

# Hydrogen Station Data Collection and Analysis

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National Renewable Energy Laboratory  
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DOE Hydrogen and Fuel Cells Program  
2018 Annual Merit Review and Peer Evaluation Meeting

Project ID TV017

## Timeline and Budget

- Project start date: 10/2011
- FY17 DOE funding: \$300k
- FY18 planned DOE funding: 115k
- Total DOE funds received to date: \$1,485k

## Barriers

- Lack of current hydrogen refueling infrastructure performance and availability data

## Partners

- Industry and agencies listed on collaborations slide

# Relevance: Evaluating Existing Stations/Equipment

## A Developing “Retail” Market

- 34 retail stations open (27 last AMR)
  - All in CA (as of April 2018)
- Supporting 2,473 registered FCEVs in CA (Oct. 2017, AB8 Report\*)
  - Up from 925 the previous year



ITM Power, Riverside, CA. Photo: NREL



First Element, Coalinga, CA. Photo: NREL

## Objectives

- Use existing stations as real-world guide for future innovations
- Identify issues for research
- Have results readily available (both public and private)

\*Joint Agency Staff Report on Assembly Bill 8 (Dec 2017)

# Approach: NFCTEC Data/Analysis/Results Handling

Bundled data (operation and maintenance/safety) delivered to NREL quarterly

Internal analysis completed quarterly

NREL's National Fuel Cell Technology Evaluation Center

Results

Confidential

Public

CDPs

DDPs

## Detailed Data Products (DDPs)

- Individual data analyses
- Identify individual contribution to CDPs
- Only shared with partner who supplied data every 6 months<sup>1</sup>

## Composite Data Products (CDPs)

- Aggregated data across multiple systems, sites, and teams
- Publish analysis results without revealing proprietary data every 6 months<sup>2</sup>

1) Data exchange may happen more frequently based on data, analysis, and collaboration

2) Results published via NREL Tech Val website, conferences, and reports

# Collaborations

Data Requirements > Data Reporting > Analysis Results > Feedback

## STATION FUNDERS

California Energy Commission  
California Air Resources Board

## STATION PROVIDERS

Air Liquide  
Air Products  
California State University Los Angeles  
First Element  
H2 Frontier  
Linde  
Proton OnSite  
Shell  
StratosFuel

## ORGANIZATIONS

California Fuel Cell Partnership  
IPHE and HySUT  
Gas Technology Institute  
H2USA  
SCAQMD

# Hydrogen Station Activities Across the U.S.

[www.afdc.energy.gov/fuels/hydrogen\\_locations.html](http://www.afdc.energy.gov/fuels/hydrogen_locations.html)

## 66 Stations

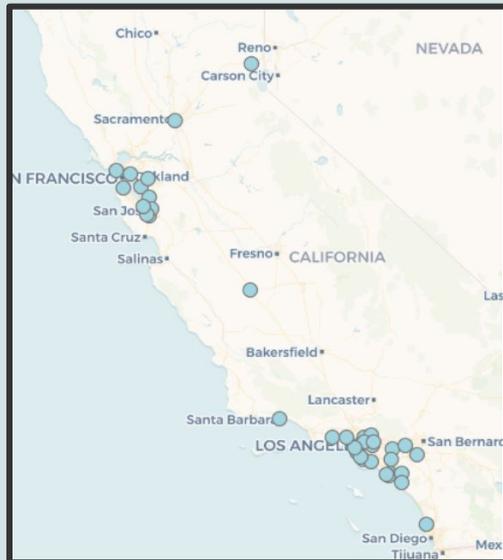
Retail and Non-Retail

**34 are Retail - Open**

## California

**34 Retail - Open**

**30 Retail - Planned**



**North East  
12 Retail - Planned**

EERE » AFDC » Fuels & Vehicles » Hydrogen

## Hydrogen Fueling Station Locations

Find hydrogen fueling stations near an address or ZIP code or along a route in the United States.

Find Public Stations

Analyze & Download Data

Enter location



Hydrogen

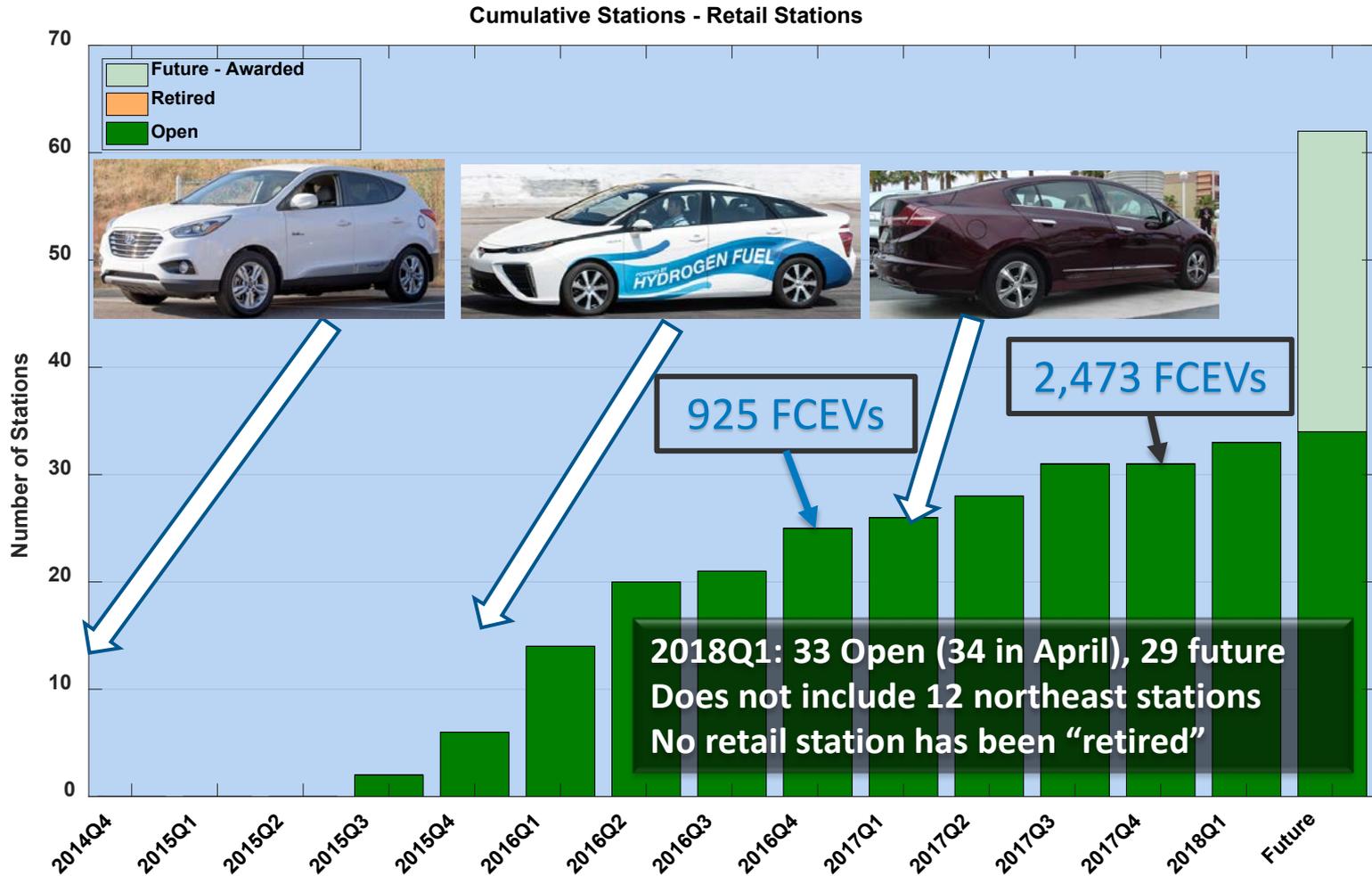


Include non-retail stations

Now Defaults to Retail Only

As of 5/4/2018

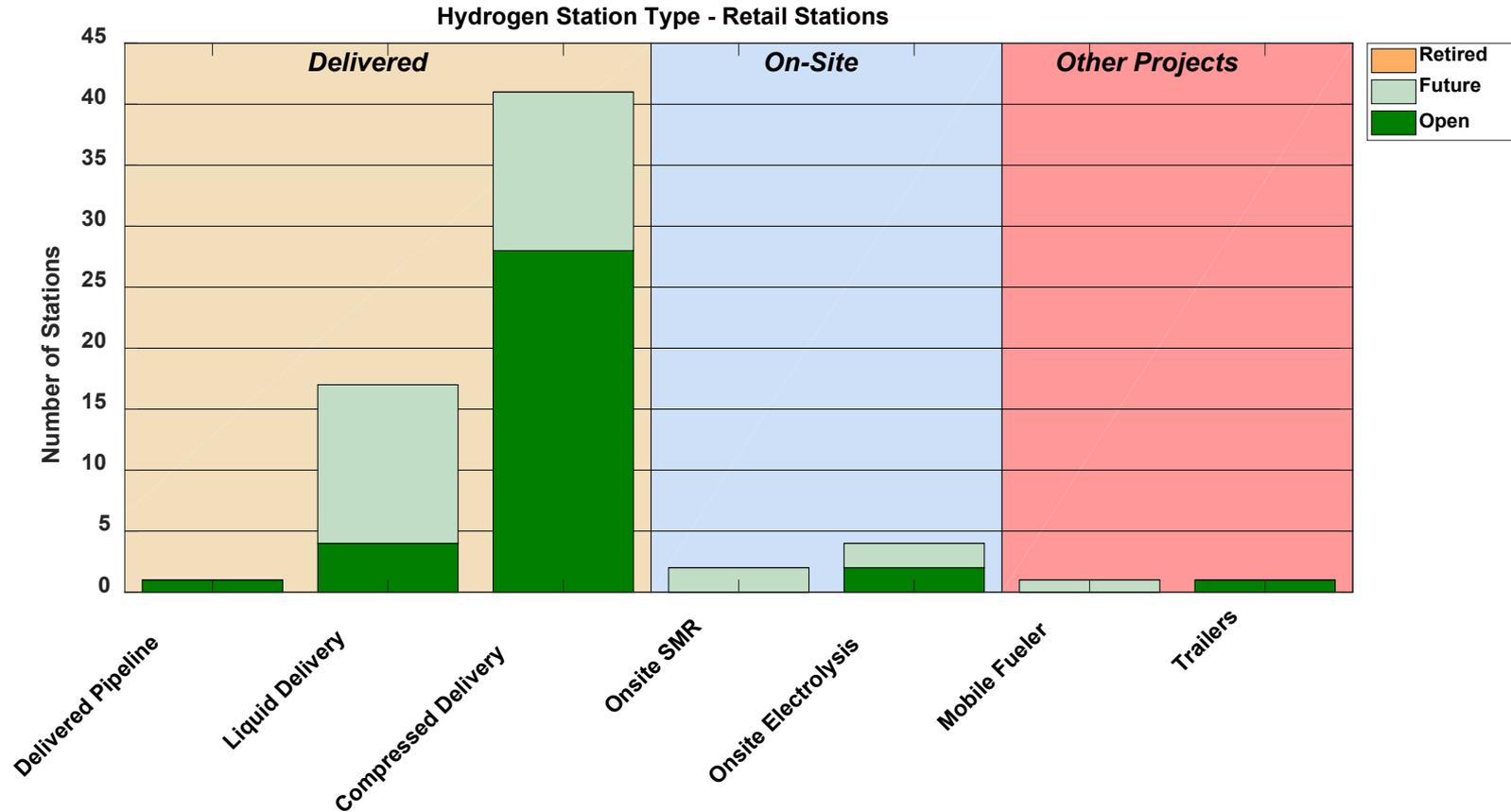
# Cumulative Number of Retail Stations



NREL cdpRETAIL\_infr\_10

Created: May-04-18 12:25 PM | Data Range: 2011Q1-2017Q4

# Station Types



- Although most retail stations are compressed H2 delivery, they also include liquid delivery, pipeline, SMR and onsite electrolysis.

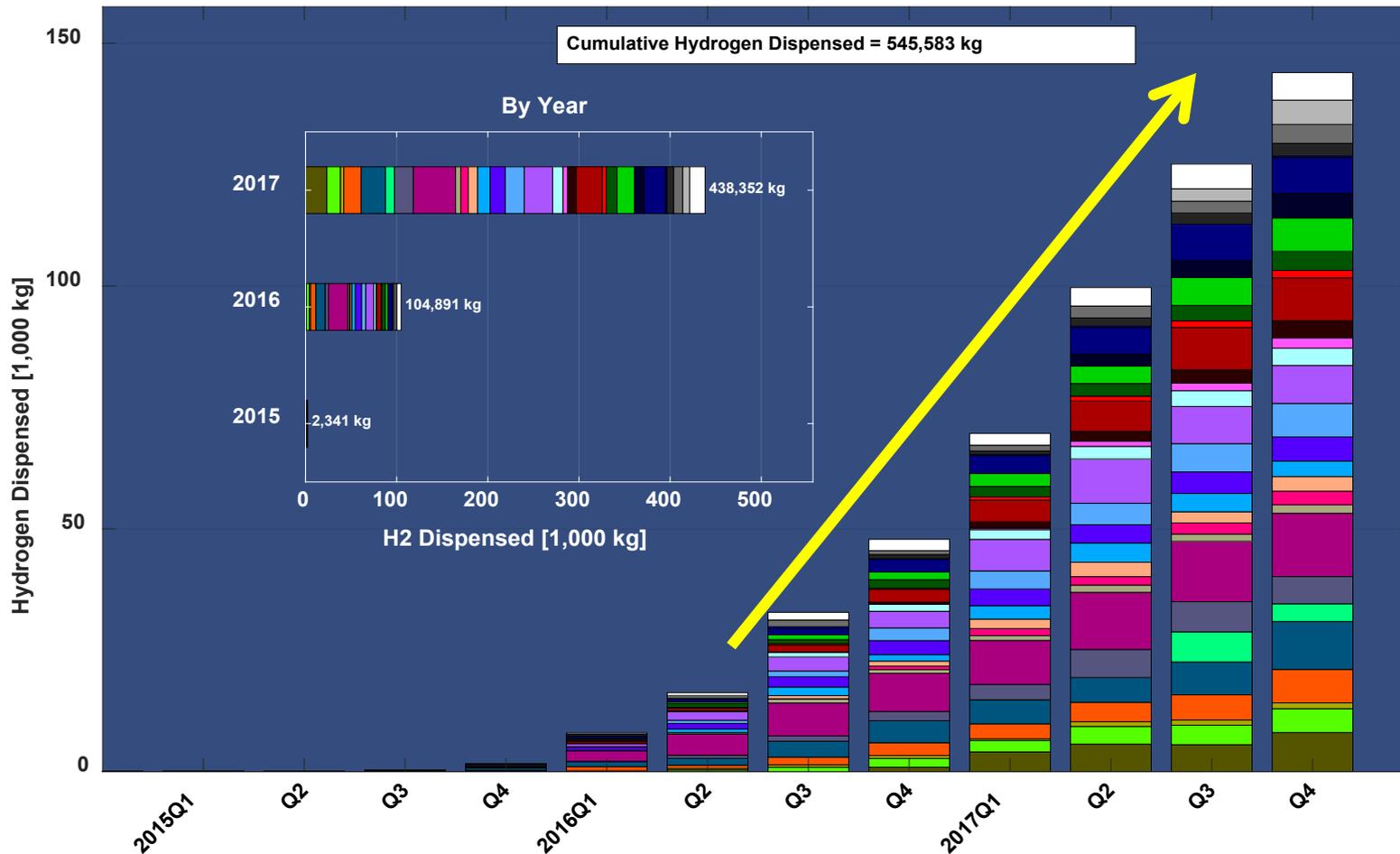


NREL cdpRETAIL\_infr\_11

Created: May-07-18 2:26 PM | Data Range: 2014Q3-2017Q4

# Accomplishments and Progress: Hydrogen Dispensed by Quarter

Hydrogen Dispensed By Quarter - Retail Stations

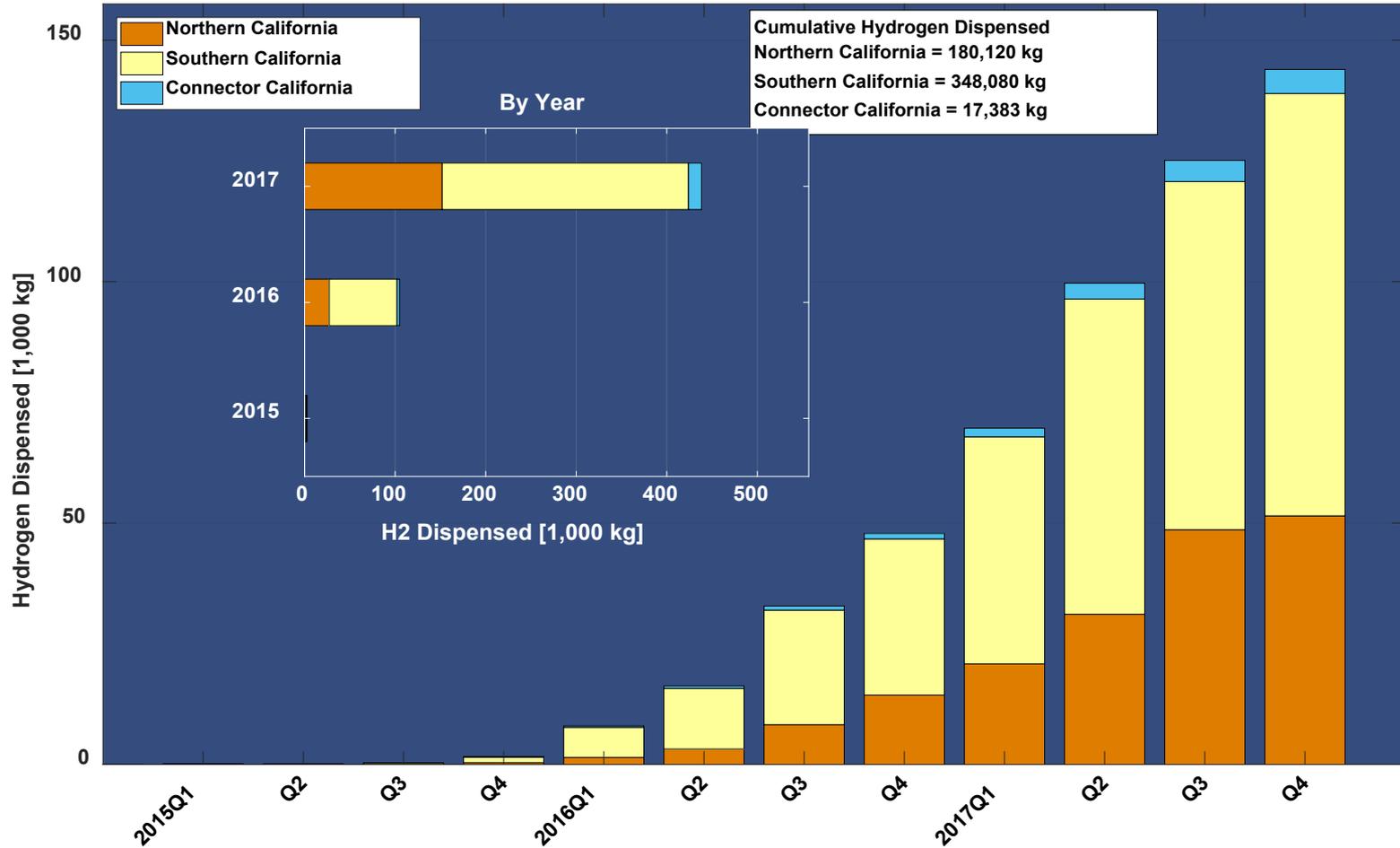


Note: Colors represent individual stations

Retail stations dispensing significantly more each quarter

# Accomplishment: Hydrogen Dispensed by Region

Hydrogen Dispensed By Region - Retail Stations

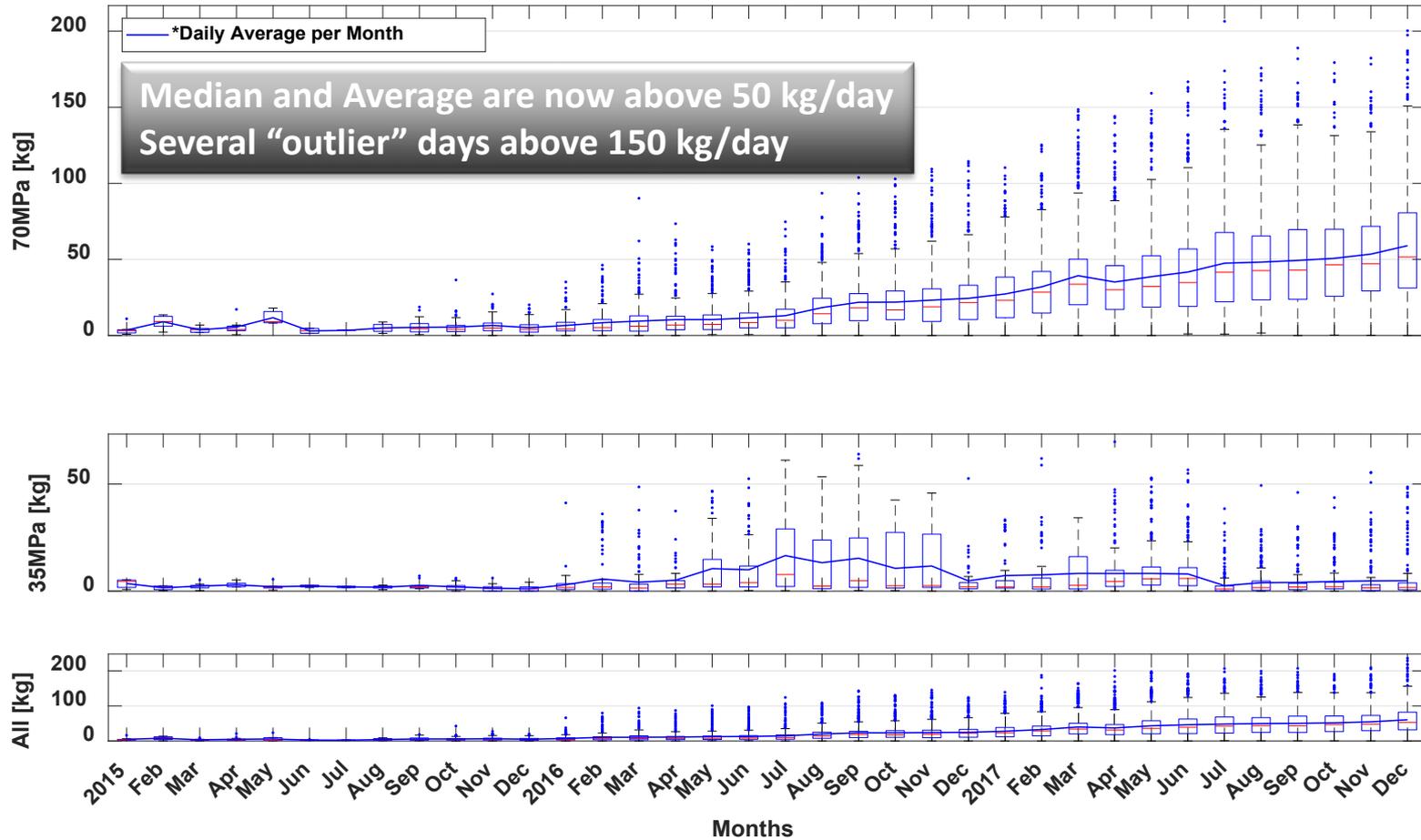


NREL cdpRETAIL\_infr\_81

Created: May-05-18 6:48 AM | Data Range: 2014Q3-2017Q4

# Accomplishments and Progress: Daily Fueling by Month – Retail Stations

Daily Fueling Amounts Over Time - Retail Stations



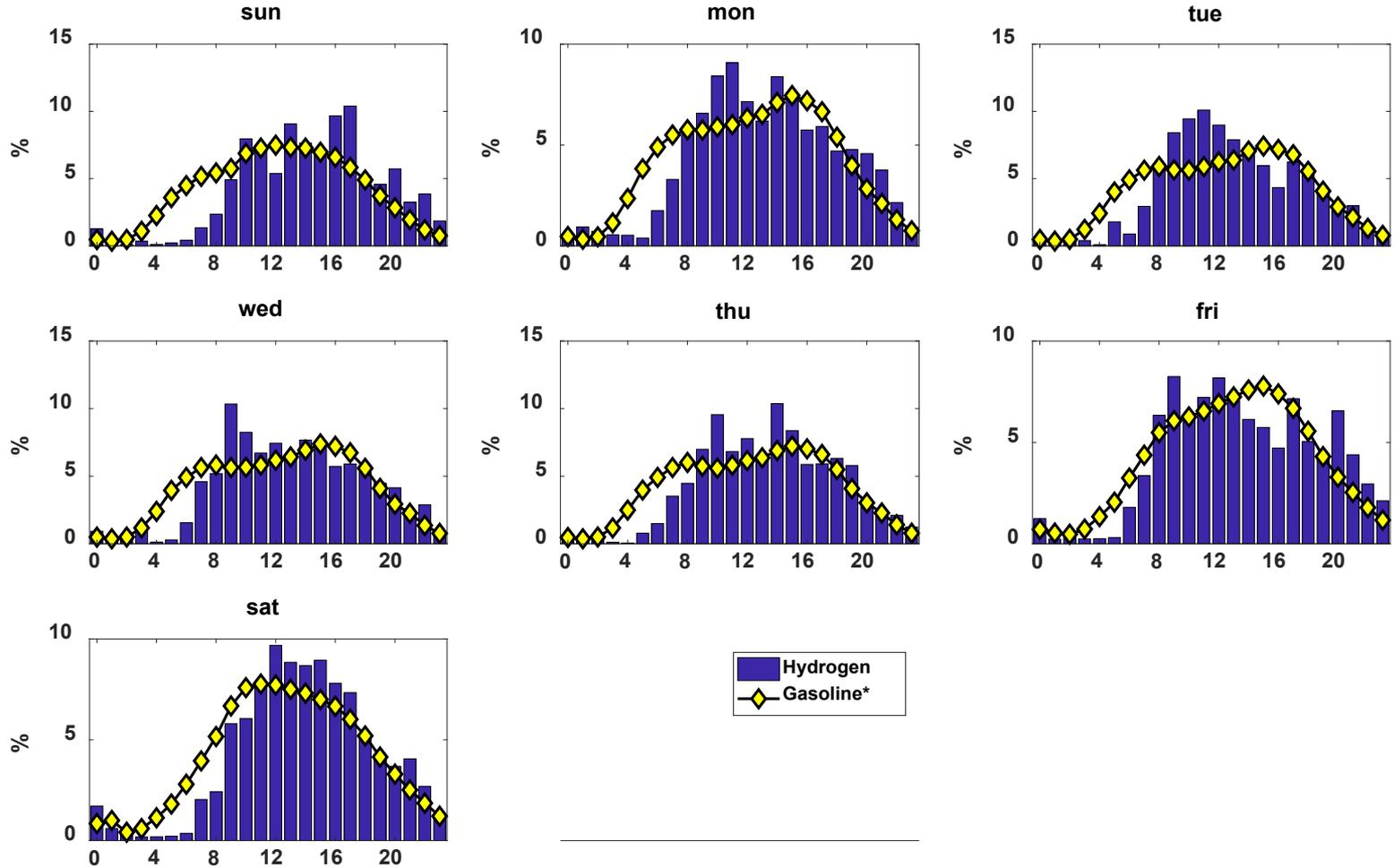
NREL cdpRETAIL\_infr\_82

Created: May-05-18 6:35 AM | Data Range: 2014Q3-2017Q4

\*Daily average only includes days with fills.

# Accomplishment: Hydrogen by Day and Hour – Connector/Destination

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

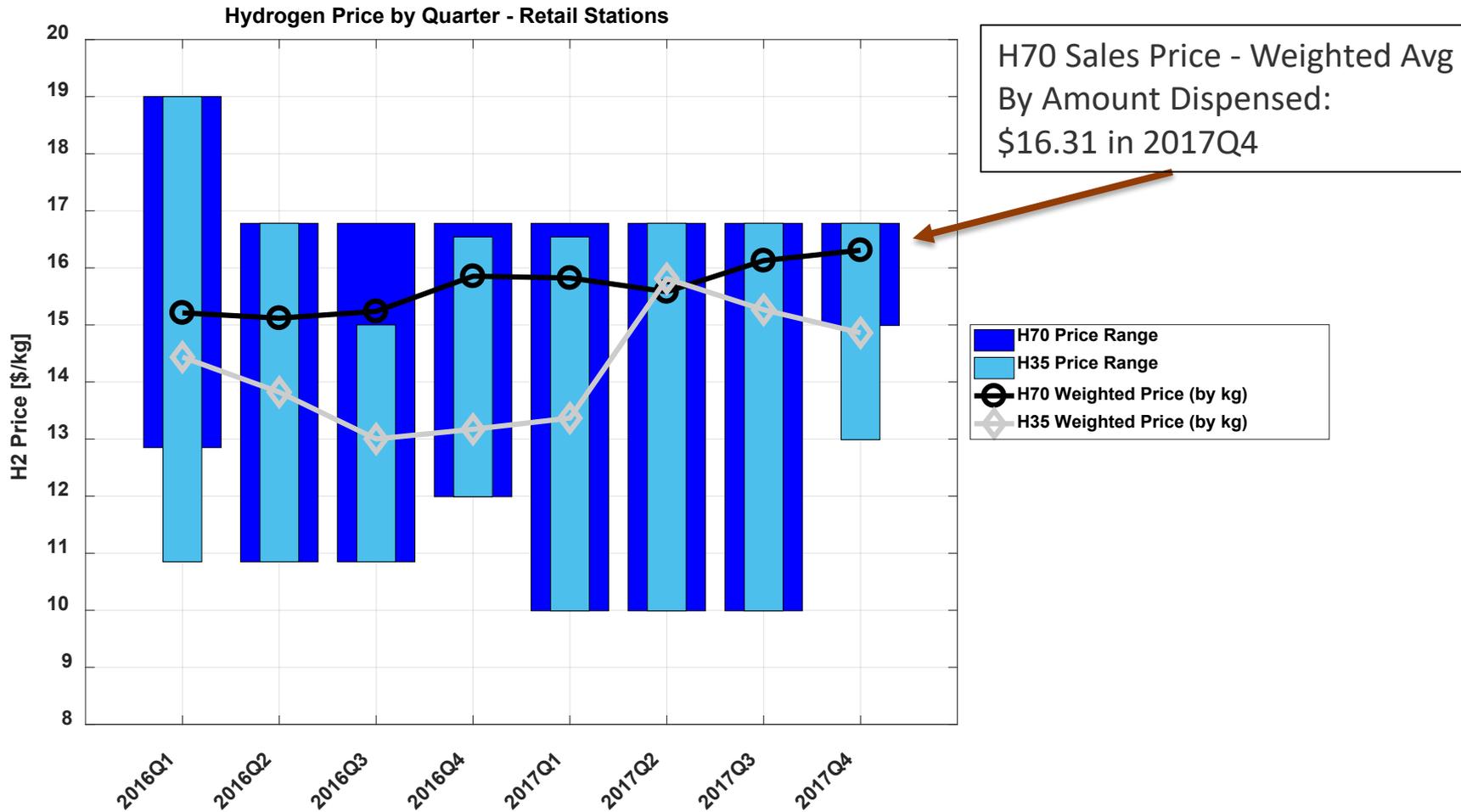


NREL cdpRETAIL\_infr\_88a

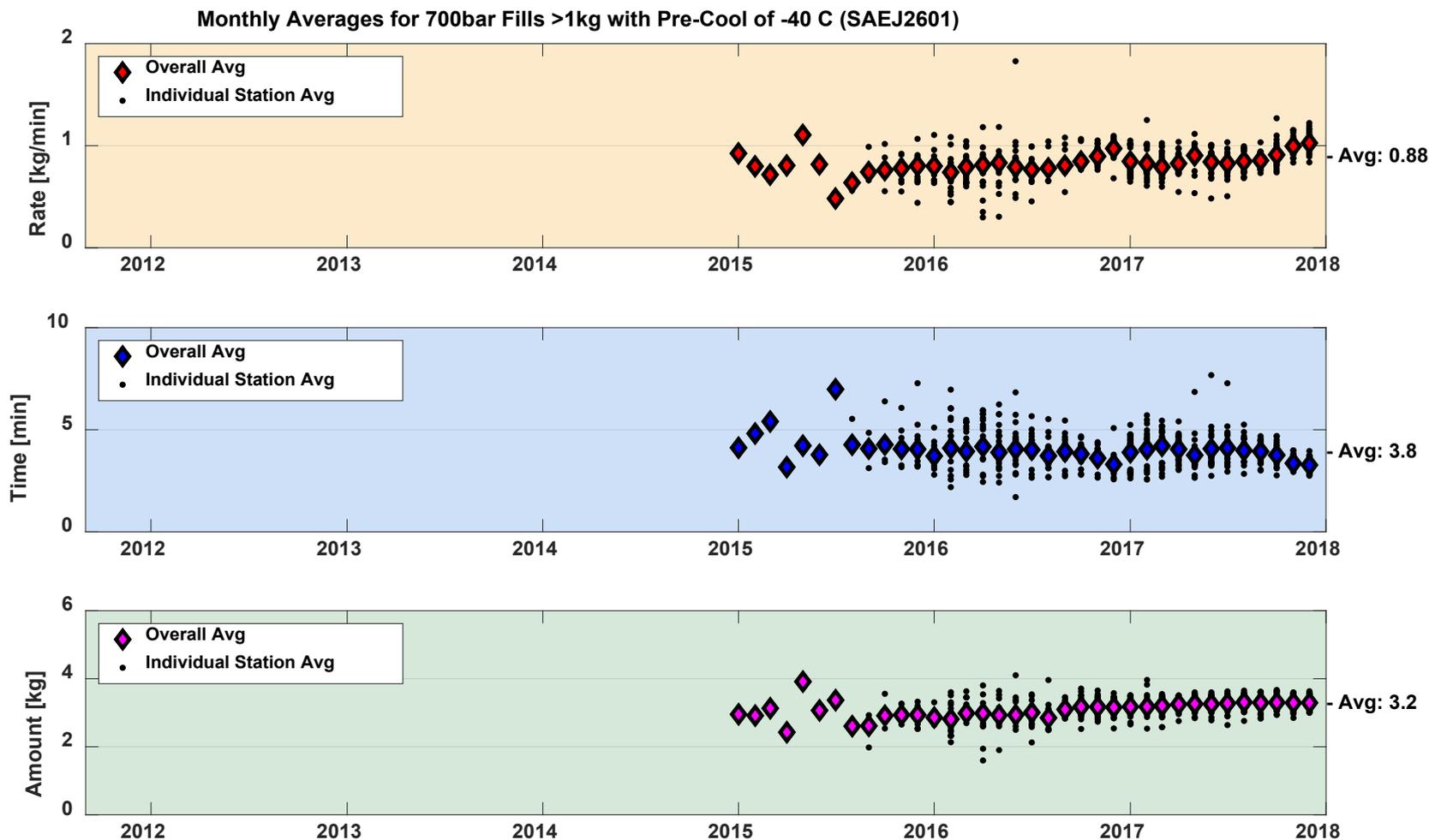
Created: May-05-18 5:35 AM | Data Range: 2014Q3-2017Q4

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

# Accomplishment: Hydrogen Price



# Accomplishments and Progress: Monthly Averages for 700bar Fills >1kg with Pre-Cool of -40C

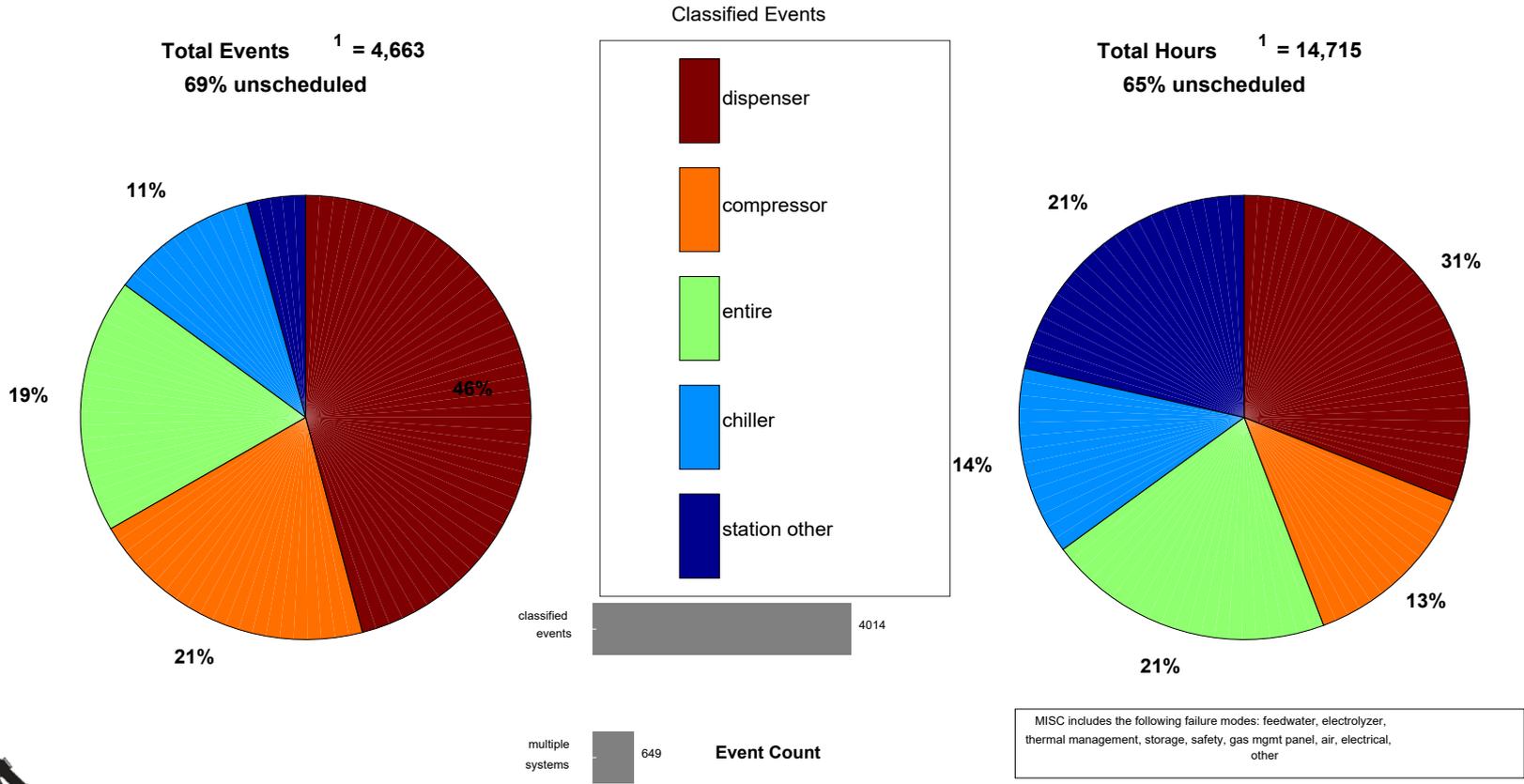


Time to fill is decreasing below the average of 3.8 minutes.  
Average amount filled increasing above average of 3.2 kg

# Accomplishments and Progress: Maintenance by Equipment Type – Retail Stations

Most maintenance remains on dispensers, followed by compressors.  
Chiller maintenance large portion of events and hours (stations fill at -40 C).

Maintenance by Equipment Type - Retail Stations



NREL cdpRETAIL\_infr\_21

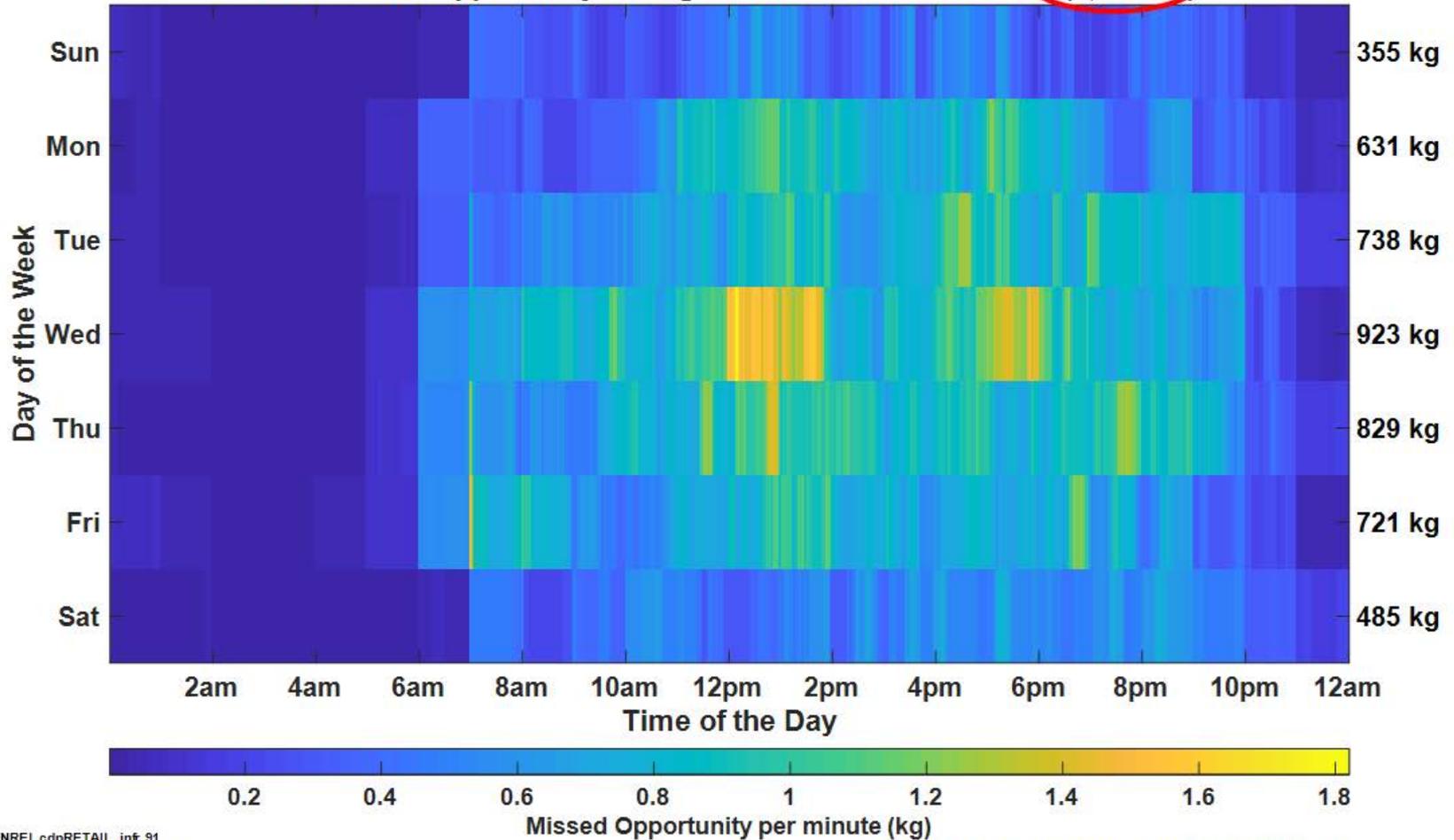
Created: May-07-18 1:50 PM | Data Range: 2014Q3-2017Q4



# Accomplishments and Progress: Missed Opportunity Fueling

Calculated from average dispensing profiles from each station and their SOSS "Offline" status.

Missed Fuel Opportunity during Q4 of 2017 for 22 stations (4,683 kg)

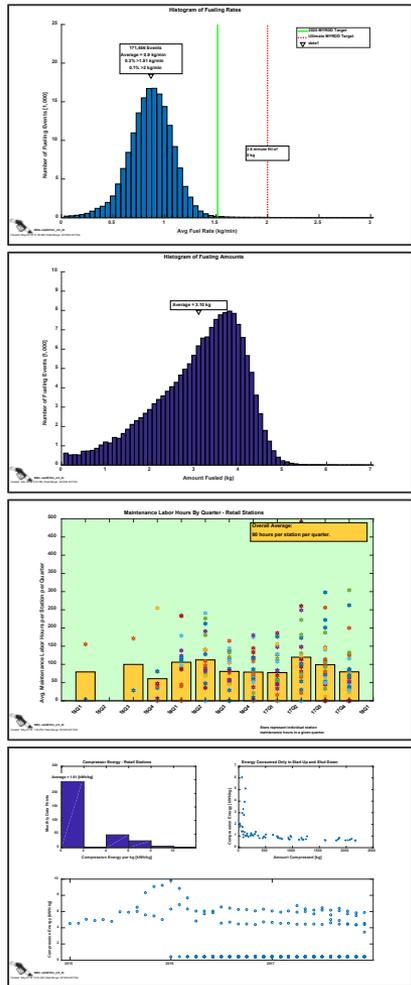


NREL cdpRETAIL\_infr\_91

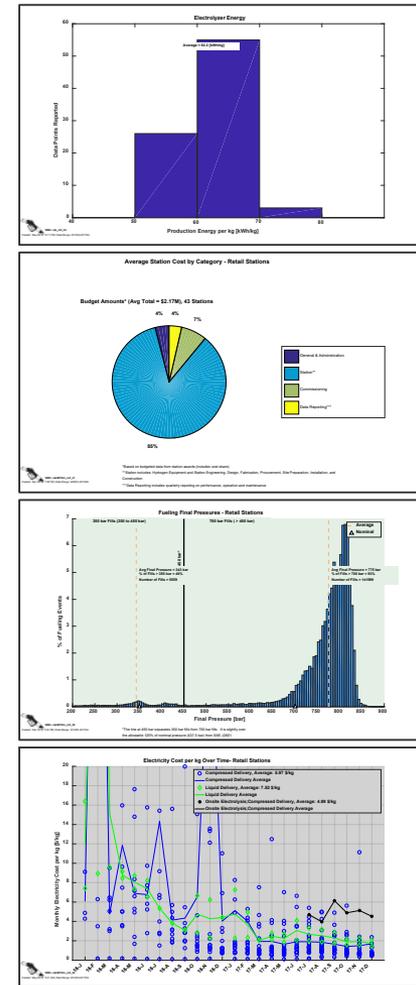
Created: May-04-18 2:10 PM | Data Range: 2014Q3-2017Q4

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

# Accomplishments and Progress: Sampling of Results – Retail Stations



<b>Fueling Rate Average</b>	0.9 kg/min
<b>Fueling Amount Average</b>	3.1 kg
<b>Fueling Time Average</b>	3.69 min
<b>Compressor Energy Average</b>	1.61 kWh/kg
<b>Total Hydrogen Dispensed (29 Stations)</b>	545,583 kg 143,938 kg - 17Q4
<b>Electrolyzer Energy Average (retail and non-retail stations)</b>	62.2 kWh/kg
<b>Maintenance Hours Average</b>	90 hours/Quarter
<b>Fueling Final Pressure Average</b>	775 bar
<b>Average Electricity Cost by Delivery Type 2017Q4</b>	\$1.70/kg – Compressed \$1.74/kg – Liquid \$4.52/kg –Electrolysis



# Proposed Future Work

- Analysis and CDP publication
  - Complete data analysis and publish results
    - Calendar 2018 Q1 and Q2
    - Calendar 2018 Q3 and Q4
- Update data collection, analysis and feedback
  - Add to utilization and dispensing profiles of stations
  - Work with station providers to deep dive into specific issues as they arise for feedback to research
  - Identify needs for future stations

Any proposed future work is subject to change based on funding levels.

# Summary

- **Relevance**
  - Independent validation of hydrogen infrastructure
- **Approach**
  - Collaborate with industry partners and agencies involved in hydrogen infrastructure
  - Continue to develop core NFCTEC and analysis capability and tools
  - Leverage years of analysis and experience from hydrogen demonstrations
- **Accomplishments and Progress**
  - Analyzed performance data from 29 open, retail stations and 4 open, non-retail stations.
  - Performed detailed reviews of individual results
  - Published results via CDPs that cover topics of station daily utilization compared to maximum demonstrated capacity, maintenance, fueling performance, operation costs, and efficiencies
- **Collaborations**
  - Working closely with industry and government partners to validate methodology and with key stakeholders to ensure relevance and accuracy of results
- **Future Work**
  - Complete analysis of hydrogen infrastructure data and publish every 6 months
  - Identify new opportunities to document hydrogen infrastructure progress and feedback results to researchers



# Thank You

[www.nrel.gov](http://www.nrel.gov)

**NREL**  
NATIONAL RENEWABLE ENERGY LABORATORY

Hydrogen & Fuel Cells

RESEARCH STAFF IMPACTS PUBLICATIONS DATA & TOOLS FACILITIES WORK WITH US

Hydrogen and Fuel Cells > Fuel Cell and Hydrogen Technology Validation

## Fuel Cell and Hydrogen Technology Validation

The NREL technology validation team works on validating hydrogen fuel cell electric vehicles; hydrogen fueling infrastructure; hydrogen system components, and fuel cell use in early market applications such as material handling, backup power, and prime-power applications. The team also analyzes the current status of state-of-the-art laboratory fuel cell technologies, with a focus on performance and durability.

Technology validation is defined as confirmation that component and system technical targets have been met under realistic operating conditions. Technology validation projects involve gathering extensive data from the systems and components under real-world conditions, analyzing this detailed data, and then comparing results to technical targets. While the raw data is protected by NREL, analysis results are aggregated into public results called composite data products. These public results show the status and progress of the technology, but don't identify individual companies.

Click on the application type to see project highlights, analysis results, and detailed reports and presentations from the hydrogen and fuel cell technology validation efforts underway at NREL.

- Fuel Cells
- Hydrogen Production & Delivery
- Hydrogen Storage
- Manufacturing R&D
- Market Transformation
- Safety, Codes, & Standards
- Systems Analysis
- Technology Validation**
  - Fuel Cell Electric Vehicles
  - Fuel Cell Buses
  - Early Fuel Cell Markets
  - Fuel Cell Technology Status
  - Hydrogen Fueling Infrastructure
  - Stationary Fuel Cell Systems
  - Hydrogen System Components

Vehicles Buses Forklifts Backup Power

Stationary Power Infrastructure Laboratory Stacks

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



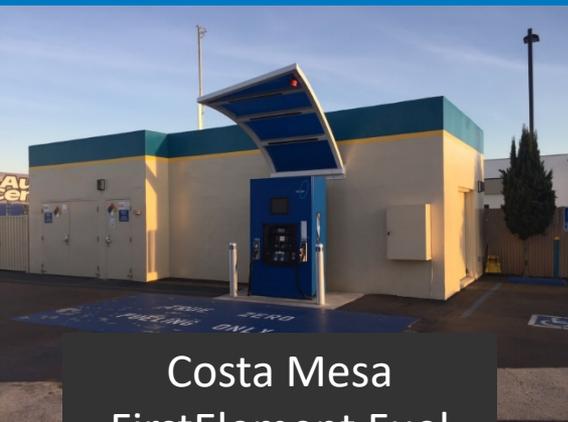
# Technical Back-Up Slides

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# Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- Reviewer comment: To collect (some) information more often (e.g., monthly) might be interesting.
  - Even though the data is collected quarterly using the templates provided, we have more resolution such as the exact time of each fill and the date of maintenance events. The CDPs for daily dispensed hydrogen binned by month and monthly averages for rates, times and amounts are examples of more resolution than quarterly.
- Reviewer comment: A supply of relevant information for hydrogen station users/customers might be of additional value. This might also lead to live information for station availability/price/etc.
  - Response: CaFCP has SOSS for availability AFDC is linked to it. We've integrated that data with fueling profiles to identify missed fueling opportunities. Price CDP shows range of prices by quarter as well as weighted average by amount dispensed.

# Competition brings diversity to stations



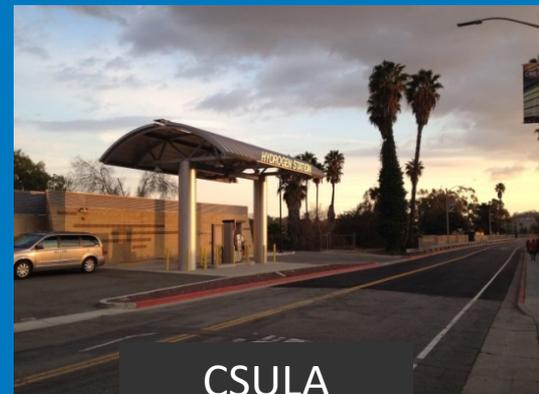
Costa Mesa  
FirstElement Fuel



Riverside  
ITM Power



Burbank  
H2 Frontier



CSULA



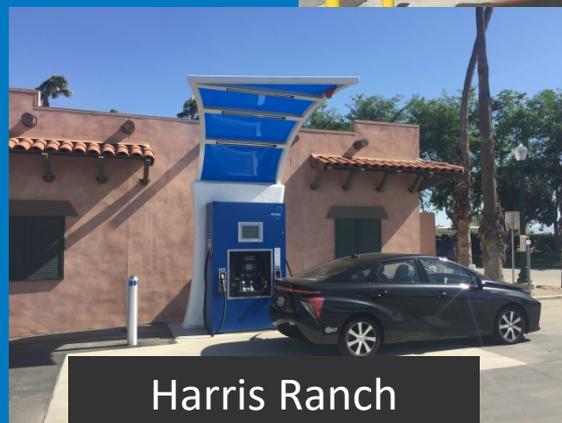
Torrance  
Shell



West Sacramento  
Linde



Anaheim  
Air Liquide



Harris Ranch  
FirstElement Fuel

Photos: NREL

# Approach: Data Templates

## Data Templates

- Aggregation requires multiple partners providing similar data
- NREL/NFCTEC templates developed to establish consistent data requirements
- Template date required in award contracts through DOE, California Energy Commission, California Air Resources Board, and SCAQMD.
- NOT static
  - Updated as needed (station downtime, fueling performance)
  - Modified for other uses (ex. Mobile Fueler)

**Maintenance<sup>1</sup>**

Template last updated on May 4, 2016 (NREL)  
Data should be from reporting quarter

**Footnotes:**  
 (1) Record all scheduled and unschedule maintenance for the infrastructure and provide notes/comments regarding observations made during maintenance.  
 (2) Pick an item from the supplied list. Add new items as needed

Calendar Quarter (ex. 2016) *insert calendar quarter*

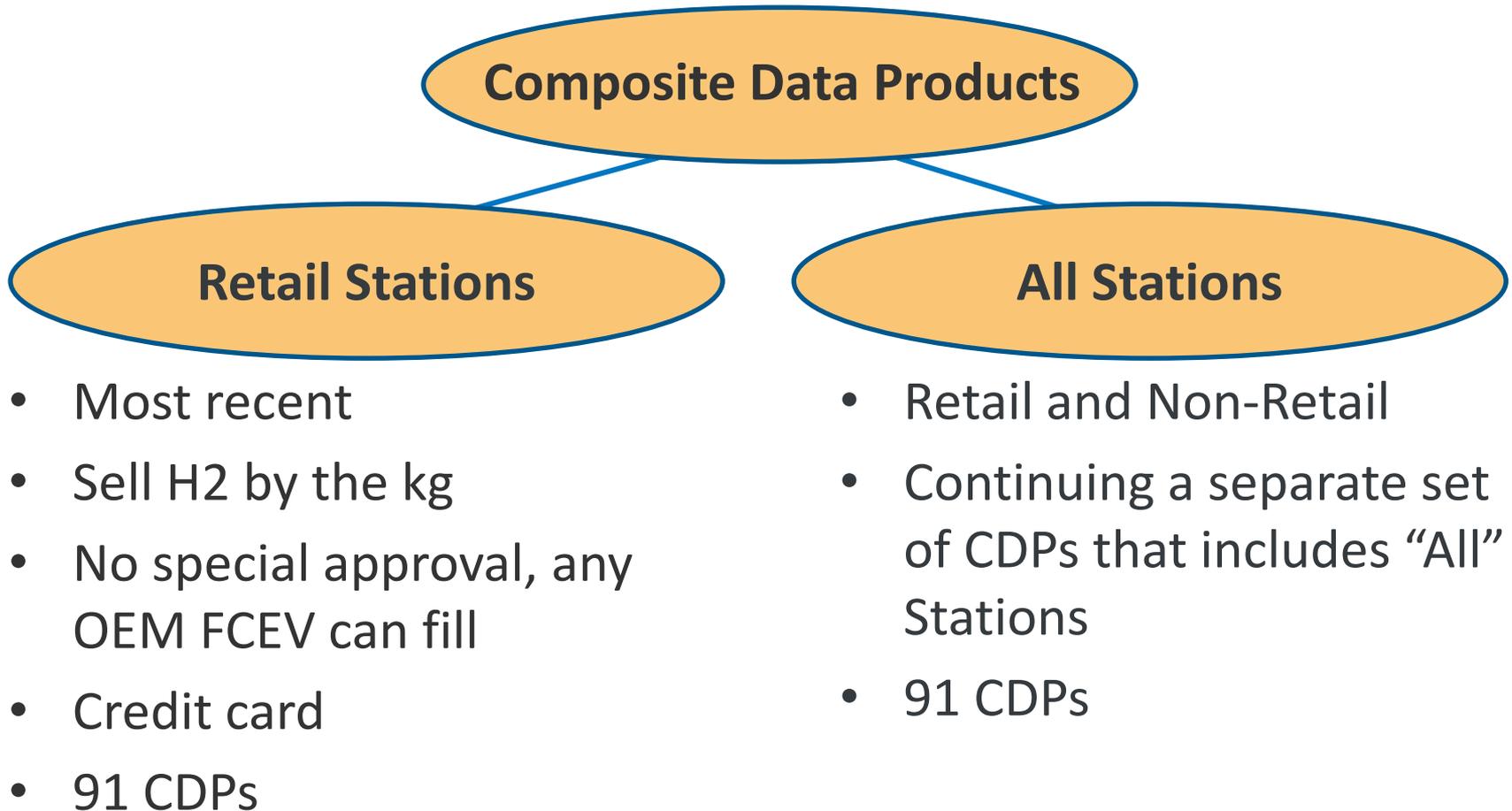
Site Name *insert site name*

**Fields designated with a purple color are optional under GFD-15-605.**

#	Date of Repair, Replacement	Component Name	replaces Category	New	replaces Maintenance Type	replaces Failure Mode	New	New	New	Category <sup>2</sup>
			Subsystem <sup>2</sup>	Component <sup>2</sup>	Action <sup>2</sup>	Cause <sup>2</sup>	Effect <sup>2</sup>	station unavailability (hours)	If still available, station performance affected (hours)	
1	10/5/2004	Example: Main Coolant Pump	THERMAL MANAGEMENT	PUMP	REPLACE	MATERIAL DEFORM/DEGRADE/FATIGUE	FUNCTIONALITY LOST	12	0	thermal management
2										
3										
4										
5										
6										

ns Site Summary Site Log Storage & Delivery Compression Dispensing Fuel Log Fill Performance Maintenance H2 Cost Safe |

# Approach: Focusing on Retail Stations



# Approach: Data Reporting

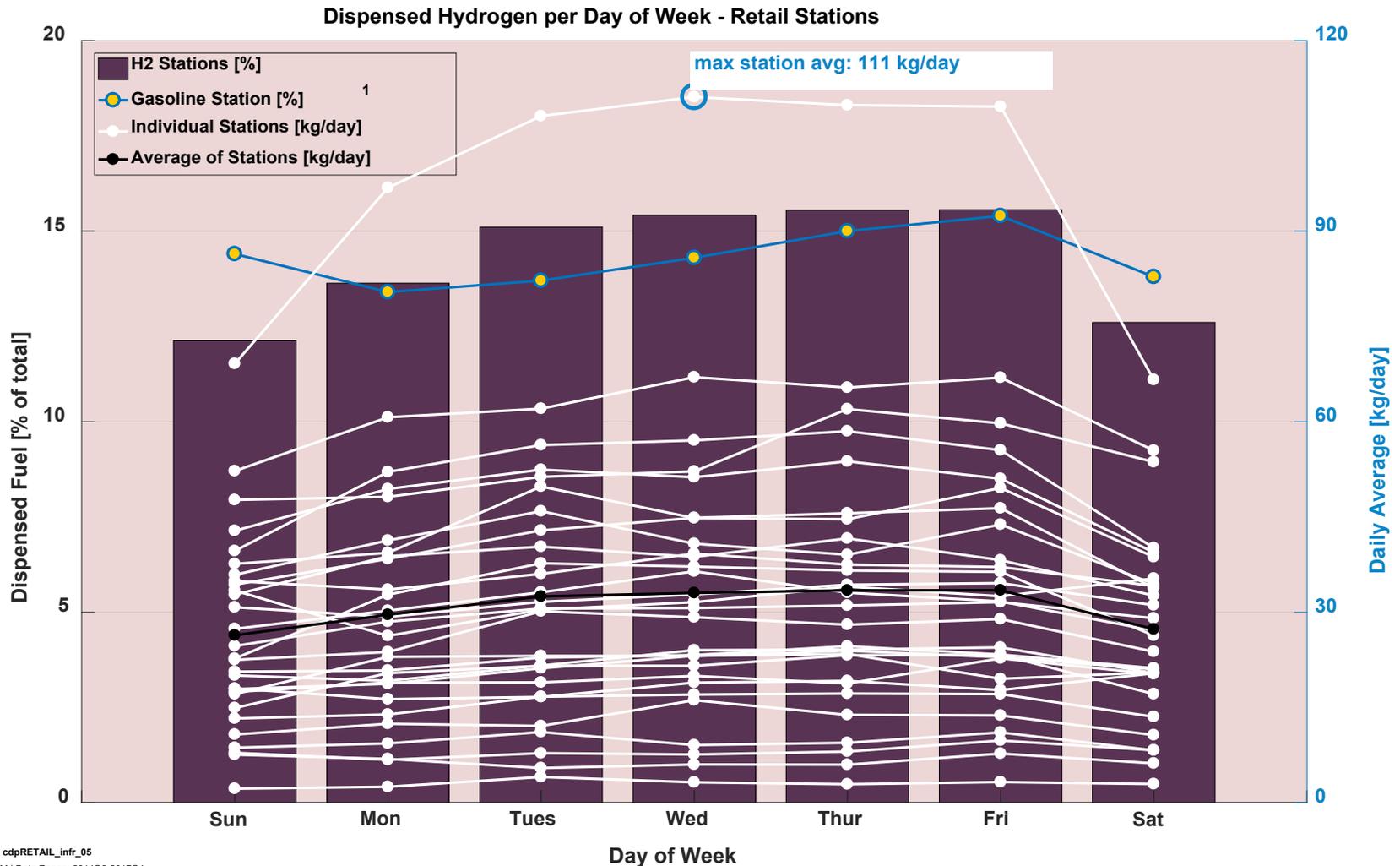
## Data Reporting

- As of 2017Q4, data reported from 29 (out of 31) open, retail stations and 4 open, non-retail stations
- MOU with CEC to collect and analyze data from their funded stations.
- The current retail stations are required to report through October 2018
- New GFO-15-605 awards (>\$44 million CEC + >\$20 million matching funds)
  - 16 Stations (NOPA Feb 2017) + 5 Stations (Revised NOPA Nov 2017)
  - 1 year minimum data reporting for CapEx and 3 years for O&M.
- New operation & maintenance awards from CEC (GFO-17-601) were announced in January 2018
  - Proposed awards to 16 stations for ~\$2.4 million

California Energy Commission Alternative and Renewable Fuel and Vehicle Technology Program Solicitation GFO-17-601 Light Duty Vehicle Hydrogen Refueling Infrastructure Operation and Maintenance (O&M) Support Grants Notice of Proposed Awards January 8, 2018					
Proposal Number	Applicant	Station Address	Funds Requested	Proposed Award	Recommendation
<b>Proposed Awards for Operation and Maintenance Support Grants</b>					
1	FirstElement Fuel, Inc.	2855 Winchester Boulevard, Campbell, CA 95008	\$80,000	\$80,000	Awardee
2	FirstElement Fuel, Inc.	2050 Harbor Boulevard, Costa Mesa, CA 92627	\$66,667	\$66,667	Awardee
3	FirstElement Fuel, Inc.	3060 Carmel Valley Road, San Diego, CA 92130	\$170,000	\$170,000	Awardee
4	FirstElement Fuel, Inc.	41700 Glimmer Boulevard, Fremont, CA 94538	\$300,000	\$300,000	Awardee
5	FirstElement Fuel, Inc.	391 West A Street, Hayward, CA 94541	\$80,000	\$80,000	Awardee



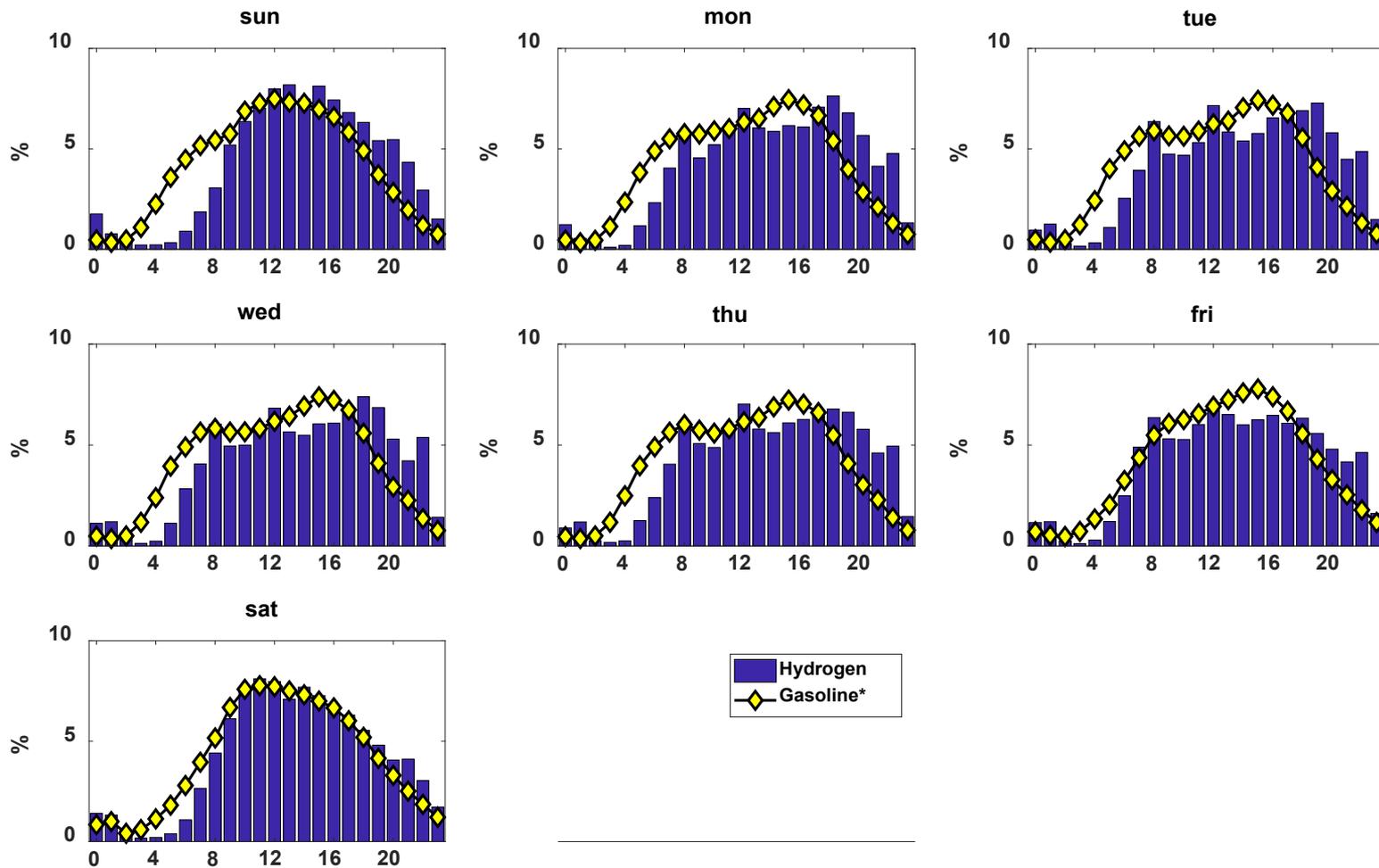
# Accomplishment: Hydrogen per Day of Week



Most hydrogen is dispensed Monday through Friday, but beginning to even out.

# Accomplishment: Hydrogen by Day and Hour – Southern CA

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



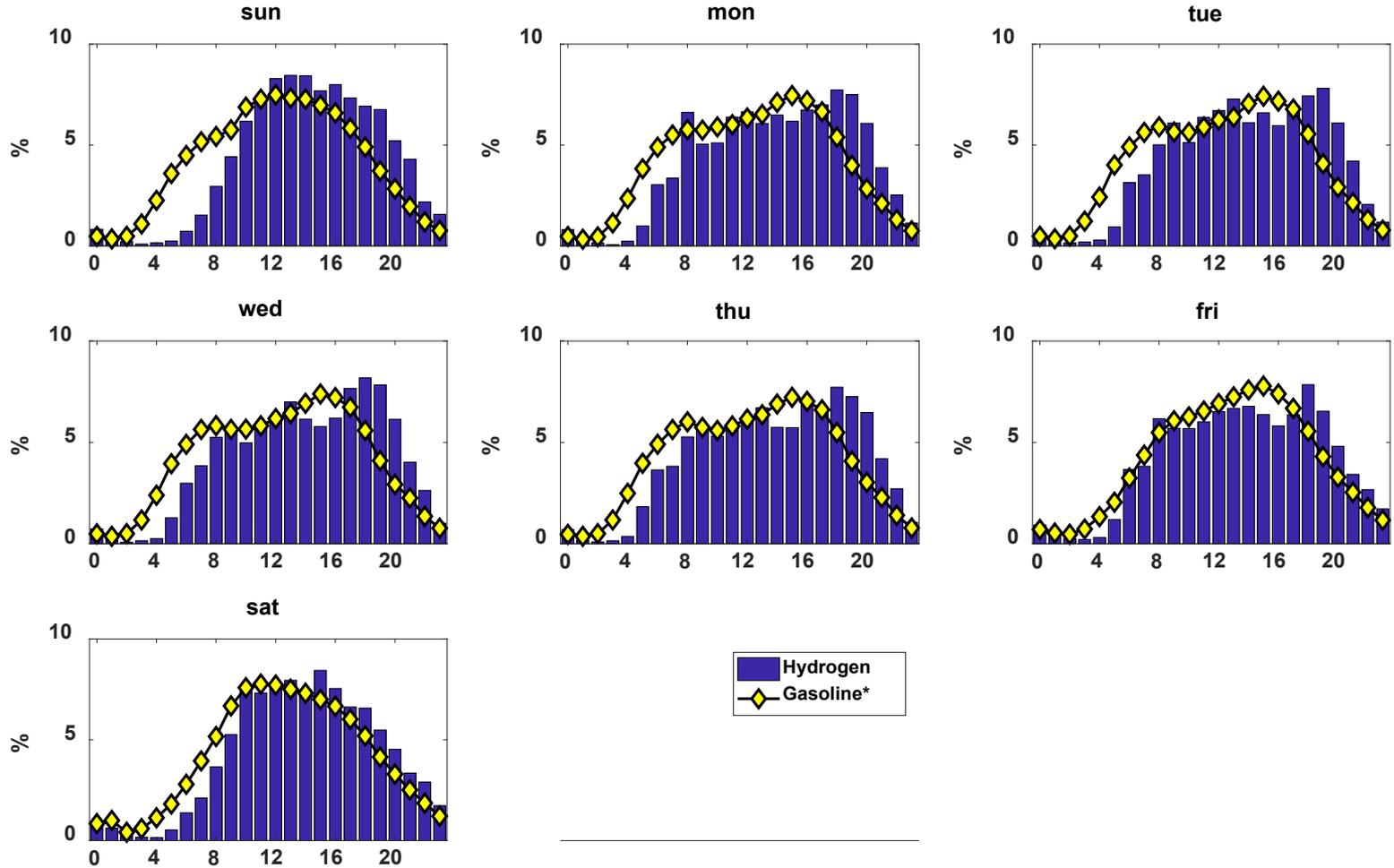
NREL cdpRETAIL\_infr\_88c

Created: May-05-18 5:36 AM | Data Range: 2014Q3-2017Q4

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

# Accomplishment: Hydrogen by Day and Hour - Northern CA

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

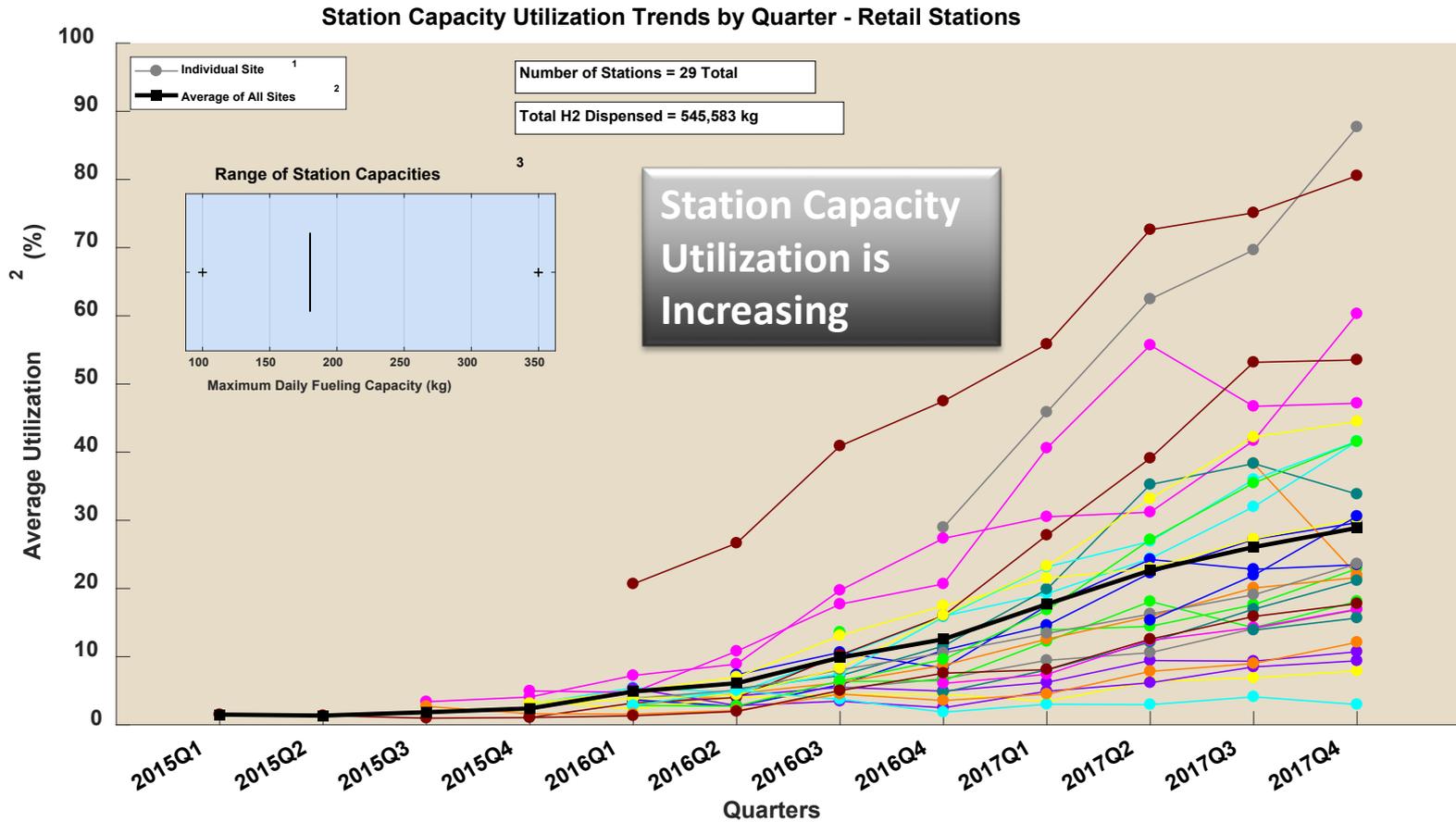


NREL cdpRETAIL\_infr\_88b

Created: May-05-18 5:35 AM | Data Range: 2014Q3-2017Q4

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

# Accomplishments and Progress: Capacity Utilization



<sup>1</sup> 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.

<sup>2</sup> Average quarterly utilization only considers quarters when at least one fill occurred.

<sup>3</sup> 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.

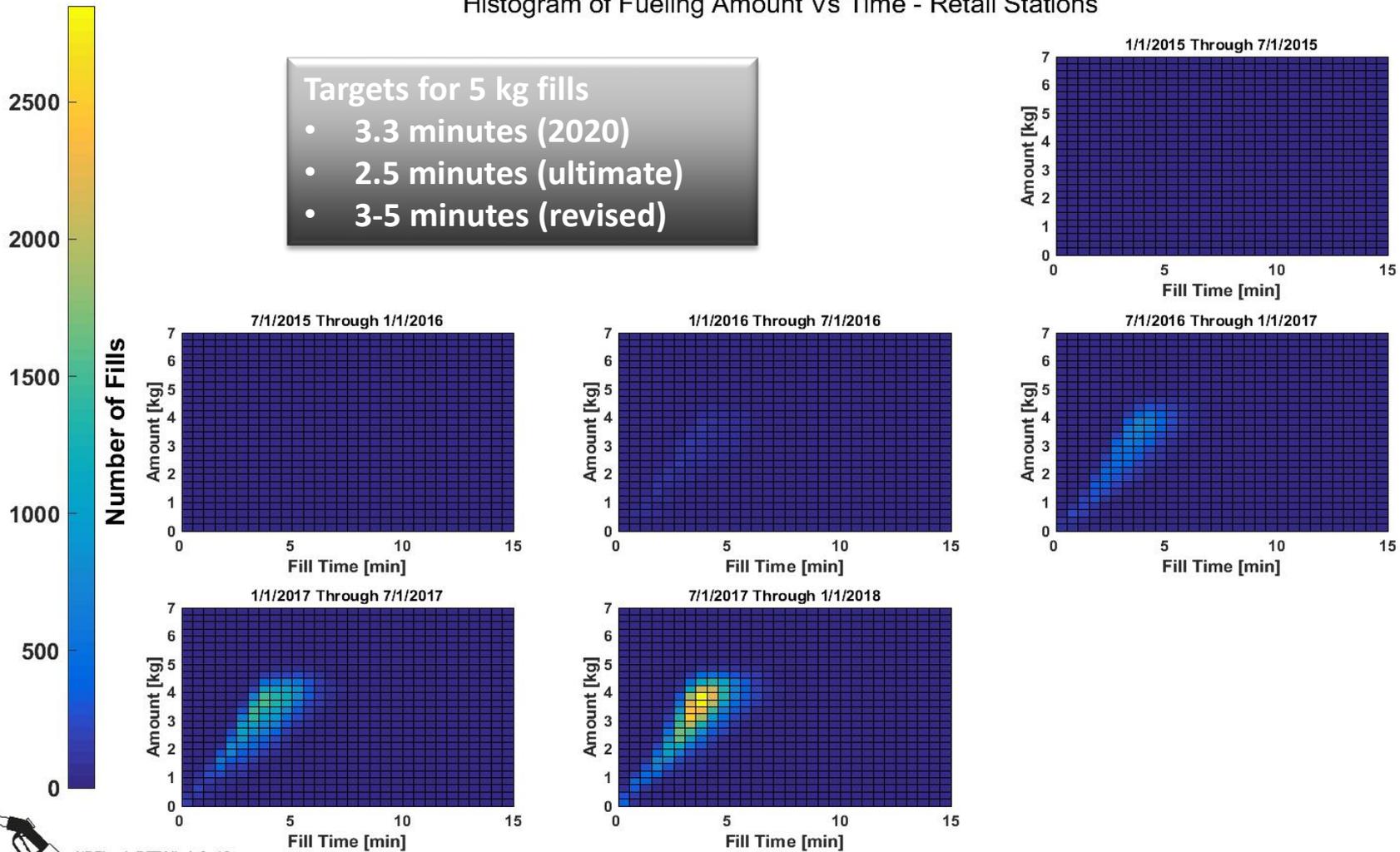


# Accomplishments and Progress: Fueling Amounts vs Times – 6 months at a time

Histogram of Fueling Amount Vs Time - Retail Stations

Targets for 5 kg fills

- 3.3 minutes (2020)
- 2.5 minutes (ultimate)
- 3-5 minutes (revised)



NREL cdpRETAIL\_infr\_18

Created: Feb-16-18 3:32 PM | Data Range: 2014Q3-2017Q4

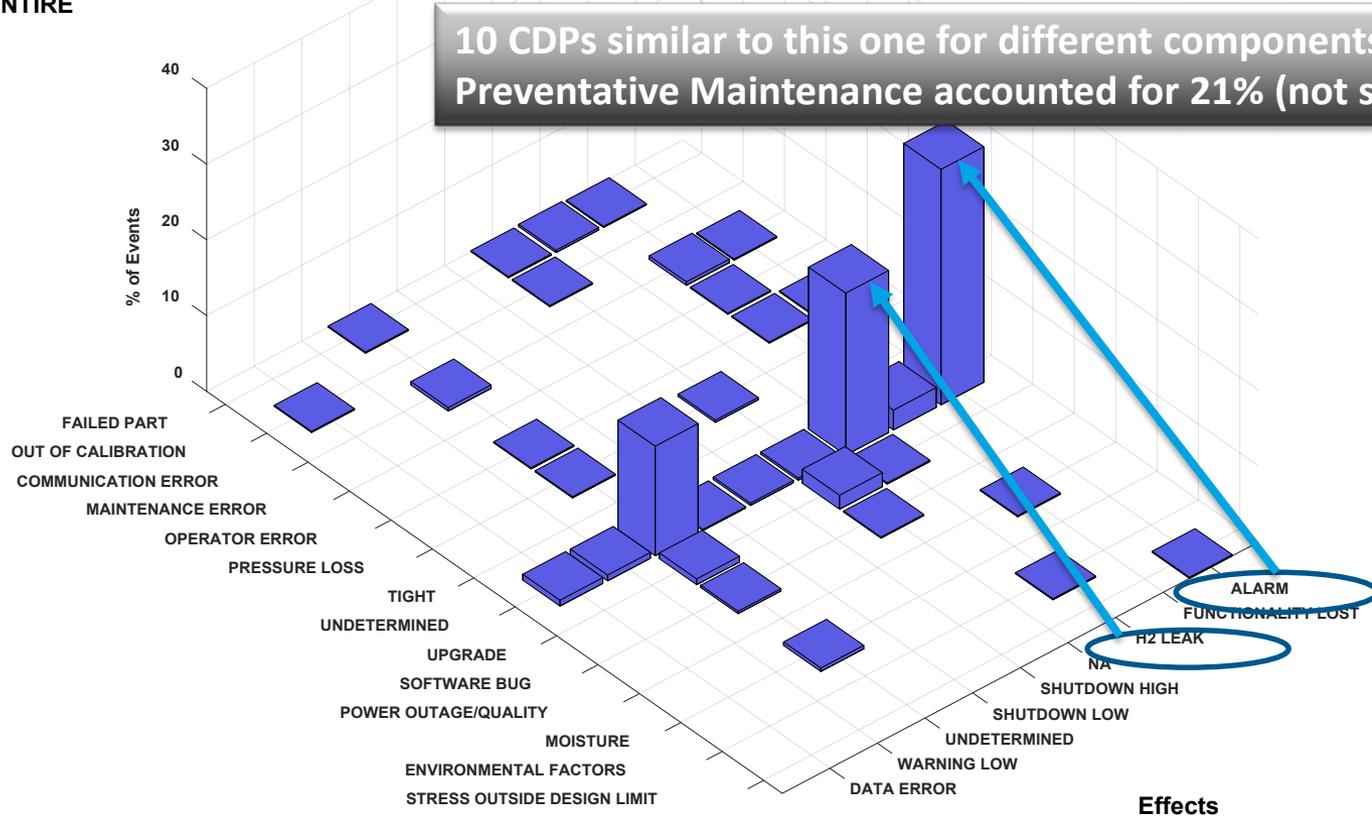
# Accomplishments and Progress: Dispenser Maintenance Cause and Effects

## Maintenance Causes and Effects - Retail Stations

Subsystem: DISPENSER

Component: ENTIRE

Preventative Maintenance accounted for 21% of all events.  
Suppressed in the plot to show detail for other causes.



Causes

Effects

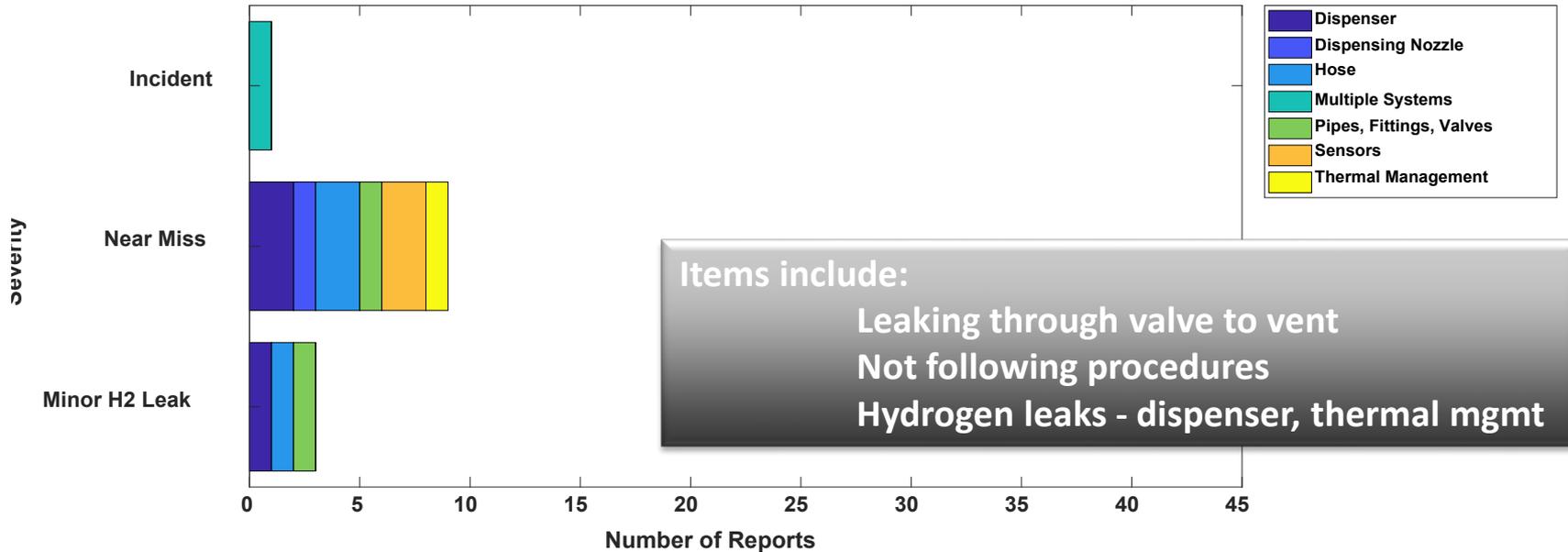


NREL cdpRETAIL\_infr\_67

Created: May-05-18 8:01 AM | Data Range: 2014Q3-2017Q4

# Accomplishments and Progress: Safety Reports by Primary Factors

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:

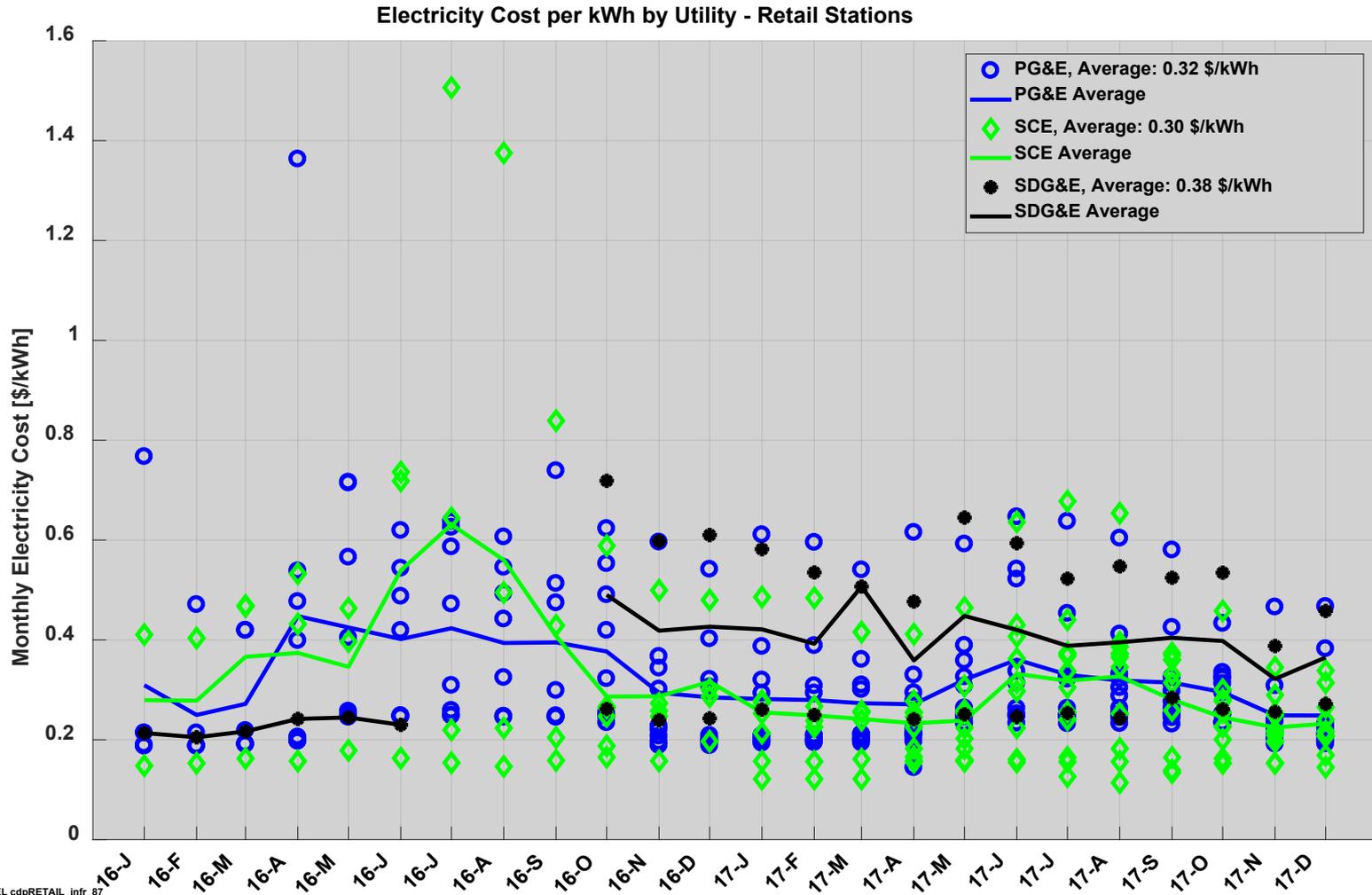
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdpRETAIL\_infr\_32

Created: Apr-23-18 3:21 PM | Data Range: 2014Q3-2017Q4

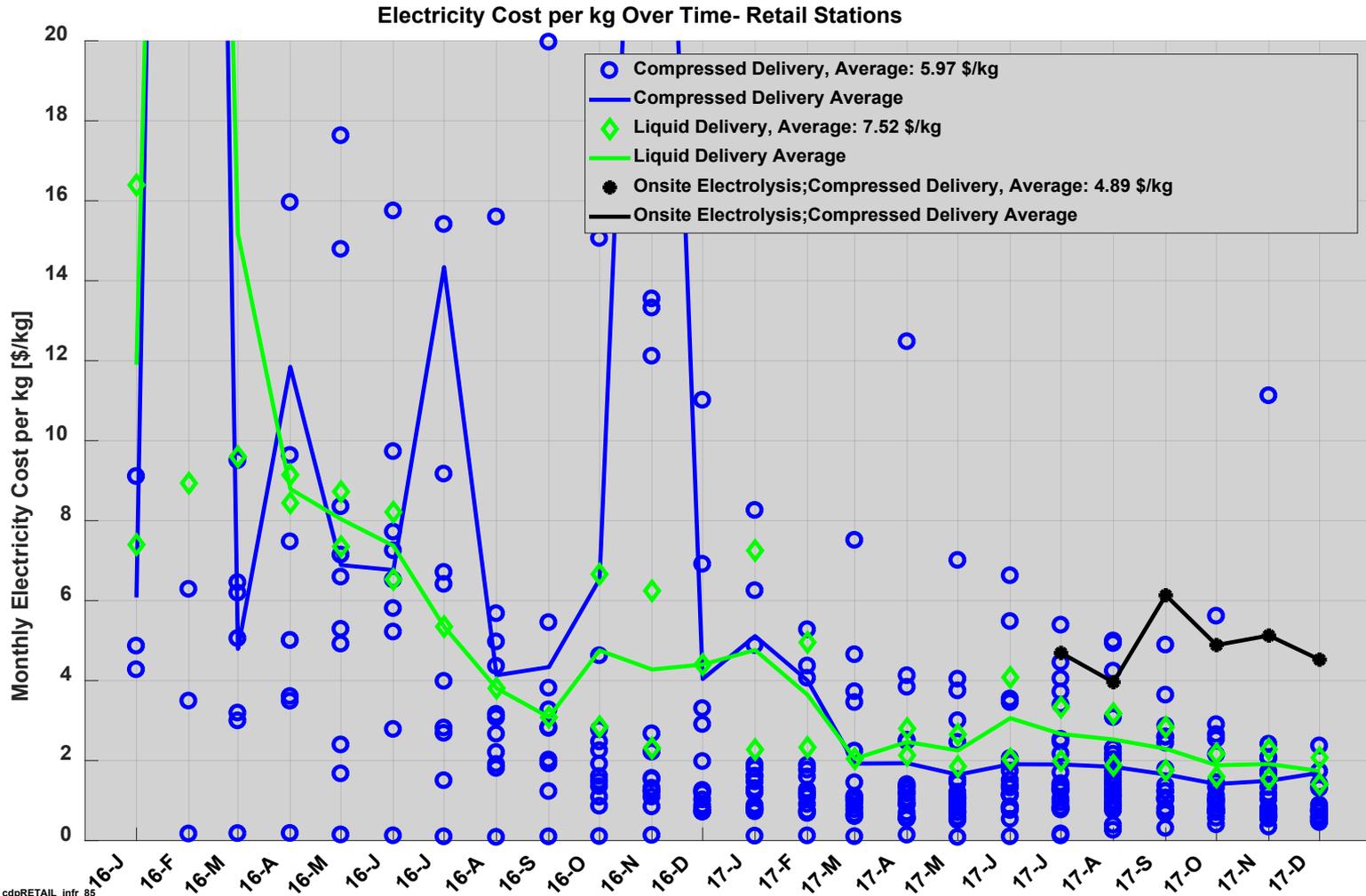
# Electricity Cost per kWh by Utility



NREL cdpRETAIL\_infr\_87

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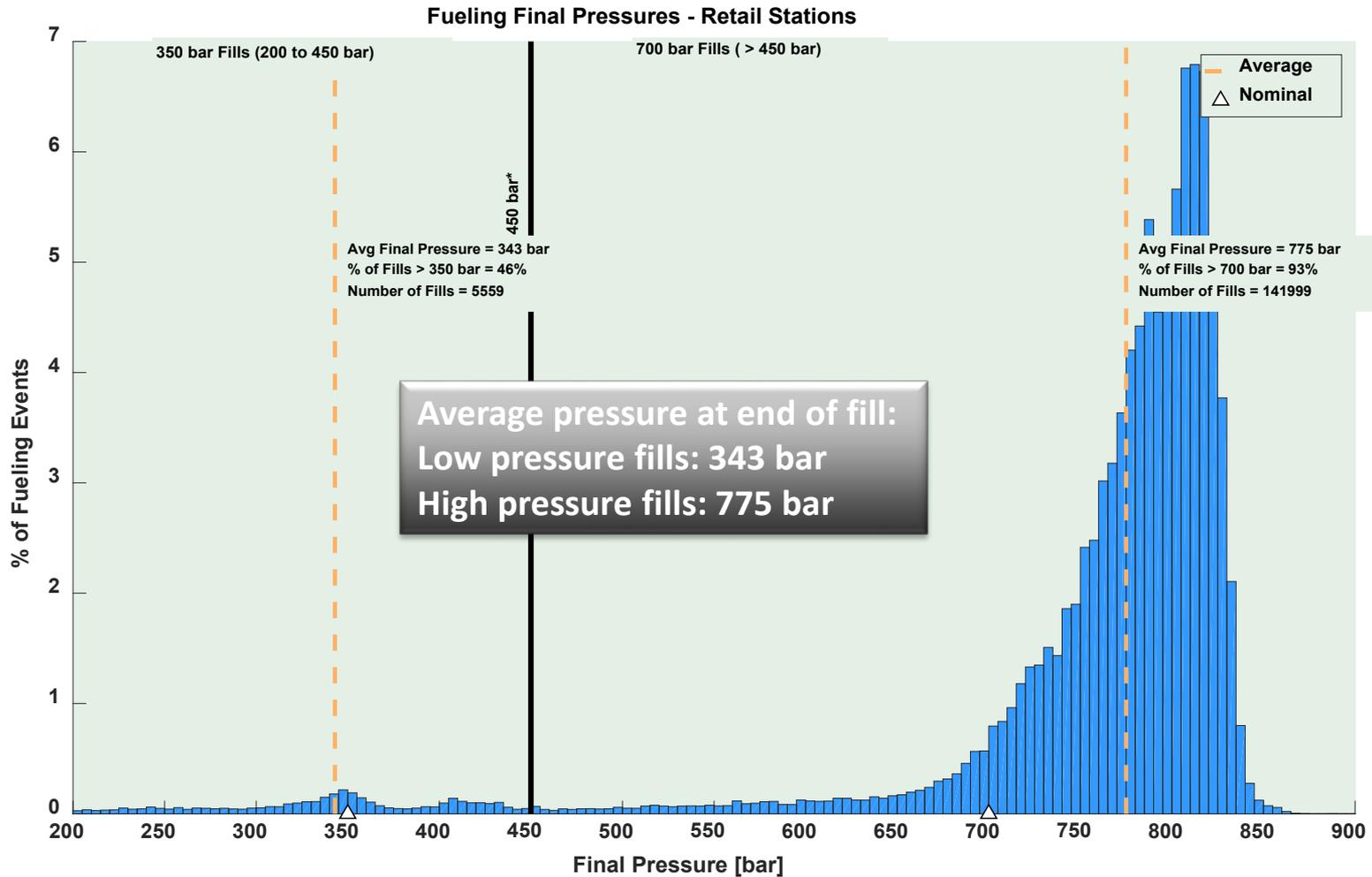
# Electricity Cost per kg Dispensed by Month



NREL cdpRETAIL\_infr\_85

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# Accomplishment: Fueling Final Pressures

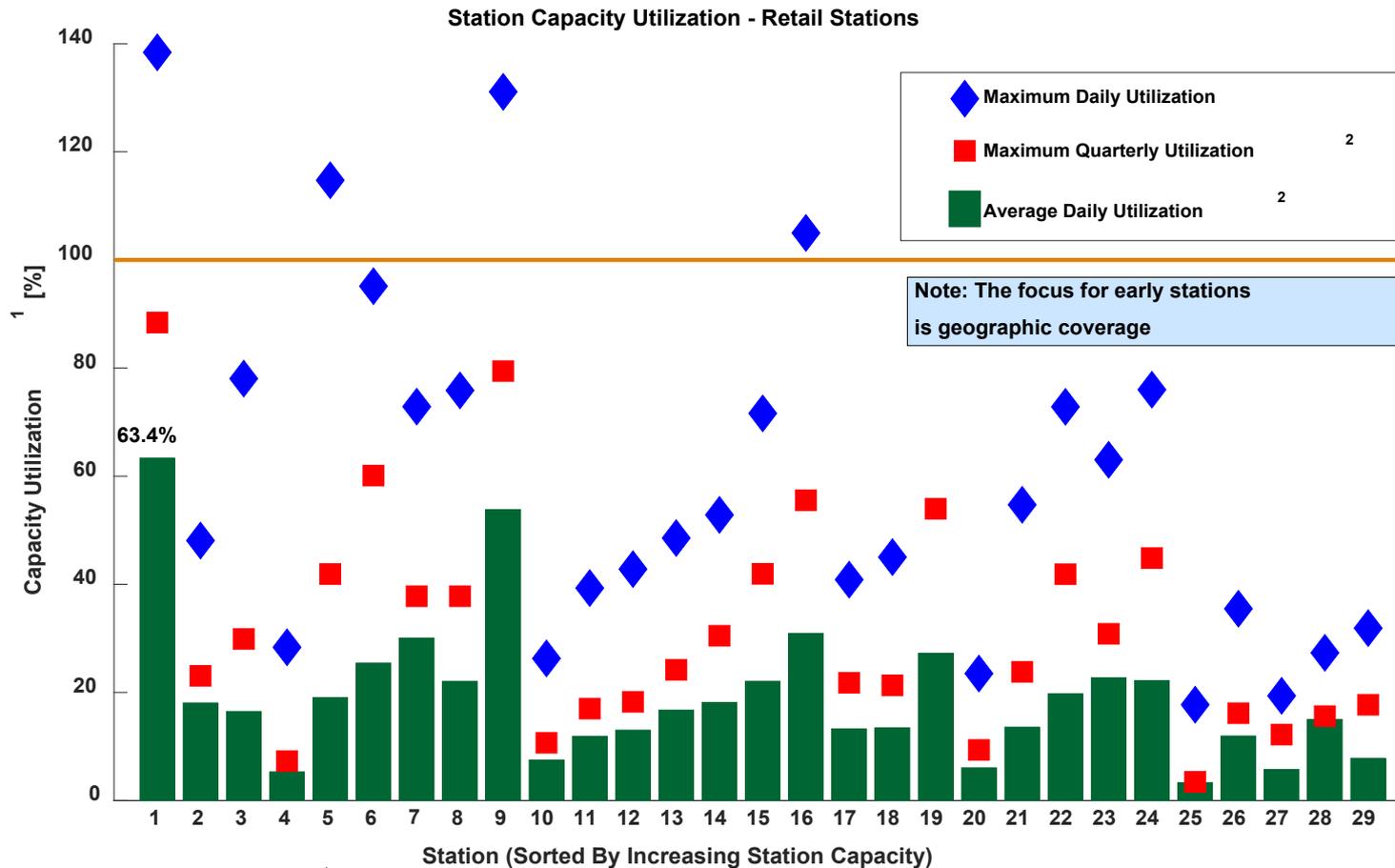


NREL cdpRETAIL\_infr\_09

Created: Feb-16-18 3:32 PM | Data Range: 2014Q3-2017Q4

\*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.

# Accomplishment: Station Capacity Utilization



 NREL cdpRETAIL\_infr\_06  
Created: Feb-16-18 3:32 PM | Data Range: 2014Q3-2017Q4

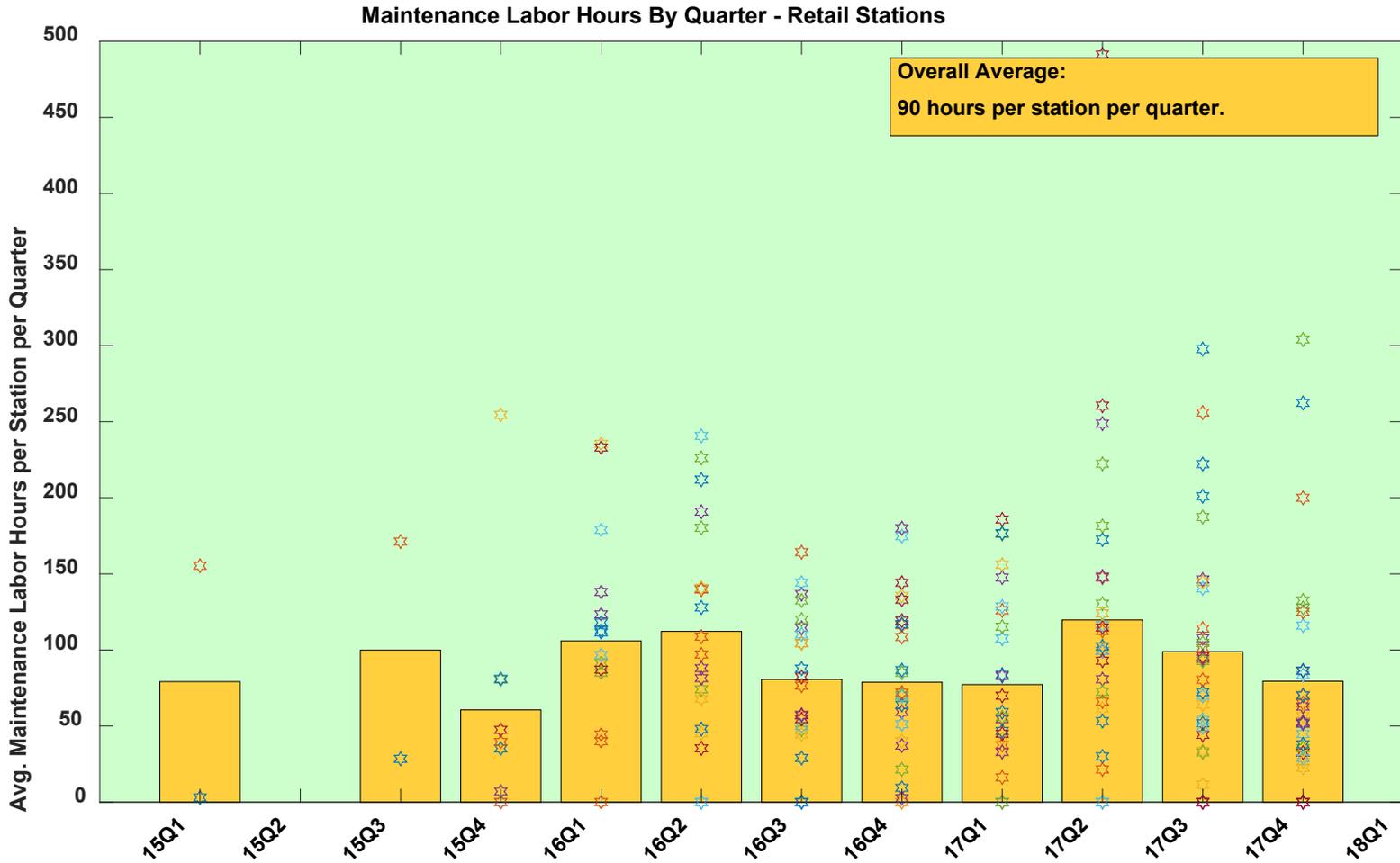
<sup>1</sup> Station nameplate capacity reflects a variety of system design considerations including system capacity, throughput, system reliability and durability, and maintenance. Actual daily usage may exceed nameplate capacity.

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

urred

Most stations are dispensing well below their stated capacity but two are over 50% on avg.

# Accomplishment: Maintenance Labor Hours by Quarter

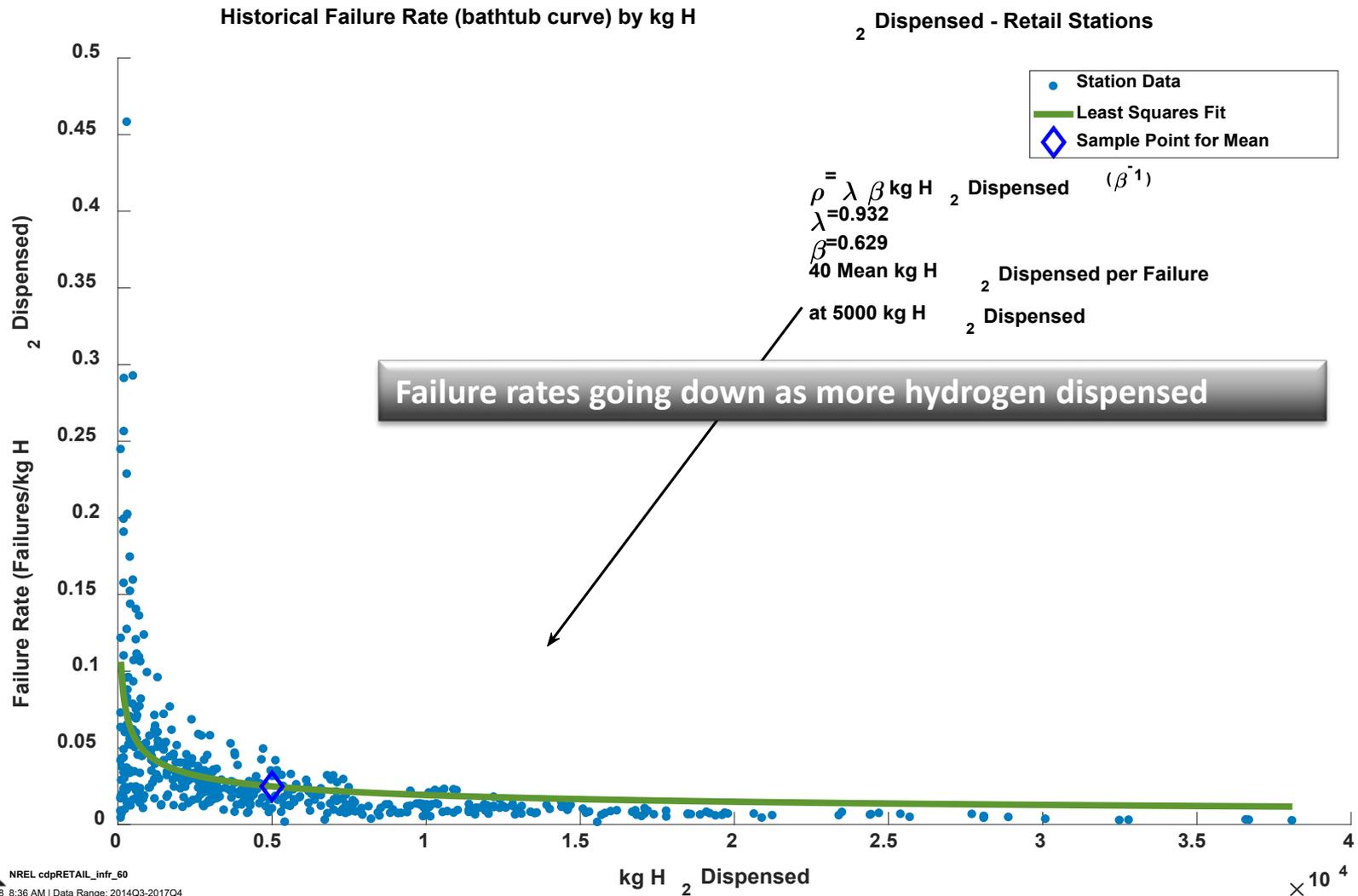


NREL cdpRETAIL\_infr\_28

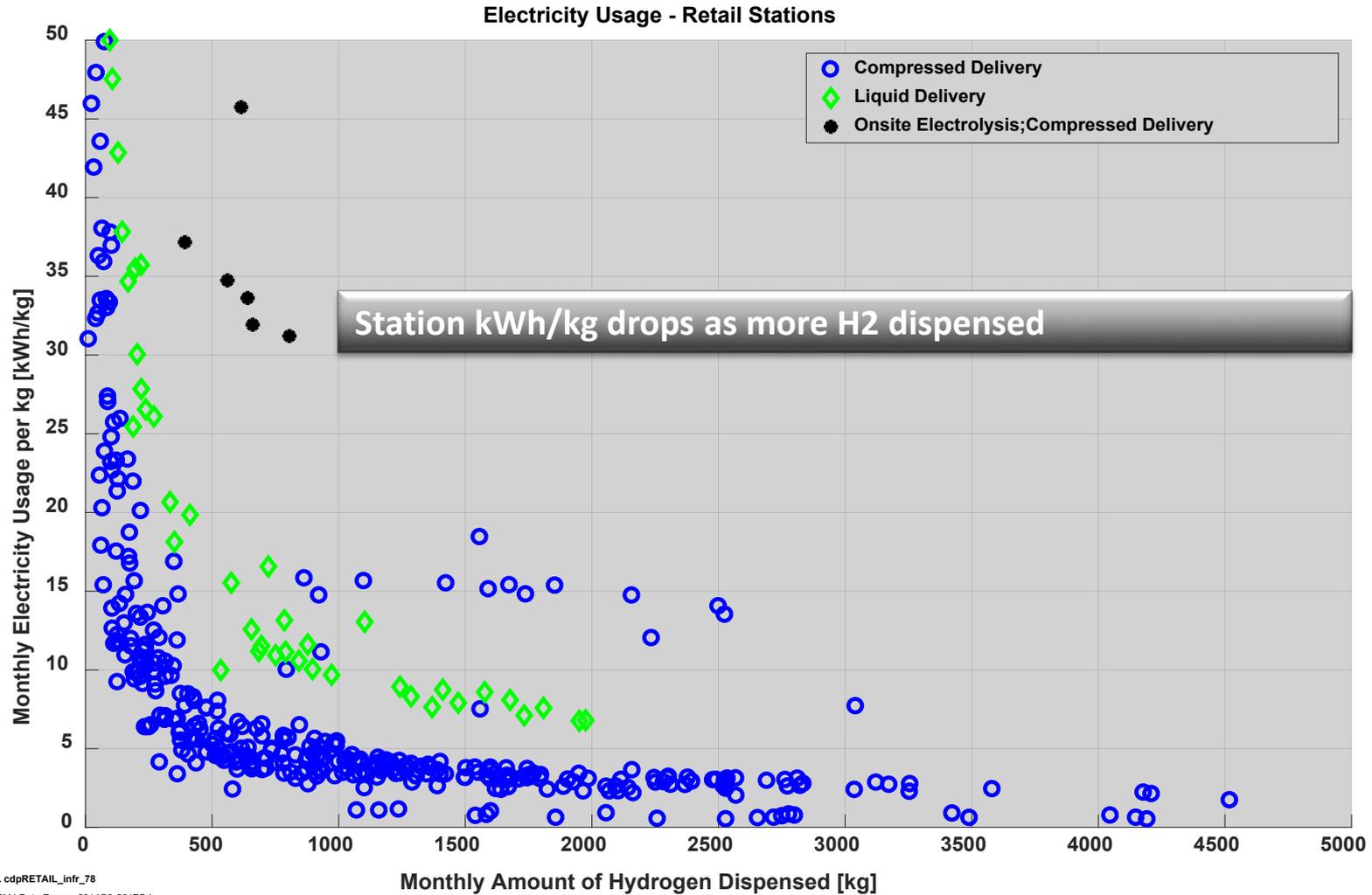
Created: May-07-18 1:56 PM | Data Range: 2014Q3-2017Q4

Stars represent individual station maintenance hours in a given quarter.

# Accomplishments and Progress: Failure Rates by kg Dispensed (bathtub curve)



# Accomplishments and Progress: Electricity Usage per kg Dispensed



NREL cdpRETAIL\_infr\_78

Created: May-15-18 4:21 PM | Data Range: 2014Q3-2017Q4