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Performance of Existing Hydrogen Stations

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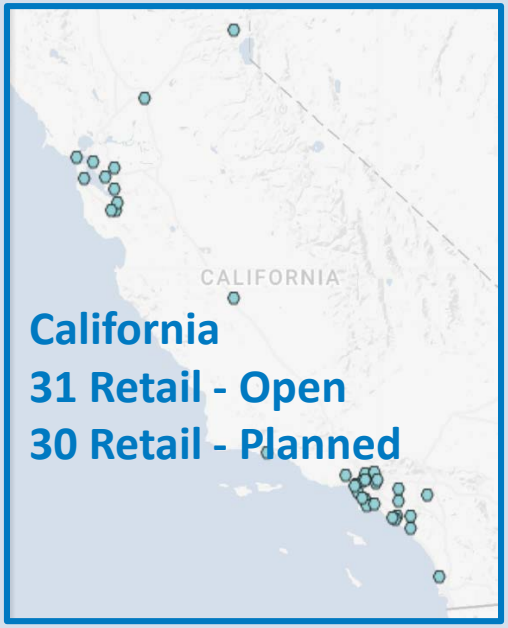
National Renewable Energy Laboratory

2017 Fuel Cell Seminar and Energy Exposition
Long Beach, California
November 8, 2017

NREL/PR-5400-70527

Significant Hydrogen Station Activities Across the U.S.

www.afdc.energy.gov/fuels/hydrogen_locations.html



California
31 Retail - Open
30 Retail - Planned

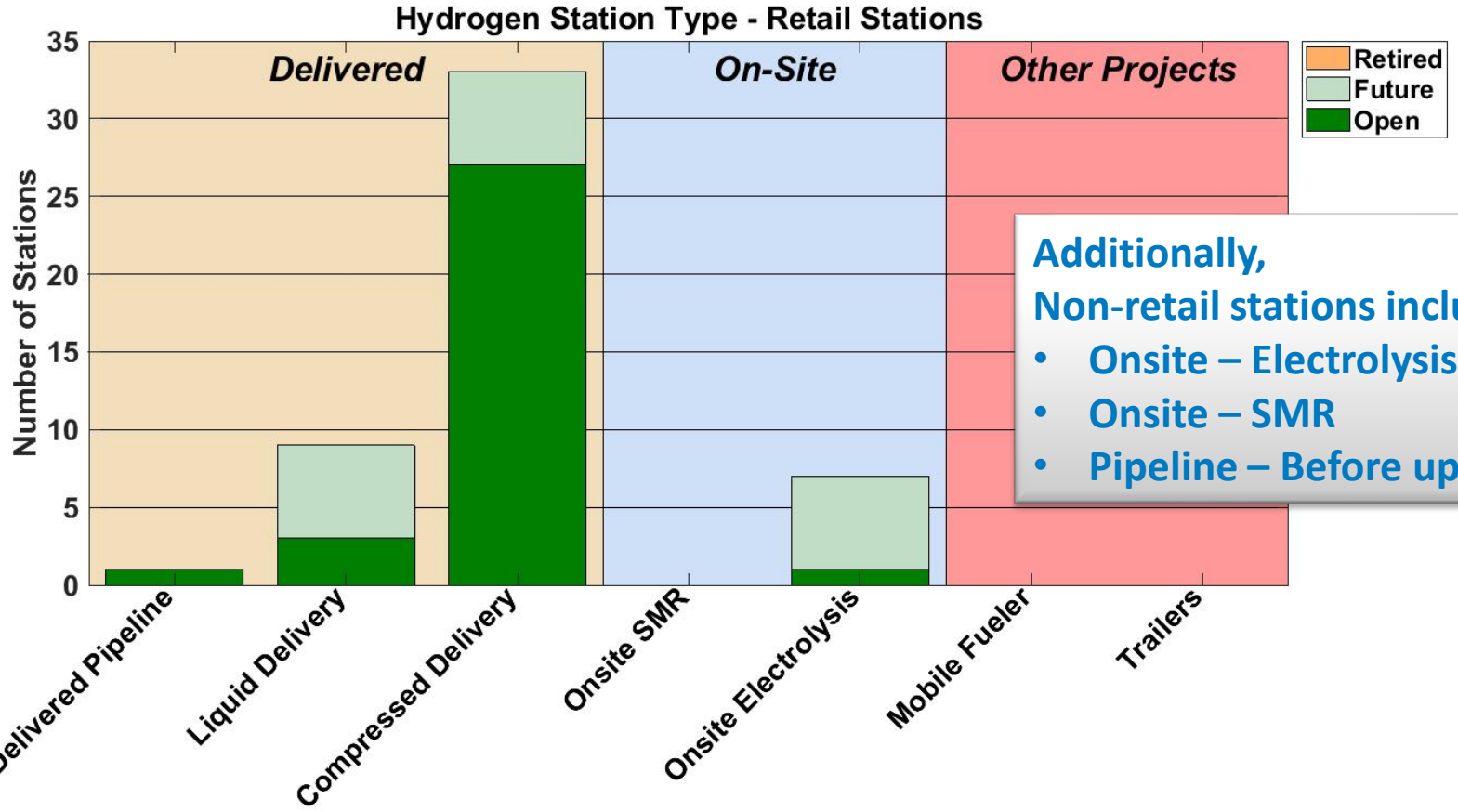
North East
12 Retail – Planned
4 coming soon

26 other stations include:

- **Private**
- **Public - Not Retail**
- **Demonstration/Research**

As of 10/26/2017

Retail Station Types (27 provided data through 2017Q2)



Additionally,
Non-retail stations include:

- **Onsite – Electrolysis**
- **Onsite – SMR**
- **Pipeline – Before upgrade**

NREL cdpRETAIL_infr_11
Created: Nov-03-17 2:39 PM | Data Range: 2014Q3

***Recently opened stations (2017Q2 & Q3) shown above but not in current analysis include:**

- **1 Pipeline (after upgrade)**
- **1 Liquid**
- **2 Compressed**

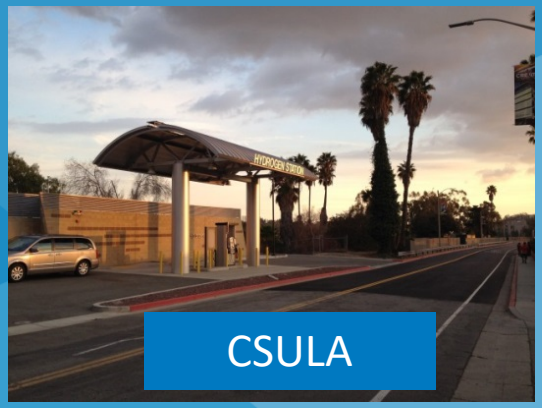
****One station double counted as it is both Onsite Electrolysis and Compressed Delivery**

Competition brings diversity to stations

Costa Mesa
FirstElement Fuel

Riverside
ITM Power

Burbank
H2 Frontier



Anaheim, Air Liquide

Torrance Shell
(pre- upgrade)

West Sacramento
Linde

Harris Ranch
FirstElement Fuel

West LA
Air Products

Photos: NREL

Multiple Partners Involved with Station Data

Requirements in contracts (using data templates)

- CEC Grant Funding Opportunities, DOE Technology Validation Projects

Data and analysis feedback through station providers and other organizations

STATION FUNDERS

California Energy Commission
California Air Resources Board
SCAQMD

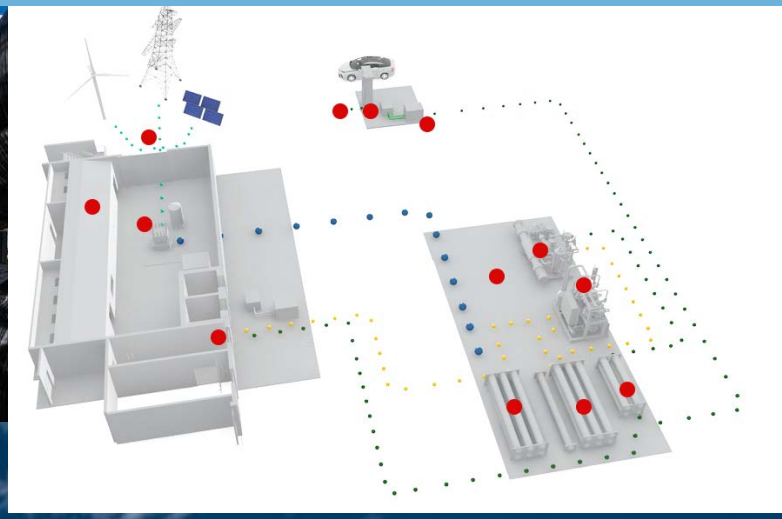
STATION PROVIDERS

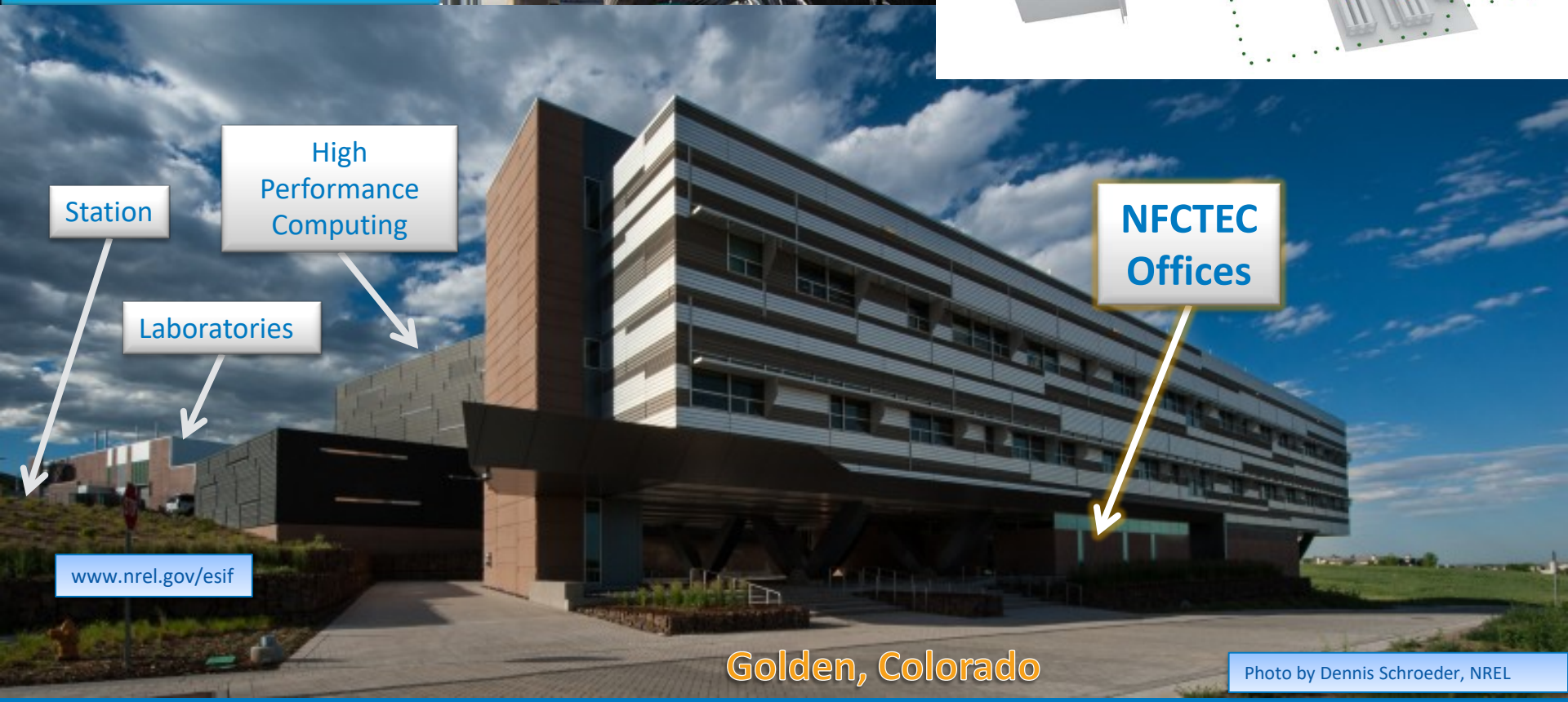
Air Liquide
Air Products
California State University Los Angeles
FirstElement Fuel
H2 Frontier
ITM Power
Linde
Proton OnSite
Shell

ORGANIZATIONS

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

NFCTEC is located at NREL's Energy Systems Integration Facility





NFCTEC Data/Analysis/Results Handling

Station data (operation and maintenance/safety) delivered to NREL

DDPs

NREL's National Fuel Cell Technology Evaluation Center

Results

Confidential

Public

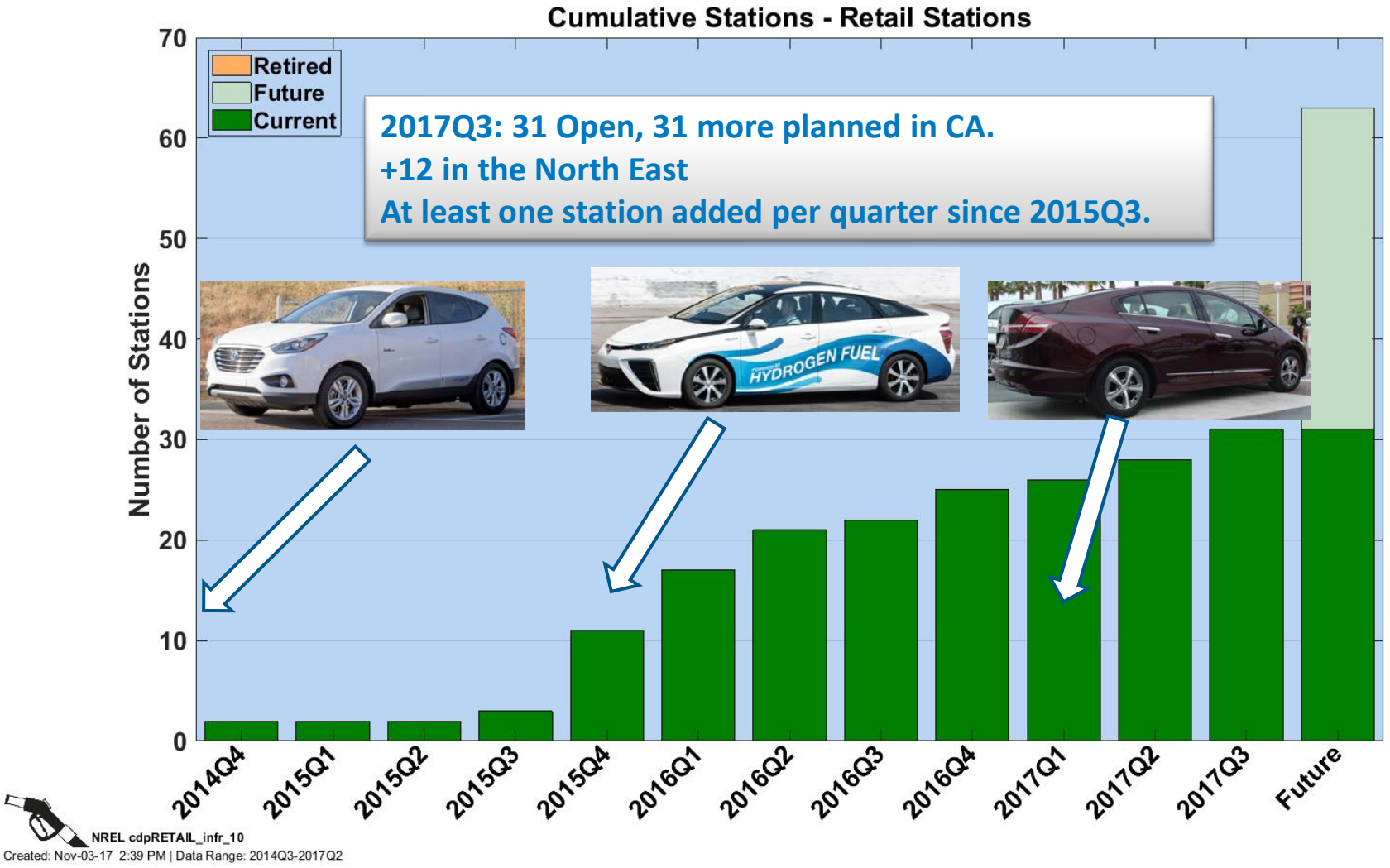
CDPs

Detailed Data Products (DDPs)
- 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]

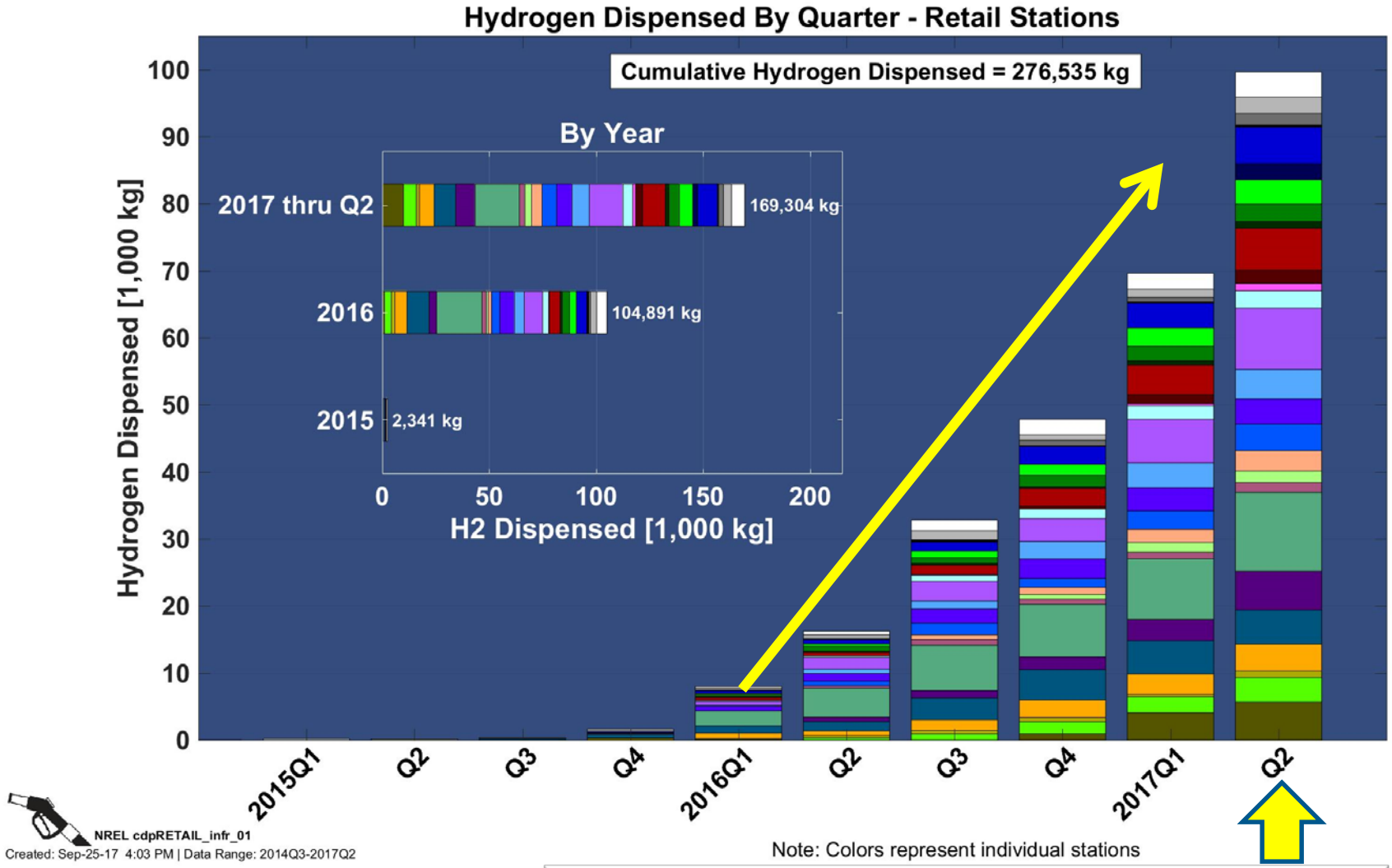
1) Data exchange may happen more frequently based on data, analysis, and collaboration
2) Results published via NREL Tech Val website, conferences, and reports

Number of Retail Stations Increasing



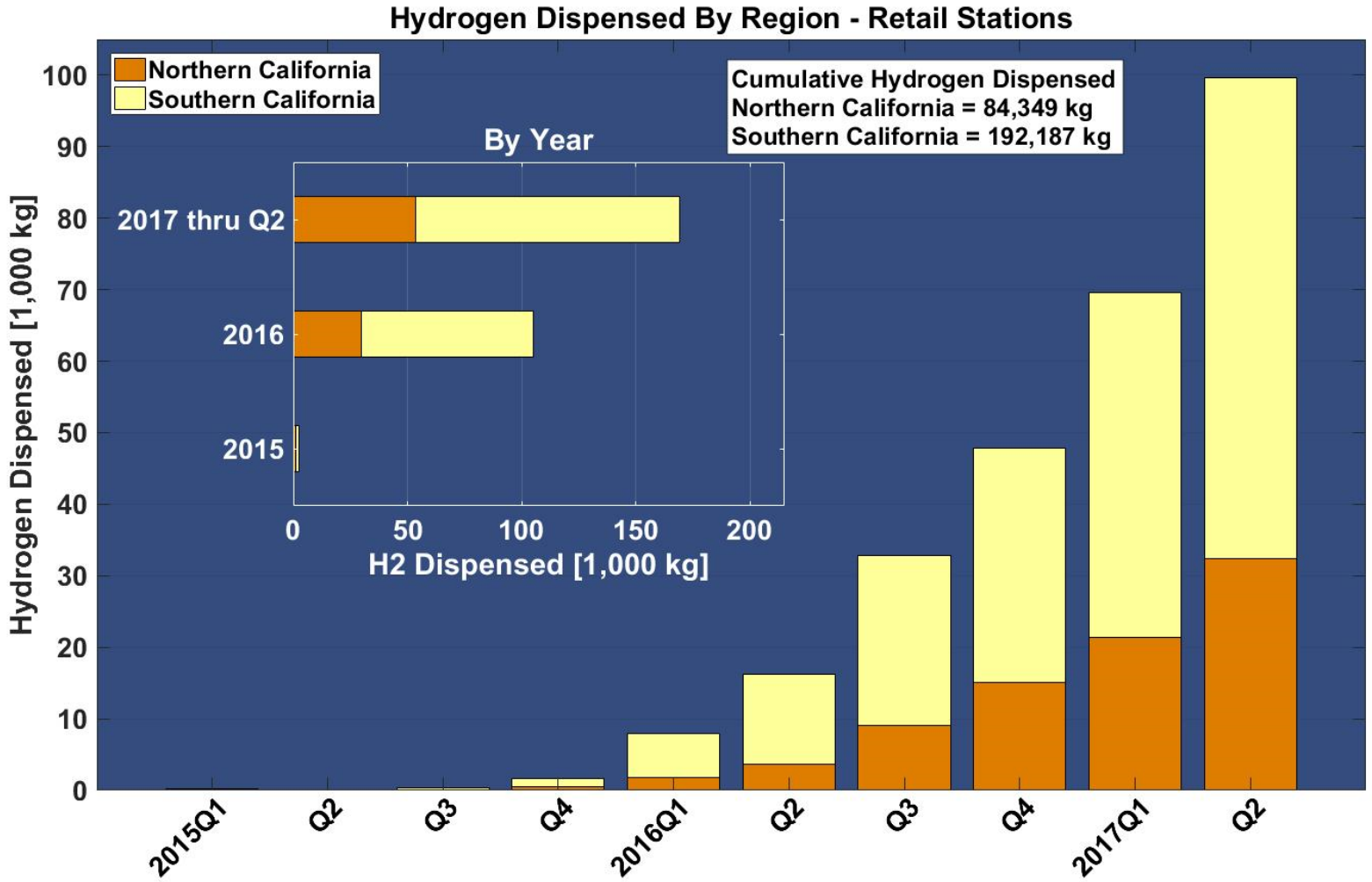
Photos: NREL

Quantity of Hydrogen Dispensed to FCEVs is Accelerating

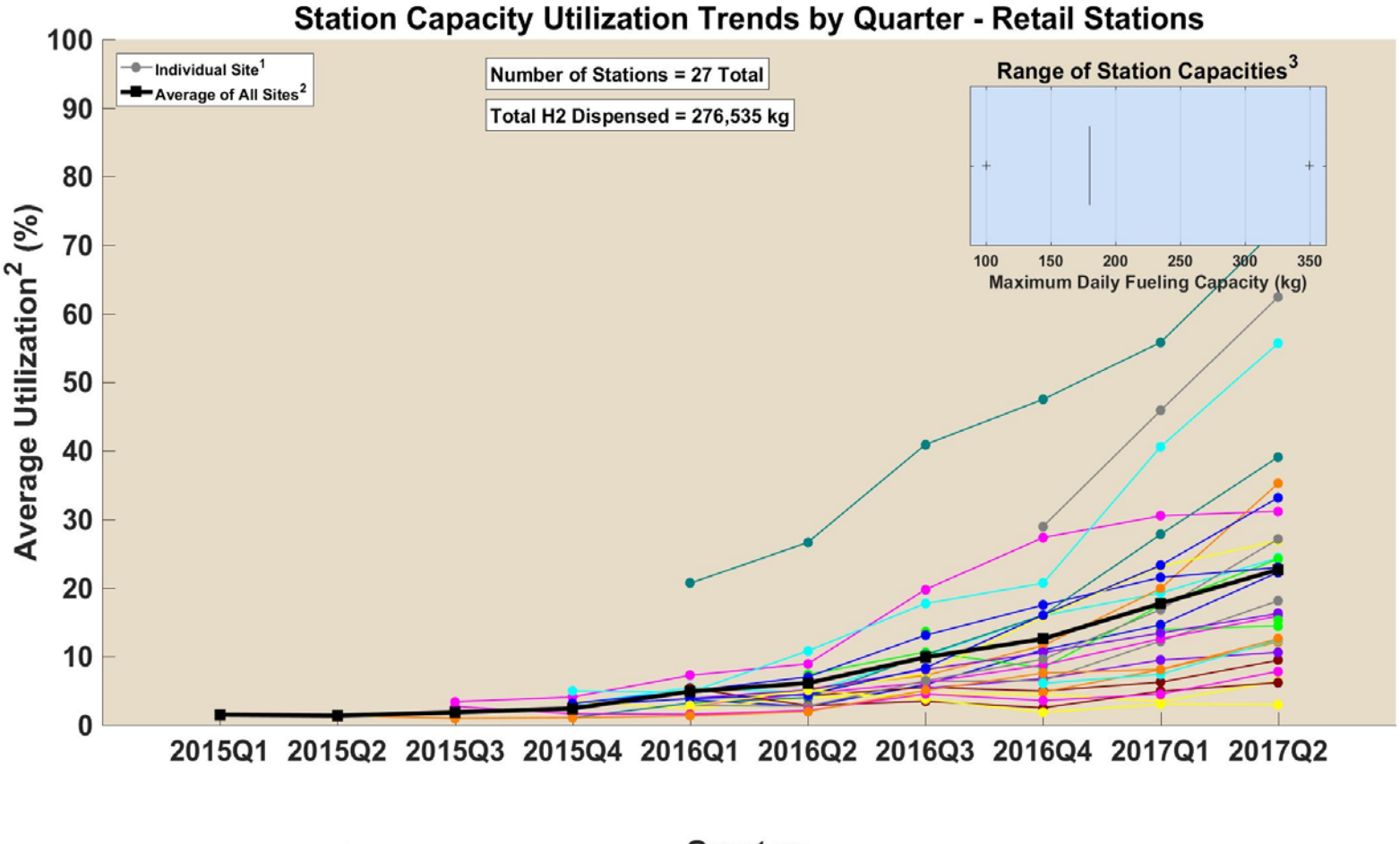


Close to 100,000 kg dispensed in 2017Q2 alone

Amount by Region – Southern California on Top



Utilization by Station Increasing – Still Room for Growth



[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.

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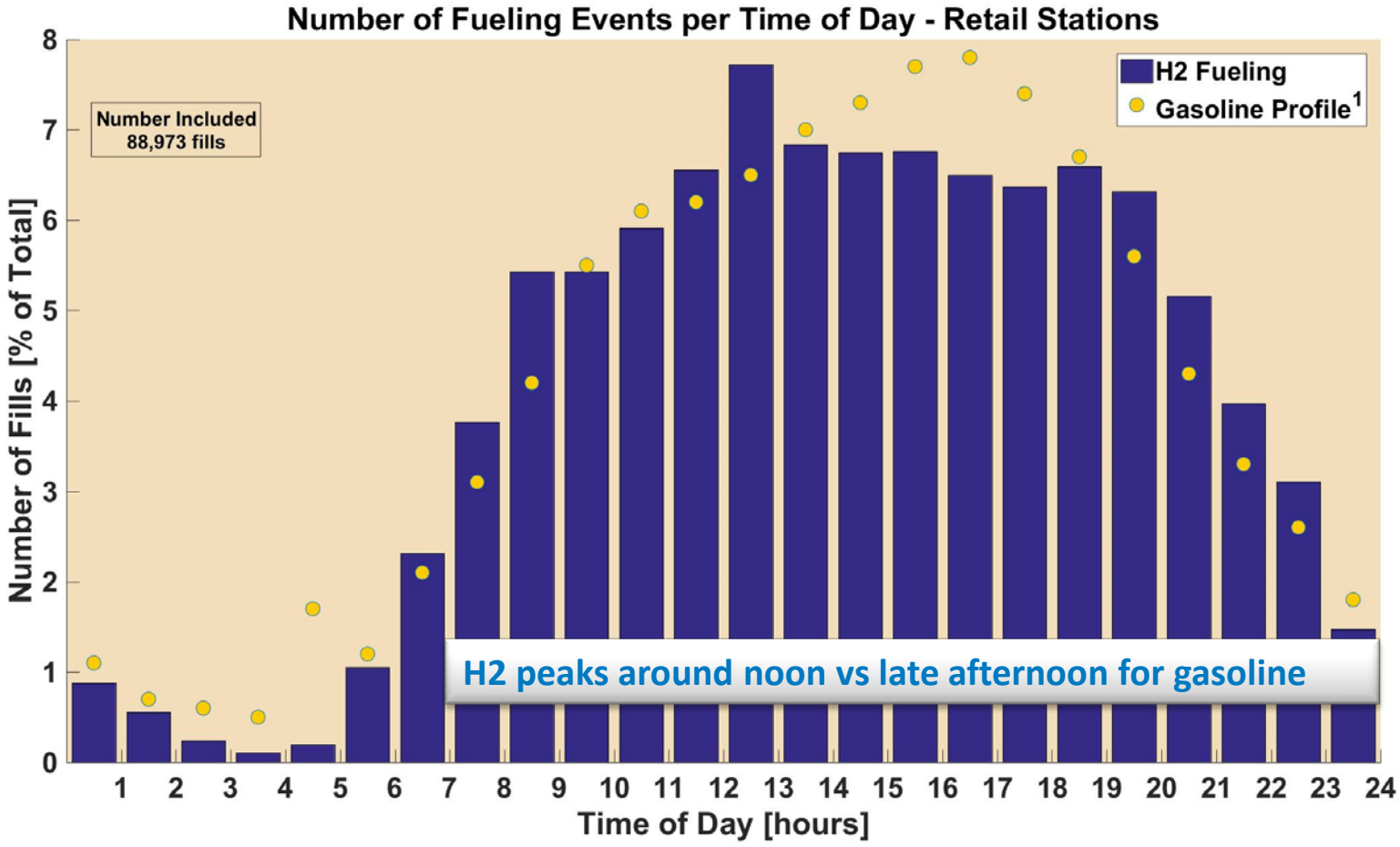
FCEV Customers Show up to Fill Similar to Gasoline



NREL cdpRETAIL_infr_15
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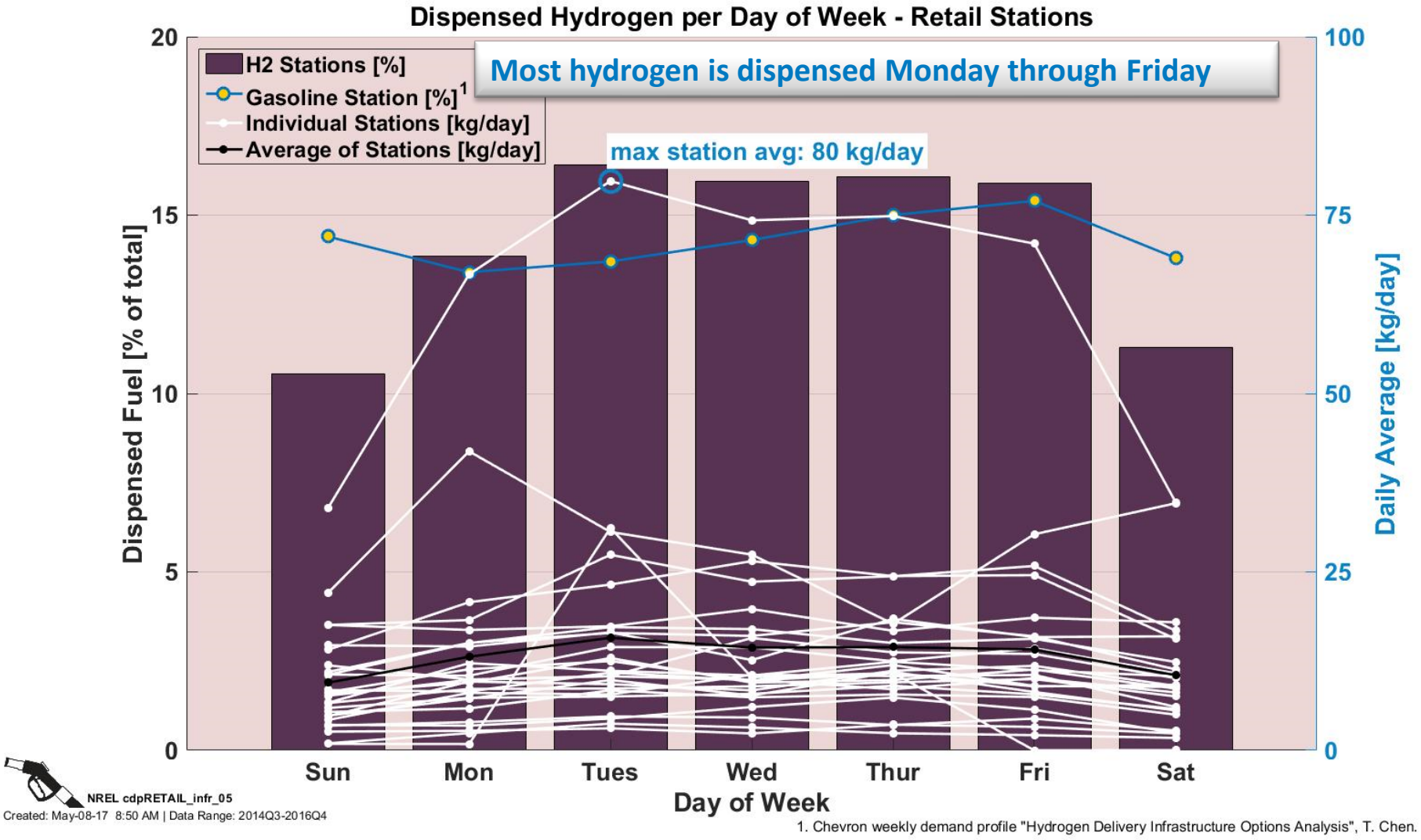
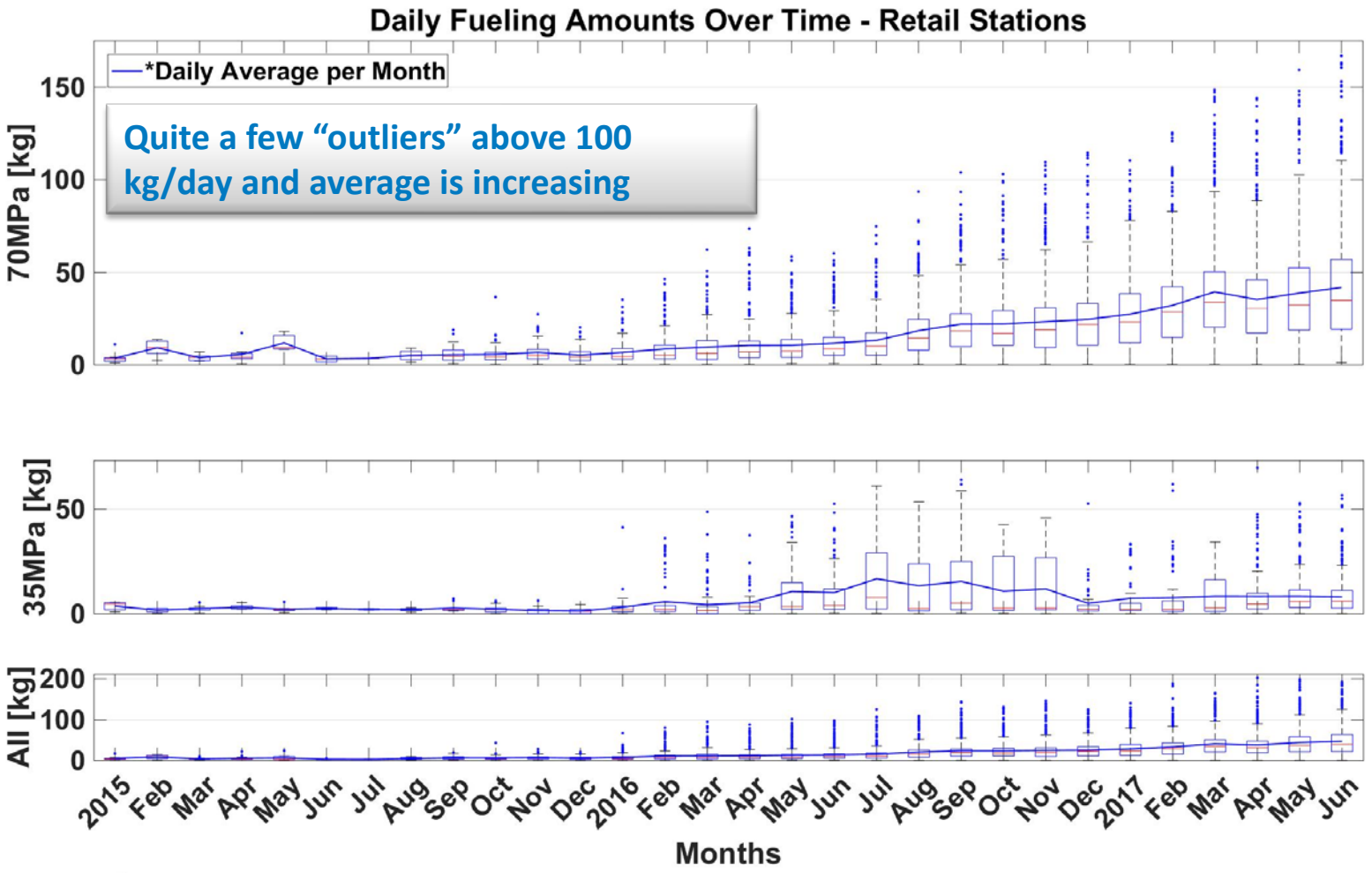
1. Friday Chevron profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.

Fewer Fills on Weekends Unlike Gasoline



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

Daily Fueling by Month – Retail Stations



NREL cdpRETAIL_infr_82
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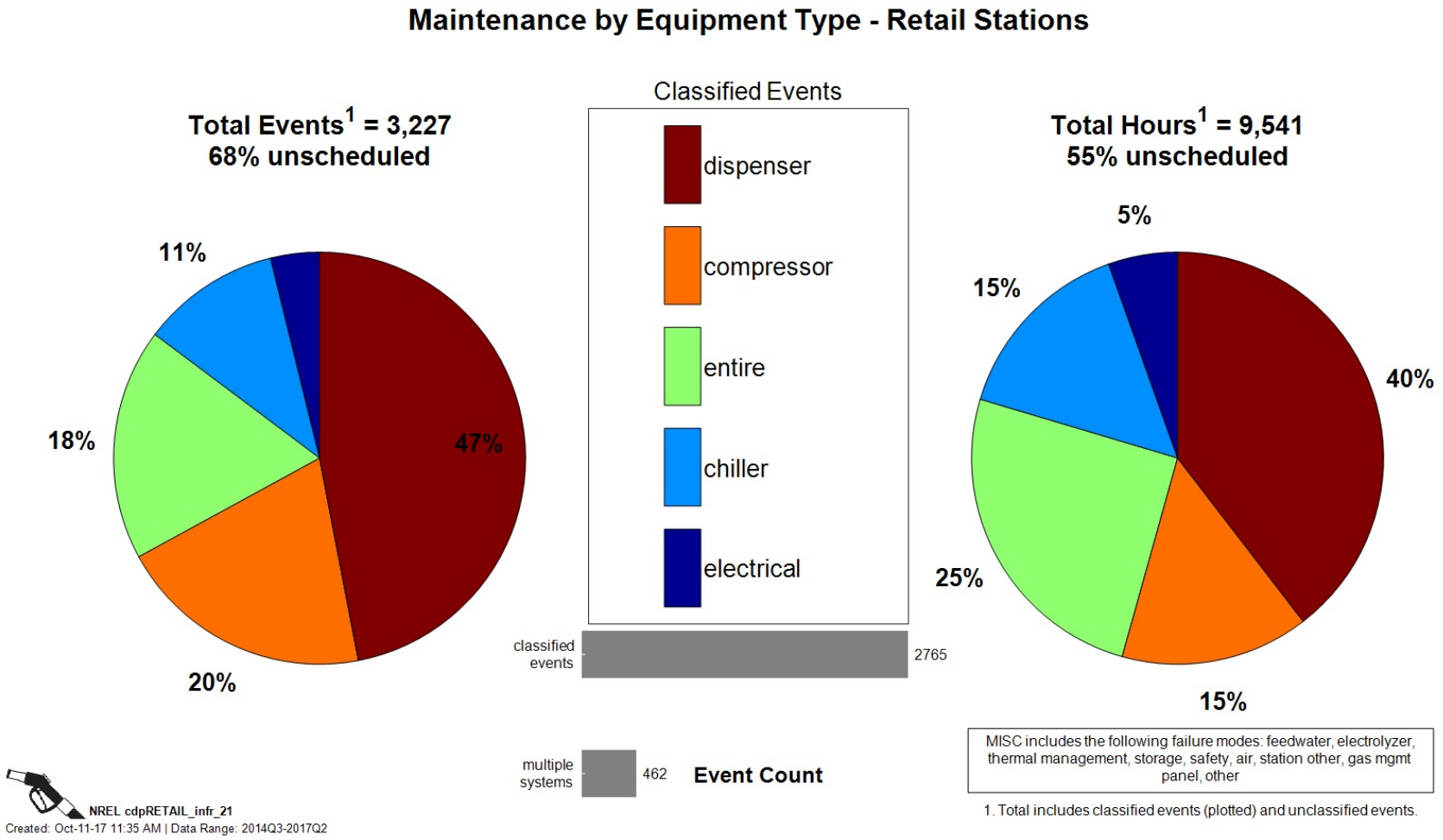
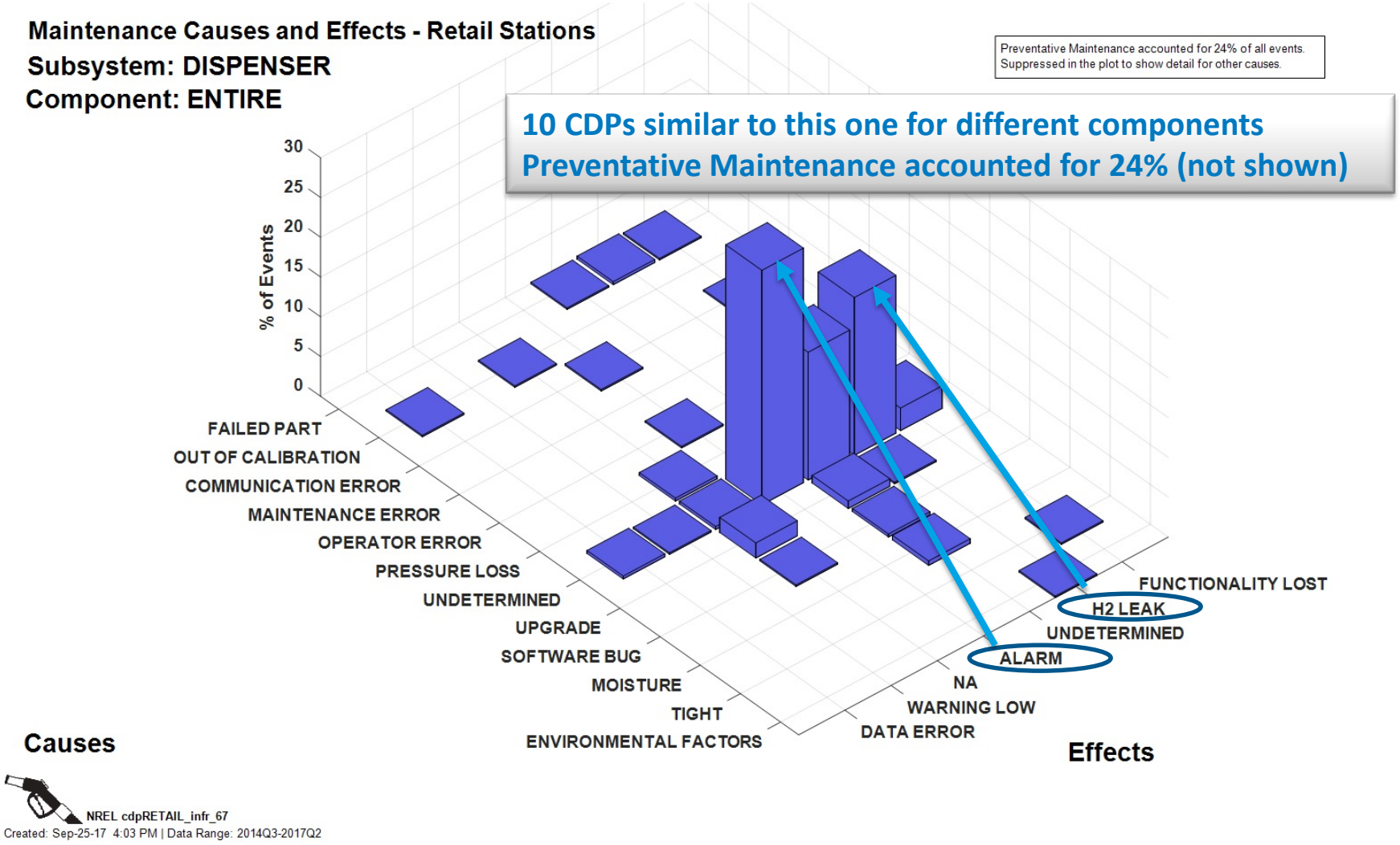
*Daily average only includes days with fills.

Maintenance by Equipment Type – Retail Stations

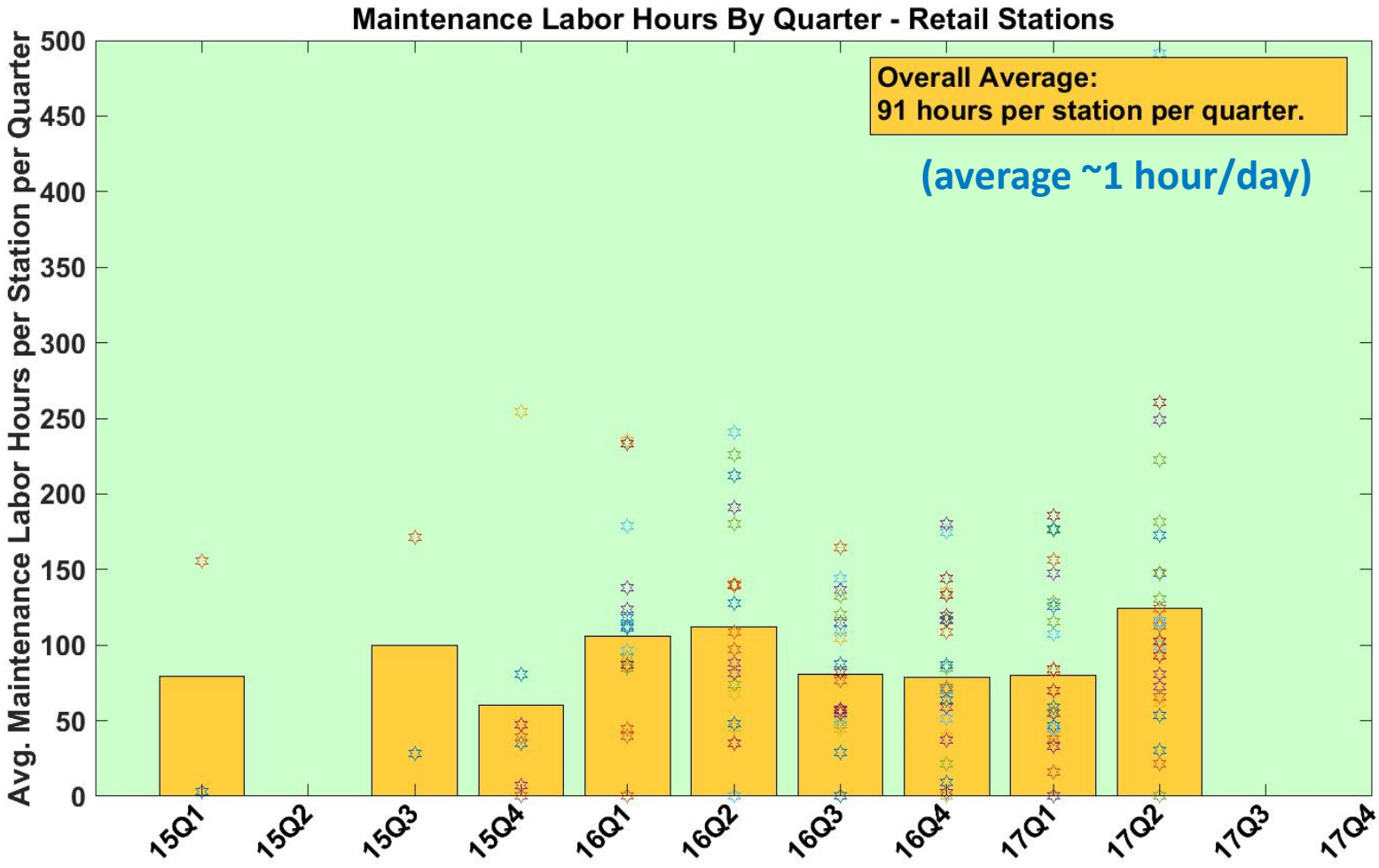
Most maintenance is now on dispensers instead of compressors.
Chiller maintenance increased (stations now fill at -40 C).



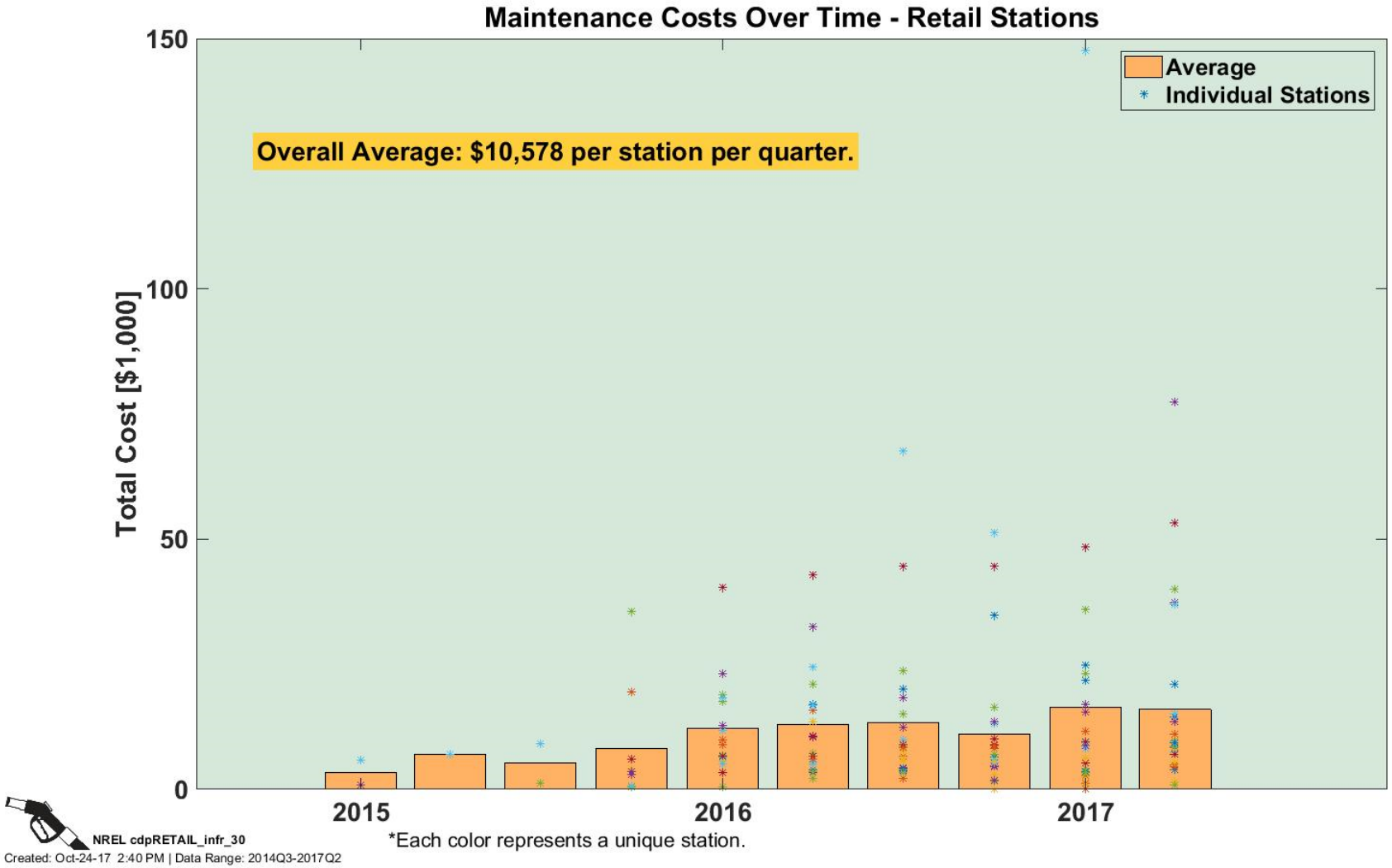
Dispenser Maintenance with Cause and Effects



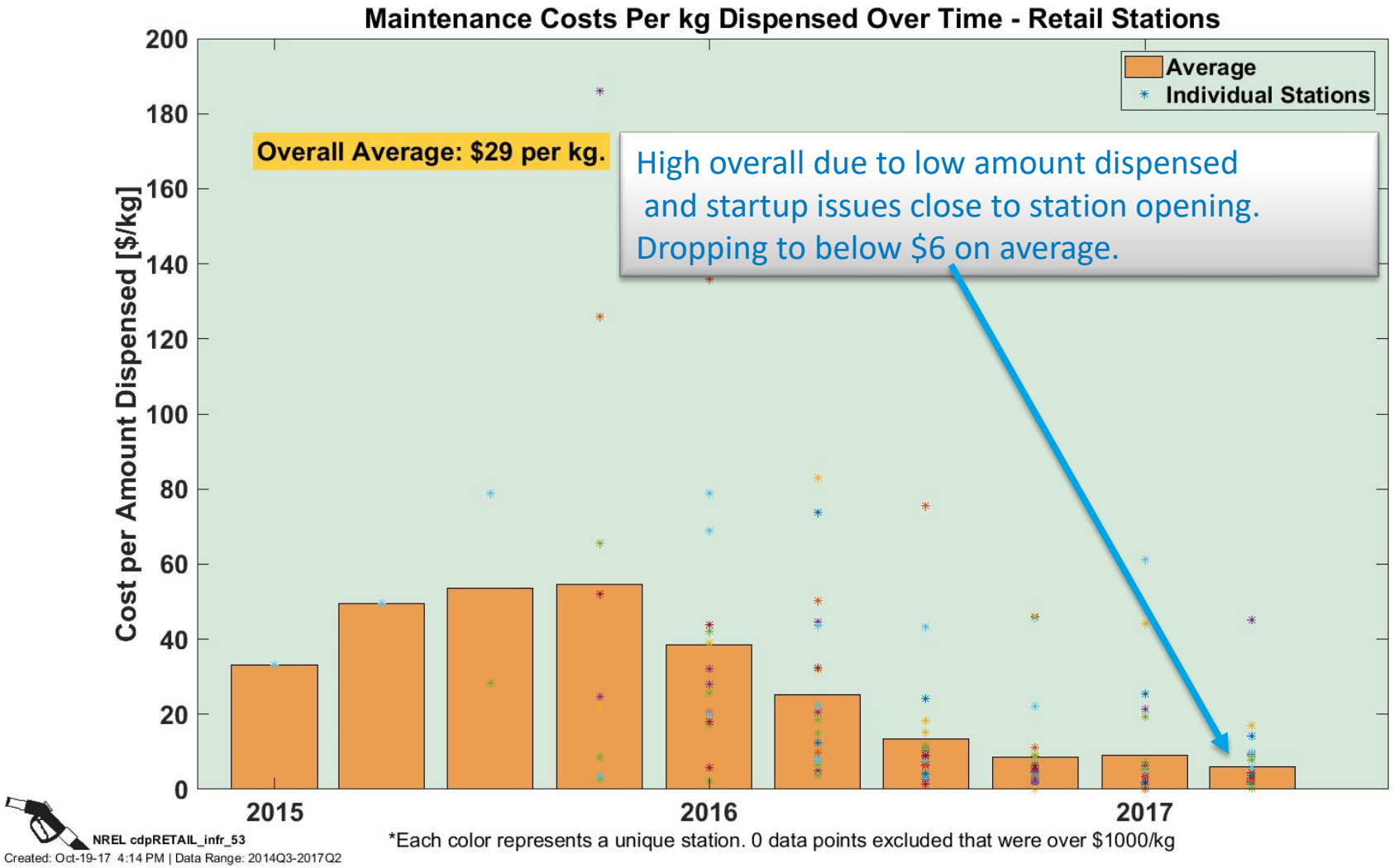
Maintenance Labor Hours by Quarter



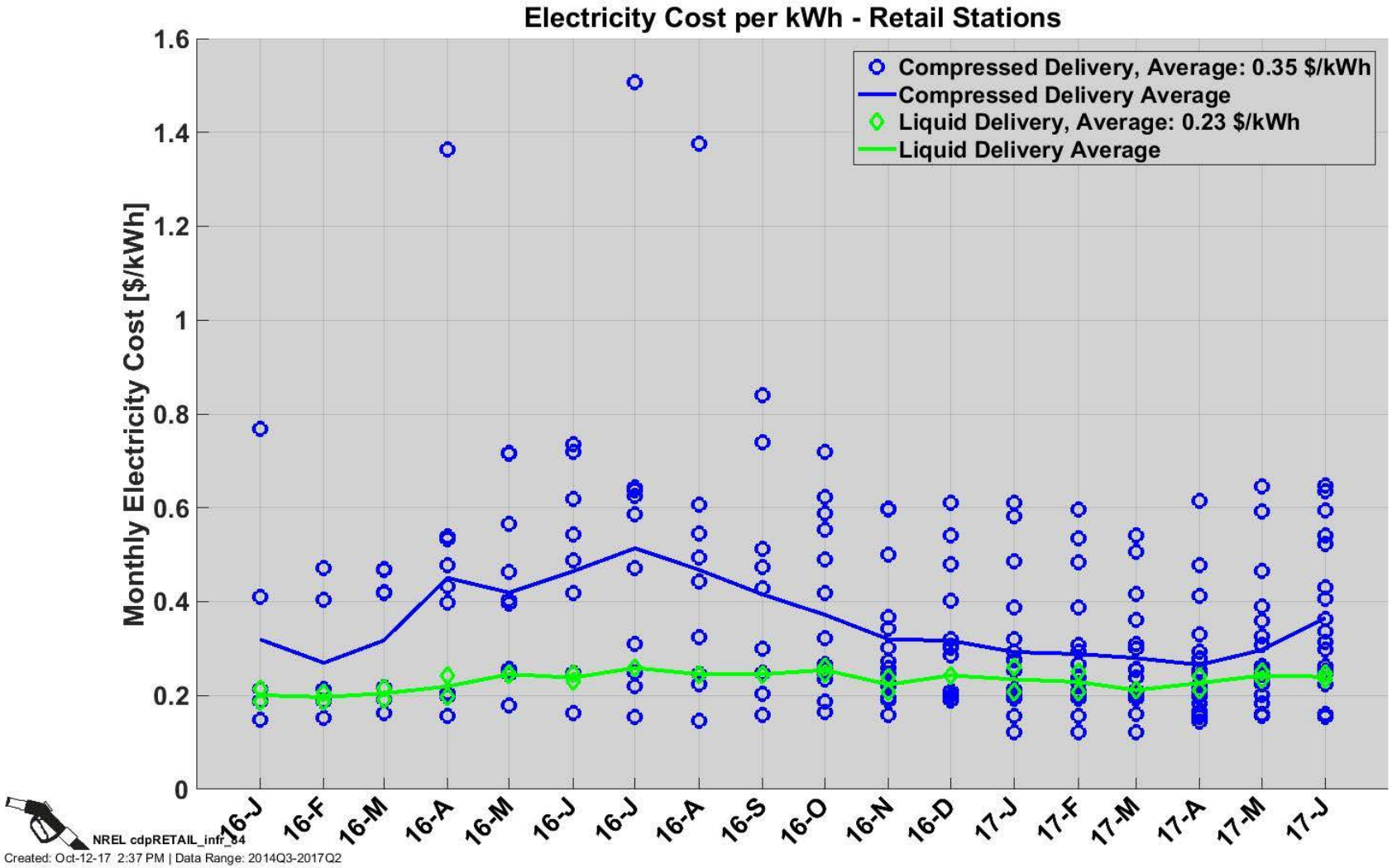
Maintenance Costs by Quarter



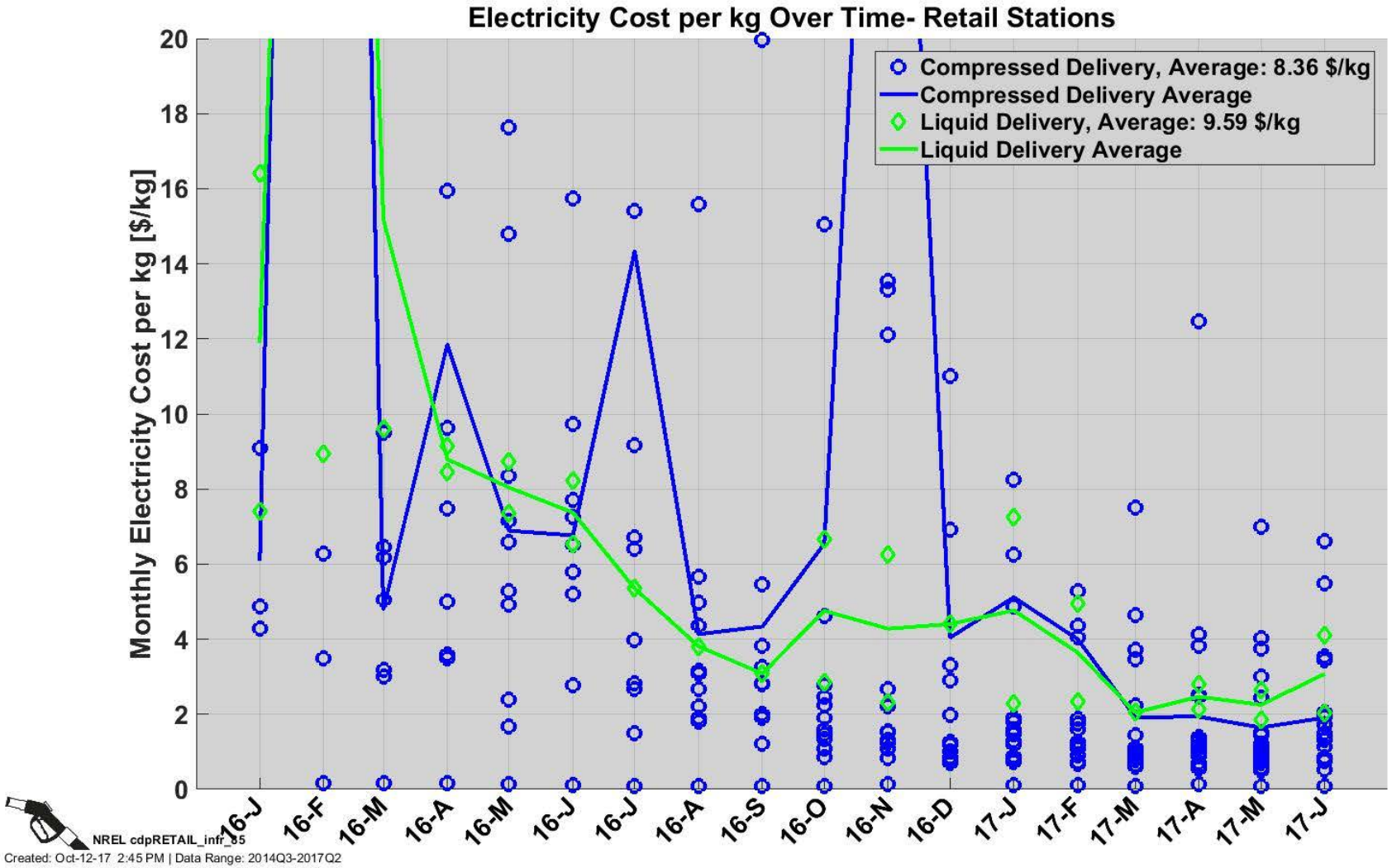
Maintenance Costs per kg Dispensed by Quarter



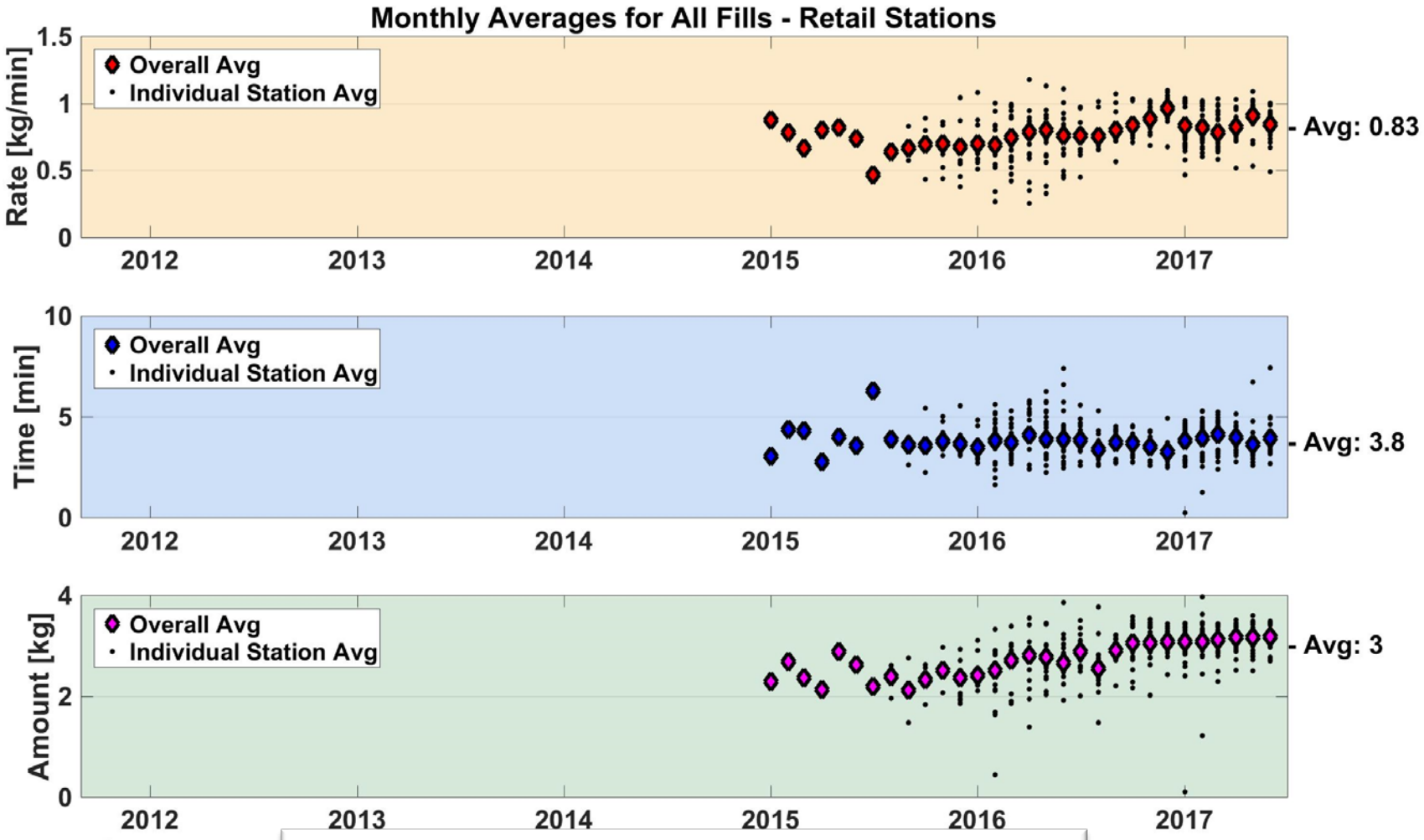
Electricity Cost per kWh by Station Type



Electricity Cost per kg Dispensed by Month Now Avg $2-3/kg

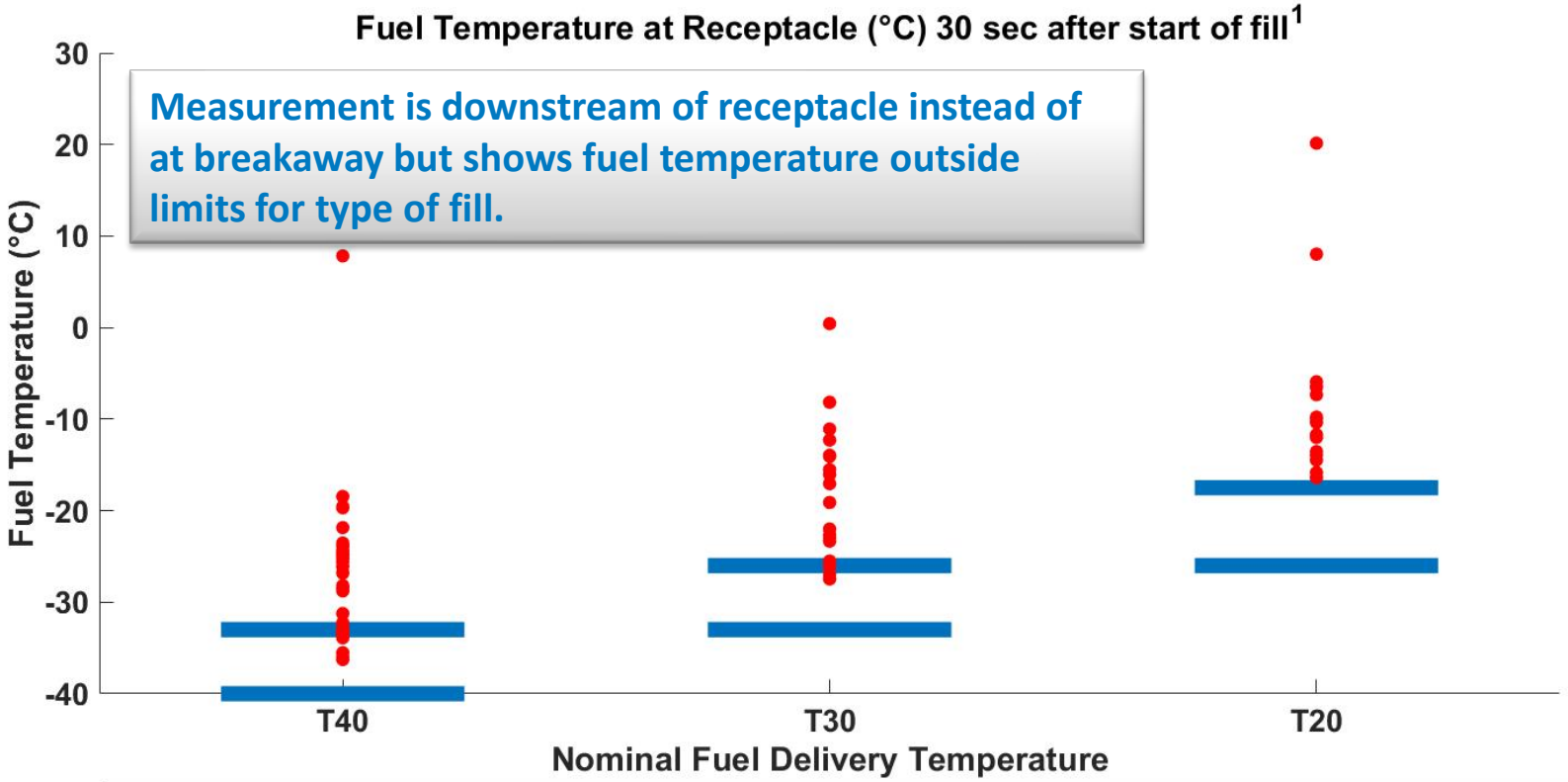


Monthly Averages for Fueling Rates, Times and Amounts



Time to fill is 3.8 minutes on average.
Average amount filled is increasing and at 3 kg.

All Stations not Reaching Required H2 Temperature after 30s



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.

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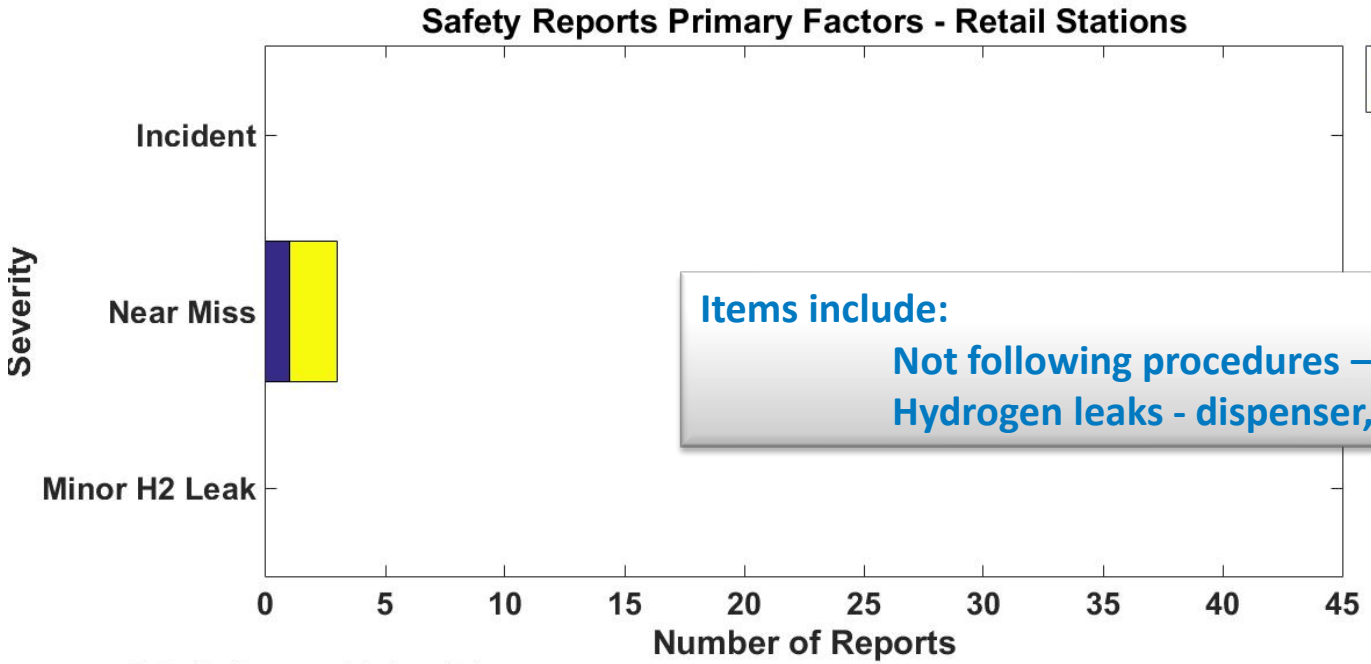
Not Many Safety Reports from Retail Stations



Items include:

Not following procedures – training needed

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_31

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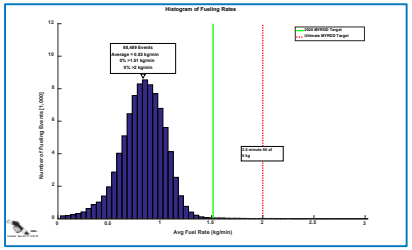
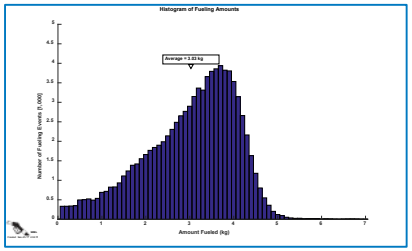
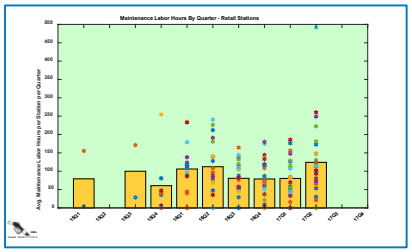
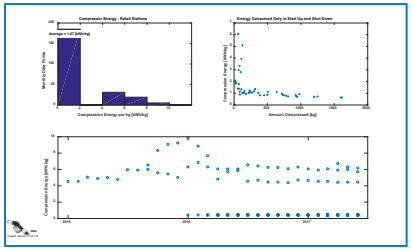
Retail Stations Highlights (Data through 2017Q2)

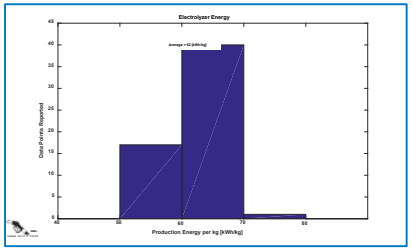


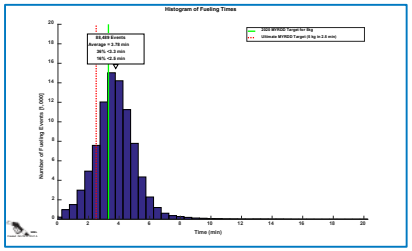


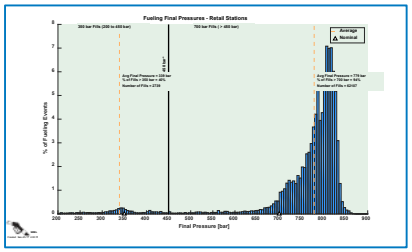


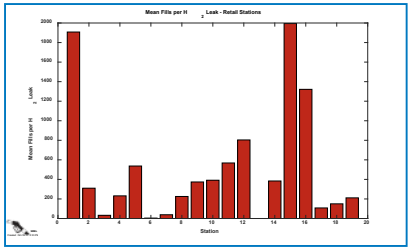


Fueling Rate Average	0.83 kg/min
Fueling Amount Average	3 kg
Fueling Time Average	3.8 min
Compressor Energy Average	1.67 kWh/kg
Total Hydrogen Dispensed	276,535 kg
Electrolyzer Energy Average (non-retail stations)	62 kWh/kg
Maintenance Hours Average	91 hours/quarter
Fueling Final Pressure Average	779 bar
Fills per H2 Leaks Average	505 Fills per H2 Leak



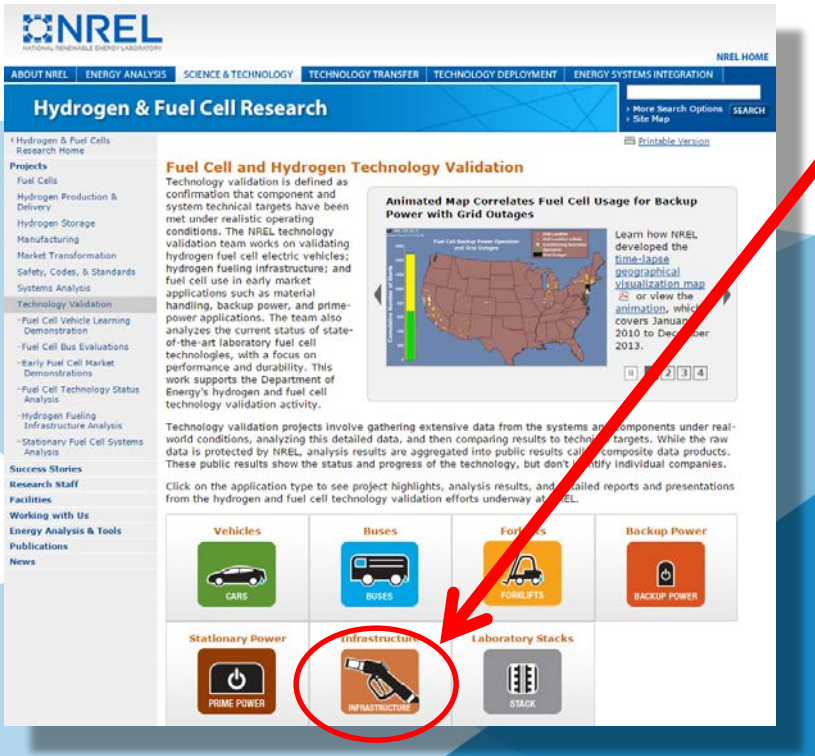






Thank You!

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



www.nrel.gov

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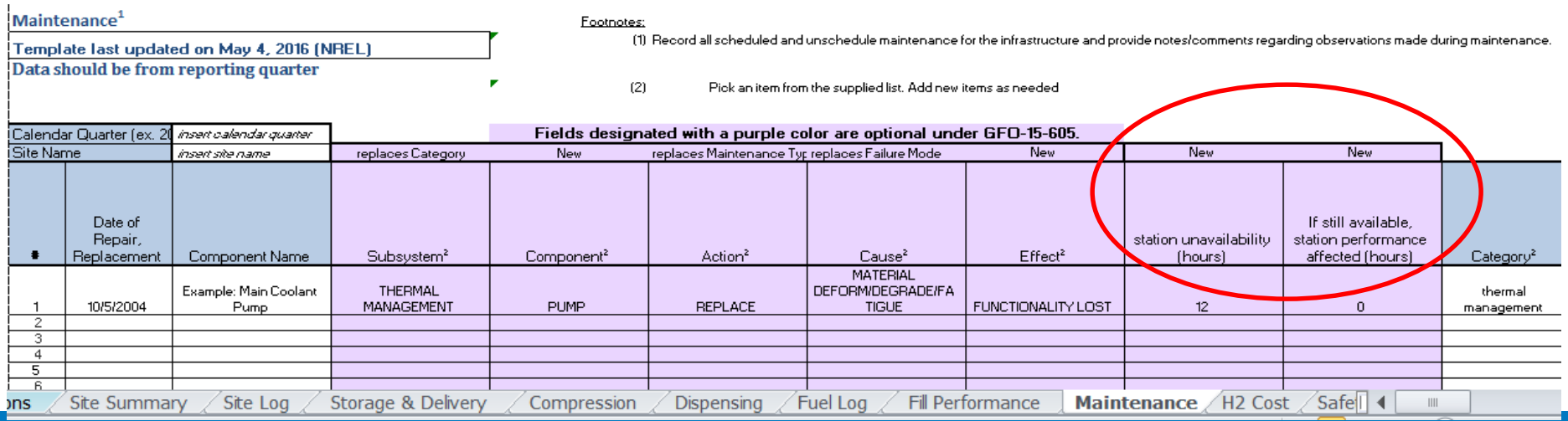
Data Templates

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)



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

Calendar Quarter (ex. 2(| insert calendar quarter

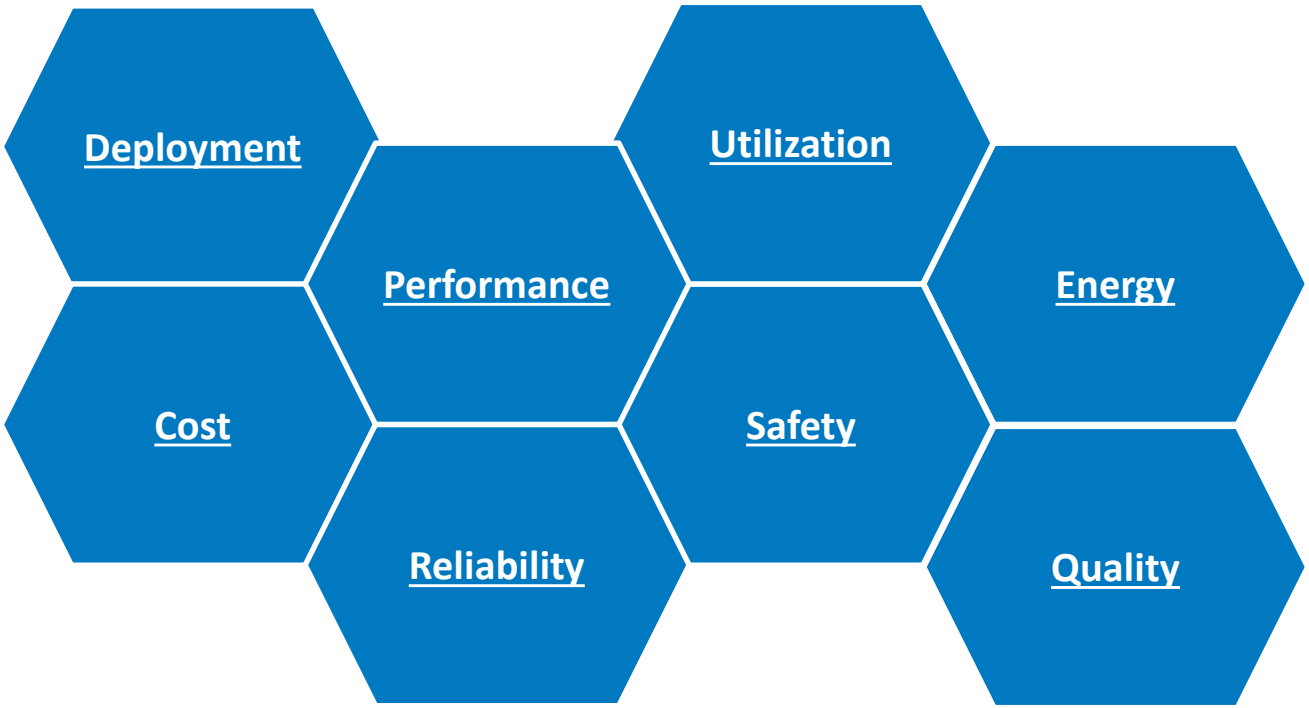
Site Name | insert site name

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

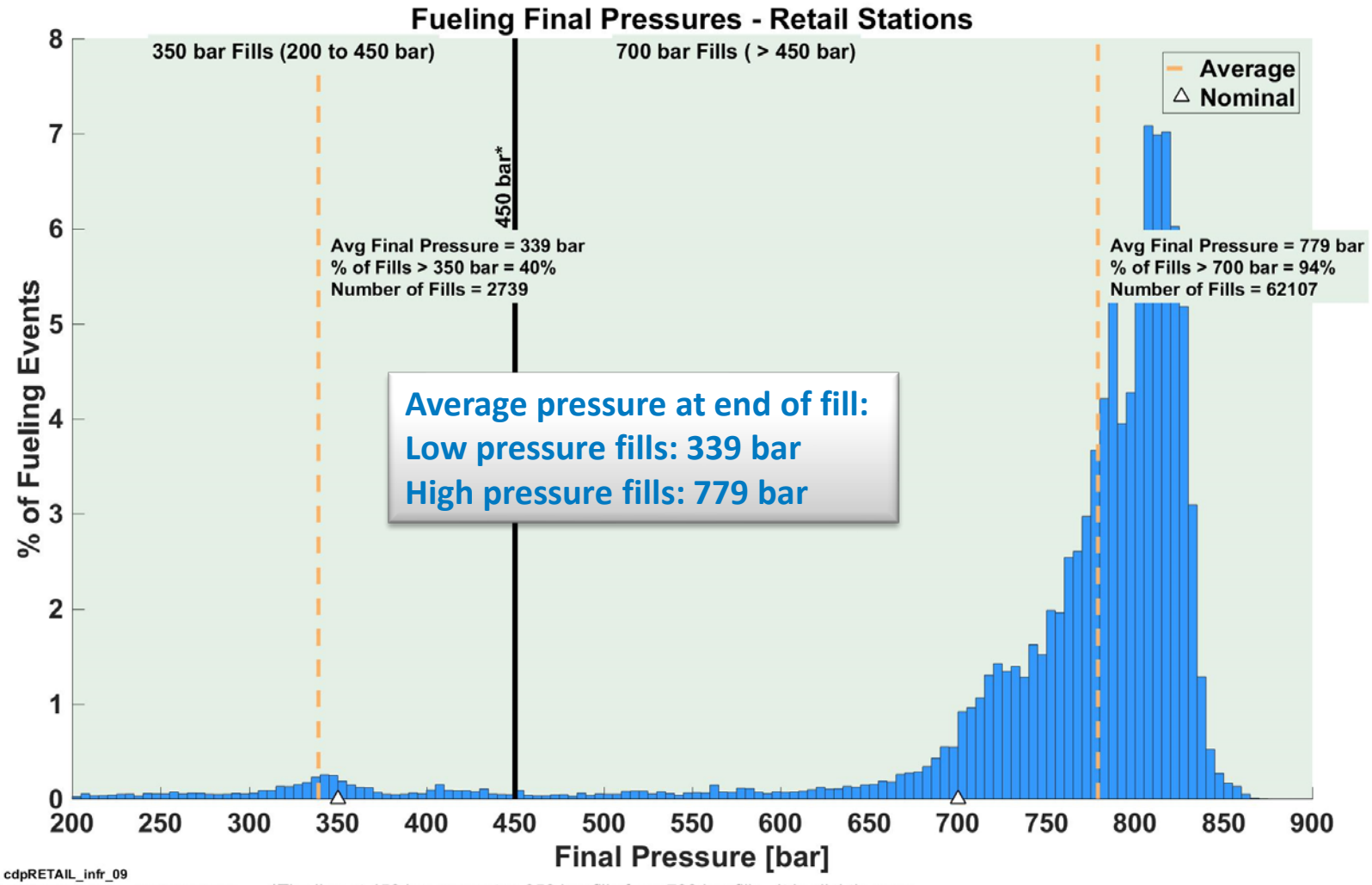
#	Date of Repair, Replacement	Component Name	replaces Category / Subsystem[2]	New / Component[2]	replaces Maintenance Type / Action[2]	replaces Failure Mode / Cause[2]	New / Effect[2]	New / station unavailability (hours)	New / If still available, station performance affected (hours)	Category[2]
1	10/5/2004	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

Analysis Categories



Fueling Final Pressures



NREL cdpRETAIL_infr_09
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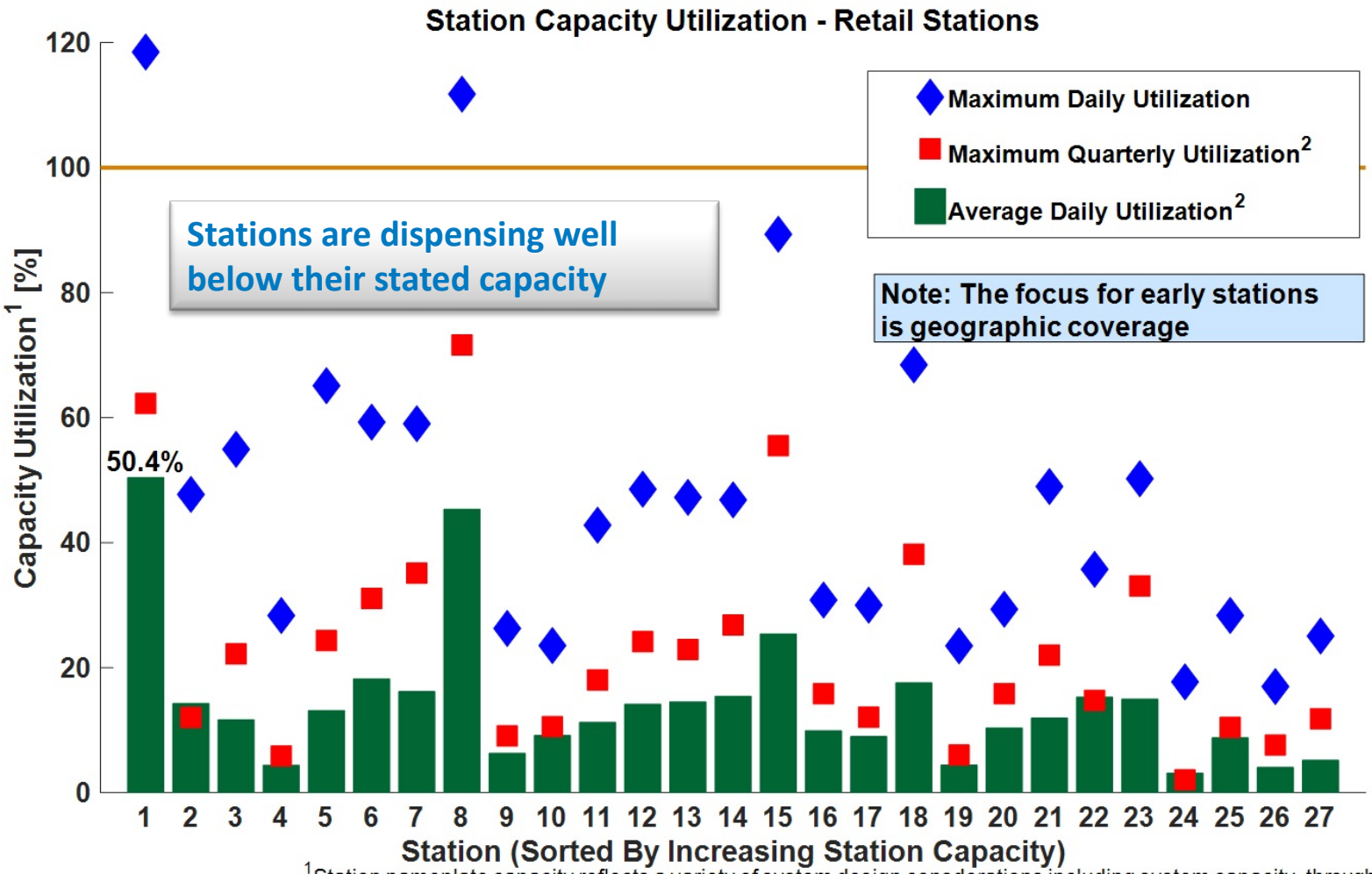
*The line at 450 bar separates 350 bar fills from 700 bar fills. It is slightly over the allowable 125% of nominal pressure (437.5 bar) from SAE J2601.

Station Capacity Utilization



NREL cdpRETAIL_infr_06
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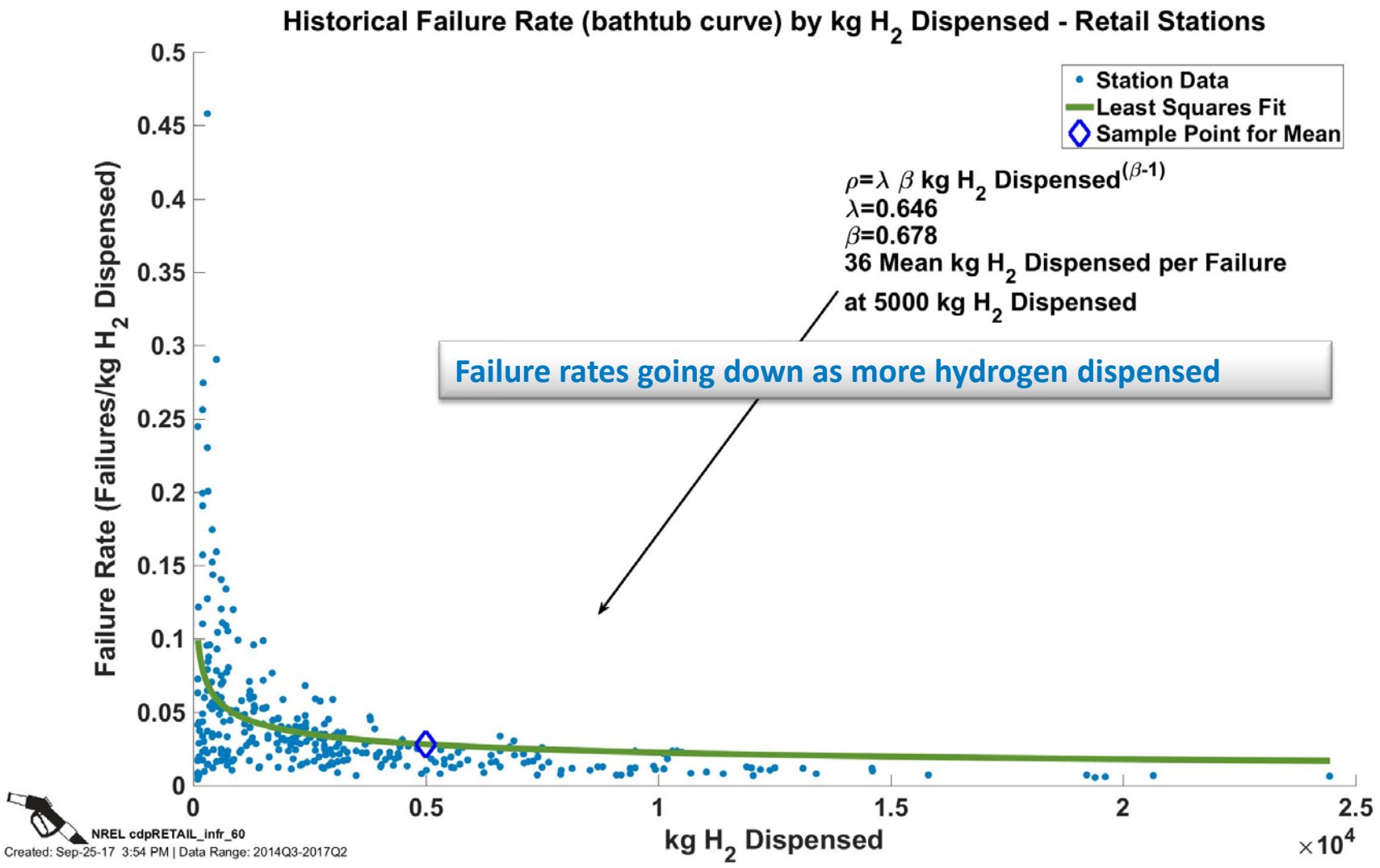
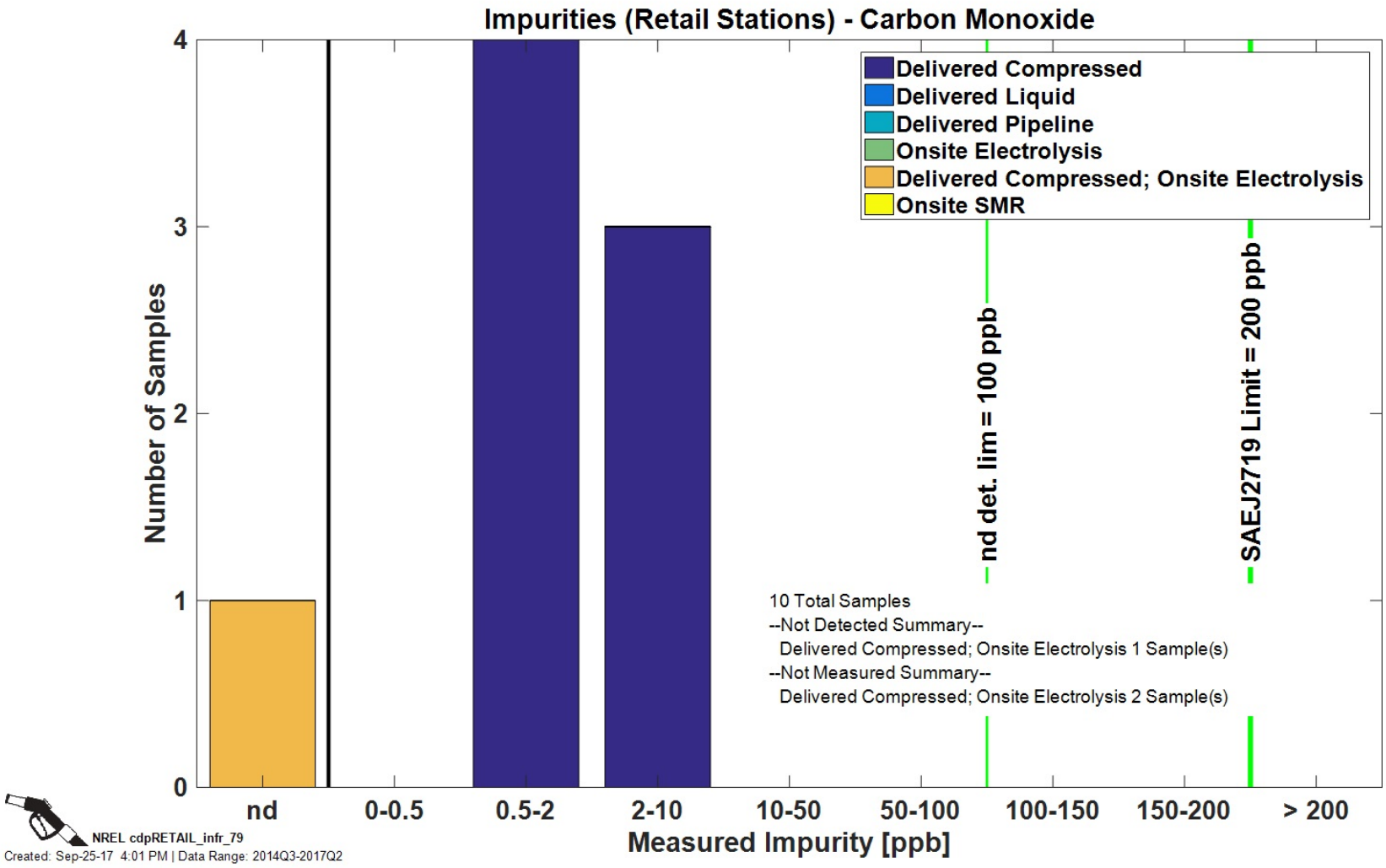
[1] Station nameplate capacity reflects a variety of system design consderations including system capacity, throughput, system reliability and durability, and maintenance. Actual daily usage may exceed nameplate capacity.

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

Failure Rates by kg Dispensed (bathtub curve)



Hydrogen Quality Example
Carbon Monoxide Measurements – Retail Stations



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.

Electricity Cost per kWh by Utility