NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Hydrogen Station Data Collection and Analysis

Sam Sprik (PI), Jennifer Kurtz, Chris Ainscough, Genevieve Saur, Shaun Onorato, Matt Ruple
National Renewable Energy Laboratory
June 14, 2018

DOE Hydrogen and Fuel Cells Program
2018 Annual Merit Review and Peer Evaluation Meeting

Project ID TV017

Overview

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

First Element, Coalinga, CA. Photo: NREL

ITM Power, Riverside, 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)

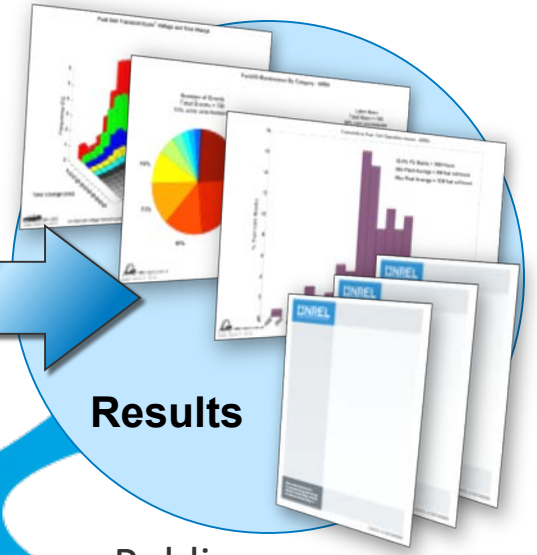
Approach: NFCTEC Data/Analysis/Results Handling

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

DDPs

Internal analysis completed quarterly

NREL's National Fuel Cell Technology Evaluation Center



Results

Confidential

Public

CDPs

Detailed Data Products (DDPs)
- Individual data analyses
- Identify individual contribution to CDPs
- Only shared with partner who supplied data every 6 months[1]

Composite Data Products (CDPs)
- Aggregated data across multiple systems, sites, and teams
- Publish analysis results without revealing proprietary data every 6 months[2]

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

66 Stations

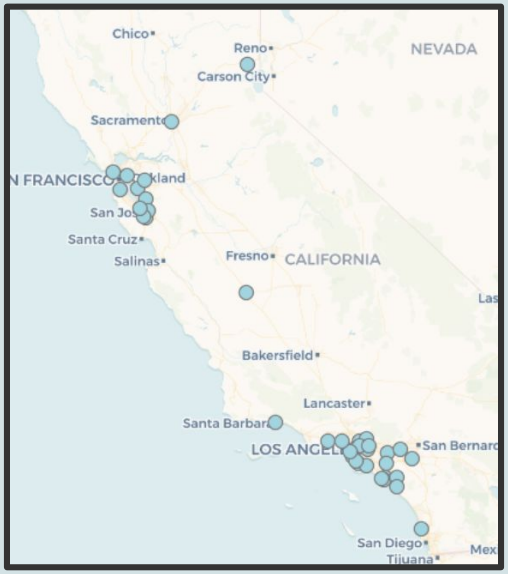
Retail and Non-Retail

34 are Retail - Open

California

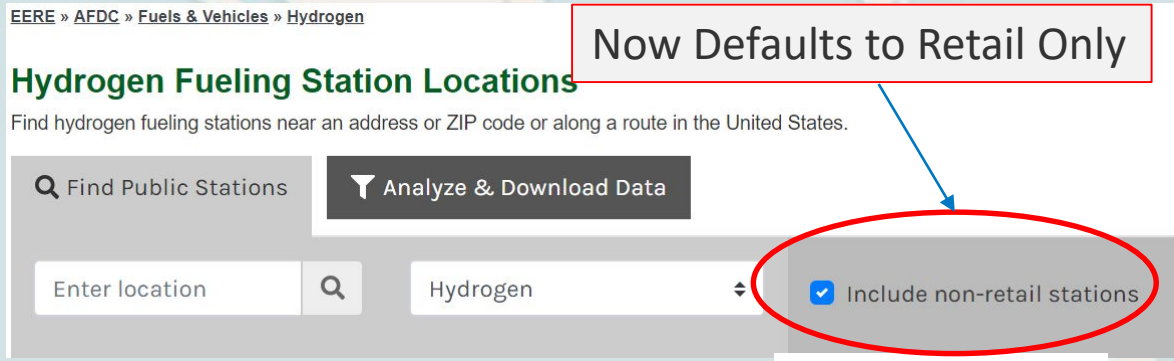
34 Retail - Open

30 Retail - Planned



North East

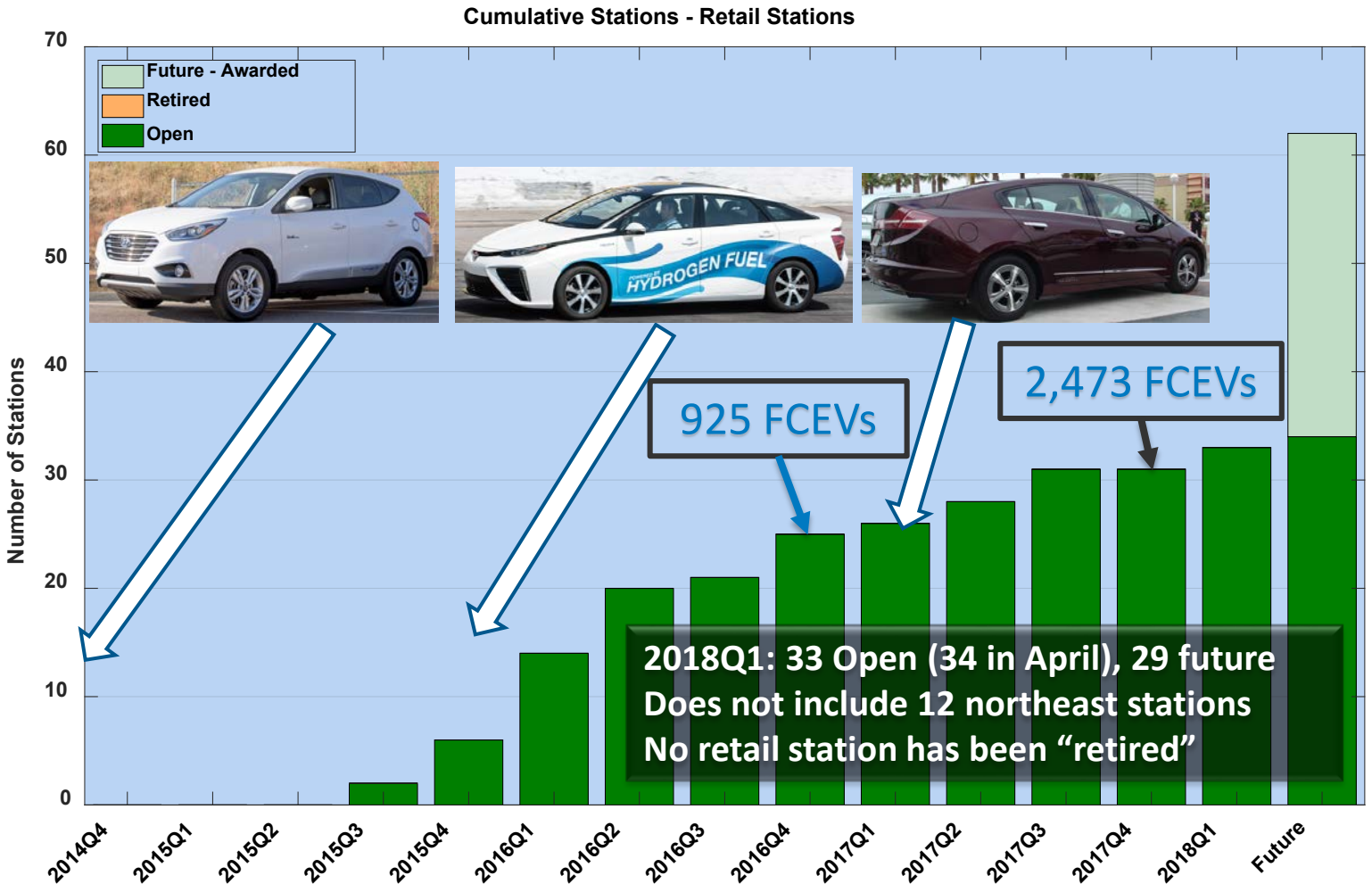
12 Retail - Planned



Now Defaults to Retail Only

As of 5/4/2018

Cumulative Number of Retail Stations



NREL cdpRETAIL_infr_10

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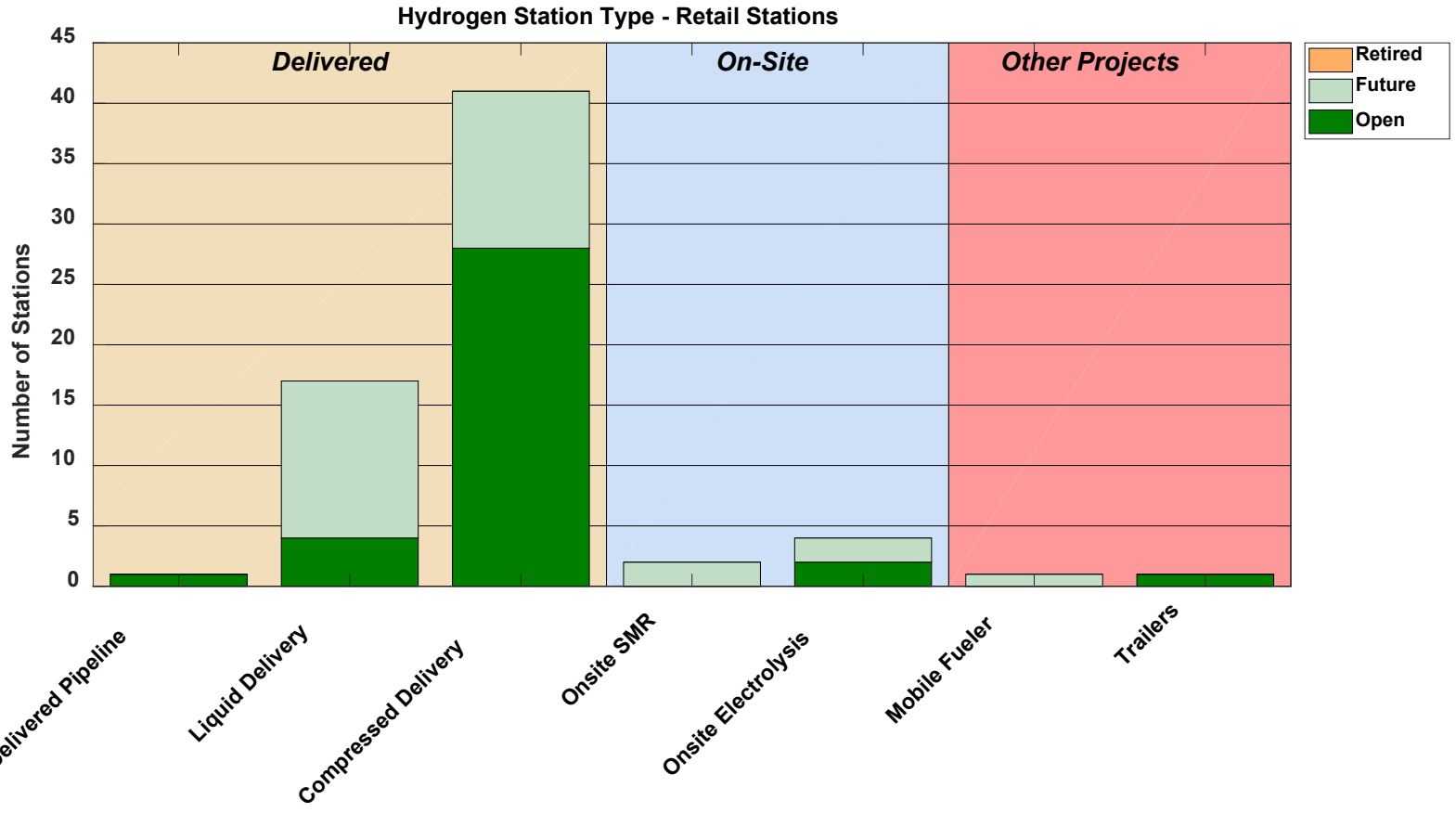
Station Types



NREL cdpRETAIL_infr_11
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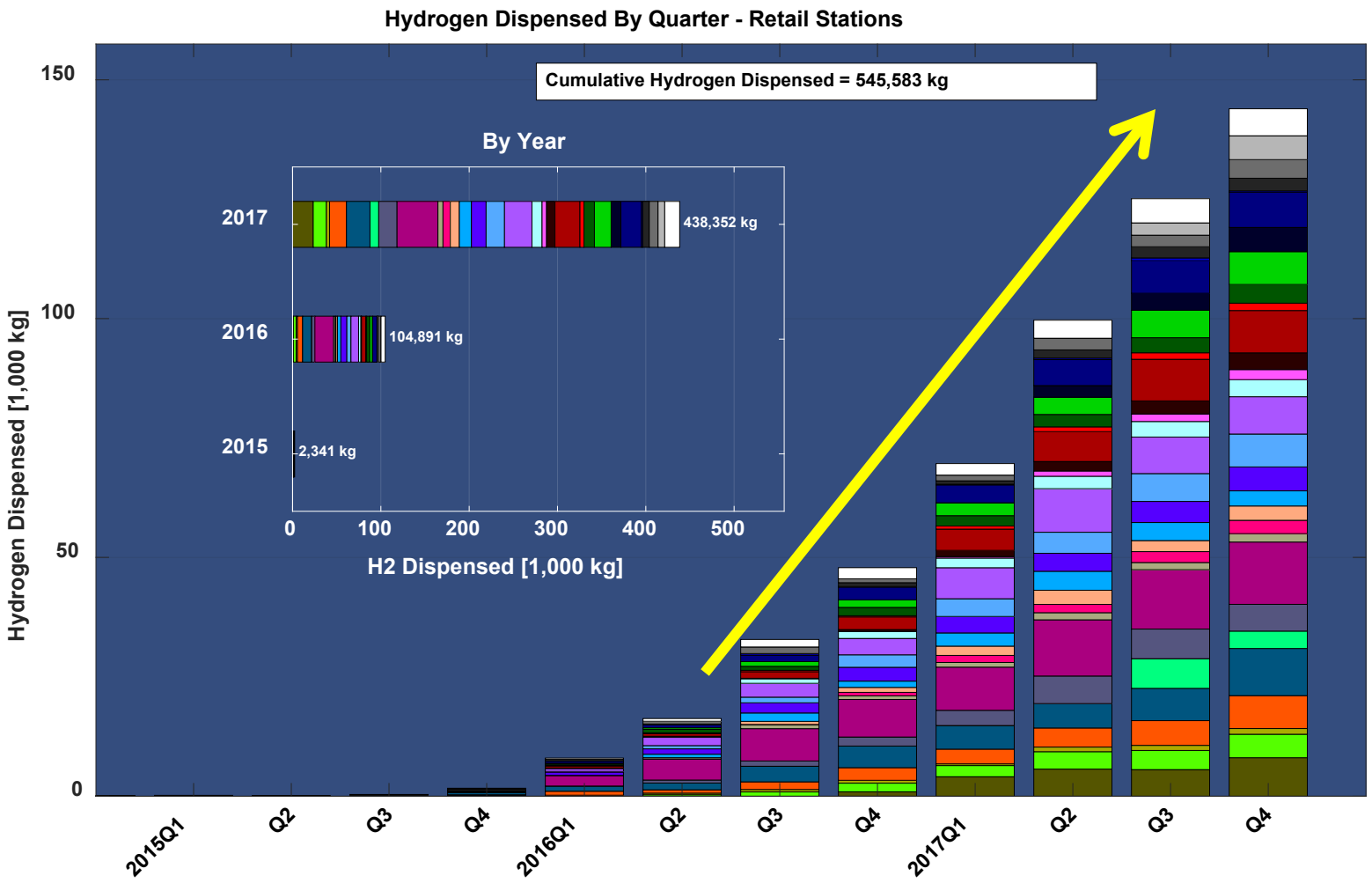
- **Although most retail stations are compressed H2 delivery, they also include liquid delivery, pipeline, SMR and onsite electrolysis.**

Accomplishments and Progress:
Hydrogen Dispensed by Quarter



NREL cdpRETAIL_infr_01
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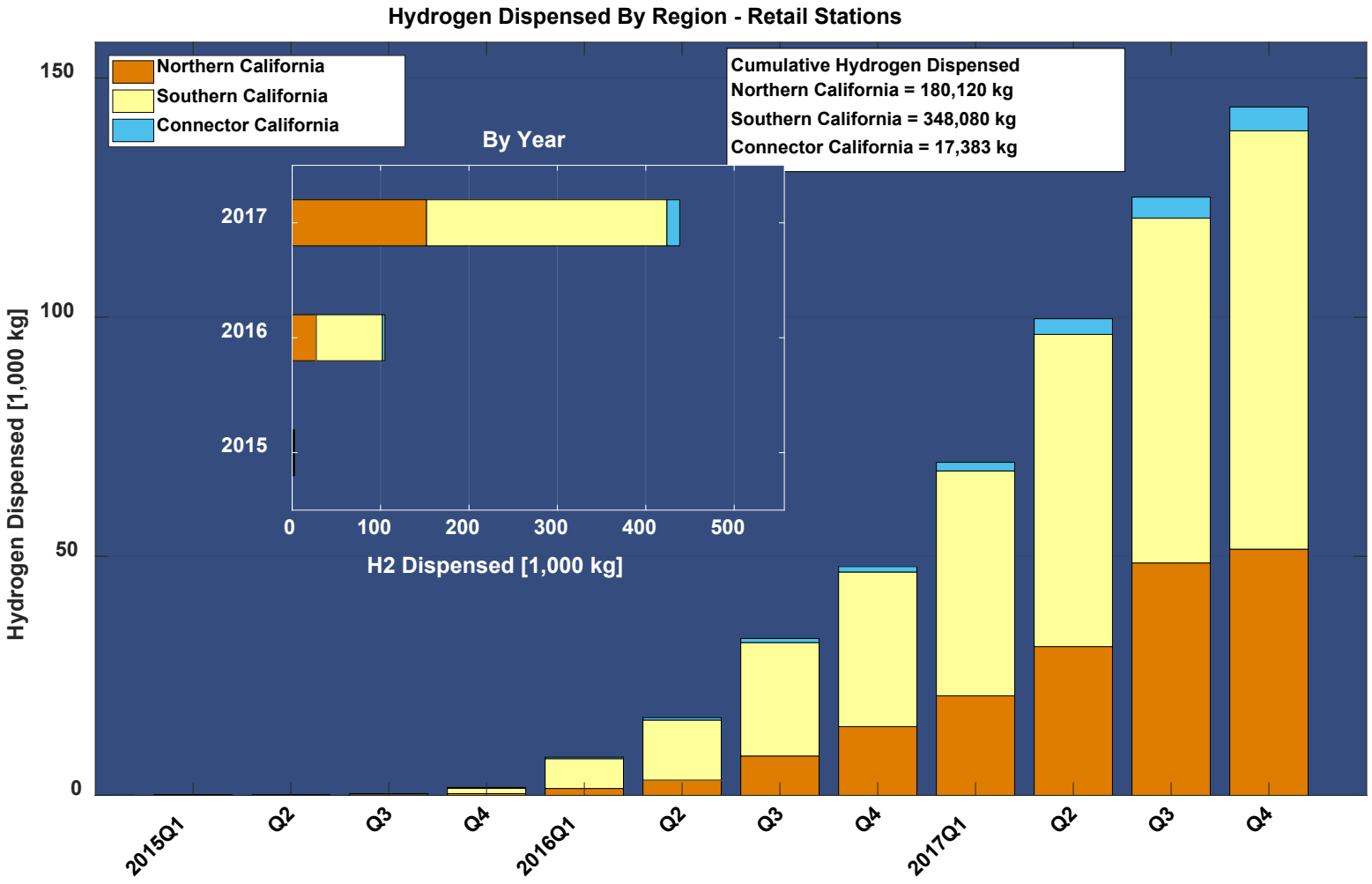
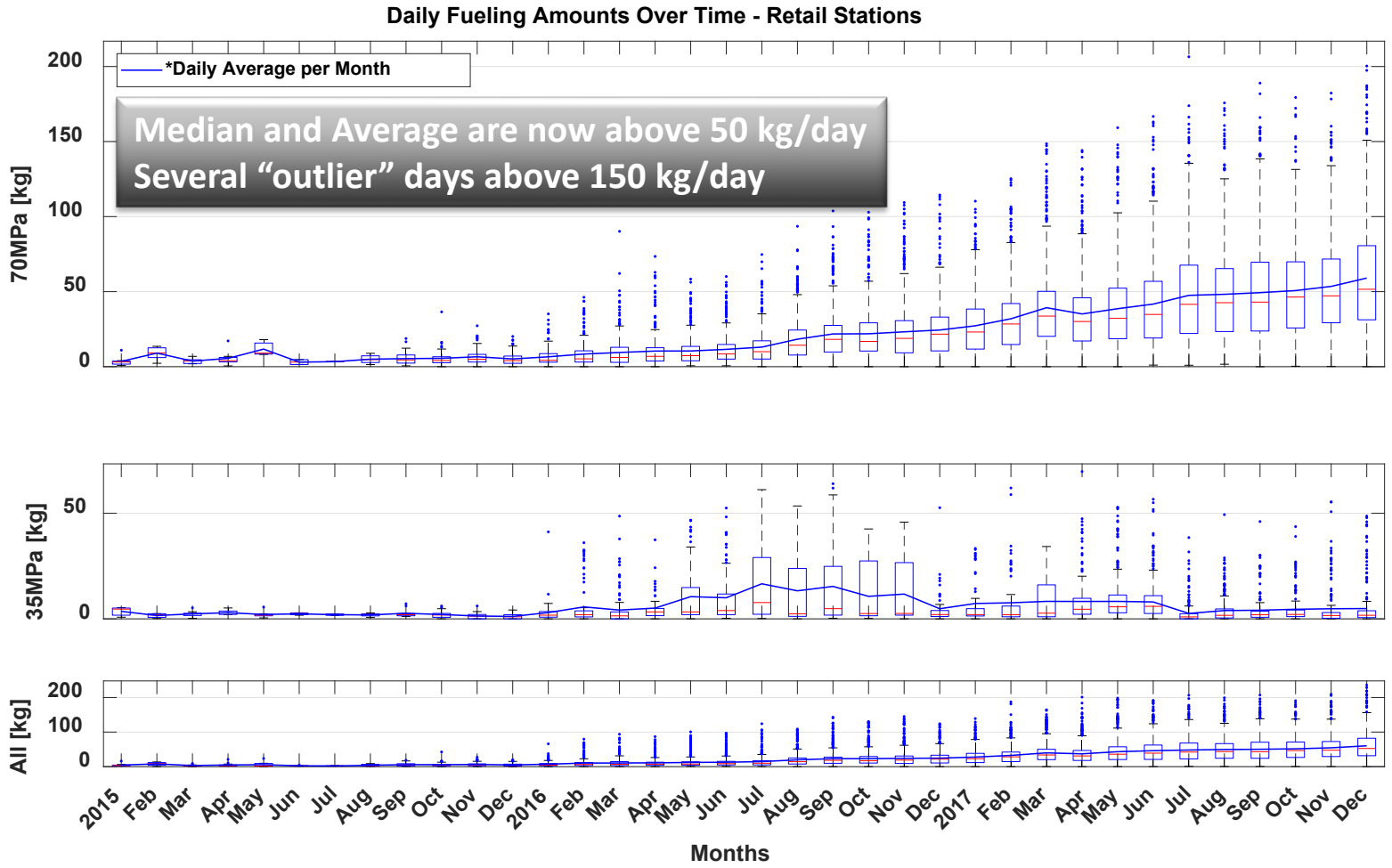
Note: Colors represent individual stations

Retail stations dispensing significantly more each quarter

Accomplishment: Hydrogen Dispensed by Region



Accomplishments and Progress:
Daily Fueling by Month – Retail Stations



NREL cdpRETAIL_infr_82

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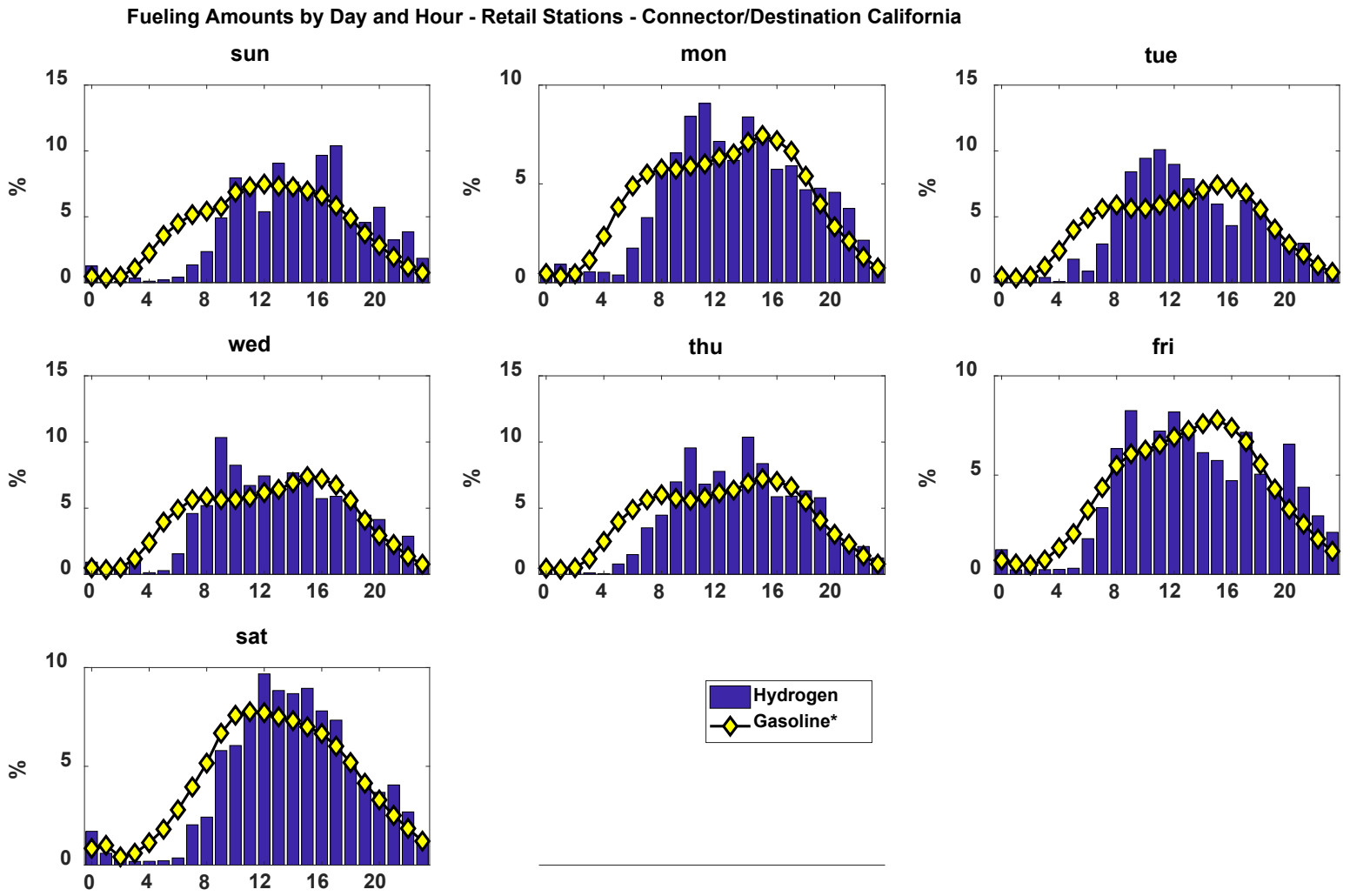
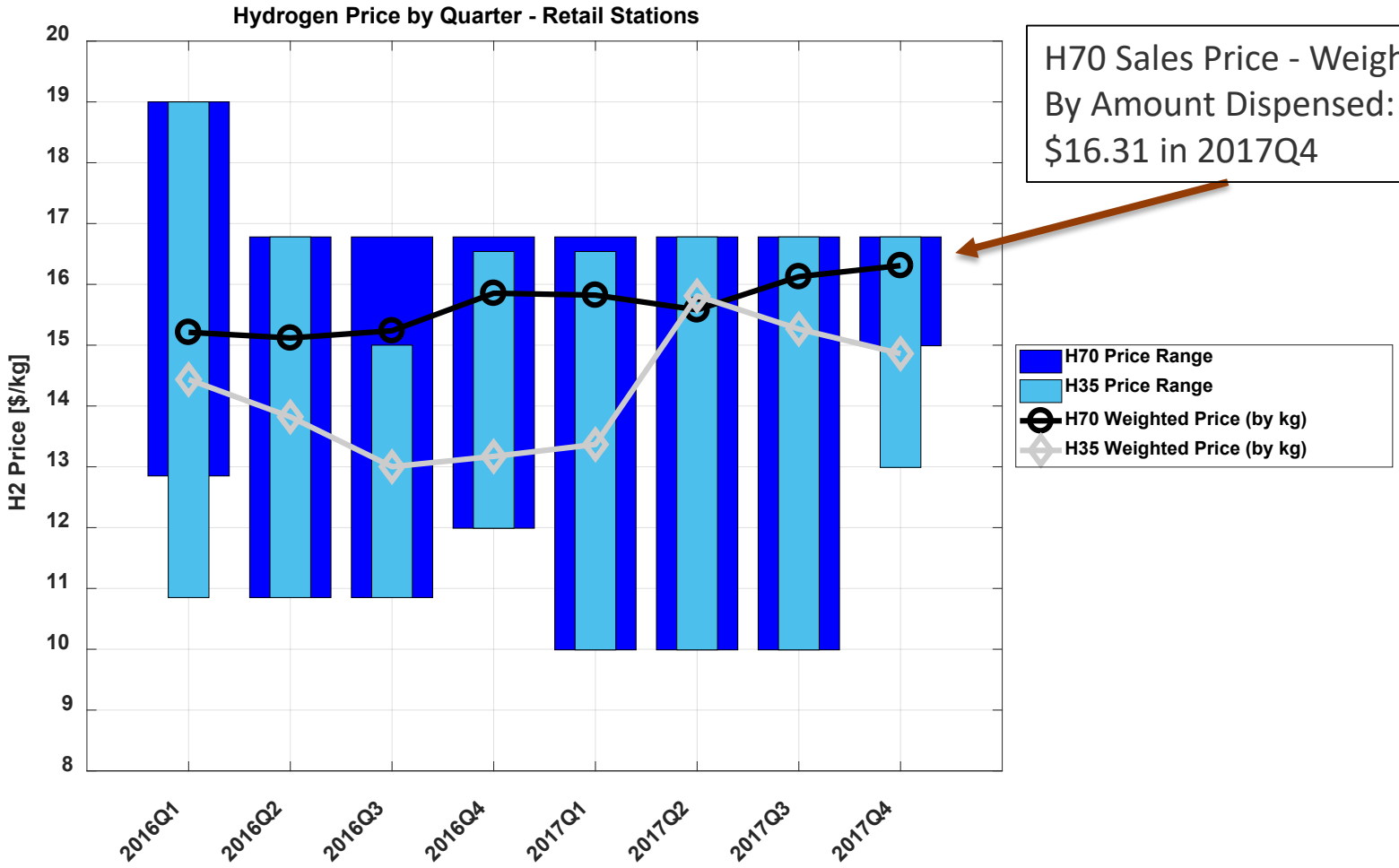
*Daily average only includes days with fills.

Accomplishment: Hydrogen by Day and Hour – Connector/Destination



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

Accomplishment: Hydrogen Price



H70 Sales Price - Weighted Avg By Amount Dispensed: $16.31 in 2017Q4

NREL cdpRETAIL_infr_89
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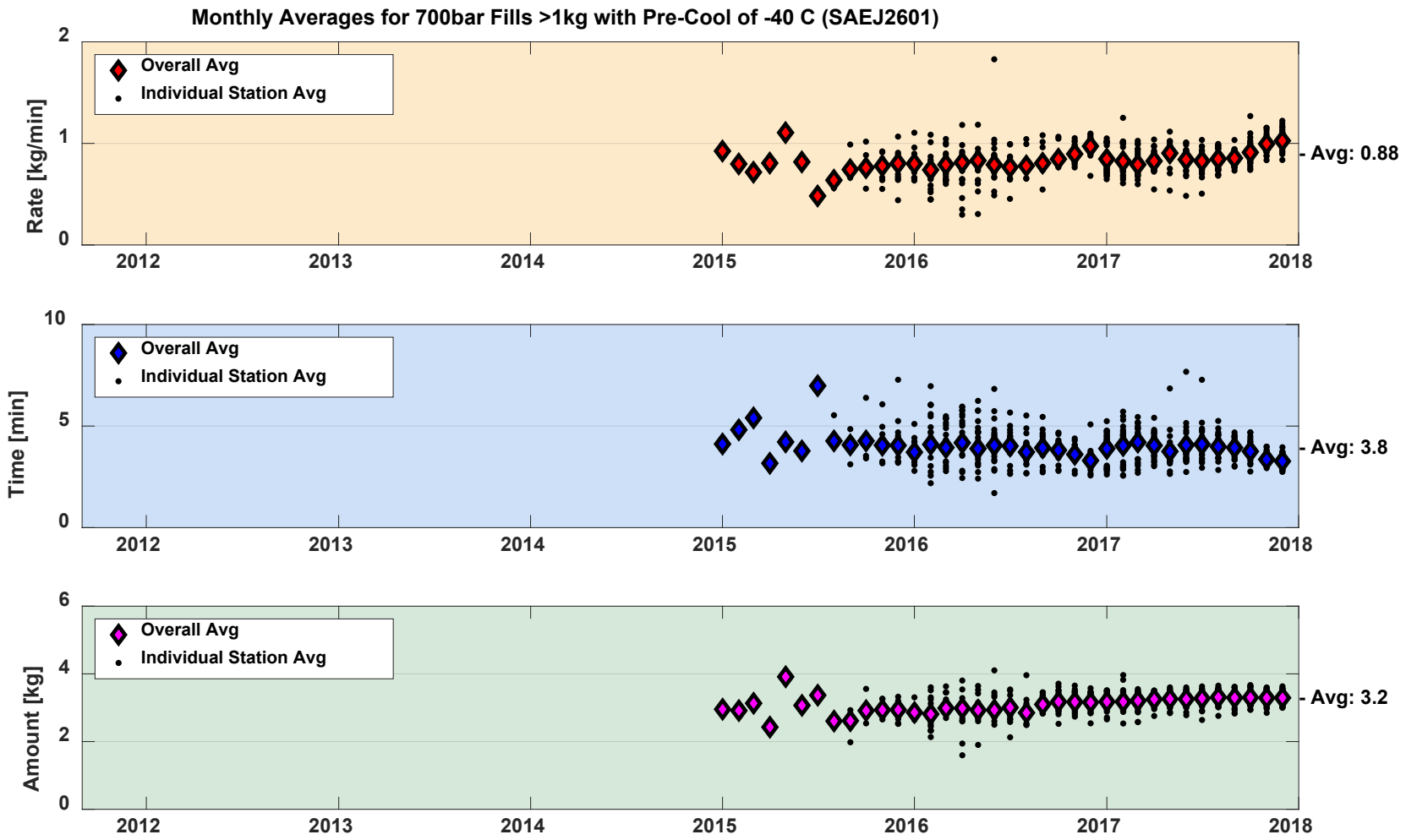
Accomplishments and Progress:
Monthly Averages for 700bar Fills >1kg with Pre-Cool of -40C



NREL cdpRETAIL_infr_57
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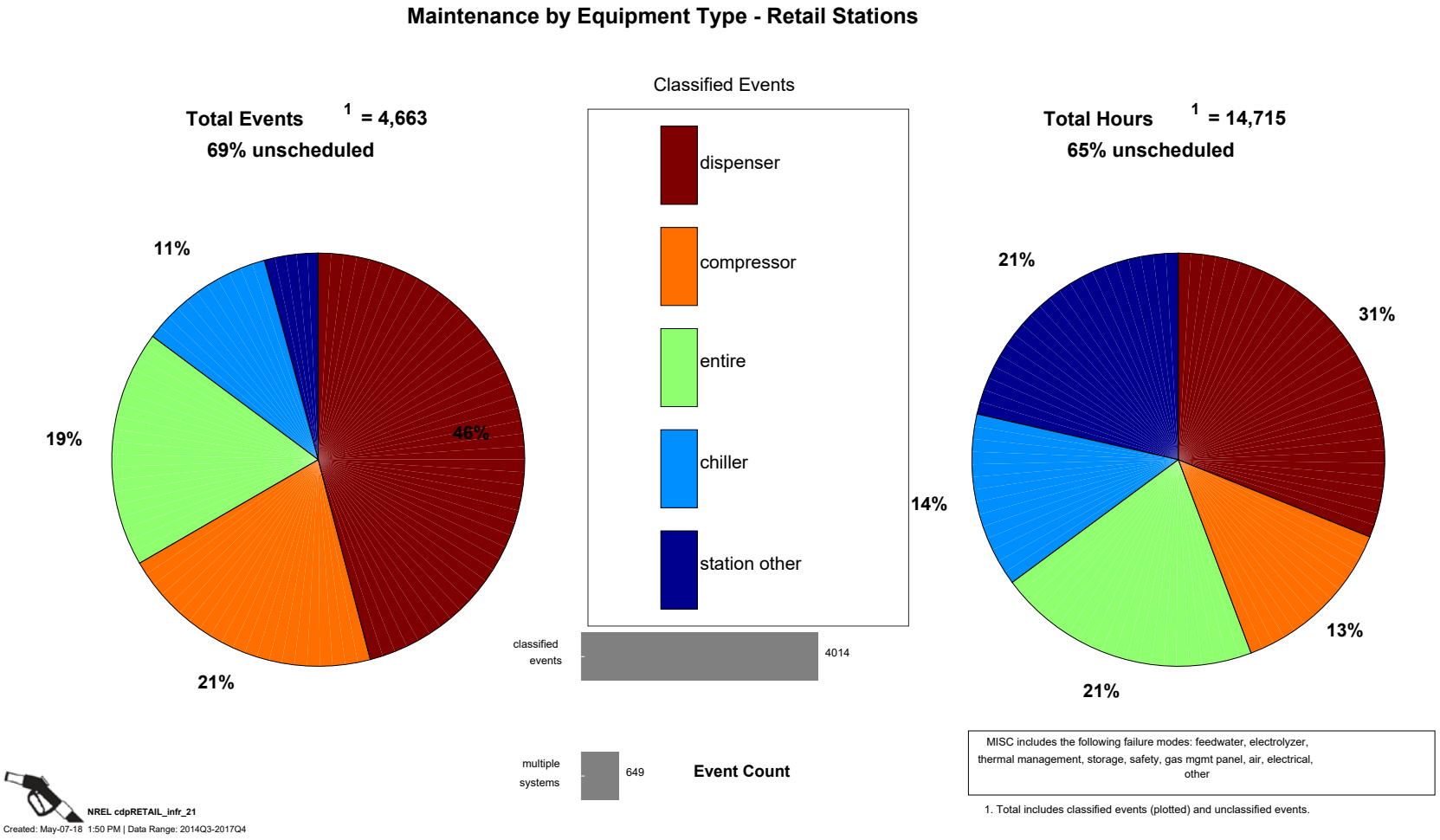
Time to fill is decreasing below the average of 3.8 minutes.
Average amount filled increasing above average of 3.2 kg

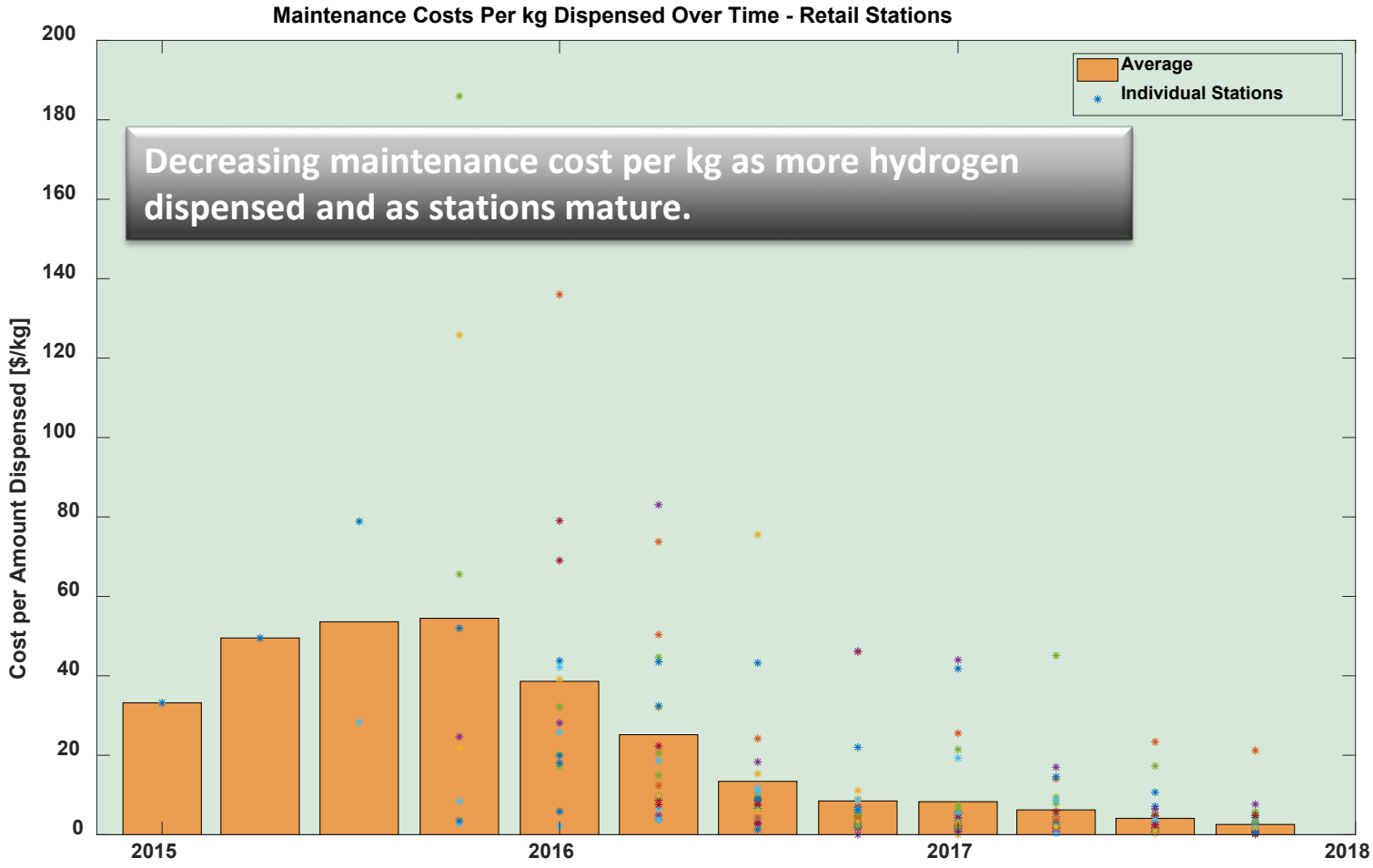
Accomplishments and Progress:
Maintenance by Equipment Type – Retail Stations

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



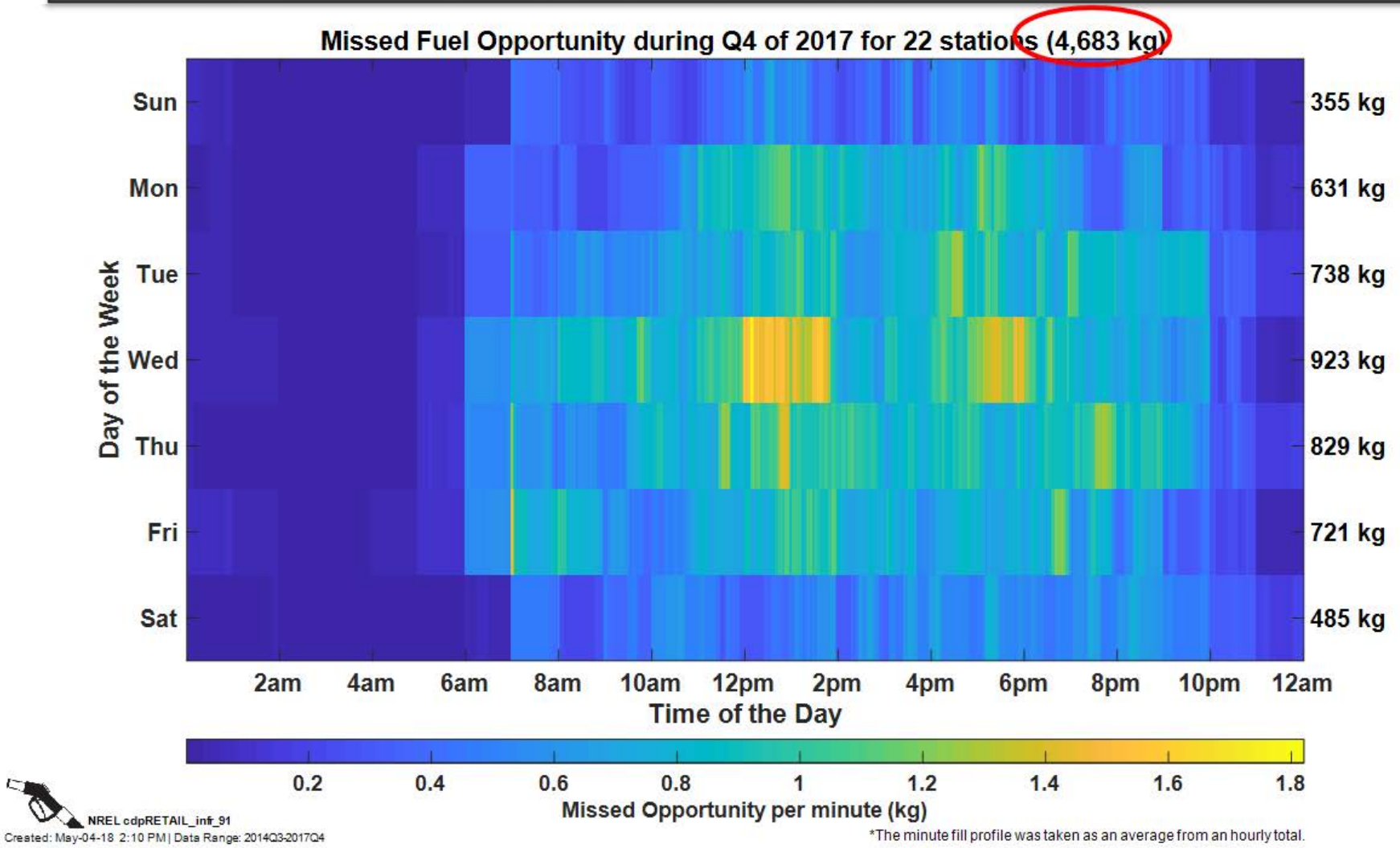
1. Total includes classified events (plotted) and unclassified events.

Accomplishments and Progress:
Dispenser Maintenance Cause and Effects

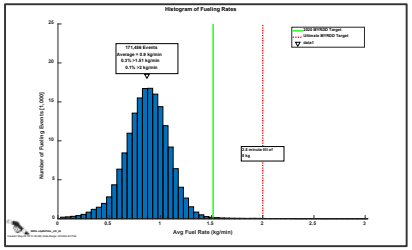


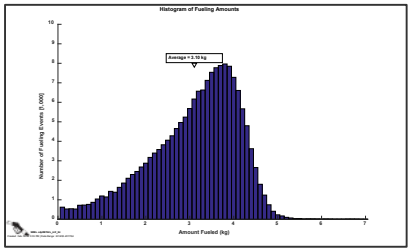
Accomplishments and Progress:
Missed Opportunity Fueling

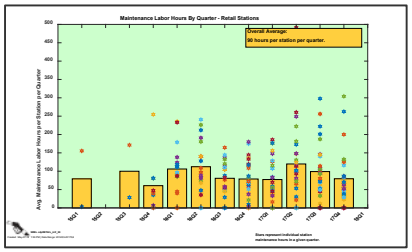
Calculated from average dispensing profiles from each station and their SOSS "Offline" status.

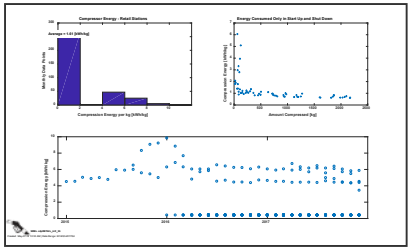


Accomplishments and Progress: Sampling of Results – Retail Stations

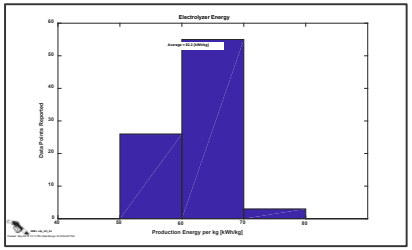


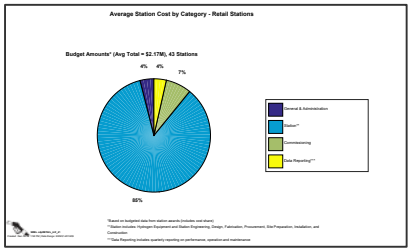


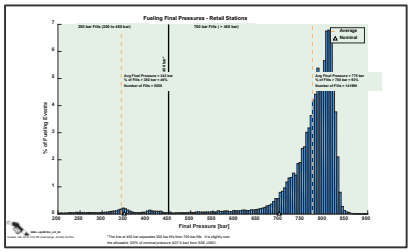


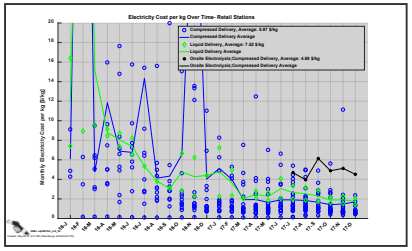


Fueling Rate Average	0.9 kg/min
Fueling Amount Average	3.1 kg
Fueling Time Average	3.69 min
Compressor Energy Average	1.61 kWh/kg
Total Hydrogen Dispensed (29 Stations)	545,583 kg 143,938 kg - 17Q4
Electrolyzer Energy Average (retail and non-retail stations)	62.2 kWh/kg
Maintenance Hours Average	90 hours/Quarter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









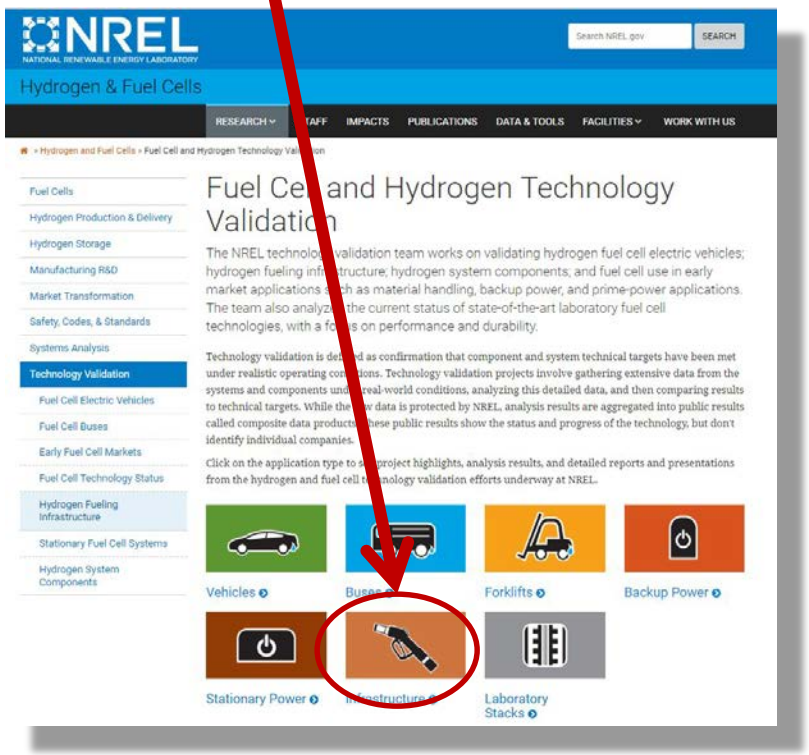
Proposed Future Work

- 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

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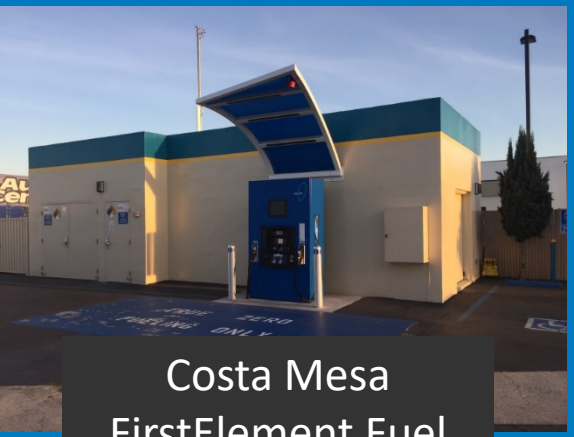
Technical Back-Up Slides

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

Anaheim
Air Liquide

Torrance
Shell

West Sacramento
Linde

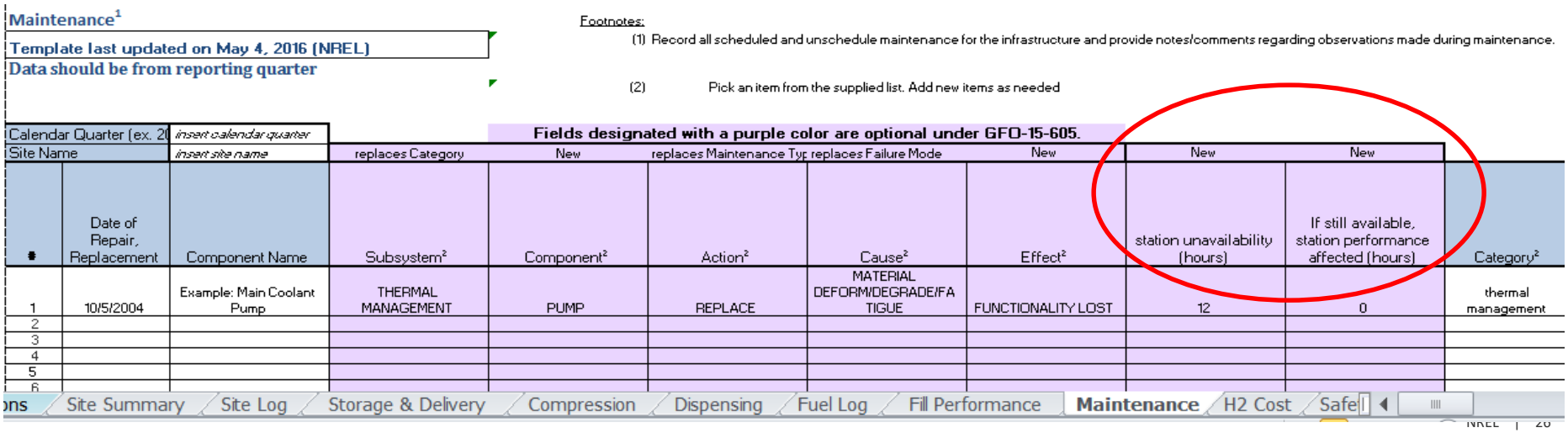
Harris Ranch
FirstElement Fuel

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[1]

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.

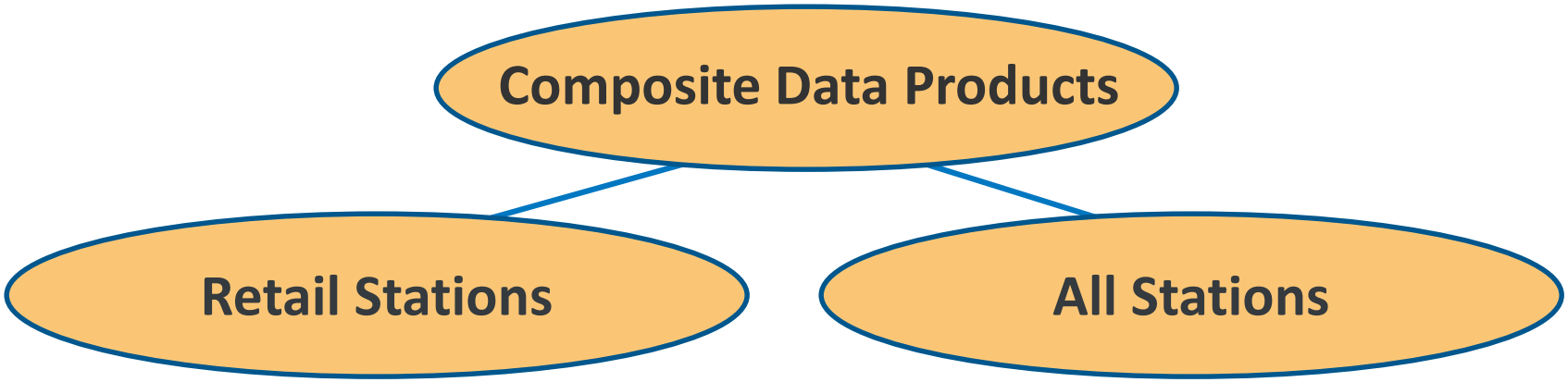
(2) Pick an item from the supplied list. Add new items as needed

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

Calendar Quarter (ex. 2(	insert calendar quarter									
Site Name	insert site name		replaces Category	New	replaces Maintenance Typ	replaces Failure Mode	New	New	New	
#	Date of Repair, Replacement	Component Name	Subsystem[2]	Component[2]	Action[2]	Cause[2]	Effect[2]	station unavailability (hours)	If still available, station performance affected (hours)	Category[2]
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										

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

Approach: Focusing on Retail Stations



- Most recent
- Sell H2 by the kg
- No special approval, any OEM FCEV can fill
- Credit card
- 91 CDPs

- Retail and Non-Retail
- Continuing a separate set of CDPs that includes “All” Stations
- 91 CDPs

Approach: Data Reporting

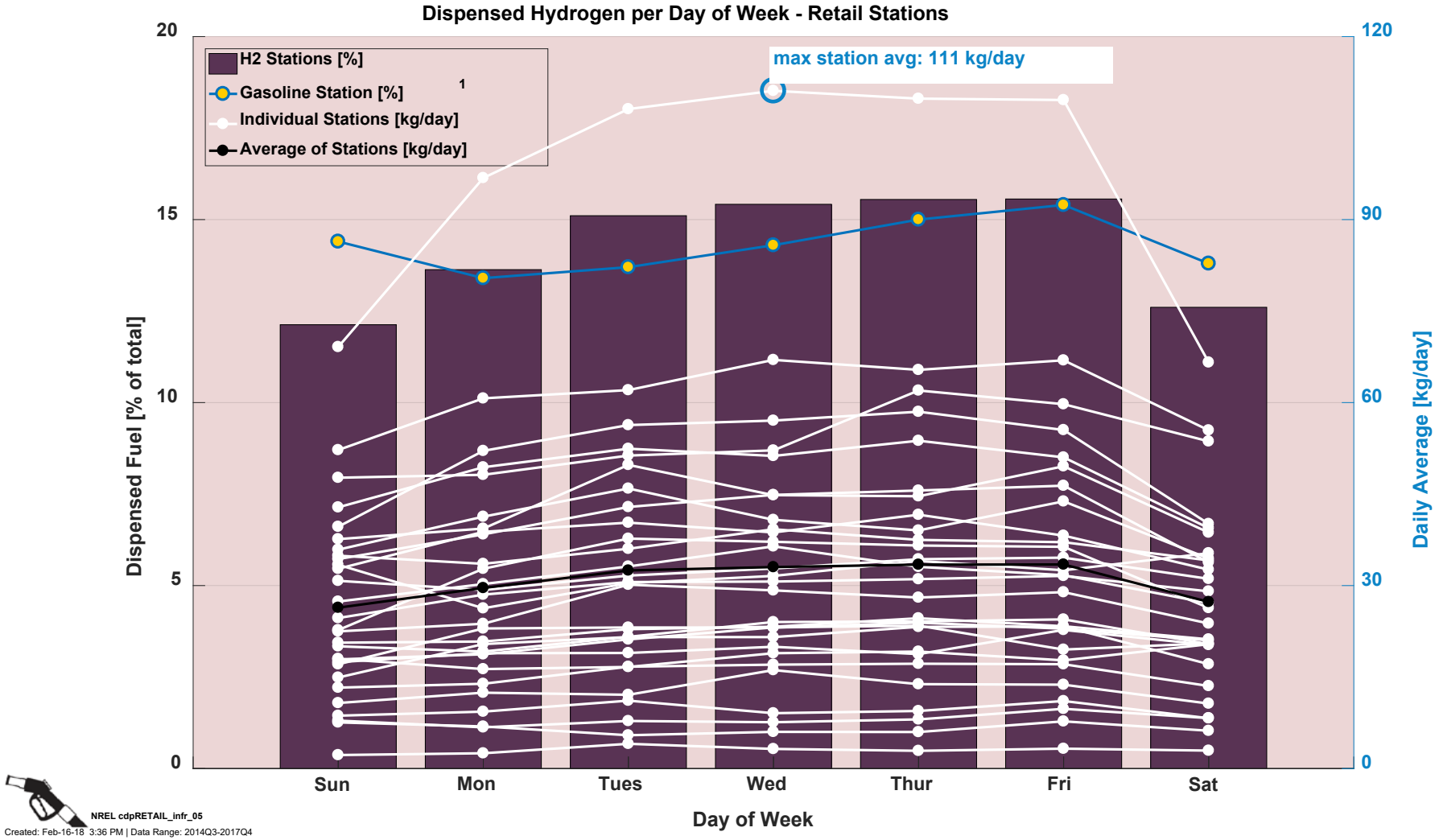
Data Reporting

- 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
Proposed Awards for Operation and Maintenance Support Grants					
1	FirstElement Fuel, Inc.	2655 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 Grimmer 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

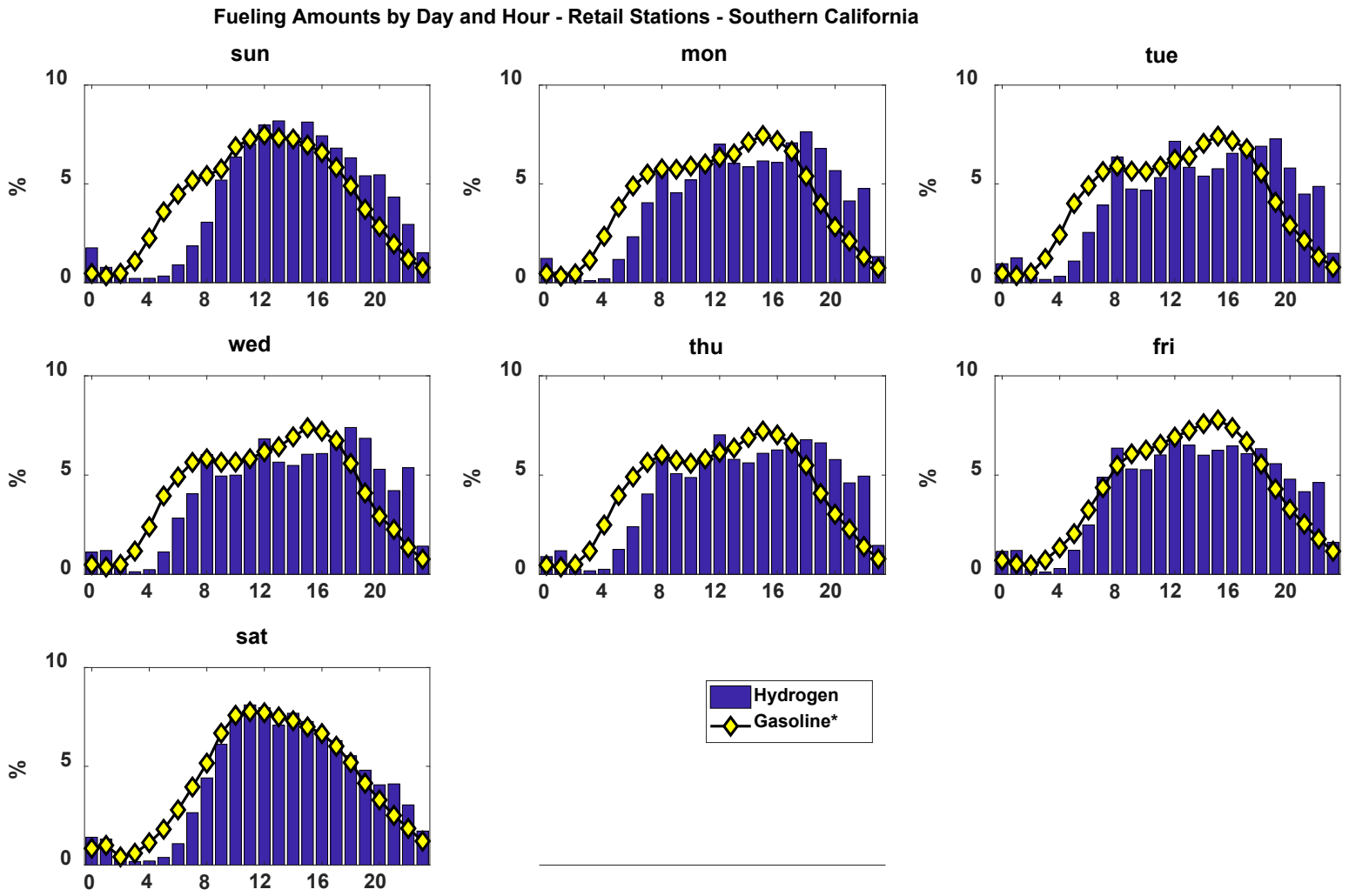
Accomplishment: Hydrogen per Day of Week



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

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

Accomplishment: Hydrogen by Day and Hour – Southern CA



NREL cdpRETAIL_infr_88c

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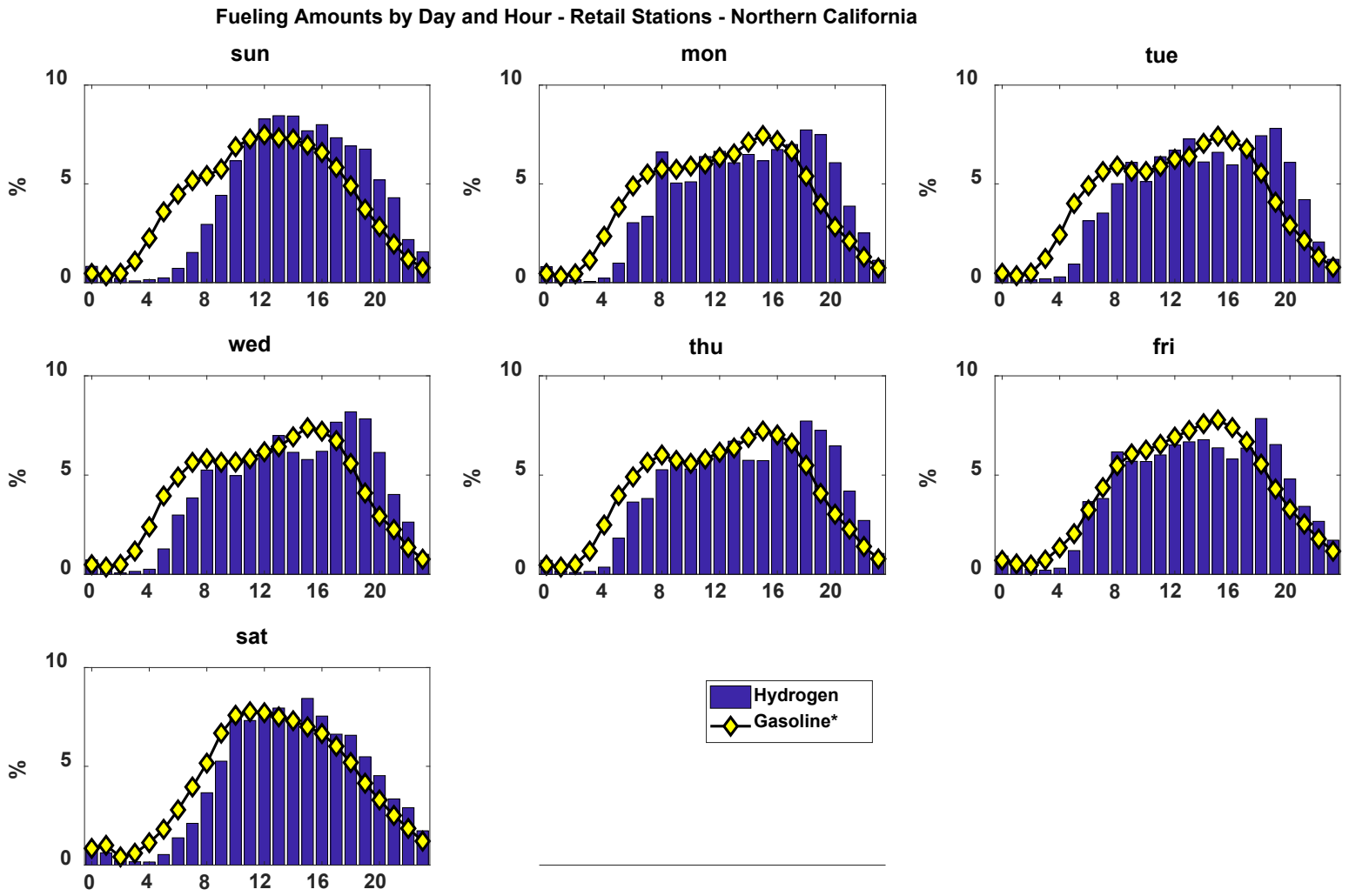
*Chevron gasoline profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.

Accomplishment: Hydrogen by Day and Hour - Northern CA



NREL cdpRETAIL_infr_88b

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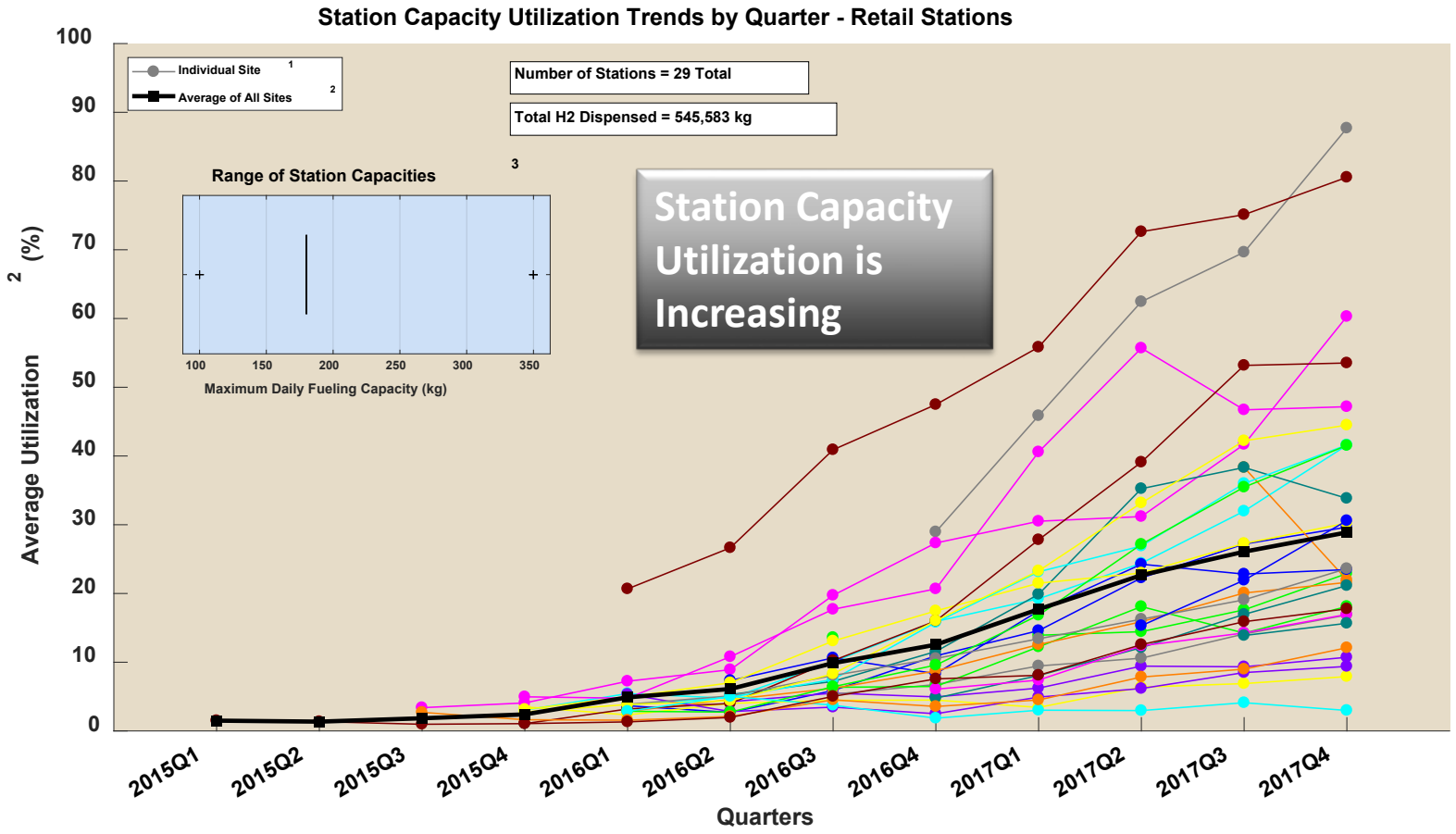
*Chevron gasoline profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.

Accomplishments and Progress:
Capacity Utilization



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

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

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

NREL cdpRETAIL_infr_44

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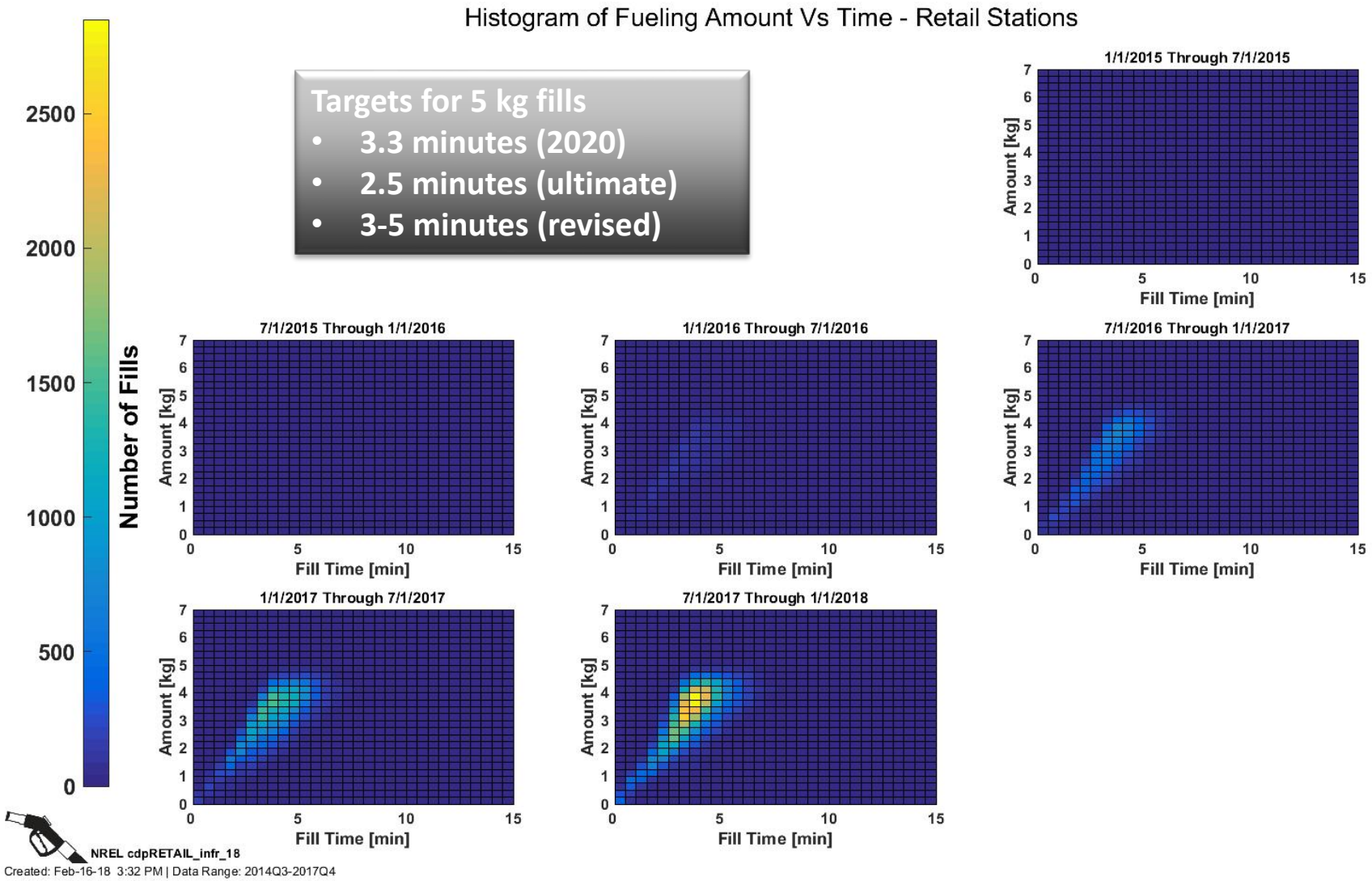
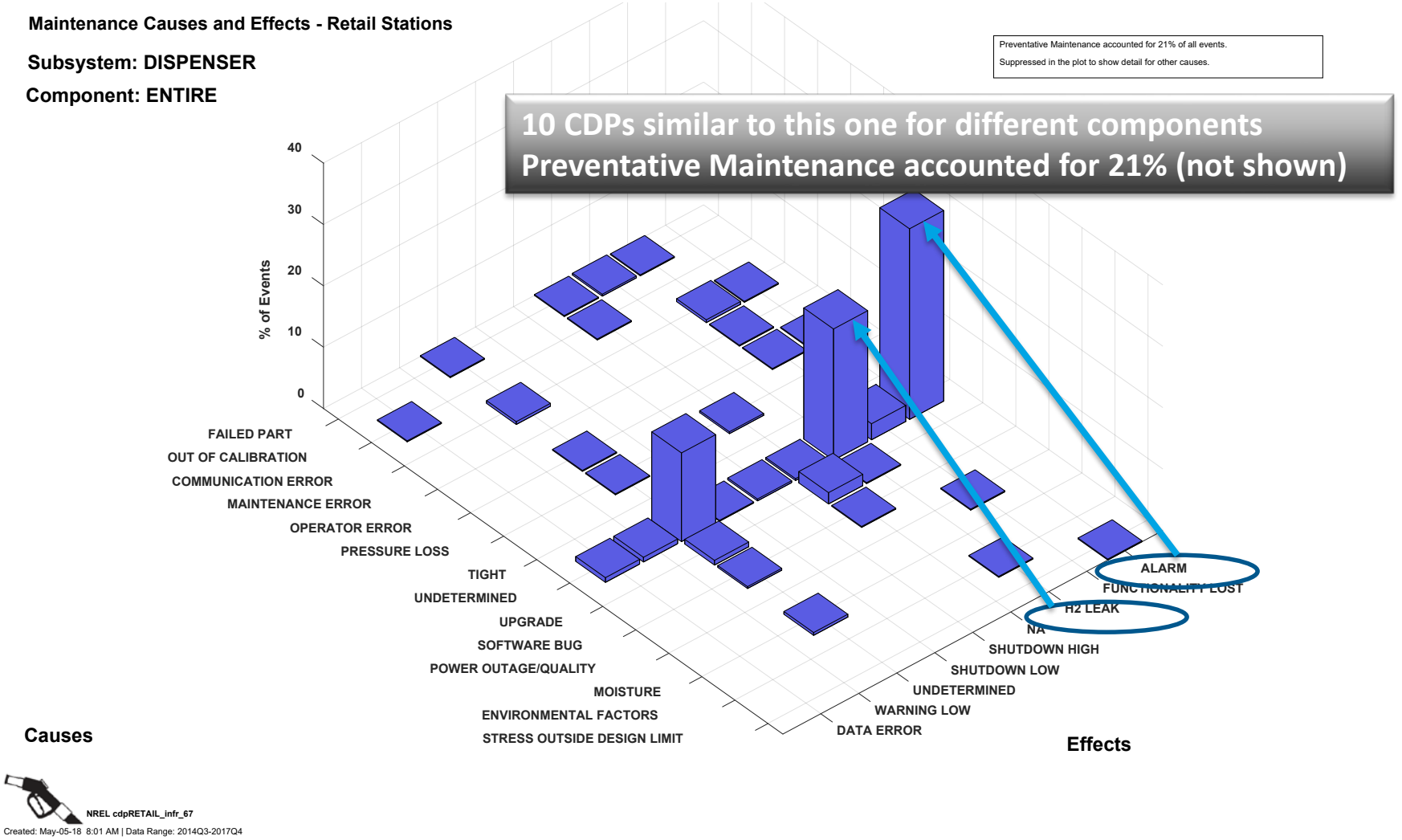
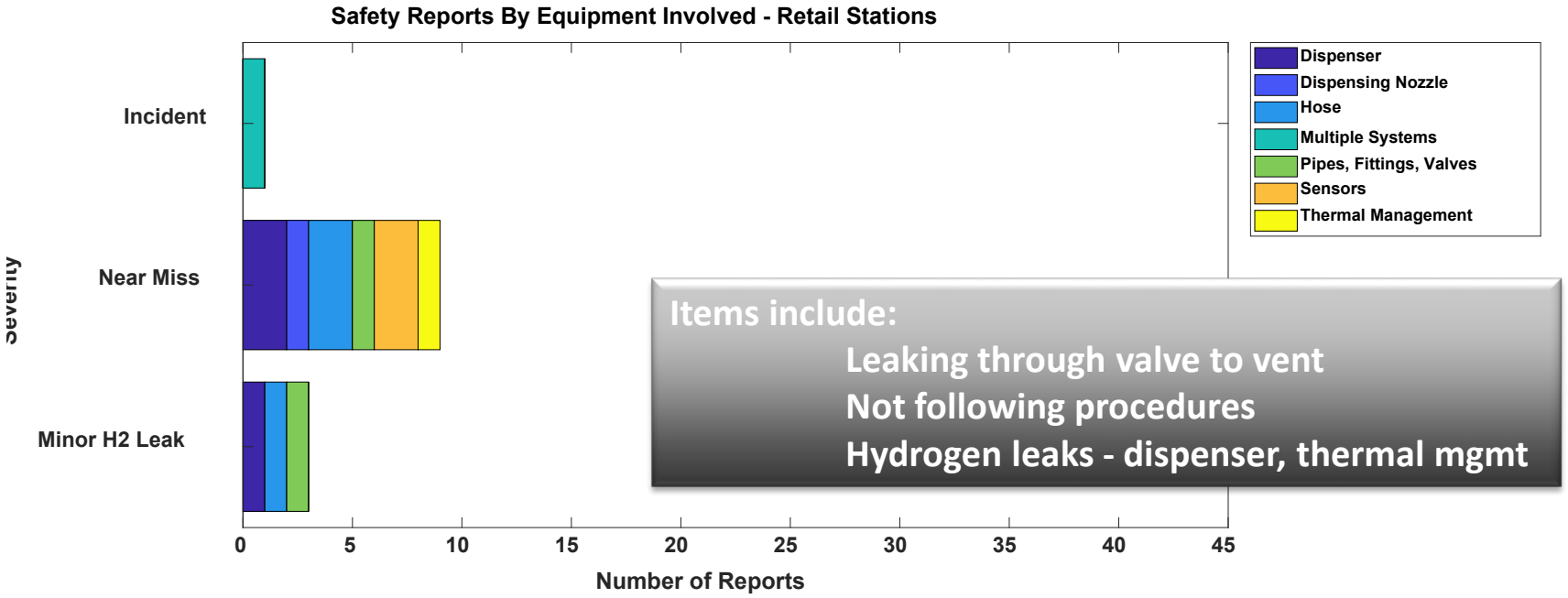
Accomplishments and Progress:
Fueling Amounts vs Times – 6 months at a time



Accomplishments and Progress:
Dispenser Maintenance Cause and Effects



Accomplishments and Progress:
Safety Reports by Primary Factors



Items include:

- Leaking through valve to vent
- Not following procedures
- Hydrogen leaks - dispenser, thermal mgmt

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

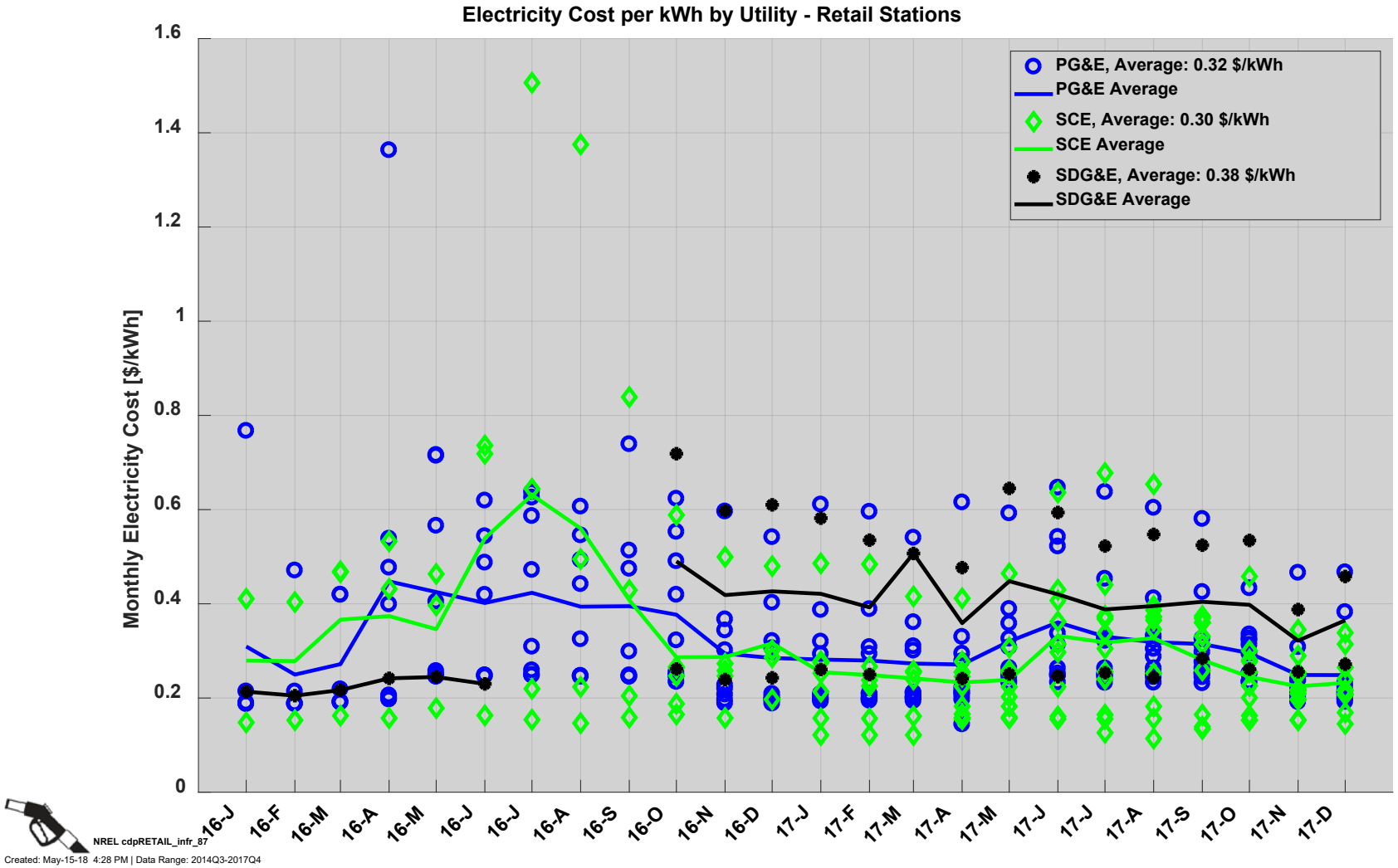
A Minor H2 Leak is:

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

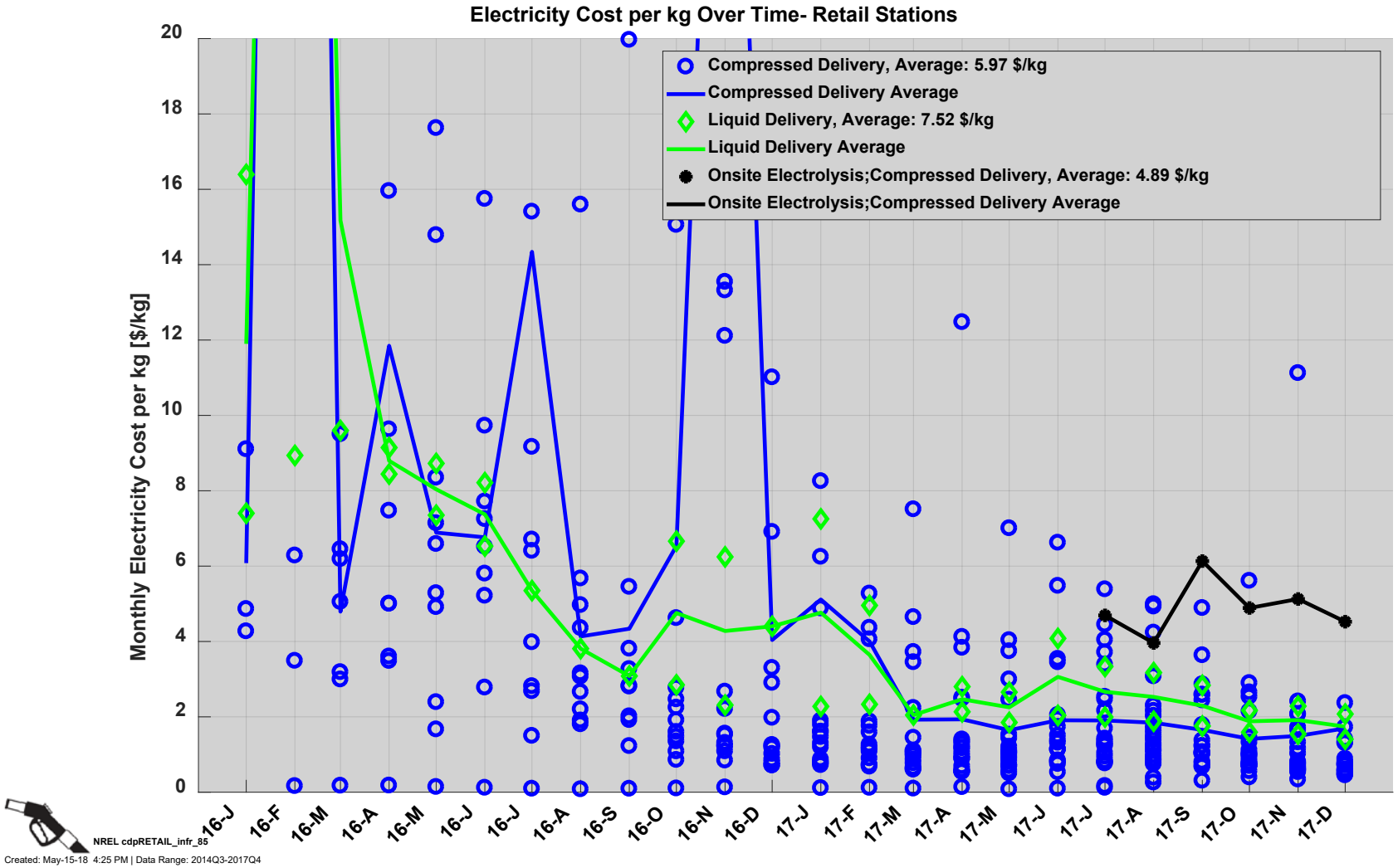
NREL cdpRETAIL_infr_32

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

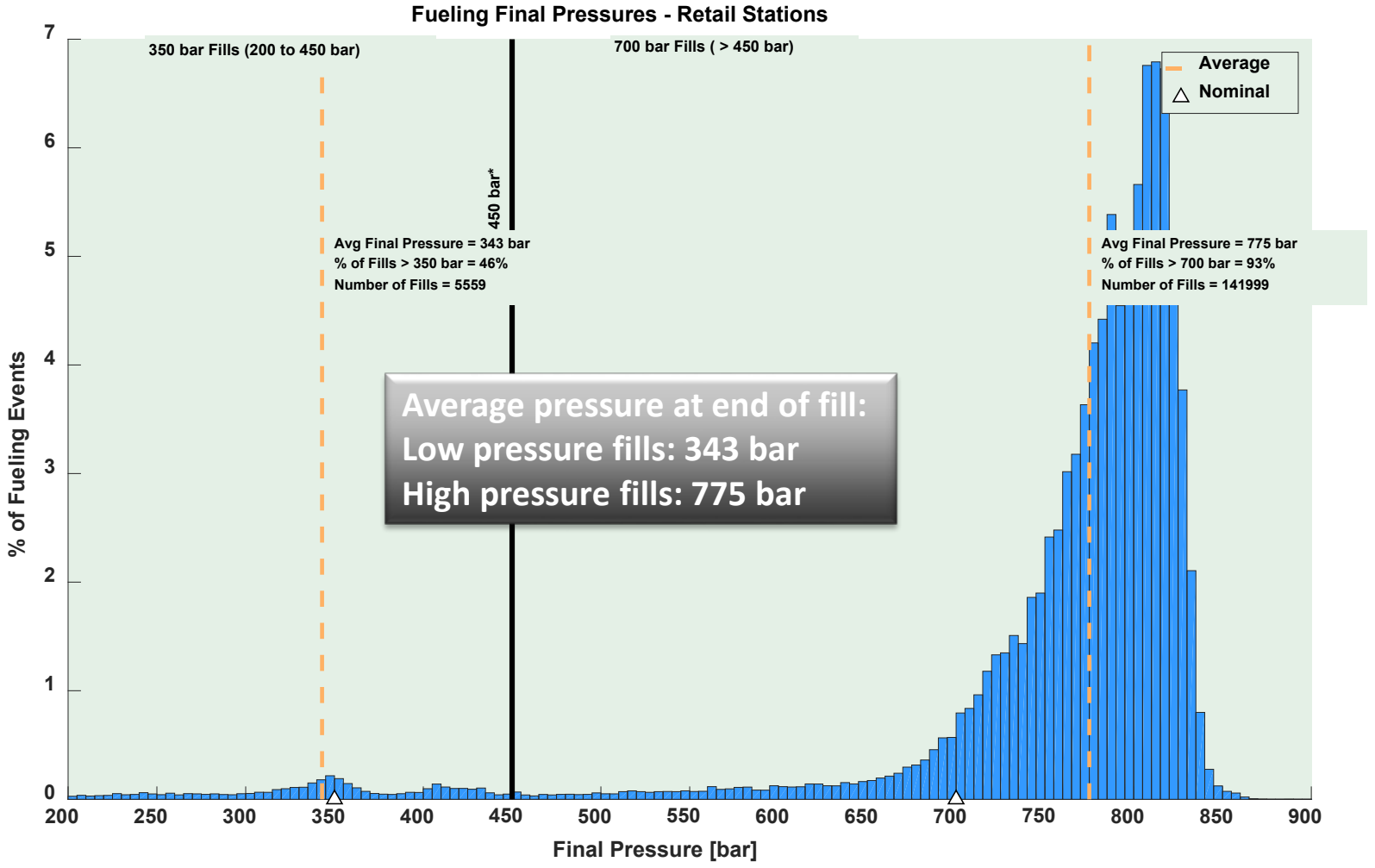
Electricity Cost per kWh by Utility



Electricity Cost per kg Dispensed by Month



Accomplishment: Fueling Final Pressures

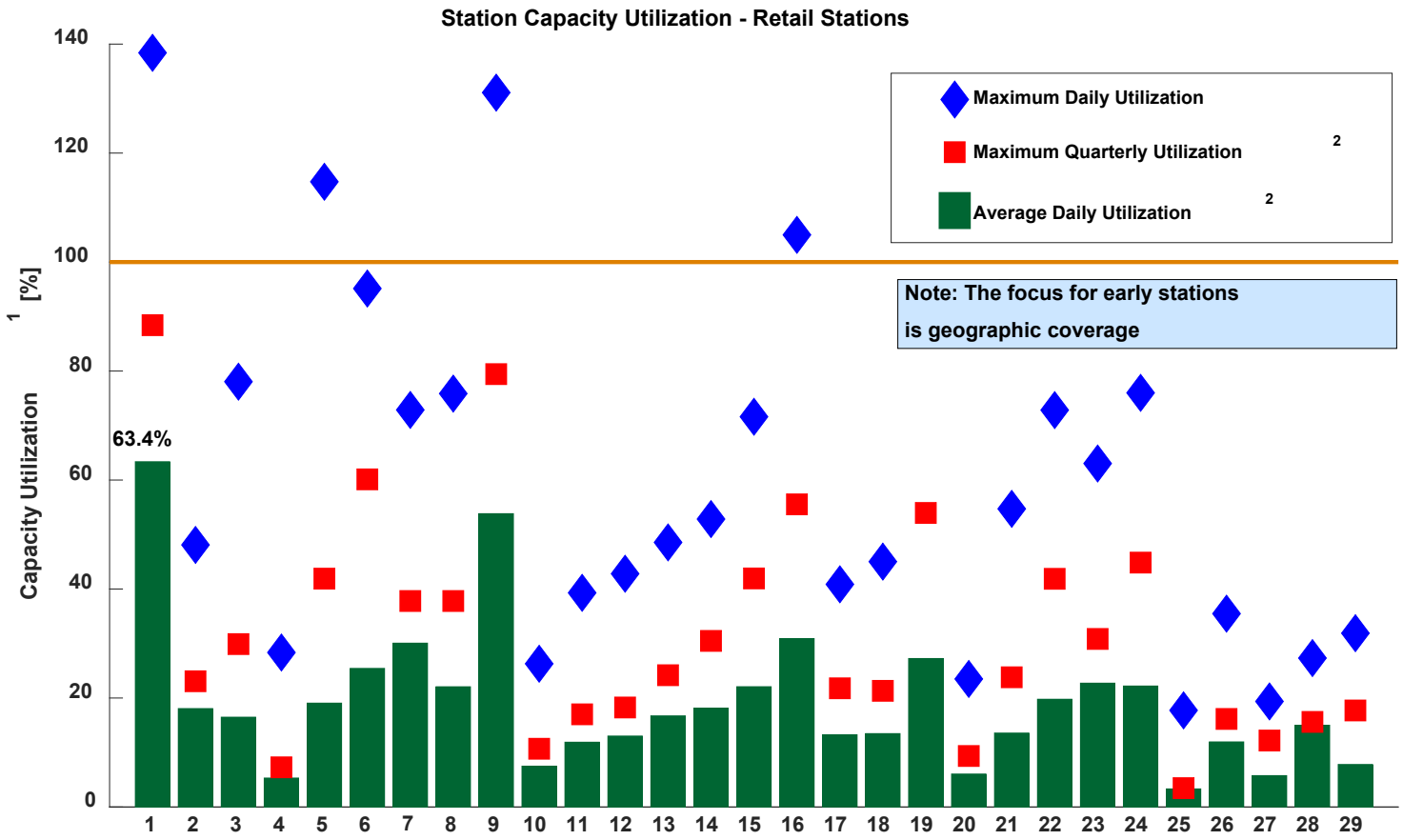


NREL cdpRETAIL_infr_09

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



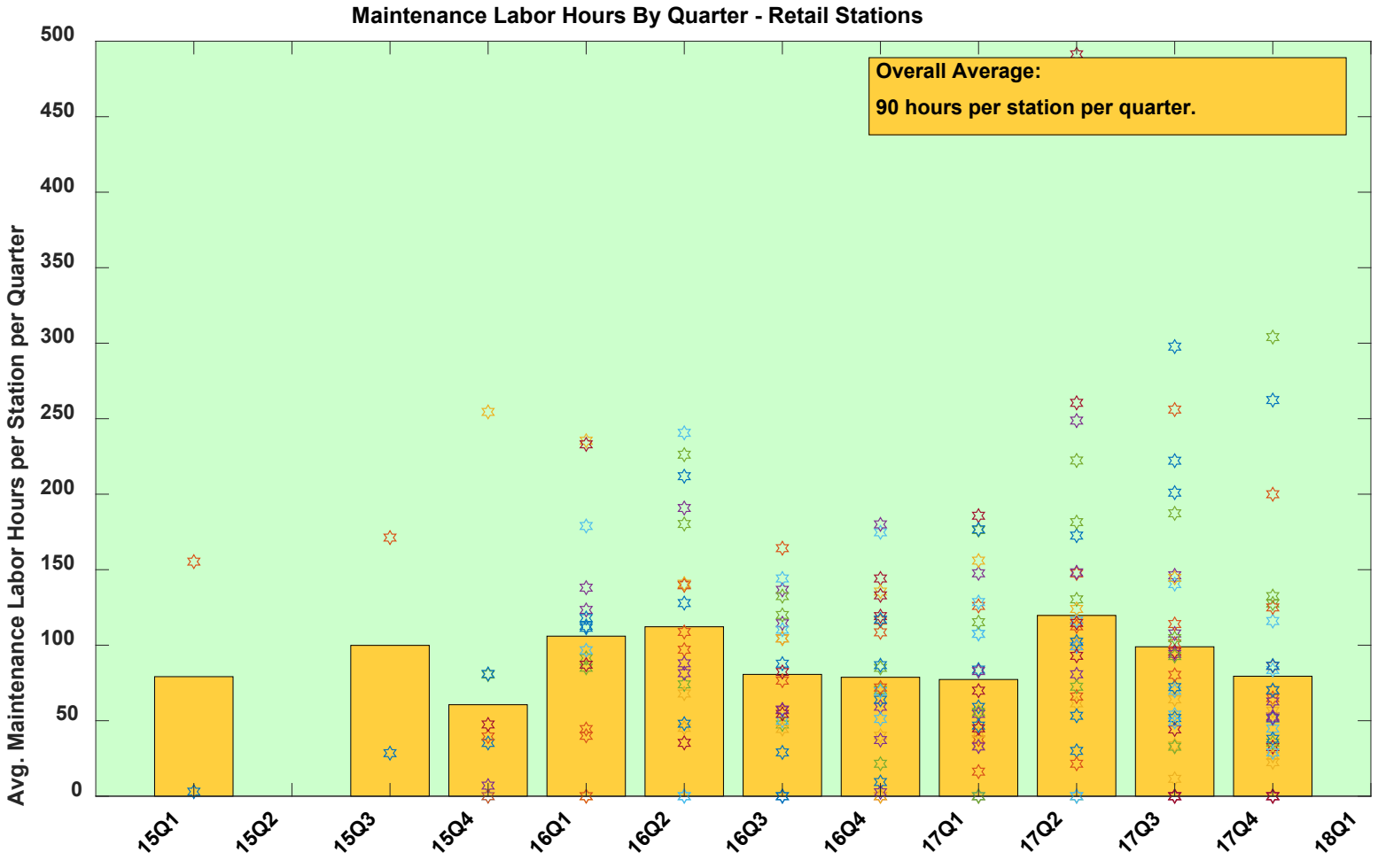
NREL cdpRETAIL_infr_06
Created: Feb-16-18 3:32 PM | Data Range: 2014Q3-2017Q4

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

[2] Maximum quarterly utilization considers all days; average daily utilization considers only days when at least one filling occ urred

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

Accomplishment: Maintenance Labor Hours by Quarter

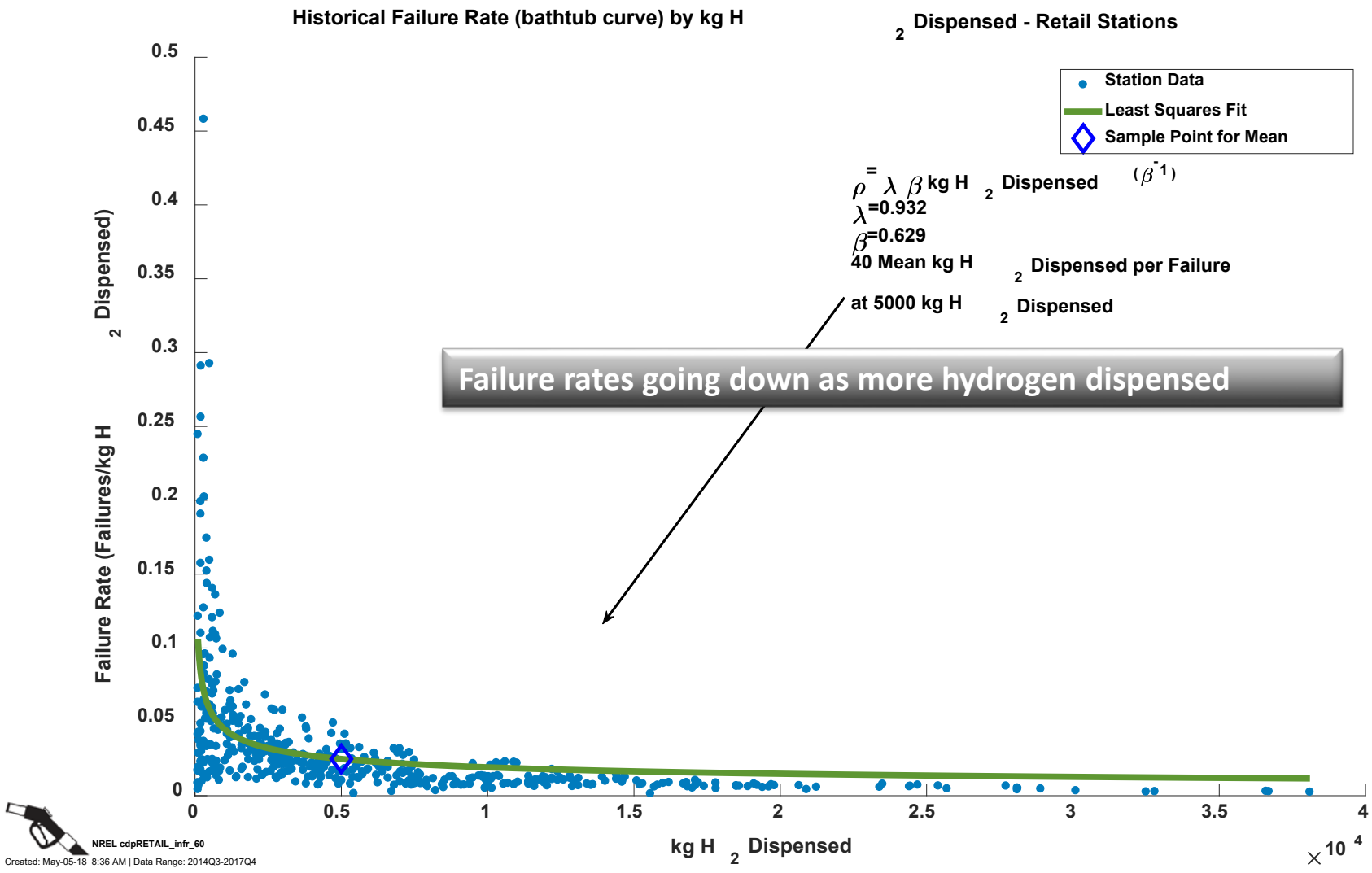


NREL cdpRETAIL_infr_28

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