Hydrogen Station Data Collection and Analysis

Genevieve Saur (PI), Sam Sprik, Jennifer Kurtz, Shaun Onorato, Spencer Gilleon, Erin Winkler

National Renewable Energy Laboratory

April 30, 2019

DOE Hydrogen and Fuel Cells Program
2019 Annual Merit Review and Peer Evaluation Meeting

Project ID: TA014

Overview

Timeline and Budget

- Project start date: 10/2011
- FY18 DOE funding: $115k
- FY19 planned DOE funding: 150k
- Total DOE funds received to date: $1,600k

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 Market

- 39 retail stations open (34 last AMR)
  - All in CA (as of April 2019)
- Supporting over 6,000 FCEVs

Air Liquide, Anaheim, CA. Photo: NREL

FirstElement Fuel, Costa Mesa, 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)

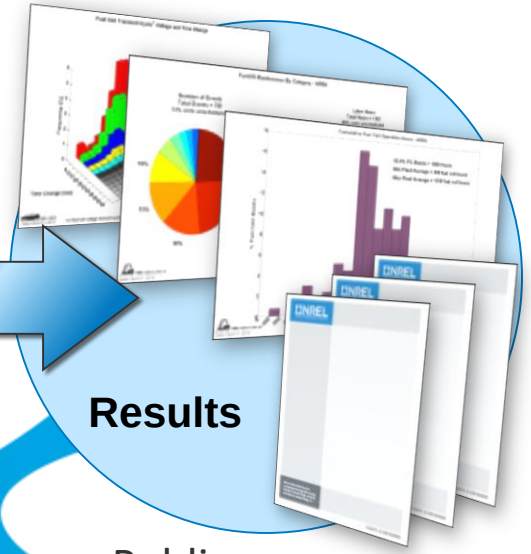
Approach: NFCTEC Data/Analysis/Results Handling

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
SCAQMD

STATION PROVIDERS

Air Liquide
Air Products
California State University Los Angeles
FirstElement Fuel
H2 Frontier
Linde
Proton OnSite/NEL
Shell
StratosFuel

ORGANIZATIONS

California Fuel Cell Partnership
IPHE and HySUT
Gas Technology Institute
CA - CDFA Division of Measurement Standards

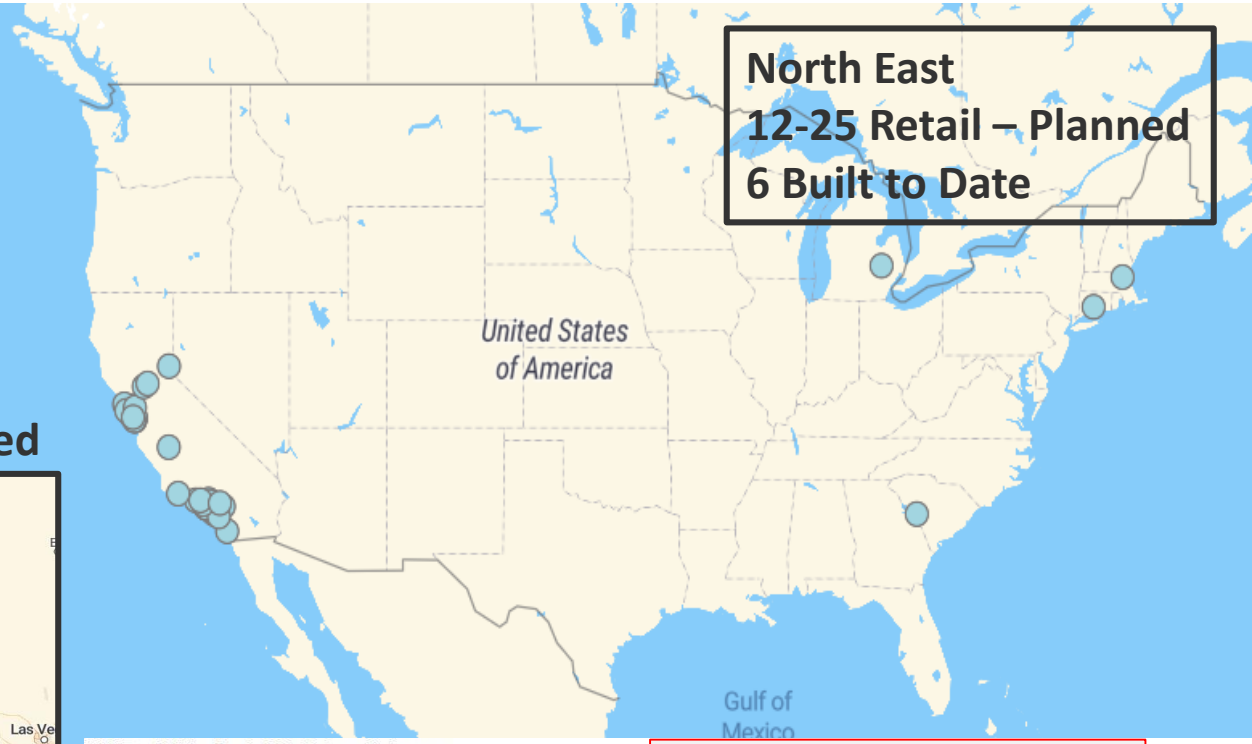
Hydrogen Stations Across the U.S.
Light Duty

45 Total Stations

Retail and Non-Retail

39 are Retail - Open

North East
12-25 Retail – Planned
6 Built to Date



California

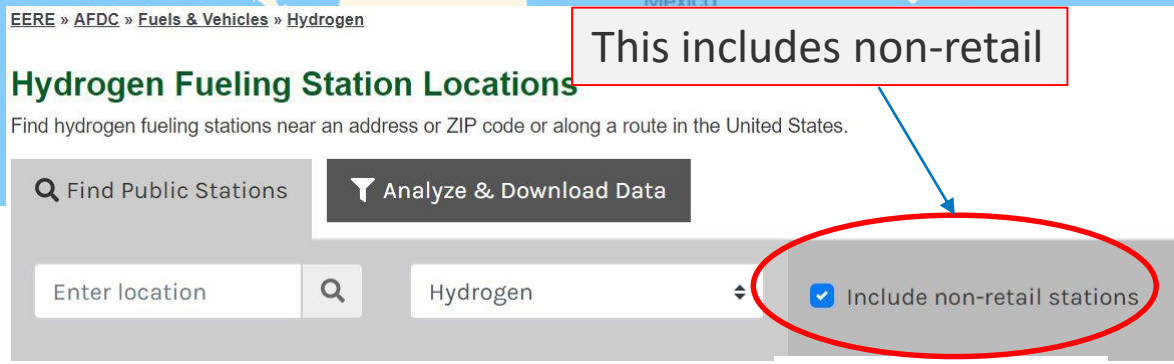
39 Retail - Open

25 Retail – Planned Awarded

California

200 targeted by 2025

1,000 targeted by 2030

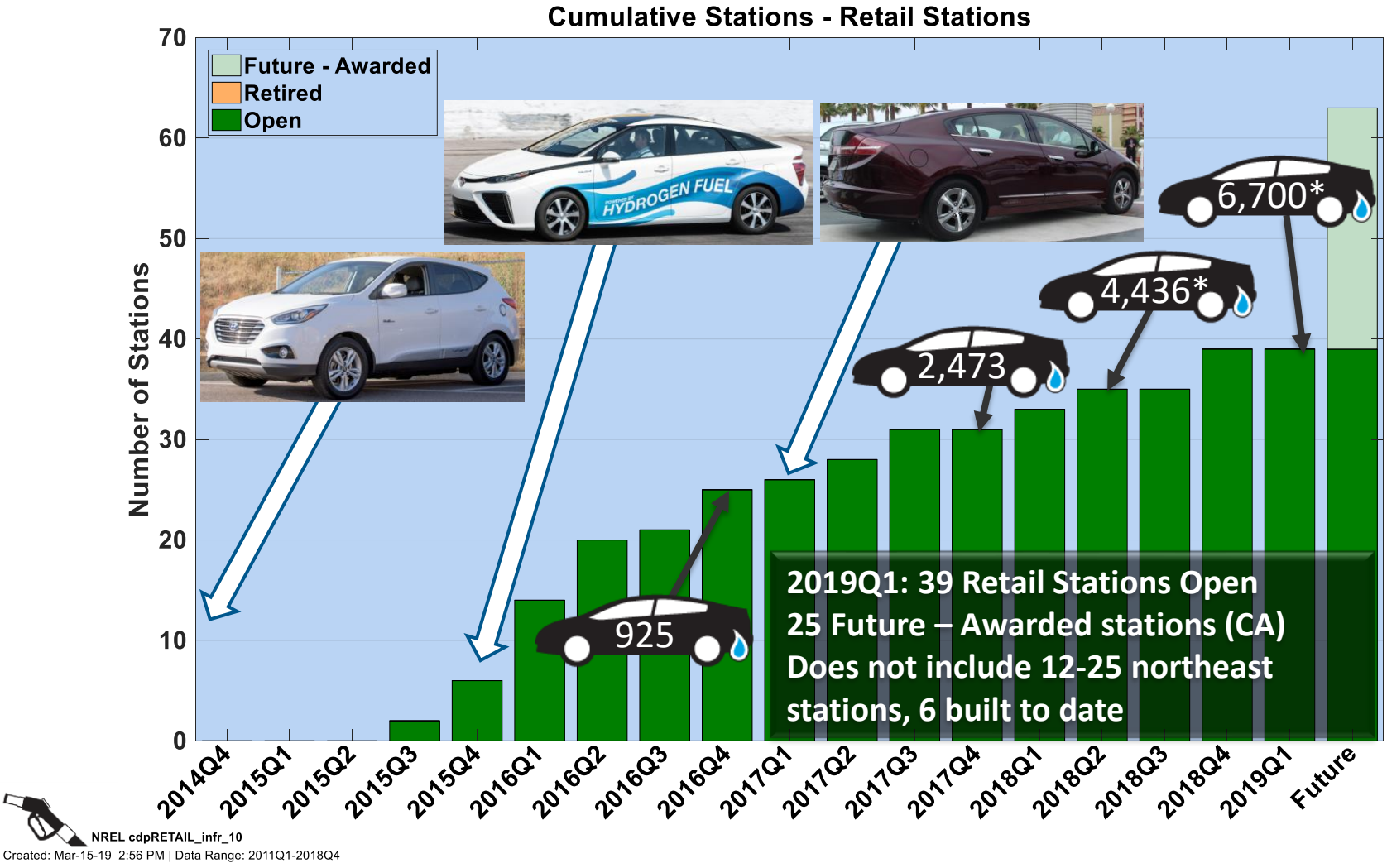


This includes non-retail

www.cafcp.org/sites/default/files/h2_station_list.pdf
www.afdc.energy.gov/fuels/hydrogen_locations.html

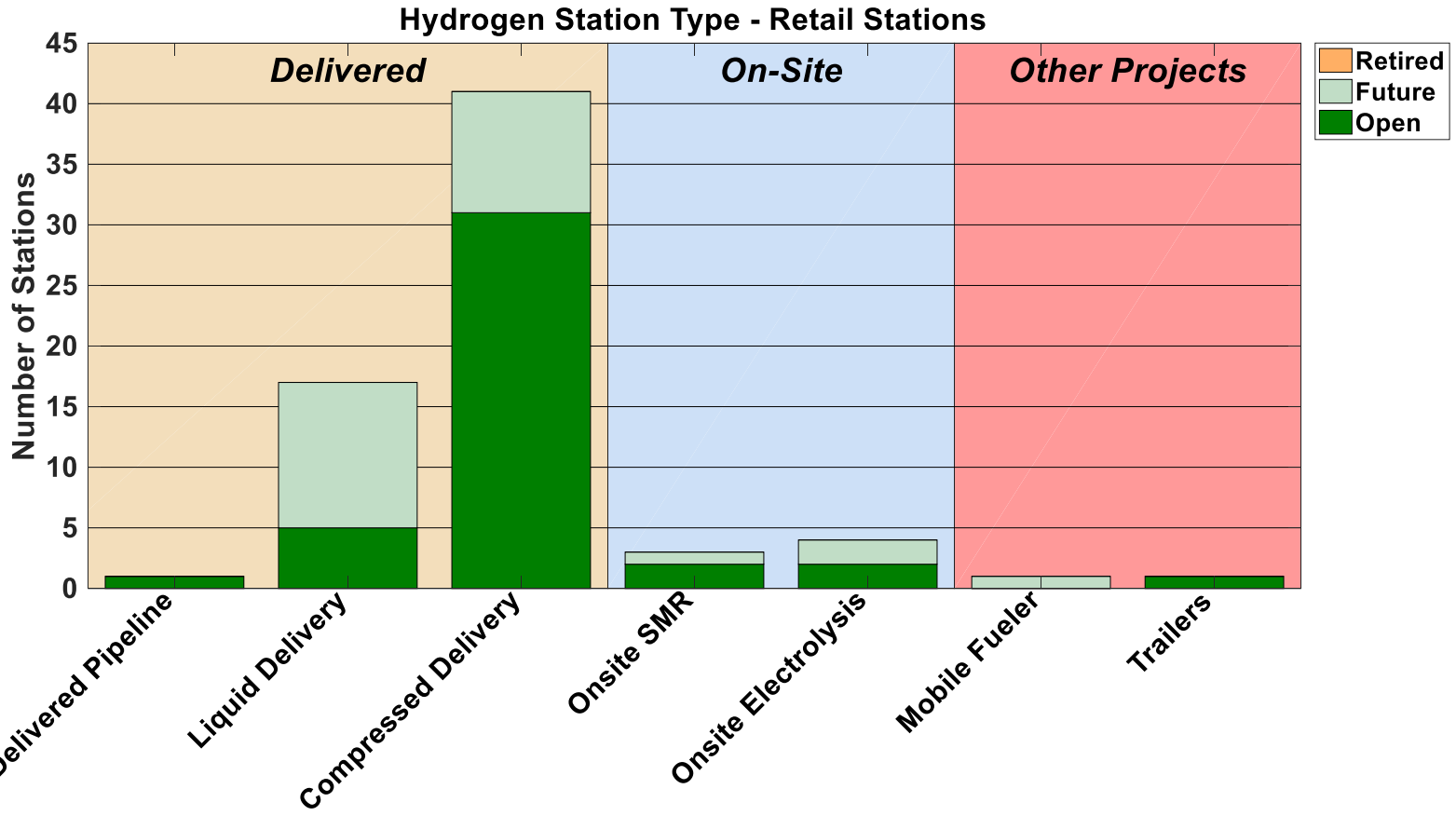
As of 3/1/2019

Cumulative Number of Retail Stations



*Argonne National Laboratory, 2019

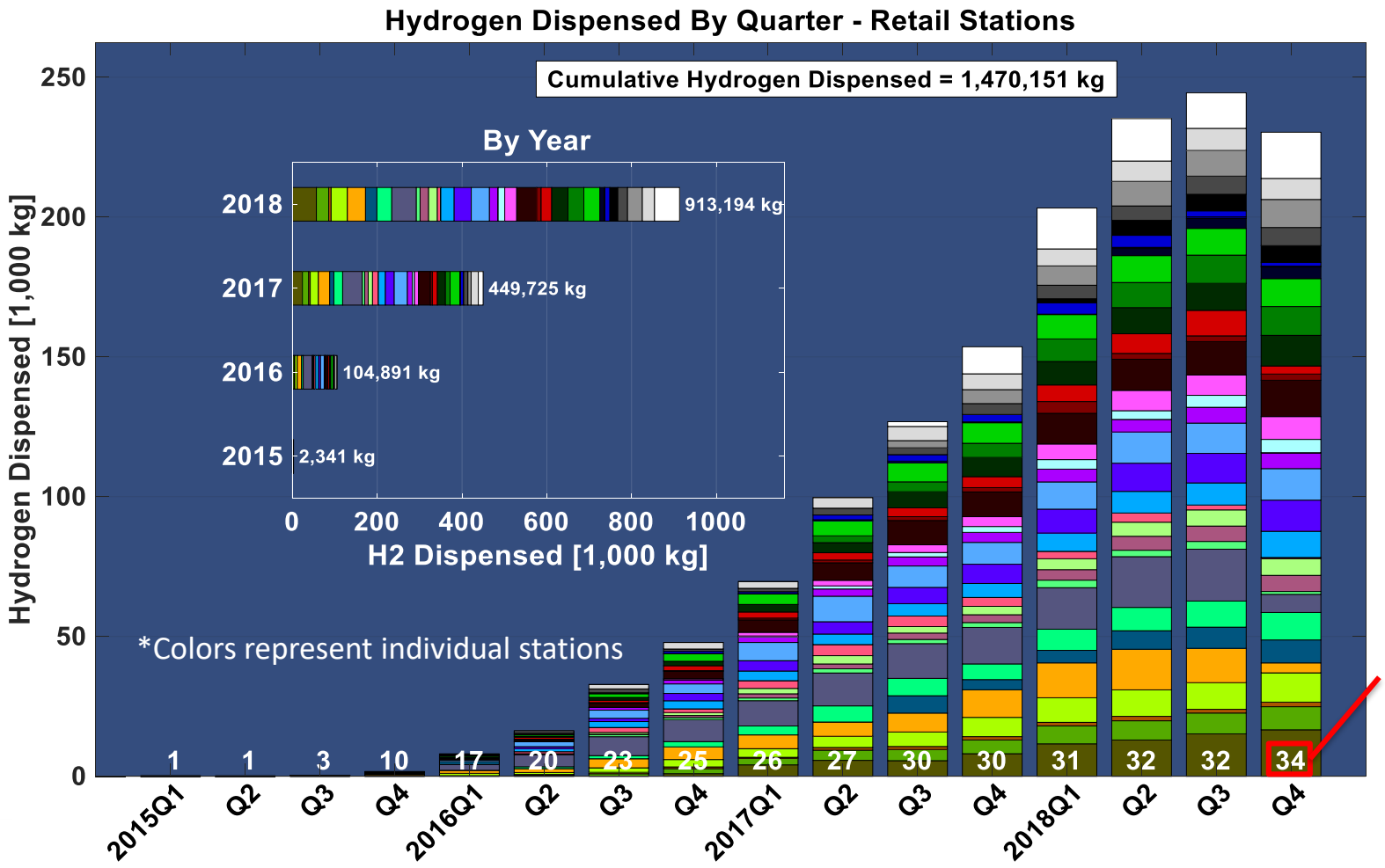
Station Types



NREL cdpRETAIL_infr_11
Created: Mar-15-19 2:56 PM | Data Range: 2011Q1-2018Q4

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

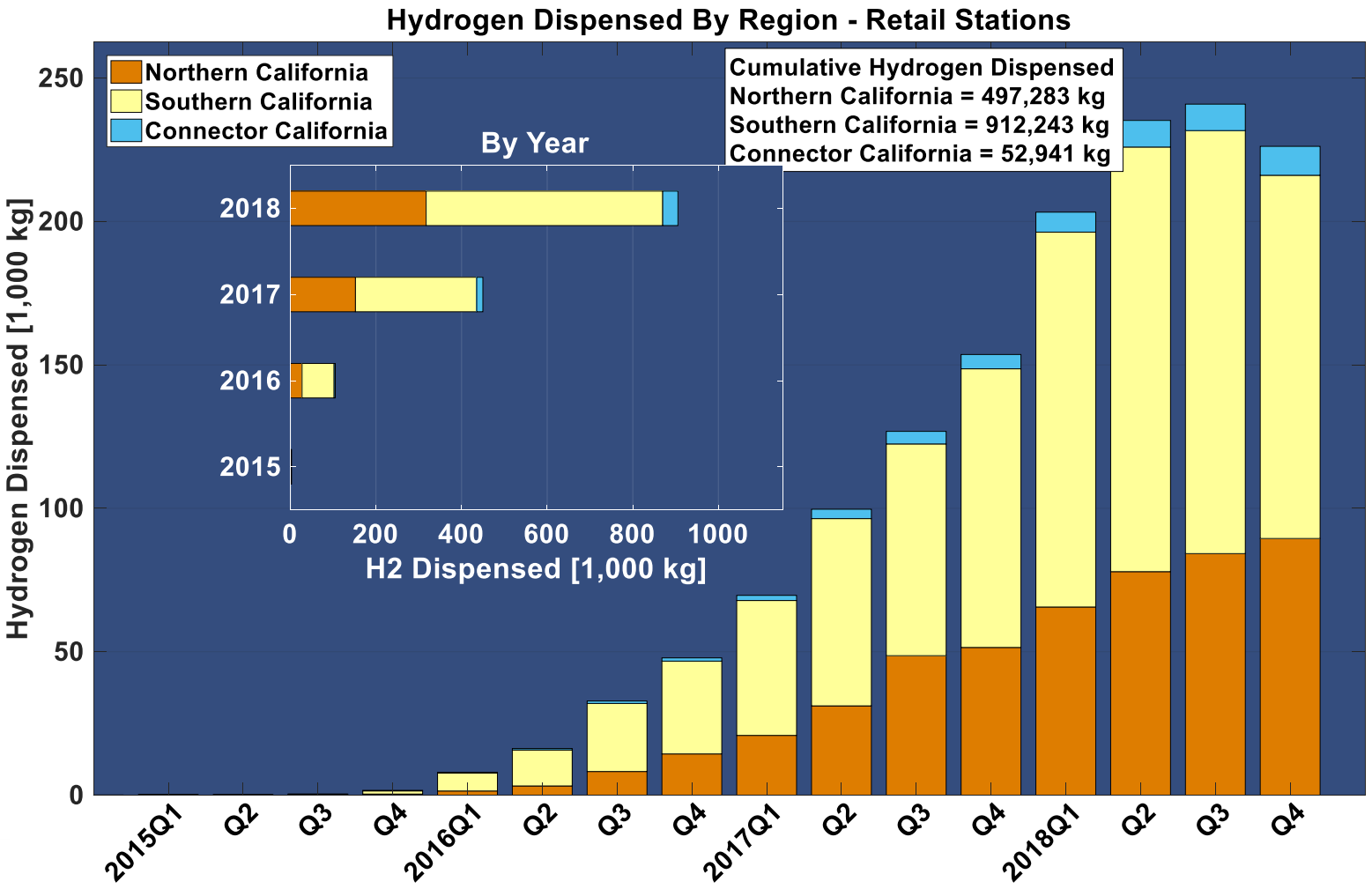
Accomplishments and Progress:
Hydrogen Dispensed by Quarter



NREL cdpRETAIL_infr_01
Created: Mar-15-19 11:55 AM | Data Range: 2014Q3-2018Q4

Retail stations dispensing significantly more each quarter. Drop in the final quarter is due to several stations not reporting data after October.

Accomplishment: Hydrogen Dispensed by Region



NREL cdpRETAIL_infr_81

Created: Mar-05-19 11:13 AM | Data Range: 2014Q3-2018Q4

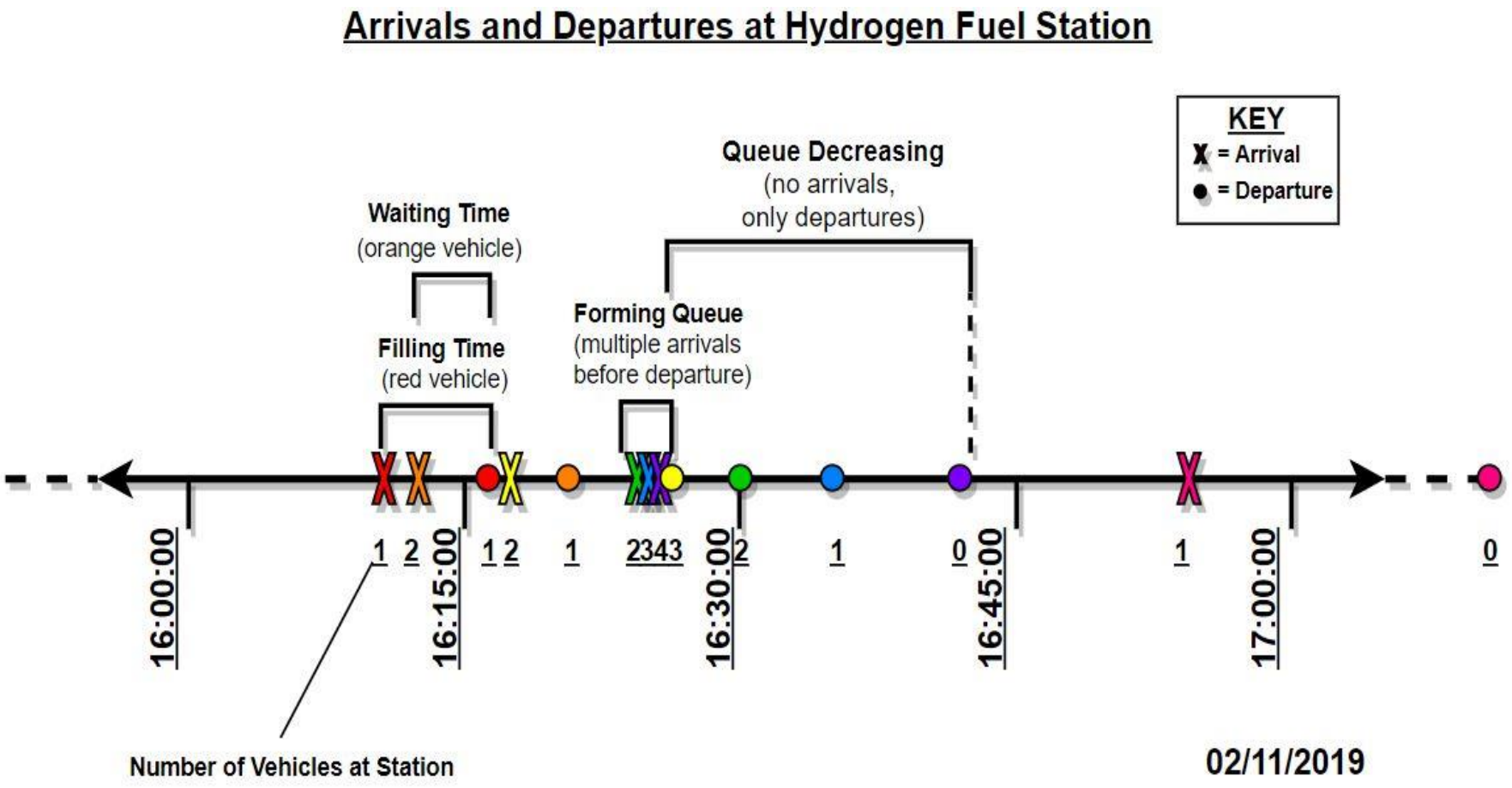
Accomplishment – Queuing at Stations

Fueling times –supplied in NREL templates (covered in CDPs)

Waiting time/queuing – NREL manually collected 2.5 days of data at FirstElement Fuel using camera footage from 2 stations.

Accomplishment: Queuing at Stations

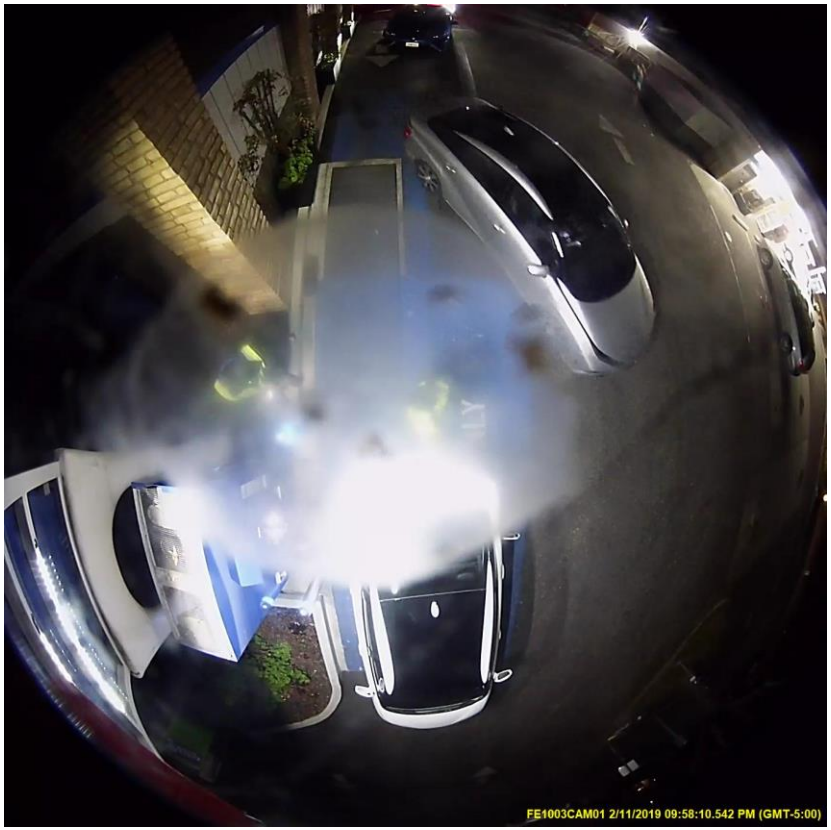
- Build more accurate queuing models, understand consumer behavior, and provide insight into station needs
- Arrival, waiting, service, departure times, and queueing behavior



Accomplishment – Queuing behavior

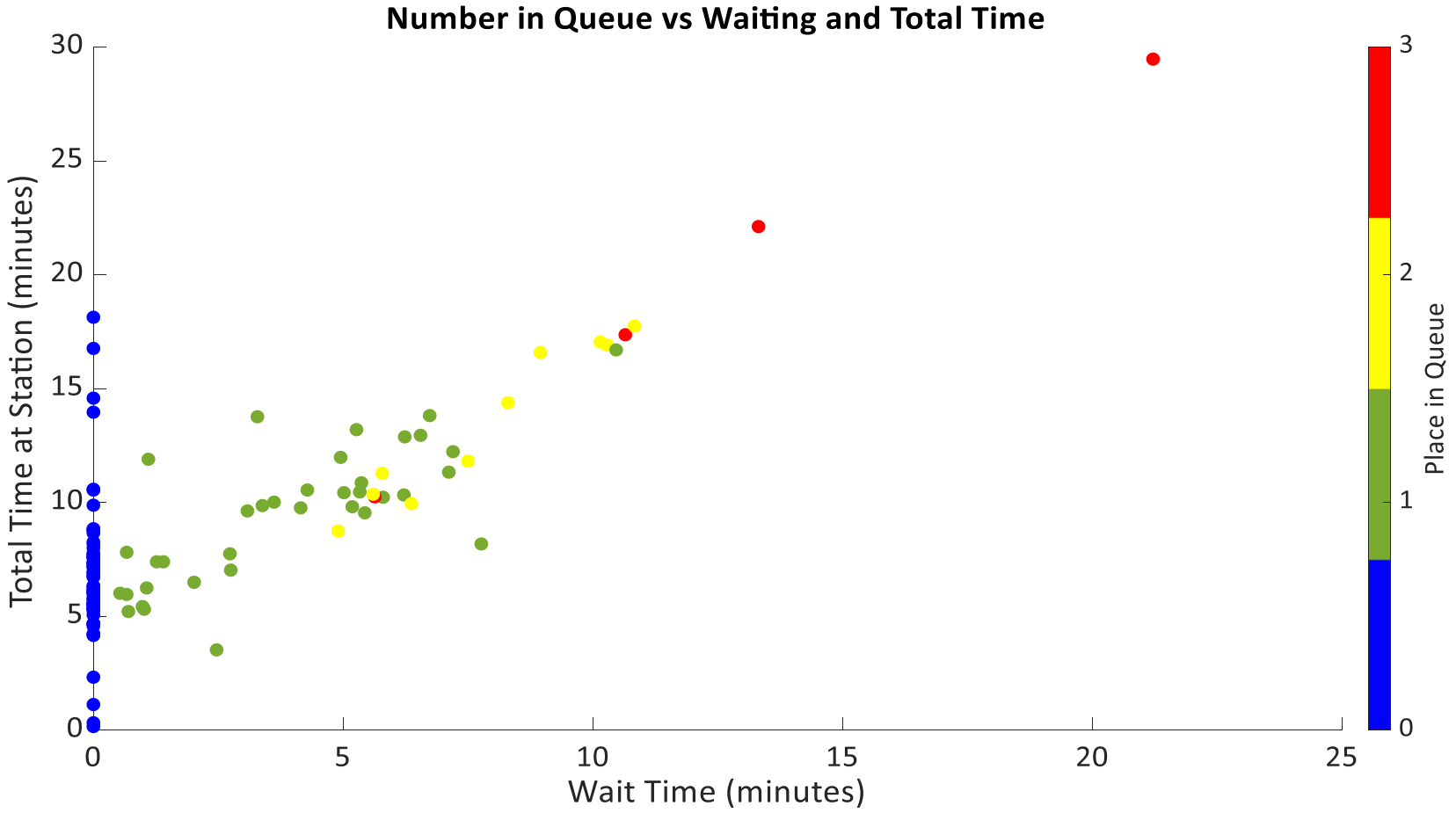
Fuel Delivery Truck
Queuing in opposite direction

Vehicle dropping out of queue



Accomplishment – Queuing at Stations

- As your place in queue is higher (more vehicles in front of you) your total time at station increases.
- Wait times seen over 20 minutes with total time at station near 30 minutes.

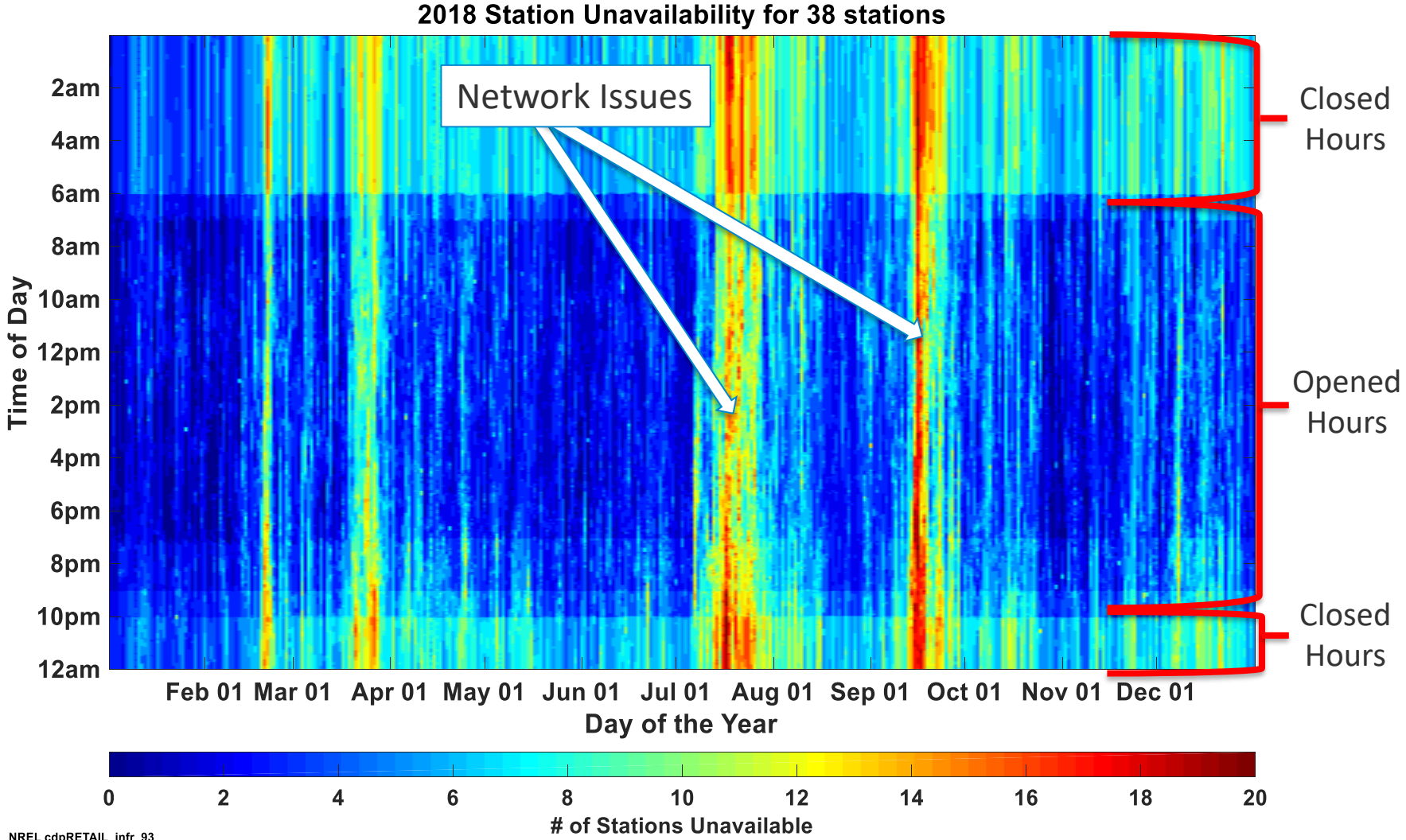


Accomplishment – Queuing Results

- Statistics based on data for total station times and arrivals per hour
  - Total Time at Station (time between arrival and departure, including waiting times)
    - Max time = 30.2 minutes
    - Median time = 7.4 minutes
    - Min time = 0.1 minutes
      - Based on a balked vehicle (accrued no waiting time, did not join the queue)
    - Min time = 1.1 minutes
      - Based on a vehicle with no wait
    - Min time = 3.5 minutes
      - Based on a queued vehicle
    - Grand mean time = 8.5 minutes
  - Number of arrivals per hour
    - Mean = 3.1 (between 7am and 11pm)
    - Grand mean = 2.9 (over entire day)
    - Median = 3 (between 7am and 11pm)
    - Max = 12 vehicles within one hour
- Based on the data:
  - A FCEV driver would expect to spend a total of about 7 minutes and 24 seconds at a station (based on the median total time at a station due to skewed data)
  - A station would expect about 3 vehicles to arrive each hour but require a current capability of servicing up to at least 12 vehicles per hour.

Accomplishments and Progress:
Station Unavailability: Number of Stations Unavailable

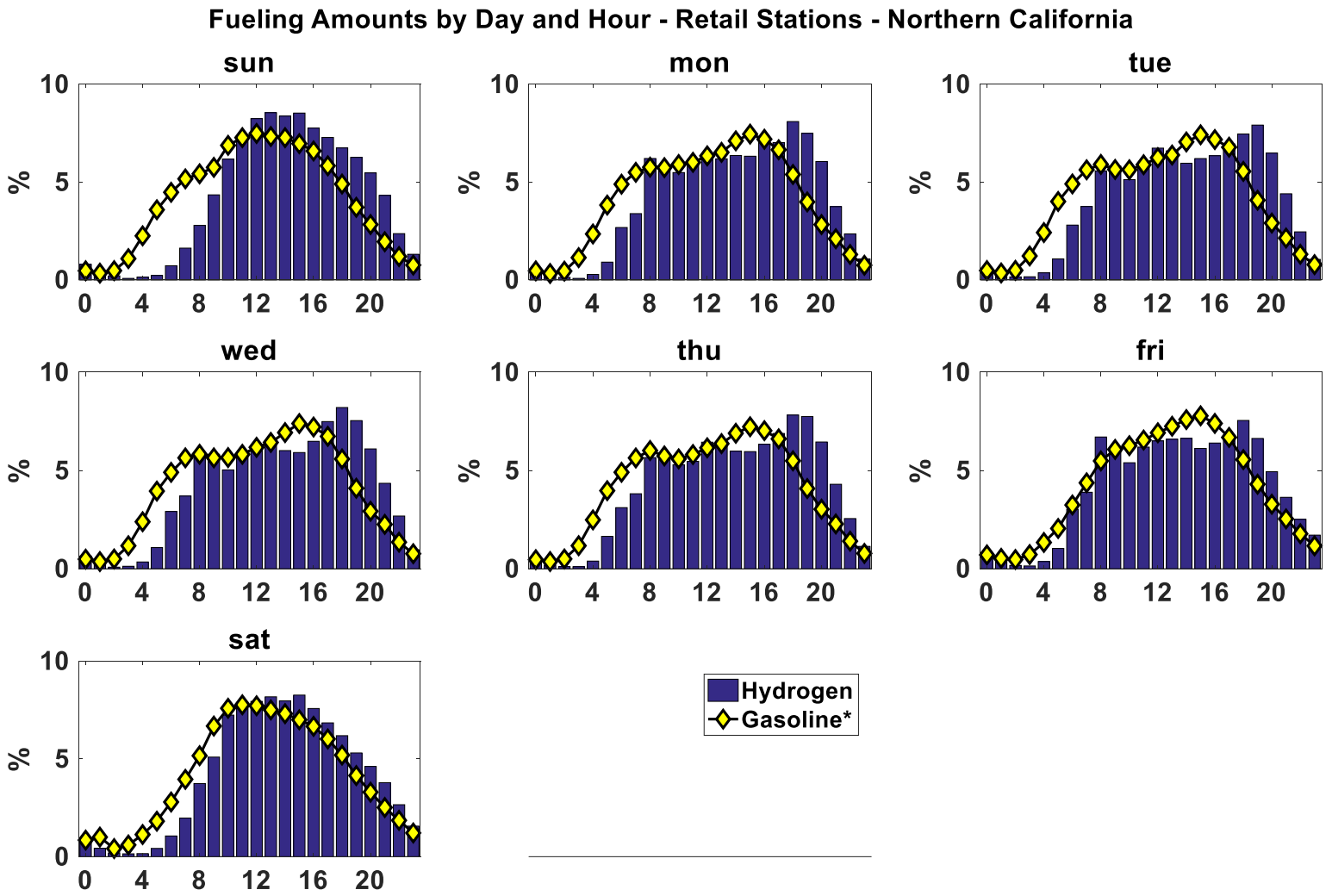
Based on SOSS "Offline" status for all of 2018.



NREL cdpRETAIL_infr_93
Created: Mar-21-19 1:27 PM | Data Range: 2012Q1-2018Q4

* 6 stations are closed overnight
32 Stations are open 24/7

Accomplishment: Hydrogen by Day and Hour – Northern California



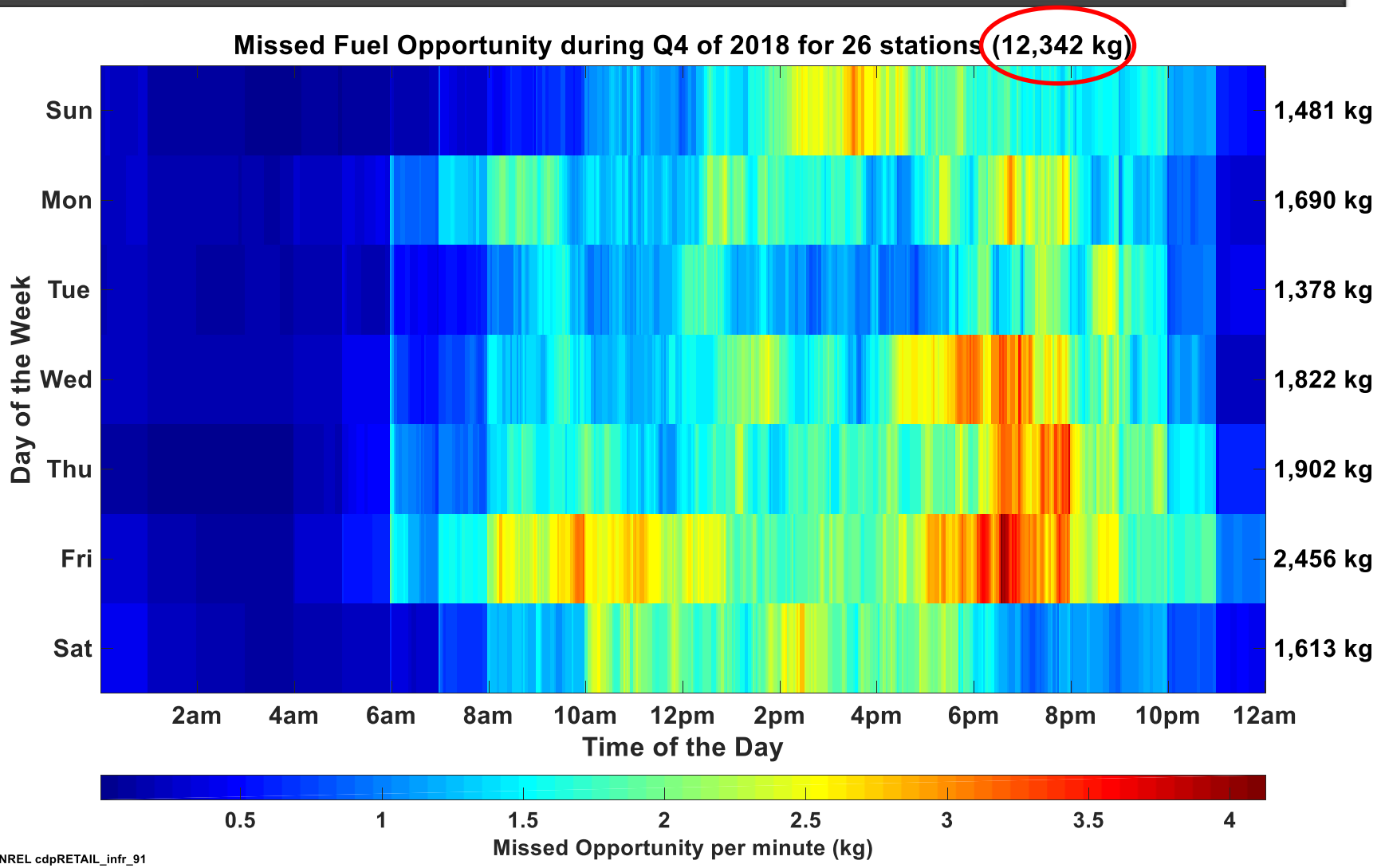
NREL cdpRETAIL_infr_88b

Created: Mar-18-19 11:15 AM | Data Range: 2014Q3-2018Q4

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

Accomplishments and Progress:
Missed Opportunity Fueling

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

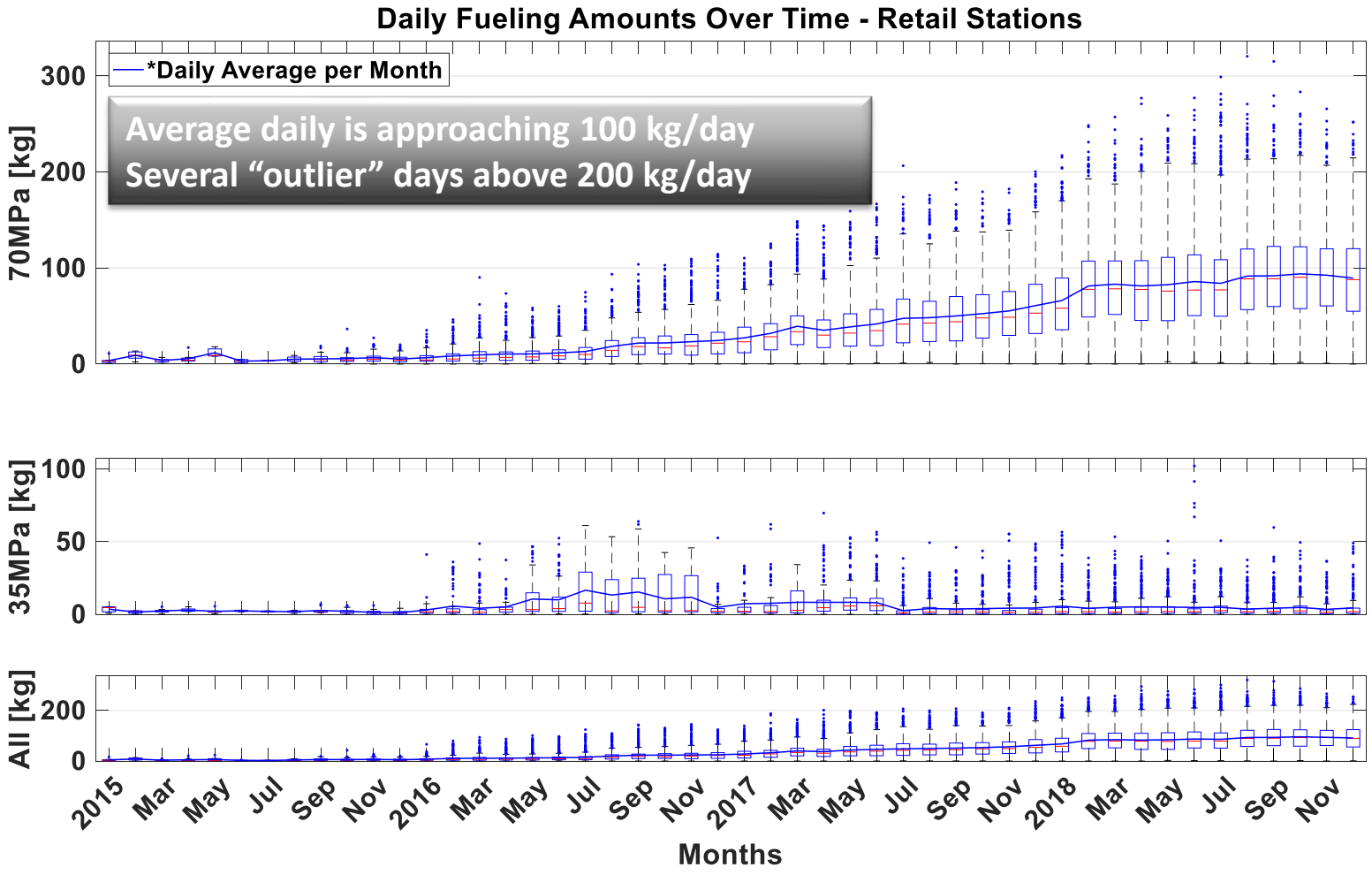


NREL cdpRETAIL_infr_91

Created: Mar-18-19 12:22 PM | Data Range: 2014Q3-2018Q4

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

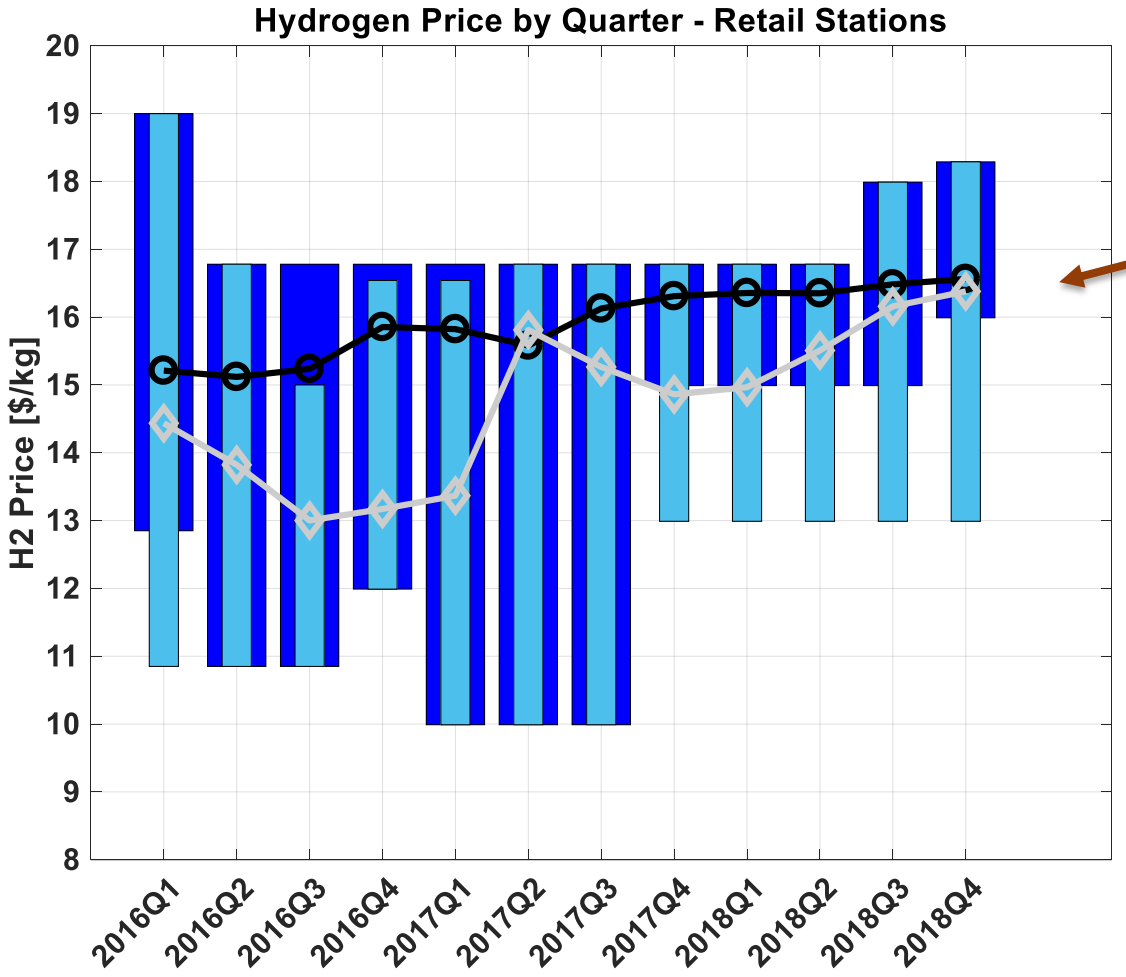
Accomplishments and Progress:
Daily Fueling by Month



NREL cdpRETAIL_infr_82
Created: Mar-05-19 11:12 AM | Data Range: 2014Q3-2018Q4

*Daily average only includes days with fills.

Accomplishment: Hydrogen Price

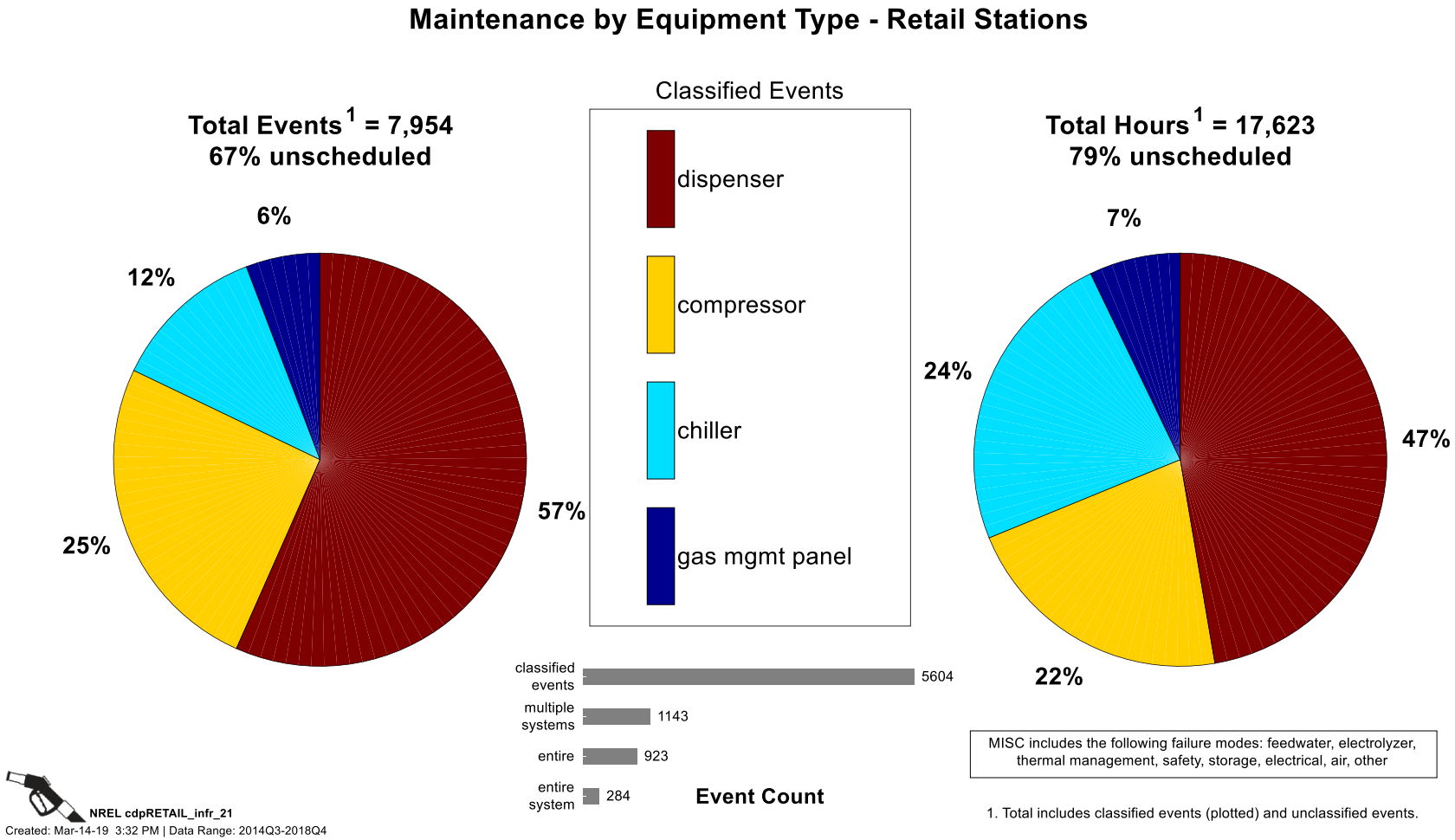


H70 Sales Price - Weighted Avg By Amount Dispensed: $16.56 in 2018Q4

NREL cdpRETAIL_infr_89
Created: Mar-05-19 11:15 AM | Data Range: 2014Q3-2018Q4

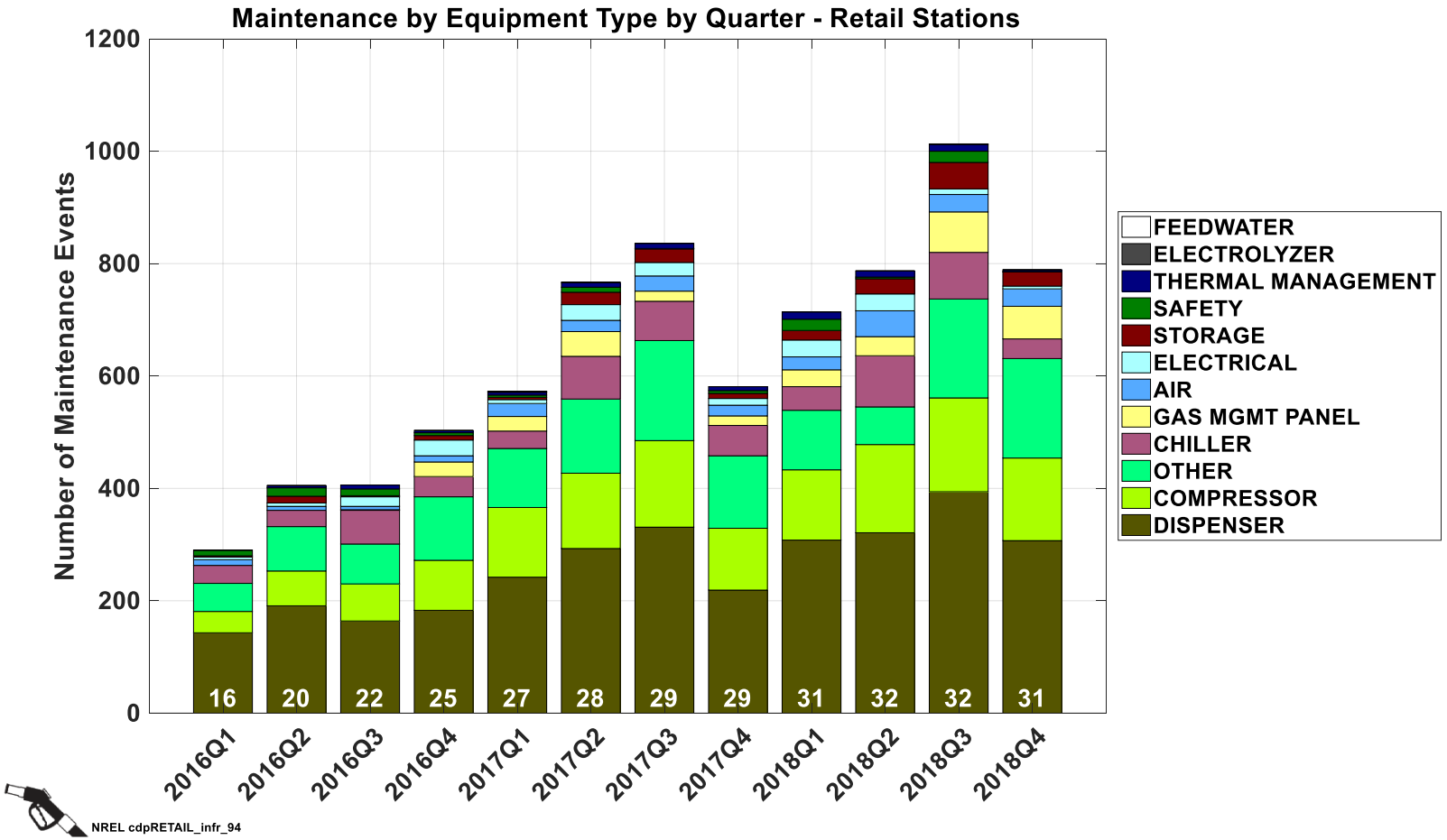
Accomplishments and Progress:
Maintenance by Equipment Type

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



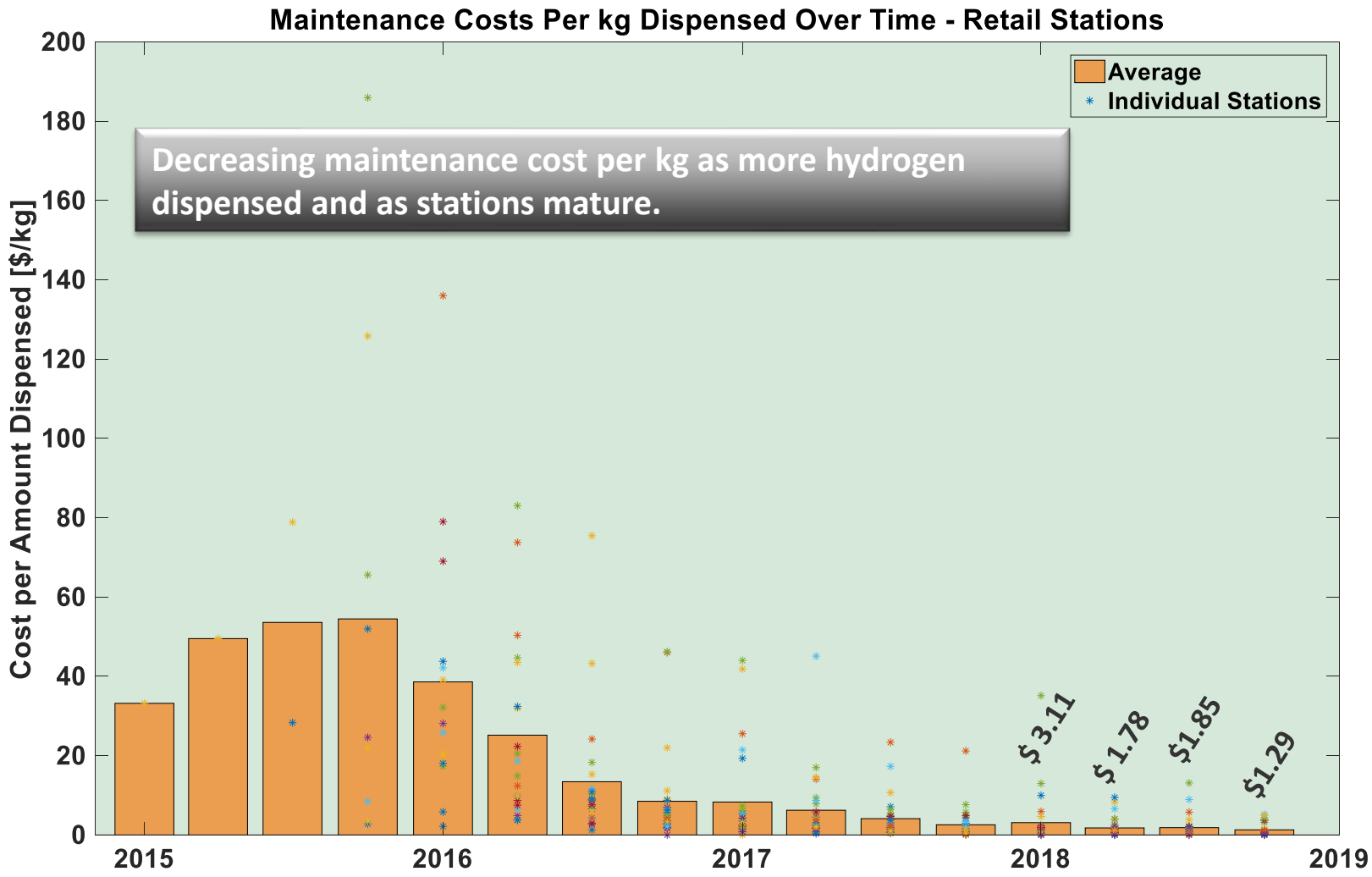
Accomplishments and Progress:
Maintenance by Equipment Type

Over time, the distribution of maintenance events by equipment type is similar.



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

Accomplishments and Progress:
Maintenance Costs per kg Dispensed



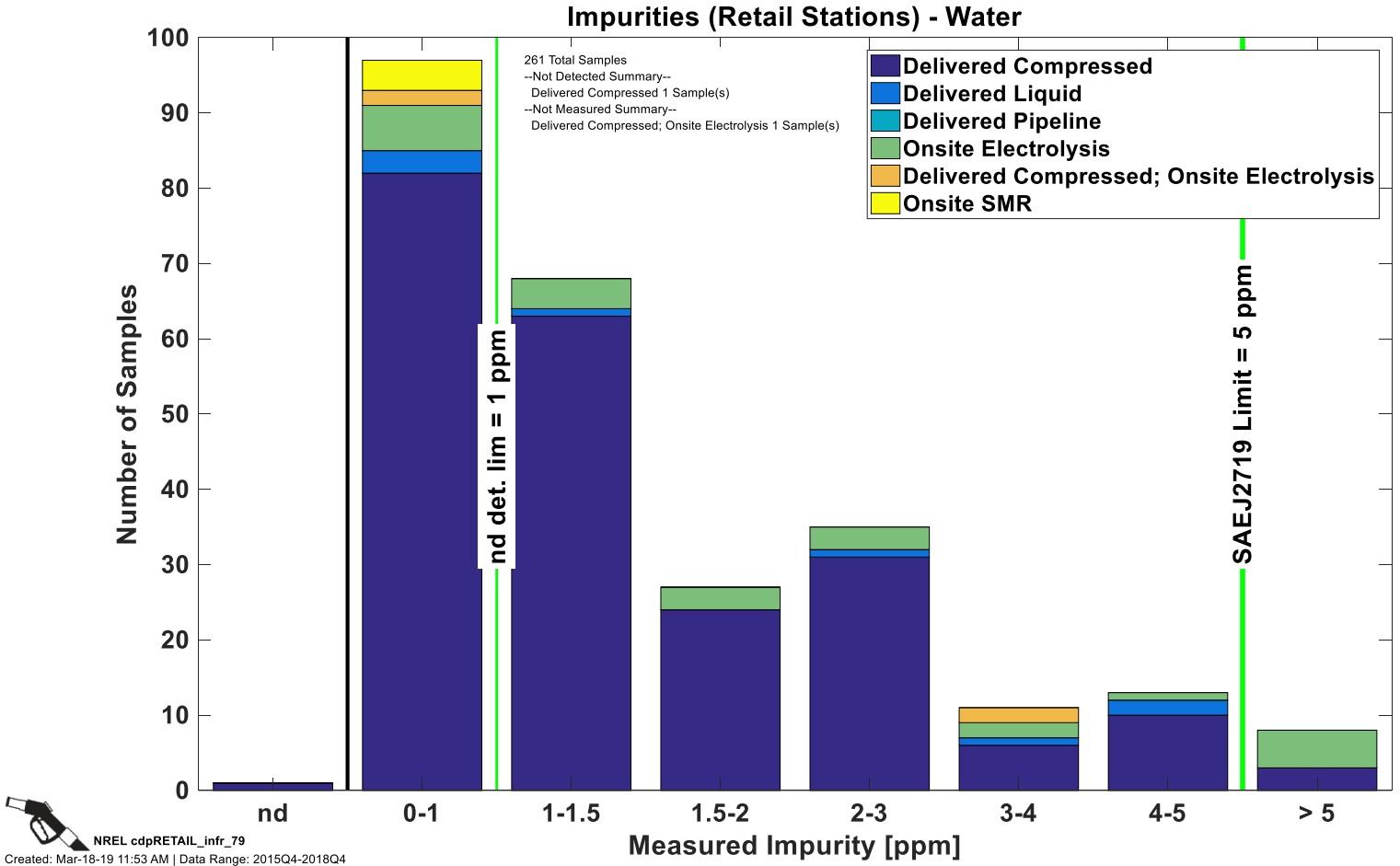
NREL cdpRETAIL_infr_53

Created: Mar-07-19 3:20 PM | Data Range: 2014Q3-2018Q4

*Each color represents a unique station. 0 data points excluded that were over $1000/kg

Accomplishments and Progress:
Impurities - Water

This year, we added large number of data points from CA Department of Food and Agriculture, Division of Measurement Standards. We show H20 here but also publish the other constituents.

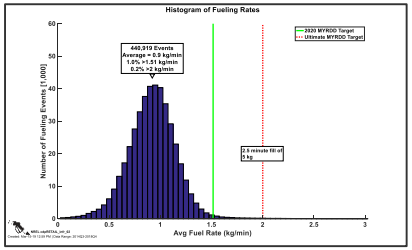


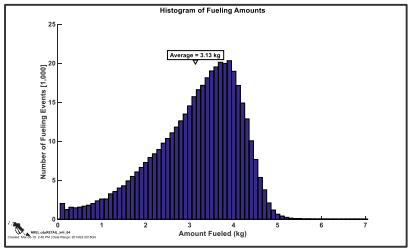
8 samples over the limit, mostly electrolysis stations

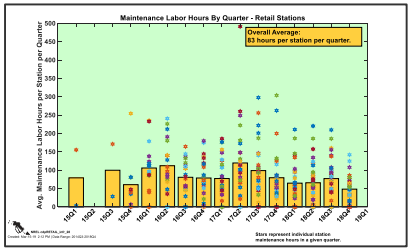
Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

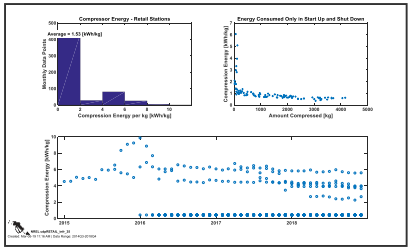
- Reviewer comment: The project is encouraged to continue development and expansion of creative new data analysis concepts to continue providing new insights into the evolving operation of hydrogen fueling station networks.
  - Response: Queuing and station availability are new analyses. We will continue to evaluate relevant topics.
- Reviewer comment: In the future, it would be good to see how component reliability and safety evolve over time. It is difficult to tell whether reliability is improving or the number of safety incidents is changing.
  - Response: We do not have many safety reports from the stations. We show maintenance by quarter in CDP 94 staying similar, but much more fuel being dispensed so we see maintenance costs per kg dispensed going down over time in CDP 53.

Accomplishments and Progress: Sampling of Results

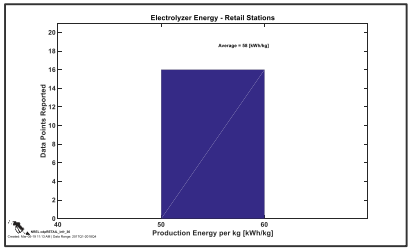


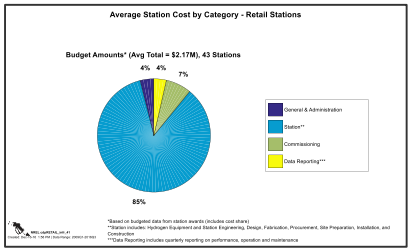


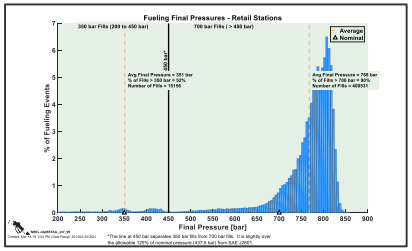


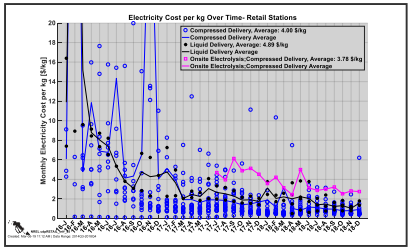


Fueling Rate Average	0.9 kg/min
Fueling Amount Average	3.1 kg
Fueling Time Average	3.52 min
Compressor Energy Average	1.53 kWh/kg
Total Hydrogen Dispensed (34 Stations)	1,470,151 kg 230,300 kg - 18Q4
Electrolyzer Energy Average	58 kWh/kg
Maintenance Hours Average	83 hours/Quarter
Fueling Final Pressure Average	768 bar
Average Electricity Cost by Delivery Type 2018Q4	$0.94/kg – Compressed $1.58/kg – Liquid $2.75/kg –Electrolysis









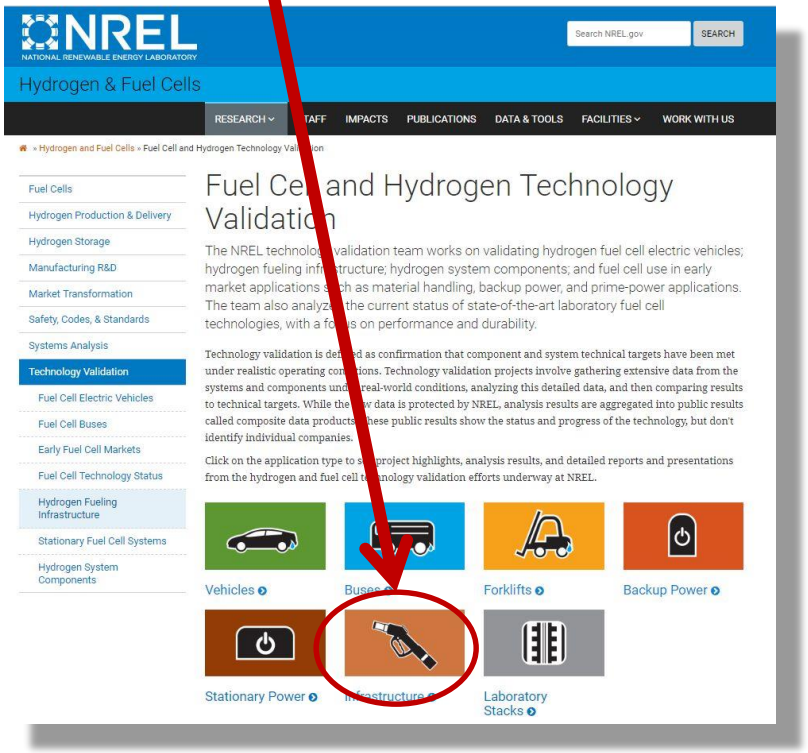
Proposed Future Work

- Analysis and CDP publication
  - Complete data analysis and publish results
    - Calendar 2019 Q1 and Q2
    - Calendar 2019 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 analysis capability and tools
  - Leverage years of analysis and experience from hydrogen demonstrations
- Accomplishments and Progress
  - Analyzed performance data from 34 open, 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



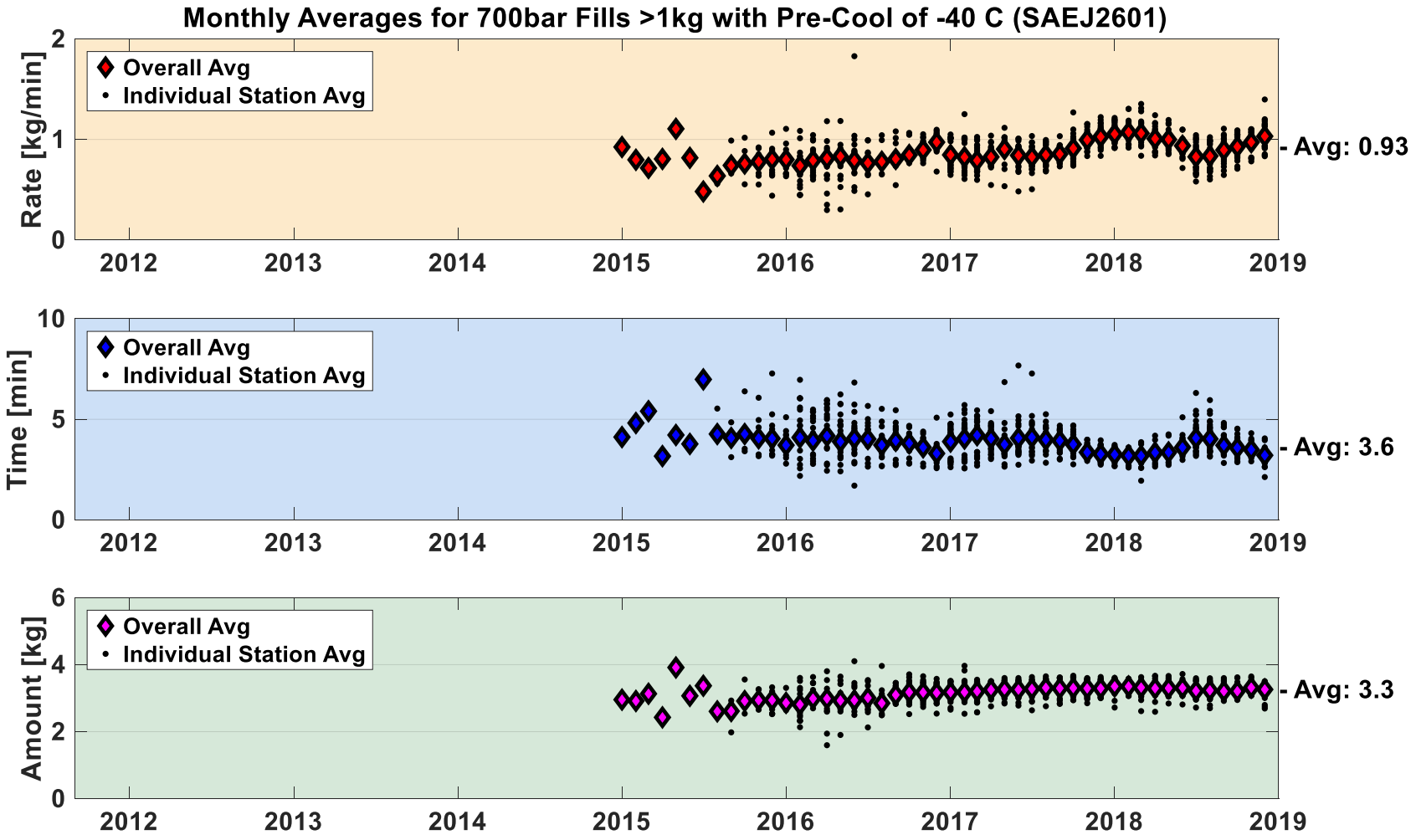
Thank You

www.nrel.gov

NREL
Transforming ENERGY

Technical Back-Up Slides

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



NREL cdpRETAIL_infr_57
Created: Mar-05-19 11:35 AM | Data Range: 2014Q3-2018Q4

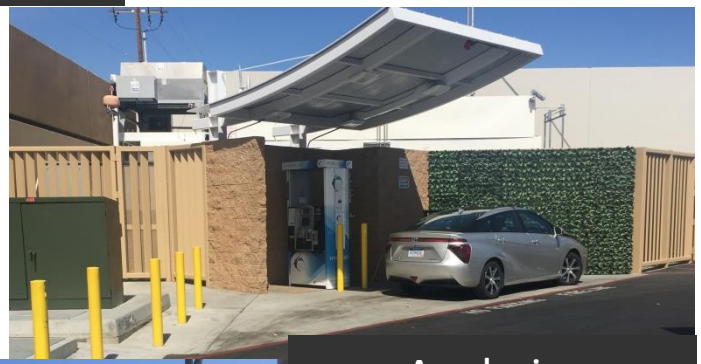
Time to fill is decreasing below the average of 3.6 minutes.
Average amount filled increasing above average of 3.3 kg

Costa Mesa
FirstElement Fuel

Riverside
ITM Power

Burbank
H2 Frontier

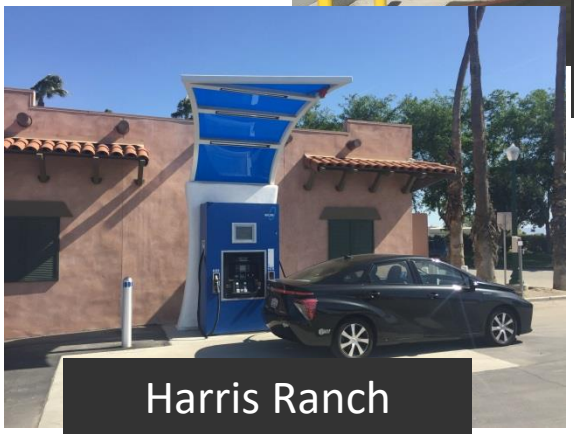
CSULA



Anaheim
Air Liquide

Torrance
Shell

West Sacramento
Linde



Harris Ranch
FirstElement Fuel

Approach: Data Reporting

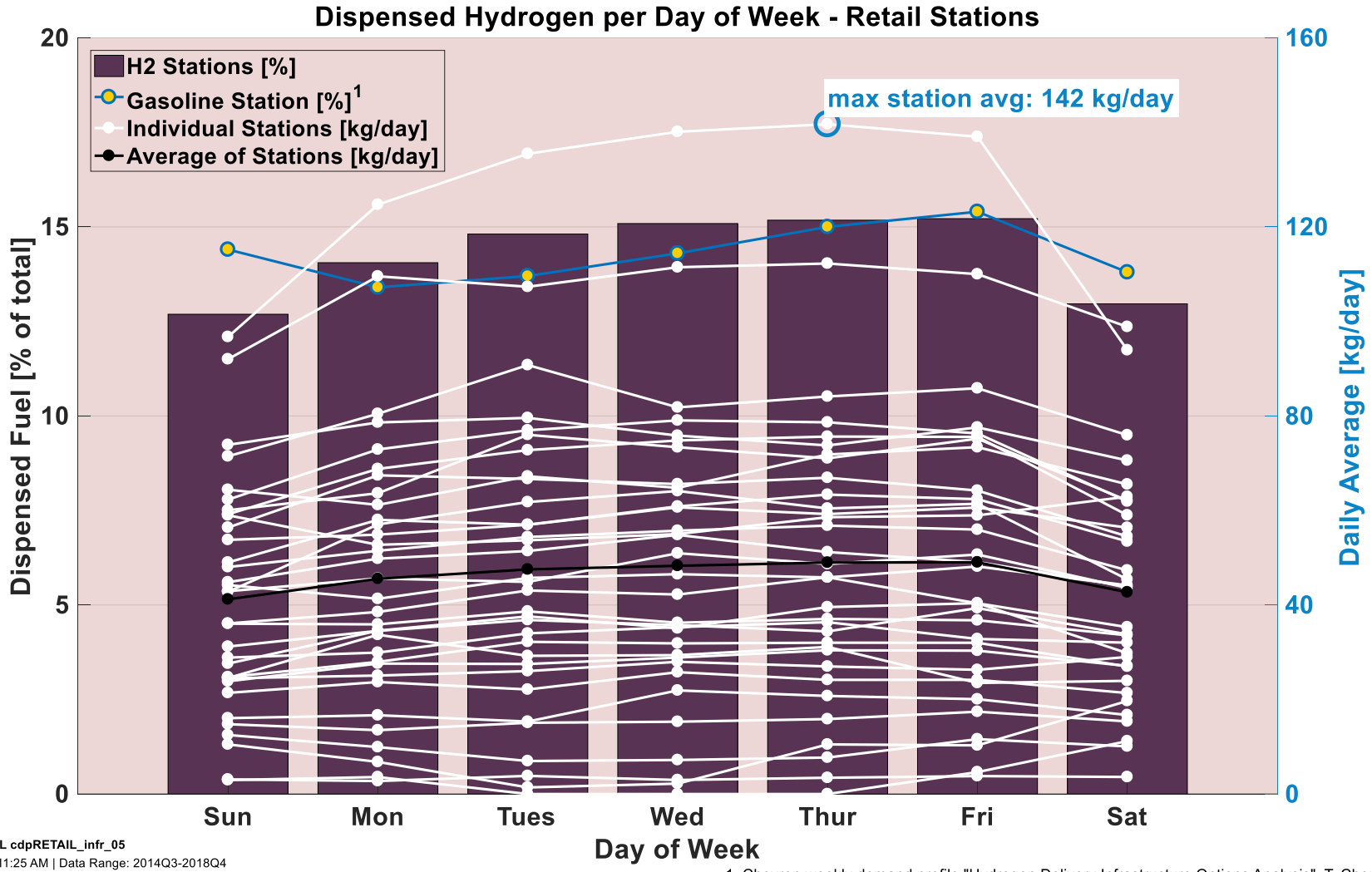
Data Reporting

- As of 2018Q4, data reported from 34 (out of 39) 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

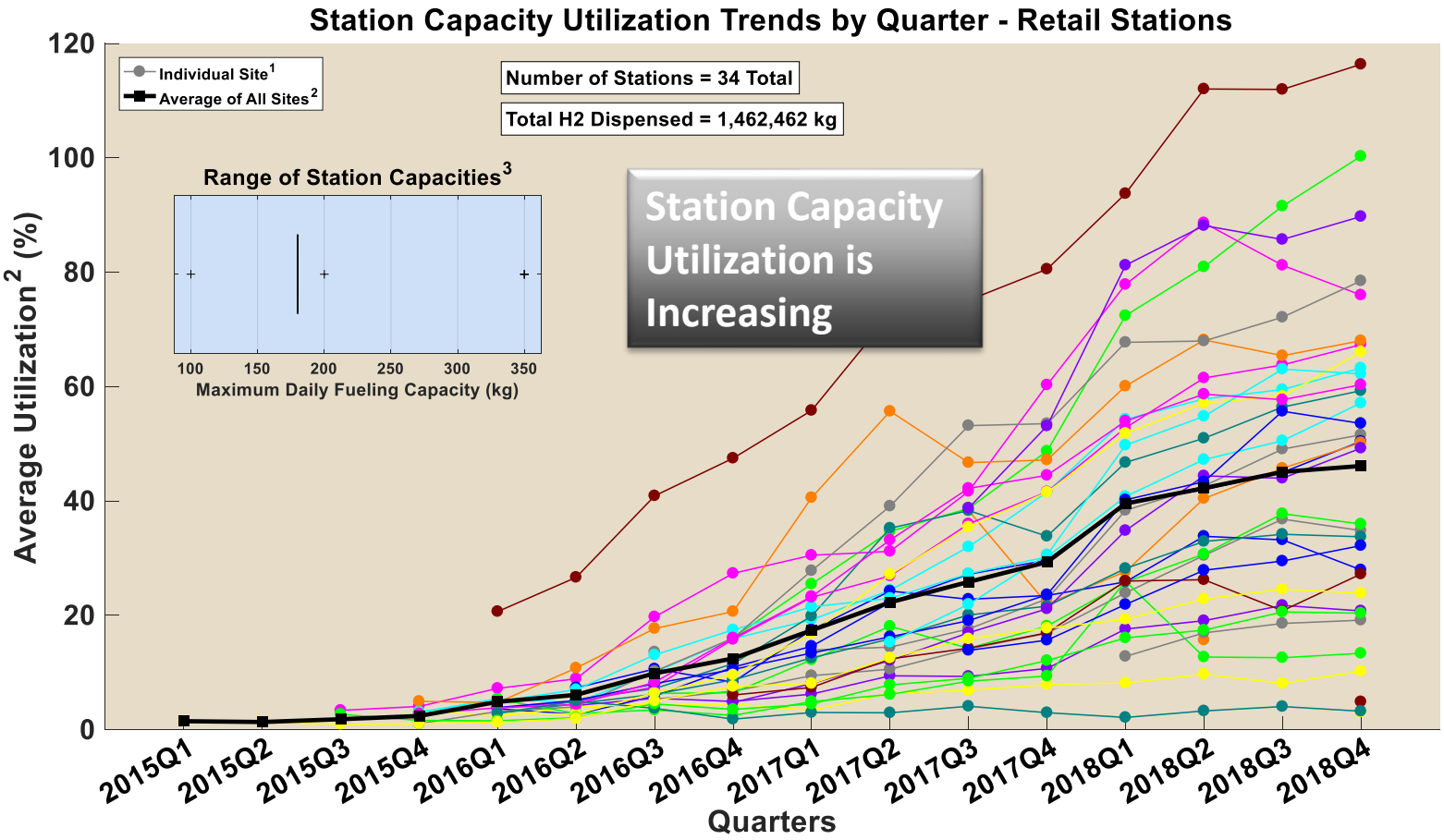


NREL cdpRETAIL_infr_05
Created: Mar-05-19 11:25 AM | Data Range: 2014Q3-2018Q4

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

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

Accomplishments and Progress:
Capacity Utilization



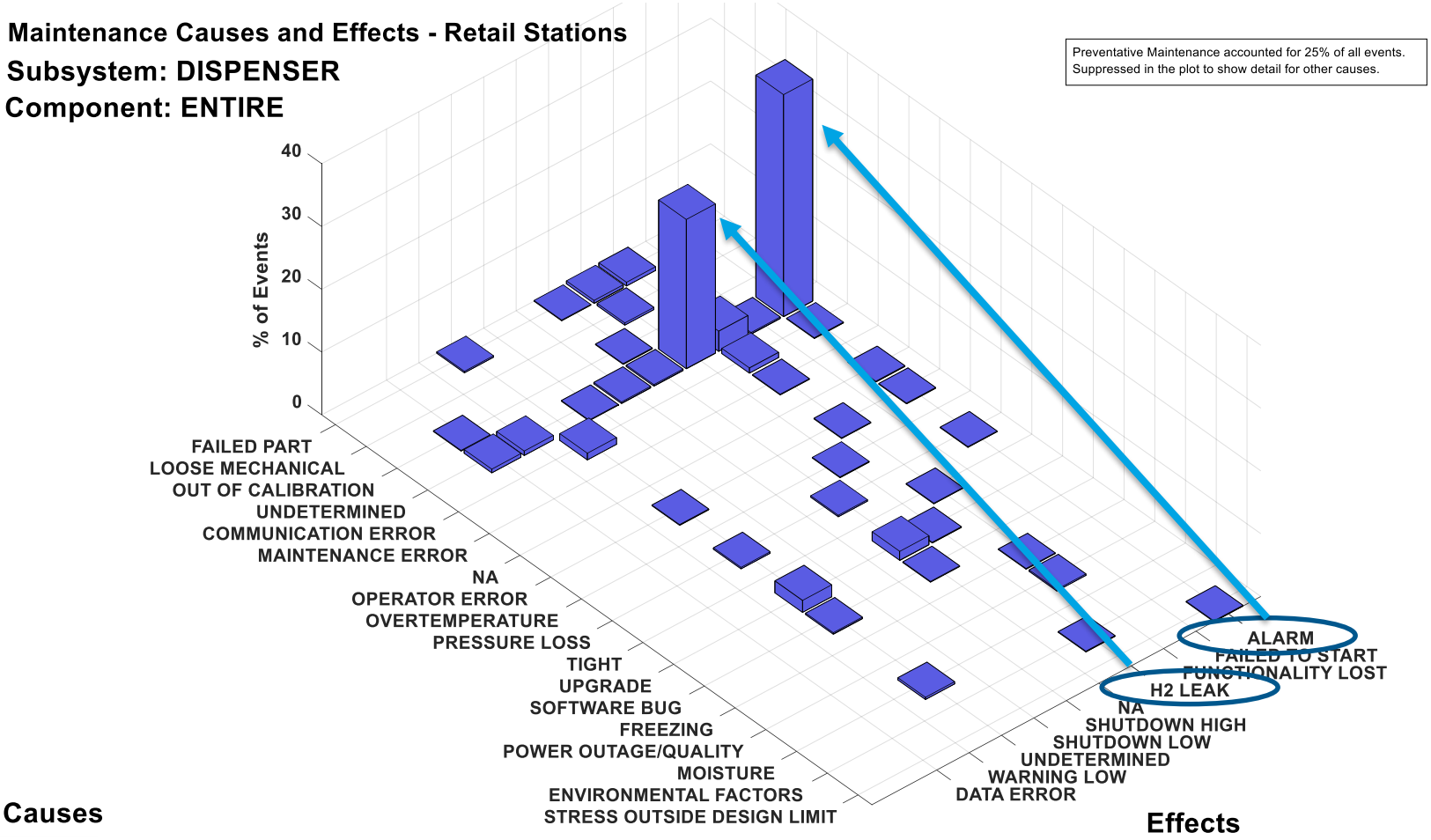
[1] Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

[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.

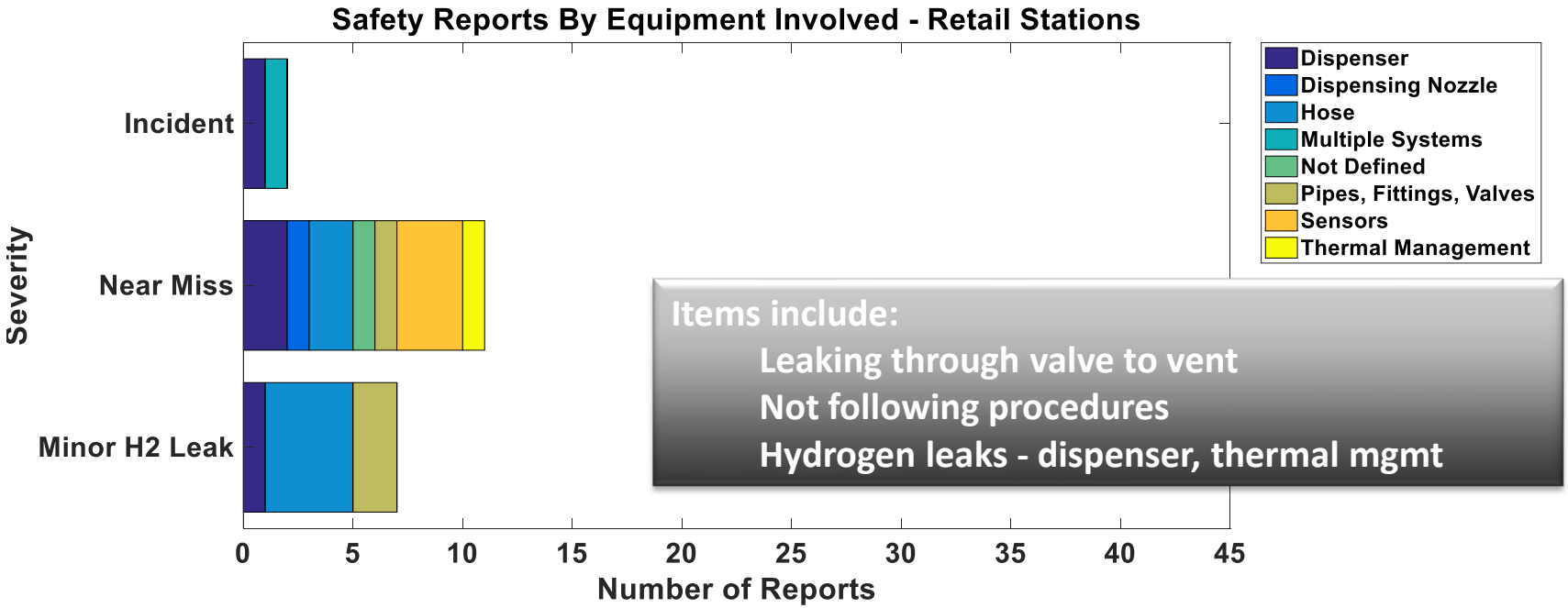
NREL cdpRETAIL_infr_44
Created: Mar-05-19 11:15 AM | Data Range: 2014Q3-2018Q4

Accomplishments and Progress:
Dispenser Maintenance Cause and Effects



10 CDPs similar to this one for different components
Preventative Maintenance accounted for 25% (not shown)

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

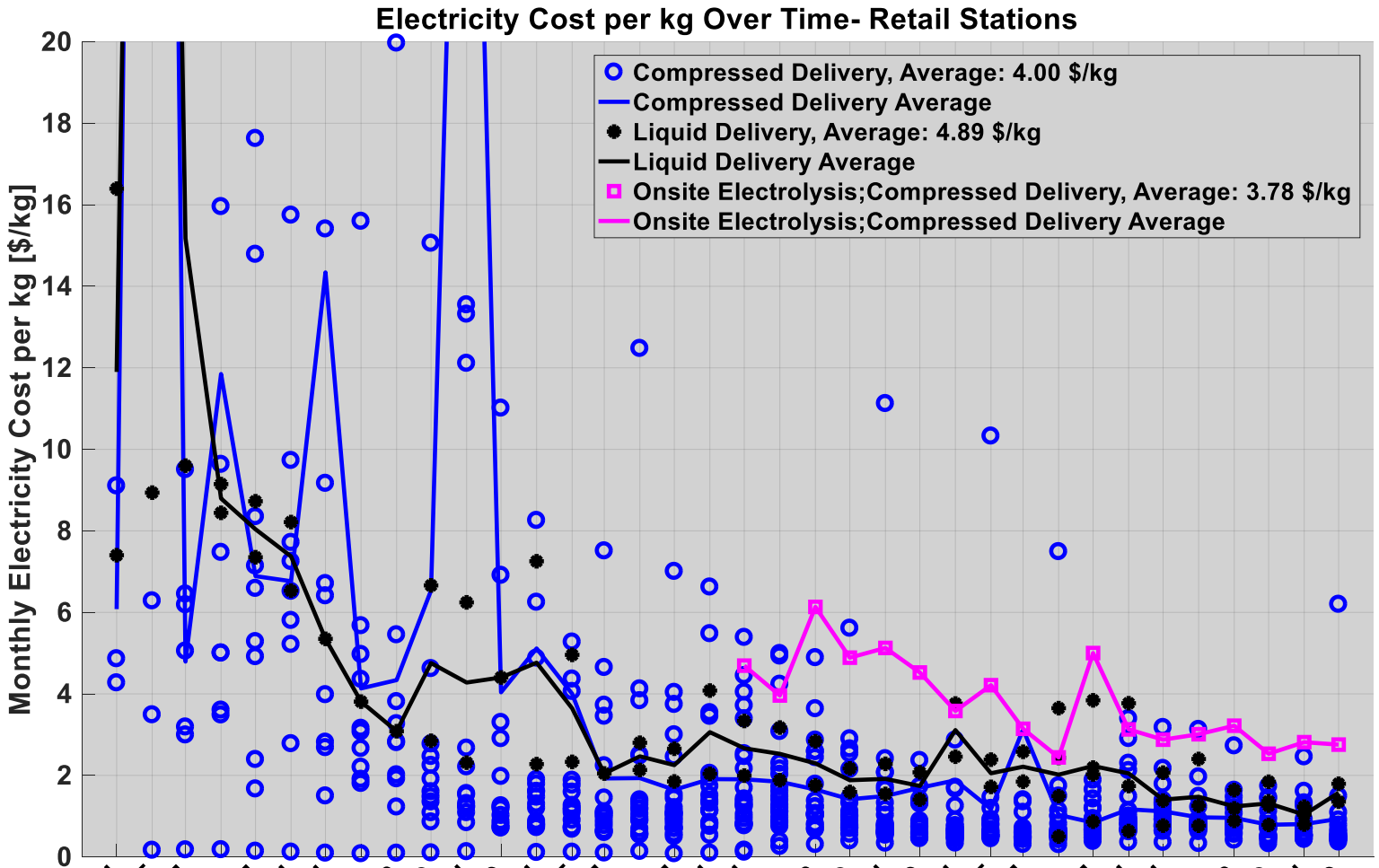
A Minor H2 Leak is:

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

NREL cdpRETAIL_infr_32

Created: Mar-18-19 12:42 PM | Data Range: 2014Q3-2018Q4

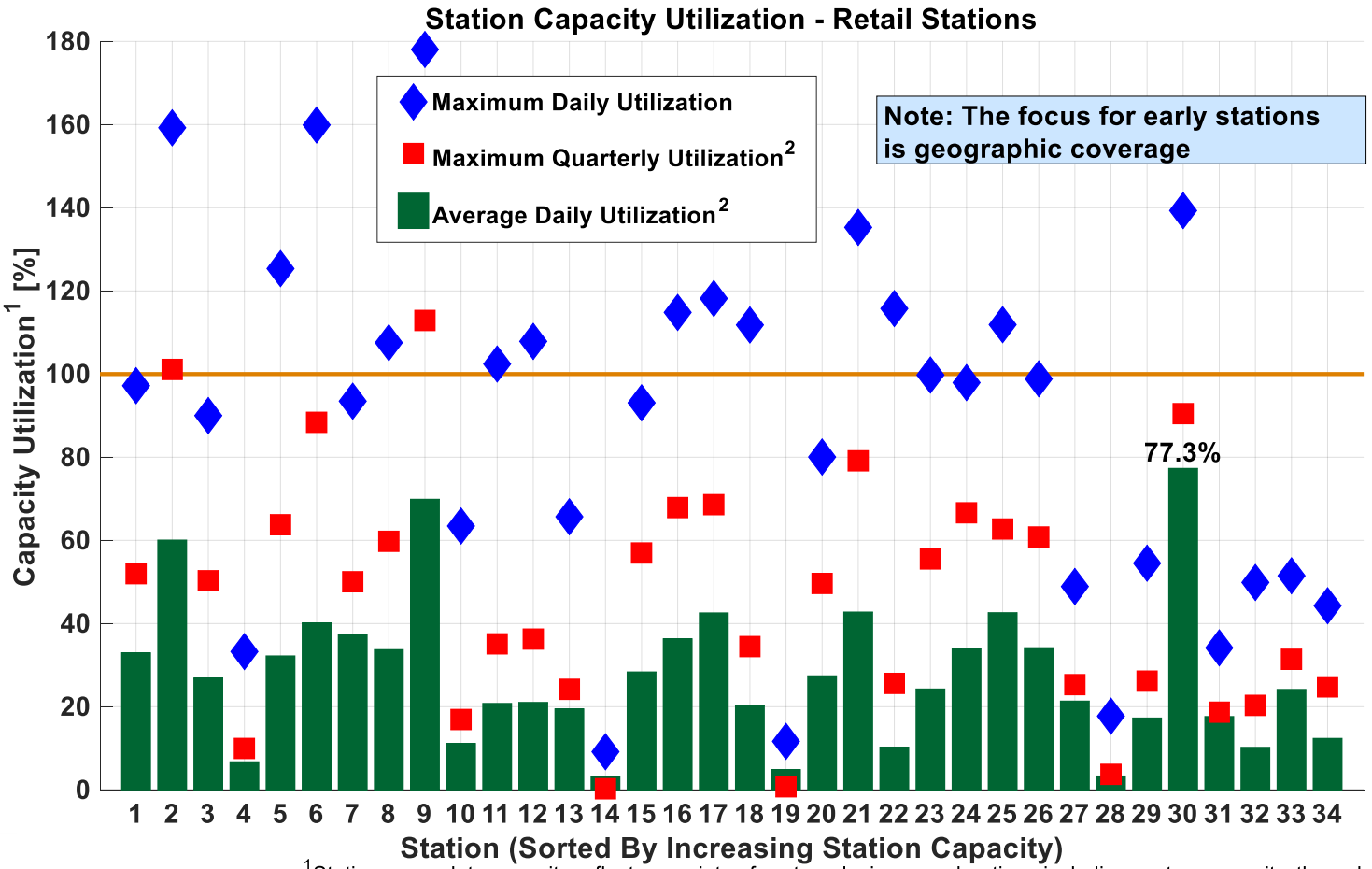
Electricity Cost per kg Dispensed by Month



NREL cdpRETAIL_Infr_85

Created: Mar-05-19 11:12 AM | Data Range: 2014Q3-2018Q4

Accomplishment: Station Capacity Utilization



NREL cdpRETAIL_infr_06
Created: Mar-15-19 2:27 PM | Data Range: 2014Q3-2018Q4

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

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

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

Reviewer-Only Slides

Critical Assumptions and Issues

- Different levels of detail in reporting from different stations.
  - Examples
    - Some don't provide cost (labor/parts)
    - Station down time due to maintenance issues not consistently provided
    - Some maintenance items simply responding to a problem and say fixed component "X", with no details.
    - Multiple items taken care of under scheduled maintenance with little detail. This ends up being classified as "entire".
- Not all stations measure energy use per component and will give a value that comes from specifications or one-time measurement.
- Working with some of the station providers to continue this activity but uncertain once their required data reporting period is up. CEC O&M awards do require 3 years of data from at least 16 stations after October 2018 and at least 1 year for their CapEx station awards.

Publications and Presentations

- Spring2019 CDPs posted on NREL site
  - Pdf(s) containing all “Retail Station” CDPs
  - Each CDP individually

www.nrel.gov/hydrogen/proj_tech_validation