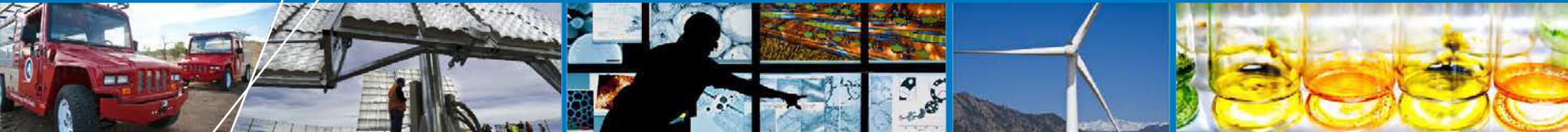


Hydrogen Station Data Collection and Analysis



***Sam Sprik (PI), Jennifer Kurtz, Chris Ainscough,
Genevieve Saur, Mike Peters***
National Renewable Energy Laboratory
June 11, 2015
2015 DOE Annual Merit Review
Washington, DC

Project ID TV017
NREL/PR-5400-64222

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: \$785k
- FY14 DOE funding: \$200k
- FY15 planned DOE funding: \$300k

Barriers

- Lack of current hydrogen refueling infrastructure performance and availability data

Partners

- California Air Resources Board (CARB)
- California Energy Commission (CEC)
- California State University, Los Angeles (CSULA)
- Gas Technology Institute (GTI)
- Hydrogen Frontier
- Linde
- Shell
- Proton OnSite

*project continuation and direction determined annually by DOE

Project Objectives: Hydrogen Infrastructure Evaluation

FY15 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

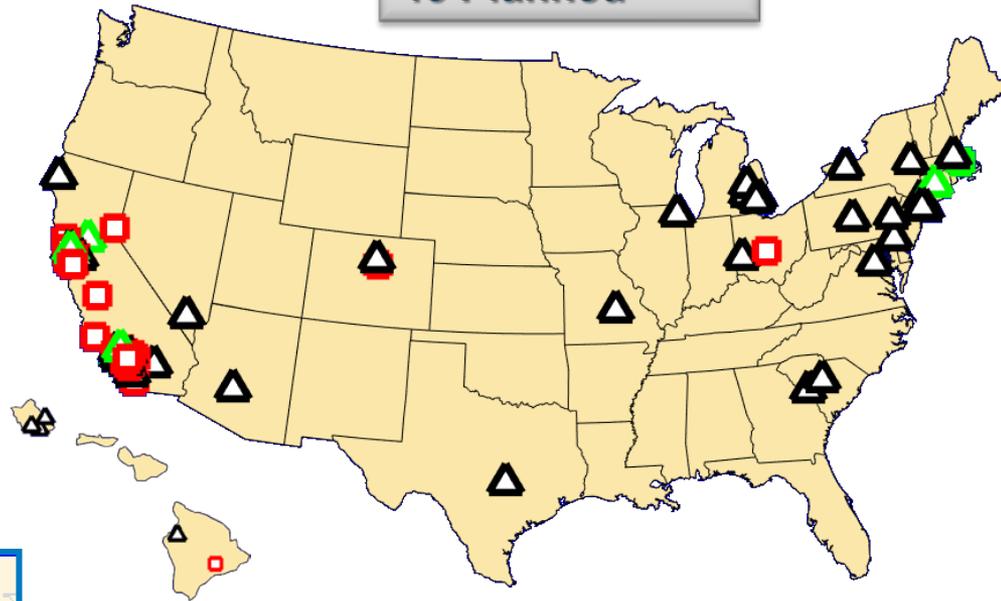
- **Location/Capacity/Utilization**
 - **Challenge:** Station coverage, hydrogen availability, minimal wait time.
 - **Metrics:** Station usage patterns and geographic locations
- **Fueling**
 - **Challenge:** Vehicles fueled in an acceptable amount of time
 - **Metrics:** Fueling rates, times, amounts, back-to-back fills, communication
- **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: Station Locations

51 Operational
46 Planned

N. California

Legend
 ▲ Operational
 ◻ Future
 — Current Project



Los Angeles Metropolitan

Los Angeles Area

- Maintain database of hydrogen stations in the U.S.
- Sync location data with:
 - Alternative Fuels Data Center (AFDC)
 - Pacific Northwest National Laboratory (PNNL)
 - FCHEA

Approach: National Fuel Cell Technology Evaluation Center (NFCTEC)

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 and Templates

Data templates developed to collect similar data from multiple projects

- Updated as new topics develop
 - Future updates needed for items such as station downtime and validating J2601 fills.
- Shared with others
 - California Air Resources Board projects
 - California Energy Commission for inclusion in Program Opportunity Notices (PONs) and awards
 - Safety and Maintenance templates/data discussed 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')				Pick List for Each Safety Category but other categories may be added		
Site Name		insert site name		EVENT DESCRIPTION	EQUIPMENT/SUBSYSTEM INVOLVED	PRIMARY FACTOR	DAMAGES AND INJURIES	SEVERITY	EVENT CATEGORY	
#	Date of Event	DETAILED EVENT DESCRIPTION	LESSONS LEARNED	SEVERITY	EVENT DESCRIPTION	EQUIPMENT/SUBSYSTEM INVOLVED	PRIMARY FACTOR	DAMAGES AND INJURIES	SEVERITY	EVENT CATEGORY
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 desulfurizer 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	H2 Release - No accumulation	Reformer	Inadequate/ Non-working Equipment	No injury or property damage	Incident	H2 Release - Ignition
2									Near Miss	H2 Release - Accumulation
3									Minor H2 Leak	H2 Release - No accumulation
4									Non-Event	Non-H2 Release
5										Non-H2 Fire

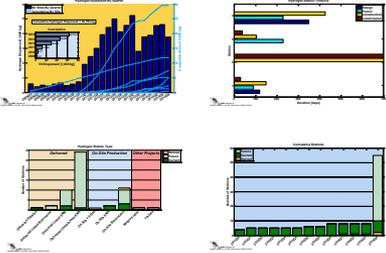
First row is for example only and should be overwritten with real data.

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

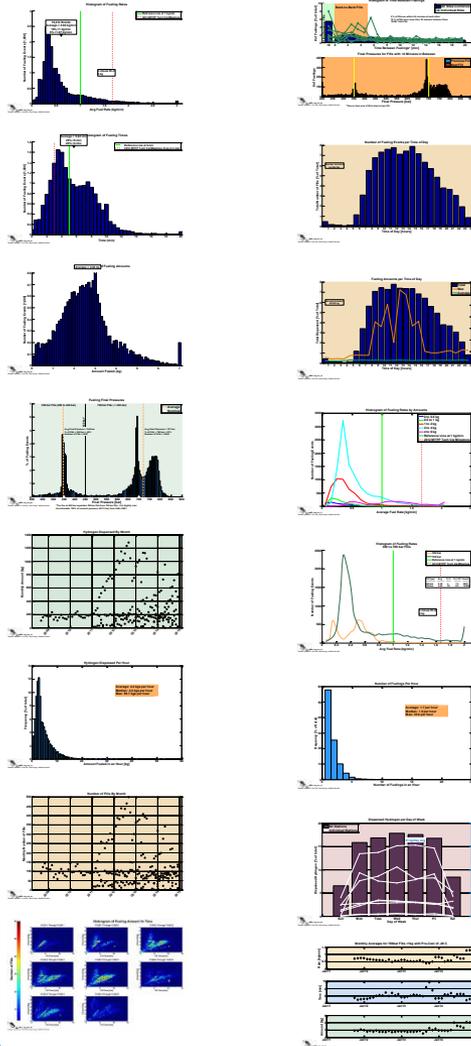
Accomplishment: 43 Infrastructure CDPs – 9 Categories



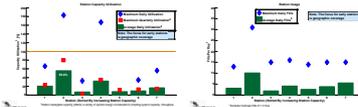
Deployment and Overview (1,10,11,27)



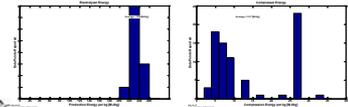
Refueling (2,3,4,5,8,9,12,13,14,15,16,17,18,19,20)



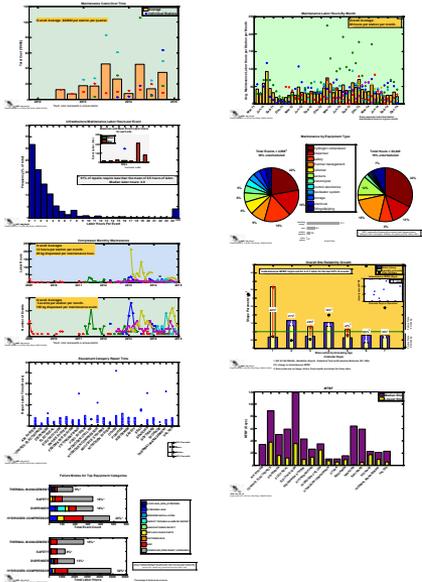
Utilization (6,7)



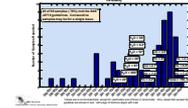
Efficiency (35,36)



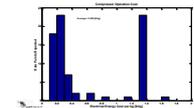
Maintenance, Reliability, Availability (21,22,23,24,26,28,30,37,38)



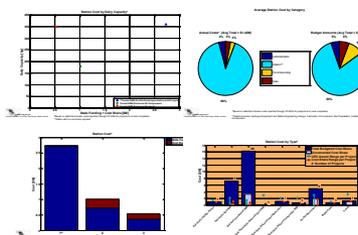
H2 Quality (25)



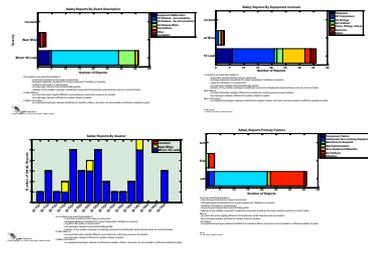
Operation Cost (39)



Station Cost (40,41,42,43)



Safety (31,32,33,34)



CDPs created from infrastructure data through 12/2014

Hydrogen & Fuel Cell Research

More Search Options
Site Map

- 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 Vehicle Learning Demonstration
 - Fuel Cell Bus Evaluations
 - Early Fuel Cell Market Demonstrations
 - Fuel Cell Technology Status Analysis
 - Hydrogen Fueling Infrastructure Analysis
 - Stationary Fuel Cell Systems Analysis
- Success Stories**
- Research Staff**
- Facilities**
- Working with Us**
- Energy Analysis & Tools**
- Publications**
- News**

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.

Animated Map Correlates Fuel Cell Usage for Backup Power with Grid Outages



Learn how NREL developed the time-lapse geographical visualization maps or view the animation, which covers January 2010 to December 2013.

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 technical 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.

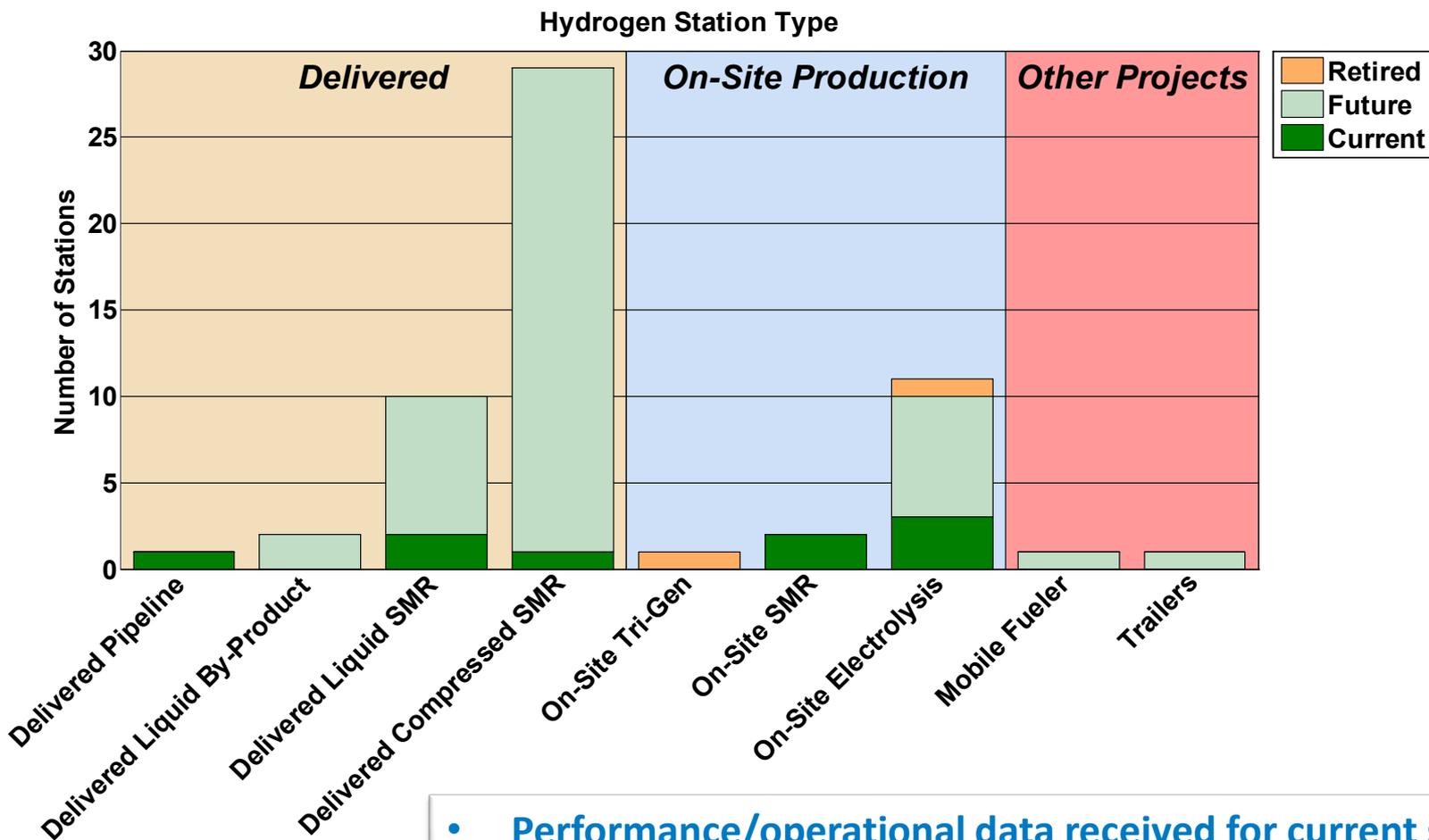
Click on the application type to see project highlights, analysis results, and detailed reports and presentations from the hydrogen and fuel cell technology validation efforts underway at NREL.

Vehicles CARS	Buses BUSES	Forklifts FORKLIFTS	Backup Power BACKUP POWER
Stationary Power PRIME POWER	Infrastructure INFRASTRUCTURE	Laboratory Stacks STACK	

Hydrogen Infrastructure Composite Data Products (CDPs)

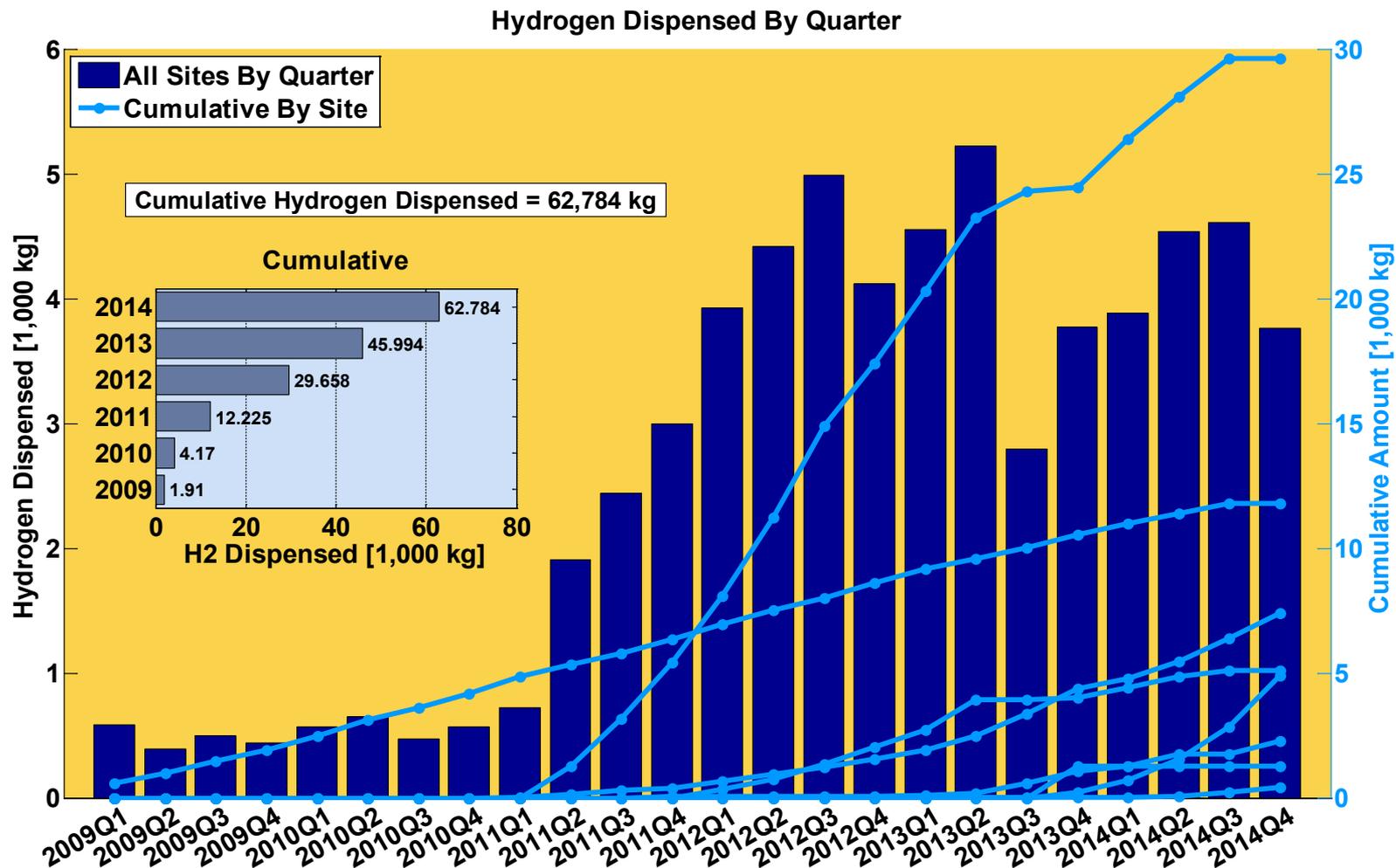
A subset of the infrastructure CDPs presented here. All CDPs, including other projects, available at www.nrel.gov/hydrogen/proj_tech_validation

Accomplishments and Progress: Hydrogen Stations by Type



- Performance/operational data received for current stations (except those recently operational)
- Award data received for future stations

Accomplishments and Progress: Hydrogen Dispensed by Quarter

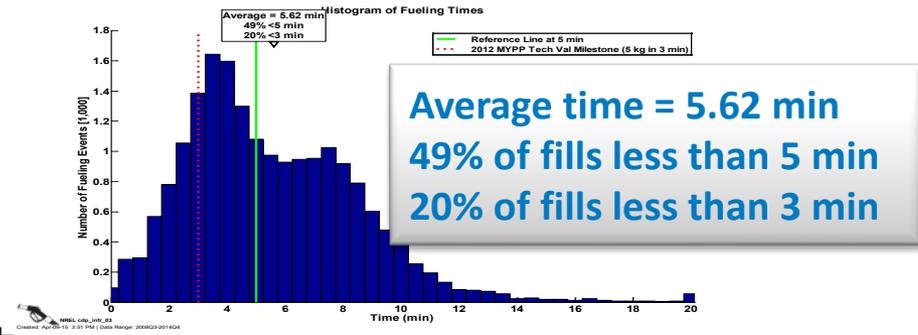
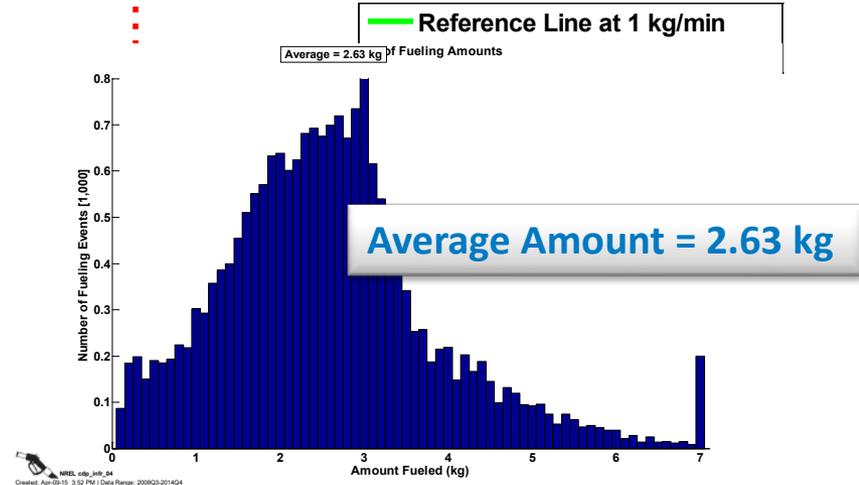
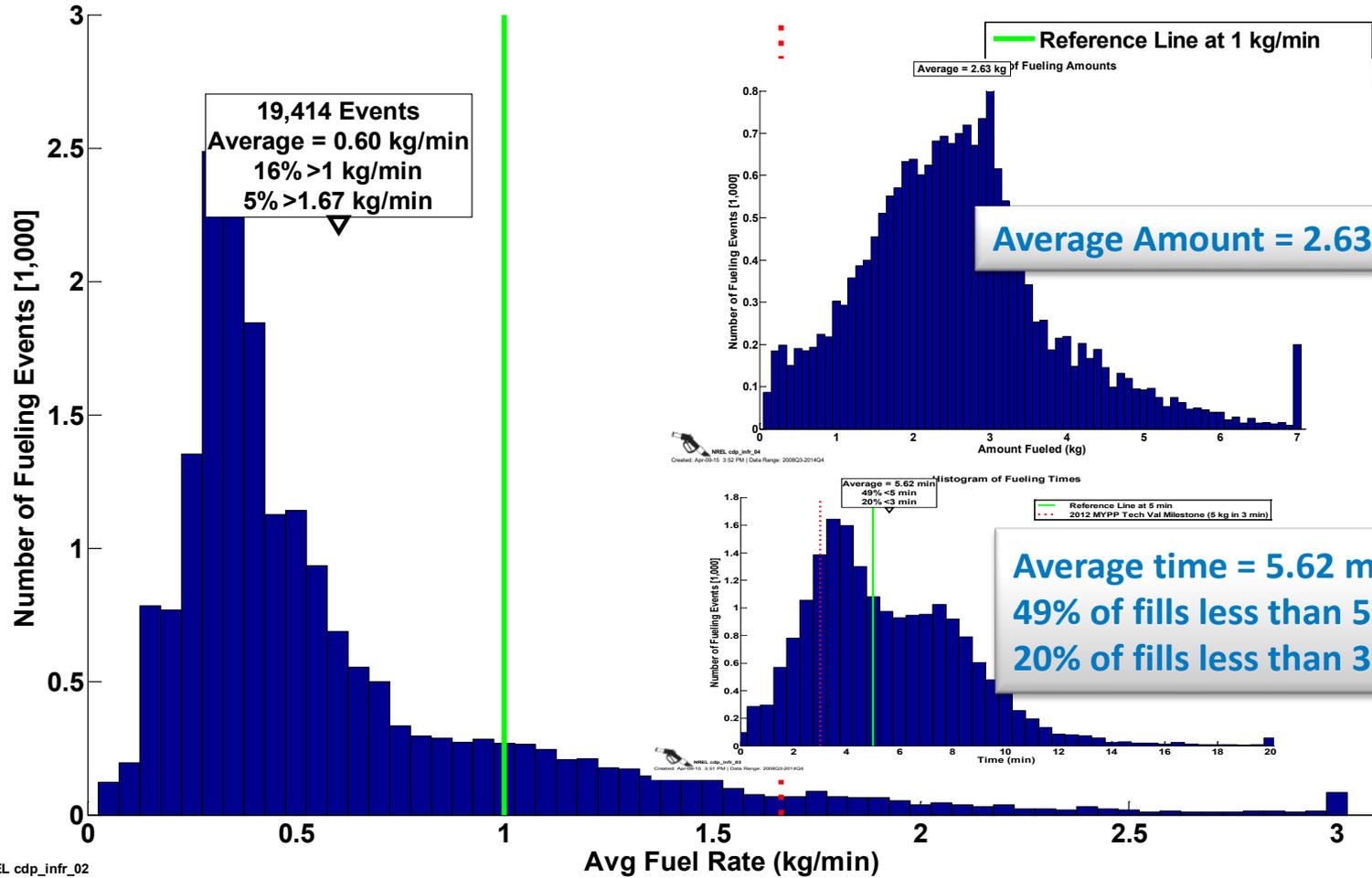


NREL cdp_infr_01

Created: Apr-29-15 8:53 AM | Data Range: 2008Q3-2014Q4

Accomplishments and Progress: Histogram of Fueling Rates, Times, Amounts

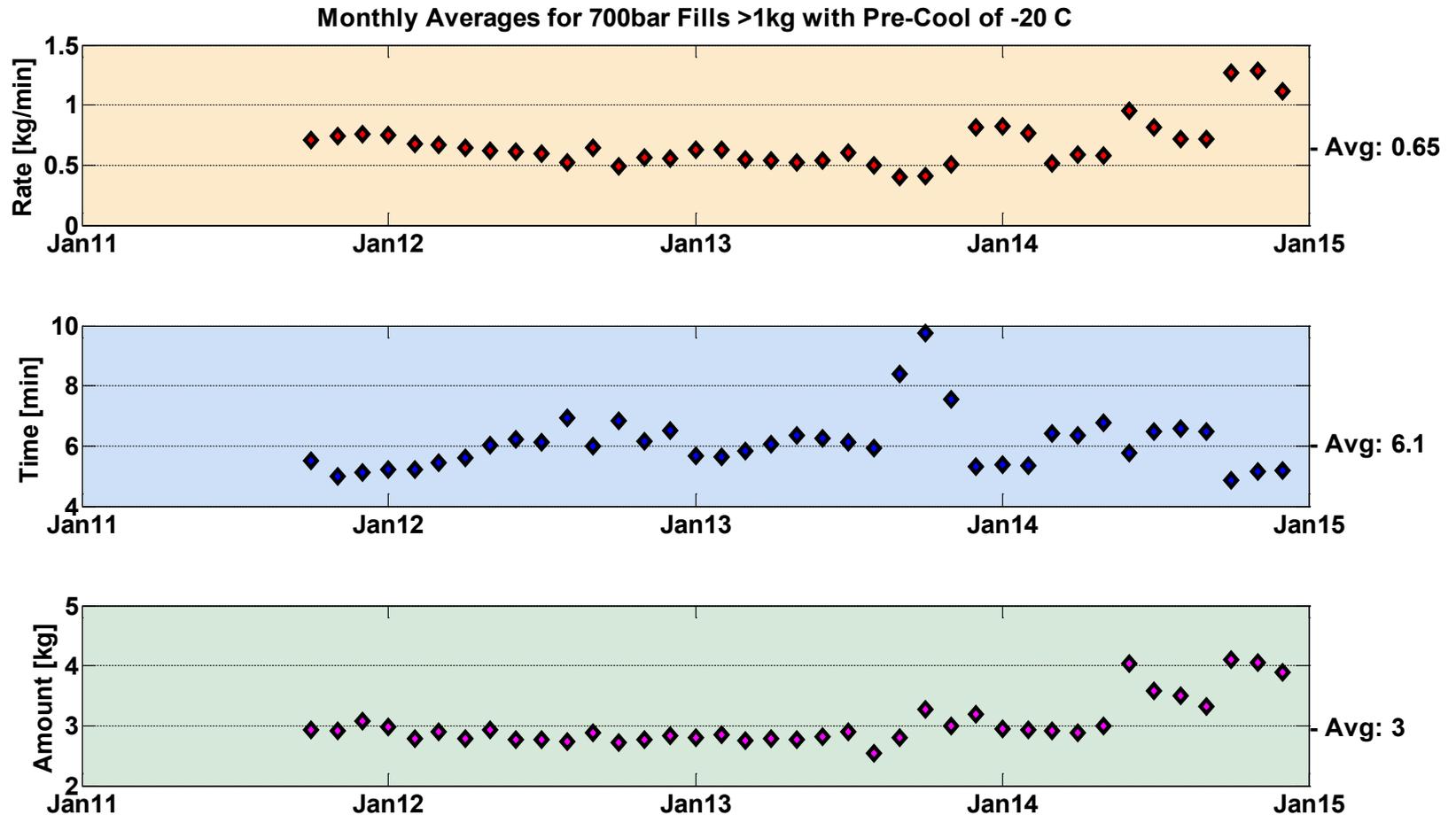
Histogram of Fueling Rates



 NREL cdp_infr_02
 Created: Apr-09-15 3:49 PM | Data Range: 2008Q3-2014Q4

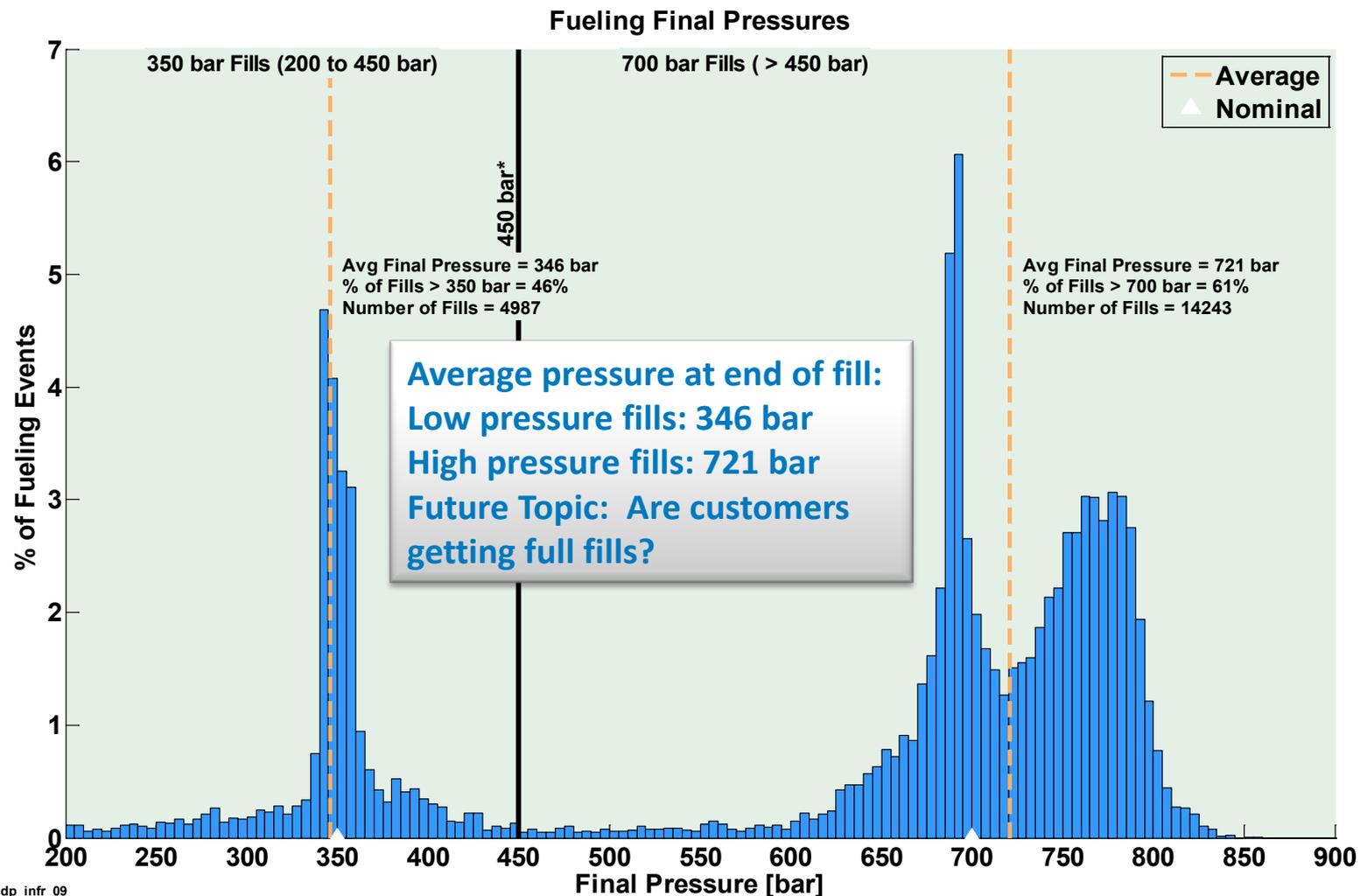
Accomplishments and Progress:

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



Averages for this subset:
Rate = 0.65 kg/min, Time = 6.1 min, Amount = 3 kg

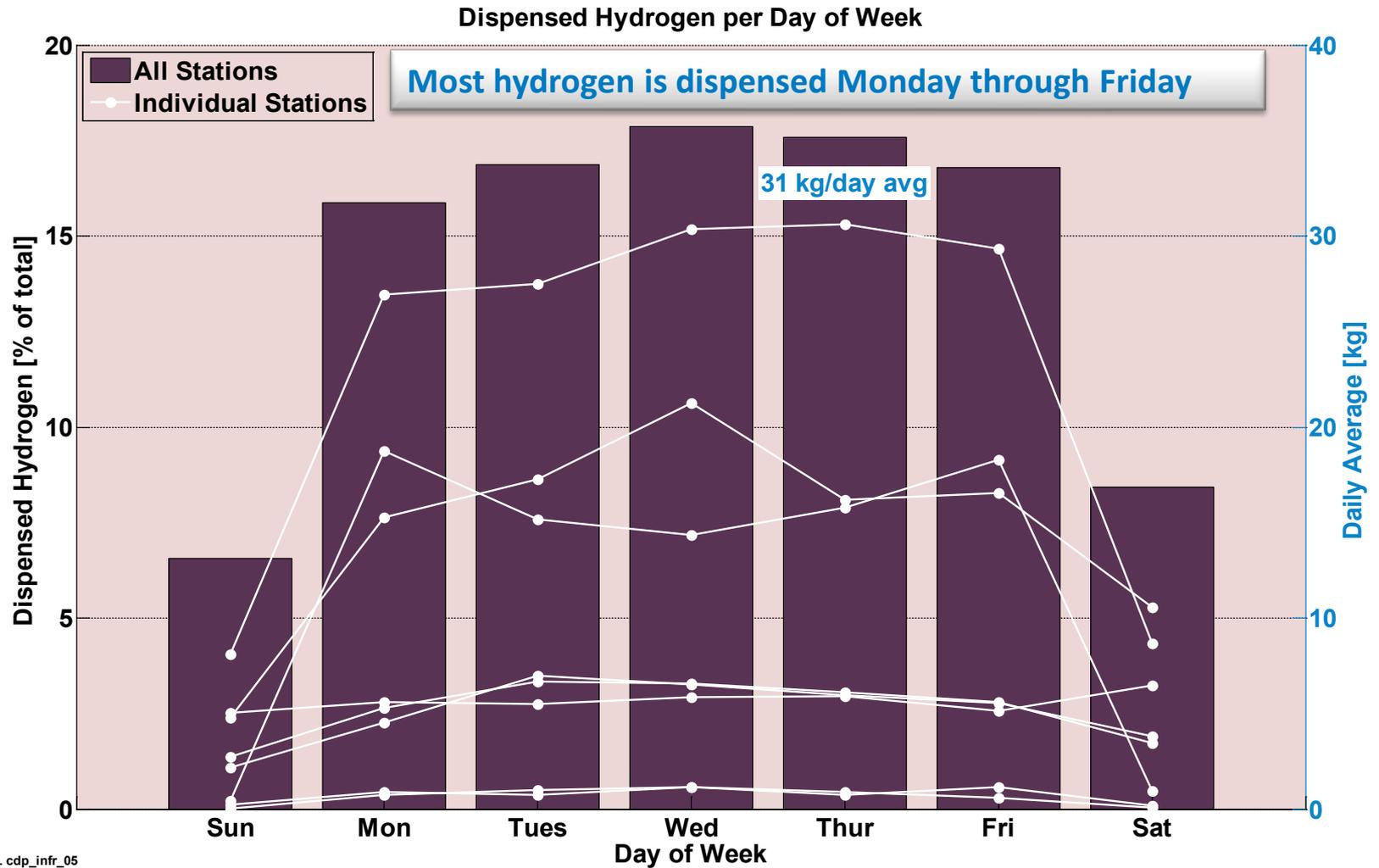
Accomplishments and Progress: Fueling Final Pressures



NREL cdp_infr_09
Created: Apr-09-15 3:58 PM | Data Range: 2008Q3-2014Q4

*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.

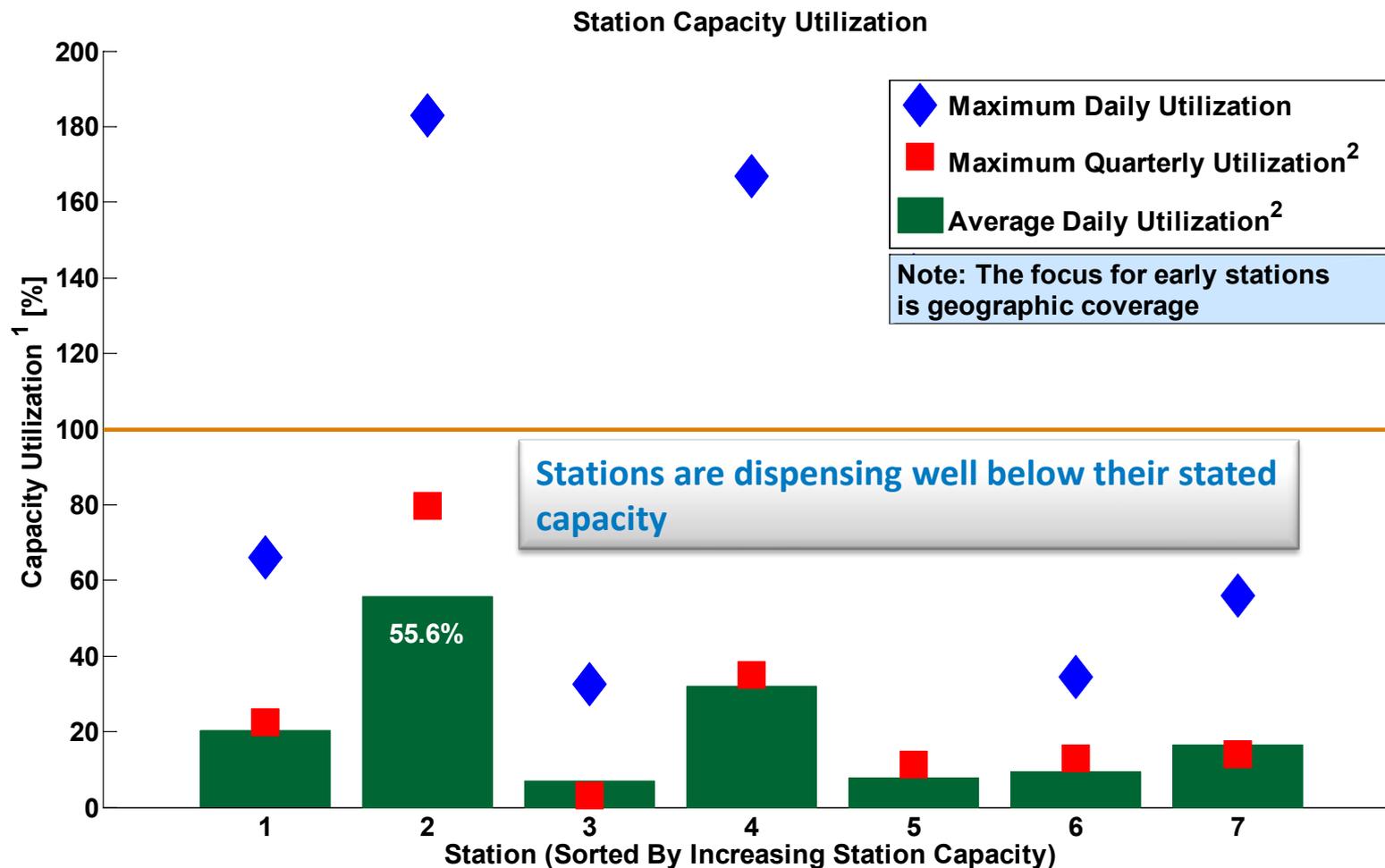
Accomplishments and Progress: Dispensed Hydrogen per Day of Week



NREL cdp_infr_05

Created: Apr-09-15 3:54 PM | Data Range: 2008Q3-2014Q4

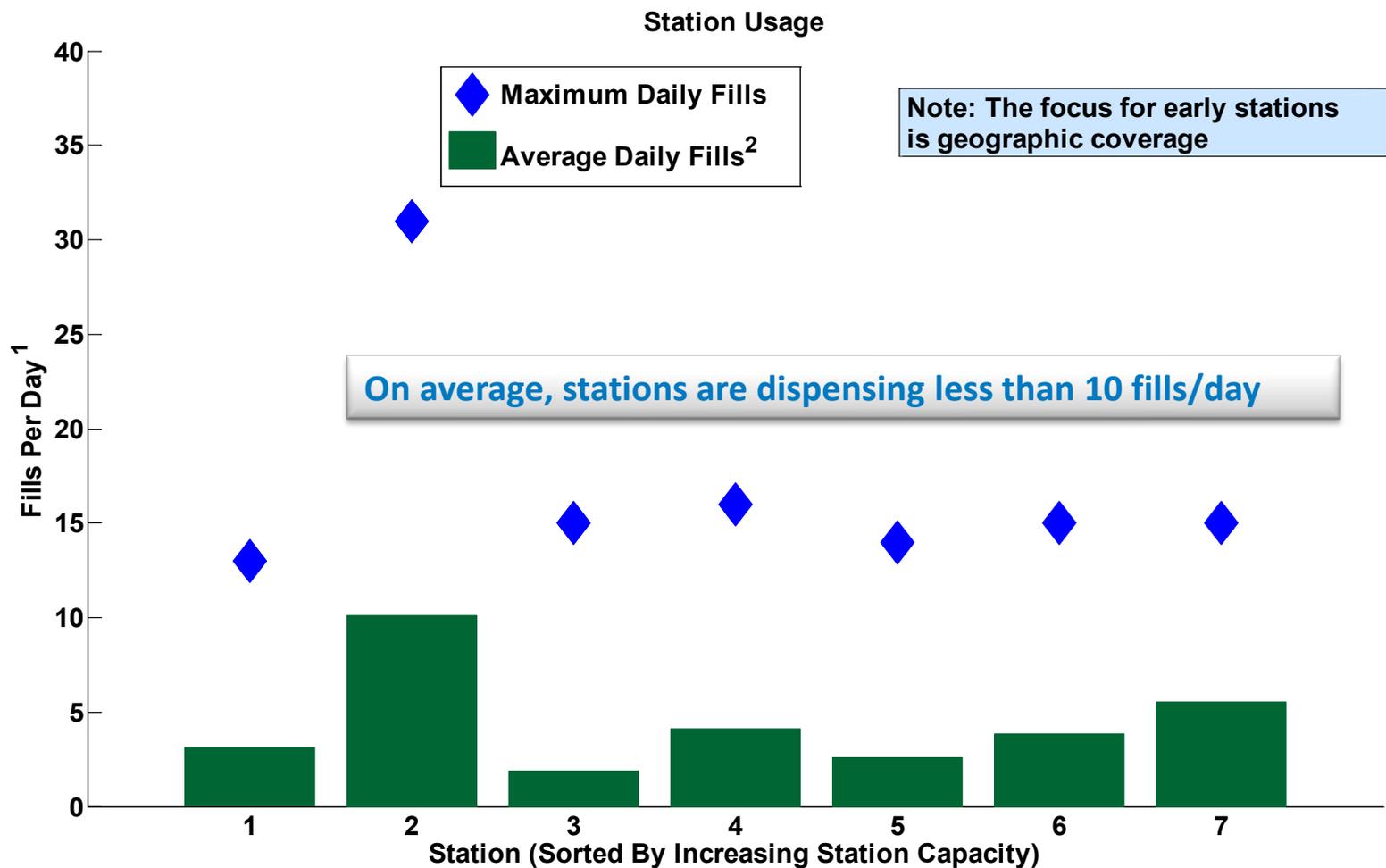
Accomplishments and Progress: Station Capacity Utilization



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

Accomplishments and Progress: Station Usage



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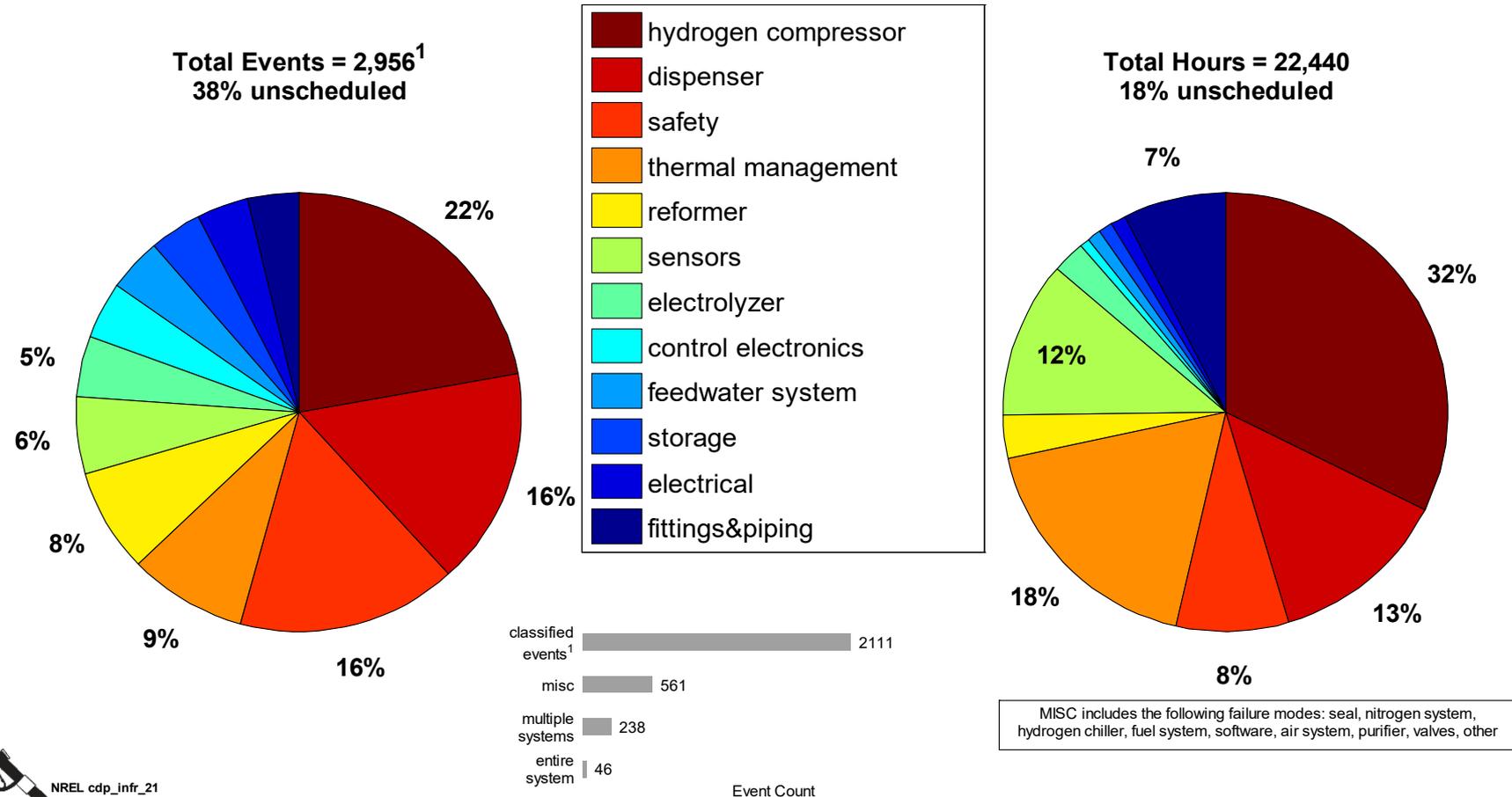
¹Excludes hydrogen fills of < 0.5 kg

²Average daily fills considers only days when at least one fill occurred

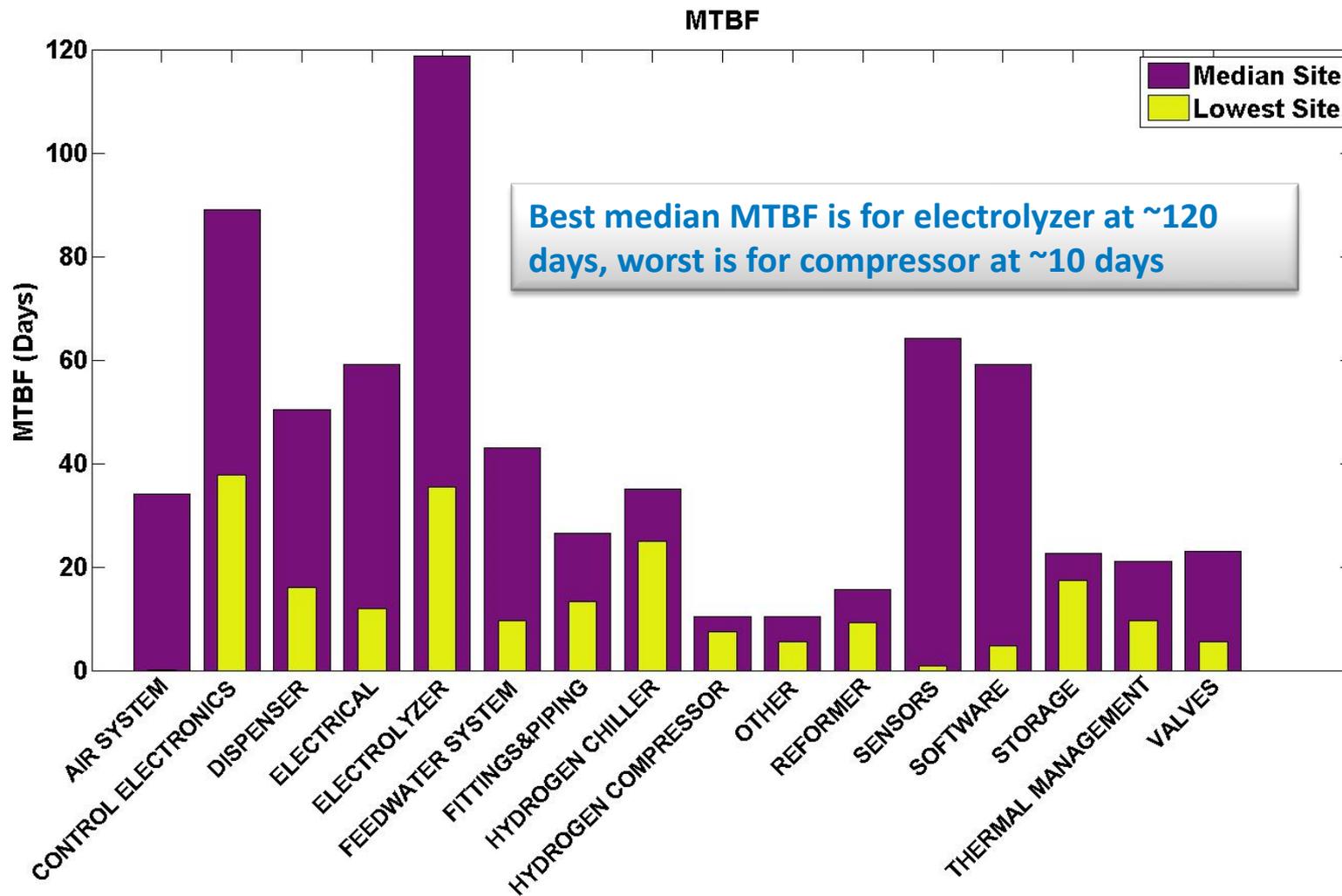
Accomplishments and Progress: Maintenance by Equipment Type

Most maintenance related to compressors and dispensers

Maintenance by Equipment Type



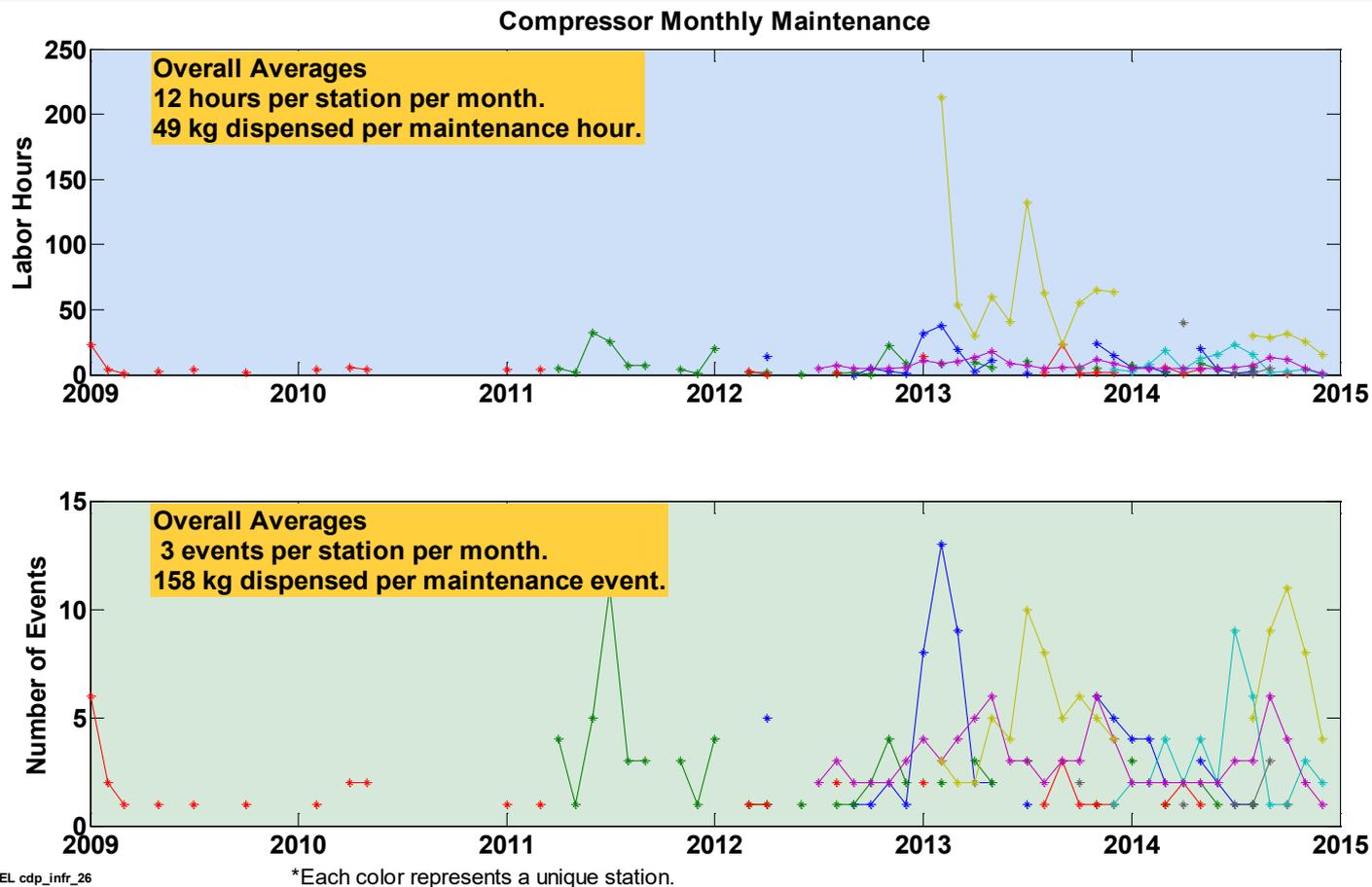
Accomplishments and Progress: Maintenance MTBF



NREL cdp_infr_38
Created: Apr-14-15 9:32 AM | Data Range: 2008Q3-2014Q4

Accomplishments and Progress: Compressor Monthly Maintenance

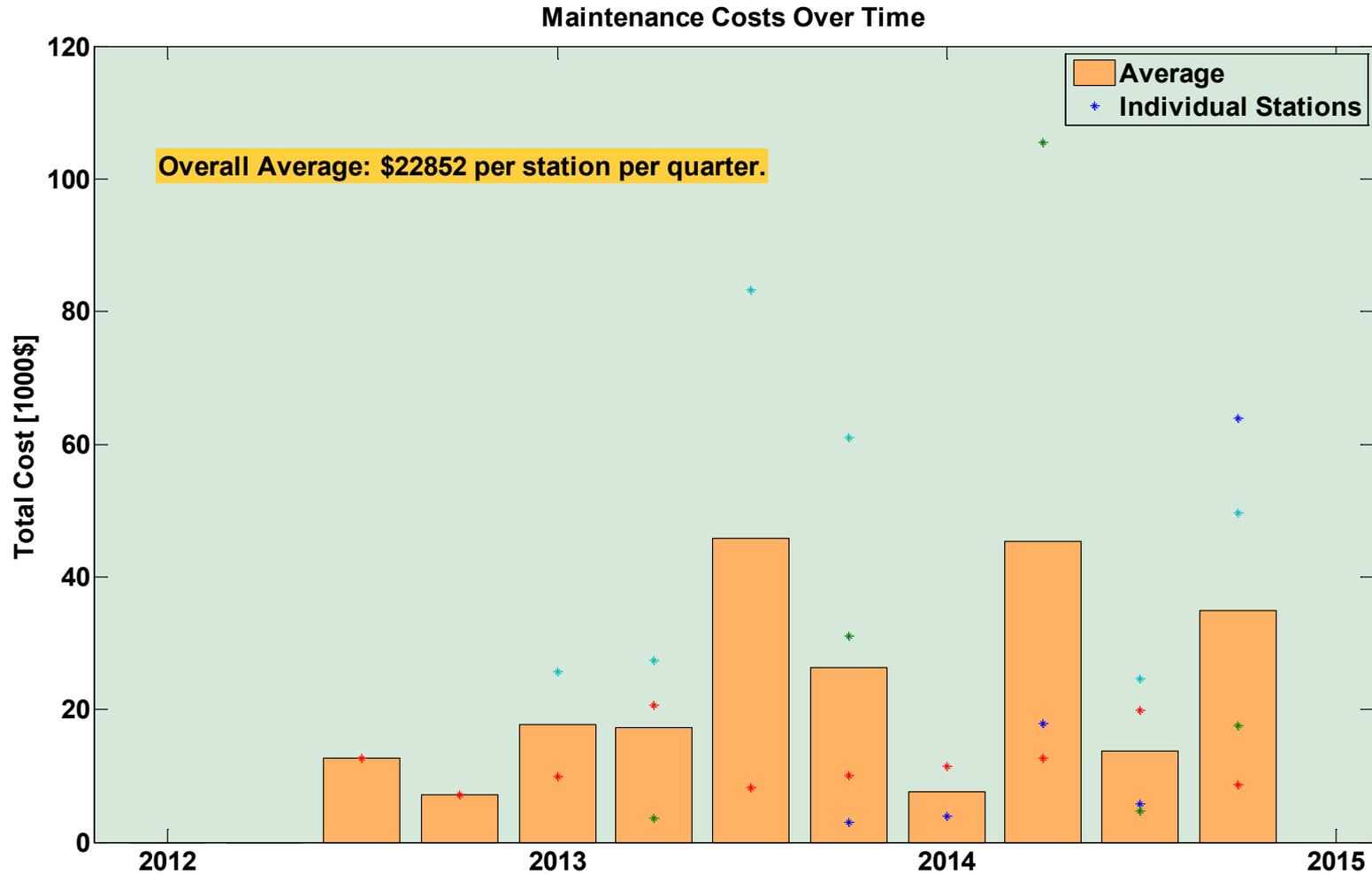
For compressors, the average per station is 3 maintenance events and 12 labor hours per month with 158 kg dispensed per maintenance event. For all maintenance items, the station average is 38 labor hours per month.



NREL cdp_infr_26

Created: Apr-28-15 11:26 AM | Data Range: 2009Q1-2014Q4

Maintenance Costs Over Time

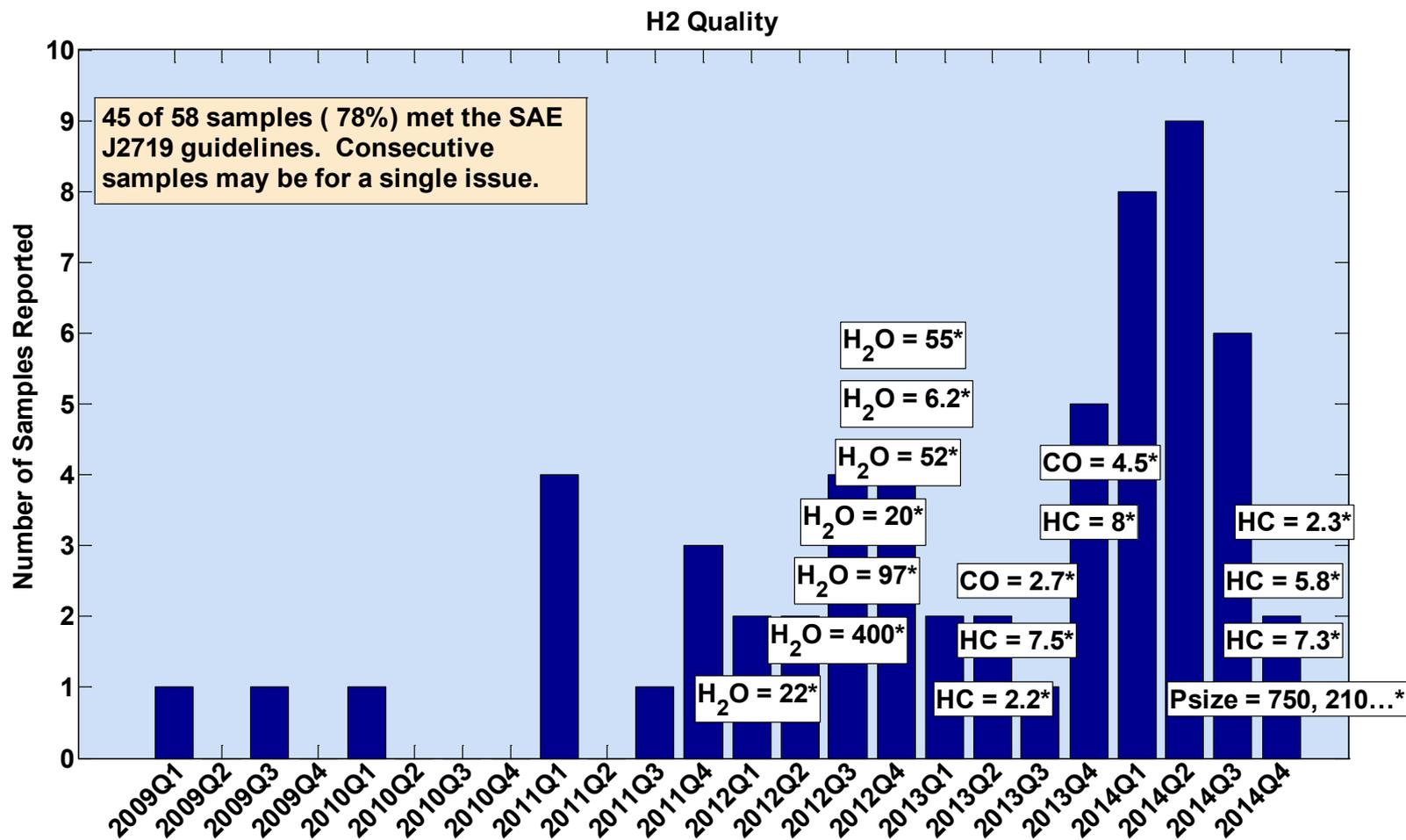


NREL cdp_infr_30

Created: May-06-15 8:31 AM | Data Range: 2009Q1-2014Q4

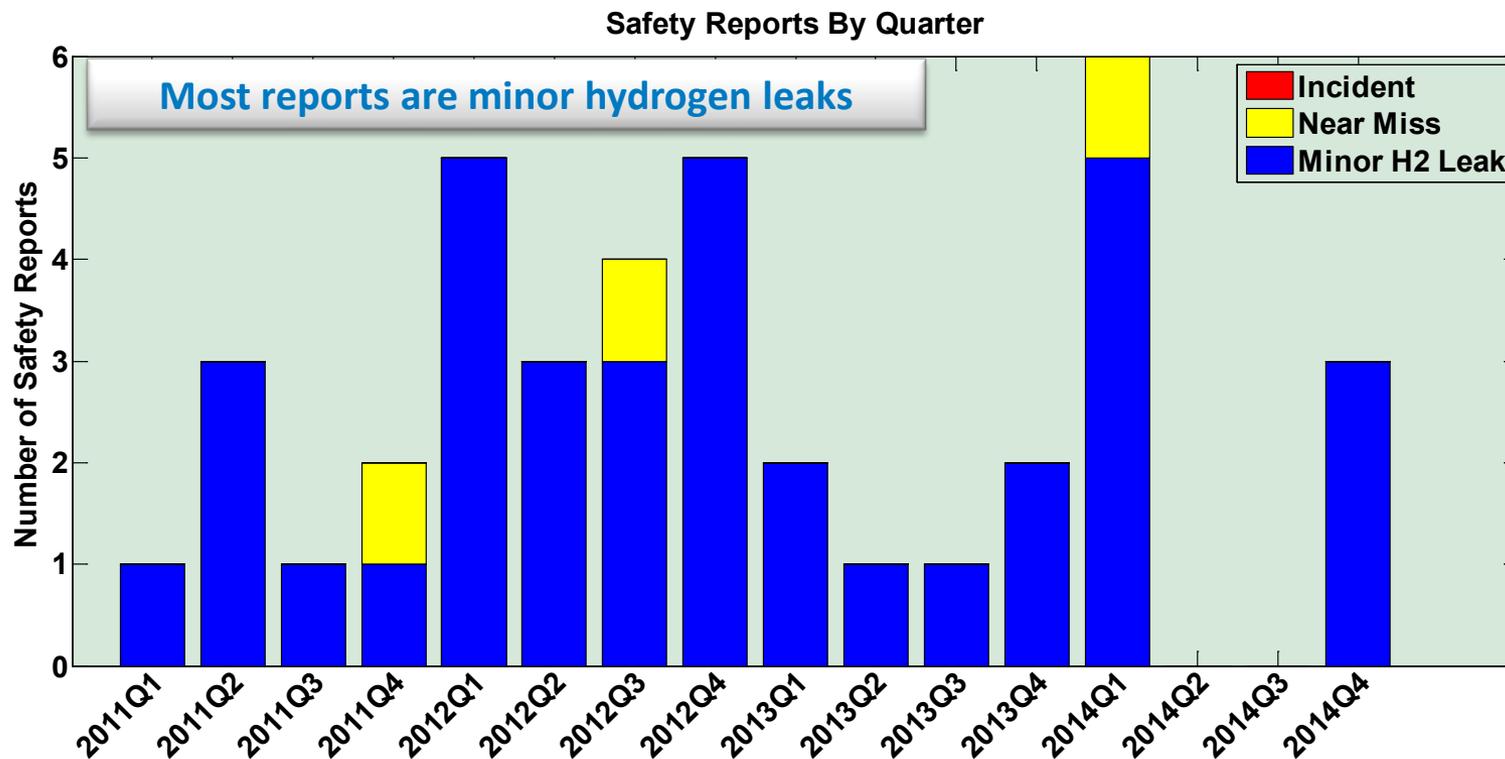
*Each color represents a unique station.

Accomplishments and Progress: H2 Quality



* 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 date

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:

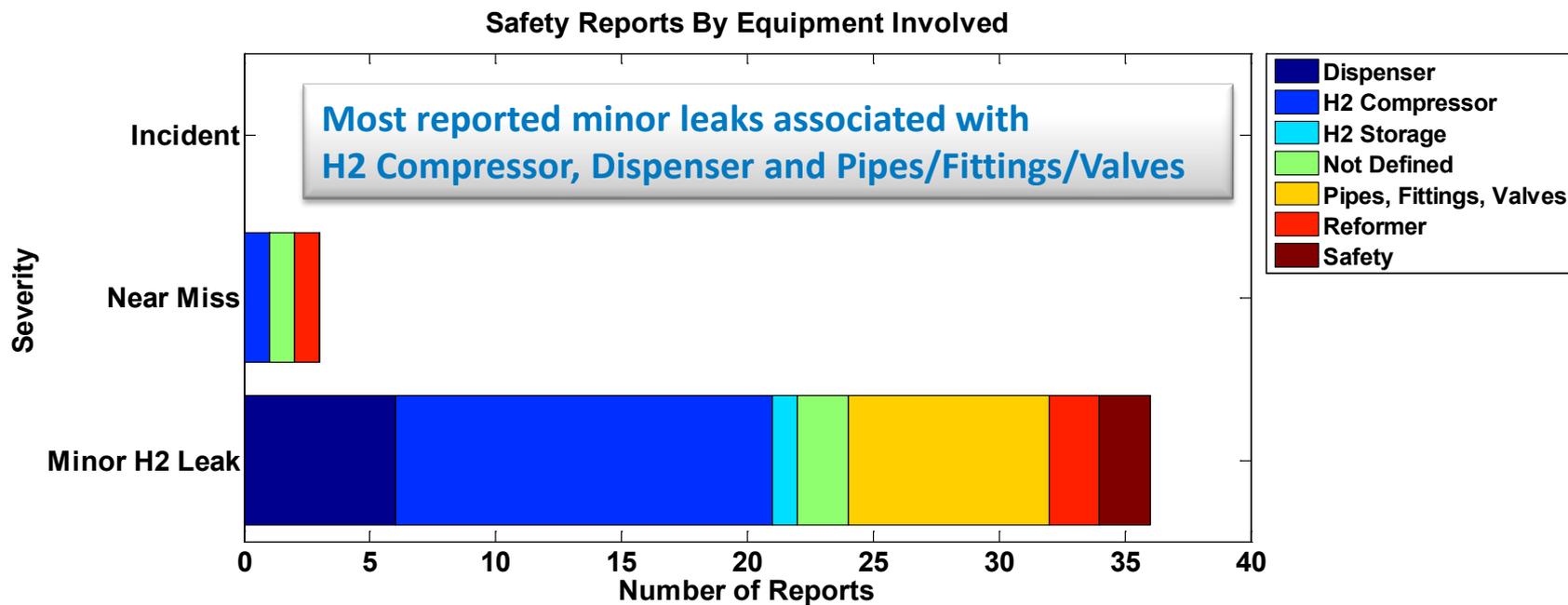
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



NREL cdp_infr_33

Created: May-04-15 11:39 AM | Data Range: 2009Q1-2014Q4

Accomplishments and Progress: Safety Reports by Equipment Involved



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:

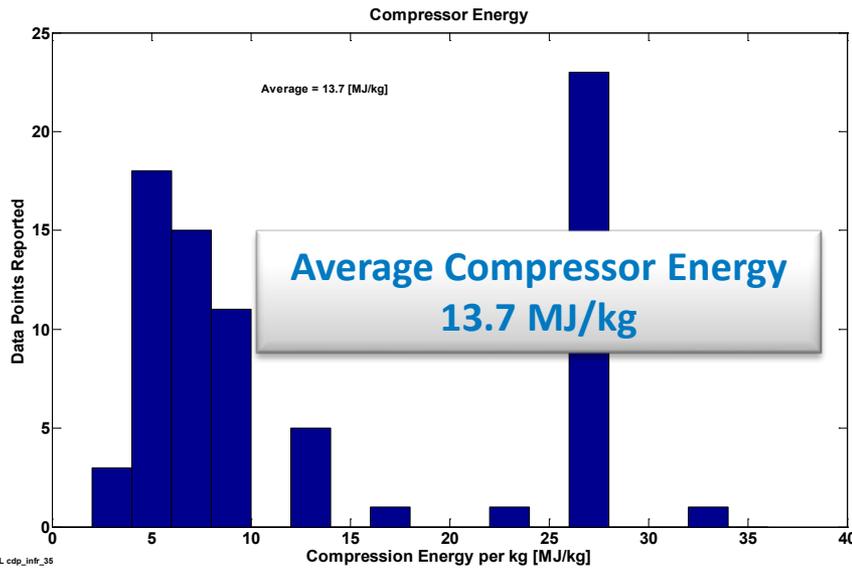
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite



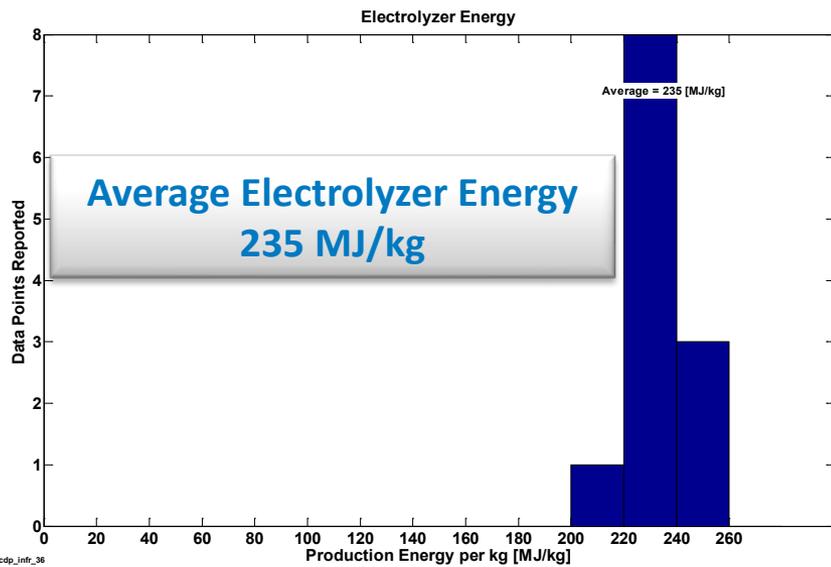
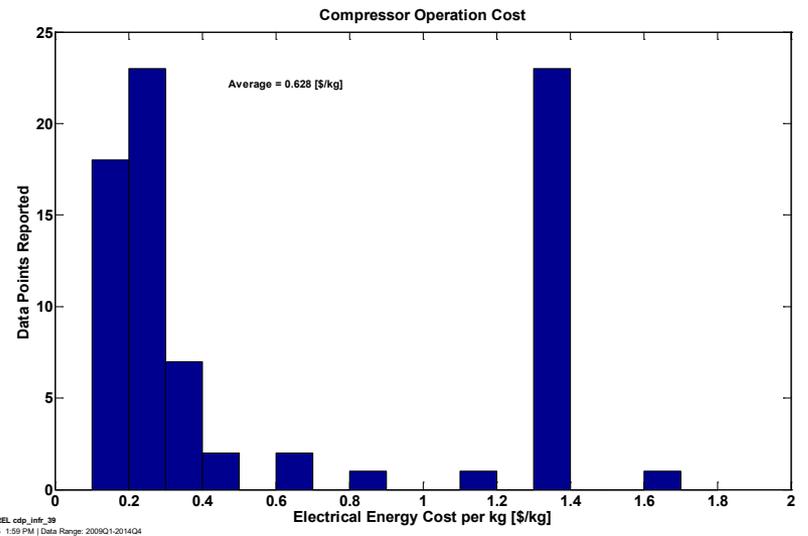
NREL cdp_infr_32

Created: May-04-15 11:39 AM | Data Range: 2009Q1-2014Q4

Accomplishments and Progress: Energy and Cost per kg of Hydrogen



**Average Compressor Energy Cost
\$0.628/kg**



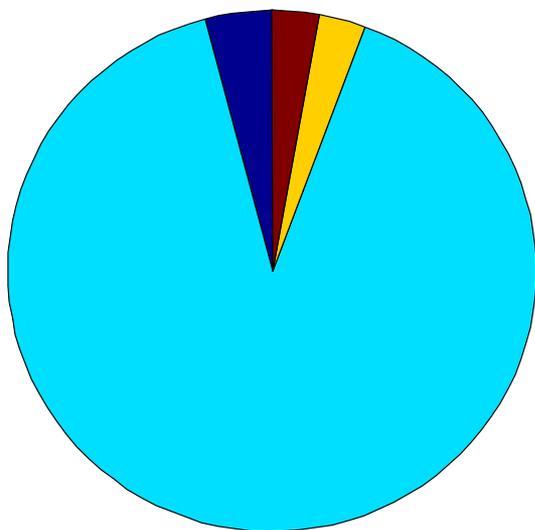
Accomplishments and Progress: Station Costs

Average Station Cost by Category

Based on award data, the stations that are near operational are expected to cost \$2.14M on average (including cost share). This includes different station types and will be updated by type as more stations come online.

Actual Costs* (Avg Total = \$1.42M)

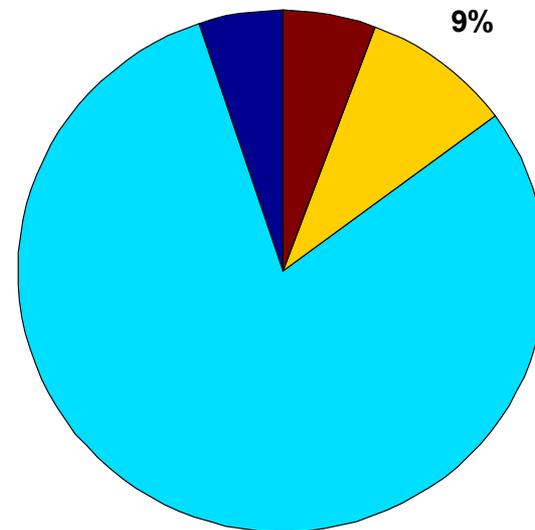
4% 3% 3%



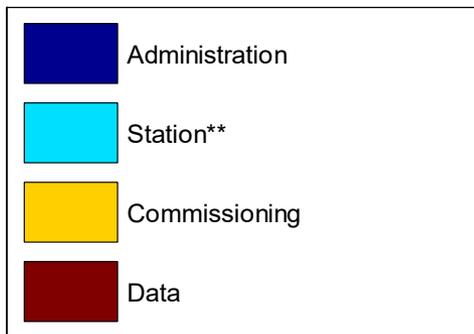
90%

Budget Amounts (Avg Total = \$2.14M)

5% 6%



80%

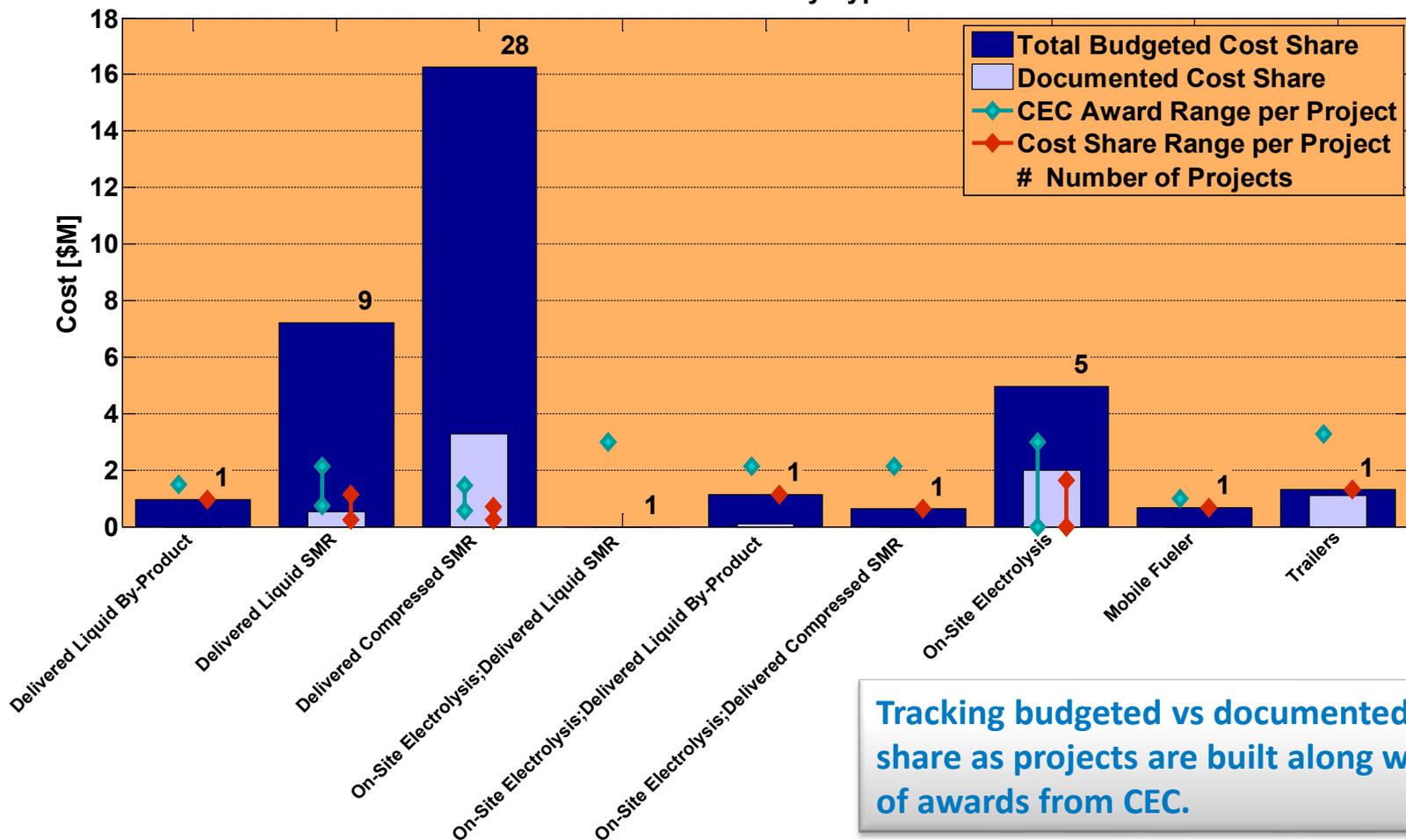


*Based on data that includes costs reported through 2014Q4 for projects at or near completion.

**Station includes: Hydrogen Equipment and Station Engineering, Design, Fabrication, Procurement, Site Preparation, Installation, and Construction

Accomplishments and Progress: Station Cost by Type

Station Cost by Type*



Tracking budgeted vs documented cost share as projects are built along with range of awards from CEC.

*Based on California Energy Commission data that includes costs reported through 2014Q4.

Collaborations

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

- **Memorandum of Understanding between CEC/NREL**
 - Data templates included in Program Opportunity Notices/Awards
 - Will provide cost data as well as performance/operation data on latest infrastructure projects
- **Partners providing data through DOE funding or voluntarily:**
 - California Air Resources Board, California State University Los Angeles, Gas Technologies Institute, Hydrogen Frontier, Linde, Shell, Proton OnSite
- **Organizations**
 - California Fuel Cell Partnership Working Group
 - H2USA Hydrogen Fueling Station Working Group
 - IPHE for international data sharing

Proposed Future Work

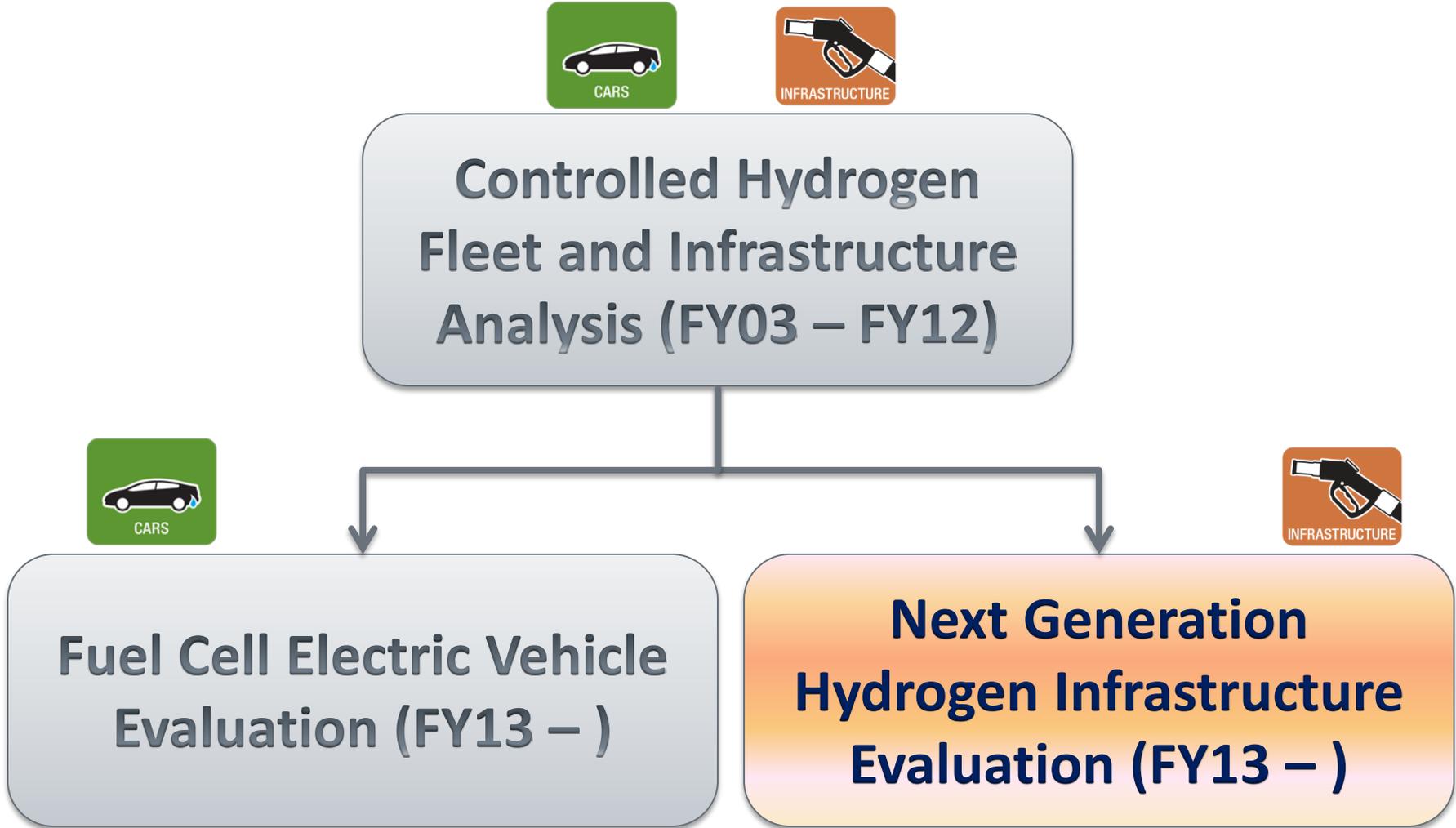
- **Fall 2015**
 - Complete quarterly analysis of CY15 Q1 and Q2 data
 - Publish analysis results (10/2015)
- **Spring 2016**
 - Complete quarterly analysis of CY15 Q3 and Q4 data
 - Publish analysis results (4/2016)
- **Update data collection and analysis to address:**
 - Availability of stations
 - Performance compared to fueling standards
 - Usage of data results by others (cost analysis, safety, network health, customer satisfaction)
 - How metrics are changing over time

Summary

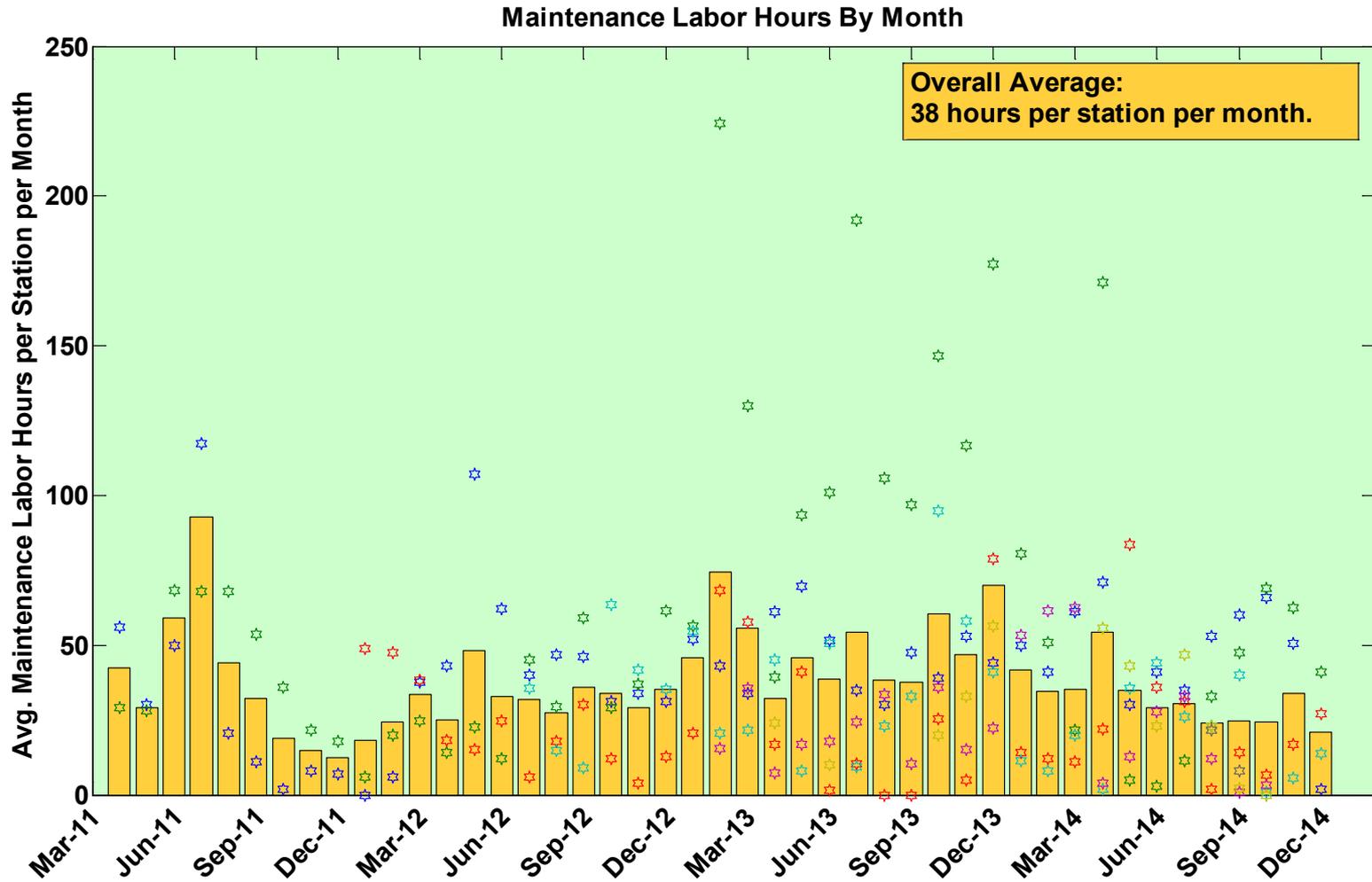
- **Relevance**
 - Independent validation of hydrogen infrastructure
- **Approach**
 - Collaborate with industry partners
 - Continue to develop core NFCTEC and analysis capability and tools
 - Leverage 7+ years of analysis and experience from the Learning Demonstration
- **Technical Accomplishments and Progress**
 - Analyzed performance data from 8 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 and update results in Fall 2015; add new analysis topics
 - Identify new opportunities to document hydrogen infrastructure progress

Technical Back-Up Slides

Approach: Relationship to Other Tech Val Projects



Accomplishments and Progress: Maintenance Labor Hours by Month



NREL cdp_infr_28

Created: May-06-15 11:34 AM | Data Range: 2009Q1-2014Q4

Stars represent individual station maintenance hours in a given month.

Reviewer-Only Slides

Critical Assumptions and Issues

- **Relationship between vehicle and station**
 - We are working on ways to fully understand the vehicle and station performance by studying refueling from both the vehicle and station perspective. We want to confirm performance gaps with increased hydrogen demand and new stations.
- **Availability of infrastructure data**
 - Infrastructure providers are at different stages of technology generations and deployments. This can create an issue with regular data delivery and analysis.
 - Different types of data provided based on the provider. Government funder, station owner, station operator, equipment provider all have different data/interests.
- **Types of stations**
 - Several different types of stations make comparisons very interesting and challenging at the same time.
 - Delivered versus on-site production (electrolysis/reforming)
 - Liquid versus compressed
 - A variety of station daily capacities
 - Established stations versus new stations (newer/older equipment and standards)

Publications and Presentations

1. Sprik, S., Kurtz, J., “**Next Generation H2 Station Spring 2015 CDPs (Through 2014Q4),**” Golden, CO: National Renewable Energy Laboratory, expected May 2015. (composite data products)
2. Sprik, S., Kurtz, J., “**Technology Validation of Fuel Cell Vehicles and Infrastructure,**” Los Angeles, CA, Fuel Cell Seminar 2014, November 2014. (presentation)
3. Sprik, S., Kurtz, J., “**Next Generation H2 Station Fall 2014 CDPs (Through 2014Q2),**” Golden, CO: National Renewable Energy Laboratory, November 2014. (composite data products)

Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- This project was not reviewed last year.