



Hydrogen Station Data Collection and Analysis

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2017 DOE Hydrogen and Fuel Cells Annual Merit Review

Project ID TV017

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Timeline and Budget

- Project start date: 10/2011*
- Total DOE funds received to date: \$1,185k
- FY16 DOE funding: \$200k
- FY17 planned DOE funding: 300k

Barriers

- Lack of current hydrogen refueling infrastructure performance and availability data

Partners

- Industry and agencies listed on collaborations slide

*project continuation and direction determined annually by DOE

Relevance: Evaluating Existing Stations/Equipment

A very young market

- 27 retail stations in CA
- 925 registered FCEVs in CA (CARB - Oct, 2016)
- Multiple technological approaches



ITM Power, Riverside, CA. Photo: NREL



First Element, Costa Mesa, CA. Photo: NREL

Objectives

- Use existing stations as real-world guide for future innovations
- Identify issues for research
- Have results readily available

Approach: NCFCTEC 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 months¹

Composite Data Products (CDPs)

- Aggregated data across multiple systems, sites, and teams
- Publish analysis results without revealing proprietary data every 6 months²

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

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

Approach: Data Templates

Data Templates

- Aggregation requires multiple partners providing the same type of data
- NREL templates in the latest California Energy Commissions Grant Funding Opportunity GFO-15-605
 - Proposed awards announced in Feb 2017
 - \$33 million, 16 stations (1 Air Liquide, 8 First Element, 7 Shell)
- Stations also reporting through DOE contracts
- NOT static
 - Updated as needed (station downtime, fueling performance)
 - Modified for other uses (ex. Mobile Fueler)

Maintenance¹

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. 2) *insert calendar quarter*

Site Name *insert site name*

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

#	Date of Repair, Replacement	Component Name	replaces Category	New	replaces Maintenance Typ	replaces Failure Mode	New	New	New	Category ²
			Subsystem ²	Component ²	Action ²	Cause ²	Effect ²	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										

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

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

ORGANIZATIONS

California Fuel Cell Partnership
IPHE and HySUT
Gas Technology Institute
H2USA
H2FIRST

Approach: Hydrogen Station Locations

- Alternative Fuels Data Center (AFDC) – U.S. H2 Stations
- 35 public stations on AFDC where anyone can fill (subject to prior authorization, station activated, OEM approval, includes retail)
- 27 retail stations (Point of Sale).
 - Only in CA.
 - 4 northeast stations soon

- AFDC links to station availability using CaFCP-SOSS
- Mobile phone availability for both →



Station Status

Public Retail Stations	H70	H35
Costa Mesa (Soft Opening)	●	●
Diamond Bar	●	●
Harris Ranch	●	●
Hayward (Soft Opening)	●	●
La Canada Flintridge (Soft Opening)	●	●
Lake Forest (Soft Opening)	●	●

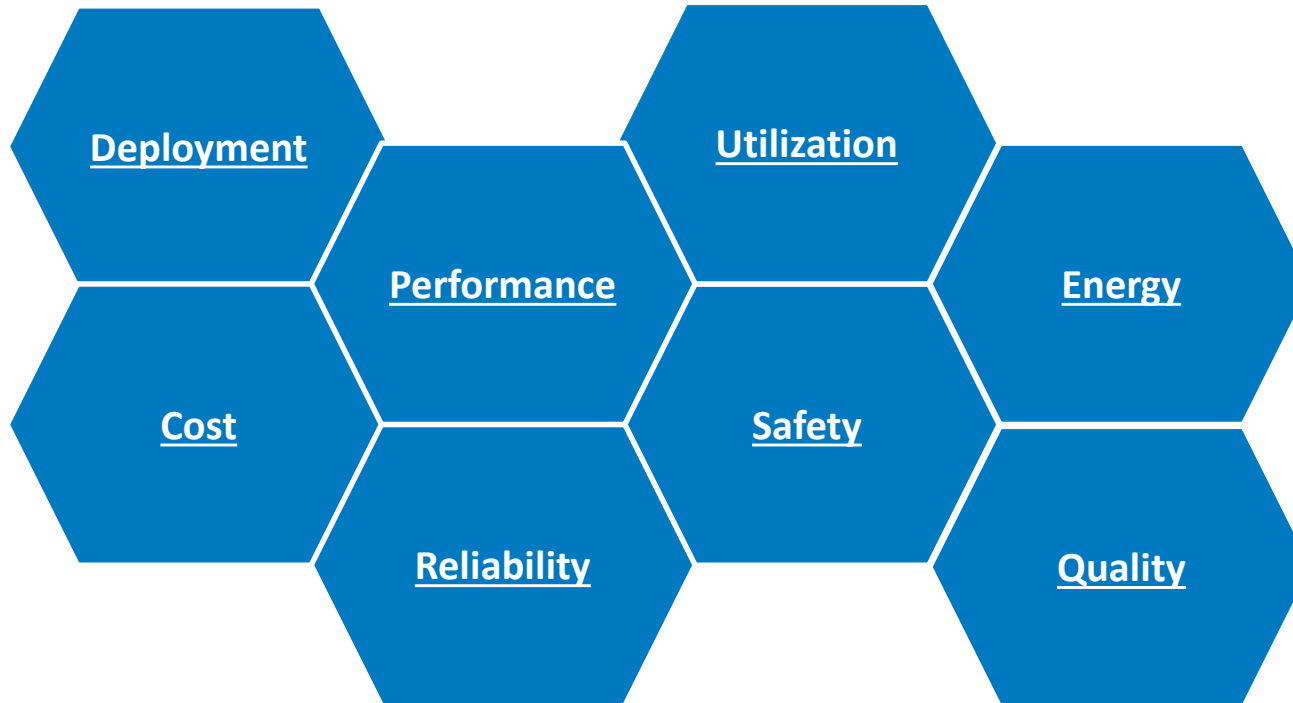
Hydrogen Station Count (serving on-road vehicles)

- 61 stations in U.S.
 - 35 “Public” Stations
 - 27 “Retail” Stations
- Stations providing performance data
 - 26 retail stations
 - 9 non-retail

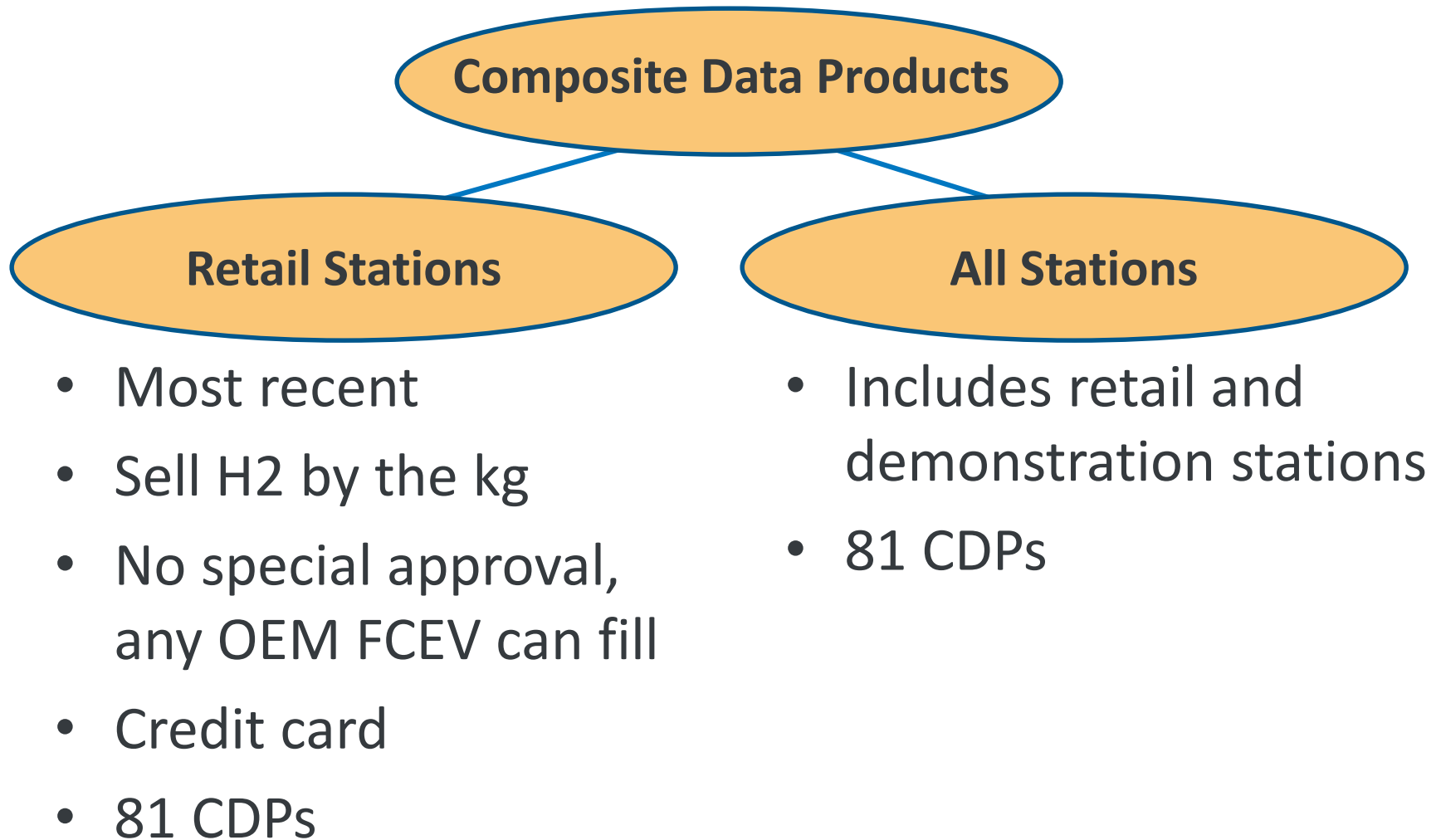


Photos: NREL

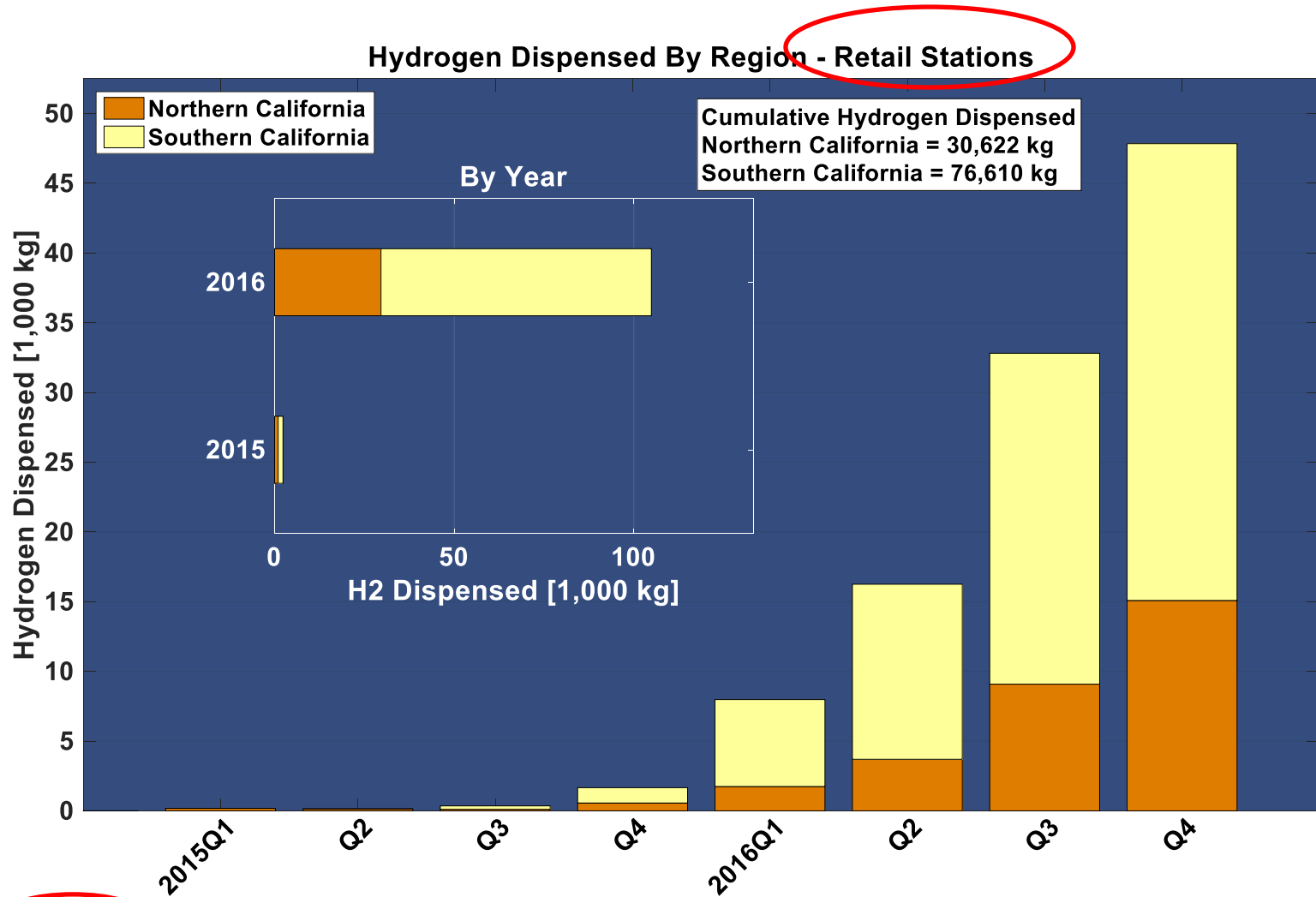
Approach: Analysis Categories



Approach: Separating out Retail Stations



Accomplishment: Separating out Retail Stations

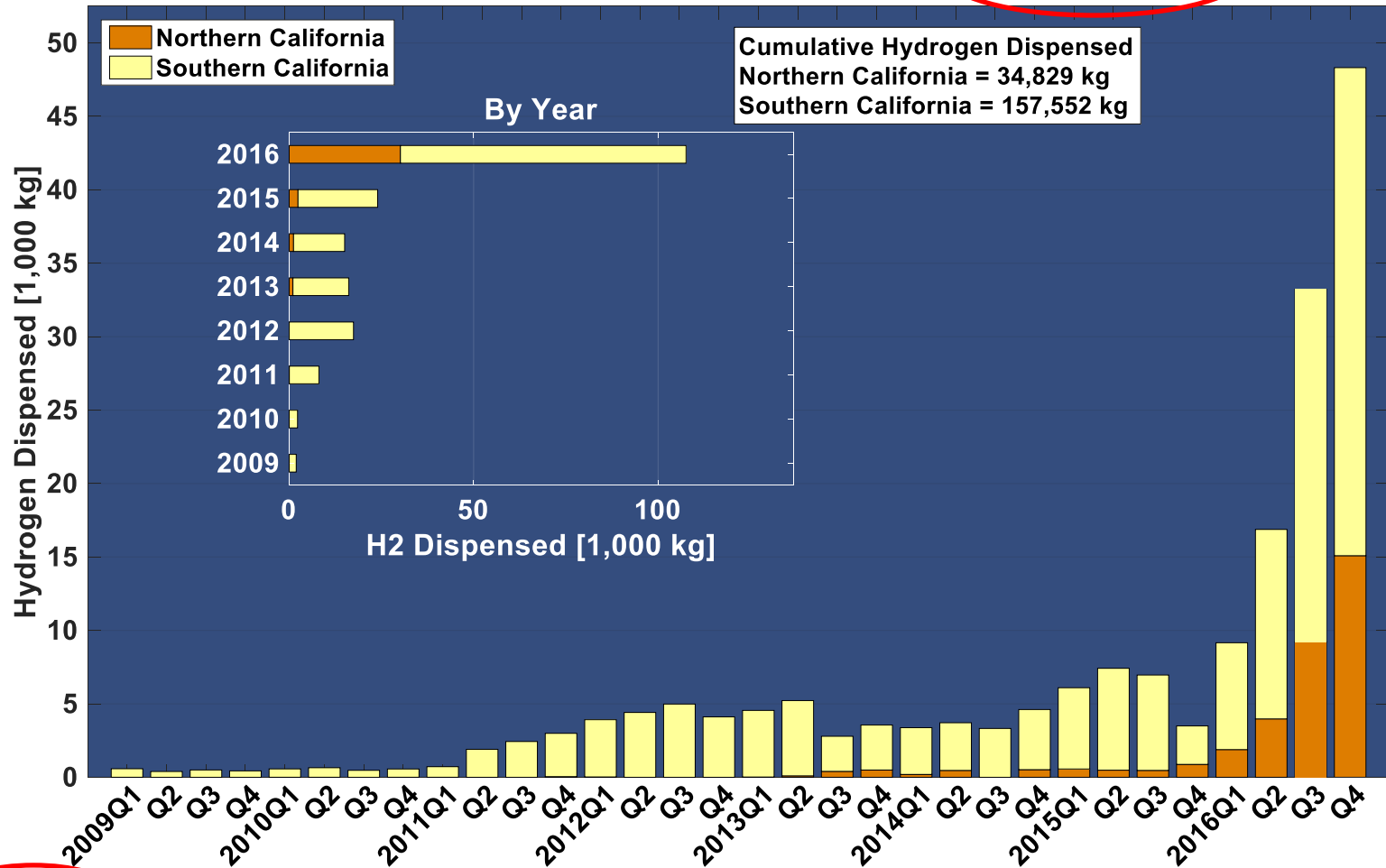


NRE_cdpRETAIL_infr_81

Created: May-05-17 3:52 PM | Data Range: 2014Q3-2016Q4

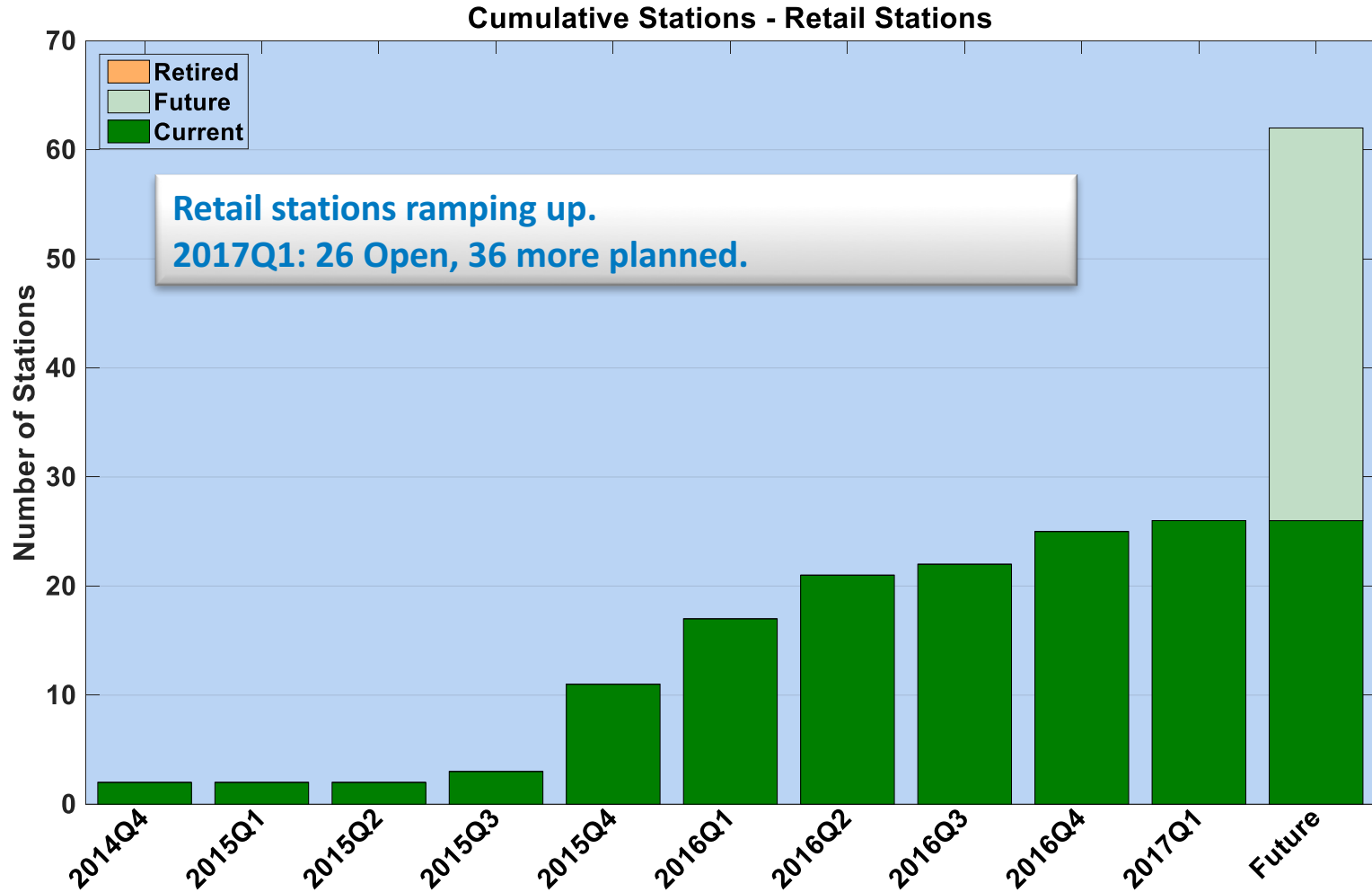
Accomplishment: Example – All Stations

Hydrogen Dispensed By Region



Created: May-05-17 3:30 PM | Data Range: 2008Q3-2016Q4

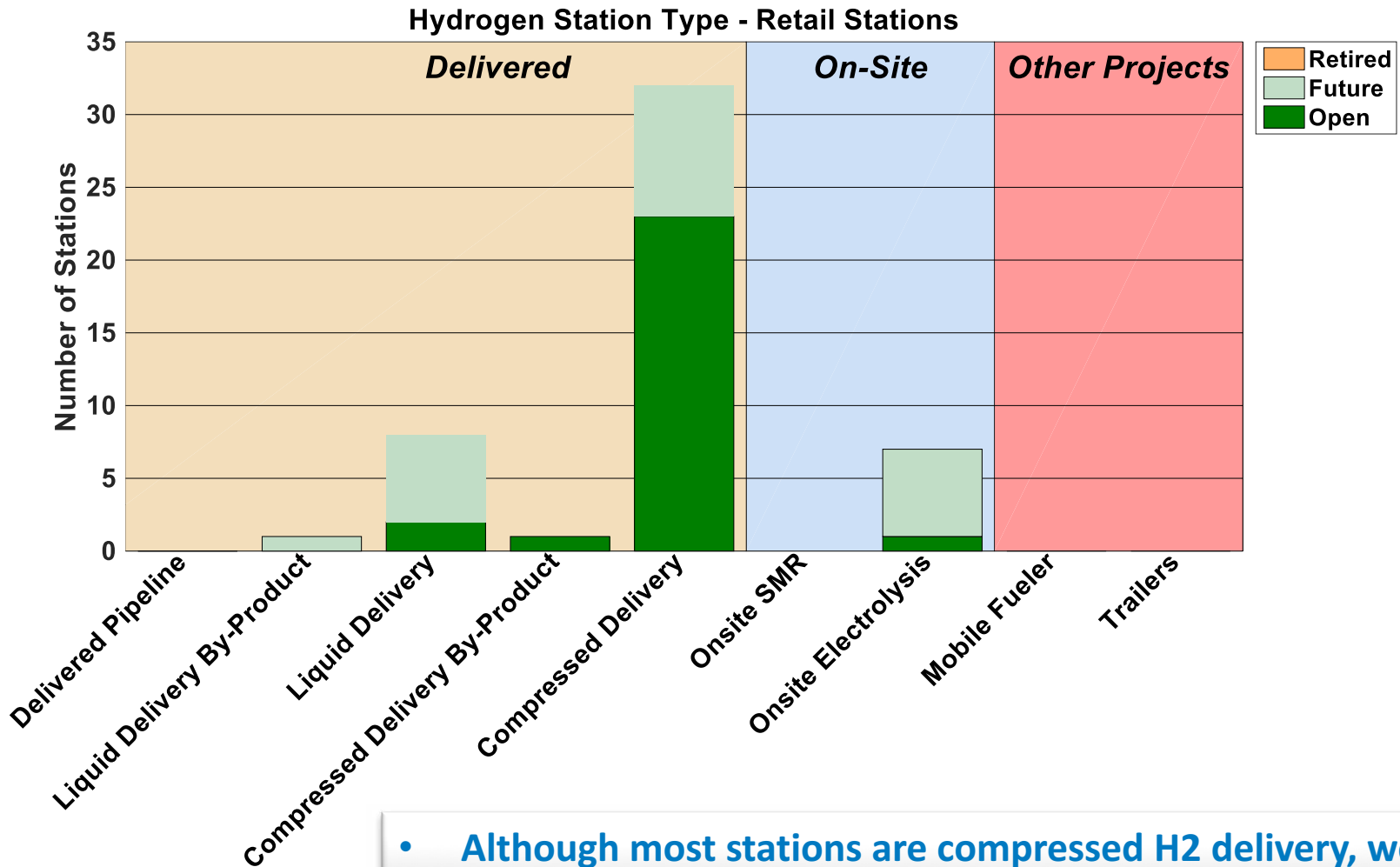
Cumulative Number of Stations



NREL cdpRETAIL_infr_10

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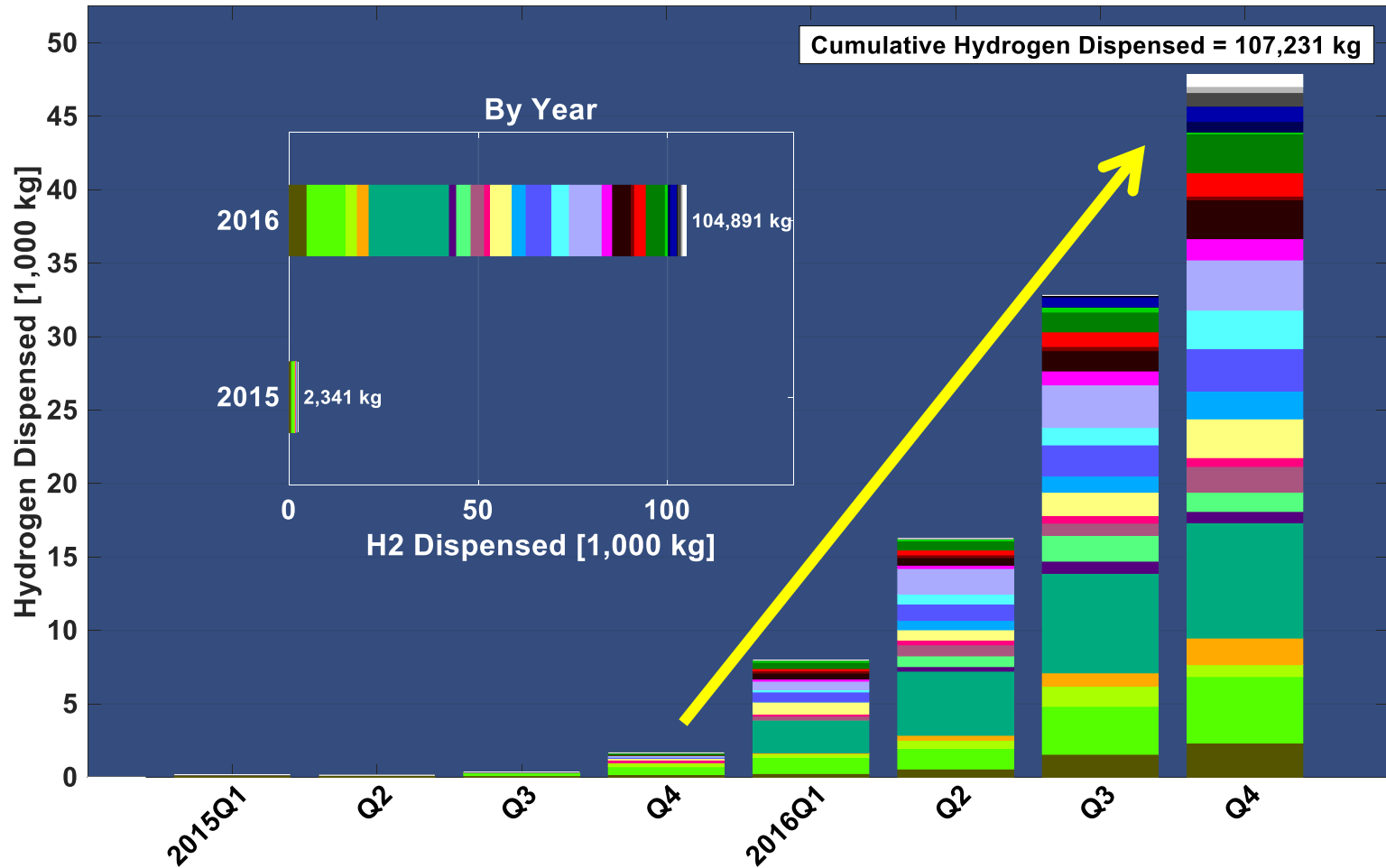
Station Types



- Although most stations are compressed H2 delivery, we also have liquid delivery and onsite electrolysis.

Accomplishments and Progress: Hydrogen Dispensed by Quarter

Hydrogen Dispensed By Quarter - Retail Stations



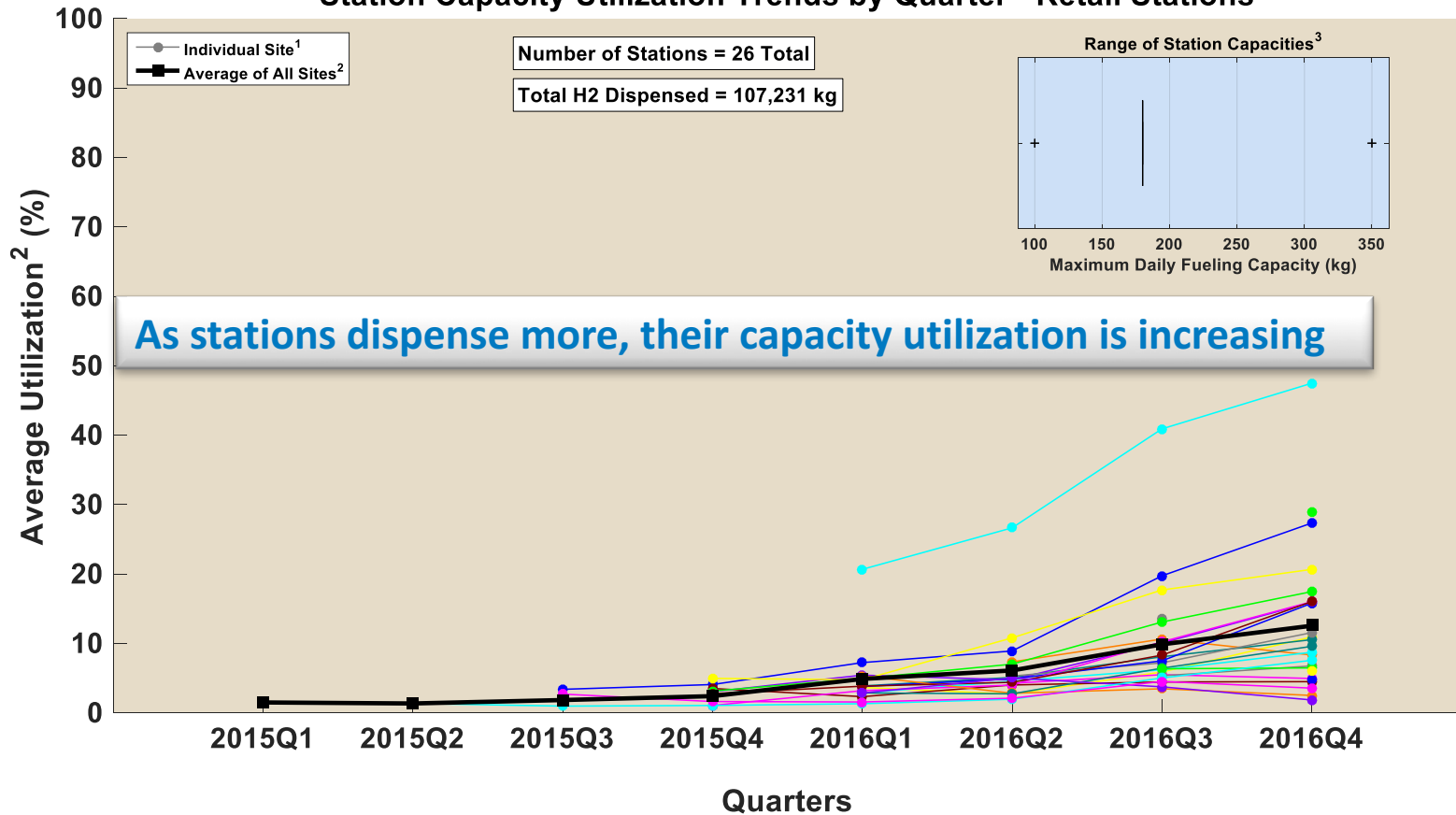
 NREL cdpRETAIL_infr_01
Created: May-05-17 3:36 PM | Data Range: 2014Q3-2016Q4

Note: Colors represent individual stations

Retail stations dispensing significantly more each quarter

Accomplishments and Progress: Capacity Utilization

Station Capacity Utilization Trends by Quarter - Retail Stations



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.

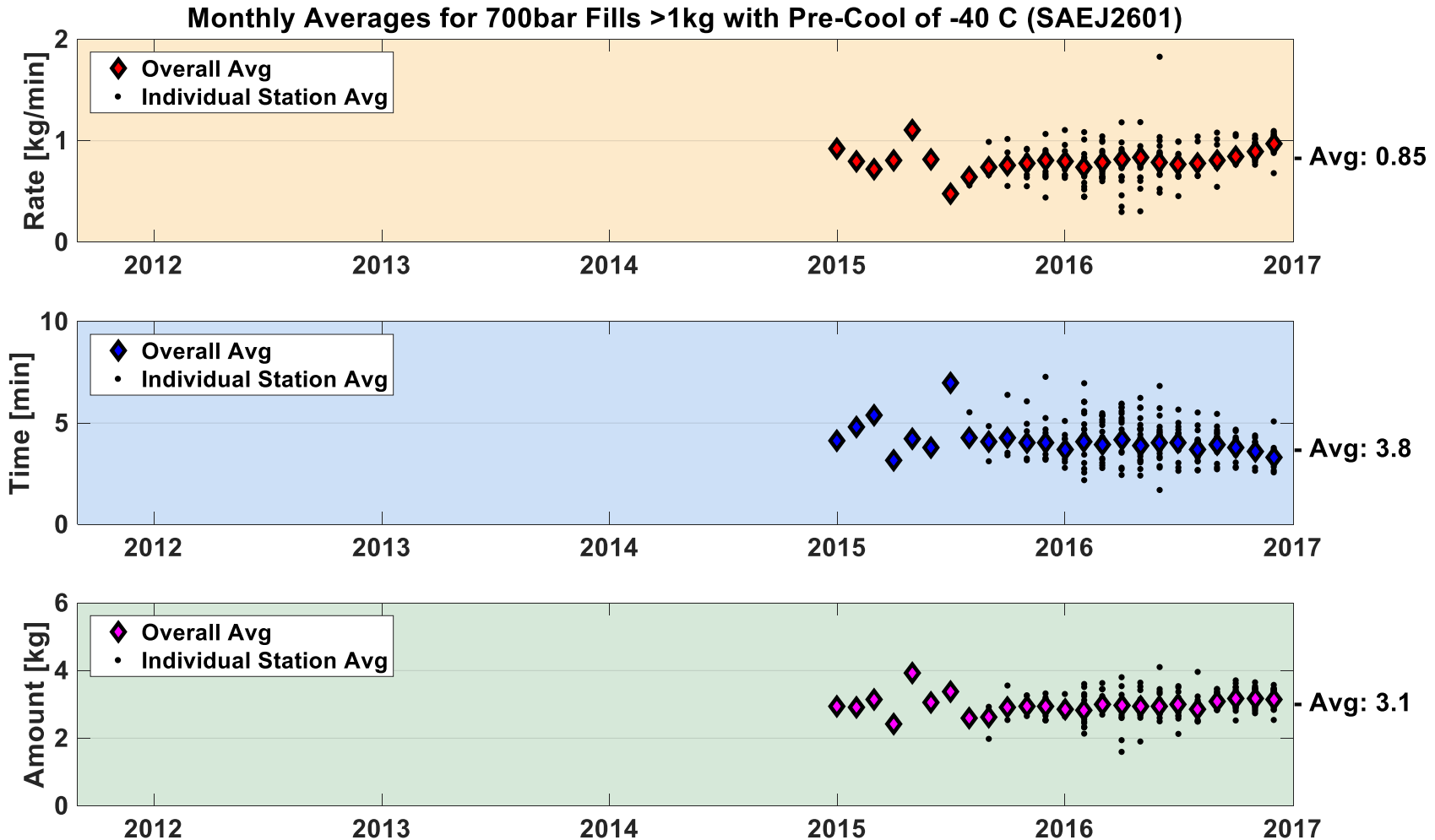
³ Station nameplate capacity is as reported to NREL and reflects a variety of system design considerations including: system capacity, throughput, system reliability, and maintenance. Actual daily usage may exceed nameplate capacity.



NREL cdpRETAIL_infr_44

Created: May-08-17 8:39 AM | Data Range: 2014Q3-2016Q4

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

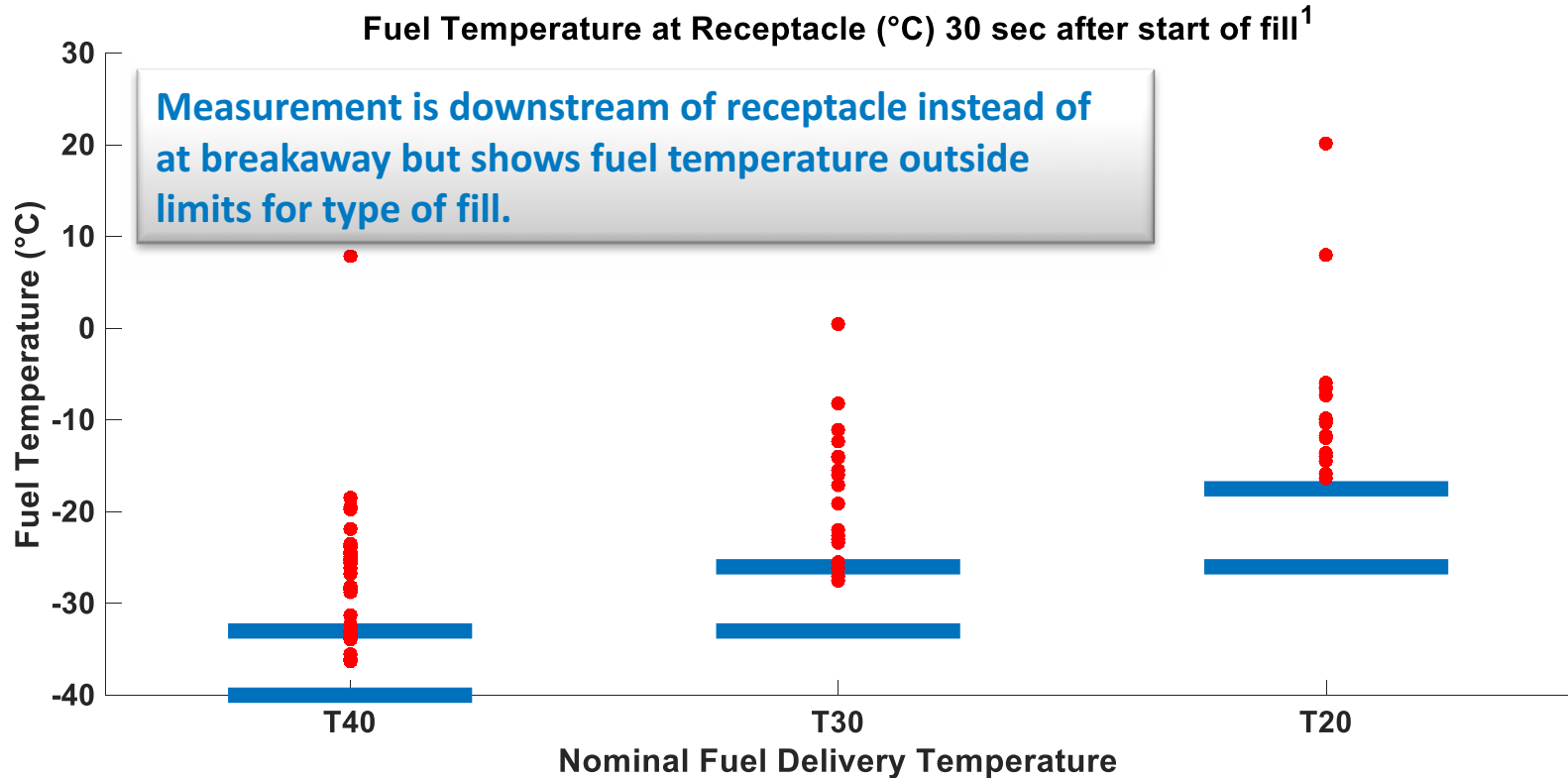


NREL cdpRETAIL_infr_57

Created: May-08-17 9:50 AM | Data Range: 2014Q3-2016Q4

**Time to fill is decreasing to 3.8 minutes on average.
Average amount filled = 3.1 kg**

Accomplishments and Progress: Fuel Delivery Temperature



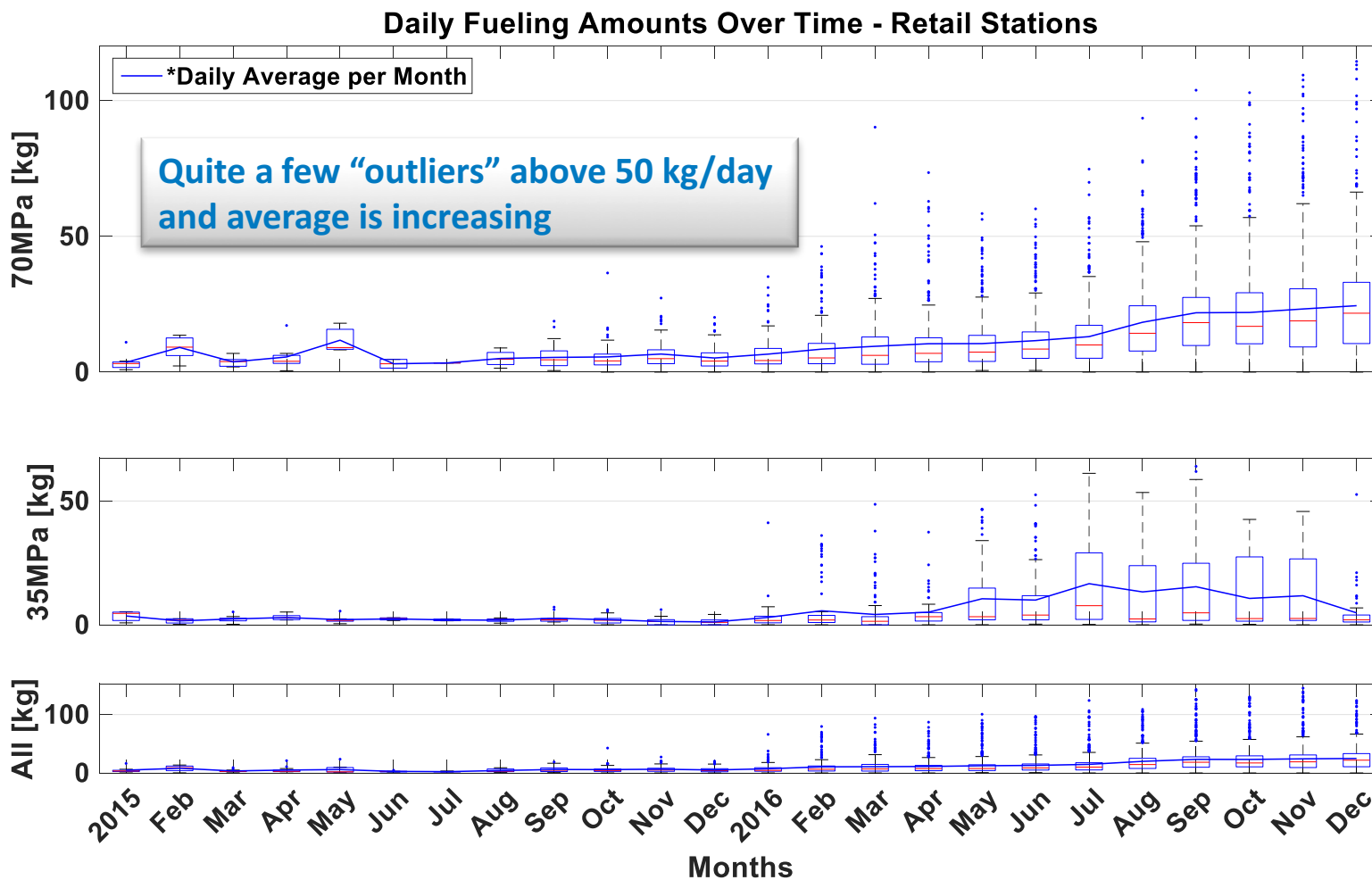
1. SAE J2601 (2014) defines fuel delivery temperature as measured near the dispenser breakaway. See paragraph 4.21. Temperature data here are from HyStEP tests measuring fuel temperature just downstream of the receptacle. SAE J2601 requires that fuel delivery temperature reach the limits shown in blue above within 30 seconds of the start of fueling.



NREL cdp_infr_77

Created: Apr-20-17 11:29 AM | Data Range: 2014Q4-2016Q4

Accomplishments and Progress: Daily Fueling by Month – Retail Stations



NREL cdpRETAIL_infr_82

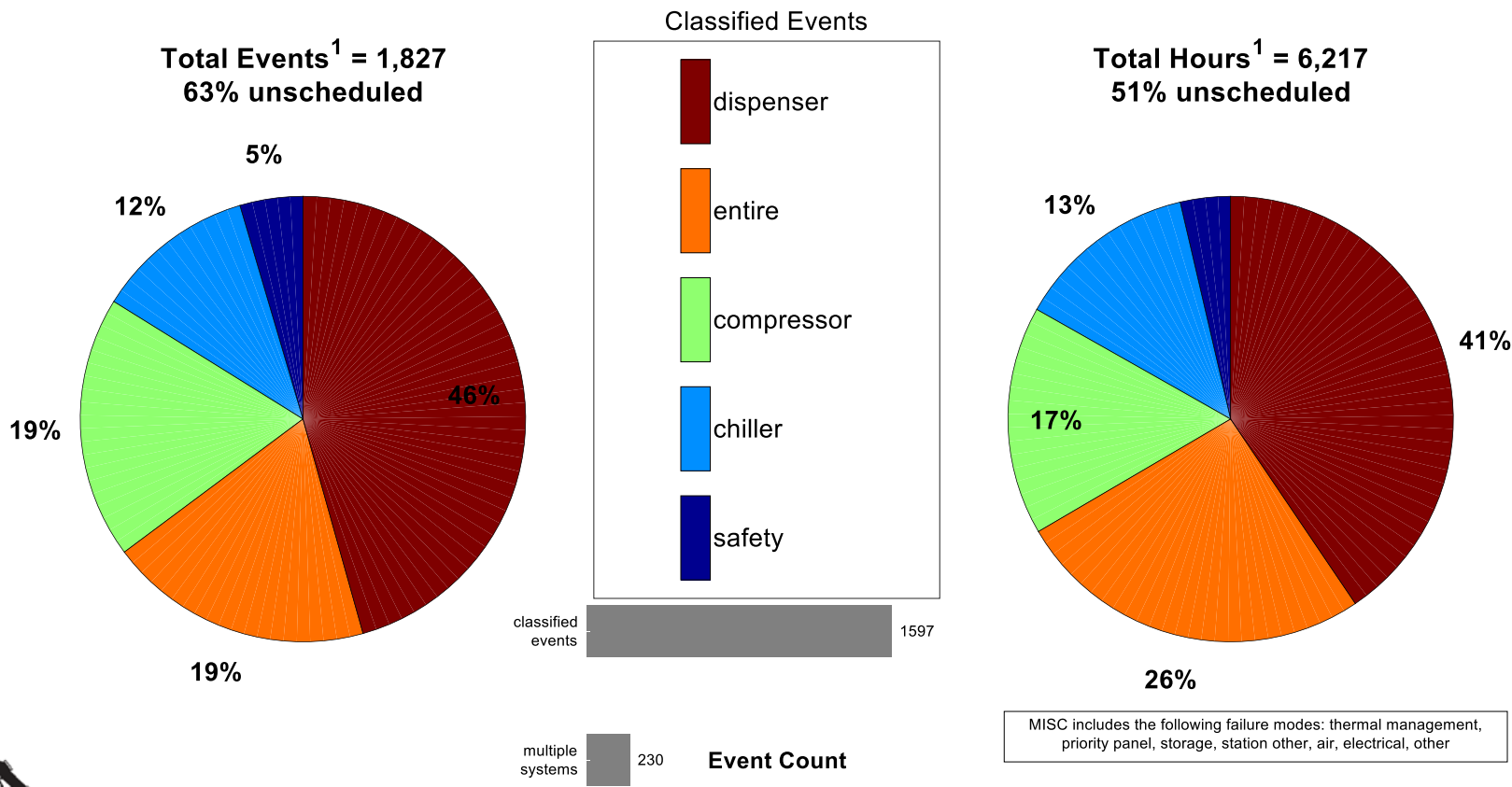
Created: May-08-17 9:12 AM | Data Range: 2014Q3-2016Q4

*Daily average only includes days with fills.

Accomplishments and Progress: Maintenance by Equipment Type – Retail Stations

Most maintenance is now on dispensers instead of compressors.
Chiller maintenance increased (stations now fill at -40 C).

Maintenance by Equipment Type - Retail Stations



MISC includes the following failure modes: thermal management, priority panel, storage, station other, air, electrical, other

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

Accomplishments and Progress: Dispenser Maintenance Cause and Effects

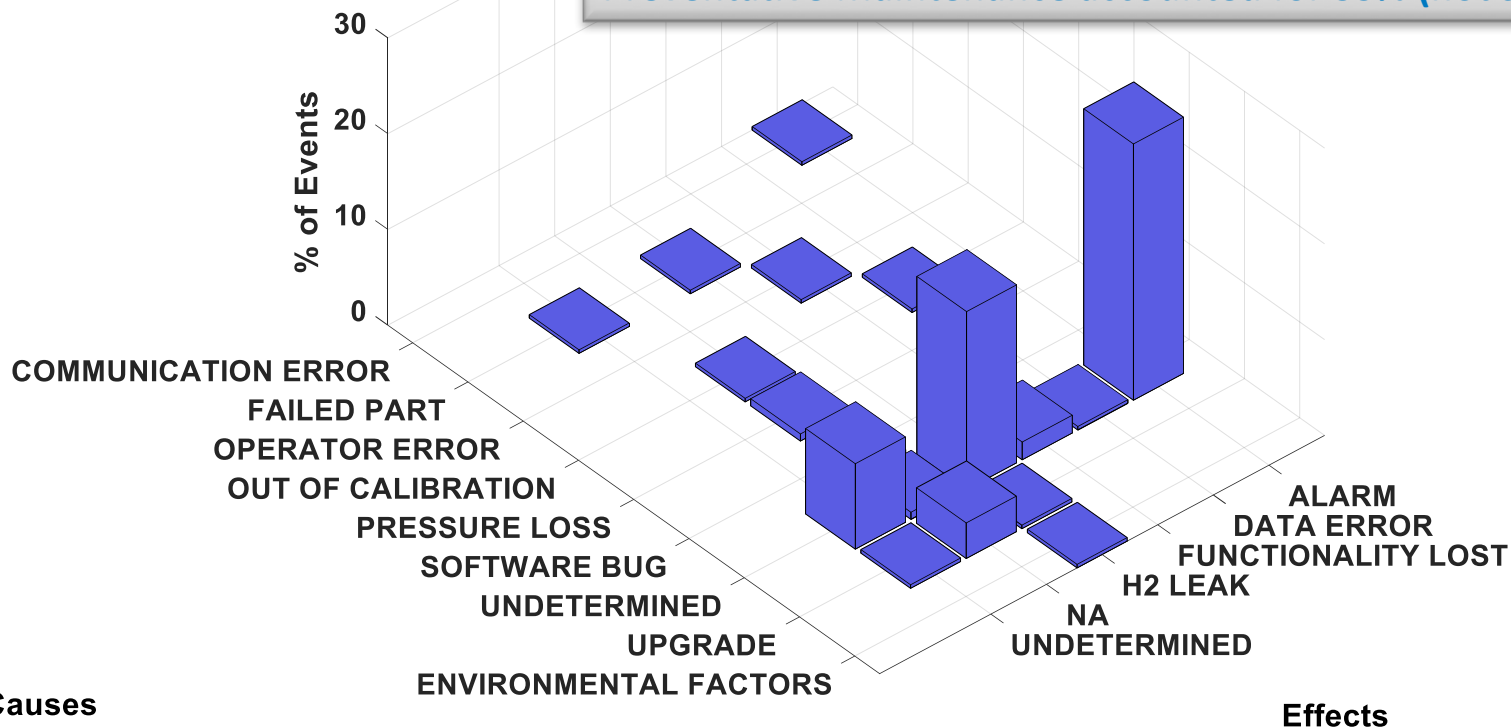
Maintenance Causes and Effects - Retail Stations

Subsystem: DISPENSER

Component: ENTIRE

Preventative Maintenance accounted for 35% of all events.
Suppressed in the plot to show detail for other causes.

10 new CDPs similar to this one for different components
Preventative Maintenance accounted for 35% (not shown)



Causes

Effects

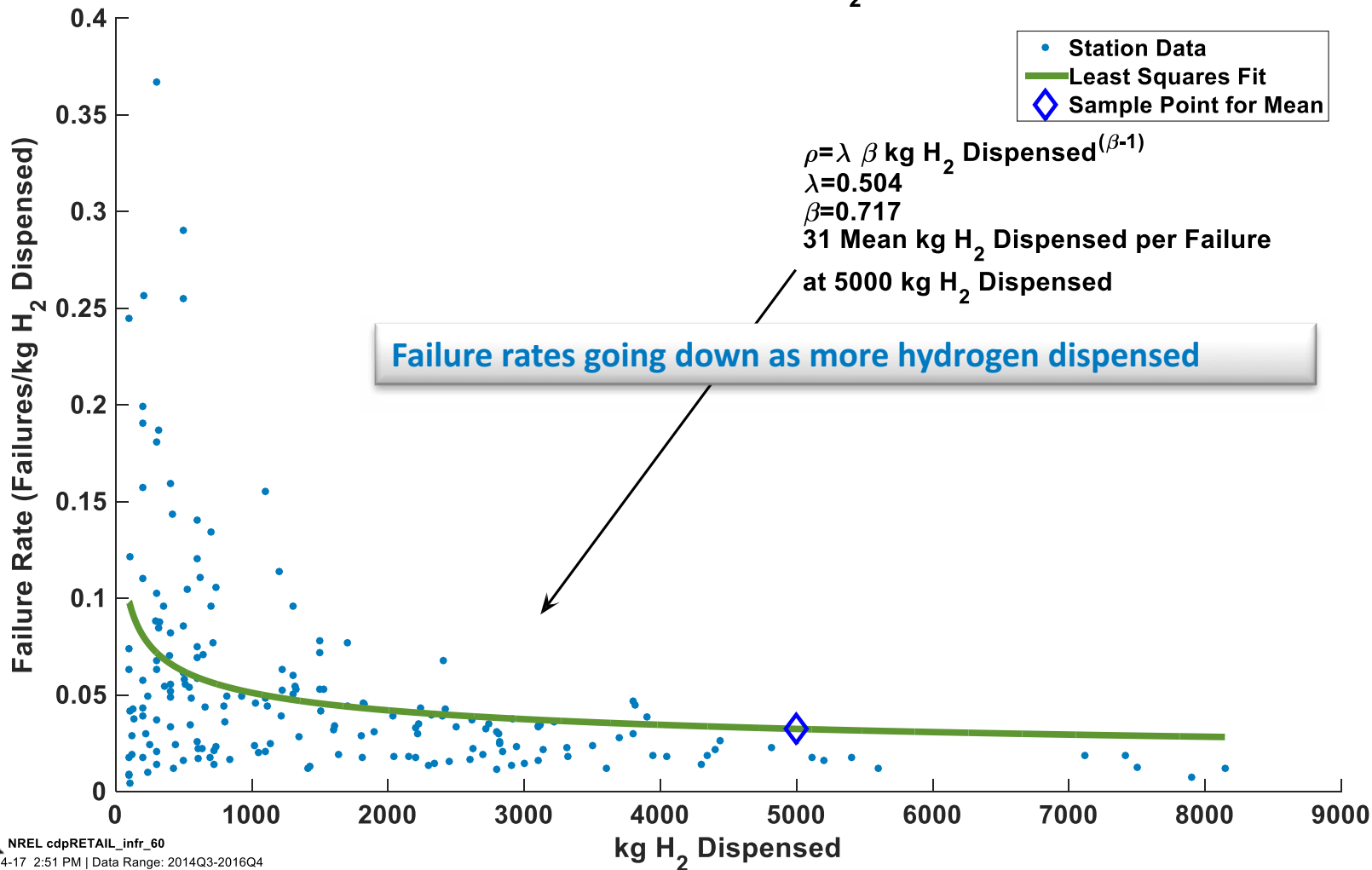


NREL cdpRETAIL_infr_67

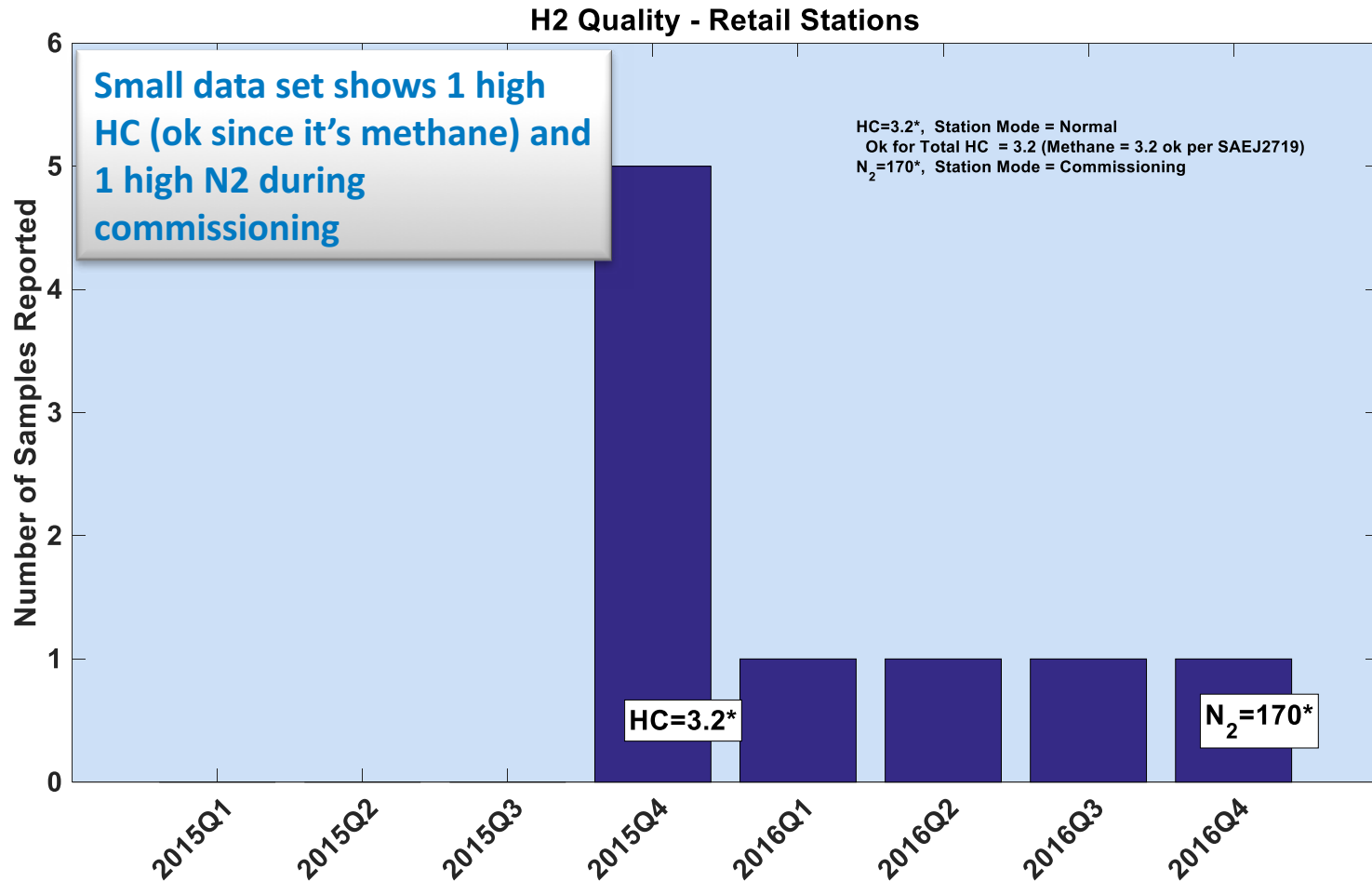
Created: May-08-17 9:05 AM | Data Range: 2014Q3-2016Q4

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

Historical Failure Rate (bathtub curve) by kg H₂ Dispensed - Retail Stations



Accomplishments and Progress: H2 Quality

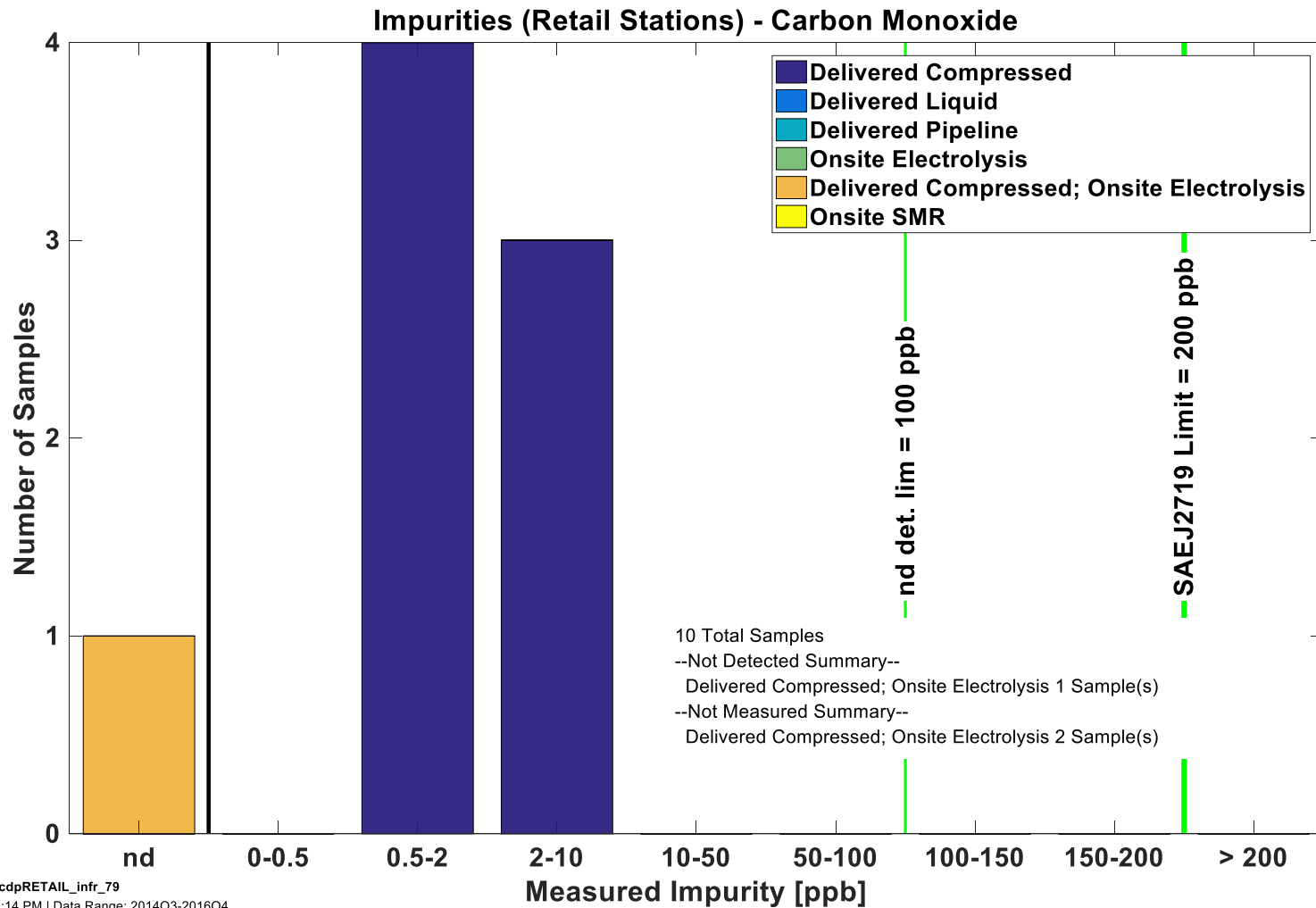


NREL cdpRETAIL_infr_25

Created: May-08-17 9:04 AM | Data Range: 2014Q3-2016Q4

*Values are in micromole/mole, except for particulate size (Psize) in micrometer. Only values that exceed SAE J2719 guideline are shown in text. Left edge of text box aligns with sample date.

Accomplishments and Progress: Carbon Monoxide Measurements – Retail Stations

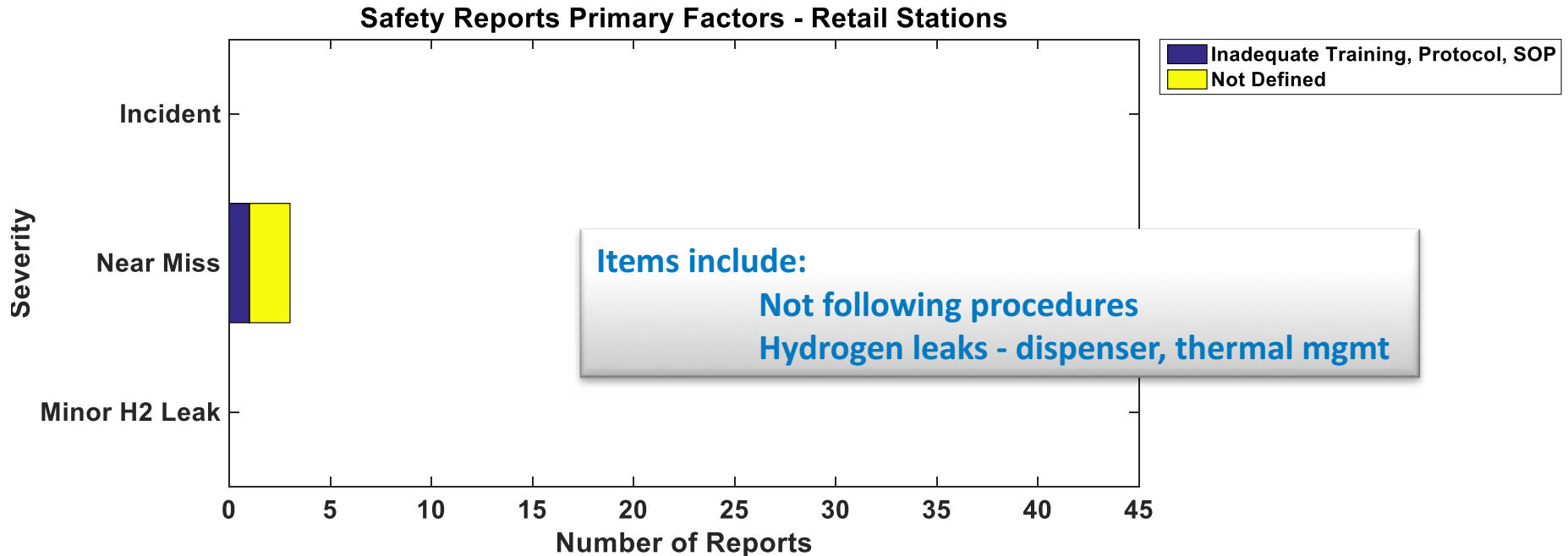


NREL cdpRETAIL_infr_79

Created: May-08-17 12:14 PM | Data Range: 2014Q3-2016Q4

Individual constituent CDPs show range of values at stations. Here CO is well below limits but is useful for fuel cell developers to see what their equipment will be exposed to at these stations.

Accomplishments and Progress: Safety Reports by Primary Factors



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:

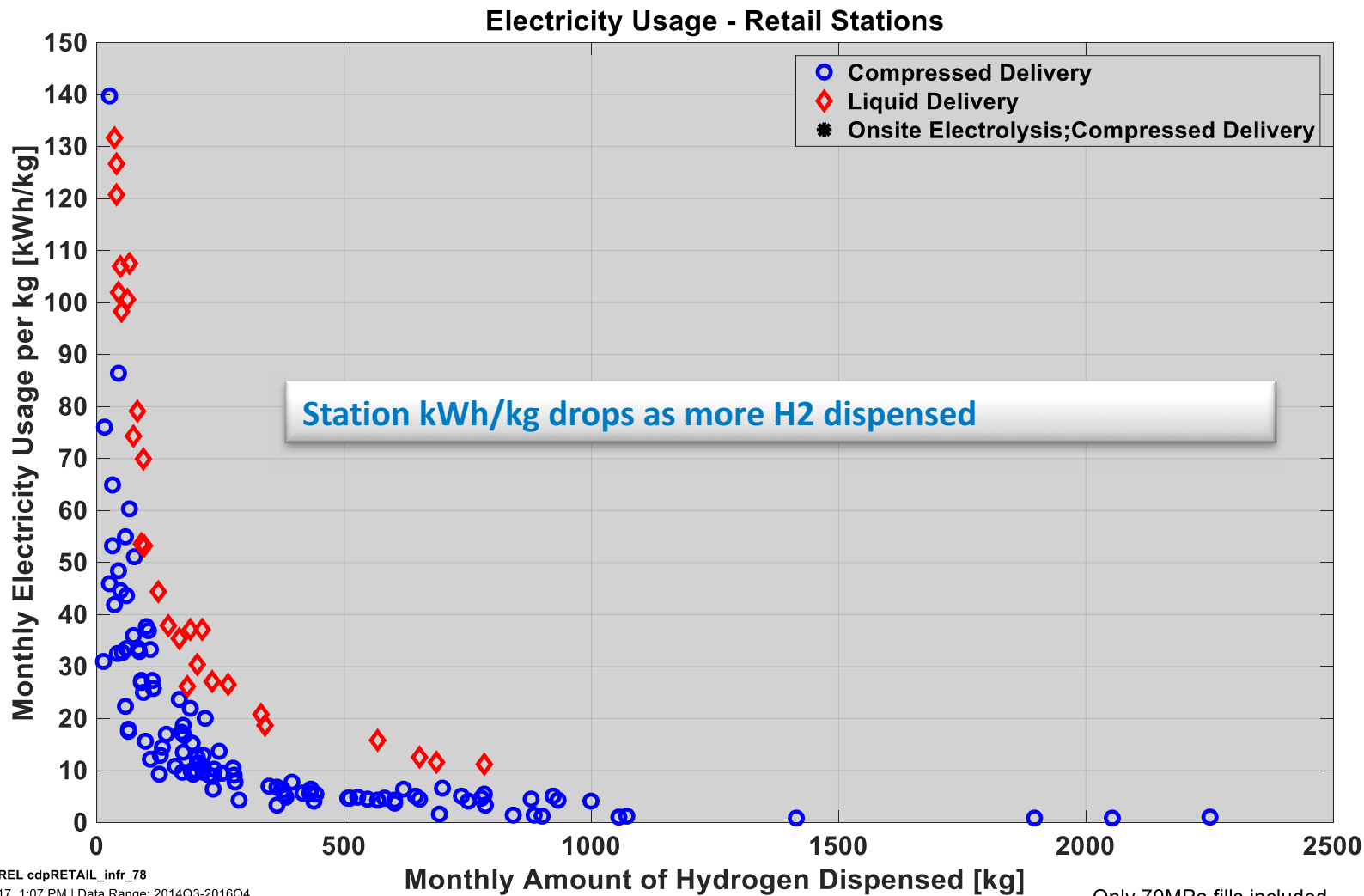
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdpRETAIL_infr_31

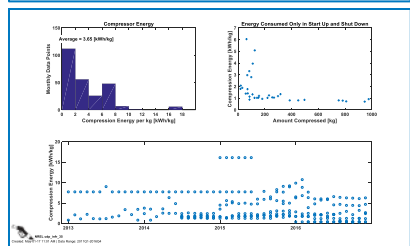
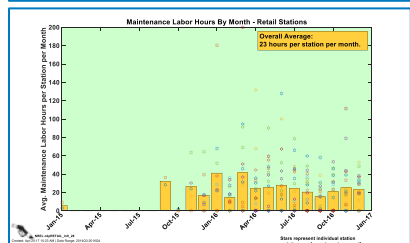
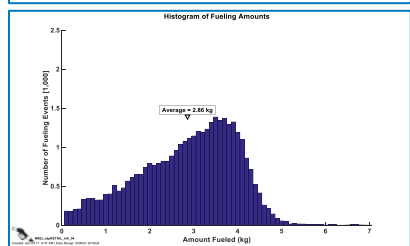
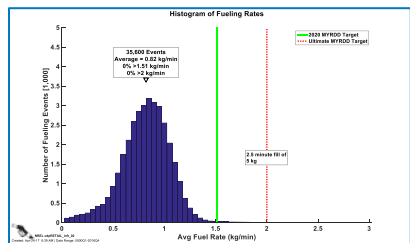
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Accomplishments and Progress: Electricity Usage per kg Dispensed

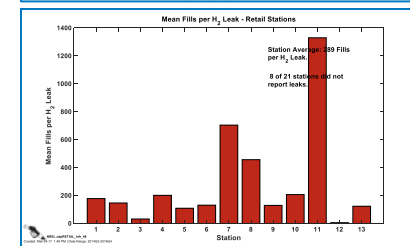
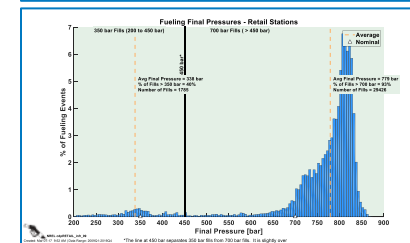
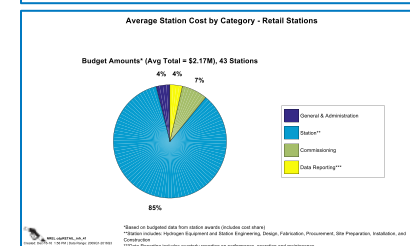
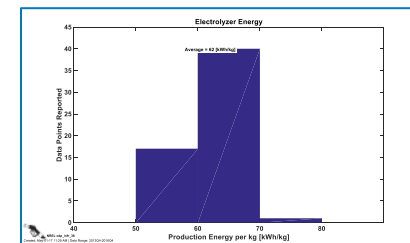


NREL cdpRETAIL_infr_78
Created: May-08-17 1:07 PM | Data Range: 2014Q3-2016Q4

Accomplishments and Progress: Sampling of Results – Retail Stations



Fueling Rate Average	0.82 kg/min
Fueling Amount Average	2.86 kg
Fueling Time Average	3.6 min
Compressor Energy Average	3.65 kWh/kg
Total Hydrogen Dispensed (26 Stations)	107,231 kg
Electrolyzer Energy Average (non-retail stations)	62 kWh/kg
Maintenance Hours Average	23 hours/month
Fueling Final Pressure Average	779 bar
Fills per H2 Leaks Average	289 Fills per H2 Leak



Accomplishments and Progress: CDPs available by topic

The screenshot shows a web browser window displaying the NREL website. The address bar shows the URL: www.nrel.gov/hydrogen/infrastructure-cdps-retail.html. The page features the NREL logo and a 40th anniversary banner (1977-2017). A search bar is located in the top right corner. The main navigation menu includes links for ABOUT, RESEARCH, WORKING WITH US, and CAREERS. The page title is "Hydrogen & Fuel Cell Research". A sidebar on the left lists various research topics, with "Hydrogen Fueling Infrastructure" highlighted. The main content area is titled "Next Generation Hydrogen Station Composite Data Products: Retail Stations" and includes a brief description of the CDPs, a "Deployment" section with a list of links, and a "Safety" section with a list of links. A "Printable Version" link is also visible.

Hydrogen & Fuel Cell Research

40 Years of Advanced Energy Innovation

ABOUT ▾ RESEARCH ▾ WORKING WITH US ▾ CAREERS ▾

Hydrogen & Fuel Cells Research Home

Projects

- Fuel Cells
- Hydrogen Production & Delivery
- Hydrogen Storage
- Manufacturing
- 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

Success Stories

Research Staff

Facilities

Next Generation Hydrogen Station Composite Data Products: Retail Stations

The following composite data products (CDPs) focus on next generation hydrogen stations and include data from retail stations only. Also view [CDPs for all stations](#) (retail and non-retail combined).

Deployment

- [Cumulative Number of Stations](#)
CDP RETAIL INFR 10, 12/21/16
- [Hydrogen Stations by Type](#)
CDP RETAIL INFR 11, 12/19/16
- [Hydrogen Station Timeline](#)
CDP RETAIL INFR 27, 12/19/16

Safety

- [Safety Reports Primary Factors](#)
CDP RETAIL INFR 31, 12/20/16
- [Safety Reports by Equipment Involved](#)
CDP RETAIL INFR 32, 12/20/16
- [Safety Reports by Quarter](#)
CDP RETAIL INFR 33, 12/20/16
- [Safety Reports by Event Description](#)
CDP RETAIL INFR 34, 12/20/16
- [Mean Fills per Hydrogen Leak](#)
CDP RETAIL INFR 48, 12/07/16
- [Mean Hydrogen Dispensed per Hydrogen Leak](#)
CDP RETAIL INFR 54, 12/07/16

Maintenance and Reliability

Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- Reviewer comment: Confusion about station count
 - There are 27 retail stations (OEMs most interested in this number)
 - Performance data from 26 current retail stations and 9 non-retail stations
- Reviewer comment: Unsure NREL can manage increasing amount of data
 - We have setup several new automatic data capture and analysis routines in our NREL Fleet Analysis Toolkit (in Matlab).
- Reviewer: Looking forward to the new stations and the separation of retail vs. demonstration.
 - Now have separate CDPs for “Retail” Stations and “All” Stations

Proposed Future Work

- Analysis and CDP publication
 - Complete data analysis and publish results
 - Calendar 2017 Q1 and Q2
 - Calendar 2017 Q3 and Q4
- Update data collection, analysis and feedback
 - Add availability of stations
 - Work with station providers to deep dive into specific issues as they arise for feedback to research
 - Identify needs for future stations
 - Increase international collaboration

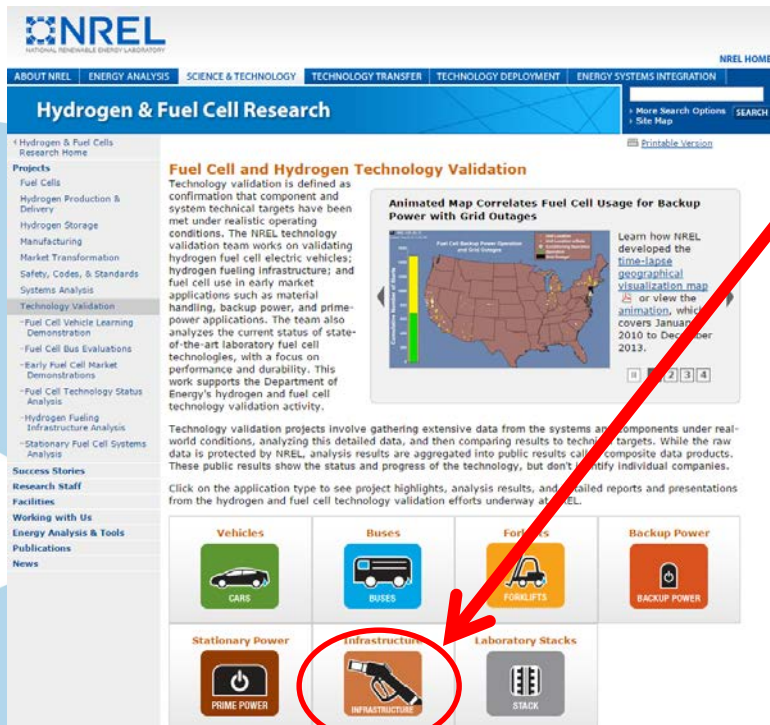
Any proposed future work is subject to change based on funding levels.

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 35 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!

CDPs available at www.nrel.gov/hydrogen/proj_tech_validation



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Hydrogen & Fuel Cell Research

Hydrogen & Fuel Cells Research Home






Printable Version

Fuel Cell and Hydrogen Technology Validation

Technology validation is defined as confirmation that component and system technical targets have been met under realistic operating conditions. The NREL technology validation team works on validating hydrogen fuel cell electric vehicles; hydrogen fueling infrastructure; 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. This work supports the Department of Energy's hydrogen and fuel cell technology validation activity.

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 technology 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.

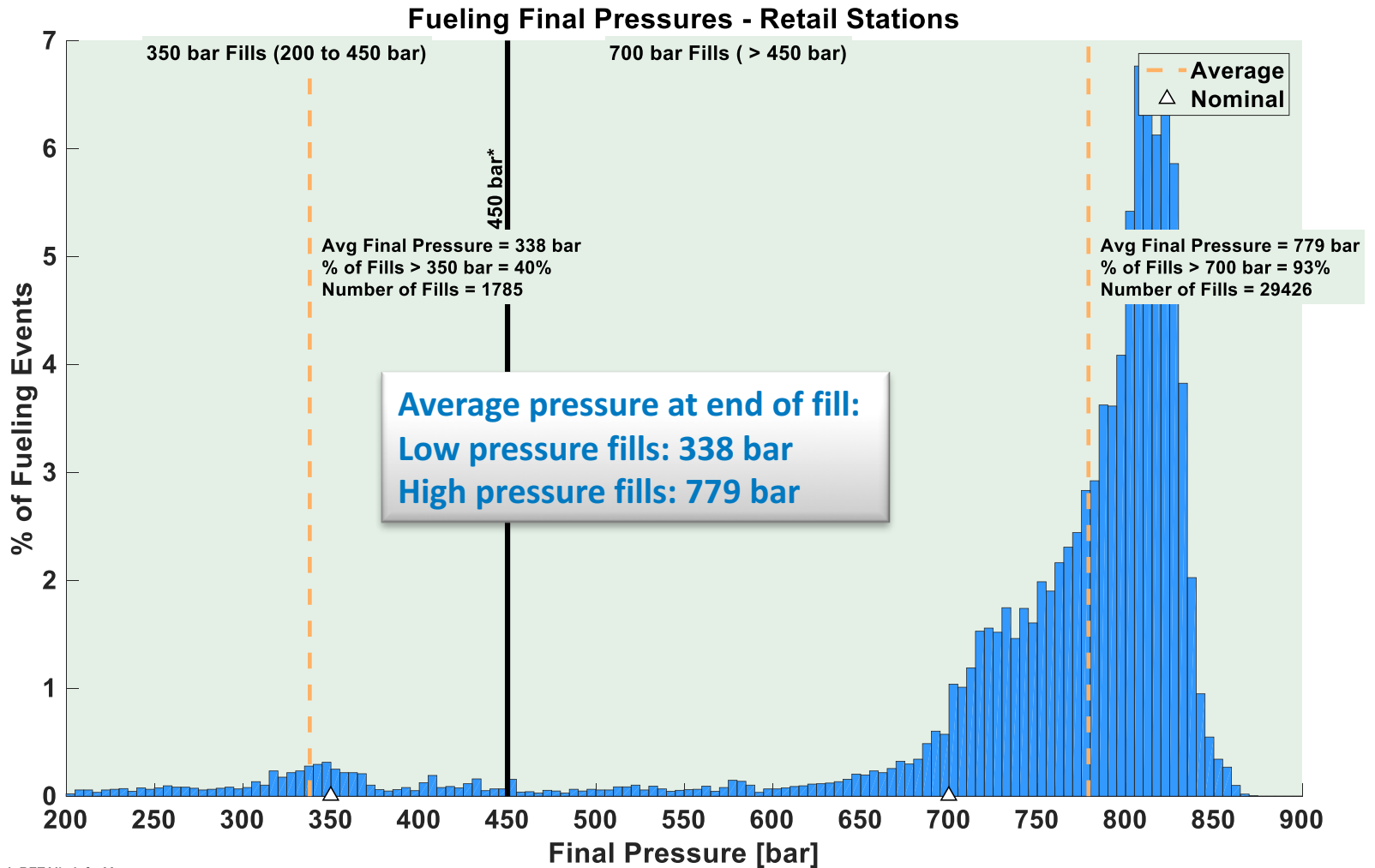
 VEHICLES CARS	 BUSES	 FORKLIFTS	 BACKUP POWER
 STATIONARY POWER PRIME POWER	 INFRASTRUCTURE	 LABORATORY STACKS STACK	

www.nrel.gov



Technical Back-Up Slides

Accomplishment: Fueling Final Pressures

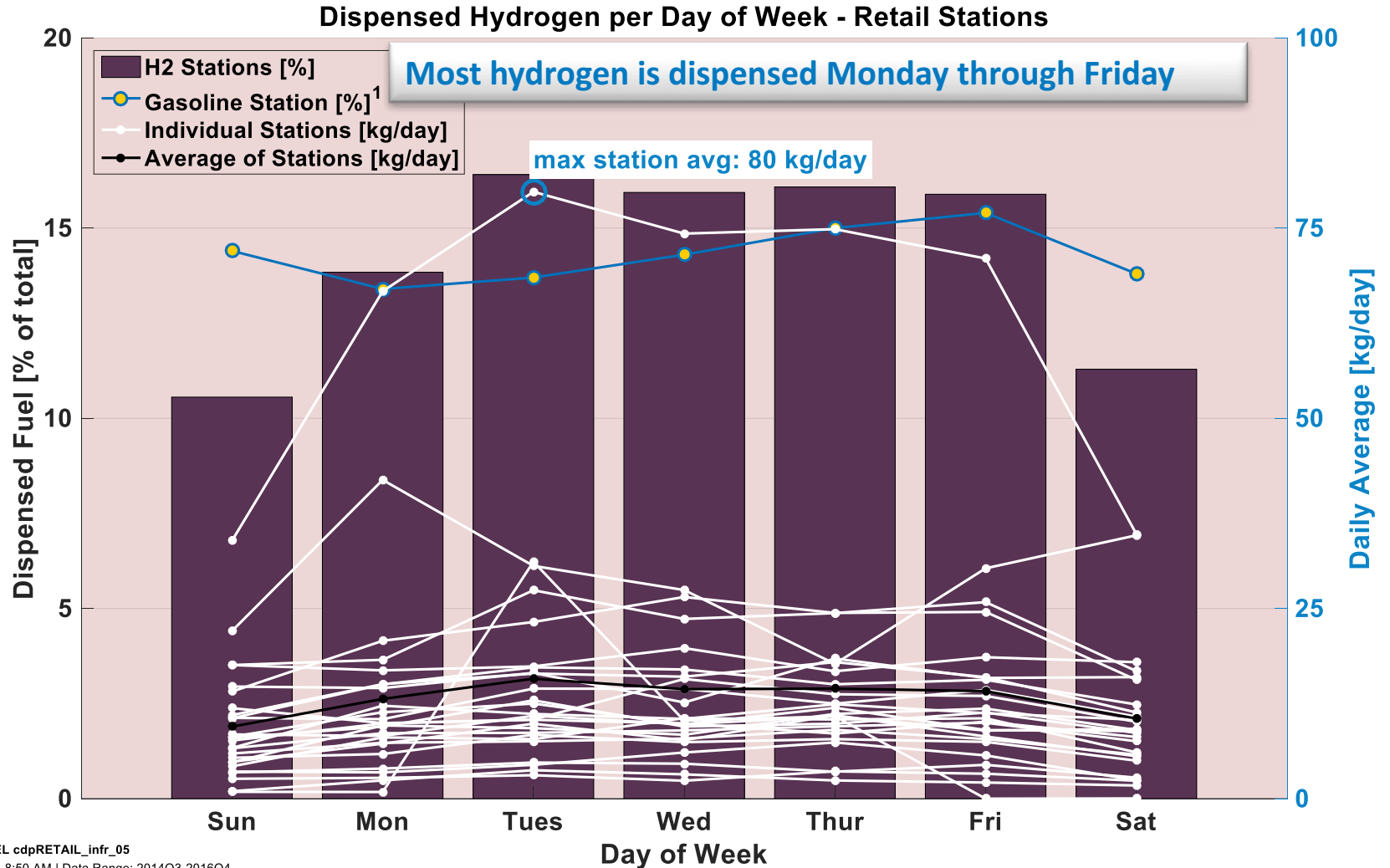


NREL cdpRETAIL_infr_09

Created: May-08-17 8:58 AM | Data Range: 2014Q3-2016Q4

*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: Hydrogen per Day of Week

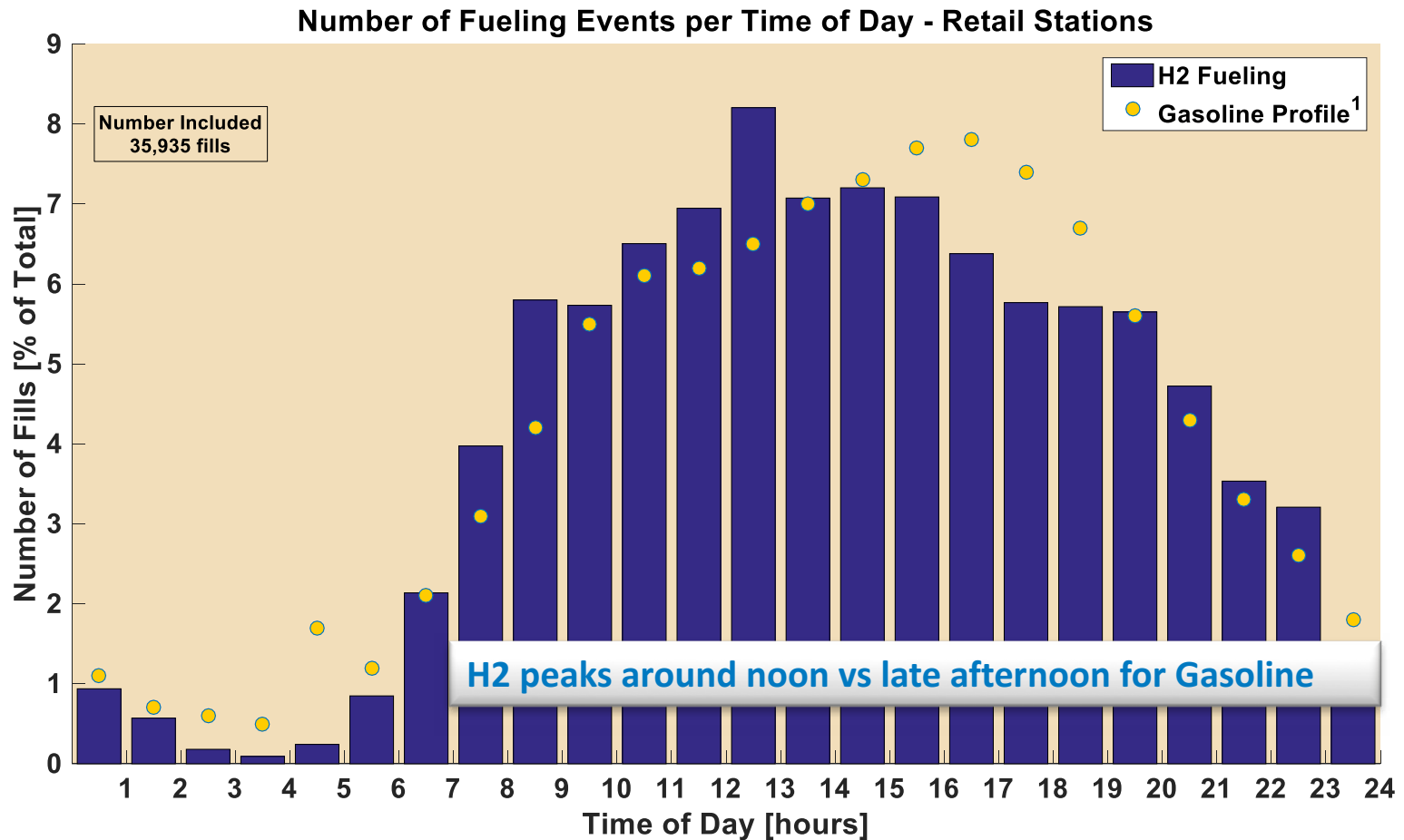


NREL cdpRETAIL_infr_05

Created: May-08-17 8:50 AM | Data Range: 2014Q3-2016Q4

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

Accomplishment: Filling by Time of Day



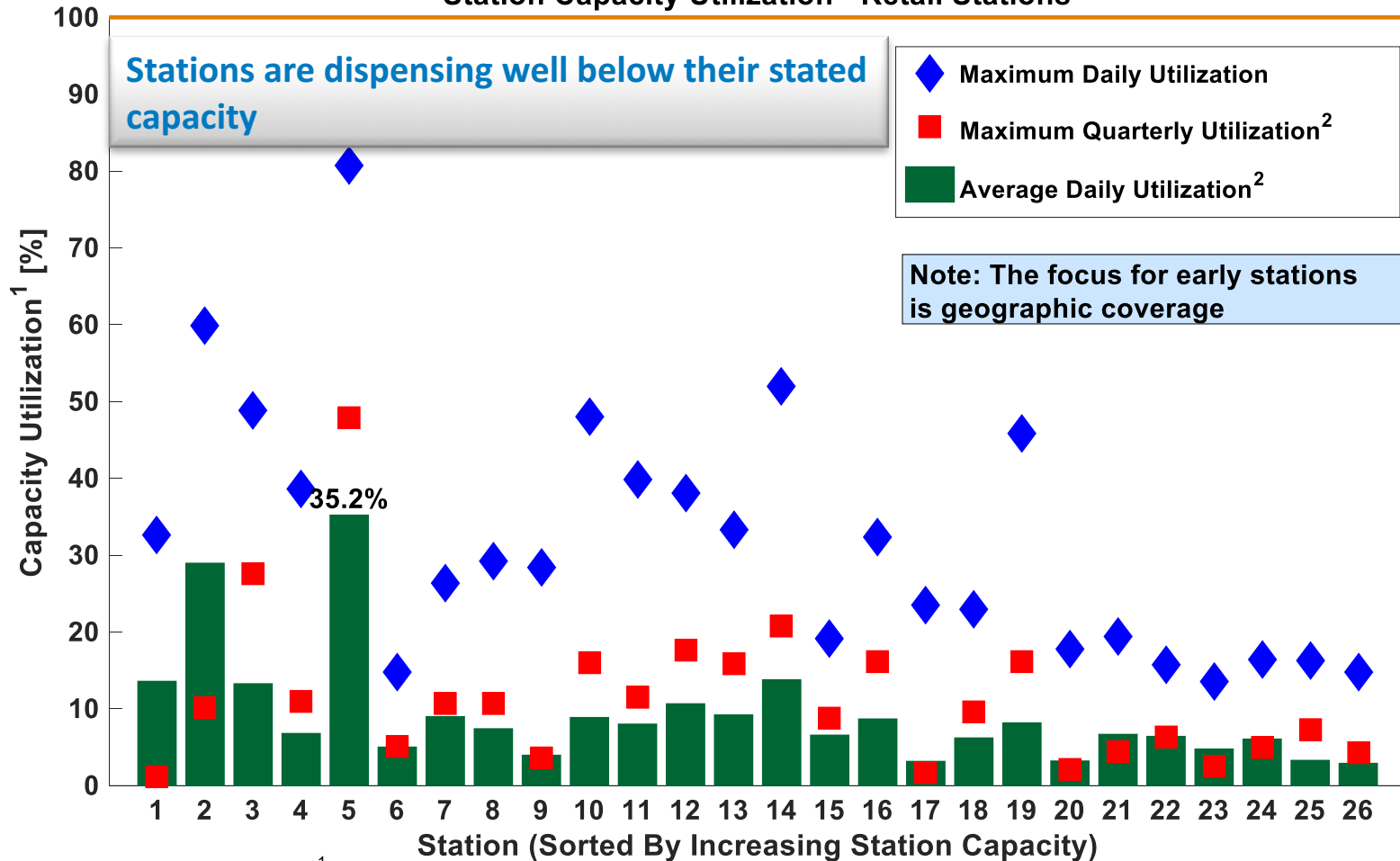
NREL cdpRETAIL_infr_15

Created: May-08-17 9:00 AM | Data Range: 2014Q3-2016Q4

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

Accomplishment: Station Capacity Utilization

Station Capacity Utilization - Retail Stations



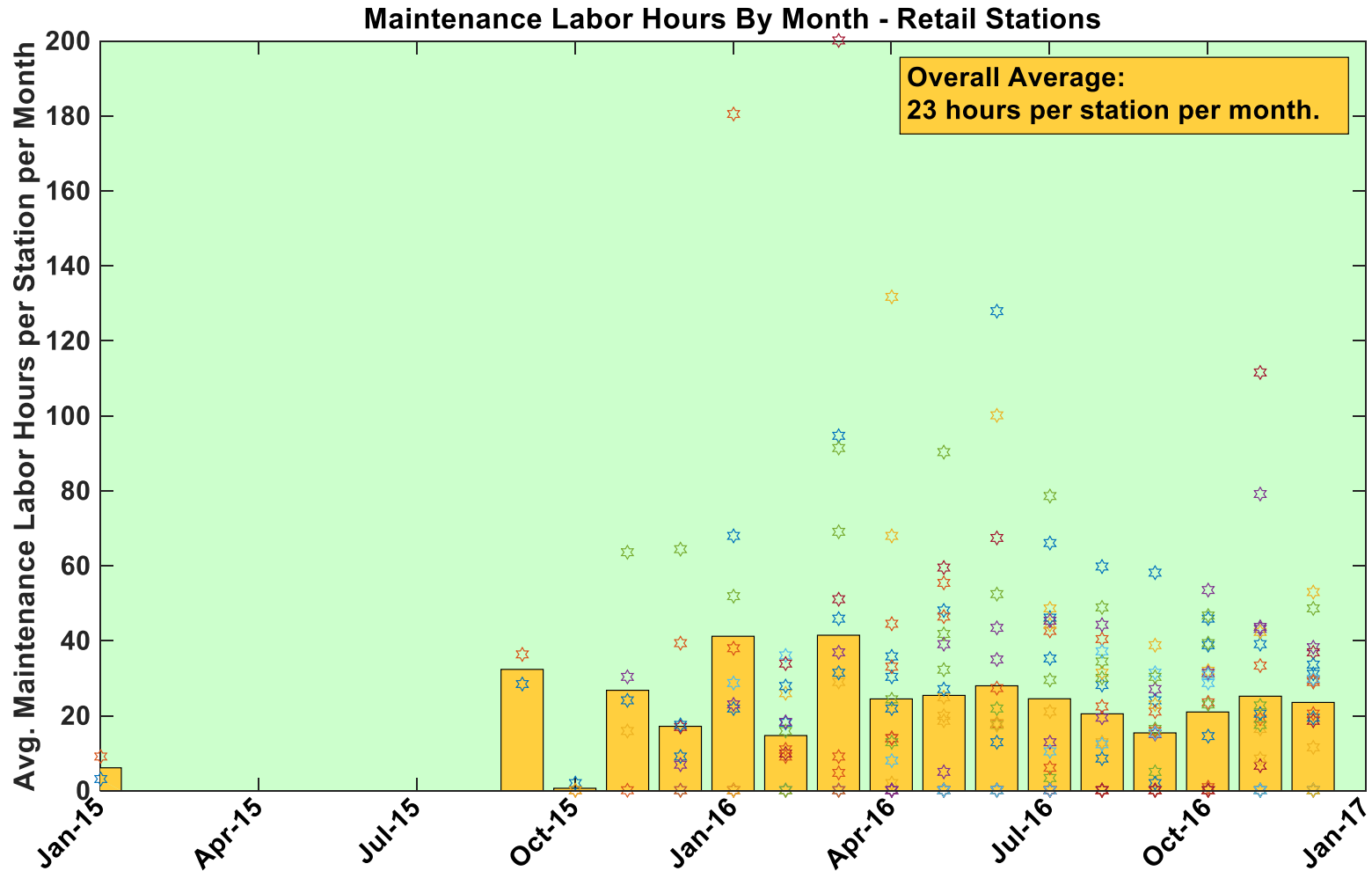
NREL cdpRETAIL_infr_06

Created: May-08-17 8:52 AM | Data Range: 2014Q3-2016Q4

¹Station 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.

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

Accomplishment: Maintenance Labor Hours by Month



NREL cdpRETAIL_infr_28

Created: Apr-24-17 10:23 AM | Data Range: 2014Q3-2016Q4

Stars represent individual station maintenance hours in a given month.