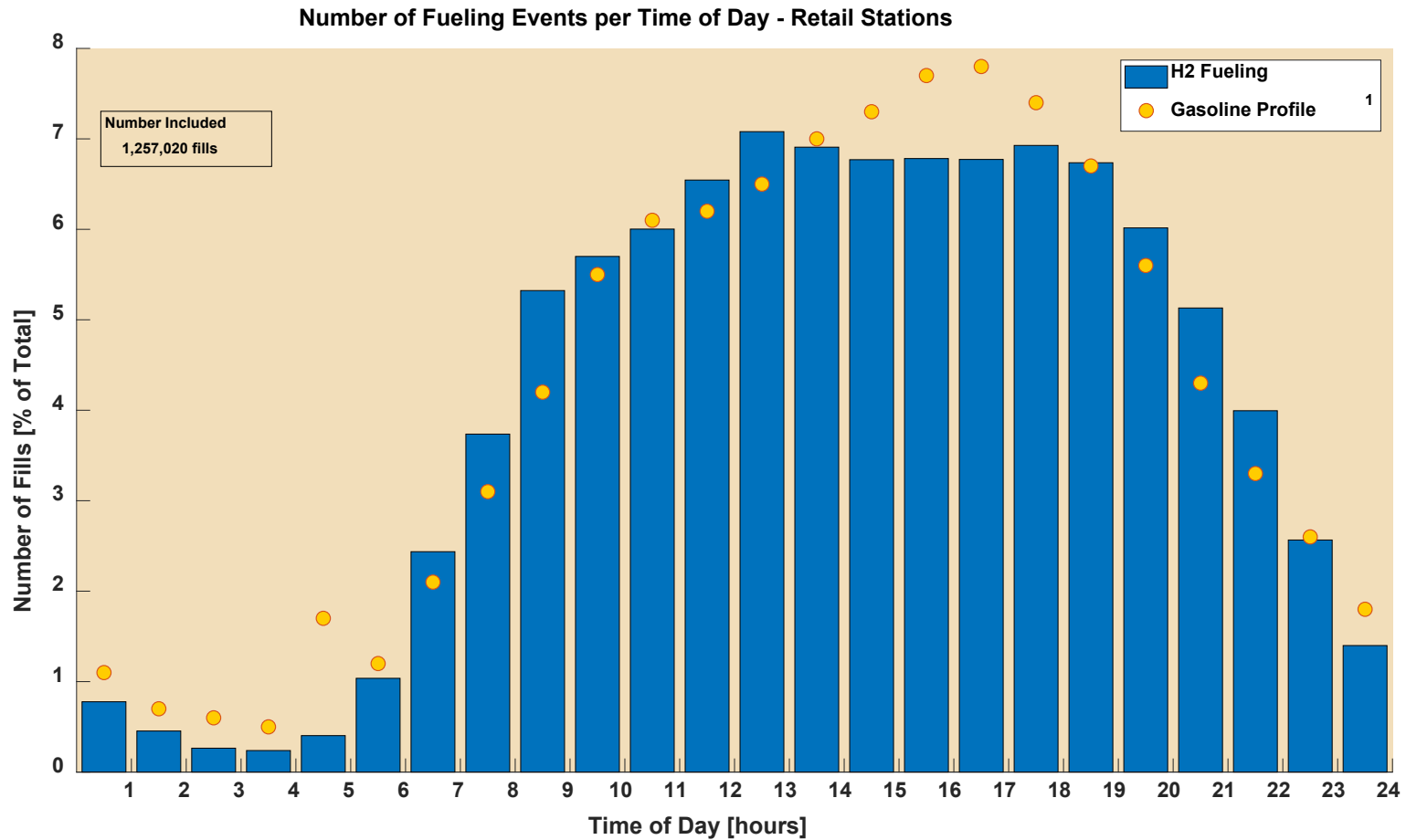
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Hydrogen Dispensed Per Hour - Retail Stations



NREL cdpRETAIL_infr_14

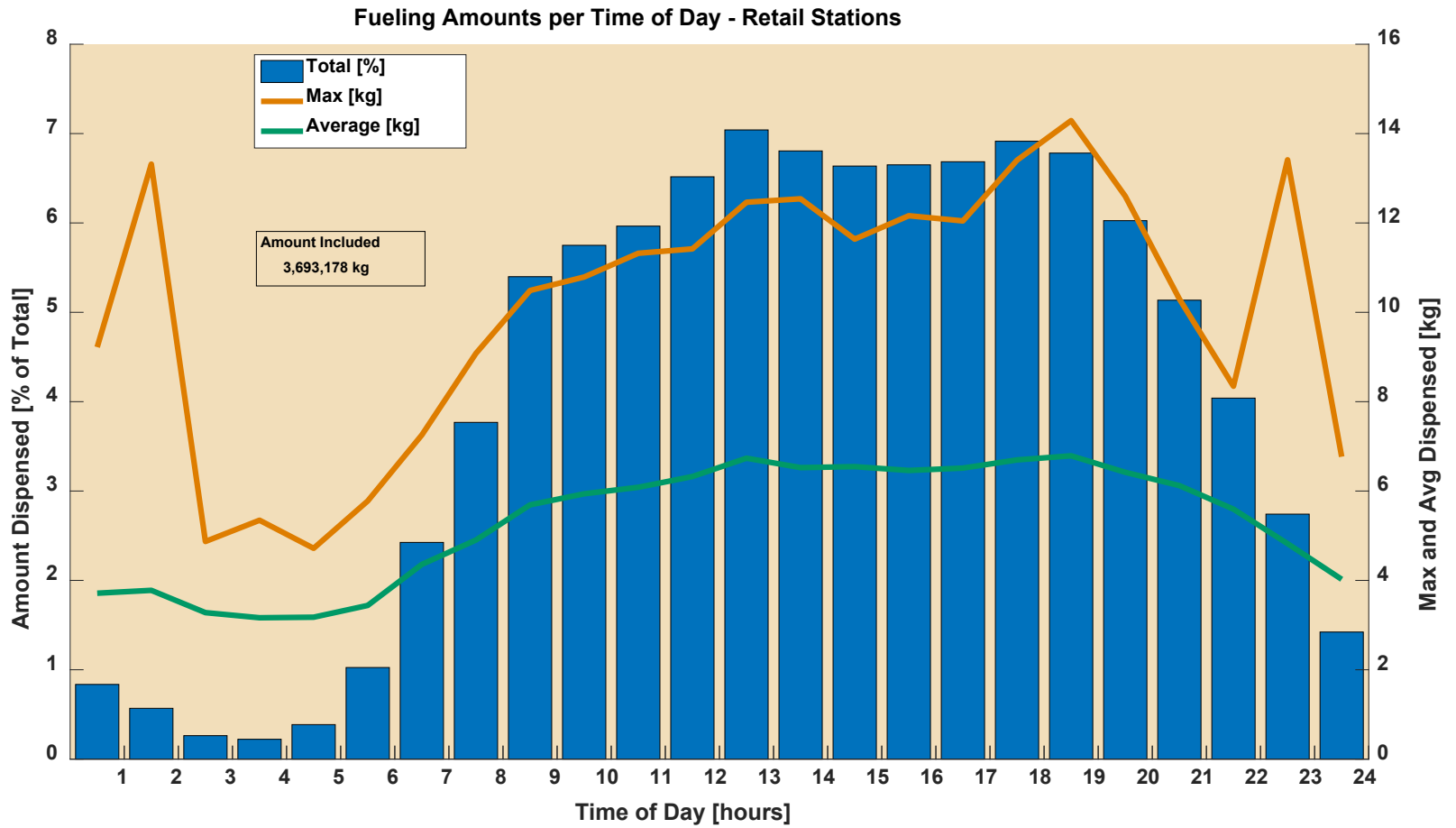
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NREL cdpRETAIL_infr_15

Created: Mar-08-22 10:40 PM | Data Range: 2014Q3-2021Q2

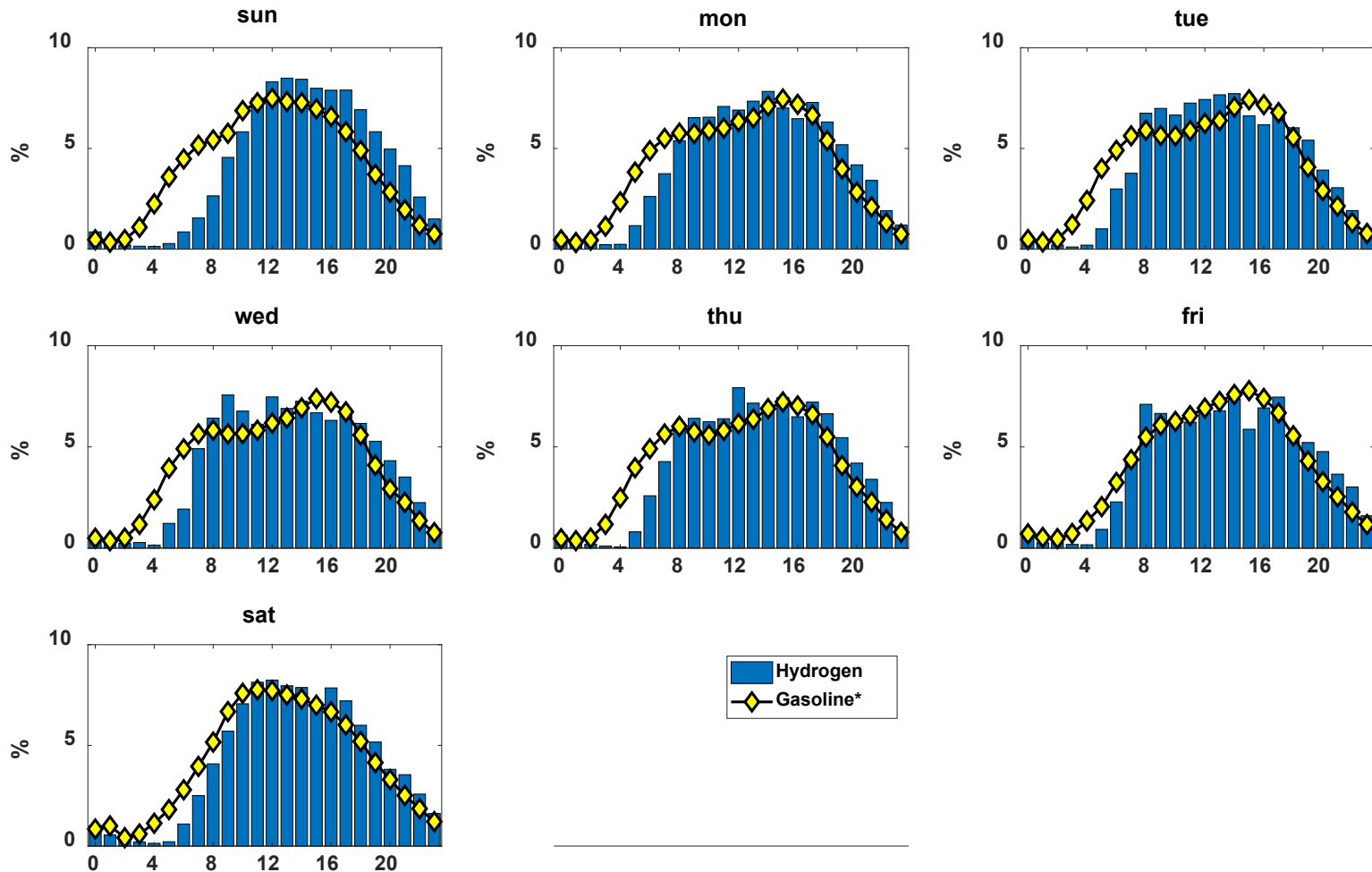
1. Friday Chevron profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.



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

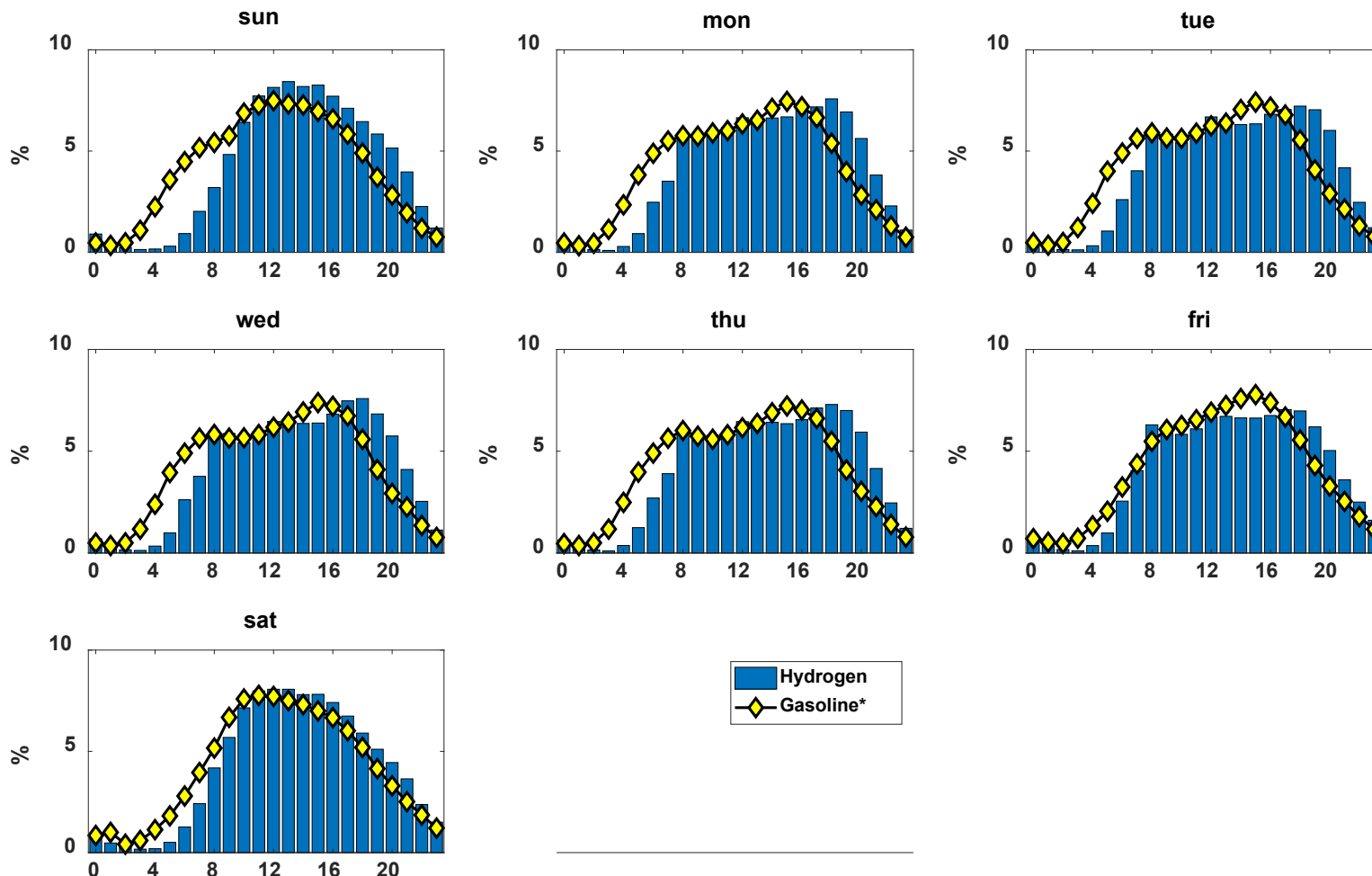
Created: Mar-08-22 4:16 PM | Data Range: 2014Q3-2021Q2

*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

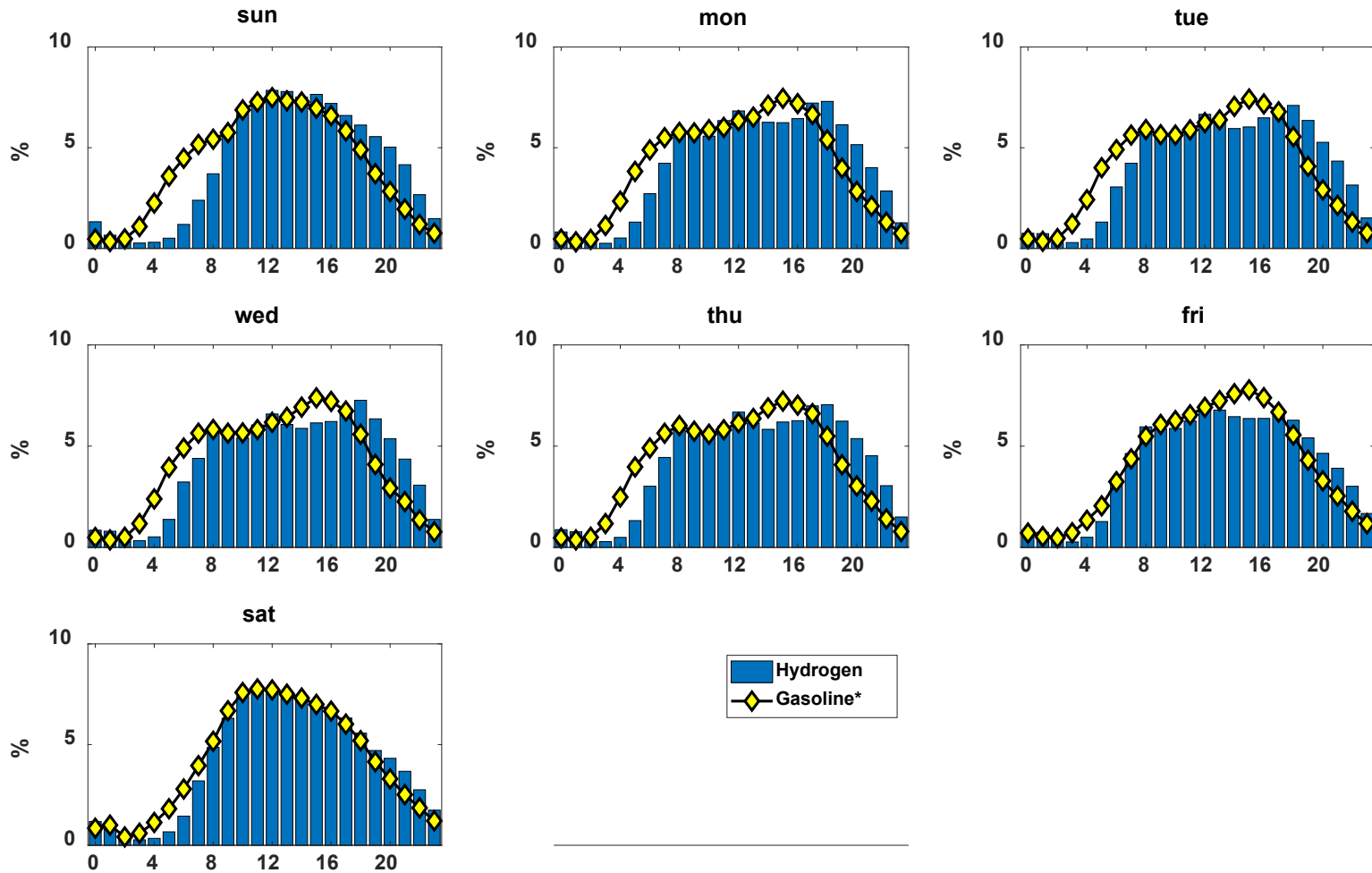
Created: Mar-08-22 4:16 PM | Data Range: 2014Q3-2021Q2

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

CDP-INFR-88c Southern California

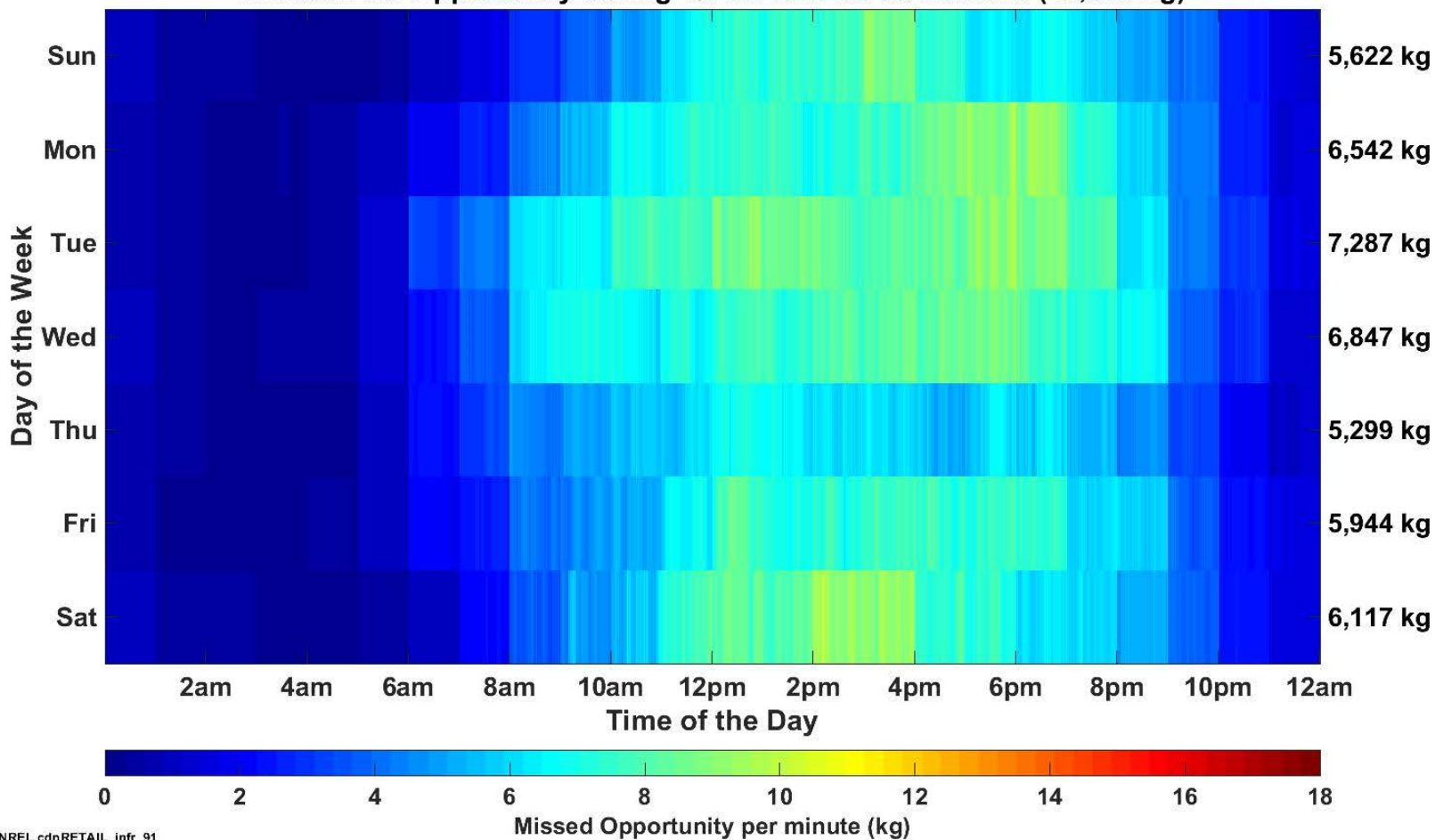
Fueling Profile by Day and Hour

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



Hydrogen
Gasoline*

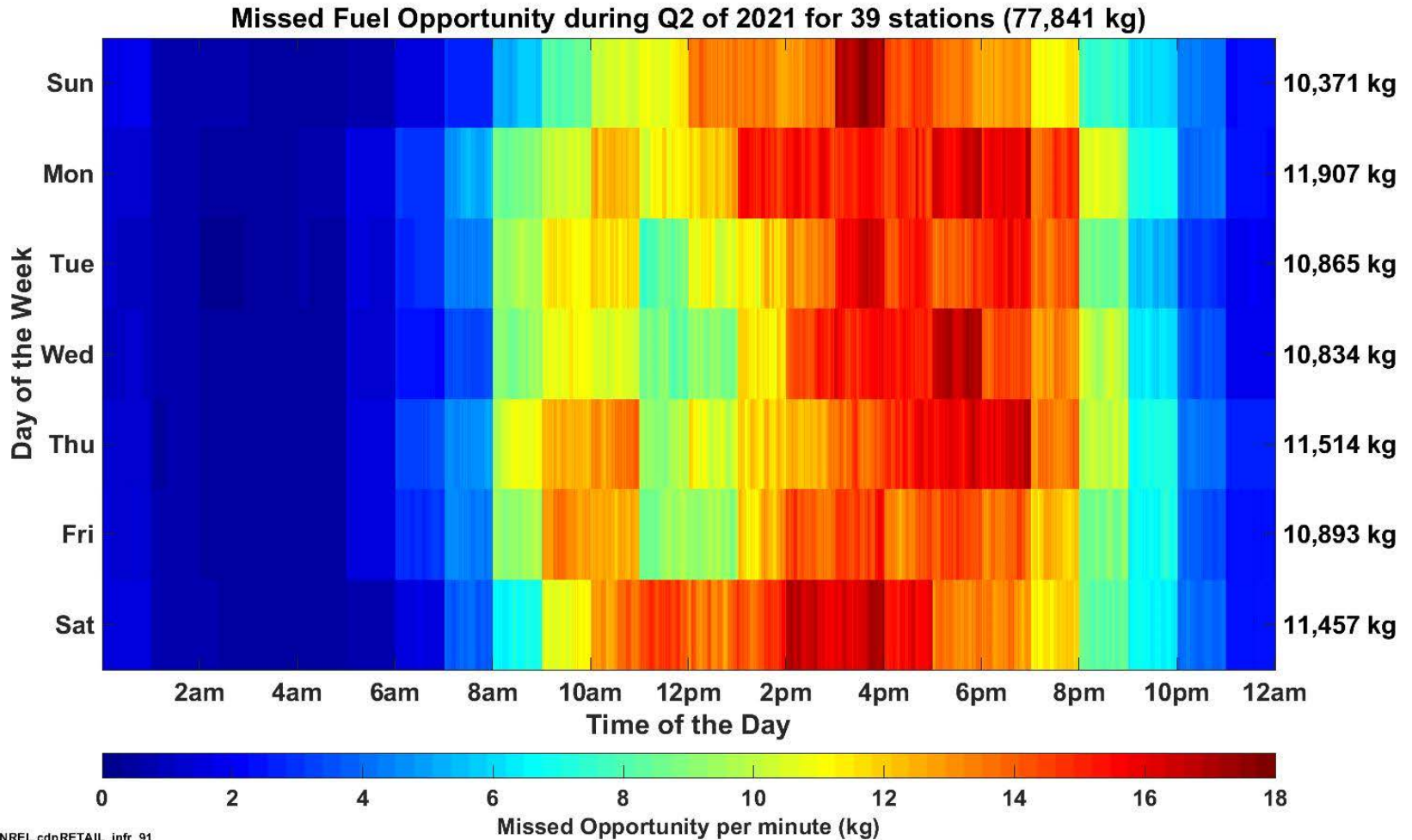
Missed Fuel Opportunity during Q1 of 2021 for 39 stations (43,656 kg)



NREL cdpRETAIL_infr_91

Created: Apr-21-22 2:36 PM | Data Range: 2013Q4-2021Q2

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

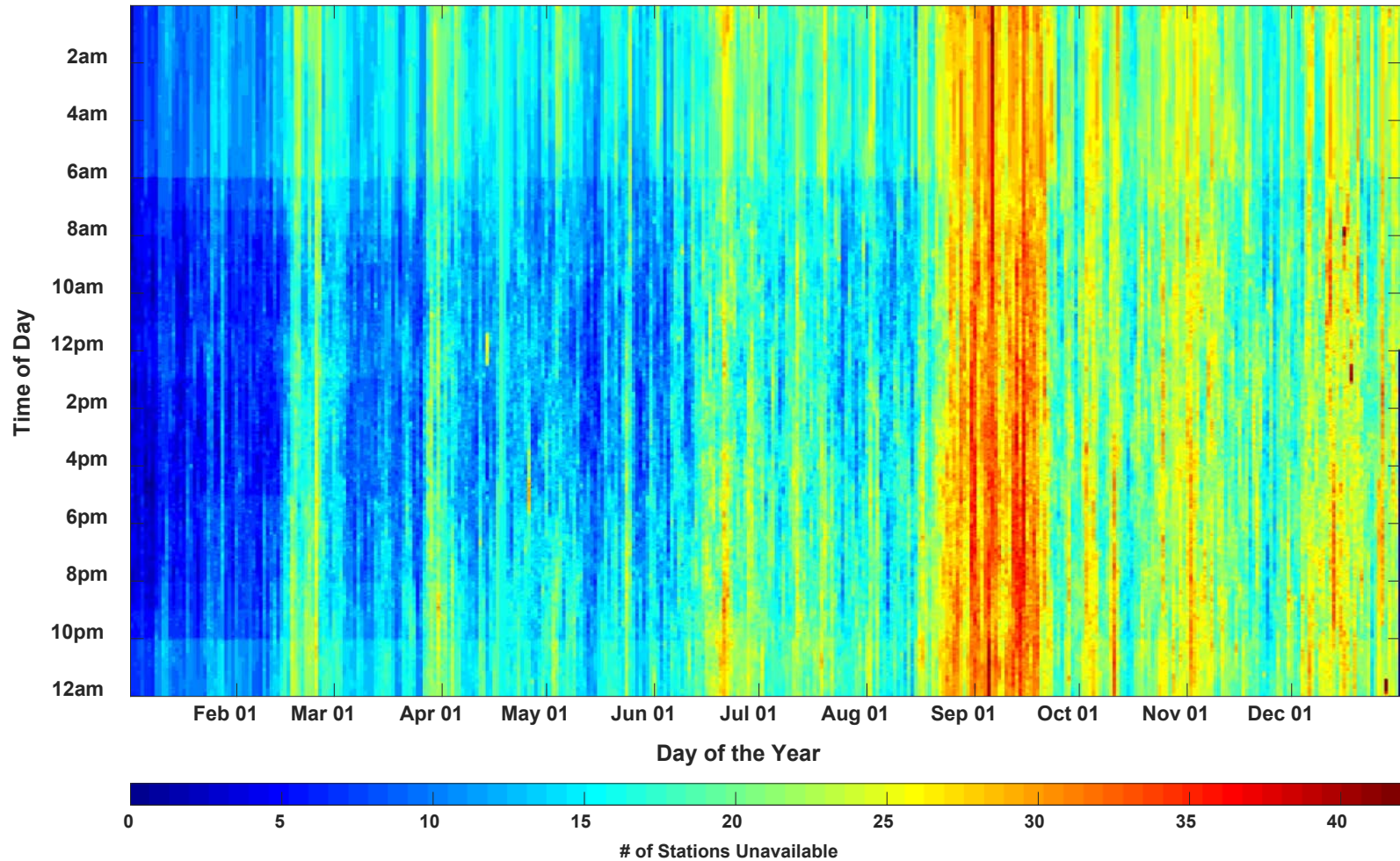


NREL cdpRETAIL_infr_91

Created: Apr-21-22 3:36 PM | Data Range: 2013Q4-2021Q2

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

2021 Station Unavailability for 51 stations

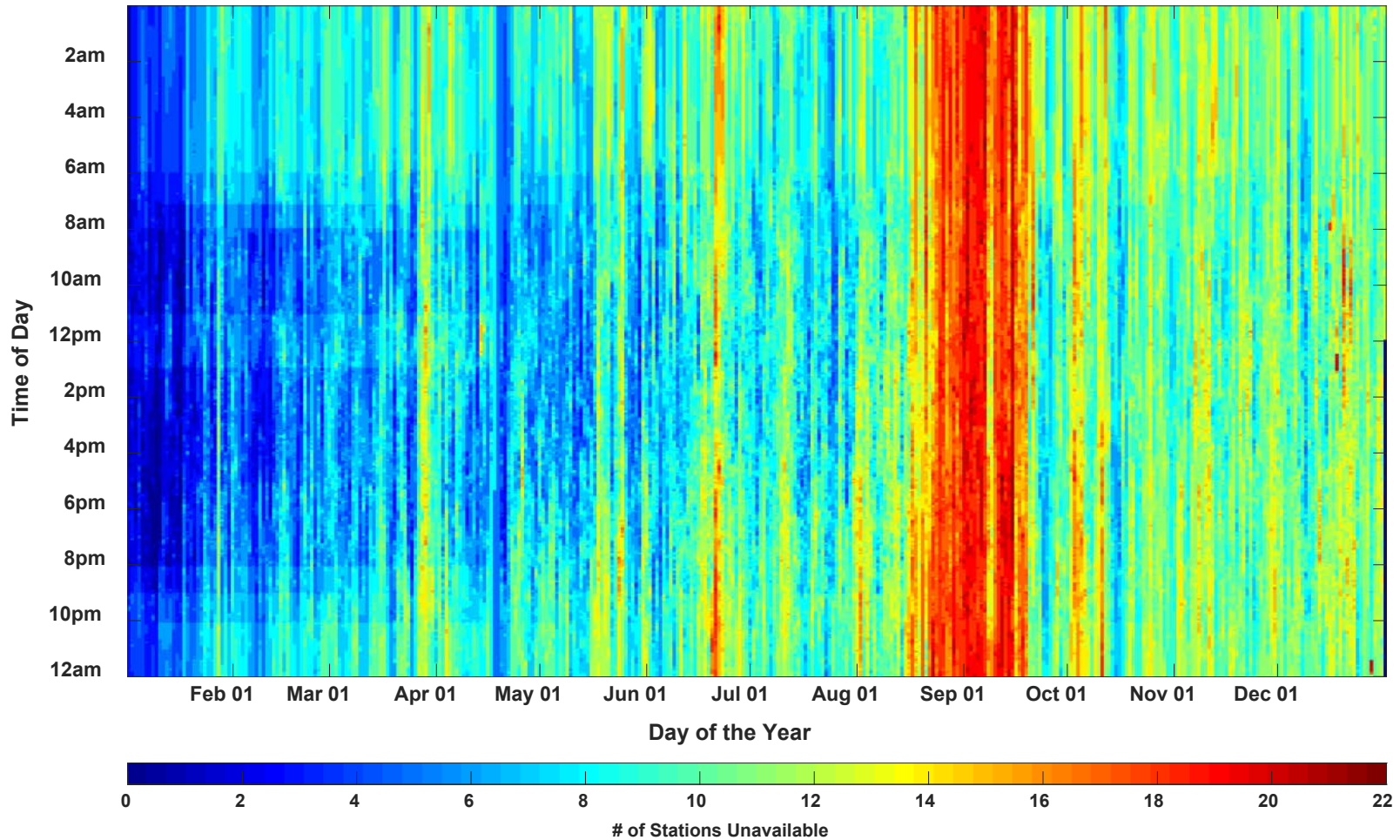


NREL cdpRETAIL_infr_93

Created: Apr-14-22 3:19 PM | Data Range: 2013Q4-2021Q2

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

2021 Station Unavailability for 23 stations
Northern California

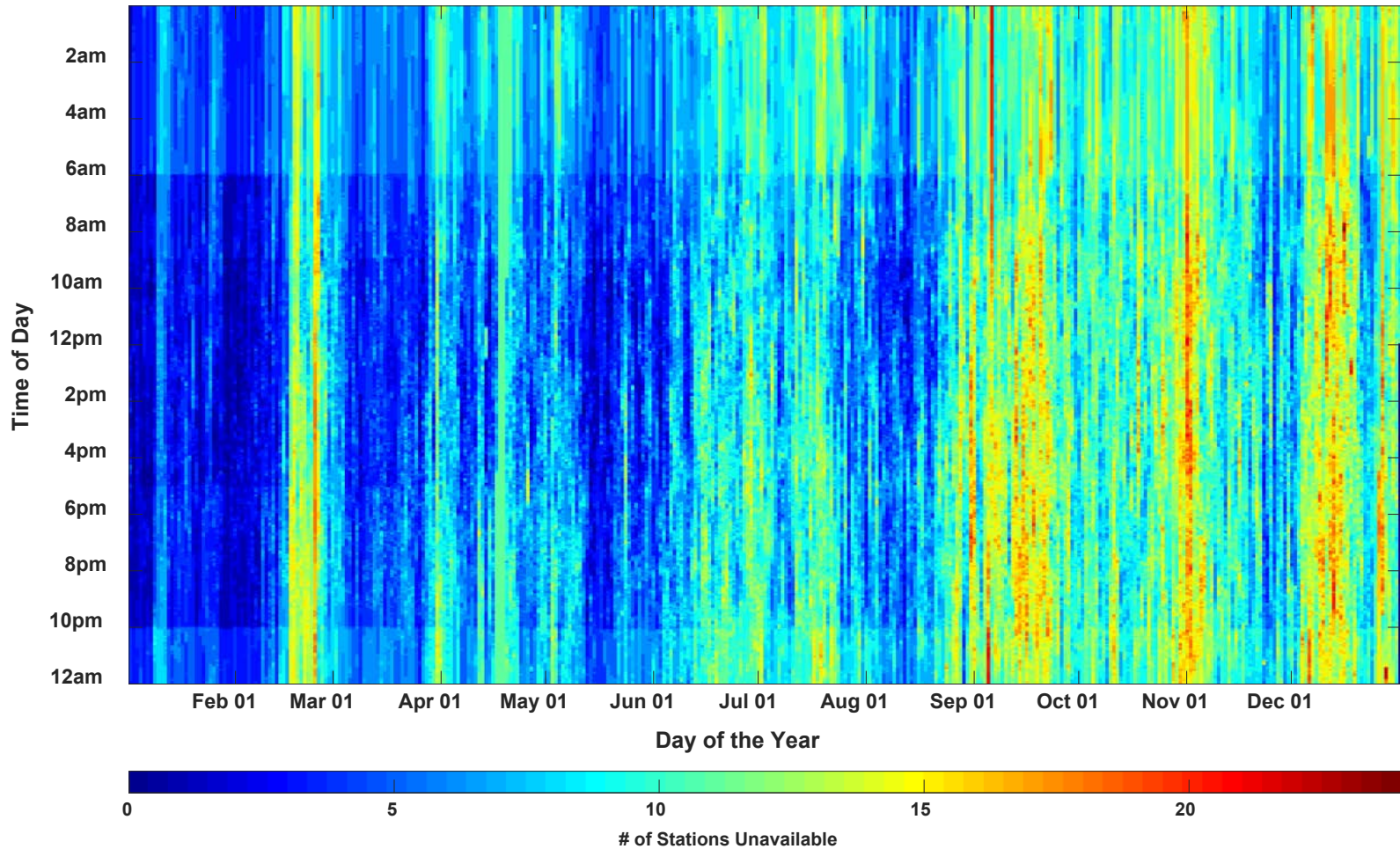


NREL cdpRETAIL_infr_95

Created: Apr-14-22 3:20 PM | Data Range: 2013Q4-2021Q2

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

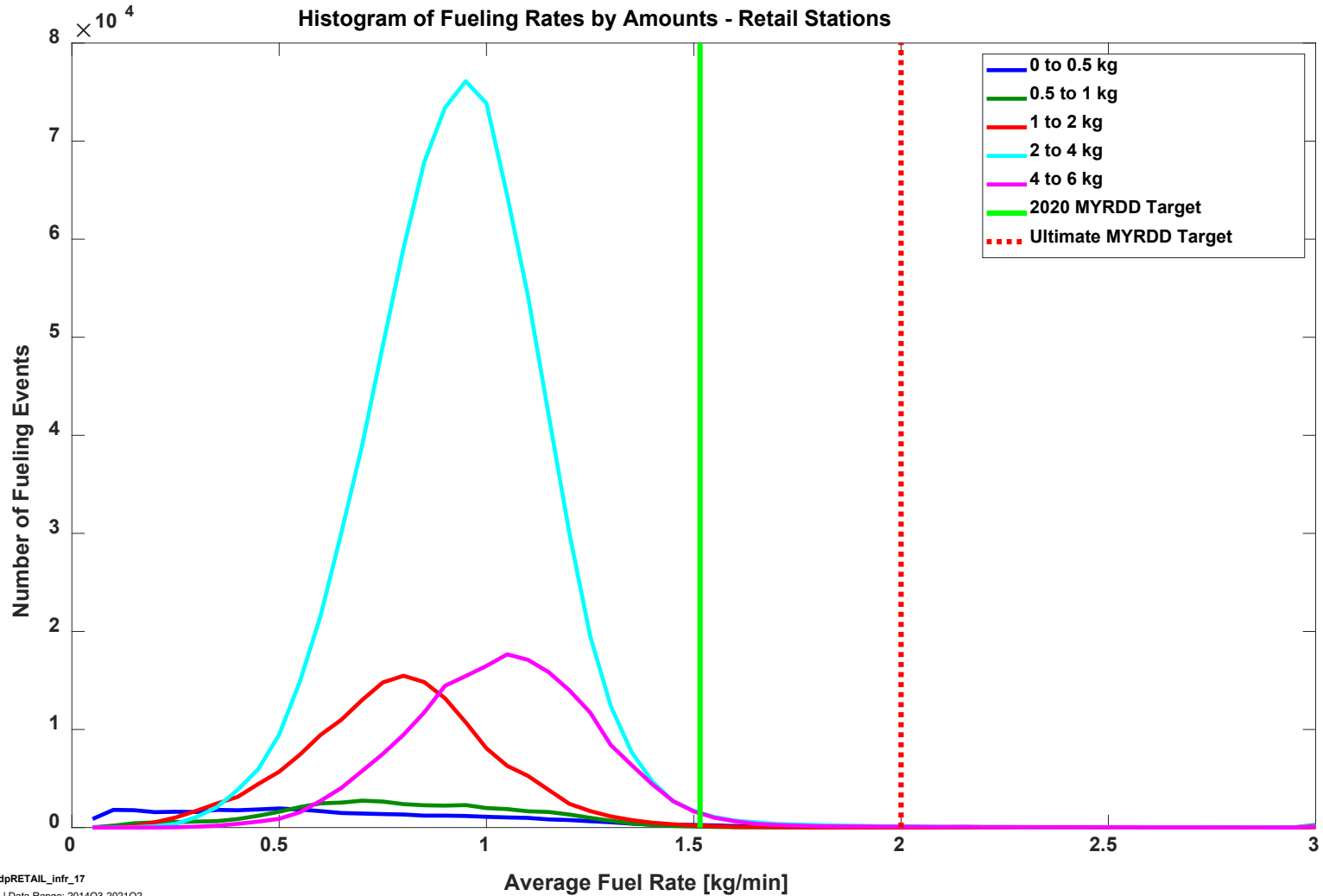
2021 Station Unavailability for 28 stations
Southern California



NREL cdpRETAIL_infr_95

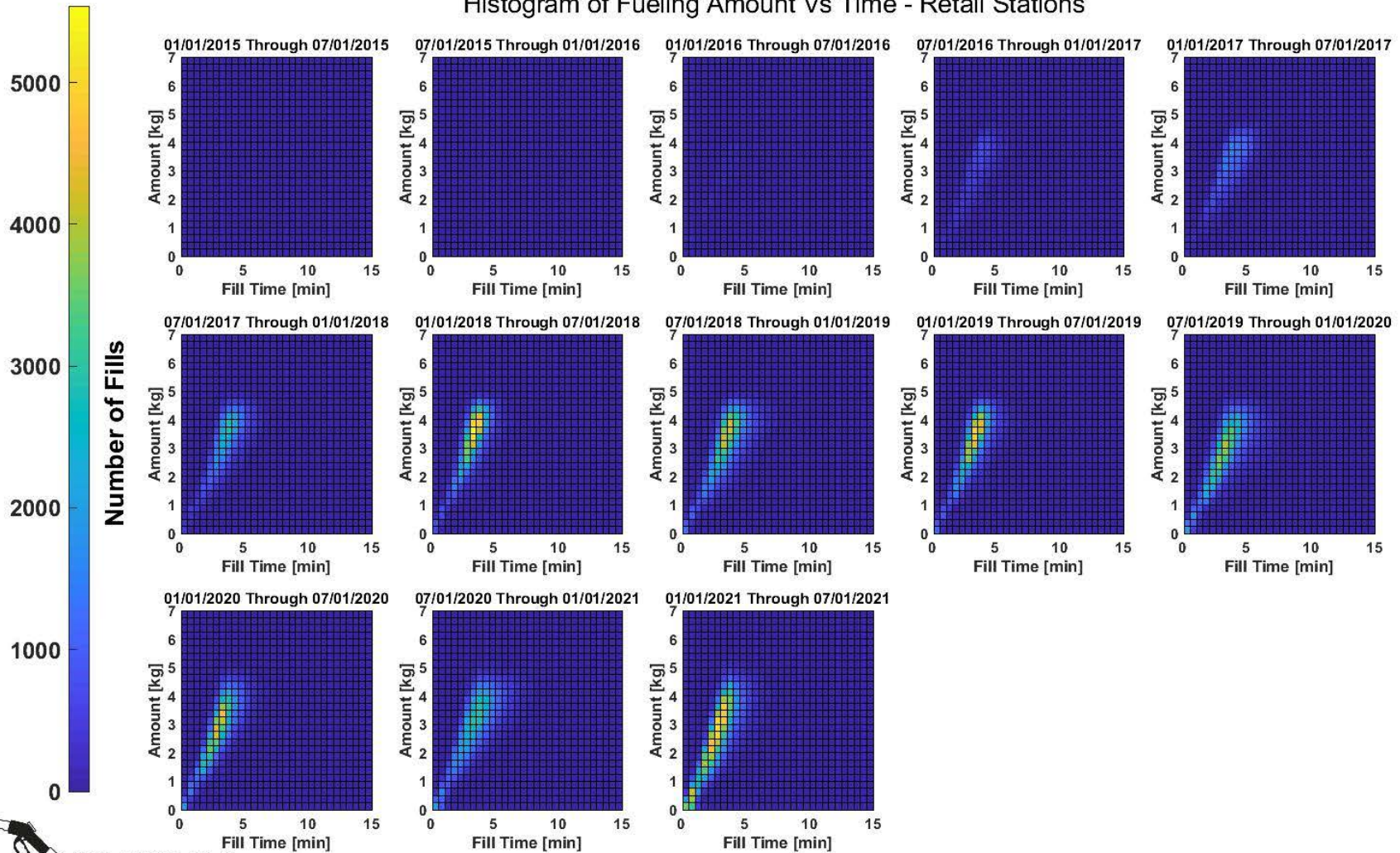
Created: Apr-14-22 3:20 PM | Data Range: 2013Q4-2021Q2

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



NREL cdpRETAIL_infr_17
Created: Mar-08-22 9:29 PM | Data Range: 2014Q3-2021Q2

Histogram of Fueling Amount Vs Time - Retail Stations

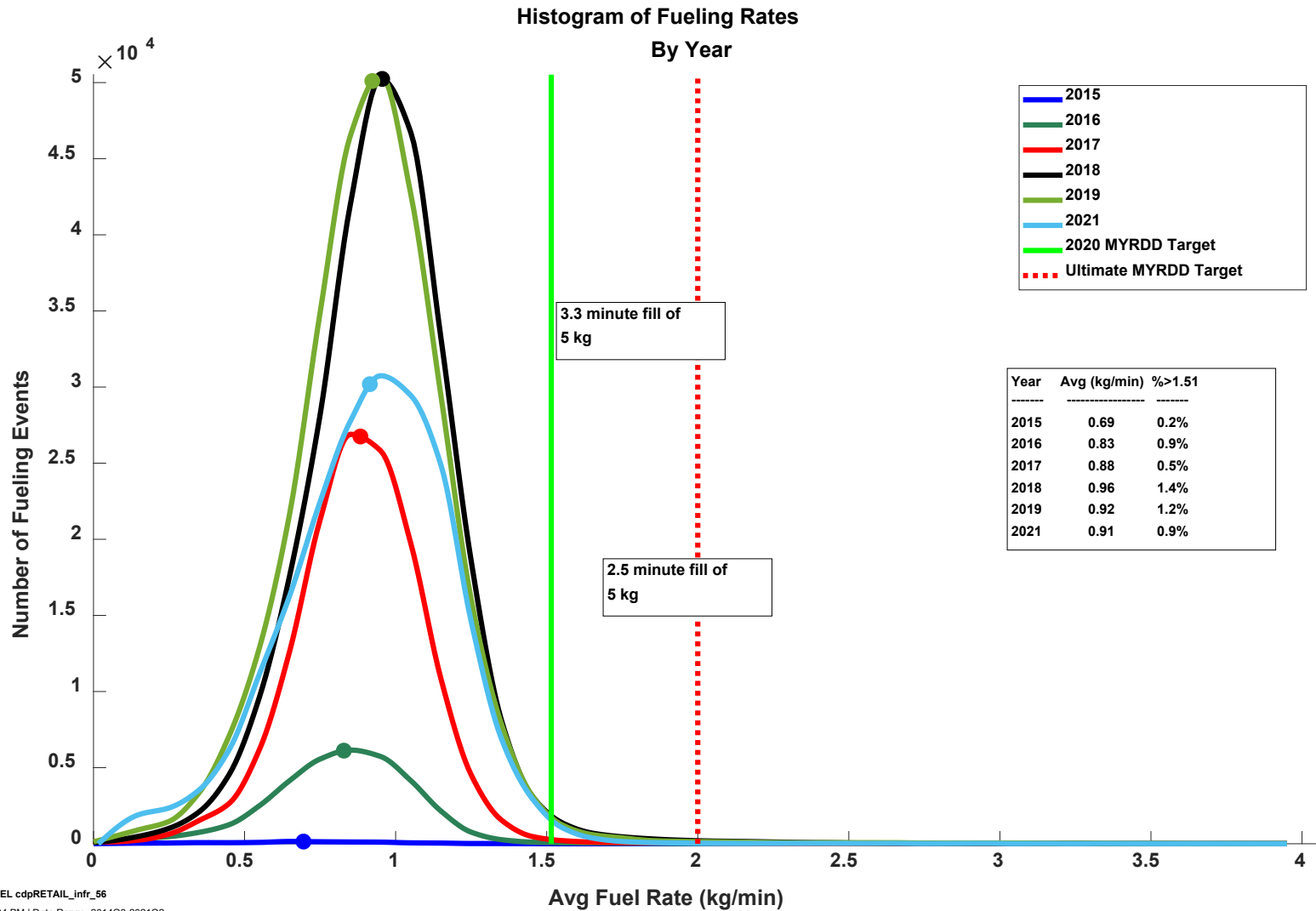


NREL cdpRETAIL_infr_18

Created: Mar-08-22 8:43 PM | Data Range: 2014Q3-2021Q2

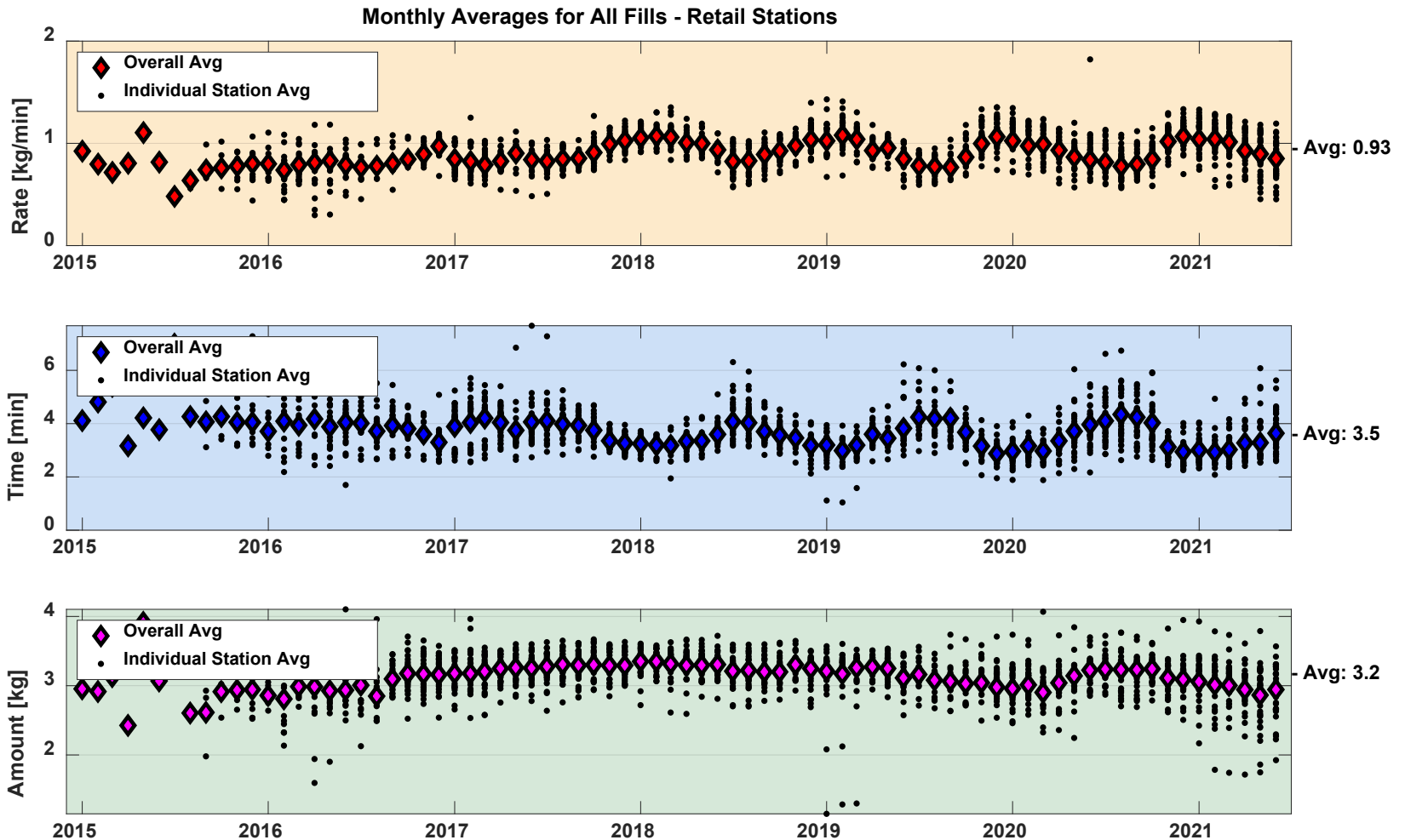
CDP-INFR-56


Fueling Rates by Year



NREL cdpRETAIL_infr_56
Created: May-03-22 2:04 PM | Data Range: 2014Q3-2021Q2

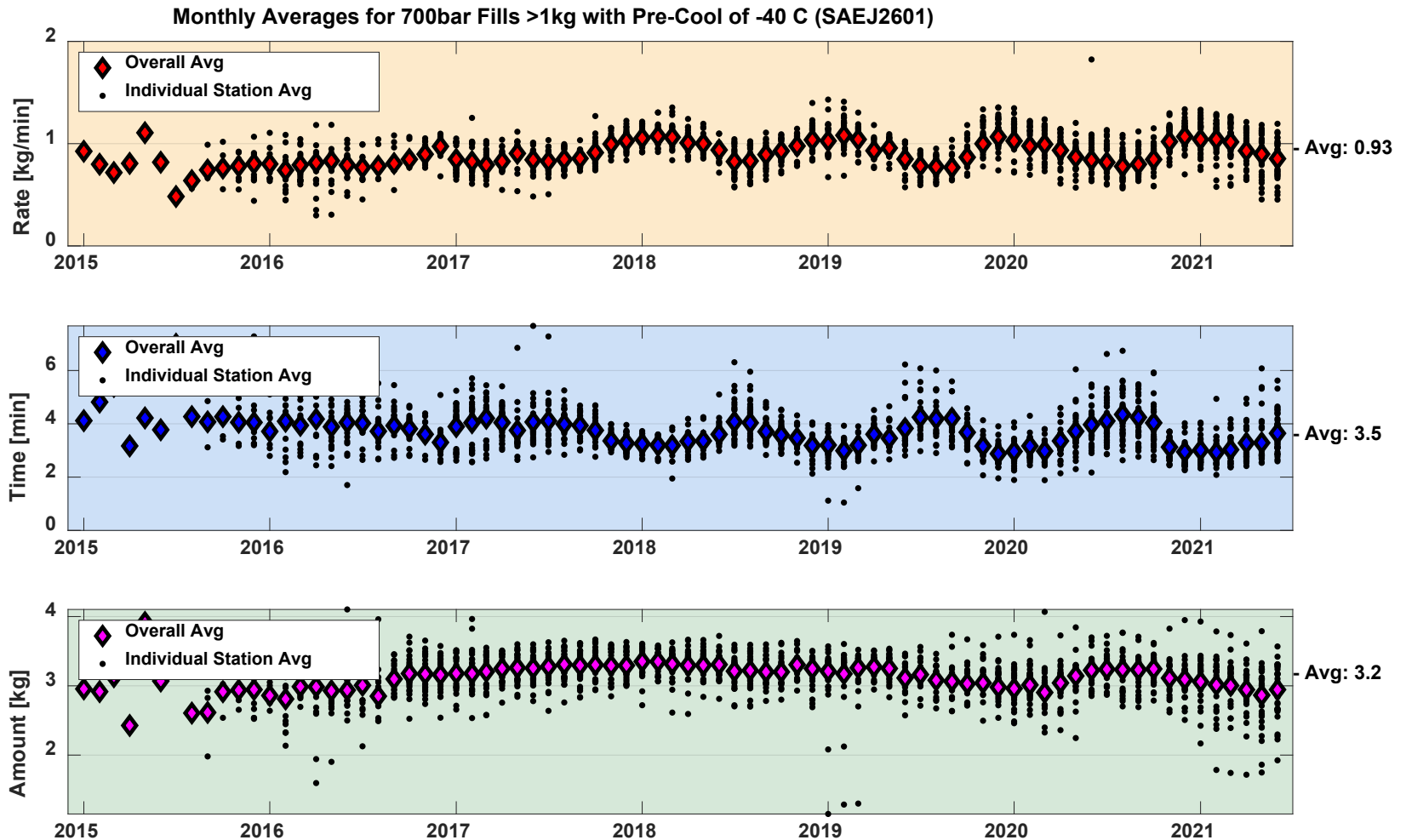
Monthly Averages: All Fills



 NREL cdpRETAIL_infr_55
Created: Mar-08-22 7:09 PM | Data Range: 2014Q3-2021Q2

CDP-INFR-57

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

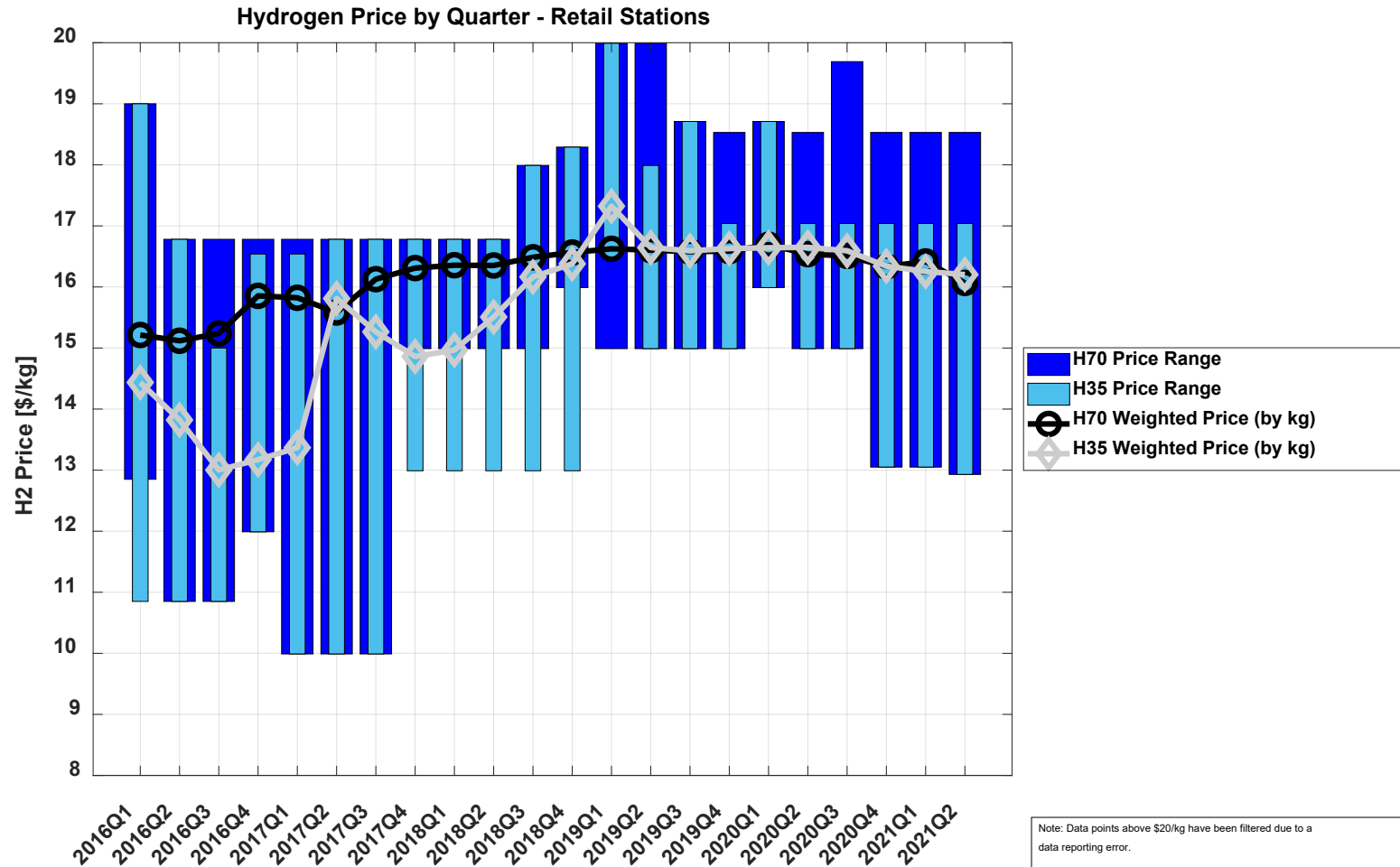


NREL cdpRETAIL_infr_57

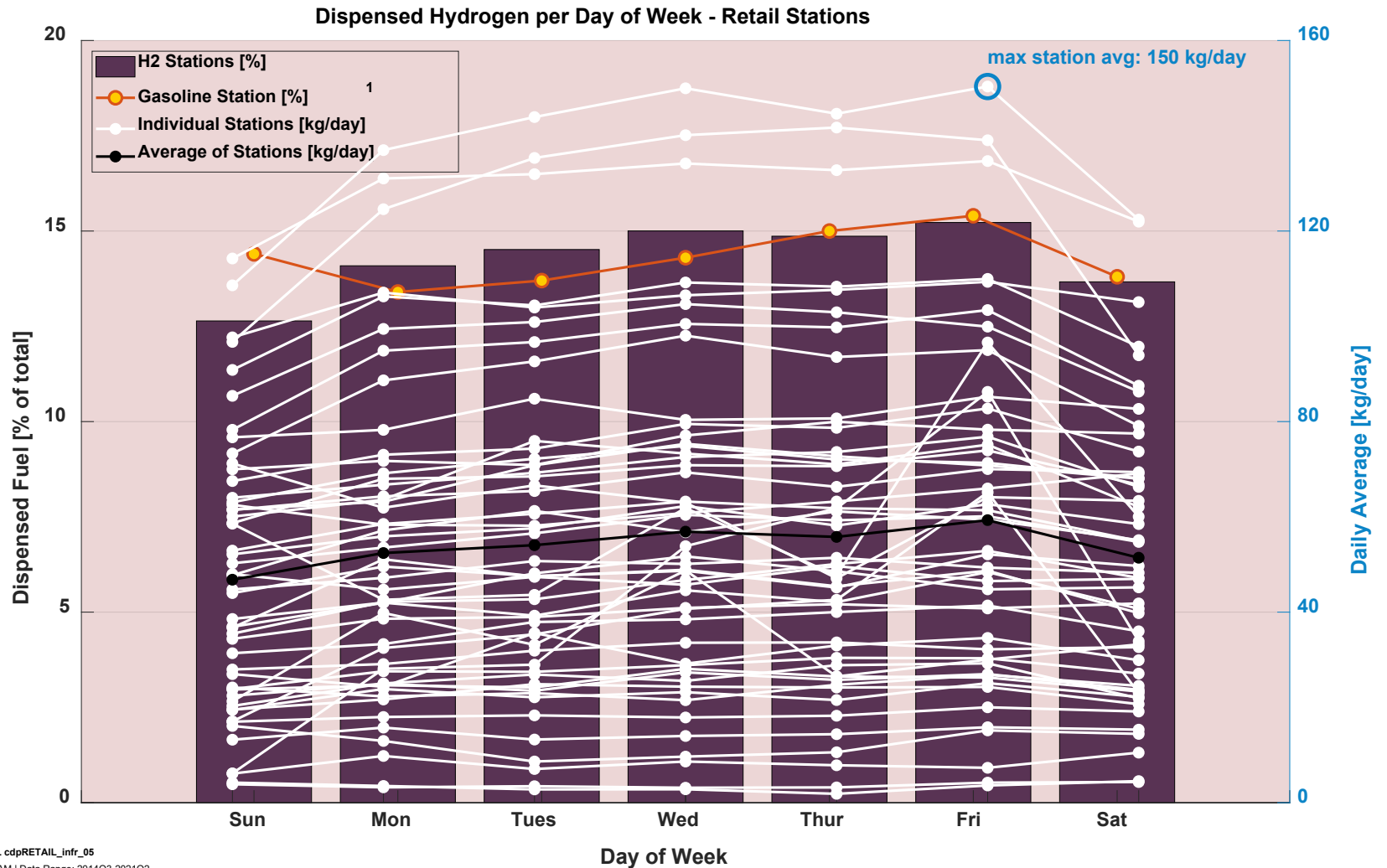
Created: Mar-08-22 5:33 PM | Data Range: 2014Q3-2021Q2

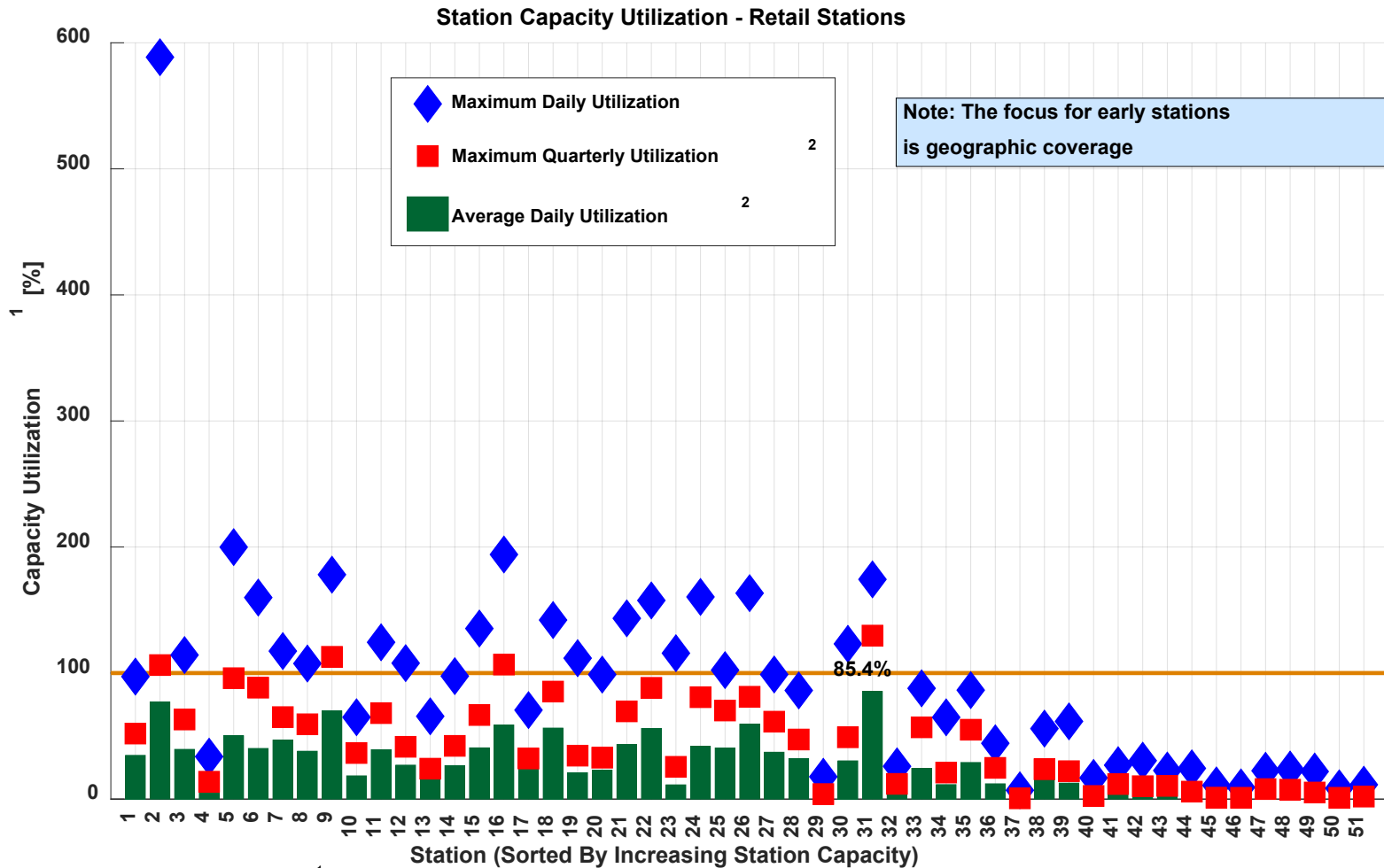
Cost

Hydrogen Price by Quarter



Utilization



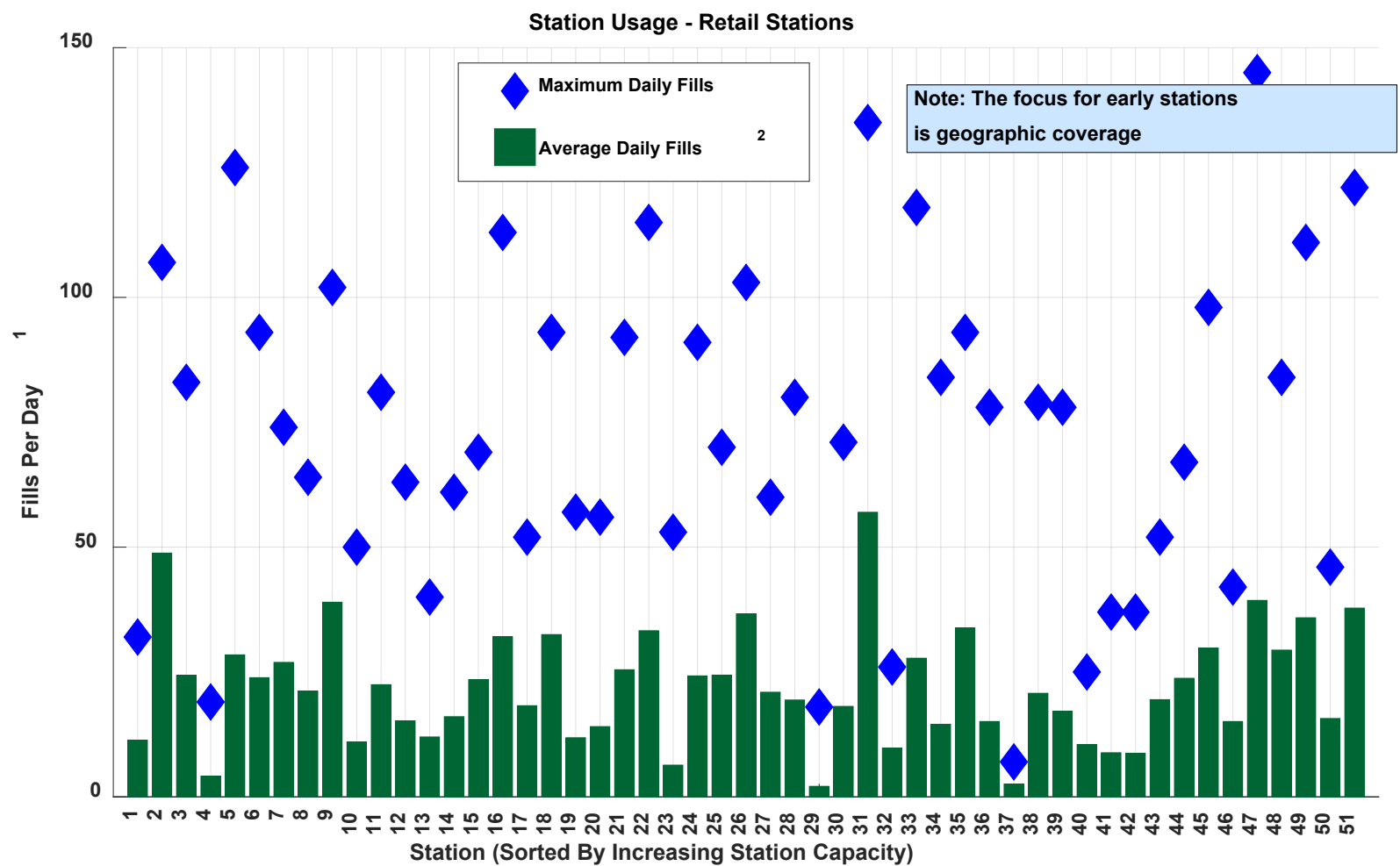


¹ Station nameplate capacity reflects a variety of system design considerations including system capacity, throughput, system reliability and durability, and maintenance. Actual daily usage may exceed nameplate capacity.

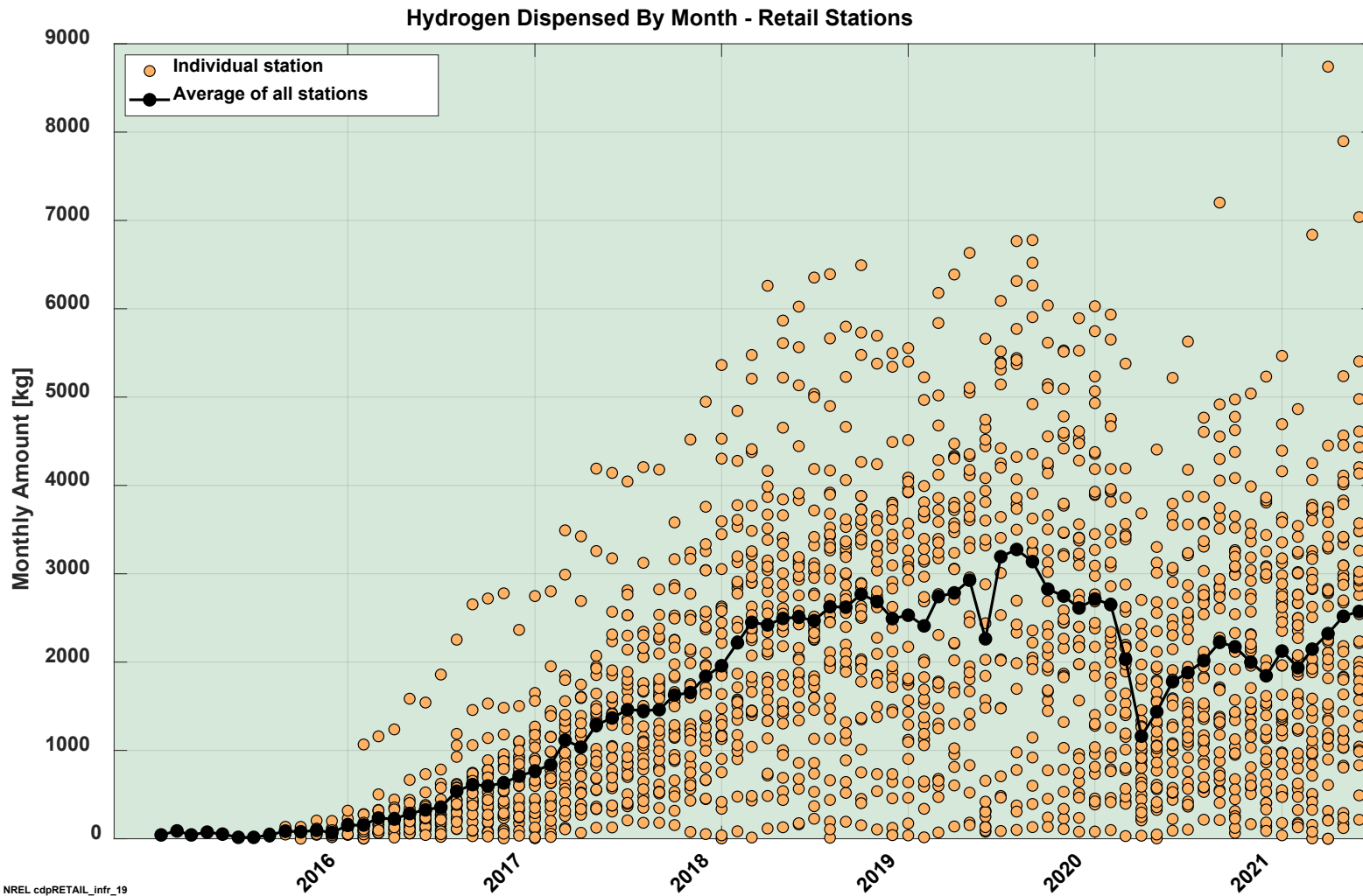
² Maximum quarterly utilization considers all days; average daily utilization considers only days when at least one filling occurred

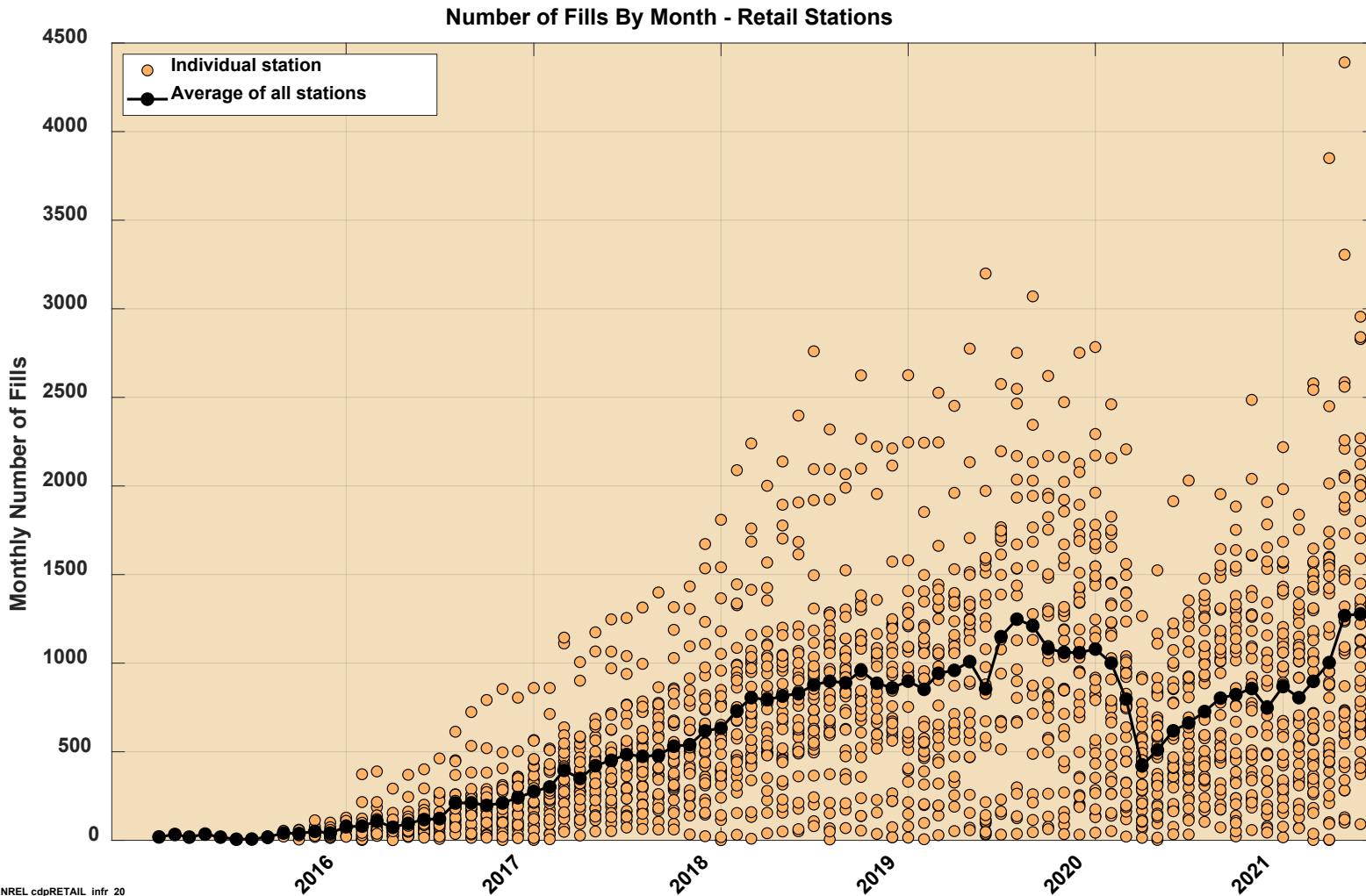
CDP-INFR-07

Station Usage



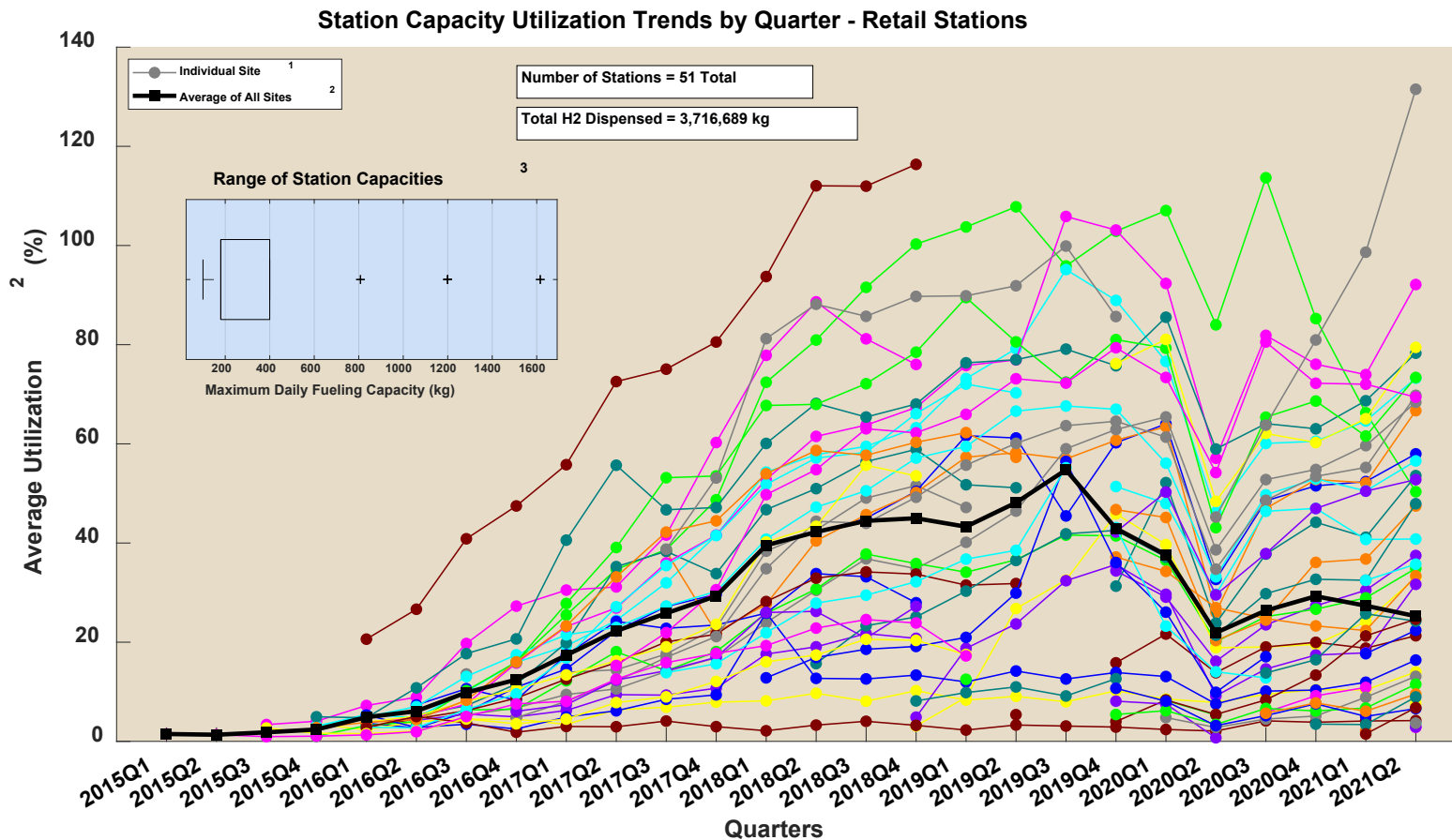
¹ Excludes hydrogen fills of < 0.5 kg
² Average daily fills considers only days when at least one fill occurred





NREL cdpRETAIL_infr_20

Created: Apr-14-22 10:21 AM | Data Range: 2014Q3-2021Q2



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.

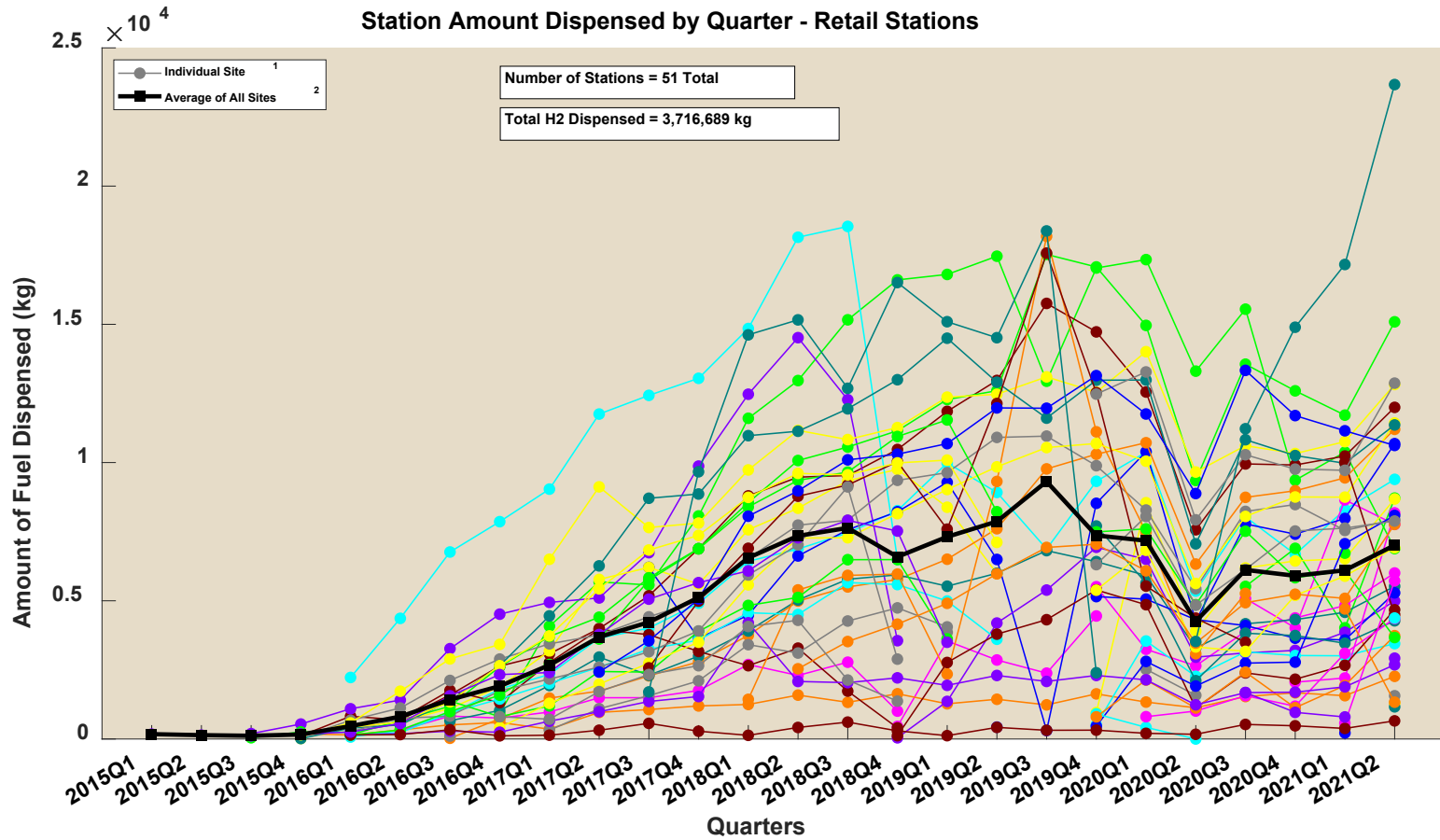
² Average quarterly utilization only considers quarters when at least one fill occurred.

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



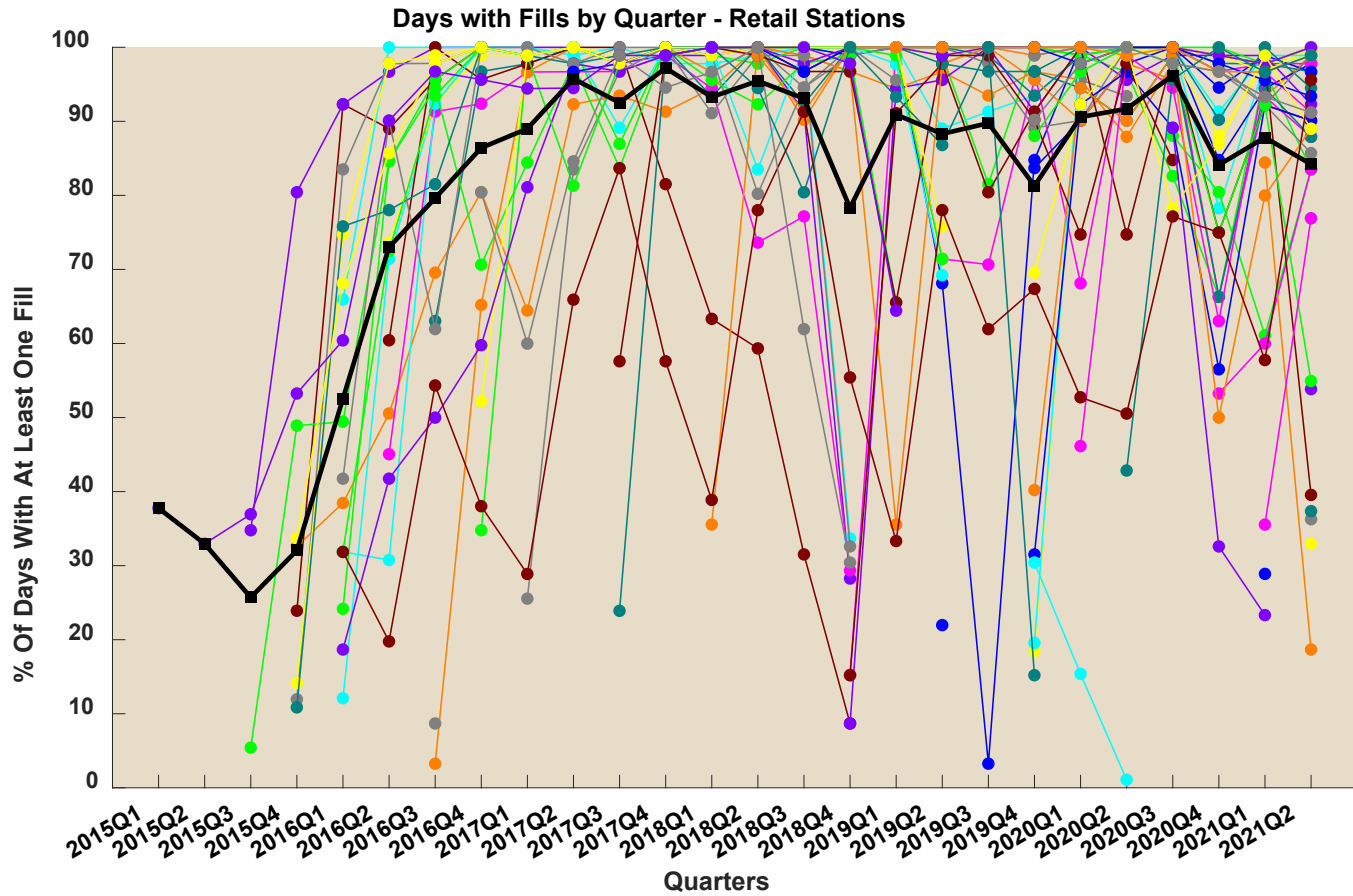
¹ Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

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



NREL cdpRETAIL_infr_45

Created: Apr-21-22 3:44 PM | Data Range: 2014Q3-2021Q2

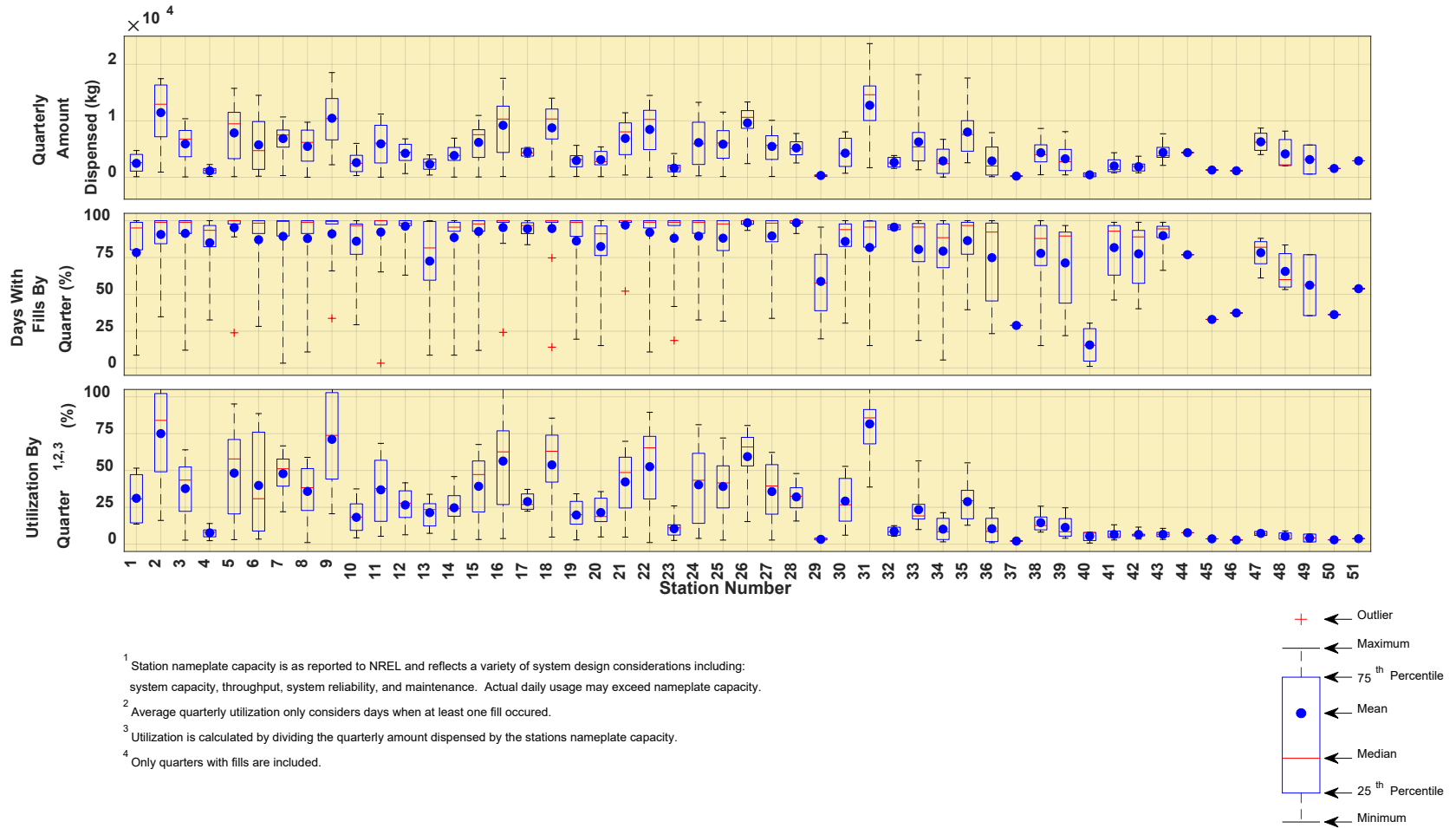


¹ Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station had no fills or was missing data. Each station is represented by a unique color.

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



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

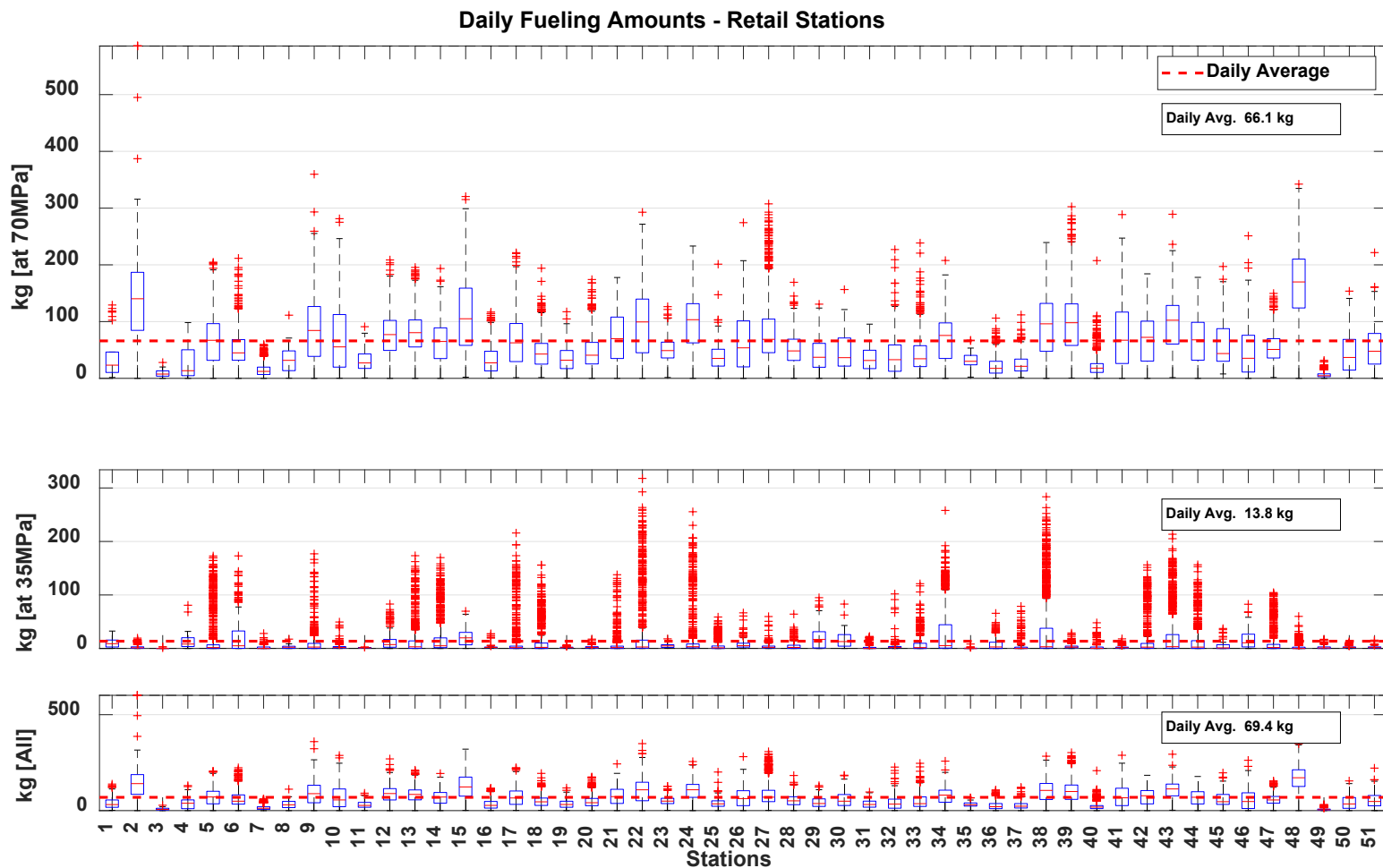
² Average quarterly utilization only considers days when at least one fill occurred.

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

⁴ Only quarters with fills are included.

CDP-INFR-80

Daily Fueling Amounts by Station

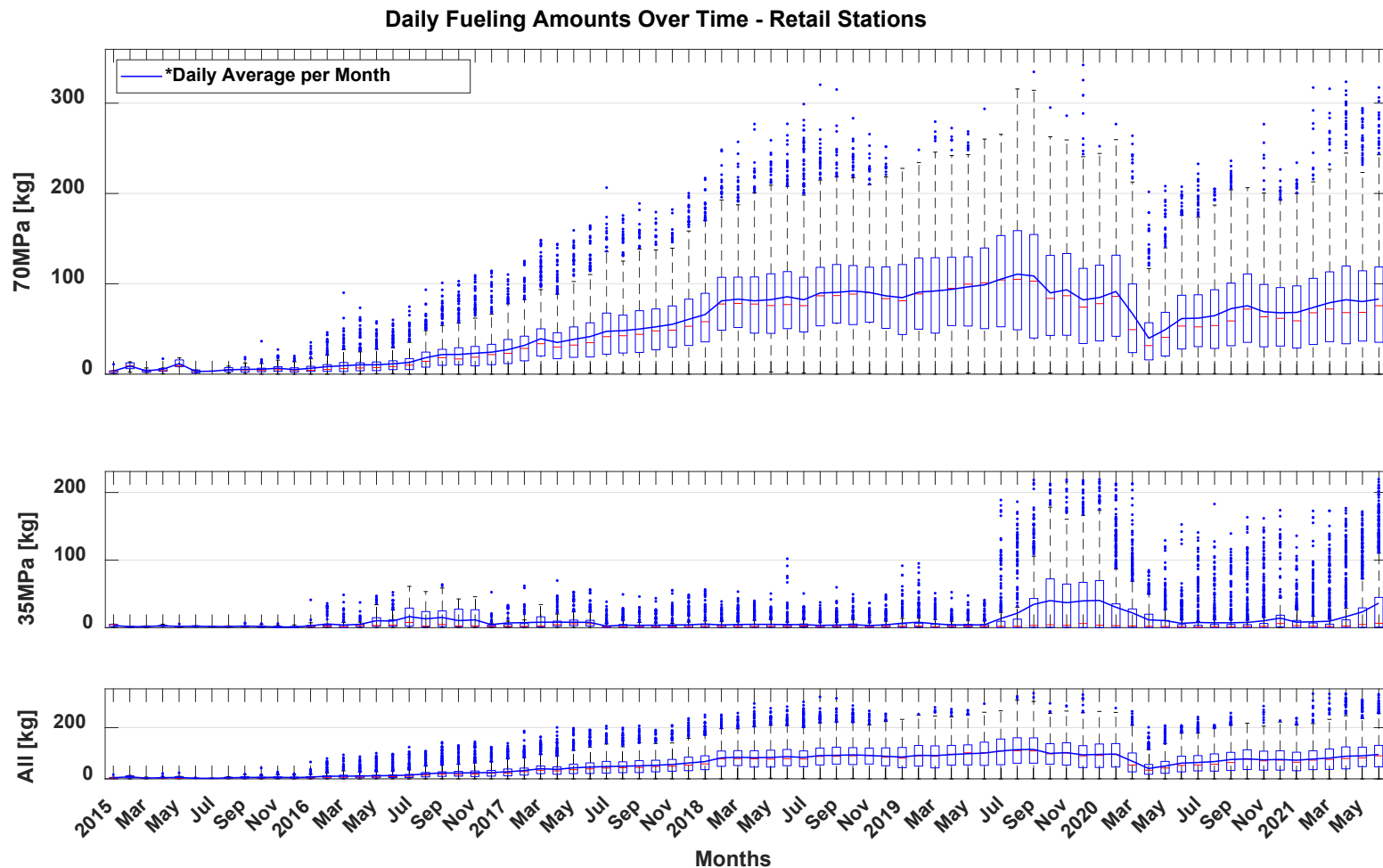


NREL cdpRETAIL_infr_80

Created: May-10-22 11:43 AM | Data Range: 2014Q3-2021Q2

Note: Some outliers clipped.

Daily Fueling Amounts by Month

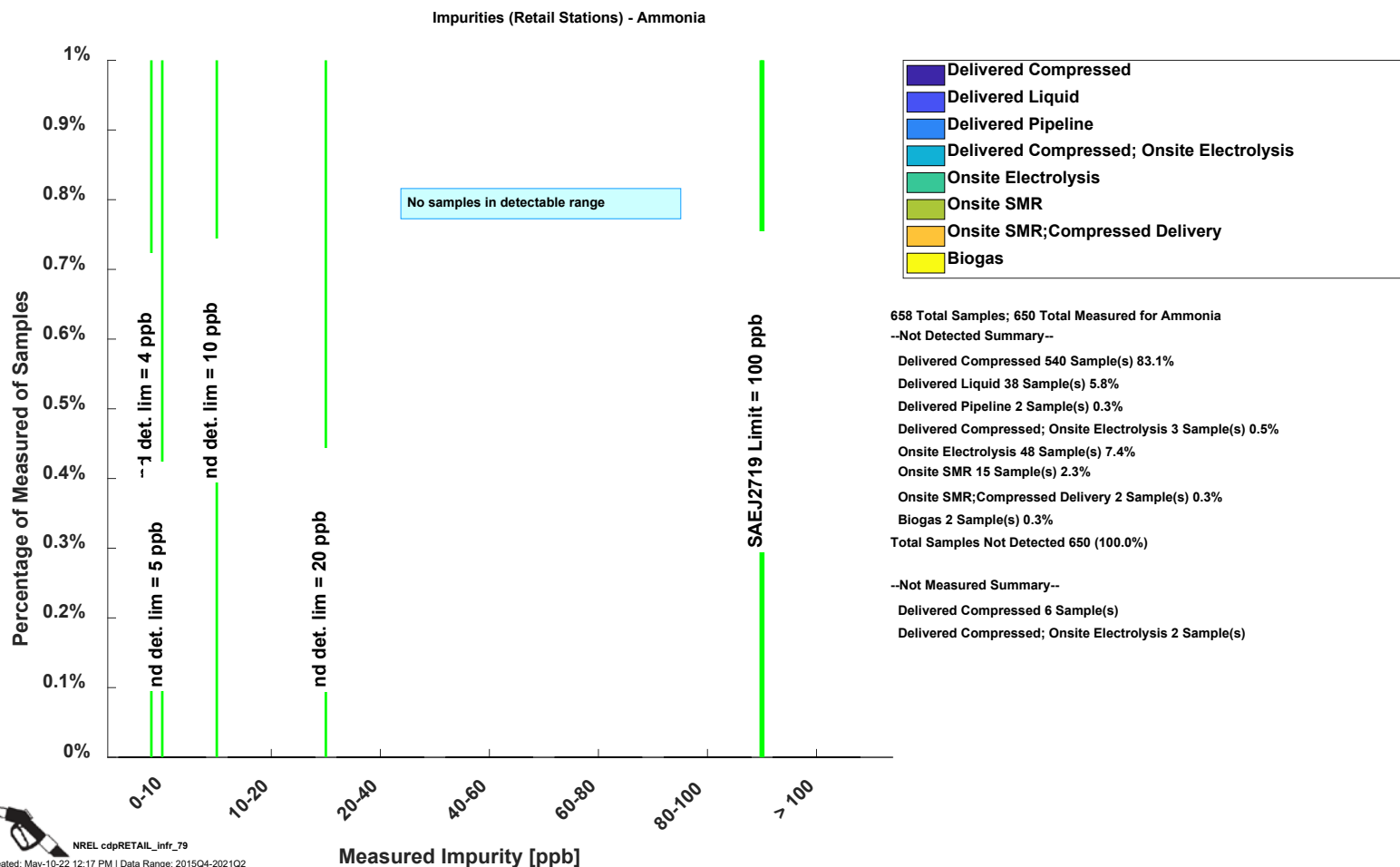


NREL cdpRETAIL_infr_82

Created: Apr-14-22 11:36 AM | Data Range: 2014Q3-2021Q2

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

Hydrogen Quality



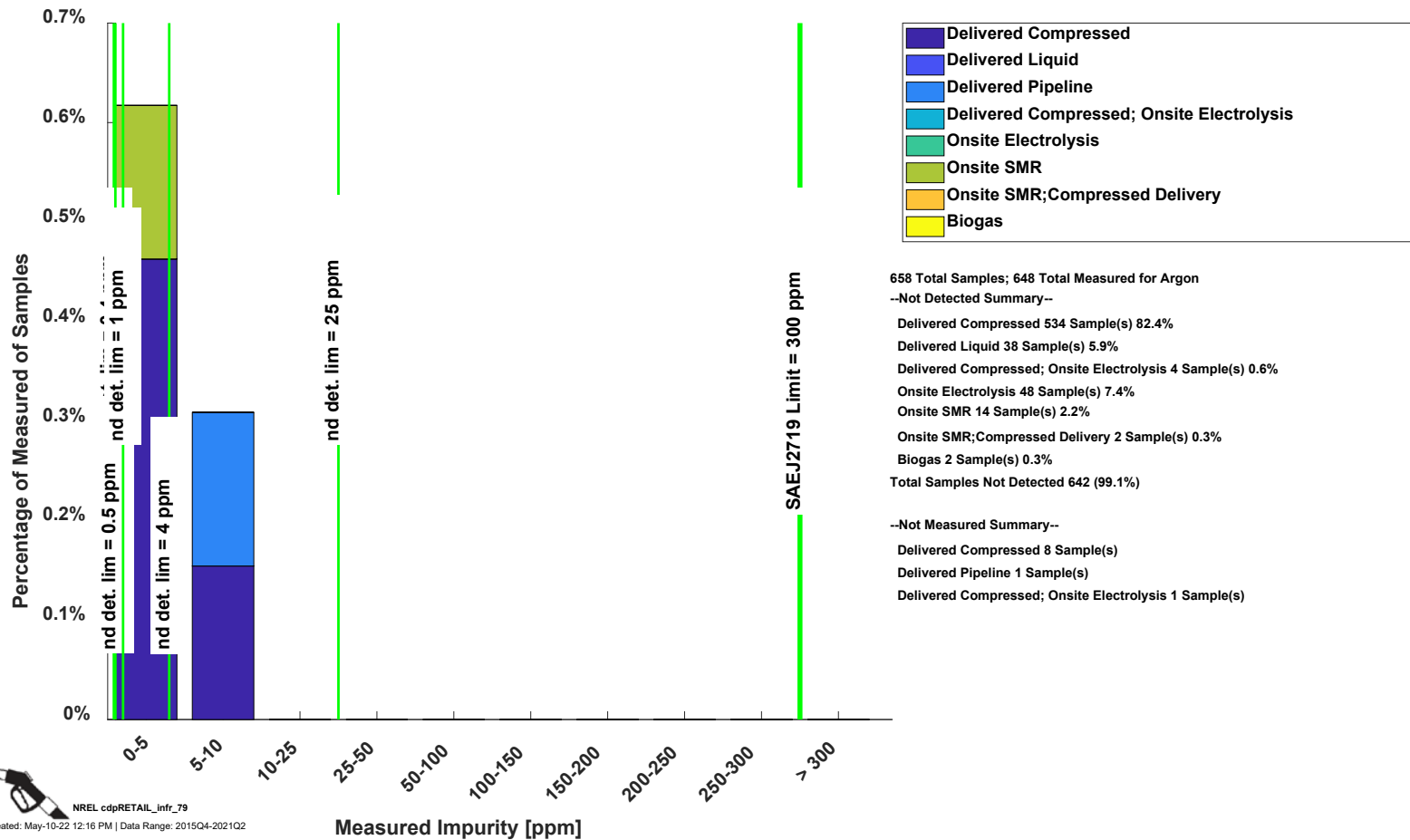
NREL cdpRETAIL_infr_79

Created: May-10-22 12:17 PM | Data Range: 2015Q4-2021Q2

CDP-INFR-79

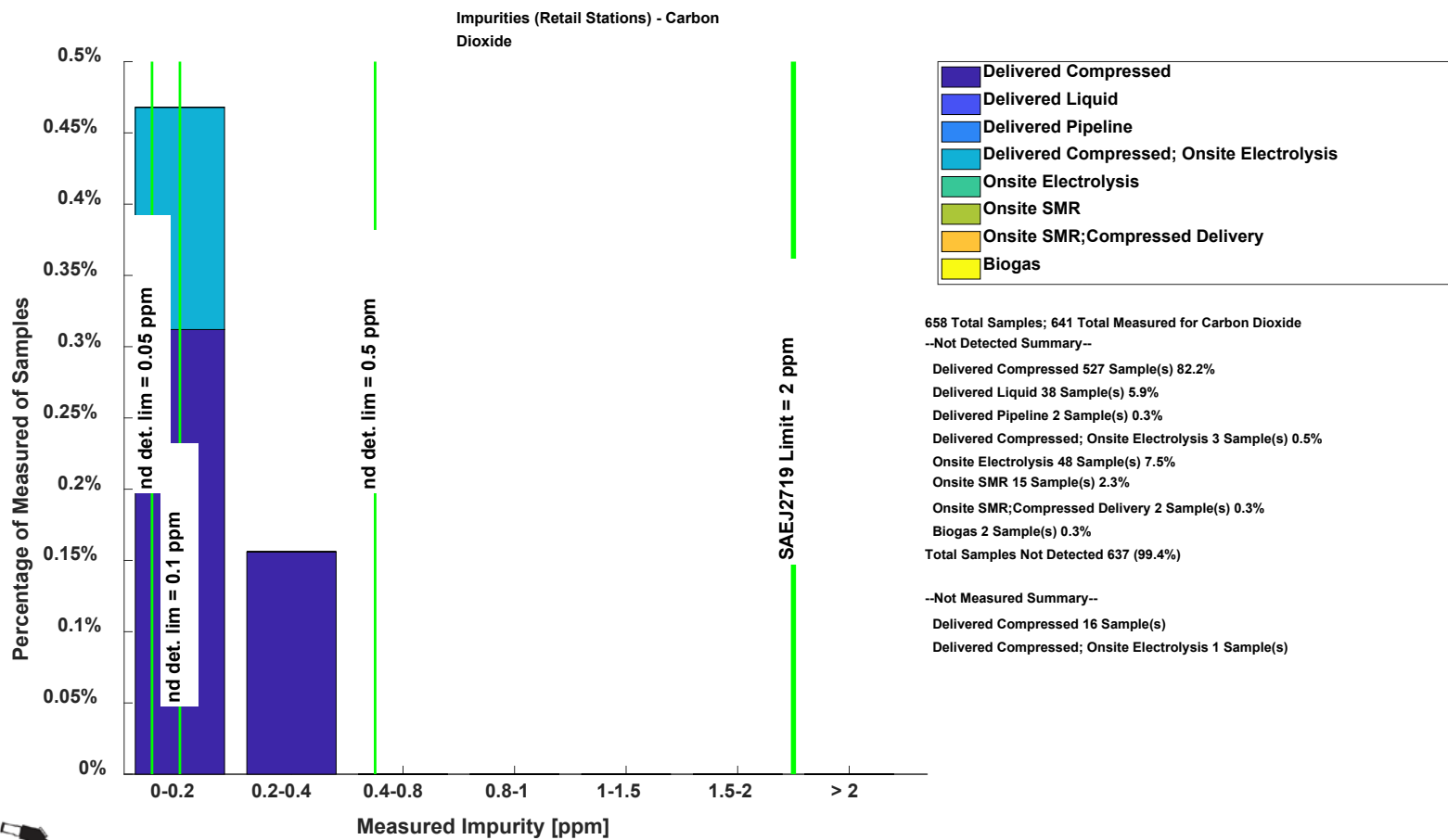
Impurities—Argon

Impurities (Retail Stations) - Argon



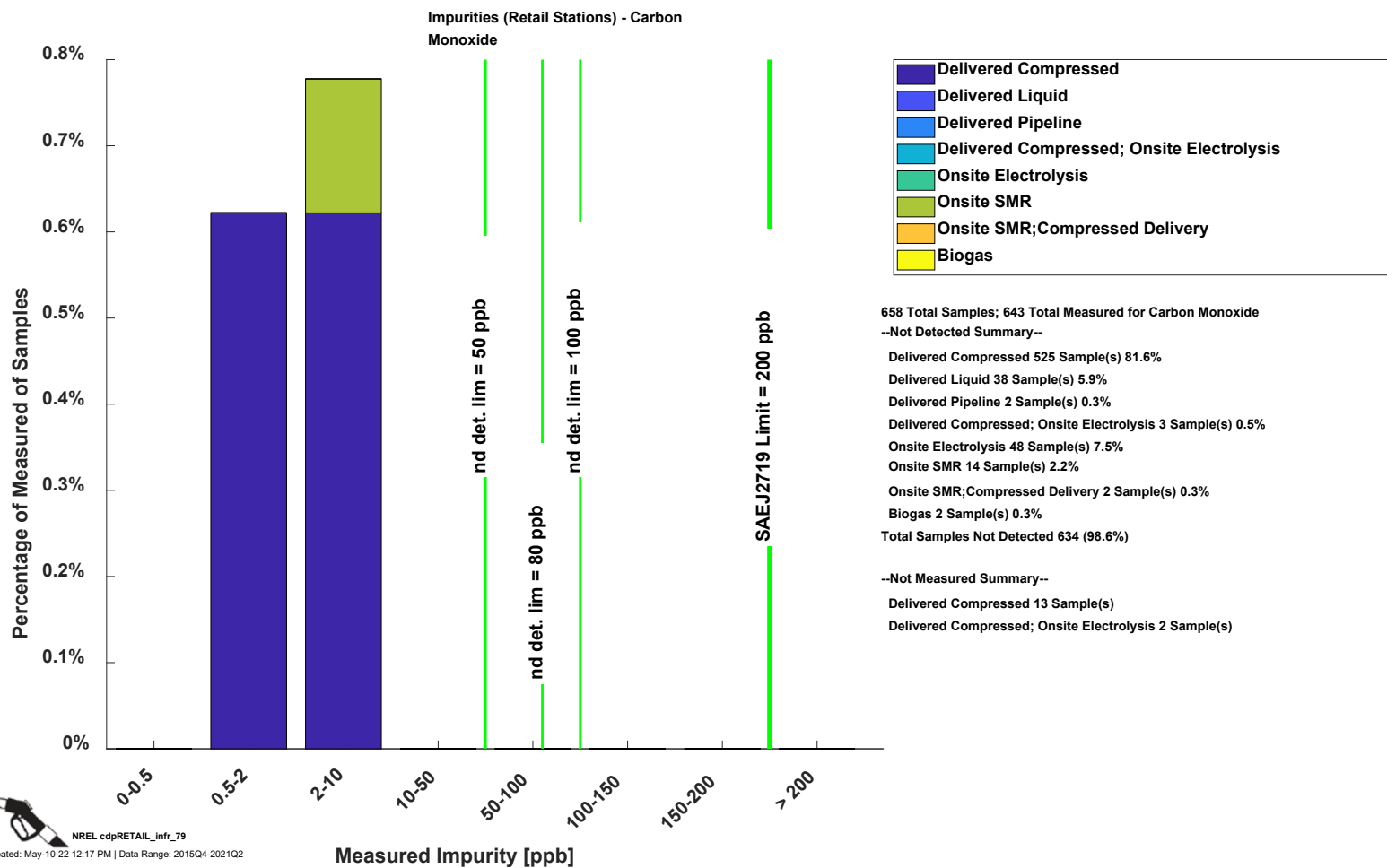
NREL cdpRETAIL_infr_79

Created: May-10-22 12:16 PM | Data Range: 2015Q4-2021Q2



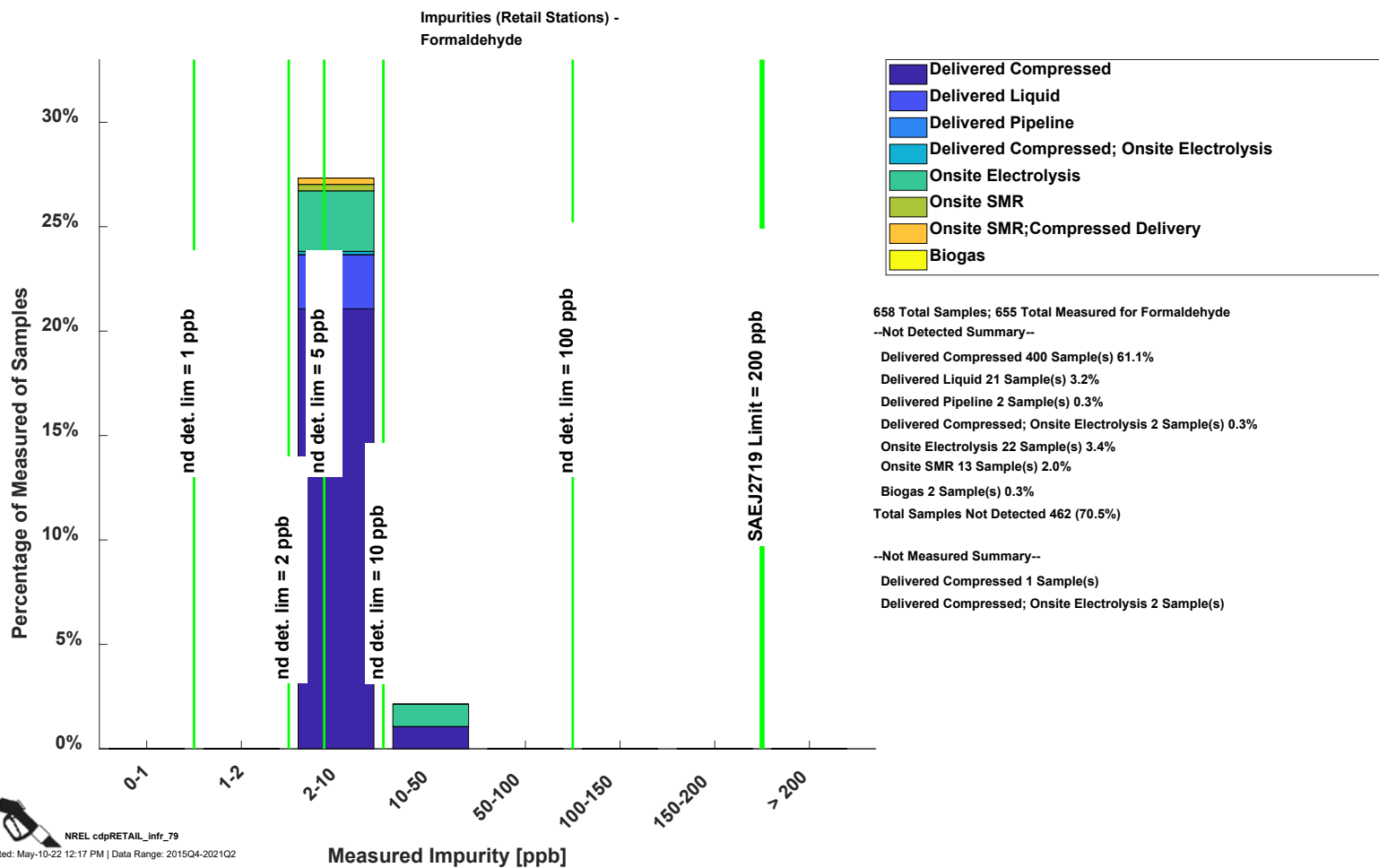
NREL cdpRETAIL_infr_79

Created: May-10-22 12:16 PM | Data Range: 2015Q4-2021Q2



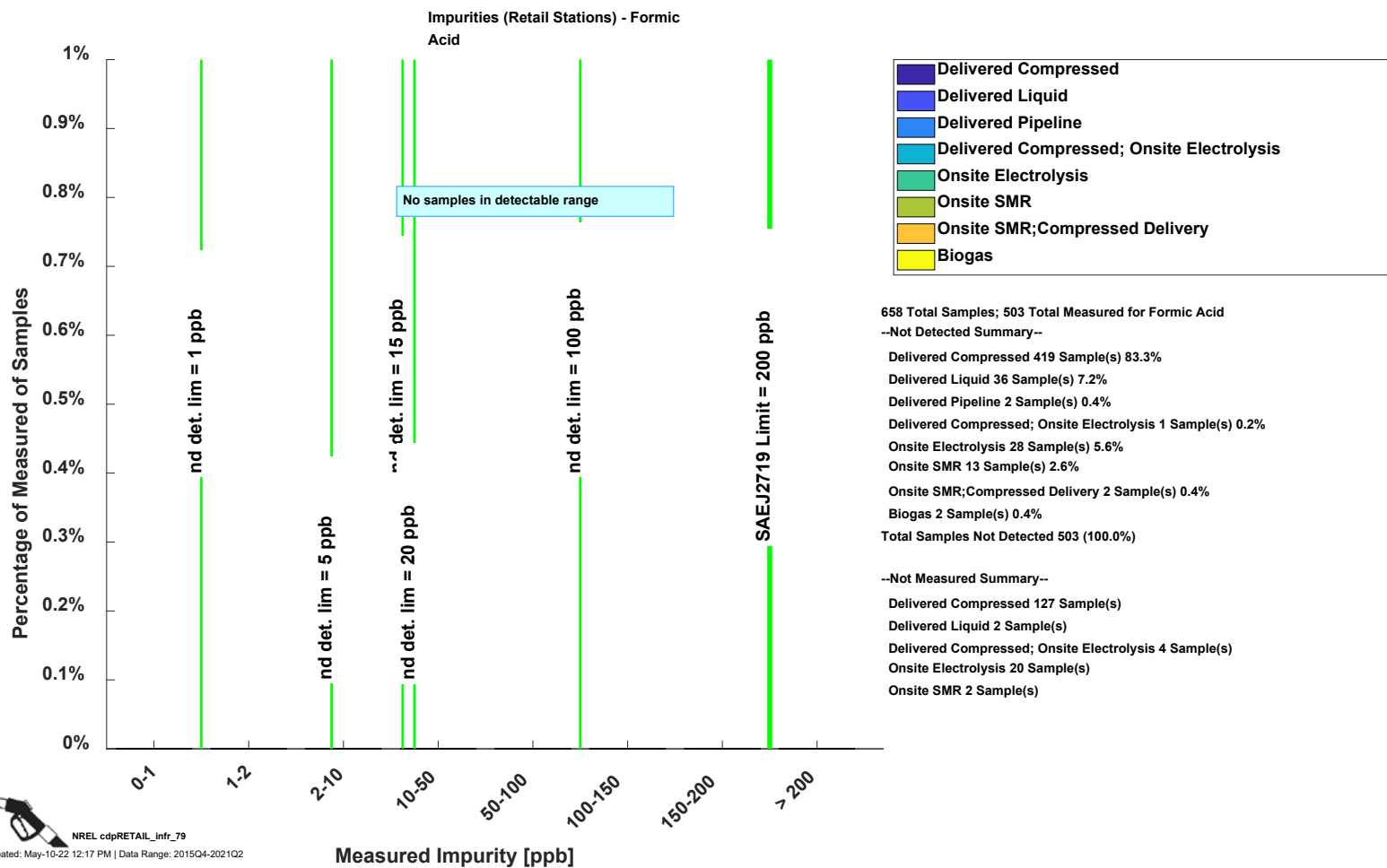
NREL cdpRETAIL_infr_79

Created: May-10-22 12:17 PM | Data Range: 2015Q4-2021Q2



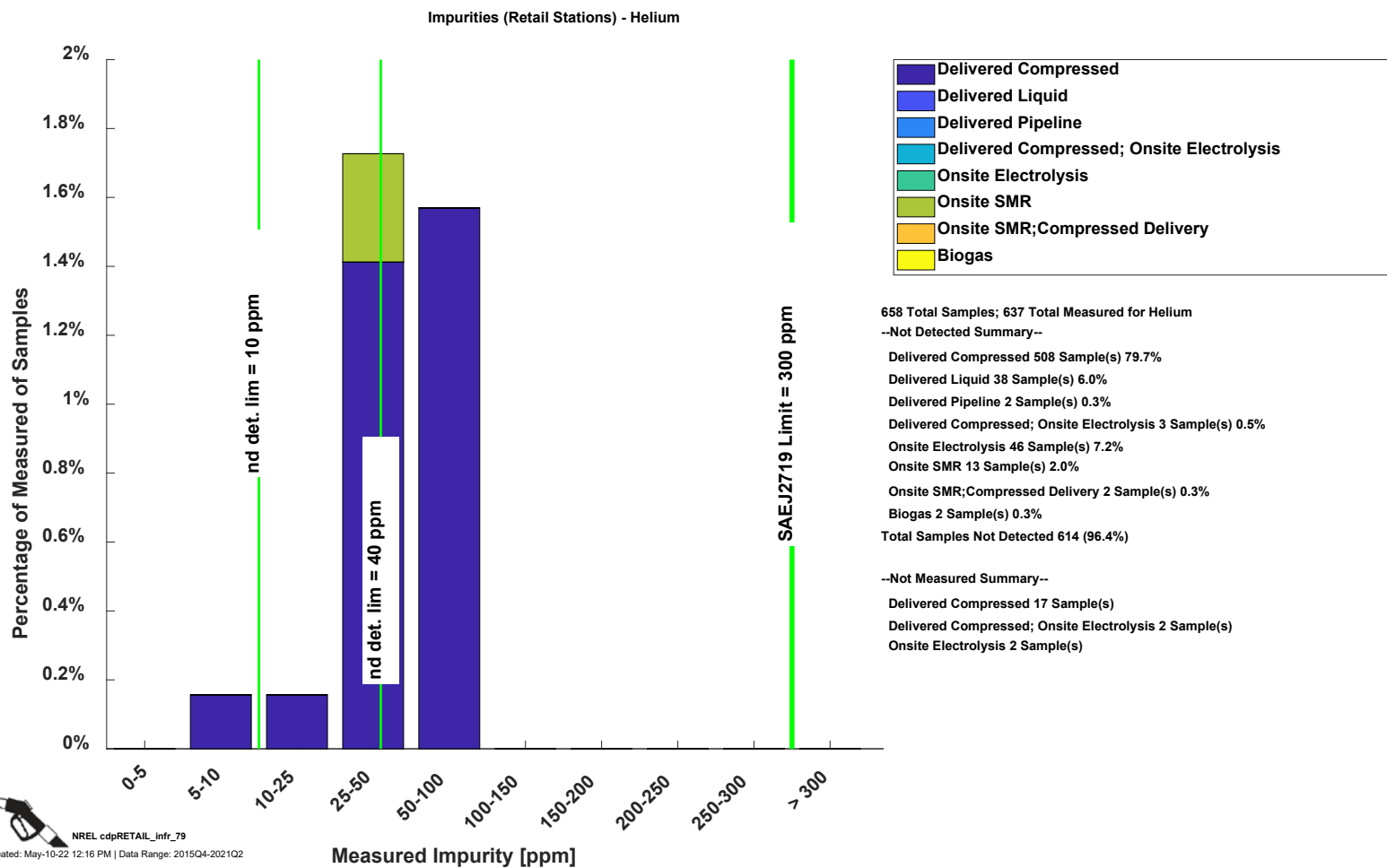
NREL cdpRETAIL_infr_79

Created: May-10-22 12:17 PM | Data Range: 2015Q4-2021Q2

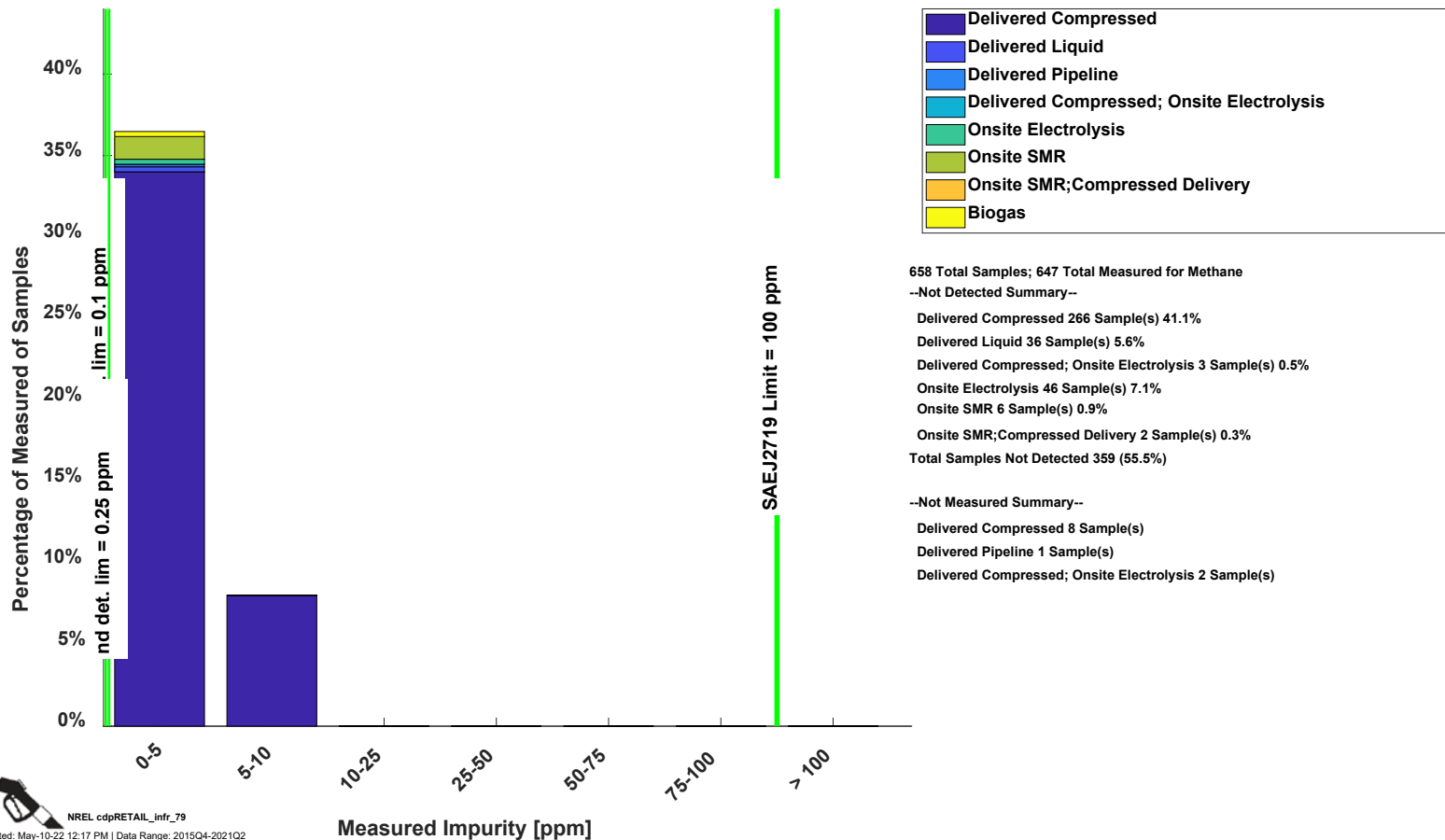


NREL cdpRETAIL_infr_79

Created: May-10-22 12:17 PM | Data Range: 2015Q4-2021Q2

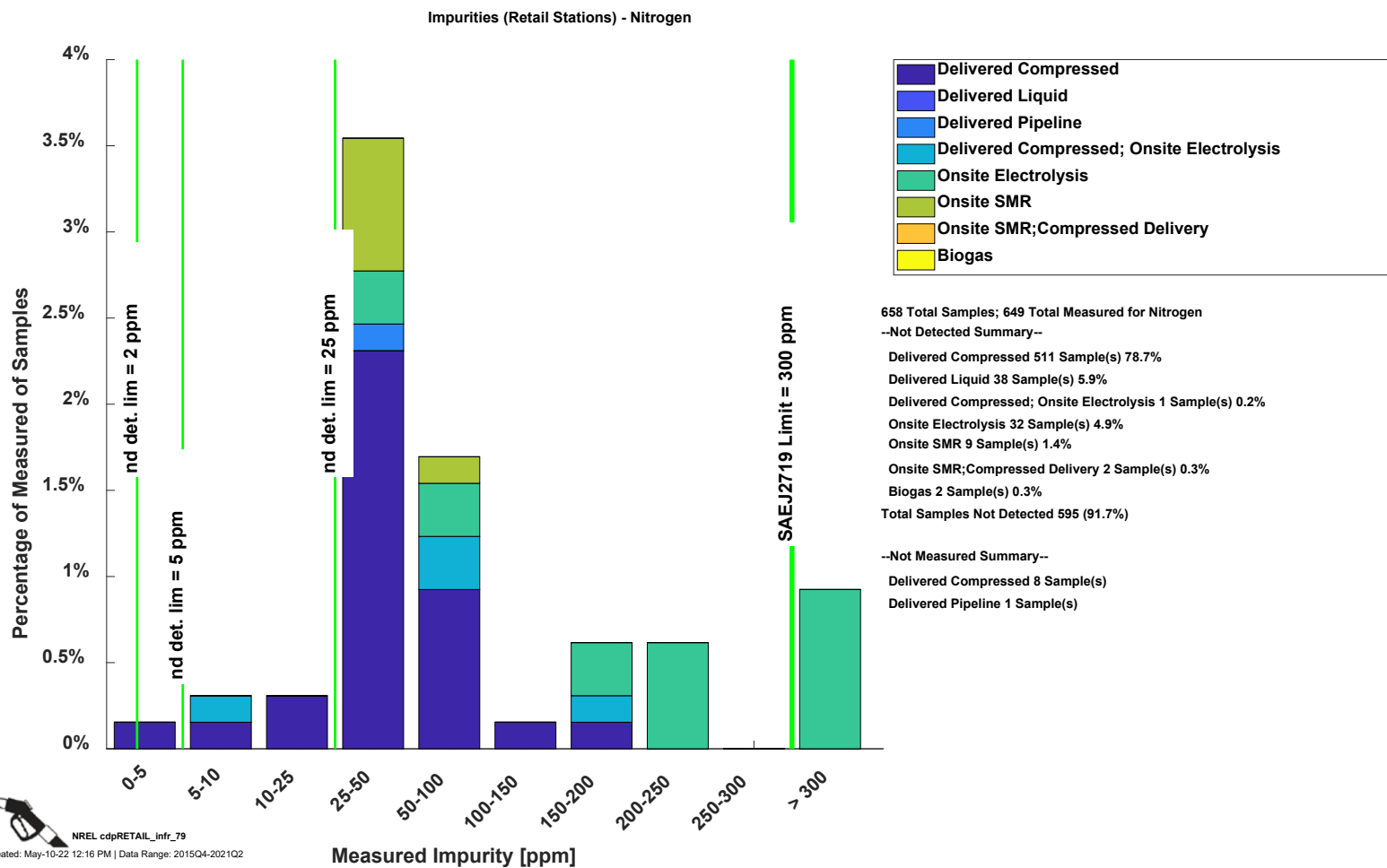


Impurities (Retail Stations) - Methane



NREL cdpRETAIL_infr_79

Created: May-10-22 12:17 PM | Data Range: 2015Q4-2021Q2

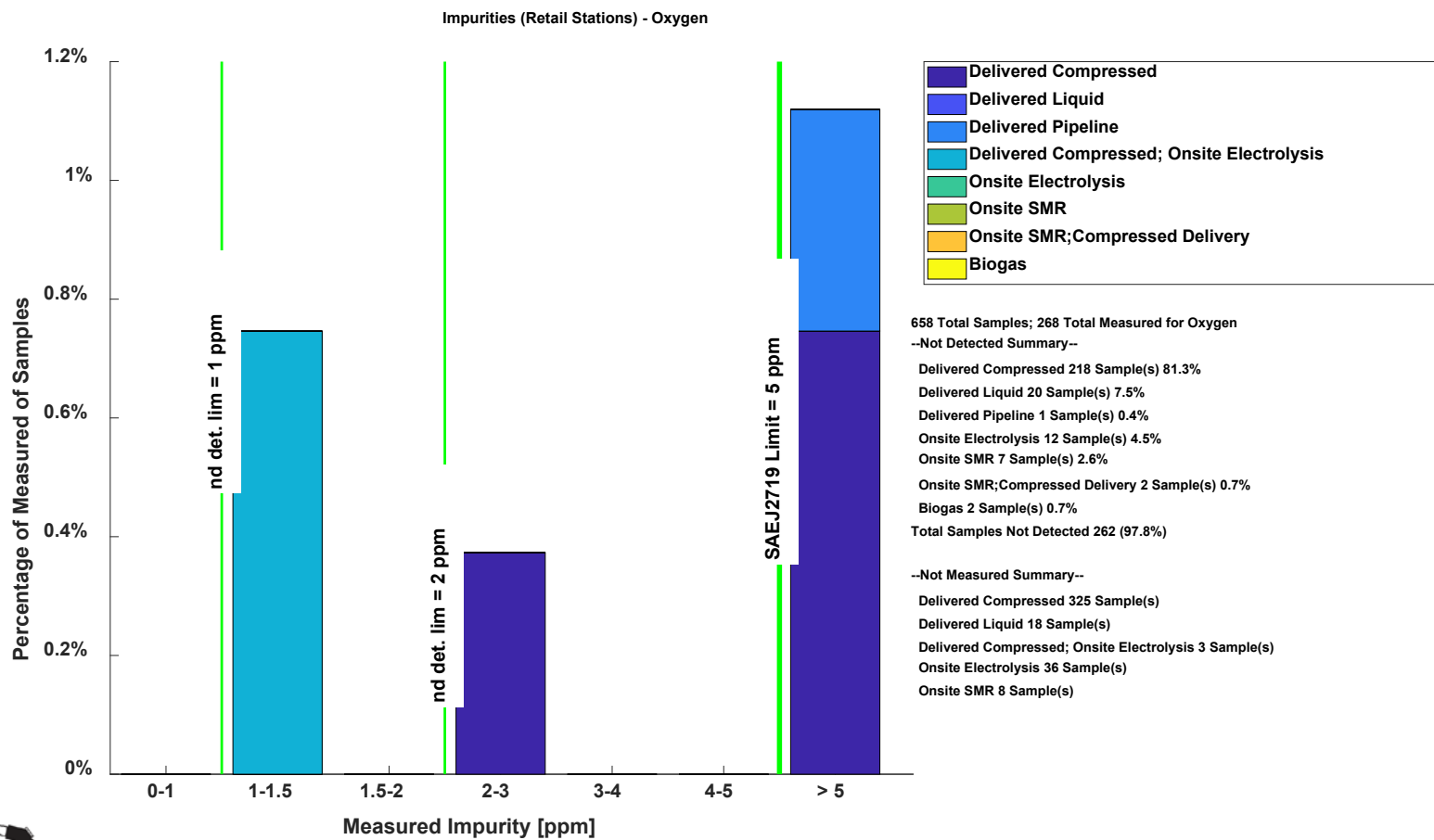


NREL cdpRETAIL_infr_79

Created: May-10-22 12:16 PM | Data Range: 2015Q4-2021Q2

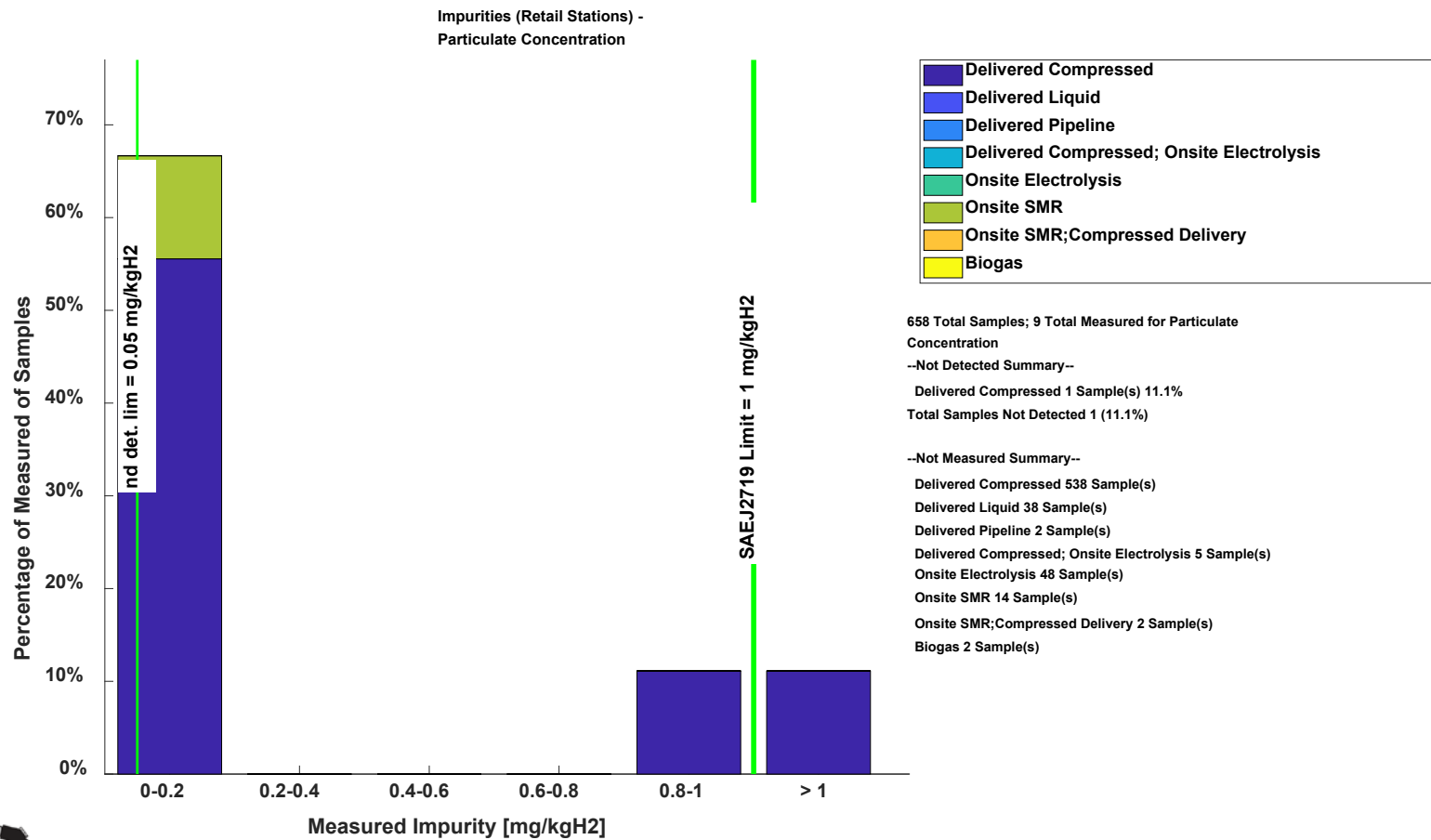
CDP-INFR-79

Impurities—Oxygen



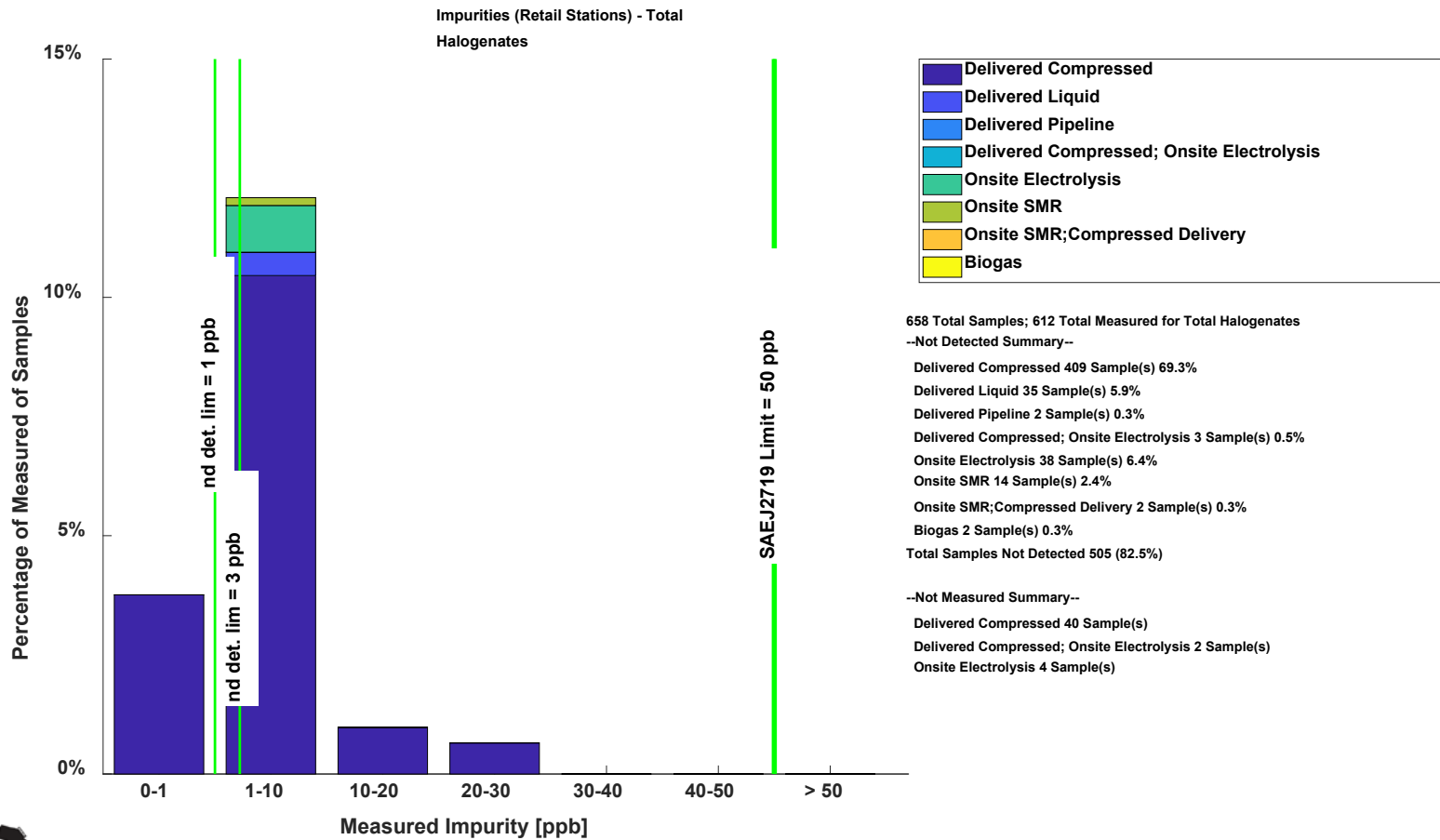
NREL cdpRETAIL_infr_79

Created: May-10-22 12:16 PM | Data Range: 2015Q4-2021Q2



NREL cdpRETAIL_infr_79

Created: May-10-22 12:17 PM | Data Range: 2015Q4-2021Q2



658 Total Samples; 612 Total Measured for Total Halogenates

--Not Detected Summary--

- Delivered Compressed 409 Sample(s) 69.3%
- Delivered Liquid 35 Sample(s) 5.9%
- Delivered Pipeline 2 Sample(s) 0.3%
- Delivered Compressed; Onsite Electrolysis 3 Sample(s) 0.5%
- Onsite Electrolysis 38 Sample(s) 6.4%
- Onsite SMR 14 Sample(s) 2.4%
- Onsite SMR; Compressed Delivery 2 Sample(s) 0.3%
- Biogas 2 Sample(s) 0.3%
- Total Samples Not Detected 505 (82.5%)

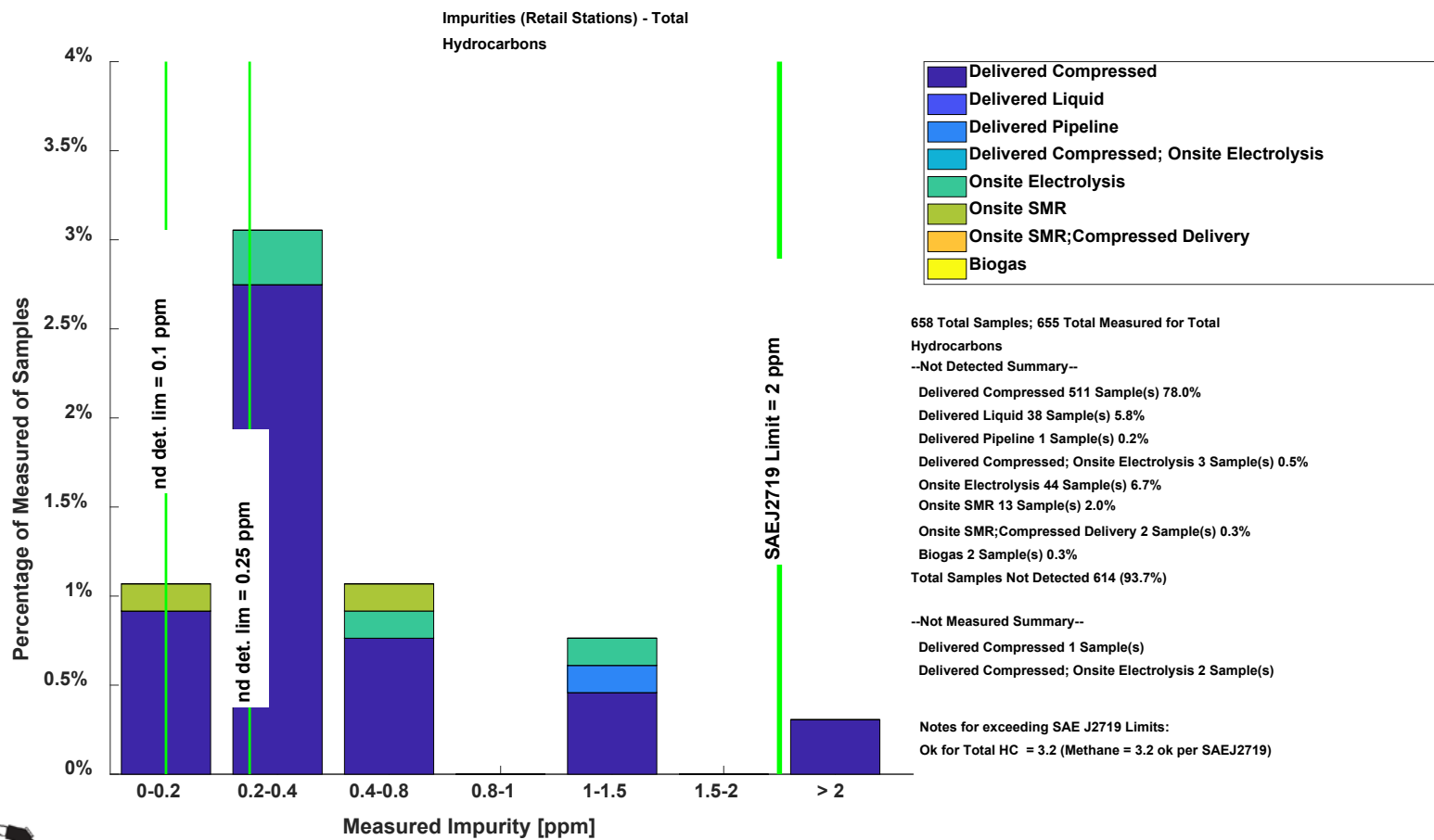
--Not Measured Summary--

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



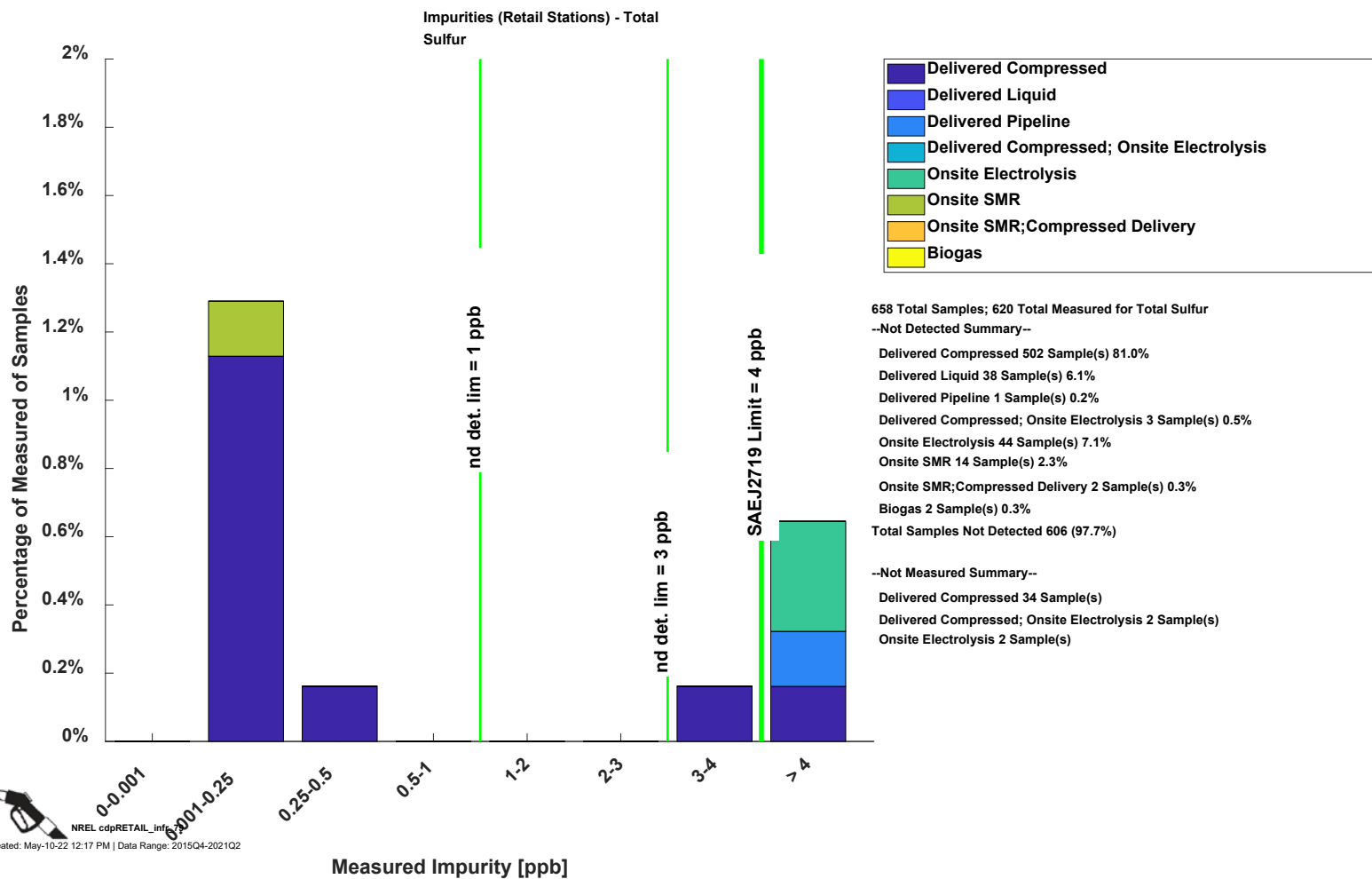
NREL cdpRETAIL_infr_79

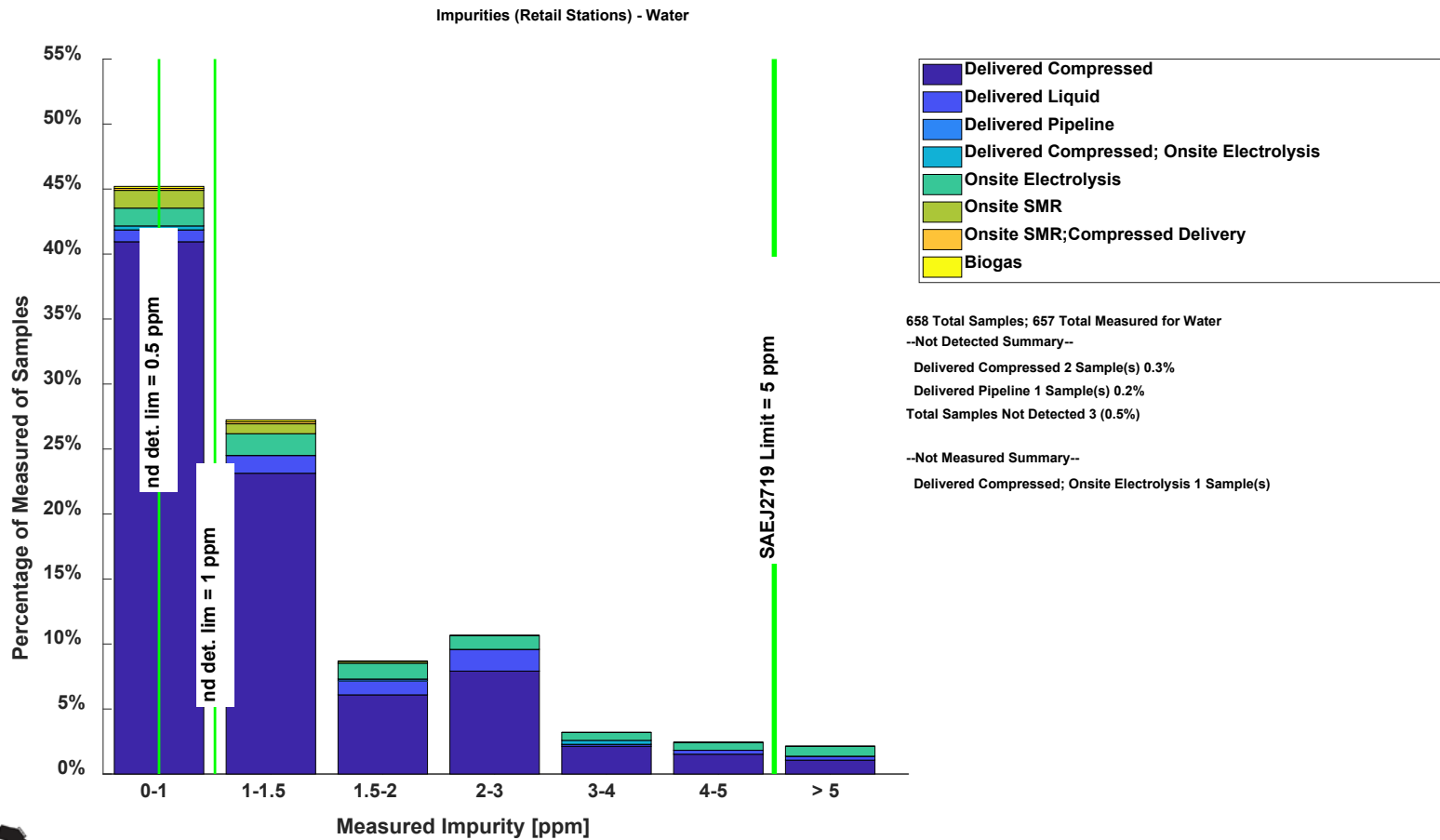
Created: May-10-22 12:17 PM | Data Range: 2015Q4-2021Q2



NREL cdpRETAIL_infr_79

Created: May-10-22 12:16 PM | Data Range: 2015Q4-2021Q2





NREL cdpRETAIL_infr_79

Created: May-10-22 12:16 PM | Data Range: 2015Q4-2021Q2