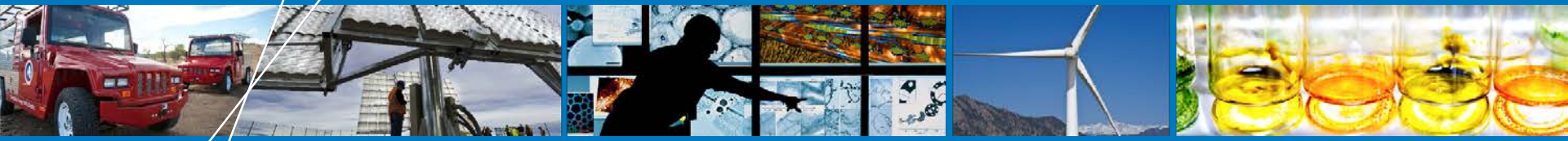
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Hydrogen Station Data Collection and Analysis



Sam Sprik (PI), Jennifer Kurtz, Chris Ainscough,
Matt Jeffers, Genevieve Saur, Mike Peters
National Renewable Energy Laboratory
June 9, 2016
2016 DOE Annual Merit Review
Washington, DC

Project ID TV017

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

Overview

Timeline and Budget

- Project start date: 10/2011*
- Total DOE funds received to date: $985k
- FY15 DOE funding: $300k
- FY16 planned DOE funding: $200k

Barriers

- Lack of current hydrogen refueling infrastructure performance and availability data

Partners

- Industry and agencies listed on collaboration slides

*project continuation and direction determined annually by DOE

Project Objectives:
Hydrogen Infrastructure Evaluation

FY16 Objectives

Analysis and reporting on infrastructure performance, cost, utilization, maintenance, and safety.

CSULA station, Los Angeles, CA. Photo: NREL

Linde Station, West Sacramento, CA. Photo: NREL

Overall Objectives

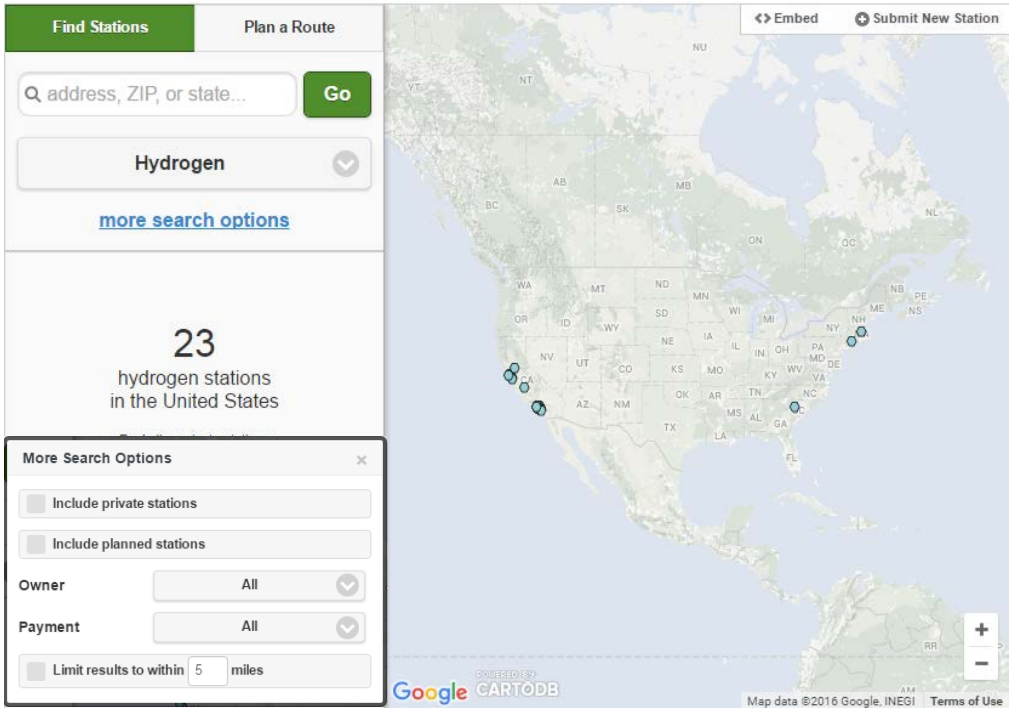
- Validate hydrogen infrastructure
- Identify status and technological improvements
- Provide feedback to hydrogen research
- Publish results for stakeholder use

Relevance: Metrics to Evaluate Infrastructure

Use metrics to clearly evaluate progress toward challenges

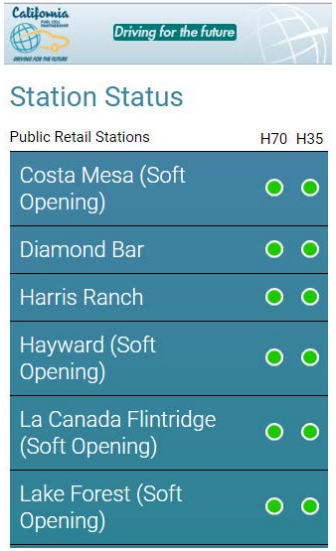
- **Location/Capacity/Utilization**
  - ***Challenge:*** Station coverage, hydrogen availability, minimal wait time.
  - ***Metrics:*** Station usage patterns and geographic locations
- **Fueling**
  - ***Challenge:*** Vehicles fueled in an acceptable amount of time
  - ***Metrics:*** Fueling rates, times, amounts, back-to-back fills
- **Maintenance/Availability**
  - ***Challenge:*** Maintenance and downtime increase cost and impact customers
  - ***Metrics:*** Maintenance patterns, reliability and availability of stations
- **Cost**
  - ***Challenge:*** Hydrogen cost is dependent on several factors including where produced, how delivered, efficiencies, and maintenance requirements
  - ***Metrics:*** Energy cost, maintenance cost, station cost
- **Station Timing**
  - ***Challenge:*** Lead time to build out infrastructure to meet vehicle demand
  - ***Metrics:*** Permitting time, building time, commissioning time

Approach: Hydrogen Station Locations



- Locations transitioned to Alternative Fuels Data Center (AFDC).
- Working on common fields and using “Retail” definition.
- Automating updates to AFDC from CaFCP and California GoBiz

- AFDC integrating station availability using CaFCP-SOSS
- Mobile phone availability for both



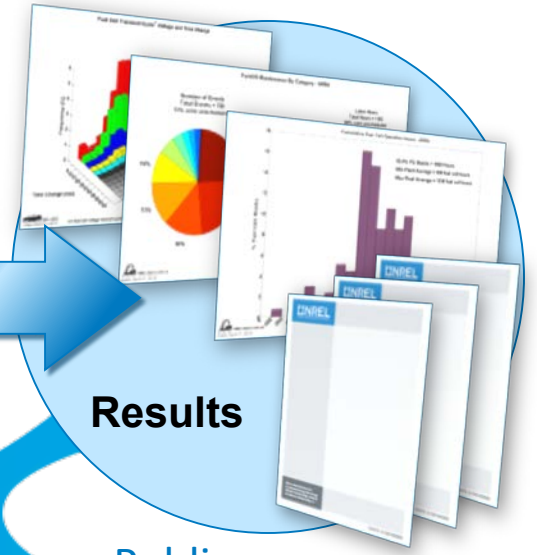
Approach: National Fuel Cell Technology Evaluation Center (NFCTEC)

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

Hydrogen Infrastructure Composite Data Products

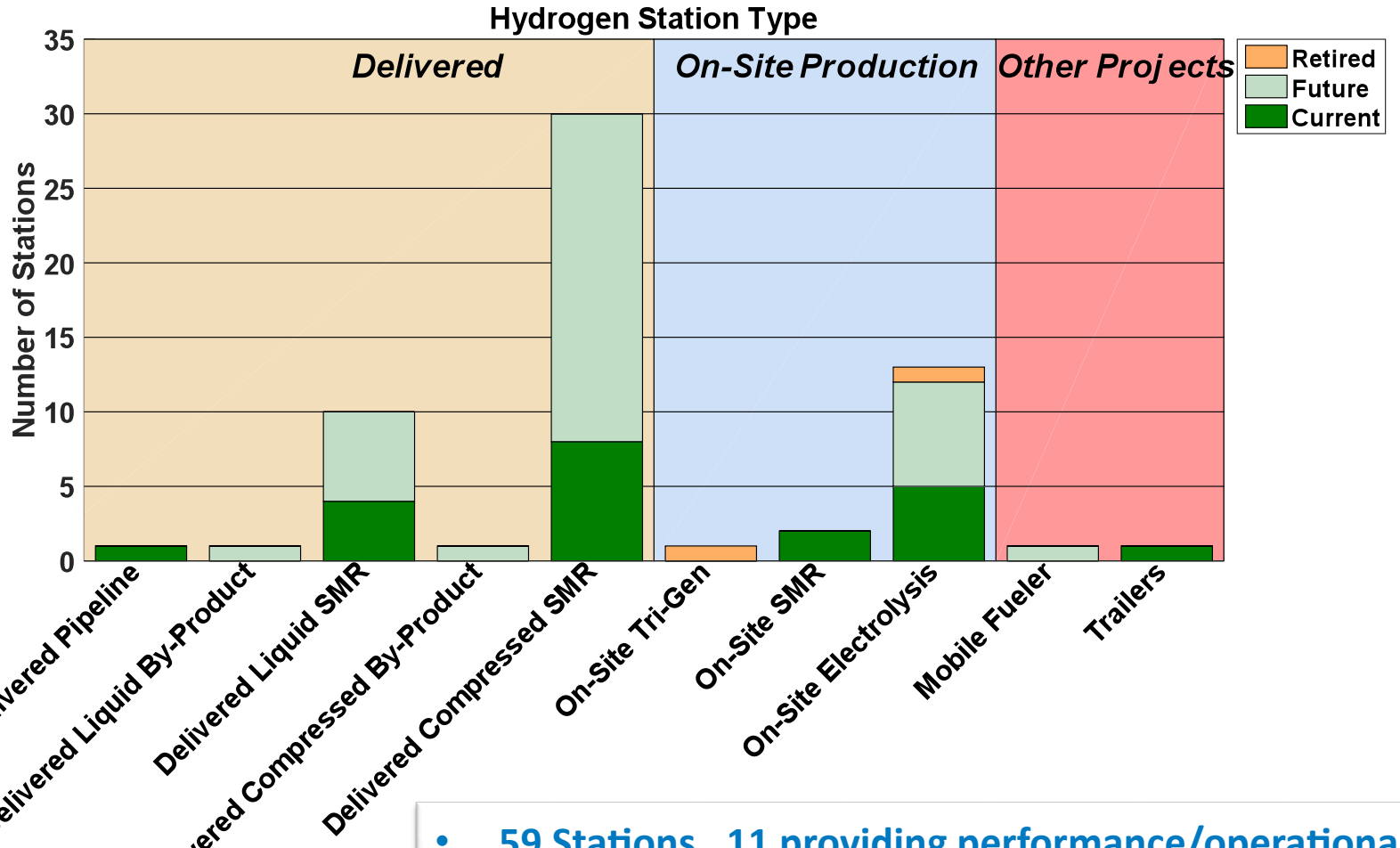
Total of 61 CDPs

43 Updated, 18 New

In 9 Categories

A subset of the infrastructure CDPs presented here. All CDPs, including other projects, available at www.nrel.gov/hydrogen/proj_tech_validation

Accomplishments and Progress:
Hydrogen Stations by Type



NREL cdp_infr_11
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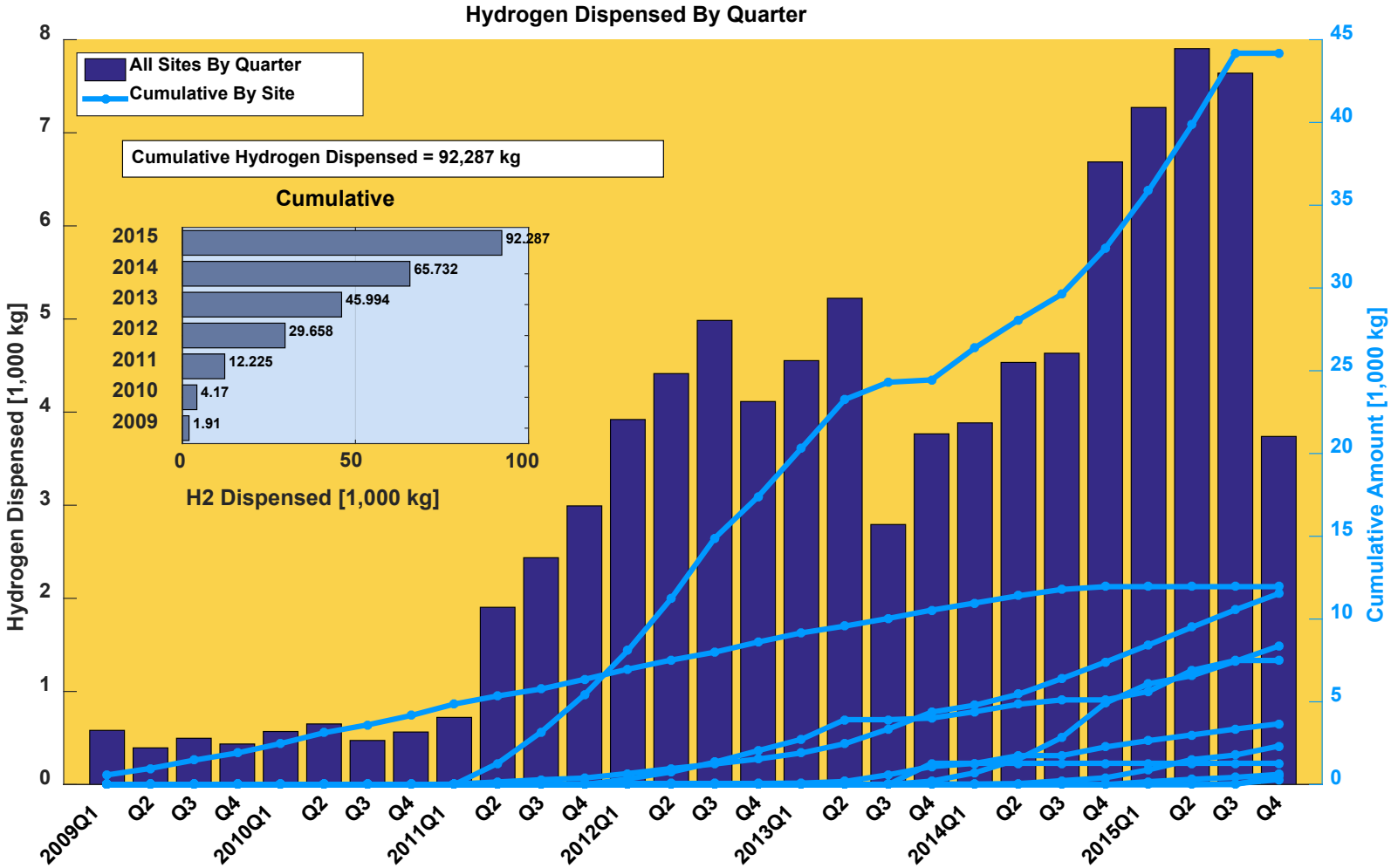
- 59 Stations. 11 providing performance/operational data
- Station cost data from CEC awards received for current and future stations

Accomplishments and Progress:
Hydrogen Dispensed by Quarter

Over 92,000 kg dispensed



NREL

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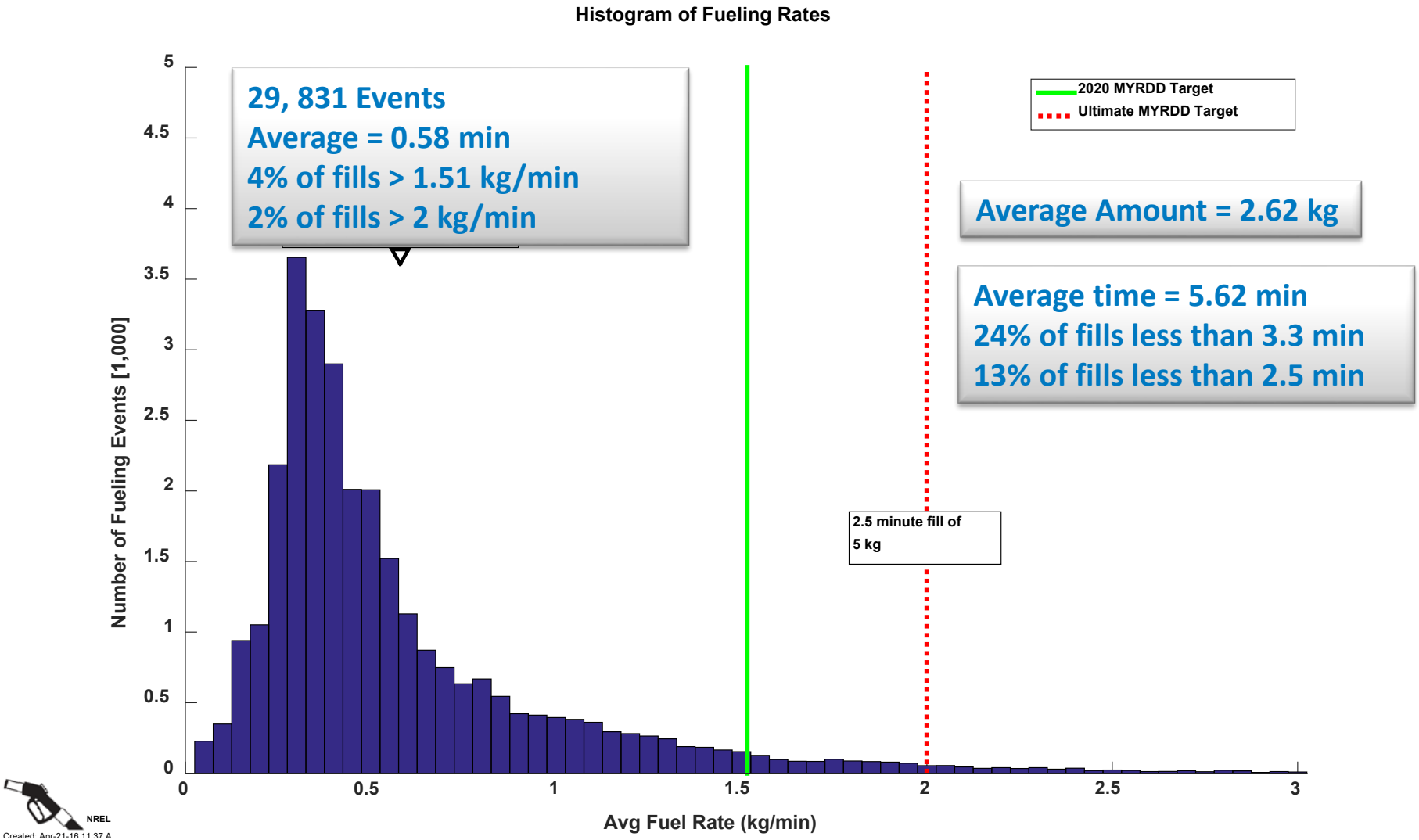
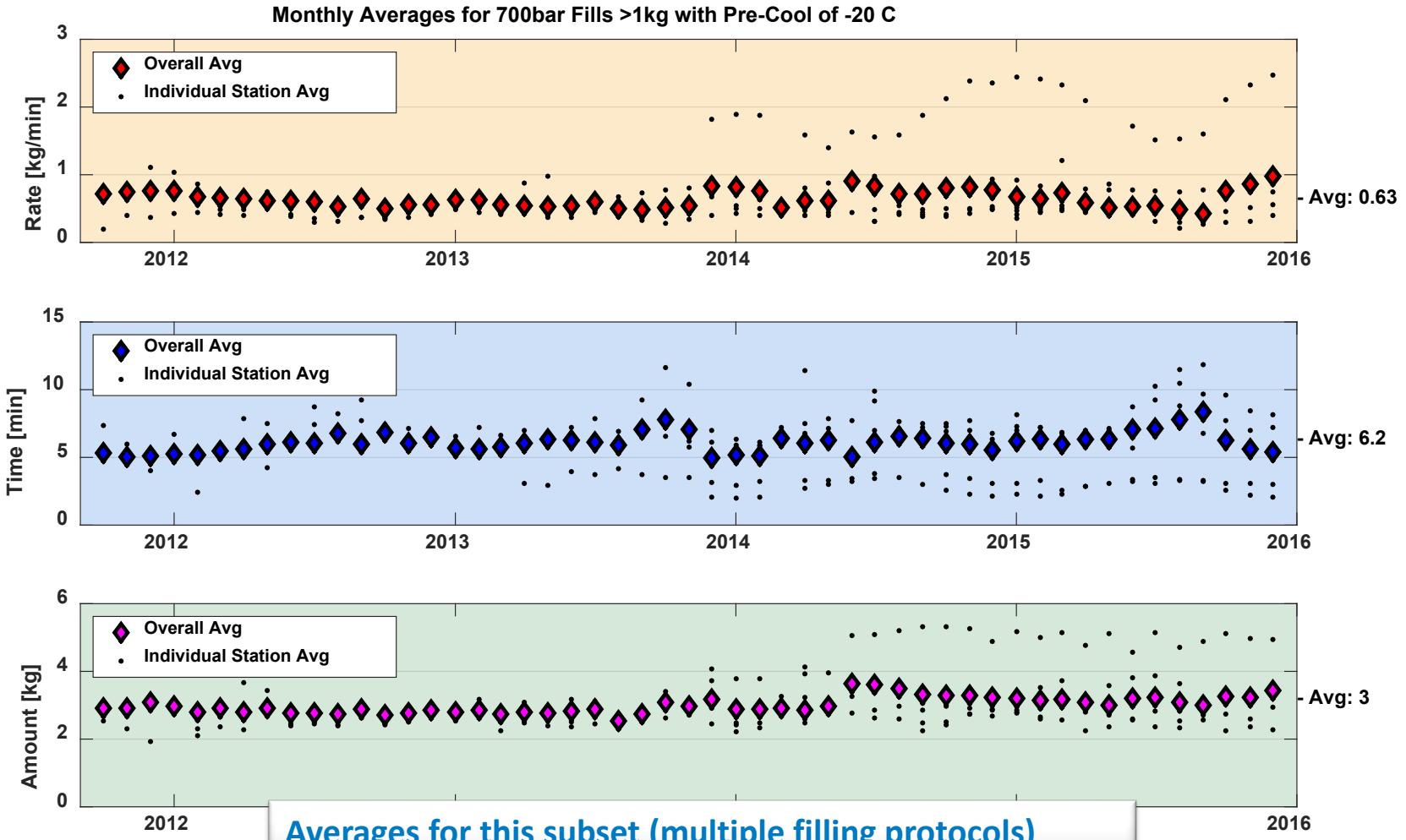
Accomplishments and Progress:
Fueling Rates, Times, Amounts (All Fills)

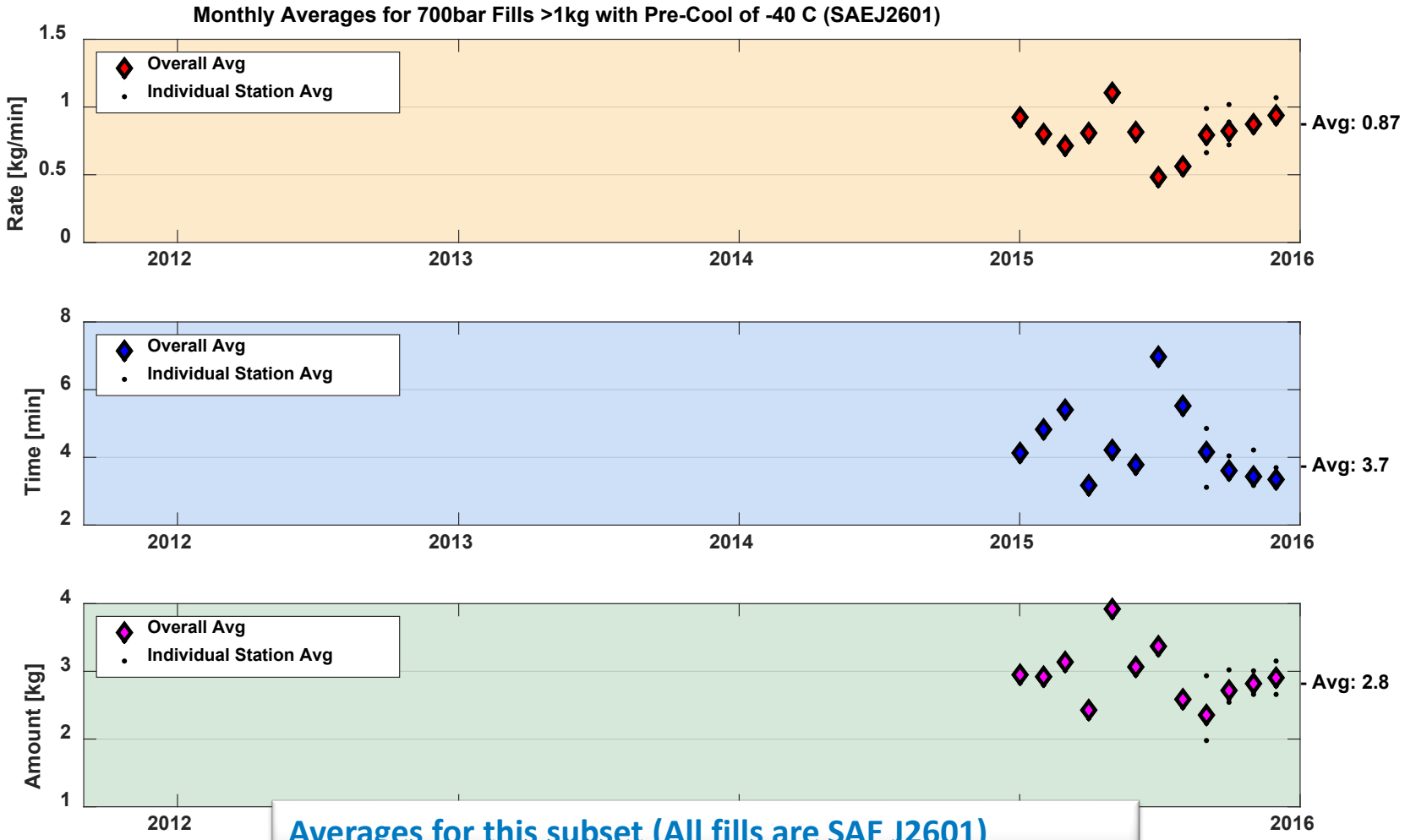


Accomplishments and Progress:
Monthly Averages for 700bar Fills >1kg with Pre-Cool of -20C



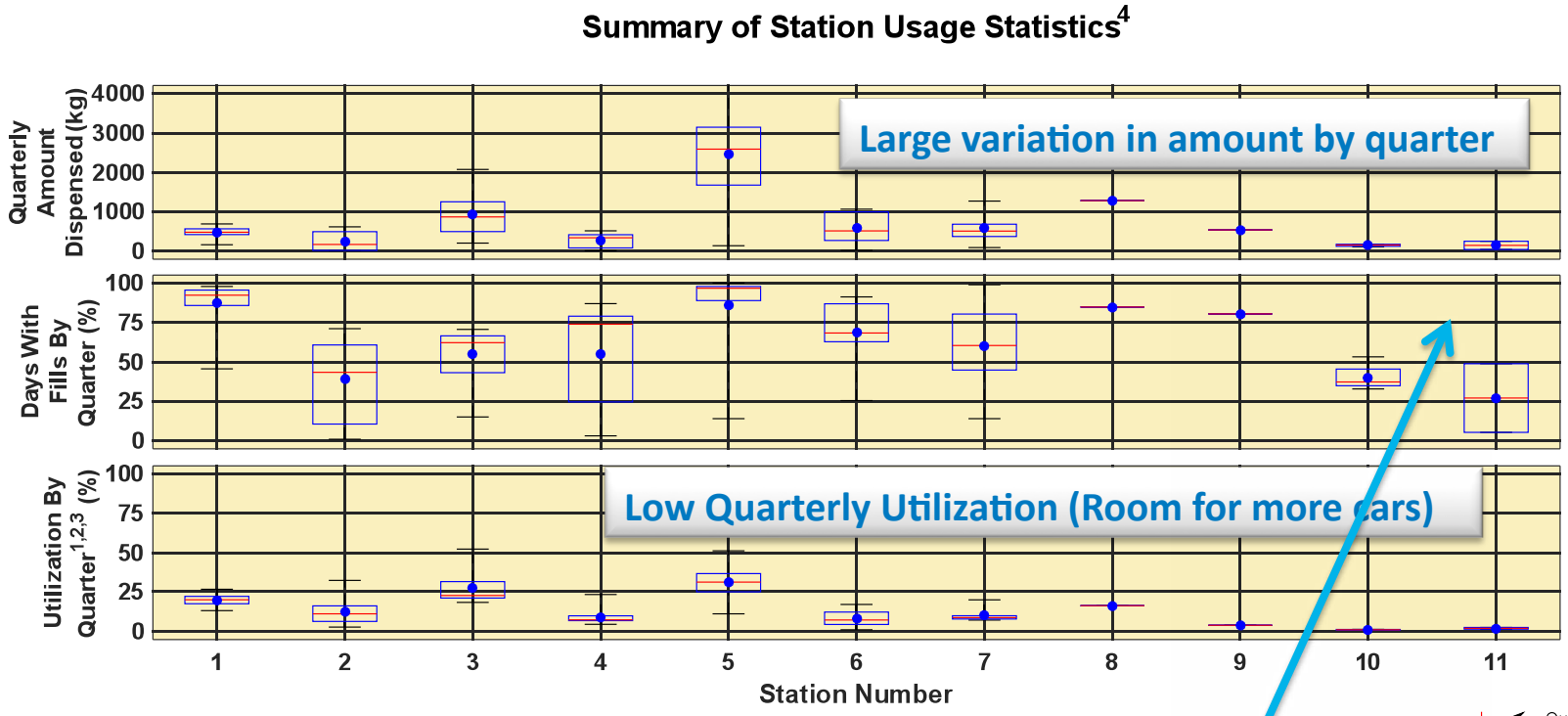
Averages for this subset (multiple filling protocols)
Rate = 0.63 kg/min, Time = 6.2 min, Amount = 3 kg

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



Averages for this subset (All fills are SAE J2601)
Rate = 0.87 kg/min, Time = 3.7 min, Amount = 2.8 kg

Accomplishments and Progress:
Station Usage



[1]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.

[2]Average quarterly utilization only considers days when at least one fill occured.

[3]Utilization is calculated by dividing the quarterly amount dispensed by the stations nameplate capacity.

[4]Only quarters with fills are included.

Stations should have at least 1 fill a day (100% on 2nd chart) as more cars enter their market.

NREL cdp_infr_47
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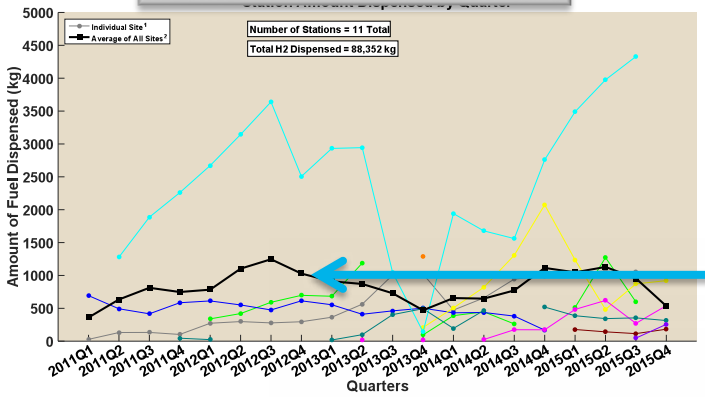
Accomplishments and Progress:
Station Usage also Plotted by Quarter

Amount by Quarter



[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 amount only considers quarters when at least one fill occurred.

NREL cdp_infr_45
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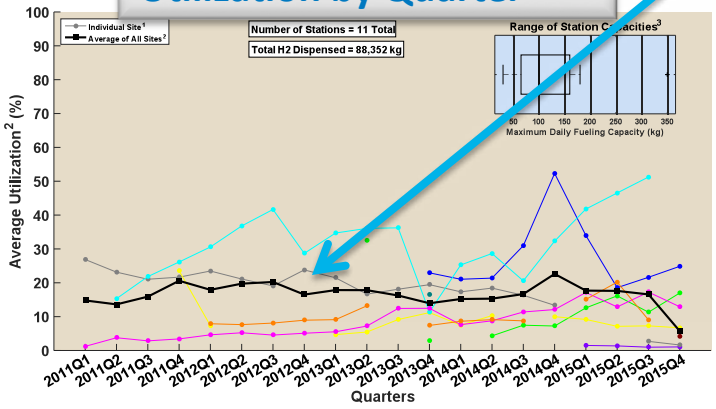
Previous CDP slide contained boxplots of quarterly data
These CDPs show the same data by time and by station.
Newer stations and newer data do not show significant trend changes.

Black line shows Average by quarter

Utilization by Quarter



[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 cdp_infr_44
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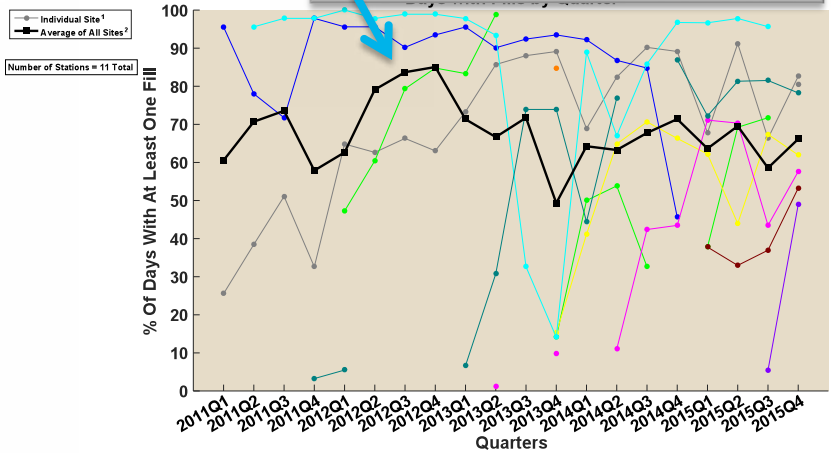
Days with Fills by Quarter



[1] Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station had no fills or was missing data. Each station is represented by a unique color.
[2] The average percent of days with fills only considers quarters in which at least one fill occurred. Stations with no filling days in a quarter are excluded from the average for that quarter. All stations with at least one fill in a quarter are given equal weight when calculating the average for the quarter.

NREL cdp_infr_46
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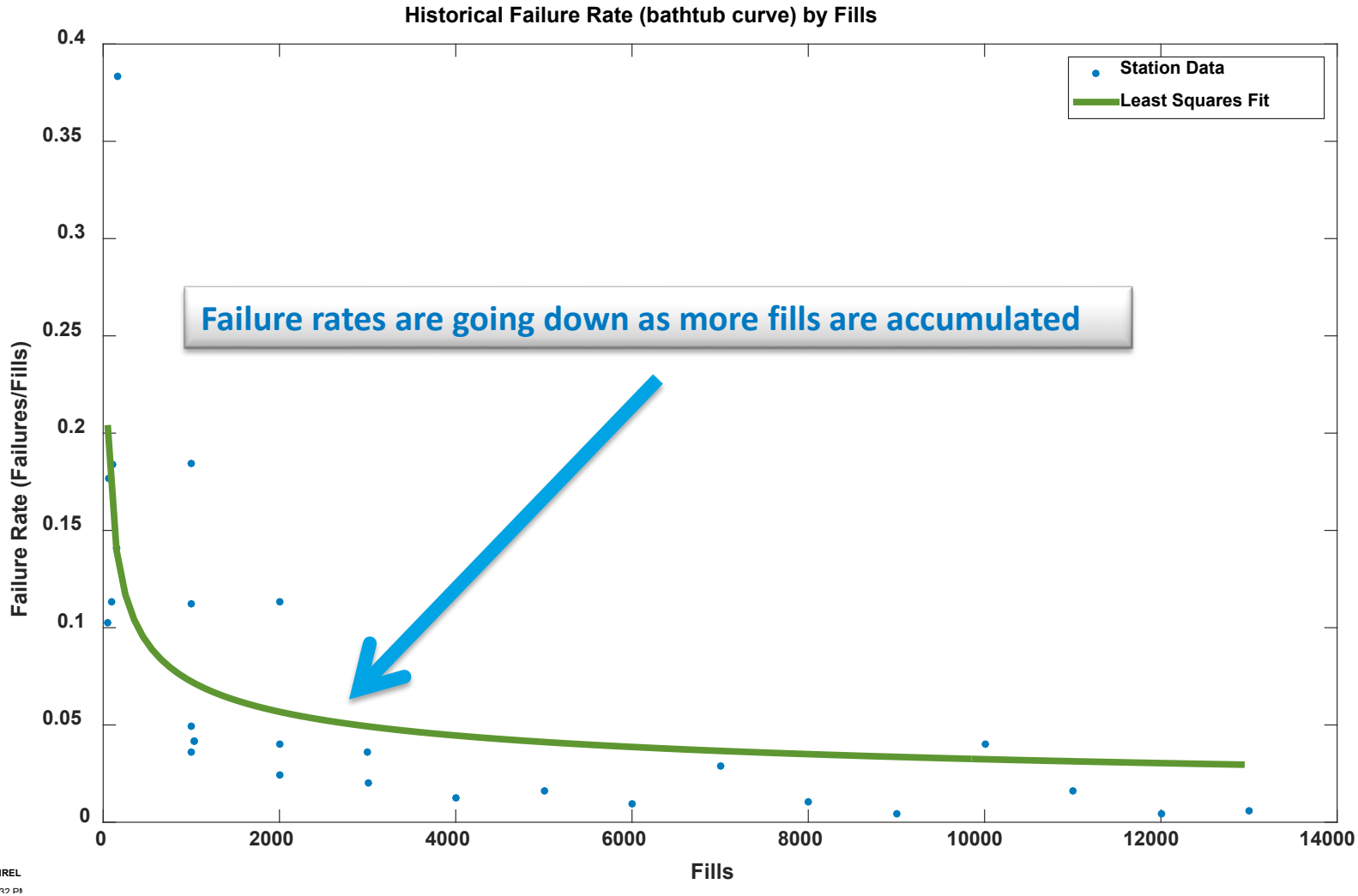
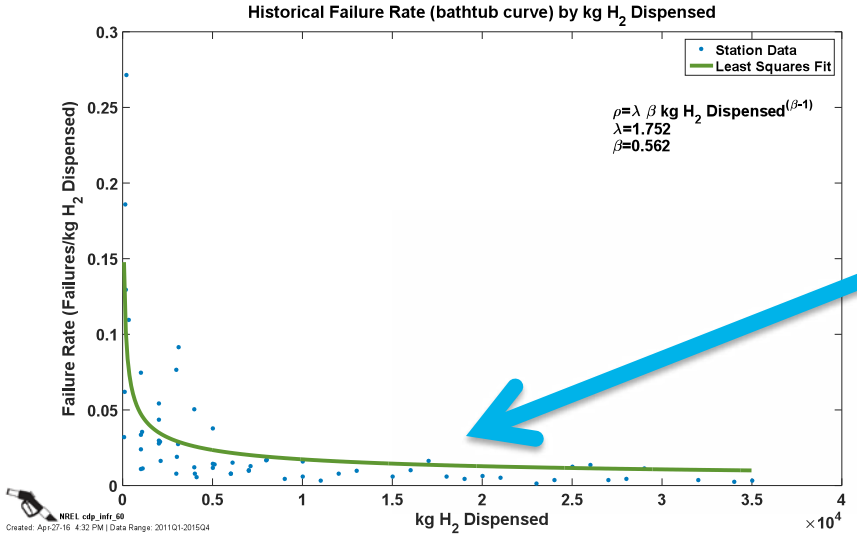
Accomplishments and Progress:
Failure Rates by Fills (bathtub curve)

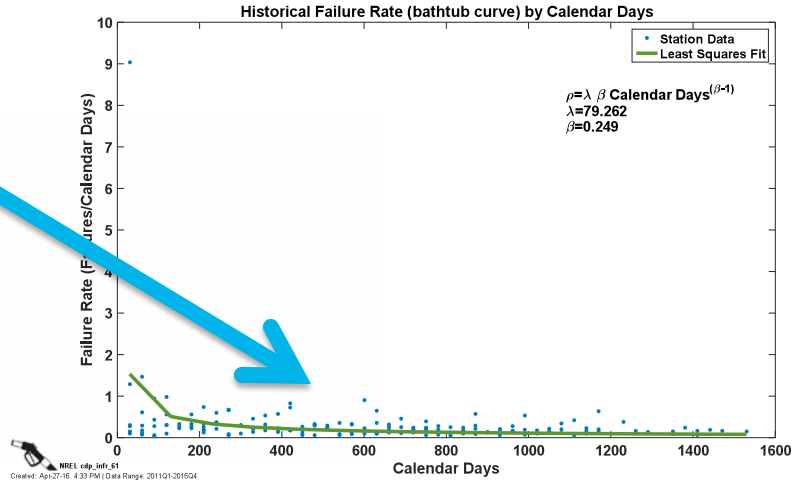


Accomplishments and Progress:
Failure Rates (bathtub curve) by Amount and by Time



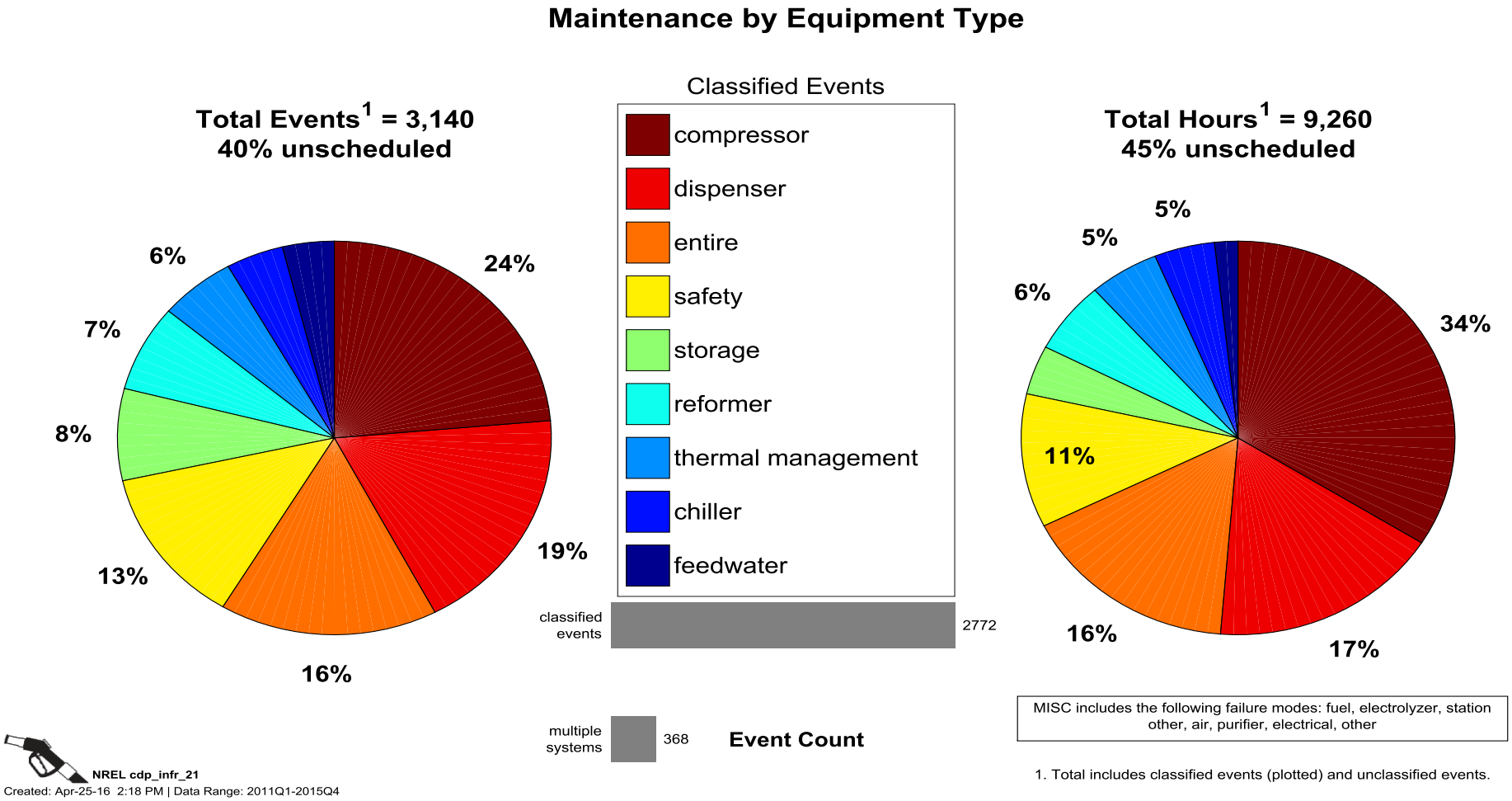
Failure rates are going down as more hydrogen is dispensed

Not as clear a trend when analyzed by calendar days.

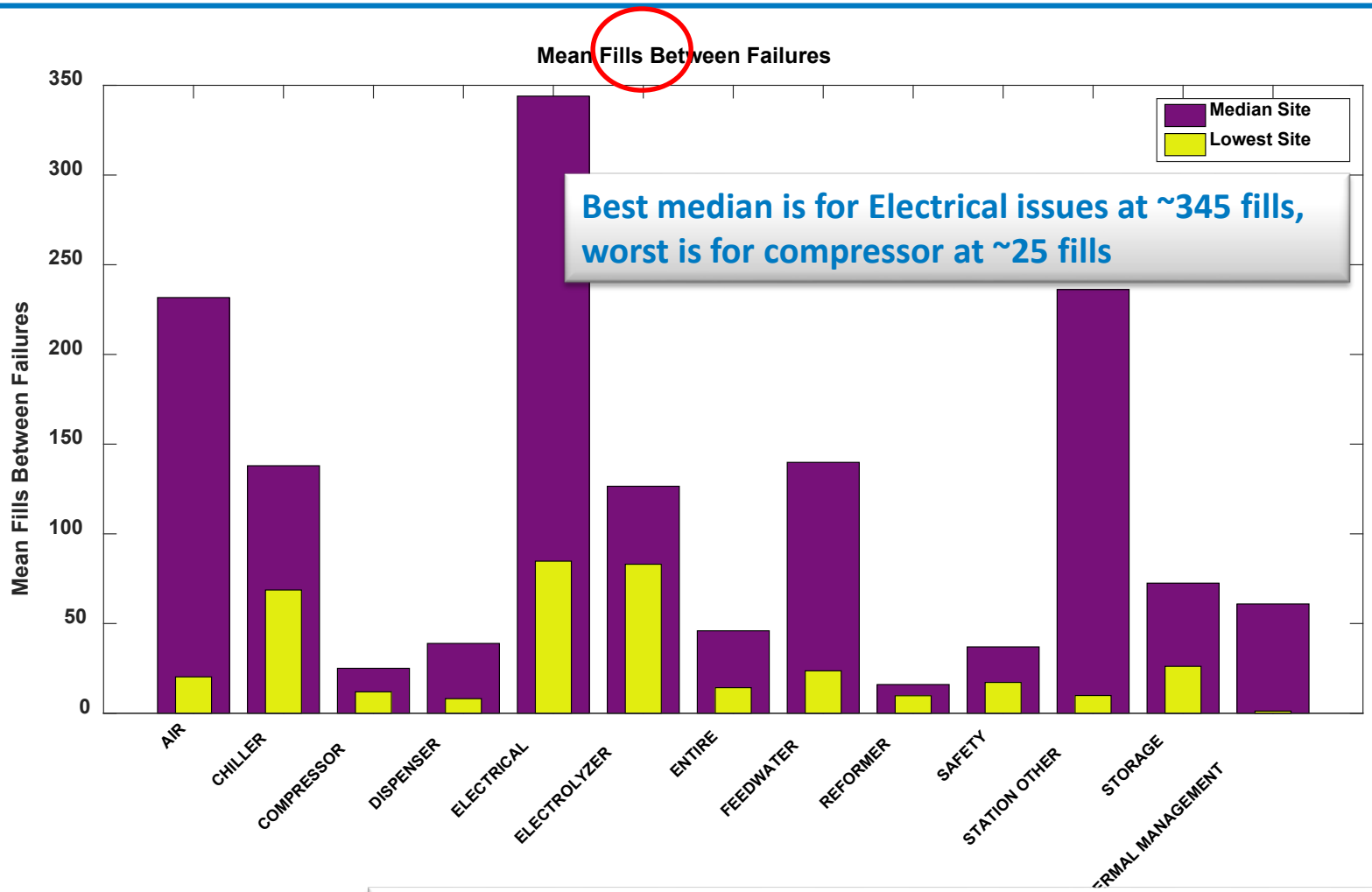


Accomplishments and Progress:
Maintenance by Equipment Type

Most maintenance related to compressors and dispensers. Entire category encompasses multiple systems and is generally preventative maintenance.



Accomplishments and Progress:
Maintenance: Mean Fills Between Failures



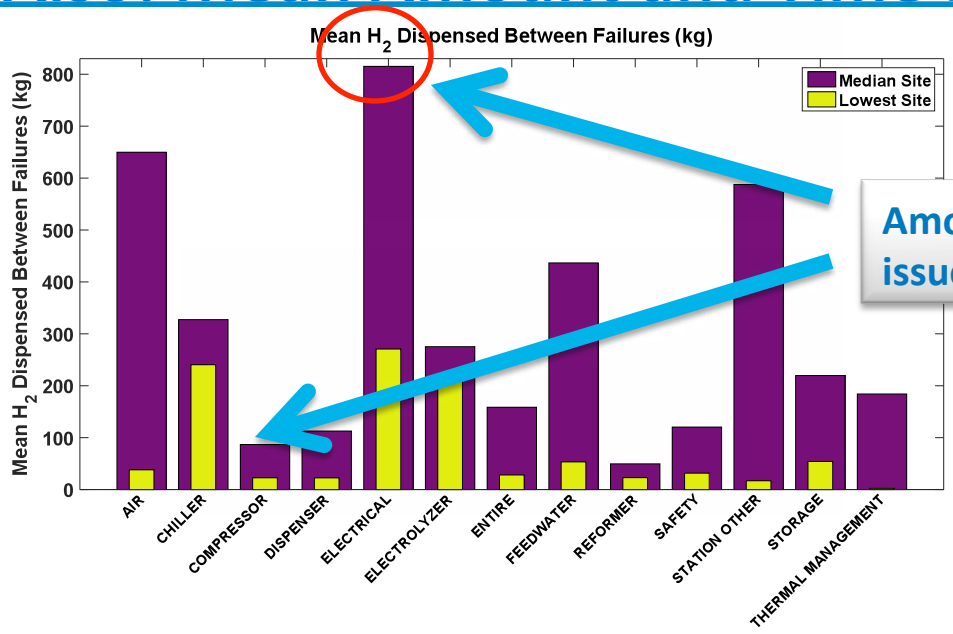
Best median is for Electrical issues at ~345 fills, worst is for compressor at ~25 fills

Median and lowest site

- Similar values mean common issue
- Values far apart mean issue to particular station

Look for more frequent updates to maintenance CDPs in coming year

Accomplishments and Progress:
Also: Mean Amount and Time Between Failures



NREL cdp_infr_51
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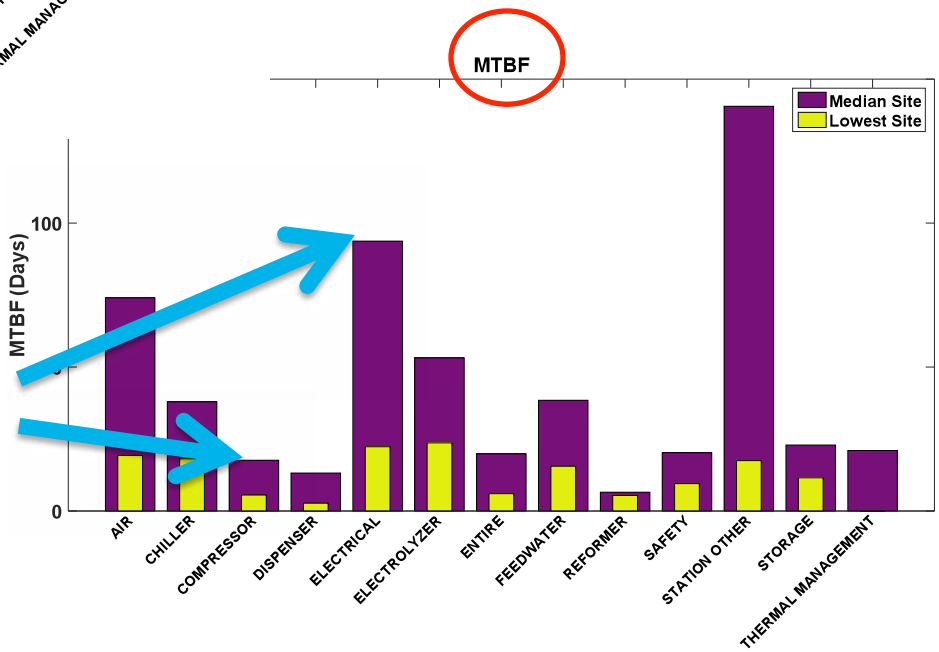
Amount: Median of ~800 kg between Electrical issues and ~100 kg between Compressor issues

Time: Median of ~95 days between Electrical and ~20 days between Compressor issues



NREL cdp_infr_38
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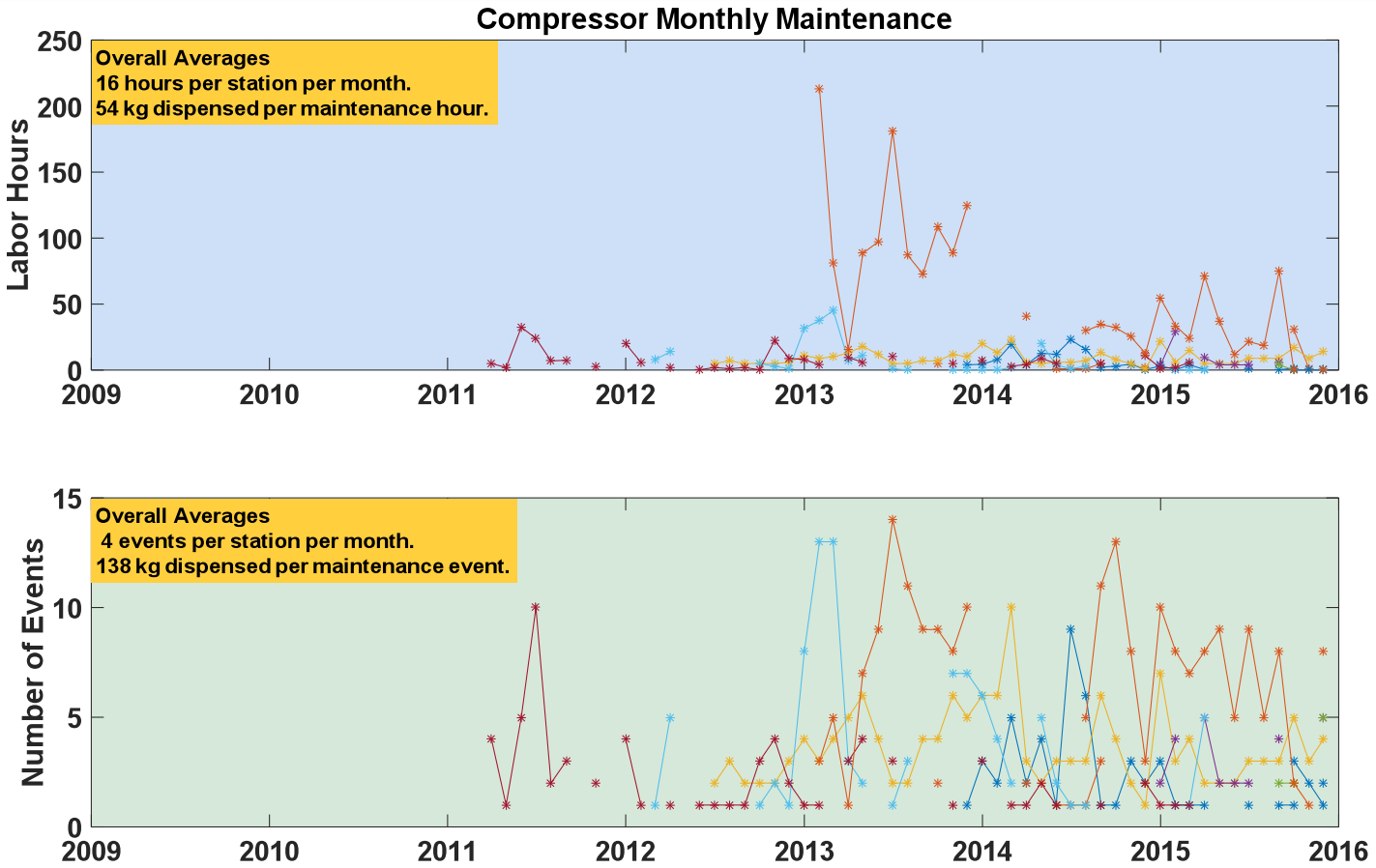
Accomplishments and Progress:
Compressor Monthly Maintenance

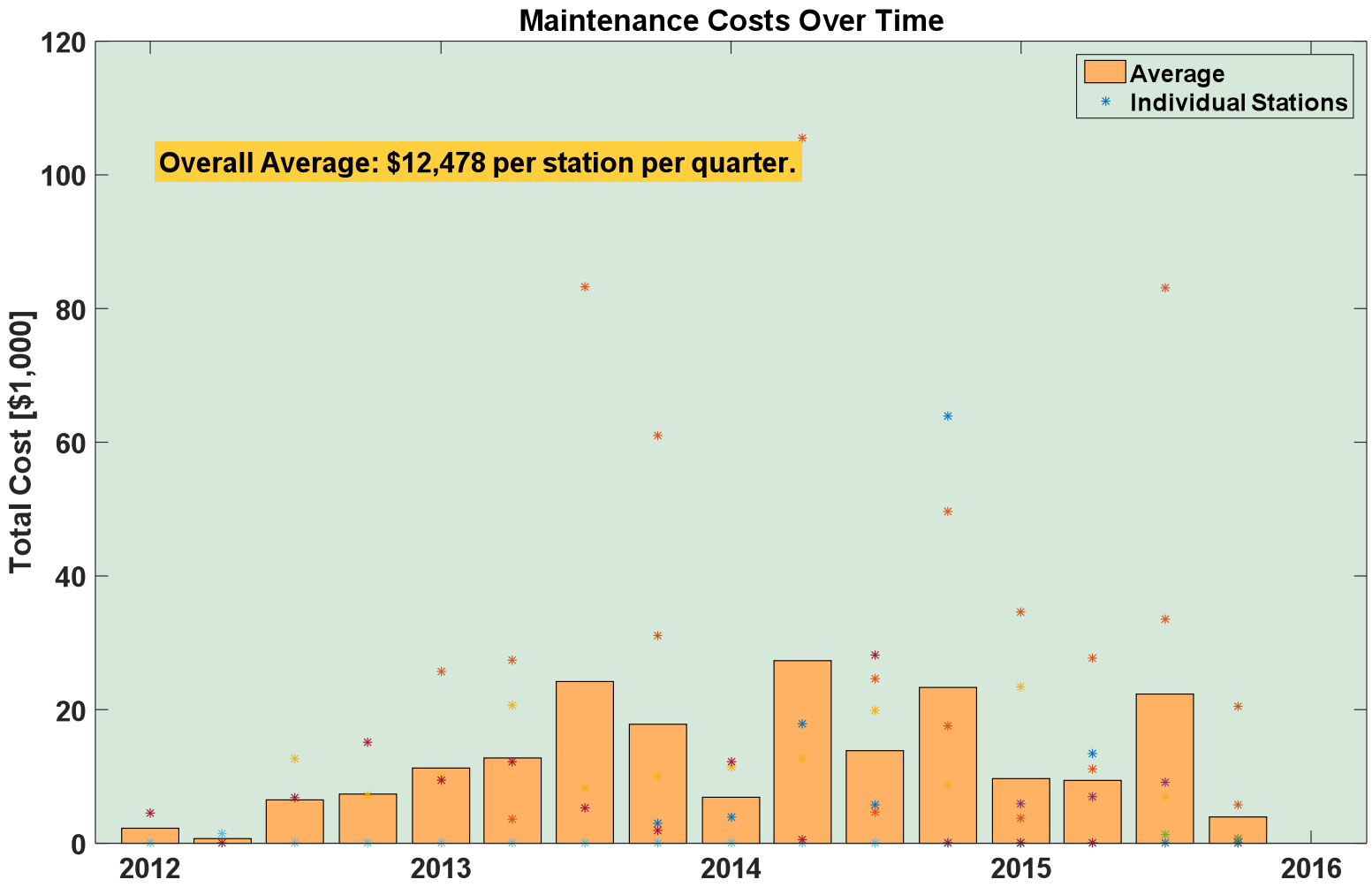
For compressors, the average per station is 4 maintenance events and 16 labor hours per month with 138 kg dispensed per maintenance event. For all maintenance items, the station average is 41 labor hours per month. Individual stations represented by different colored lines.



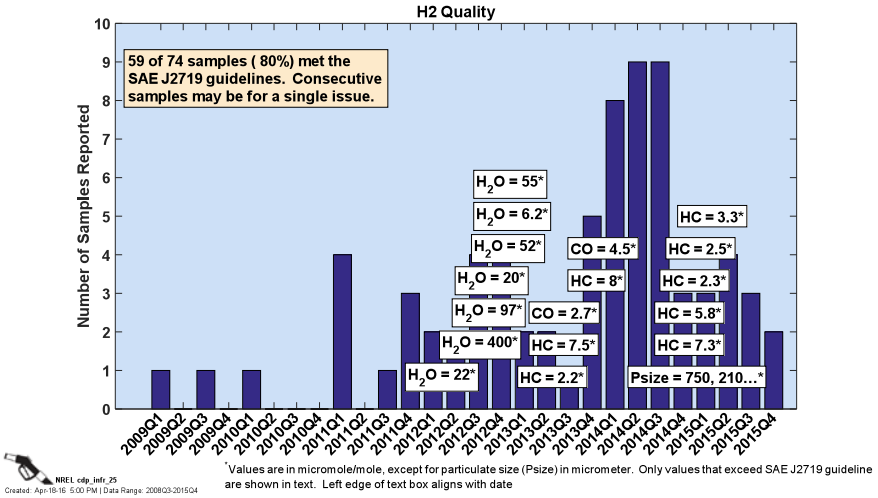
NREL cdp_infr_26
Created: Apr-25-16 2:18 PM | Data Range: 2011Q1-2015Q4

*Trendlines connect continuous months 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.

Accomplishments and Progress:
Maintenance Costs Over Time



Accomplishments and Progress:
H2 Quality



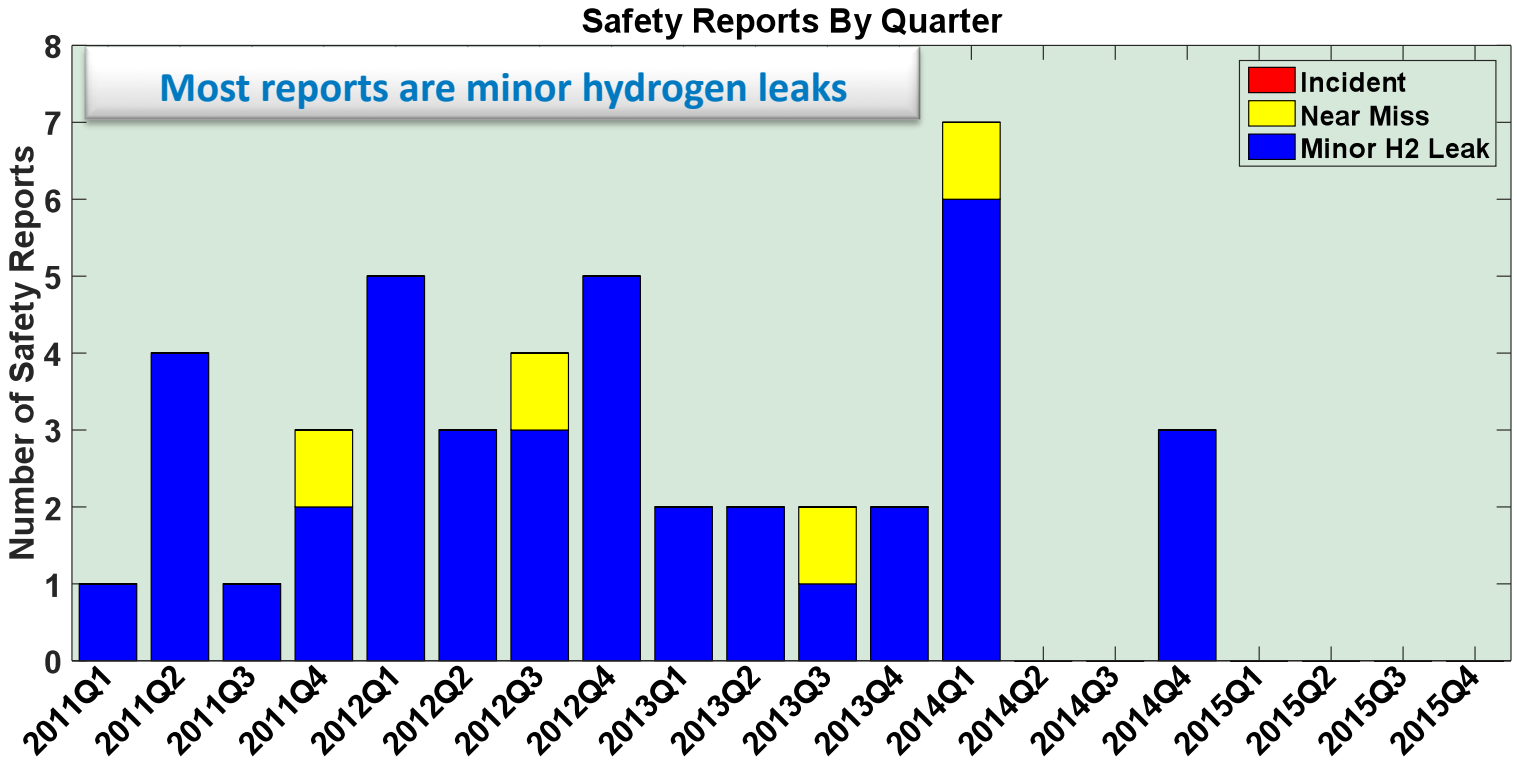
59 of 74 samples (80%) met the SAE J2719 guidelines. Consecutive samples may be for a single issue. Boxes show when item in box is out of spec

- Interest in seeing a statistical distribution of each constituent at the stations
- Useful even if stations are meeting the standard
- Helps auto/fuel cell manufacturers to understand what their stacks will encounter in the real world
- Working on providing statistical distribution of constituents coming from the stations to SAE J2719 and other stakeholders for review

Sampling Frequency

- Future awards expected every 3 months (Quarterly)
- Current awards expected every 6 months (Bi-Annually)

Accomplishments and Progress:
Safety Reports by Quarter



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)

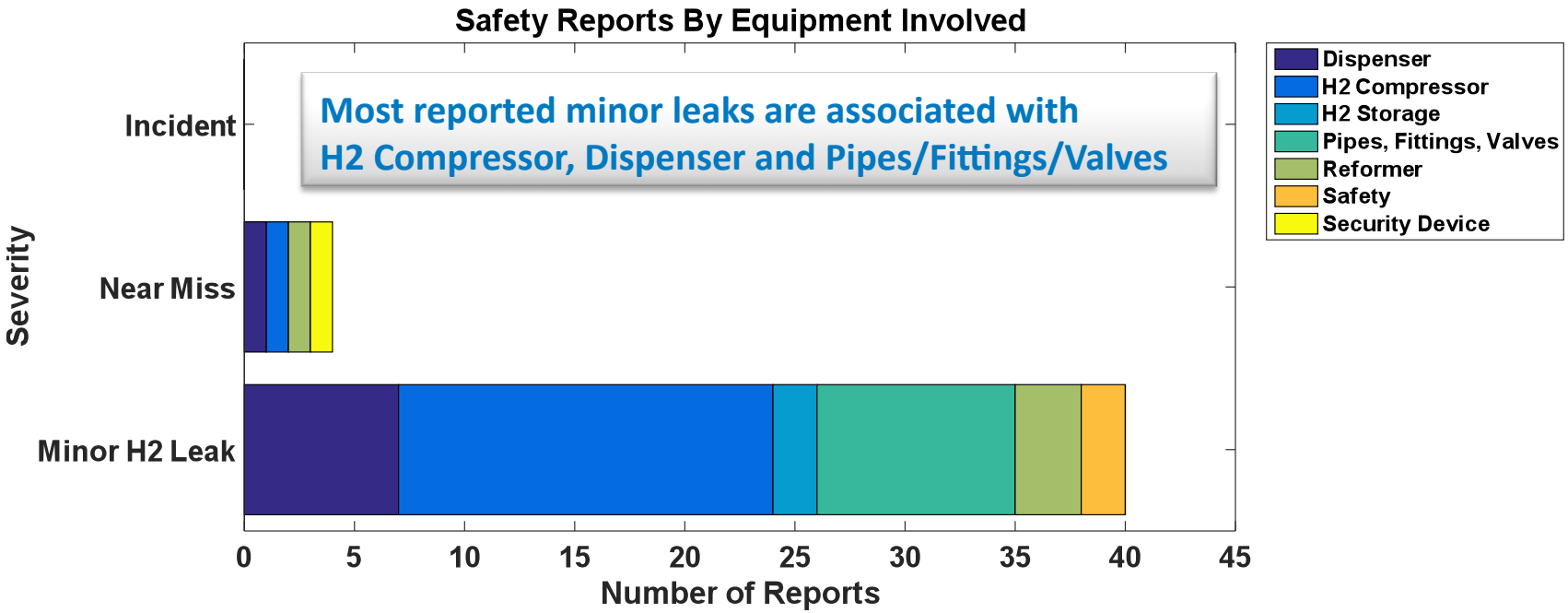
A Near Miss is:

- 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:

NREL cdp_infr_33
Created: May-01-16 11:41 AM | Data Range: 2008Q3-2015Q4

Accomplishments and Progress:
Safety Reports by Equipment Involved



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- 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

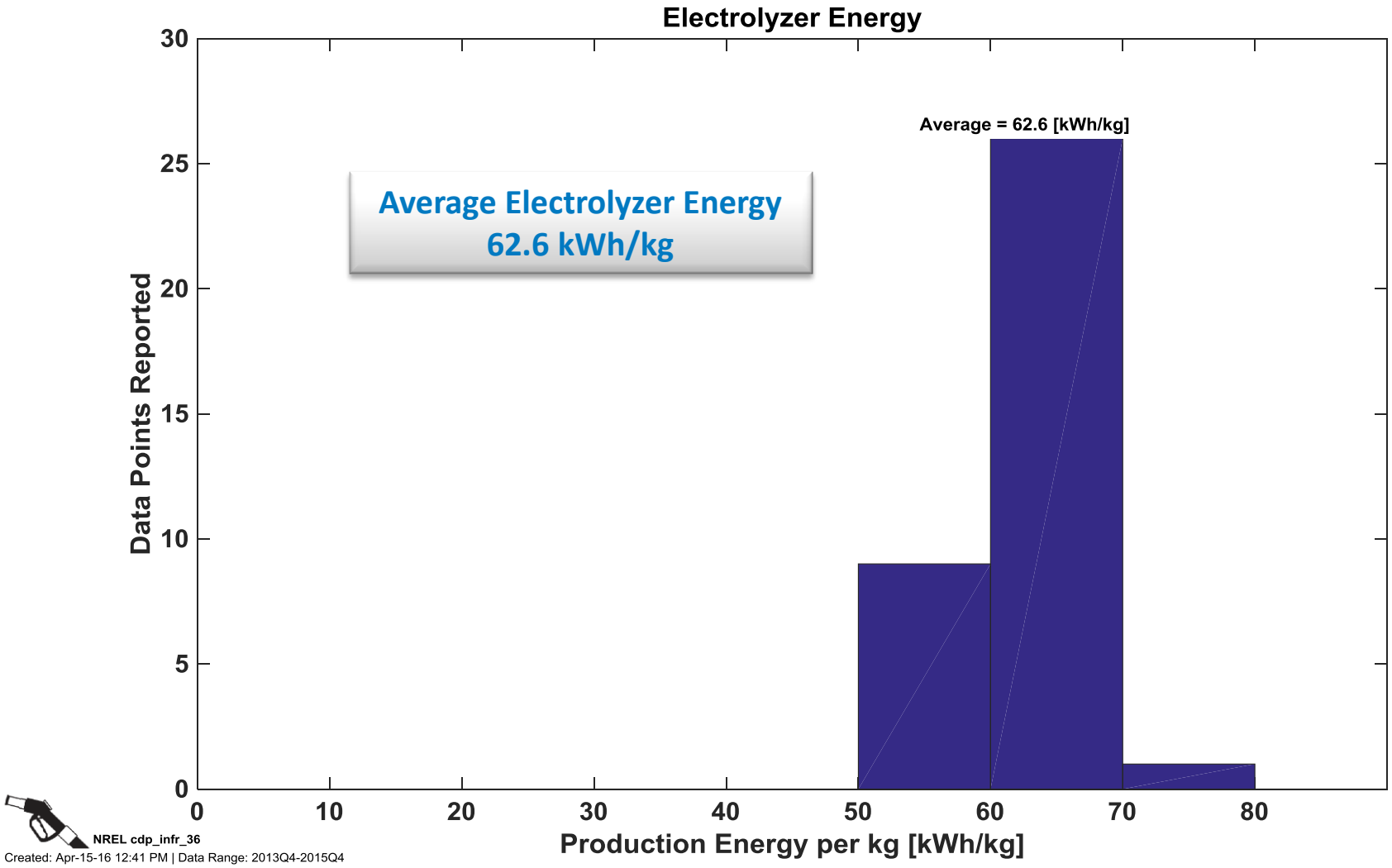
A Minor H2 Leak is:

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

NREL cdp_infr_32

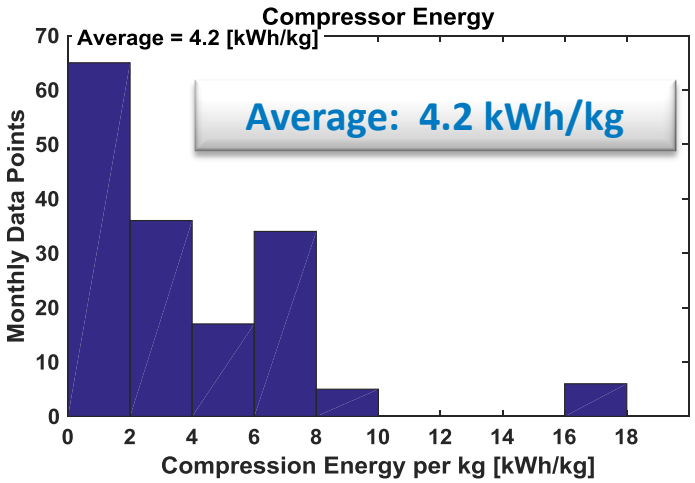
Created: May-01-16 11:40 AM | Data Range: 2008Q3-2015Q4

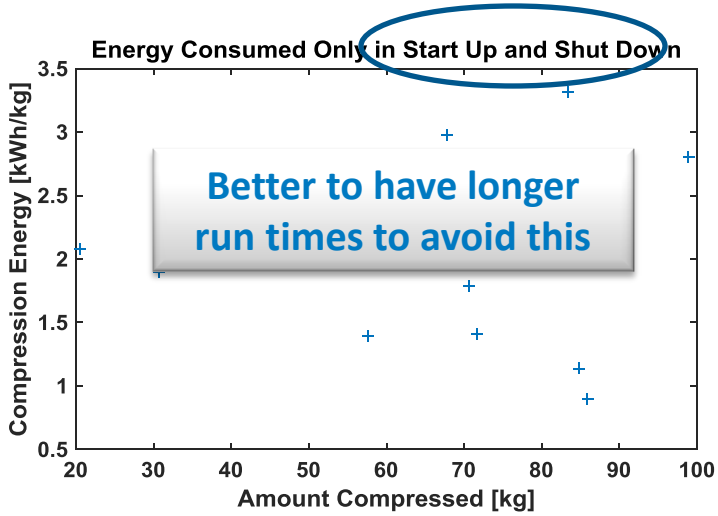
Accomplishments and Progress:
Electrolyzer Energy Use per kg of Hydrogen

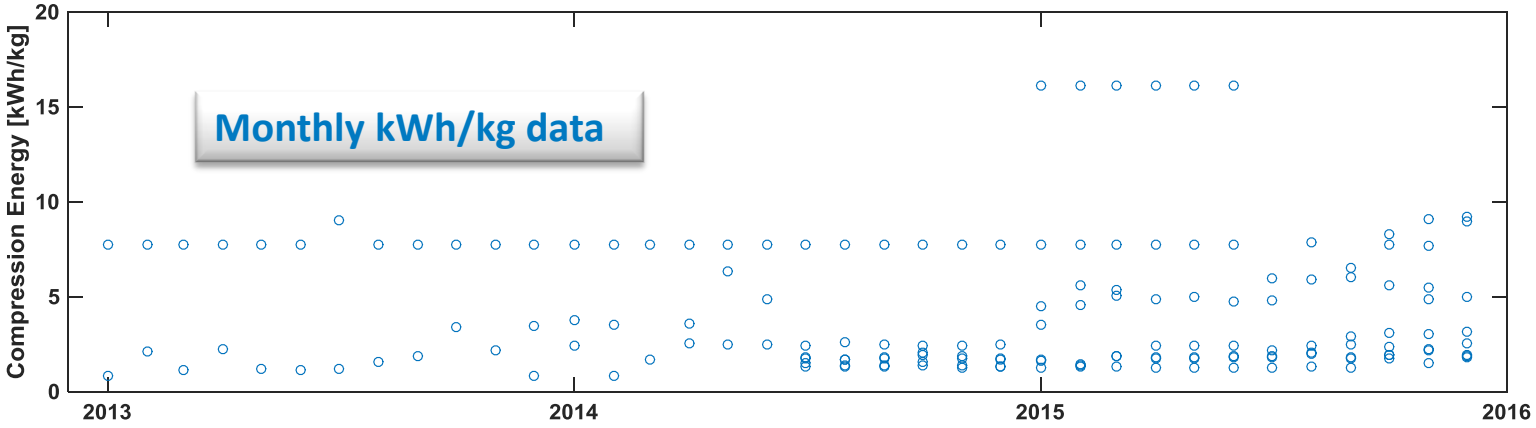


Accomplishments and Progress:
Compressor Energy and Cost per kg of Hydrogen

Average Compressor Energy Cost: $0.665/kg



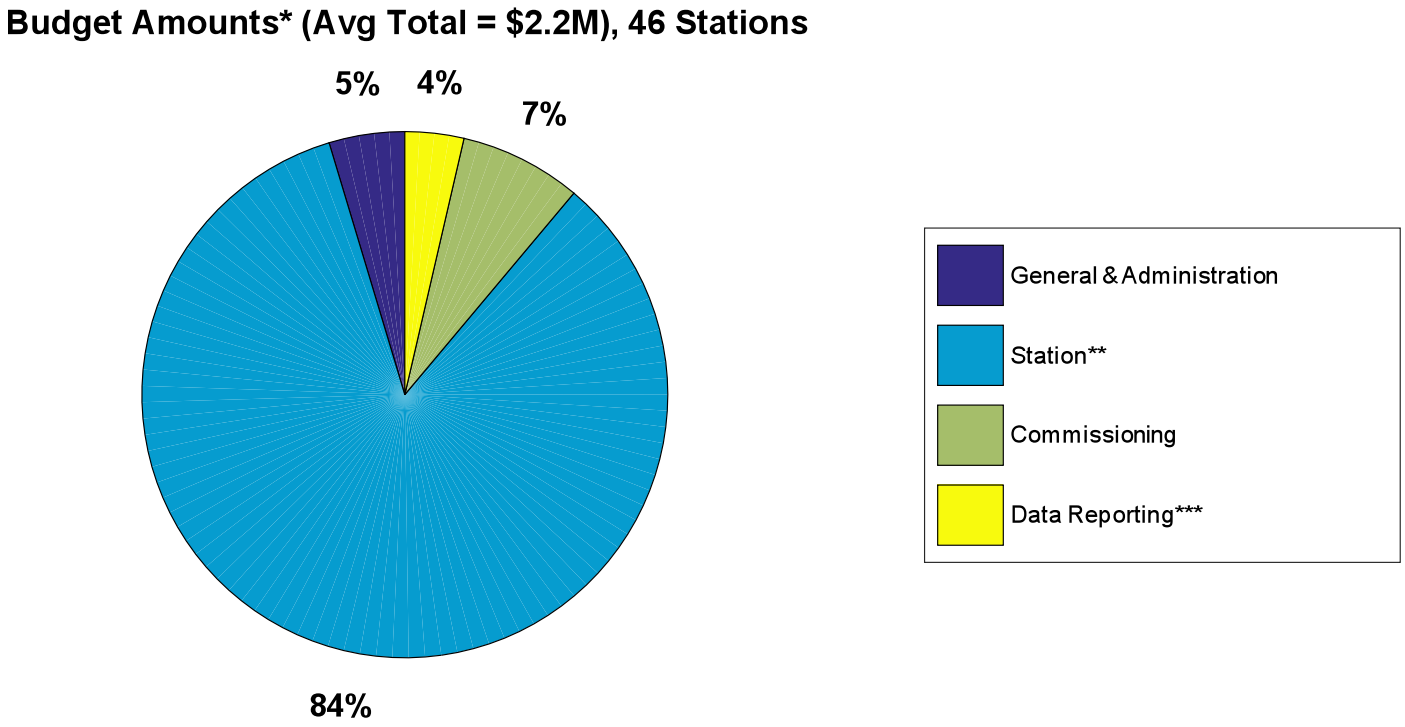




NREL cdp_infr_35
Created: Apr-26-16 4:12 PM | Data Range: 2011Q1-2015Q4

Accomplishments and Progress: Station Costs

Based on award data, the stations are expected to cost $2.2M on average (including cost share). This is an average over a variety of station types



NREL cdp_infr_41
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*Based on budgeted data from station awards (includes cost share)
**Station includes: Hydrogen Equipment and Station Engineering, Design, Fabrication, Procurement, Site Preparation, Installation, and Construction
***Data Reporting includes quarterly reporting on performance, operation and maintenance

Accomplishments and Progress:
Responses to Previous Year Reviewers' Comments

- Comment: Despite the fact that templates were produced, the level of details and harmony of data between stations is having an impact on the conclusions that follow from the NREL analysis. One can sometimes regret that the analysis is given with no indication of the data set's representatively.
  - **Response:** Not all data providers are bound by the templates. There is an effort to include the templates in any government funded award as a requirement. Even when templates are required, data is reported with different levels of detail. Future publications will provide more information on and separate out different types of stations. Data from many recently opened stations is expected in 2016. Care will still be taken to not attribute data to an individual partner
- Comment: Ideally, data are collected automatically and not entered manually by station operators into the forms described. The project should (1) start identifying next-generation "open" retail stations in data reporting separately from previous-generation non-retail stations (e.g., behind fence, non-retail, and non–SAE International J2601 compliant) and (2) consider using the "open" definition as developed by the California Fuel Cell Partnership and California infrastructure stakeholders (e.g., vehicle original equipment manufacturers, station providers, and state government).
  - **Response**: Most data providers work on automating the data collection. Most of the stations coming online will be of the "open" "retail" type. Once there are enough of the new type of stations in the data set there will be a separation of that data. Started already with the fueling rates, times, and amounts.

Accomplishments and Progress:
Responses to Previous Year Reviewers' Comments

- Comment: There is no indication as to whether NREL can manage, or needs to prepare for, data processing and analysis for reporting from 40+ additional California hydrogen stations and 10+ Northeast stations.
  - **Response:** The NFCTEC is equipped to handle multiple data sets with the tools developed and has the expertise to process many projects and datasets. The templates are continually updated to be able to collect the latest information that is pertinent to the infrastructure. What really helps us out here is data submissions that are consistent, of good quality and inclusive of all the details requested.
- Comment: Collect more detailed information about reported downtime/failures/issues with compressors.
  - **Response:** Compressor operation and maintenance will continue to be analyzed and will be separated out for new generation once there are enough of them in the dataset. Bus data is generally analyzed in a separate tech val project but will look for opportunities to display side-by-side or include in data sets. Will continue to request more detailed data in the templates and from partners on compressor failures. We will be working on more frequent maintenance updates in coming year.

Collaborations

Data, feedback, and interactions with infrastructure partners make this project work

- **Partners involved with through DOE awards and voluntarily**
  - California Air Resources Board, California State University Los Angeles, Gas Technologies Institute, Hydrogen Frontier, Linde, Shell, Proton OnSite
- **California Energy Commission/NREL MOU**
  - Worked with CEC to include NREL templates as data reporting requirement in latest Grant Funding Opportunity (GFO) (proposals due in July)
    - Station awards required to report data for 1 year
    - Station O&M awards required to report data for 3 years
  - New stations (from past awards) beginning to report data through O&M grant funding
- **Other organizations enhancing this activity**
  - California Air Resources Board
  - California Fuel Cell Partnership
  - California GoBiz
  - IPHE for international data sharing –sharing data for CDPs
  - H2USA
  - H2FIRST
  - Alternative Fuels Data Center (AFDC)

Collaborations: Station Project Partners

INFRASTRUCTURE

Partners providing data:

- California Air Resources Board
- California Energy Commission
- California State University LA
- Gas Technologies Institute
- Linde
- H2 Frontier
- Proton OnSite
- Shell
- IPHE and HySUT

Proposed Future Work

- **Analysis and CDP publication**
  - Complete quarterly analysis of CY16 Q1 and Q2 data and publish results (10/2016)
  - Complete quarterly analysis of CY16 Q3 and Q4 data and publish results (4/2017)
- **Update data collection and analysis to address:**
  - Availability of stations
  - In depth review of any new safety items
  - Increased frequency of maintenance data reporting
  - Separate newer “Retail” stations from demonstration stations
  - Work with others involved in Safety and Risk Assessment activities where this data may be useful

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
- **Technical Accomplishments and Progress**
  - Analyzed performance data from 11 stations and cost data from planned stations
  - Performed detailed reviews of individual data 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, with more frequent maintenance updates
  - Identify new opportunities to document hydrogen infrastructure progress and share data with safety and risk assessment activities

Thank you

All CDPs, including other projects, available at www.nrel.gov/hydrogen/proj_tech_validation

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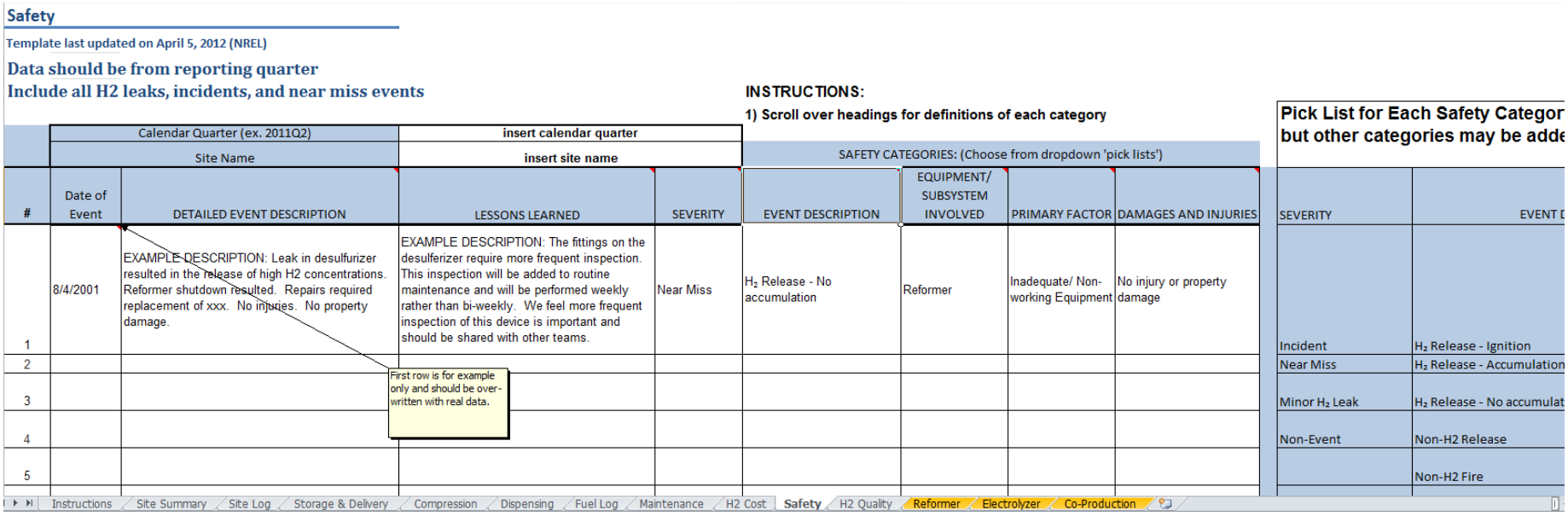
Technical Back-Up Slides

Approach: Data and Templates

Data templates developed to collect similar data from multiple projects

- **Continual updating as new topics develop**
  - Future updates needed for items such as fueling profiles and availability.
- **Shared with others**
  - California Air Resources Board Stations
  - California Energy Commission for inclusion in Grant Funding Opportunity (GFO) and awards
  - Safety and Maintenance templates/data used with International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) to coordinate international data sharing



Safety

Template last updated on April 5, 2012 (NREL)

Data should be from reporting quarter
Include all H2 leaks, incidents, and near miss events

INSTRUCTIONS:
1) Scroll over headings for definitions of each category

	Calendar Quarter (ex. 2011Q2)	insert calendar quarter		SAFETY CATEGORIES: (Choose from dropdown 'pick lists')			
	Site Name	insert site name					
#	Date of Event	DETAILED EVENT DESCRIPTION	LESSONS LEARNED	SEVERITY	EVENT DESCRIPTION	EQUIPMENT/ SUBSYSTEM INVOLVED	PRIMARY FACTOR	DAMAGES AND INJURIES
1	8/4/2001	EXAMPLE DESCRIPTION: Leak in desulfurizer resulted in the release of high H2 concentrations. Reformer shutdown resulted. Repairs required replacement of xxx. No injuries. No property damage.	EXAMPLE DESCRIPTION: The fittings on the desulferizer require more frequent inspection. This inspection will be added to routine maintenance and will be performed weekly rather than bi-weekly. We feel more frequent inspection of this device is important and should be shared with other teams.	Near Miss	H_2 Release - No accumulation	Reformer	Inadequate/ Non-working Equipment	No injury or property damage
2								
3								
4								
5								

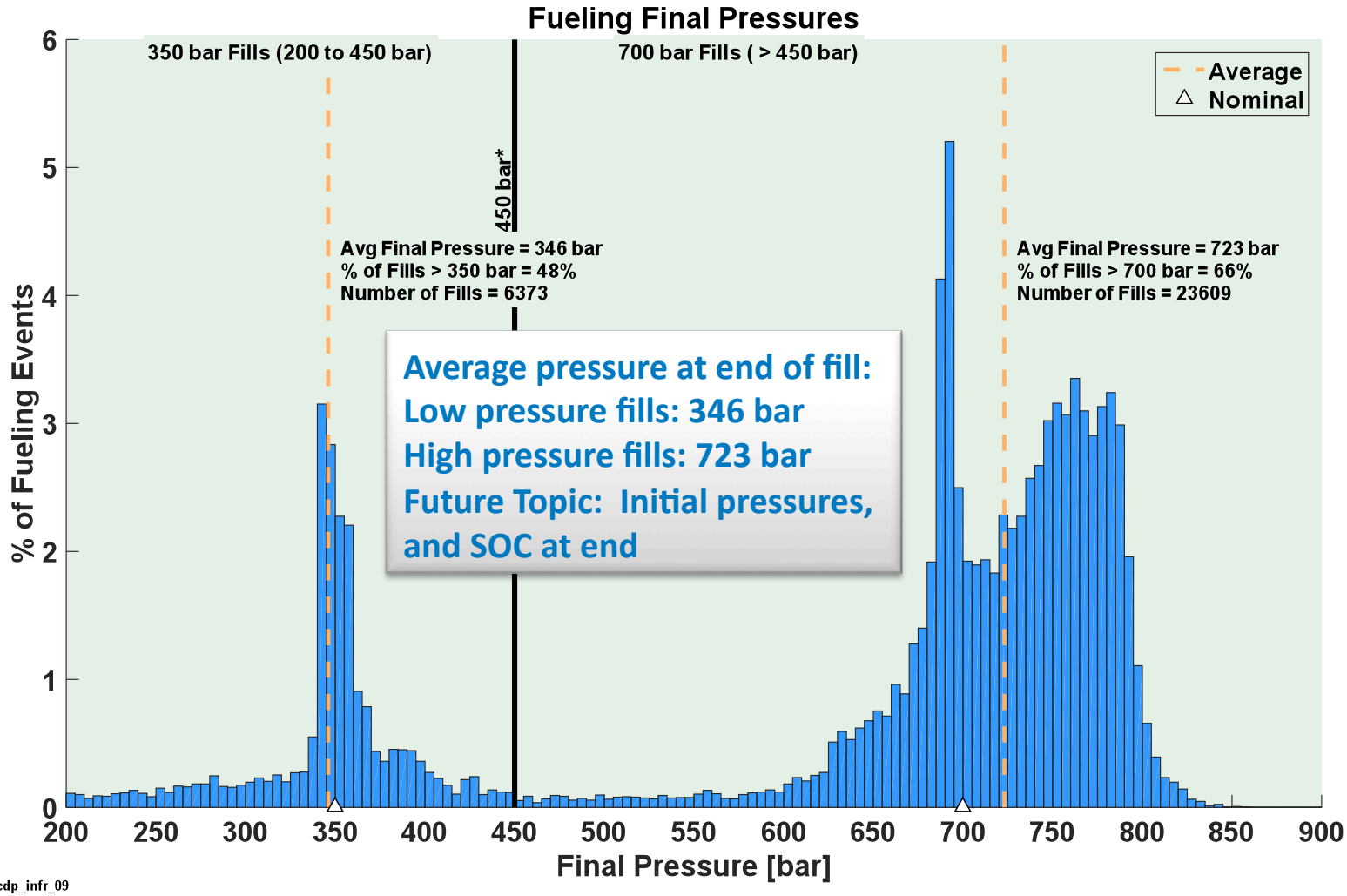
First row is for example only and should be over-written with real data.

Pick List for Each Safety Categor
but other categories may be adde

SEVERITY	EVENT D
Incident	H_2 Release - Ignition
Near Miss	H_2 Release - Accumulation
Minor H_2 Leak	H_2 Release - No accumulat
Non-Event	Non-H2 Release
	Non-H2 Fire

Instructions | Site Summary | Site Log | Storage & Delivery | Compression | Dispensing | Fuel Log | Maintenance | H2 Cost | Safety | H2 Quality | Reformer | Electrolyzer | Co-Production

Accomplishments and Progress: Fueling Final Pressures

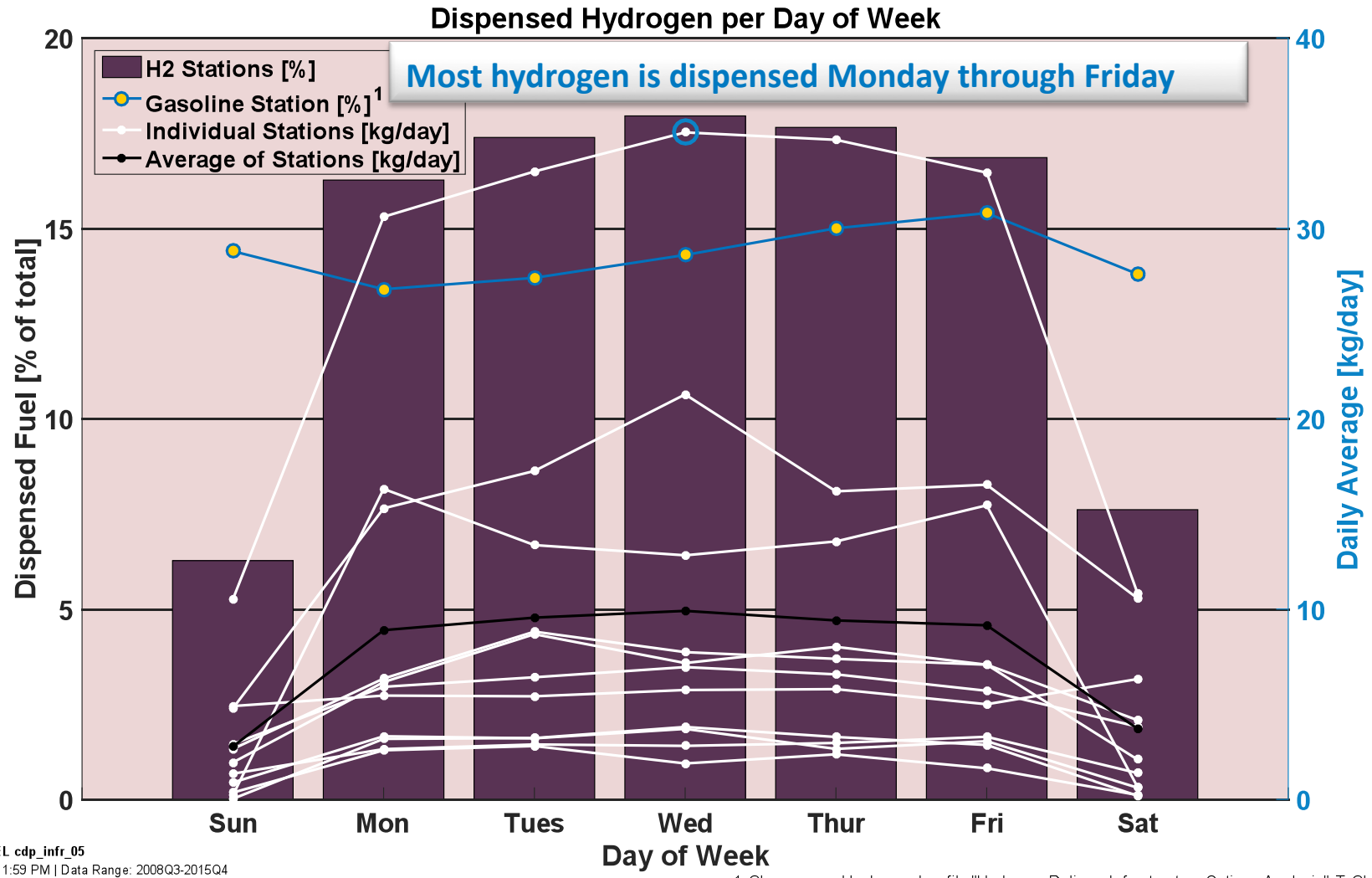


NREL cdp_infr_09

Created: Apr-15-16 12:20 PM | Data Range: 2008Q3-2015Q4

*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.

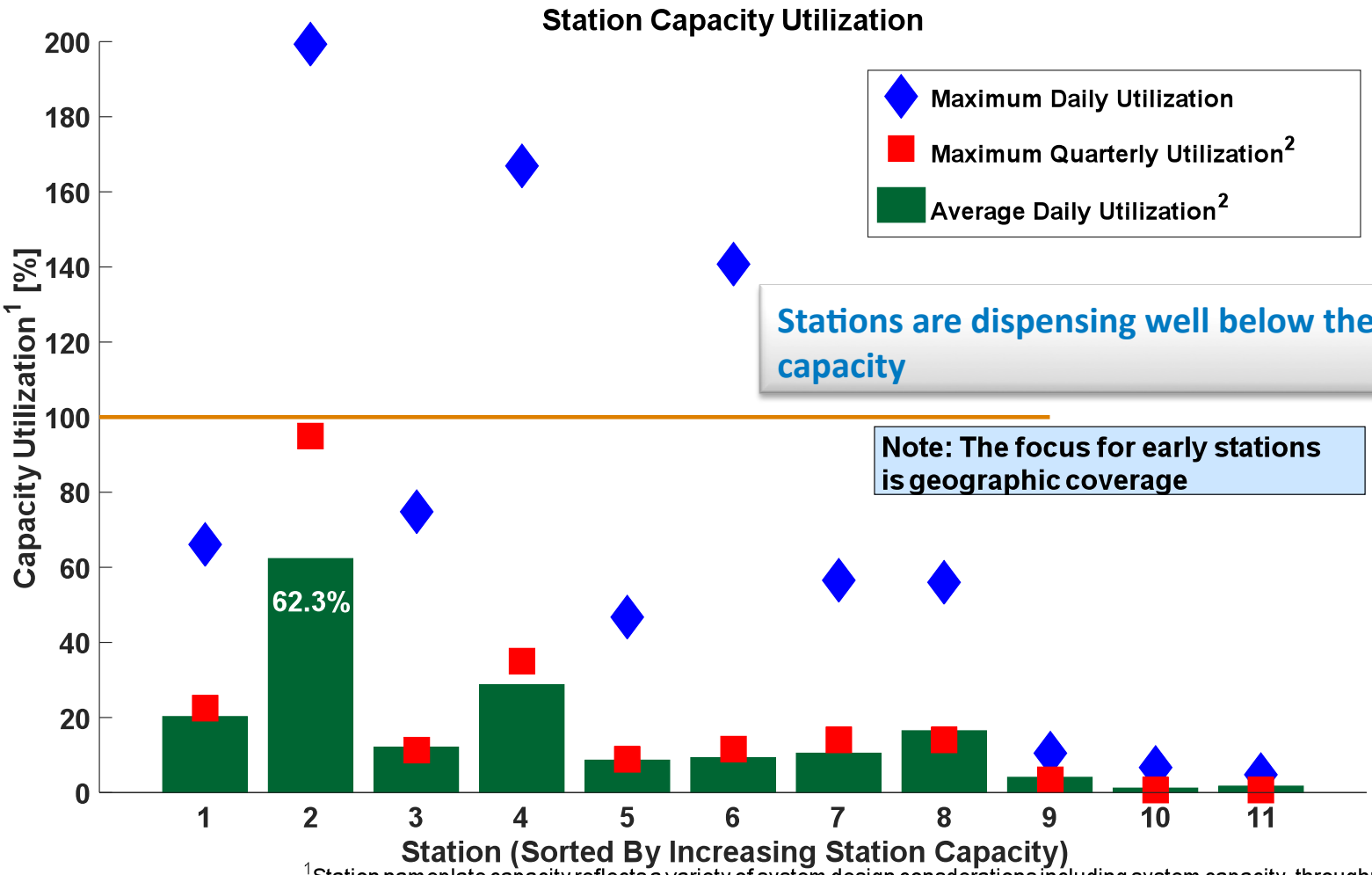
Accomplishments and Progress:
Dispensed Hydrogen per Day of Week



NREL cdp_infr_05
Created: Apr-25-16 1:59 PM | Data Range: 2008Q3-2015Q4

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

Accomplishments and Progress: Station Capacity Utilization



Stations are dispensing well below their stated capacity

Note: The focus for early stations is geographic coverage

NREL cdp_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

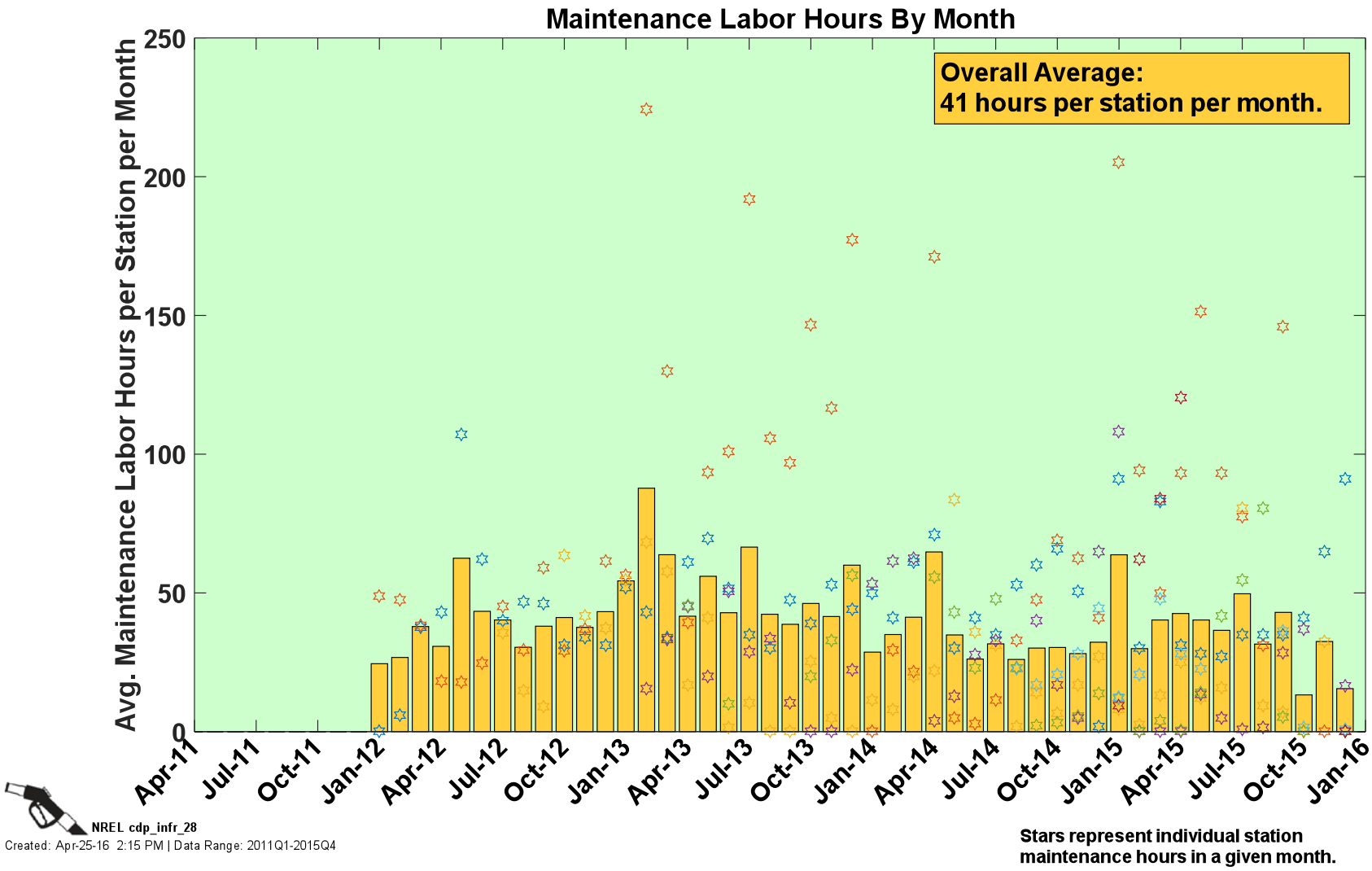
Safety (& Maintenance) Learnings

From Safety Reports Template

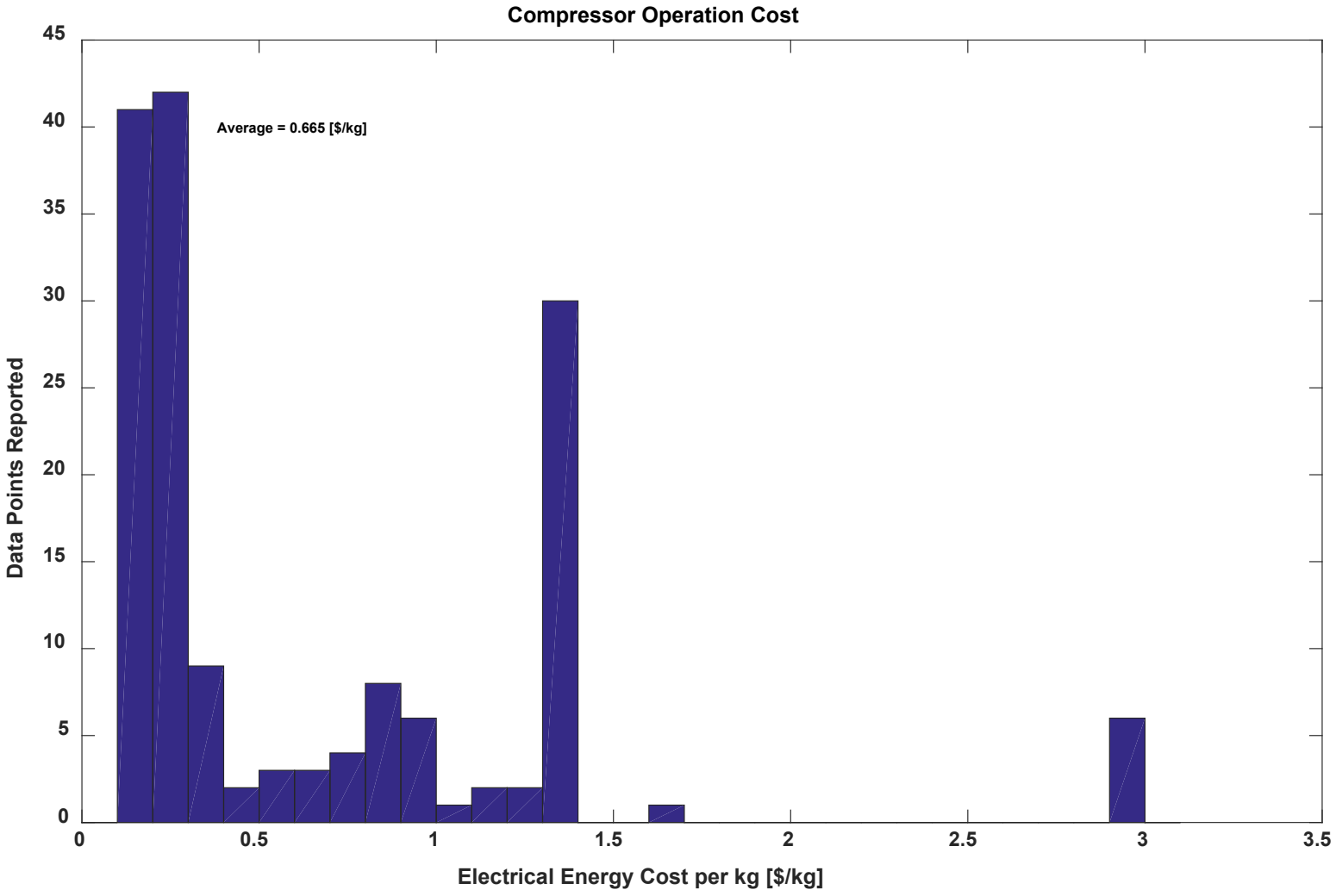
Categories and simple descriptions

- Alarms not communicated
- Breakaway leak
- Check compressor oil filter
- Check integrity of delivered equipment
- Compressor leaking at startup normal?
- Does isolated leak need to shut down station?
- Electrical glitch
- Estop activated after hearing escaping gas-nitrogen
- Estop activated when nozzle stuck on car
- Estop activated without cause
- Estop flooded prevented restart
- False Alarm - No Fire
- Fill and leak check together caused shutdown - false leak alarm
- Filter to catch scrap from material processing
- Forgot to turn back on after maintenance
- Freezing and thawing caused moisture in communication connector
- Frozen cooling block - defrost
- HTO sensor fault
- Heat trace short caused false fire alarm
- Heavy rain triggered fire alarm
- Hose vent failure - nozzle stuck on car
- Loose wire intermittent problems
- Loud popping could be relief valve
- Mass balance alarm bug
- Mass balance alarm caused by high ambient temperature
- Power Issue - 3 Phase
- Predict service life better
- Proper installation prevents leaks
- Rain on sensor causing alarm
- Regular inspection of compressor valves
- Regular leak checks
- Regular station inspection
- Reset
- Spider web obscuring sensor
- Thermocouple failure shutdown station
- Vibration from normal activity shutdown dispenser
- Vibration isolation

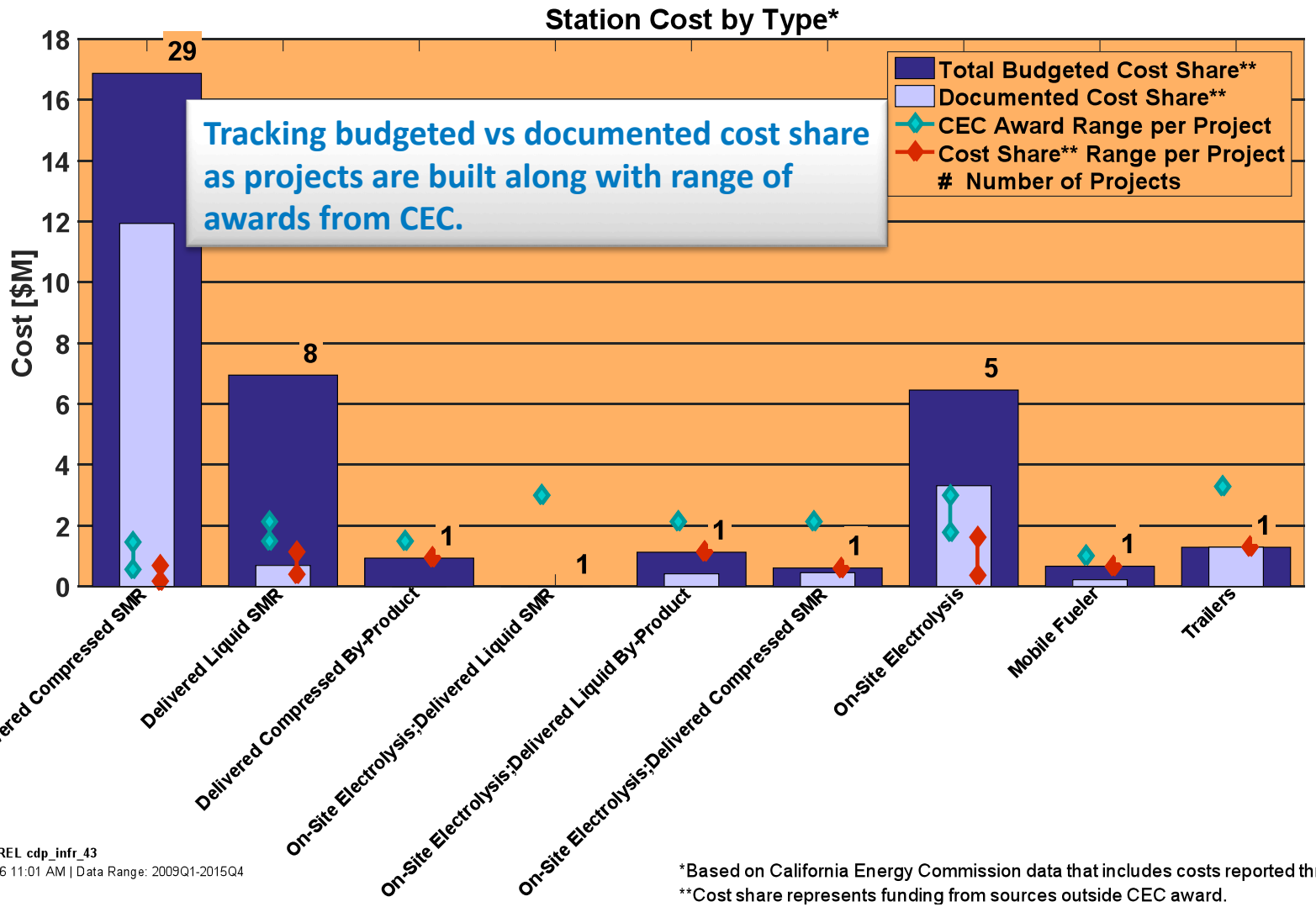
Accomplishments and Progress:
Maintenance Labor Hours by Month



Accomplishments and Progress:
Compressor Operation Cost



Accomplishments and Progress:
Station Cost by Type



NREL cdp_infr_43
Created: Apr-26-16 11:01 AM | Data Range: 2009Q1-2015Q4

*Based on California Energy Commission data that includes costs reported through 2015Q4.
**Cost share represents funding from sources outside CEC award.