

Next Generation Hydrogen Infrastructure Evaluation



**2013 DOE Annual Merit Review
and Peer Evaluation Meeting**

***Sam Sprik, Chris Ainscough, Jen
Kurtz, Michael Peters***

May 16, 2013

Project ID# TV017

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

Overview

Timeline

- Project start date: Oct 2011
- Project end date: Sep 2013*

Budget

- Total project:
 - \$ 200k (FY12)
 - \$ 285k (planned FY13)
- Contractor Share
 - \$ 0

MYRDD Barriers Addressed

- Lack of current hydrogen refueling infrastructure performance and availability data

Partners

- Hydrogen Frontier
- CSULA
- CARB / Shell
- Proton Onsite
- GTI / Linde
- Shell

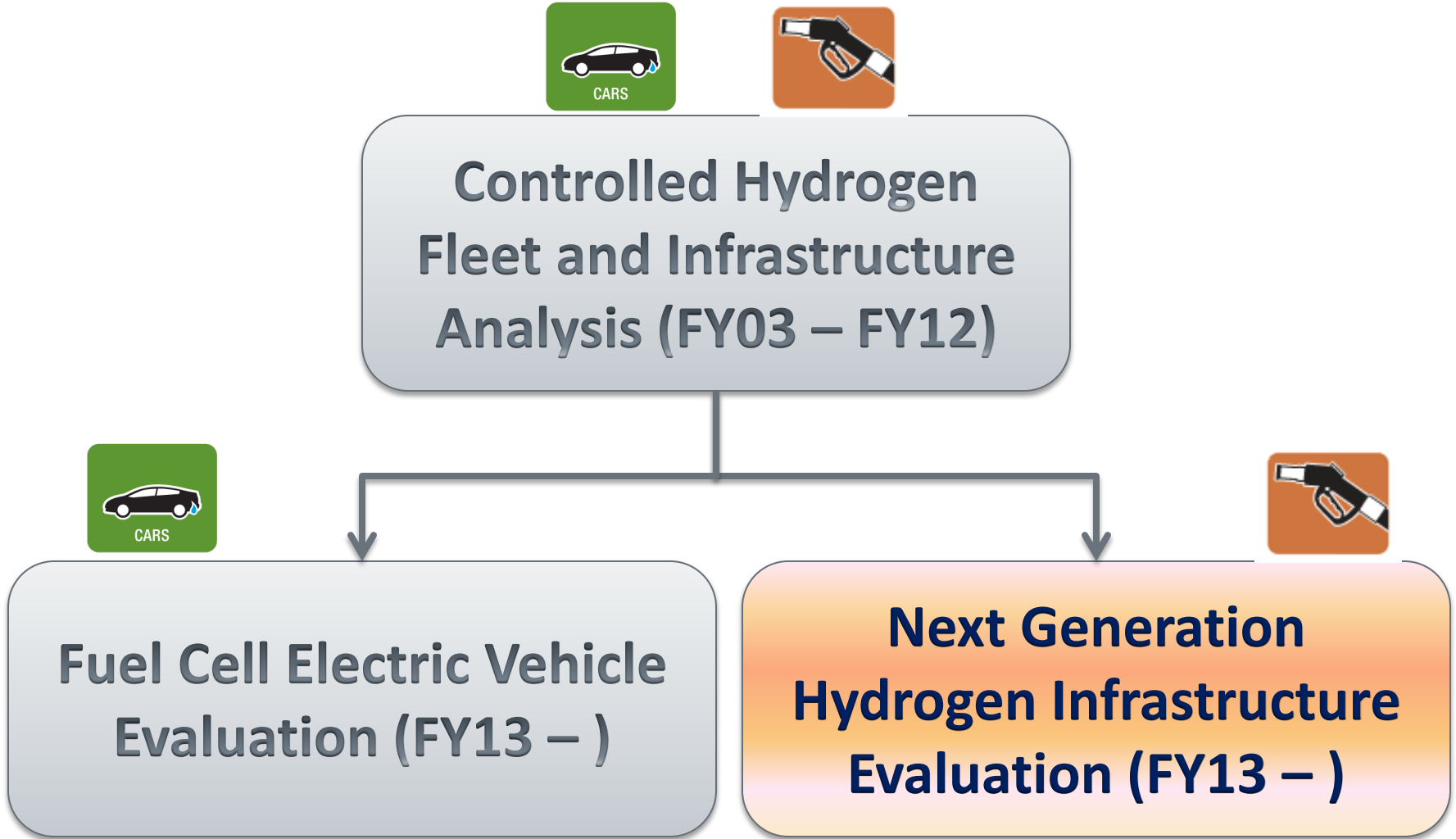
*Project continuation is determined annually by DOE

Relevance: Meeting Vehicle Needs

Use metrics to clearly evaluate progress toward challenges

- **Location/Capacity/Utilization**
 - **Challenge:** Stations need to provide coverage to meet the needs of vehicle drivers in the pre-commercial stage as well as have hydrogen availability with minimal wait time
 - **Metrics:** Station usage patterns and geographic locations
- **Fueling**
 - **Challenge:** Vehicles need to be fueled in an acceptable amount of time
 - **Metrics:** Fueling rates, times, amounts, back-to-back fills, communication...
- **Maintenance/Availability**
 - **Challenge:** Maintenance and other factors may cause station downtime and increase cost
 - **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 Timing**
 - **Challenge:** Need enough lead time to build infrastructure to meet vehicle demand
 - **Metrics:** Permitting time, building time, commissioning time...

Approach: Relationship to Other Tech Val Projects



Approach: FOA-626 (H₂ Infrastructure Data)

Validation of Hydrogen Refueling Station Performance and Advanced Refueling Components

- **Objectives of FOA**

- Provide H₂ infrastructure data to NREL's Hydrogen Secure Data Center (HSDC) for analysis and aggregation
- Test, demonstrate, and validate hydrogen technologies in real-world environments

Approach: FOA-626 Status (H₂ Infrastructure Data)

- 4 awardees announced July 18, 2012
- All awards completed
- Project kickoff Jan 2013
- Data to be delivered to NREL's HSDC in 2013
- Project to run for 4 years through 2 phases
- Will learn from state-of-the-art stations

Energy Department Investments to Advance Hydrogen Infrastructure and Fueling Technologies

Projects to Reduce Costs and Drive Higher Performance

July 18, 2012

As part of the Energy Department's commitment to give American businesses more options to cut energy costs and reduce reliance on imported oil, the Department today announced a \$2.4 million investment to collect and analyze performance data for hydrogen fueling stations and advanced refueling components. The five projects—located in California, Illinois, and Connecticut—will track the performance and technical progress of innovative refueling systems at planned or existing hydrogen fueling stations to find ways to lower costs and improve operation. These investments are part of the Department's commitment to support U.S. leadership in advanced hydrogen and fuel cell research and help industry bring hydrogen technologies into the marketplace at lower cost.

These new projects will collect data and monitor the performance of hydrogen fuel stations, advanced components and other innovative hydrogen technologies using renewable energy or natural gas. By analyzing performance in real-world environments, these projects will help hydrogen fueling equipment manufacturers improve the designs of existing systems to achieve higher efficiencies and test new system components. Additionally, this data will help focus future research and development efforts, driving American manufacturing competitiveness in the next generation of hydrogen and fuel cell technologies.

In addition, the Energy Department released today the [final report](#) from a technology validation project that collected data from more than 180 fuel cell electric vehicles. Over six years, these vehicles made more than 500,000 trips and traveled 3.6 million

Approach: FOA-626 Winners Selected

Summary from press release (July 18, 2012)

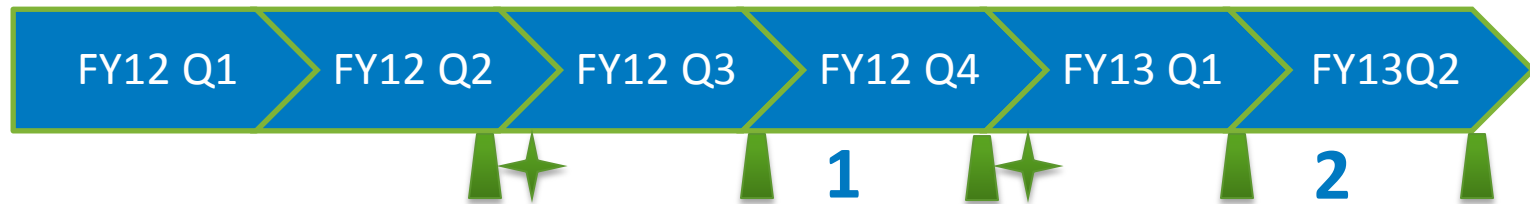
- **California Air Resources Board (Sacramento, California)**
 - 1 station with natural gas to hydrogen, 180 kg of storage, and 60 kg of back-to-back fills in under an hour (DOE Award: \$150,000)
- **California State University and Los Angeles Auxiliary Services, Inc. (Los Angeles, California)**
 - 1 station at CSULA with 24 hour public access and will fill up to 20 hydrogen powered vehicles daily (DOE Award: \$400,000)
- **Gas Technology Institute (Des Plaines, Illinois)**
 - 5 stations with their compressor technology, public access, and will analyze operational, transactional, safety, and reliability data (DOE Award: \$400,000)
- **Proton Energy Systems (Wallingford, Connecticut)**
 - 2 stations that generate hydrogen from water through onsite solar-powered electrolysis and will collect data on operation, maintenance and energy consumption (DOE Award: \$400,000)
 - Also, second project to deploy an advanced high-pressure electrolyzer at a station and nearly double the dispensing capacity of its storage tanks (DOE Award: \$1 million)

Approach: Analysis Objectives

Analyze operational data on existing hydrogen stations to provide status and feedback in the following areas:

- Capacity
- Utilization
- Station build time
- Maintenance/availability
- Fueling
- Geographic coverage

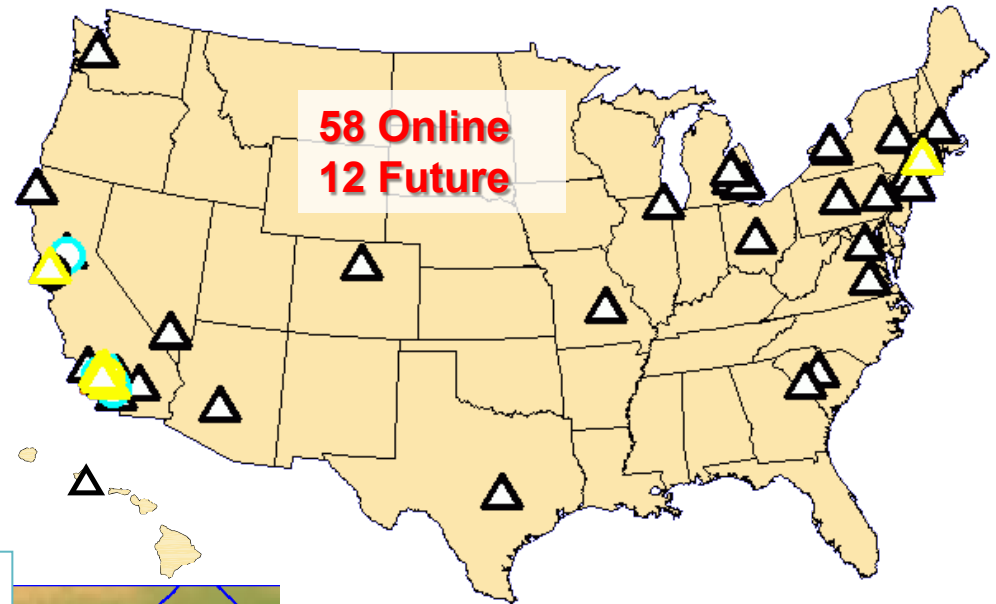
Approach: Milestones



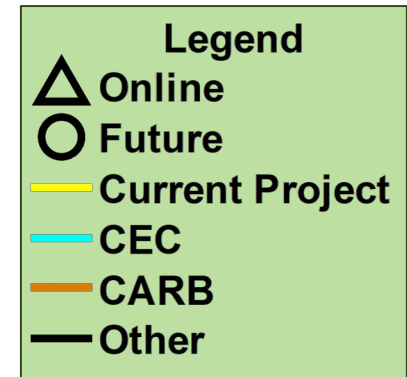
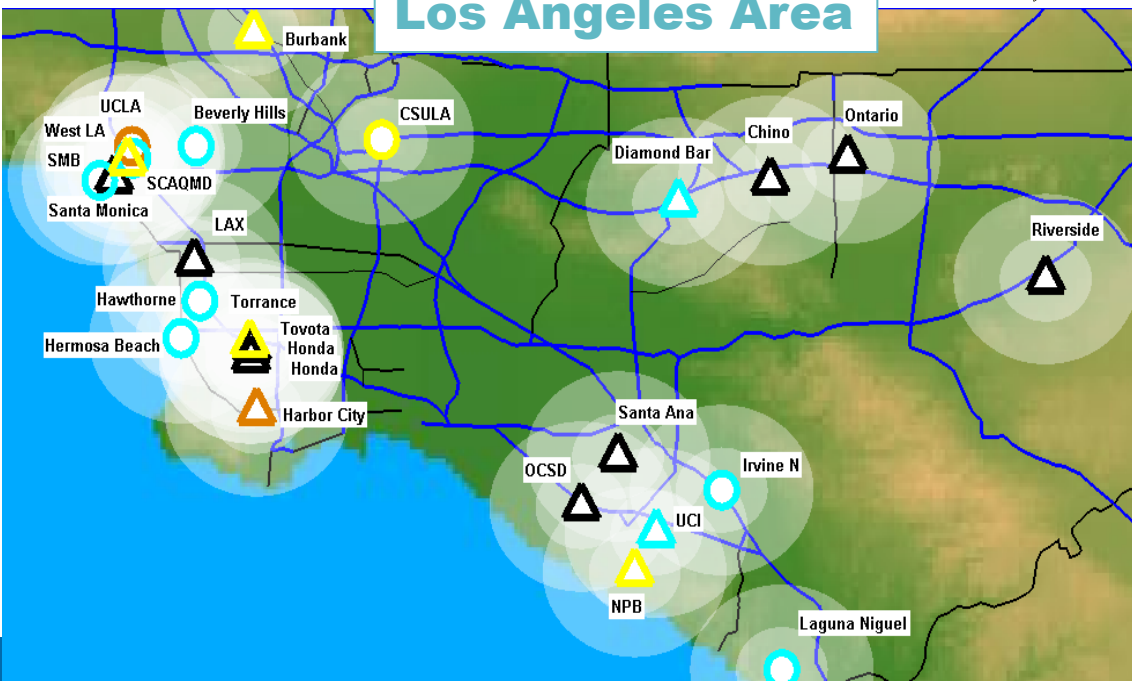
- ▲ Quarterly data analysis (based on available data)
- ★ Publication of composite data products
 1. FOA 626 awardees announced–July 18, 2012
 2. Infrastructure projects kickoff–Jan 29, 2013

Approach: Station Locations

- Maintain database of current stations in the U.S.
- Station coverage



Los Angeles Area



Accomplishment: Infrastructure Data Templates

Site Summary Storage & Delivery Compression Dispensing **Fuel Log** Maintenance H2 Cost Safety H2 Quality Reformer **Electrolyzer** Co-Pro

Templates enable collection of similar data from all the stations

- Aggregated results from data collected
- Templates distributed to project partners for data collection and feedback

Infr Template Rev Dec02 2011 (company date).xlsx - Microsoft Excel

Home Insert

1 **Fuel Log**

2 Template last updated on December 02, 2011 (NREL)

3 Data should be from reporting quarter

4

5 Calendar Quarter insert calendar quarter

6 Site Name insert site name

(1) Refueling Rate: The capability of the on-site refueling system (from storage tank to on the vehicle) shall be tested to determine the hydrogen flow rate and reported qua
Refueling time starts and stops upon fuel flow starting and stopping (i.e., set-up exc

Date/Time (m/d/yy HH:MM:SS)	Fuel Price (\$/kg)	Dispenser ID (if multiple)	H2 Filled (kg)	Fill Time (s)	Final Pressure (bar)	Fill Type	Veh Name or Type	Comments	Fill Rate (kg/min) (kg H2/Fill Time)
5/1/01 15:30:24	\$5.00	Disp350A	2.5	180	350	Communication	ECO-FCV01		0.8
5/1/01 15:30:24	\$5.00	Disp700B	15	480	700	Non-Communication	BusCo-Transit Bus	Bus Demo	1.9
5/1/01 15:30:24	\$5.00	Disp350B							

Infr Template Rev Dec02 2011 (company date).xlsx - Microsoft Excel

Home Insert Page Layout Formulas Data Review View Acrobat

1 **Electrolyzer Log**

2 Template last updated on December 02, 2011 (NREL)

3

4 Calendar Quarter (ex. 2011Q2) insert calendar quarter

5 Site Name insert site name

6 Electrolyzer Type e.g., PEM, Solid Oxide, etc.

7 Electricity Source e.g., Gnd, Wind, PV, etc.

8

9 Data should be from reporting quarter

Category	Units	Month		
		Month1	Month2	Month3
Hydrogen Produced	kg	450		
Operation Time	hours	400		
Water Consumed, Directly	gallons	4140		
Converted + Waste + Other	gallons	4140		
Electricity Used	kWhr	6000		
Electricity Cost (ex. monthly bill)	dollars	\$300		
Total Energy Consumed in Conversion (1) (Electrical, Thermal,				

Approach: Station Data (Continual Collection)

- **H₂ produced or delivered by month**
- **On-site efficiency, conversion efficiency, compression energy, storage and dispensing energy**
- **Maintenance**
- **Safety**
- **Hydrogen quality**
- **Fueling**
- **Cost of non-H₂ energy for compression, dispensing, conversion**
- **Cost items (by month)**

Approach: Station Data (Site Summary)

- **Station description**
- **Production capacity**
- **Dispensing capacity**
- **Survivability (max/min temperature)**
- **Nominal pre-cooling temp and SAE 2601 type**
- **Storage type(s) and capacities and at what pressure(s)**
- **Number of dispensers at what pressure(s)**
- **Compressor(s) information**
- **Time to design, permit, construct, and commission**
- **Footprints: storage, production, dispensing**

Approach: Hydrogen Secure Data Center

Bundled data (operation & maintenance/safety) delivered to NREL quarterly

Internal analysis completed quarterly

NREL's Hydrogen Secure Data 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

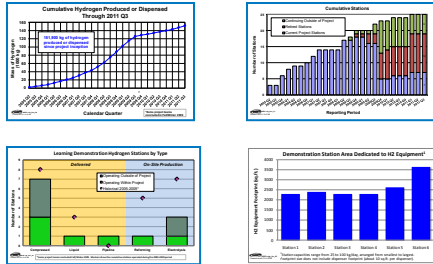
2) Results published via NREL Tech Val website, conferences, and reports

Approach: Previously Published CDPs (Learning Demo)

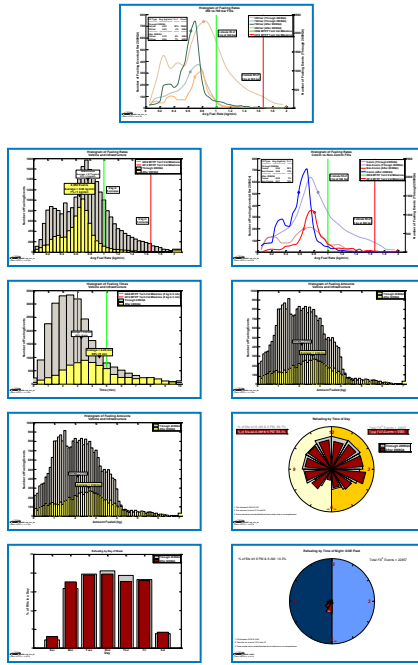
Infrastructure CDP # and Category



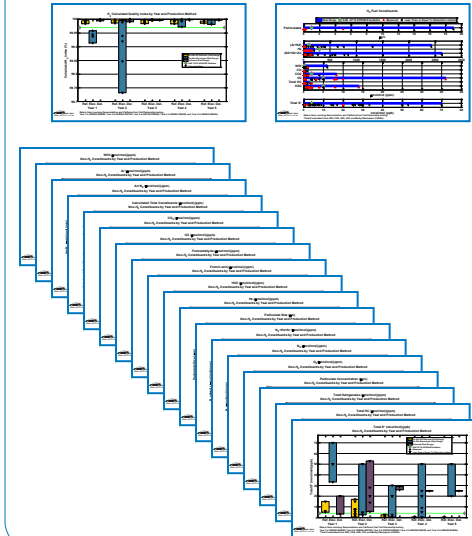
Deployment & Overview (26,31,32,93)



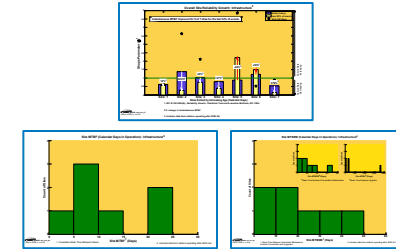
Refueling (14,18,29,38,39,42,43,50, 52, 72)



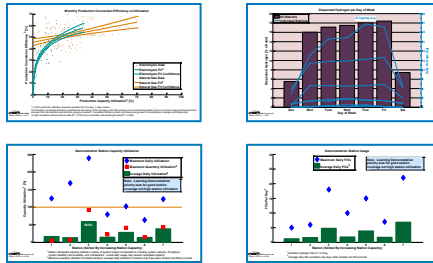
H2 Quality (27,28mult)



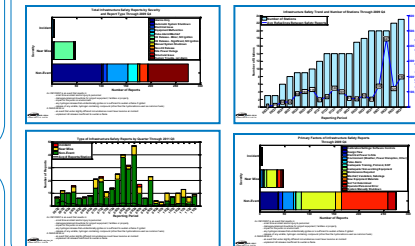
Reliability (97,98,99)



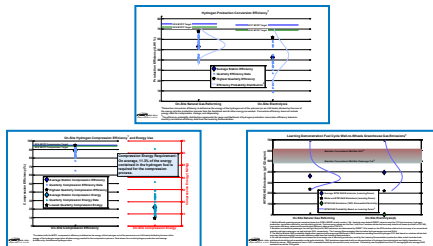
Utilization (60,83,91,92)



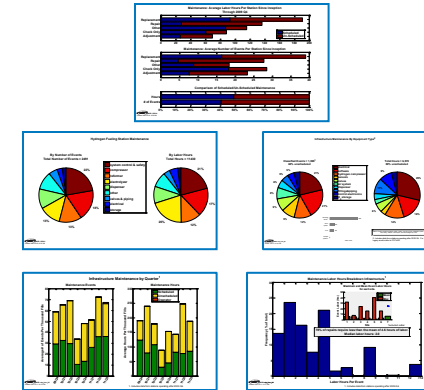
Safety (20,35,36,37)



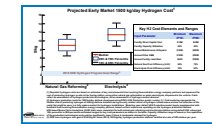
Efficiency/Emissions (13,61,62)



Maintenance (30,63,64,95,96)



Cost (15)



Accomplishment: Analysis

- **NREL Fleet Analysis Toolkit (NRELFAT)**
 - Developed first under fuel cell vehicle Learning Demonstration
 - Restructured architecture and interface to effectively handle new applications and projects and for analyses flexibility
 - Leverage analysis already created
- **Publish results**
 - Detailed and composite results
 - Target key stakeholders such as fuel cell and hydrogen community and end users



Leveraged analysis code from previous projects and created new code useful for other projects such as material handling equipment.

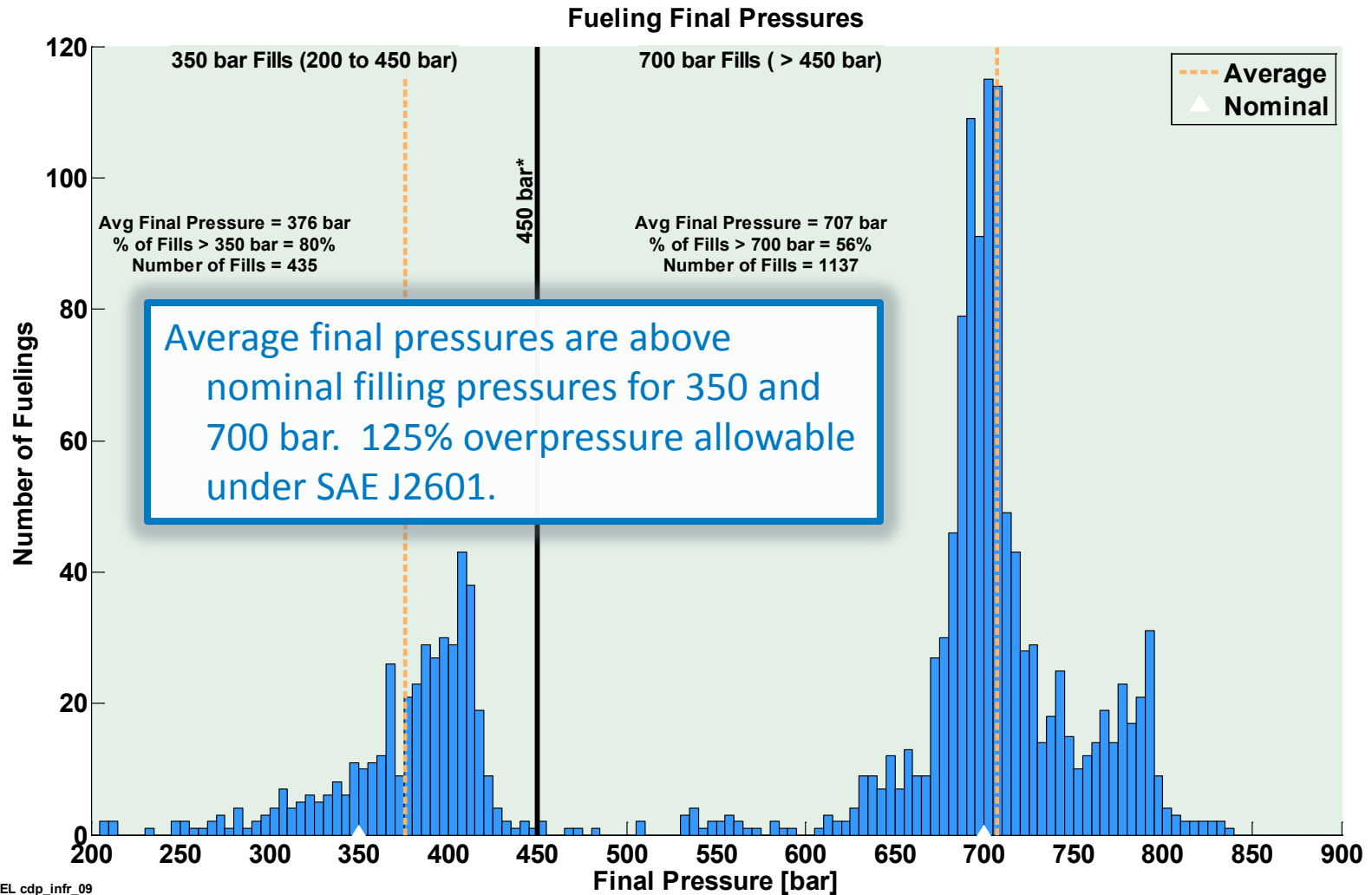
Accomplishments

- Analyzed data for station(s) providing data through CY2012Q4
- Visited several current stations
- Published new Fall 2012 CDPs
- Tracked current stations in database
- Kicked off infrastructure projects (January 2013)

Fall 2012 CDPs with Comparisons to Other Applications

Accomplishment: CDP-INFR-09

Fueling Final Pressures

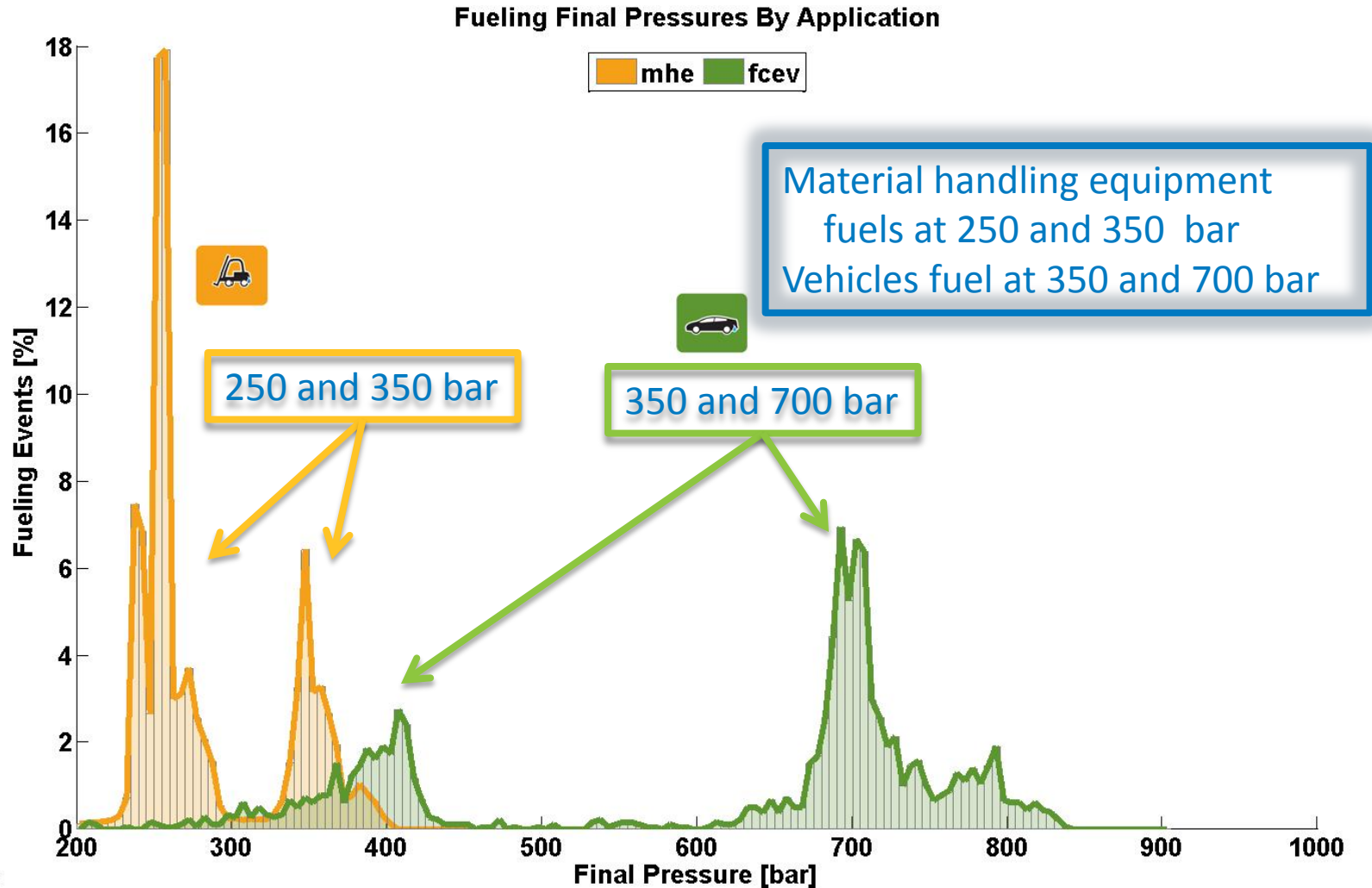


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*The line at 450 bar separates 350 bar fills from 700 bar fills. It is slightly over the allowable 125% of nominal pressure (437.5 bar) from SAE J2601.

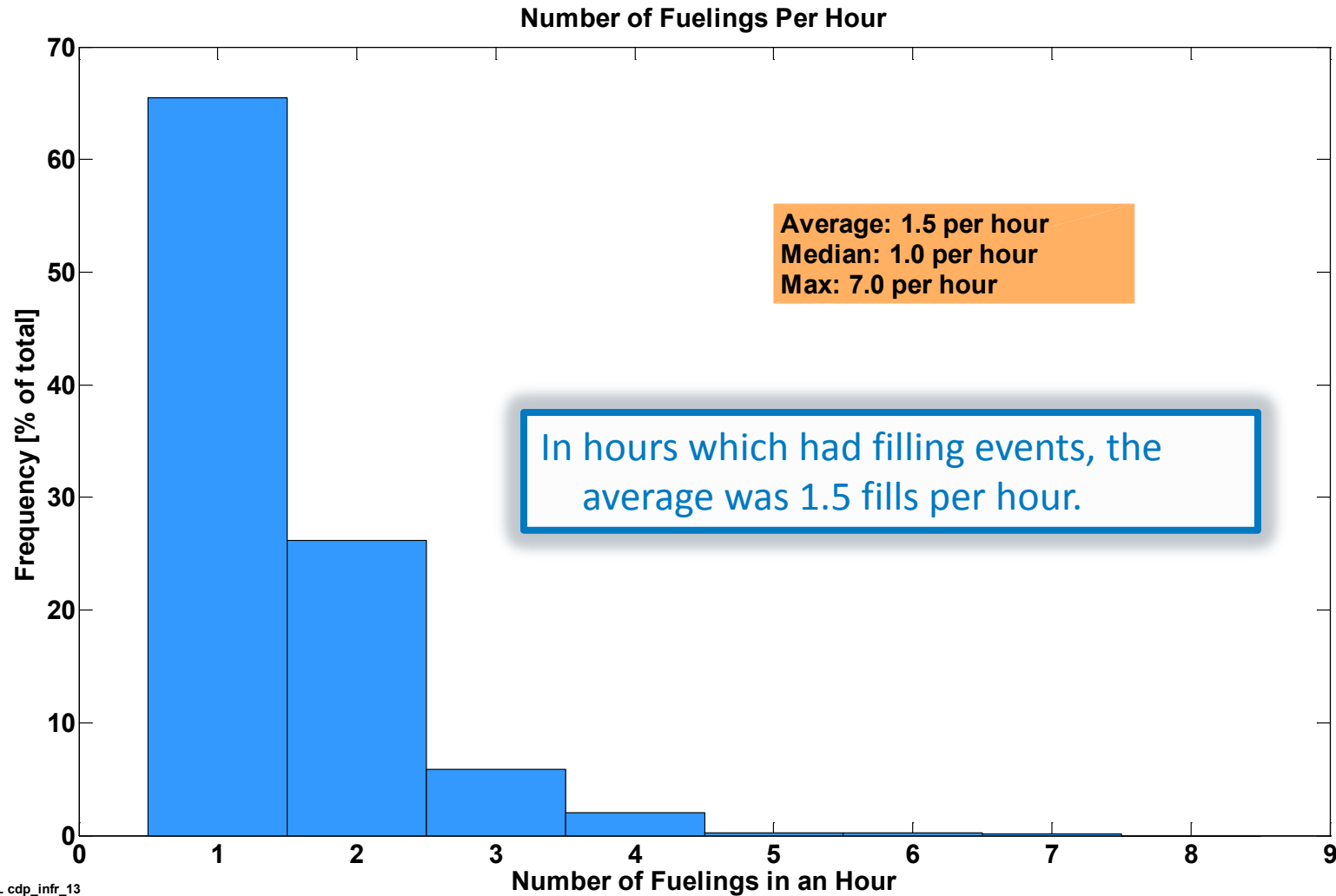
Accomplishment: CDP-XApp-12

Fueling Final Pressures by Application



Accomplishment: CDP-INFR-13

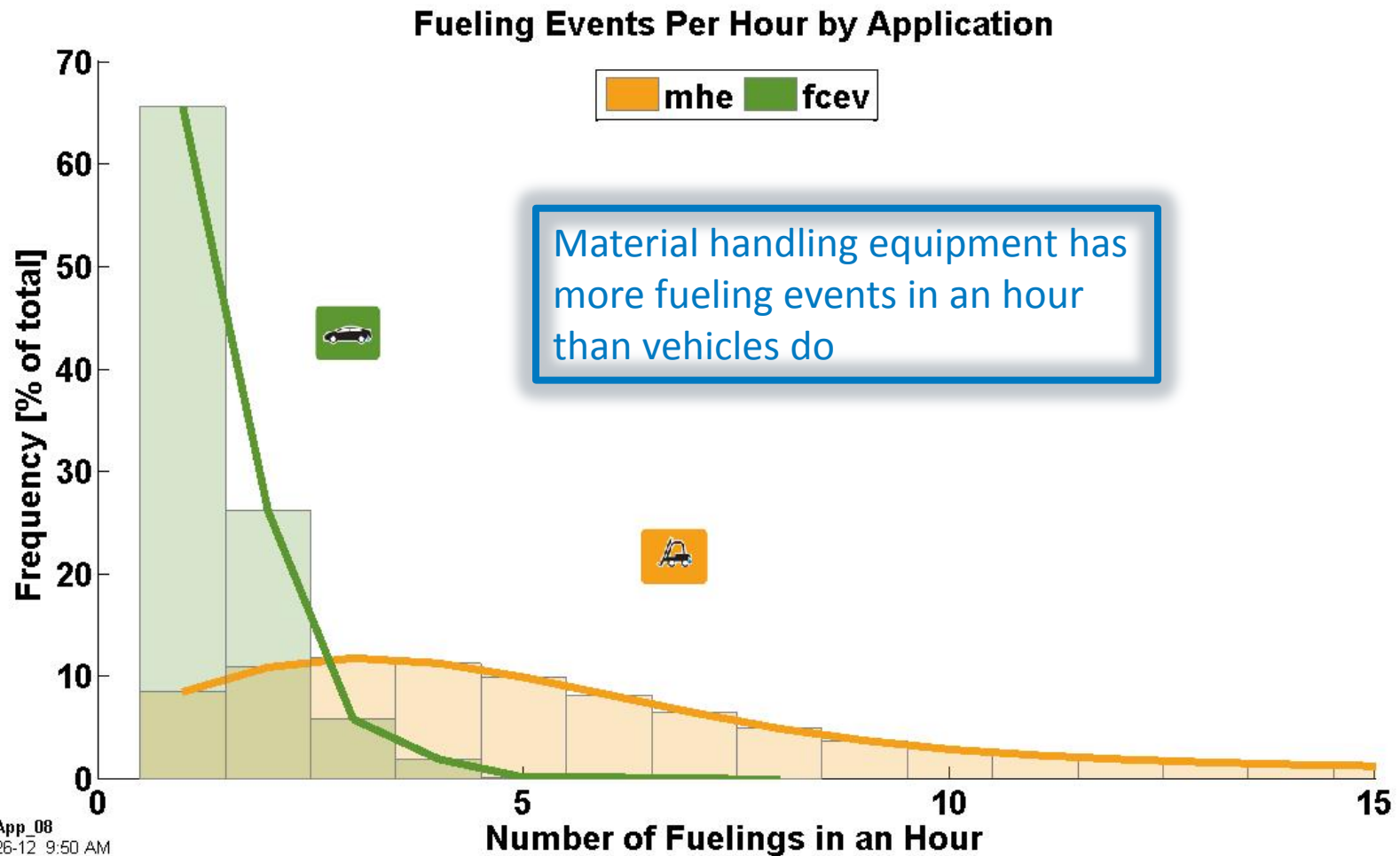
Number of Fueling Events per Hour



Only for hours in which there were fueling events

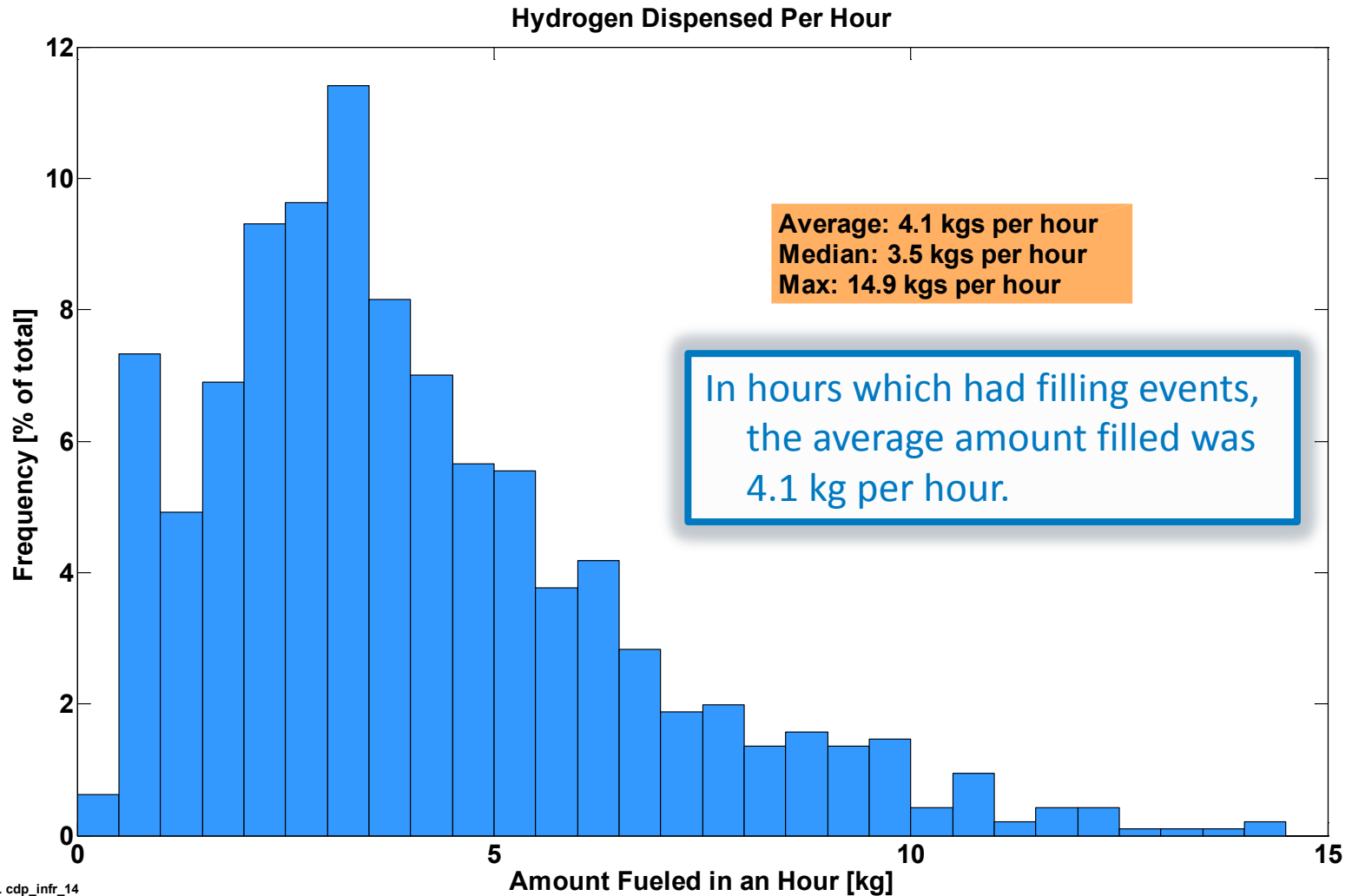
Accomplishment: CDP-XApp-08

Fueling Events per Hour by Application



Accomplishment: CDP-INFR-14

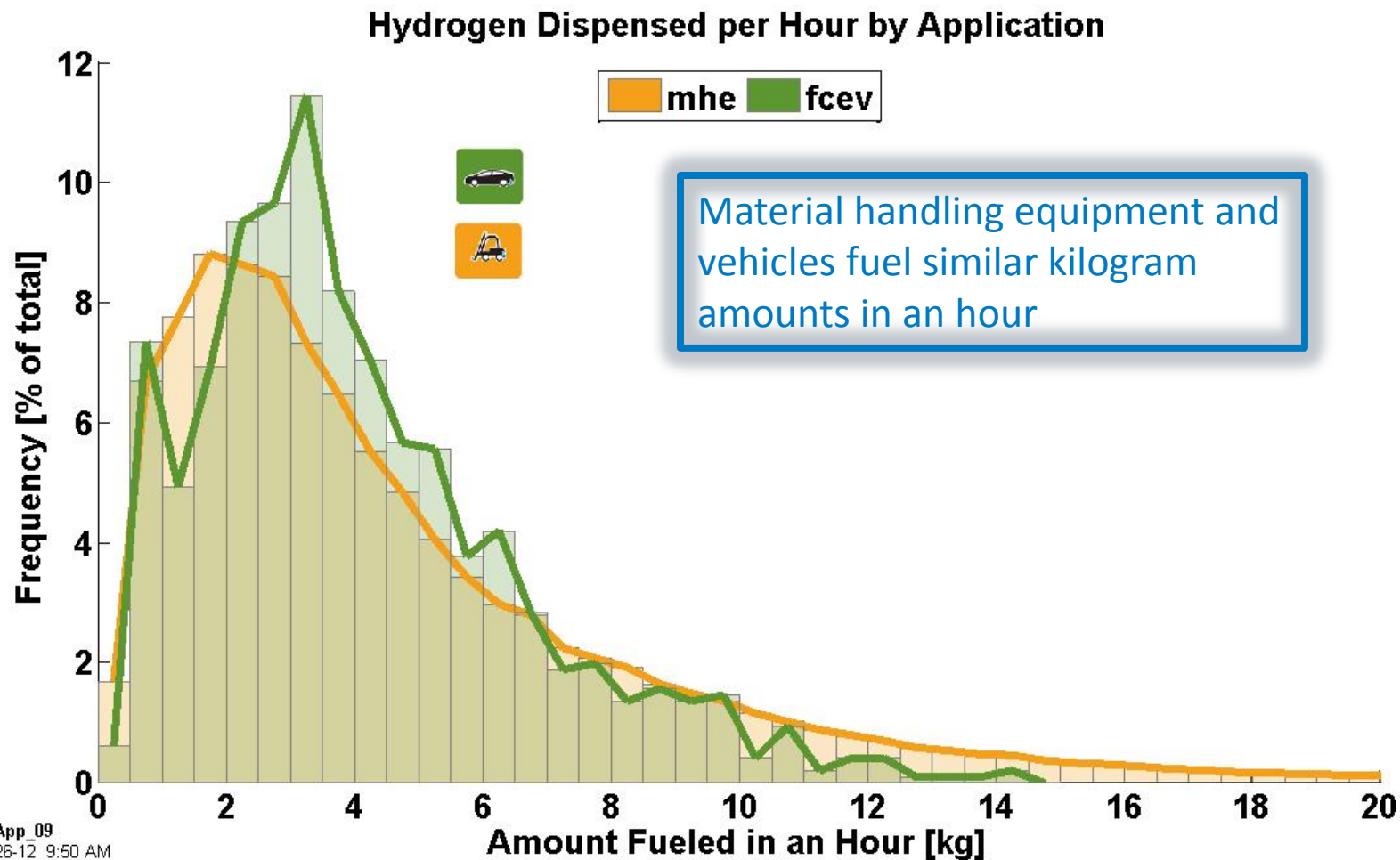
Hydrogen Dispensed per Hour



Only for hours in which there were fueling events

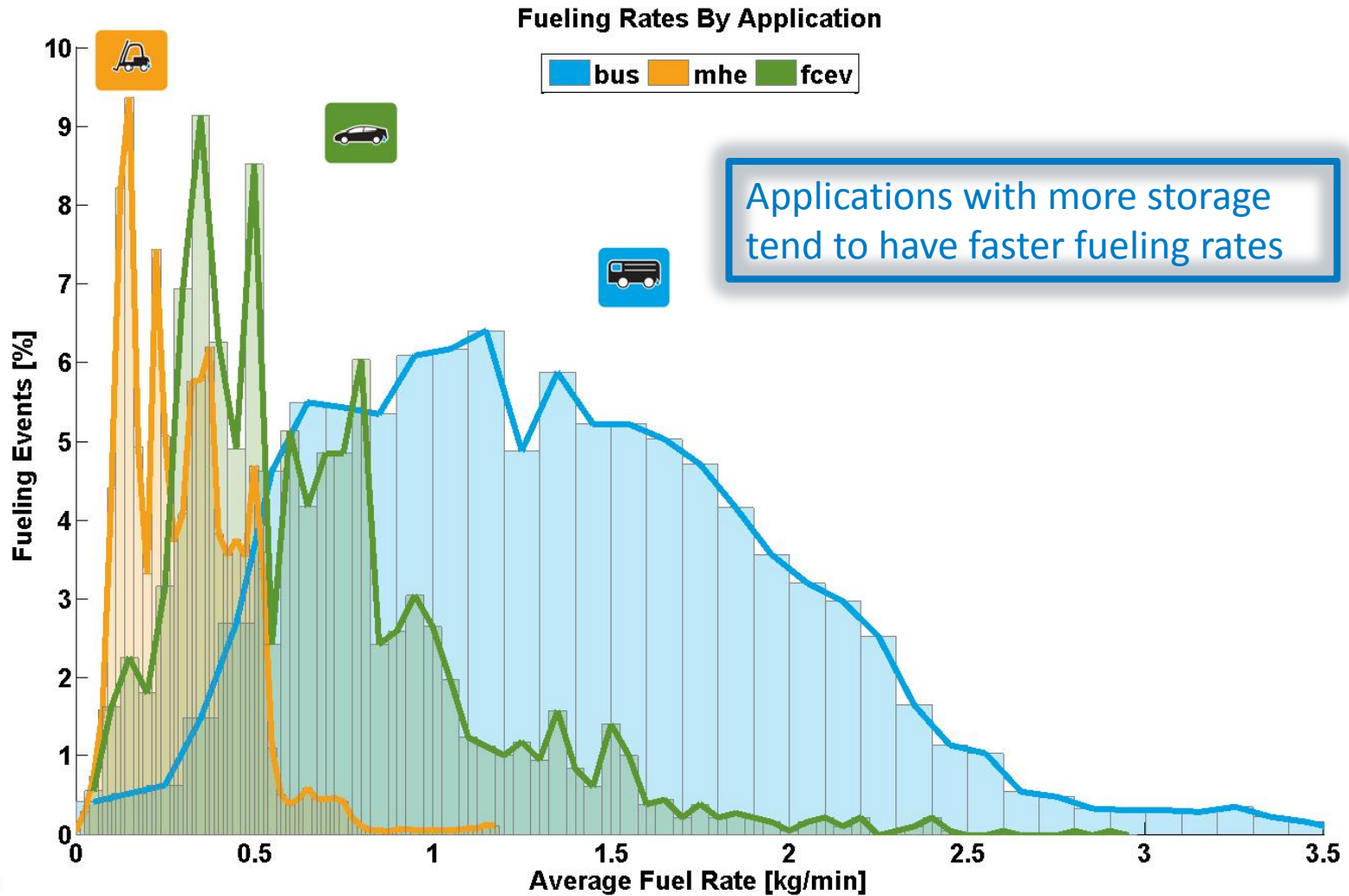
Accomplishment: CDP-XApp-09

Hydrogen Dispensed per Hour by Application



Accomplishment: CDP-XApp-04

Fueling Rates by Application



Collaborations

- **Station Operators**

- Gas Technologies Institute (GTI)
- Linde
- Hydrogen Frontier
- Shell
- California State University Los Angeles (CSULA)
- Proton OnSite

- **Organizations**

- California Fuel Cell Partnership (CaFCP)
- California Air Resources Board (CARB)
- California Energy Commission (CEC)

Collaborations: CaFCP Working Group

- **Participate in CaFCP working group meetings and station implementation team toward:**
 - Developing recommendations for future stations
 - Staying current with California hydrogen activities and needs

Future CDPs Planned

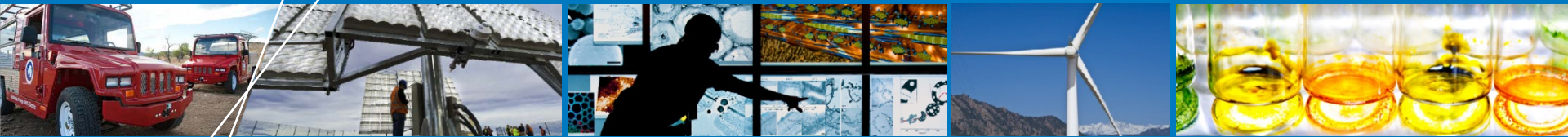
- **Separate out fueling events (rates, etc.) by topic (as data allow)**
 - Pre-cooling temp
 - Amount filled
 - Simultaneous fueling
 - Back-to-back
- **Maintenance**
 - Frequency, MTBF, most frequent, most costly...

Proposed Future Work

- Add stations to the analysis as they come online
- Create new CDPs that describe the current state of pre-commercial stations
- Provide feedback on infrastructure status to stakeholders, continue collaborations, and seek feedback on important metrics
- Feed shortfalls back to developers, and track consumer behavior

Project Summary

- **Relevance:** Hydrogen stations need to be able to meet vehicle needs.
- **Approach:** Analyze station operational data, building upon tools and capabilities from Learning Demo.
- **Accomplishments and Progress:** Updated database of stations, held project kickoffs, and completed analysis of current station data.
- **Collaborations:** Currently working with station operators and California organizations.
- **Future Work:** As new stations open and provide data, NREL will add them to the analysis to get a good picture of the current state of hydrogen infrastructure.

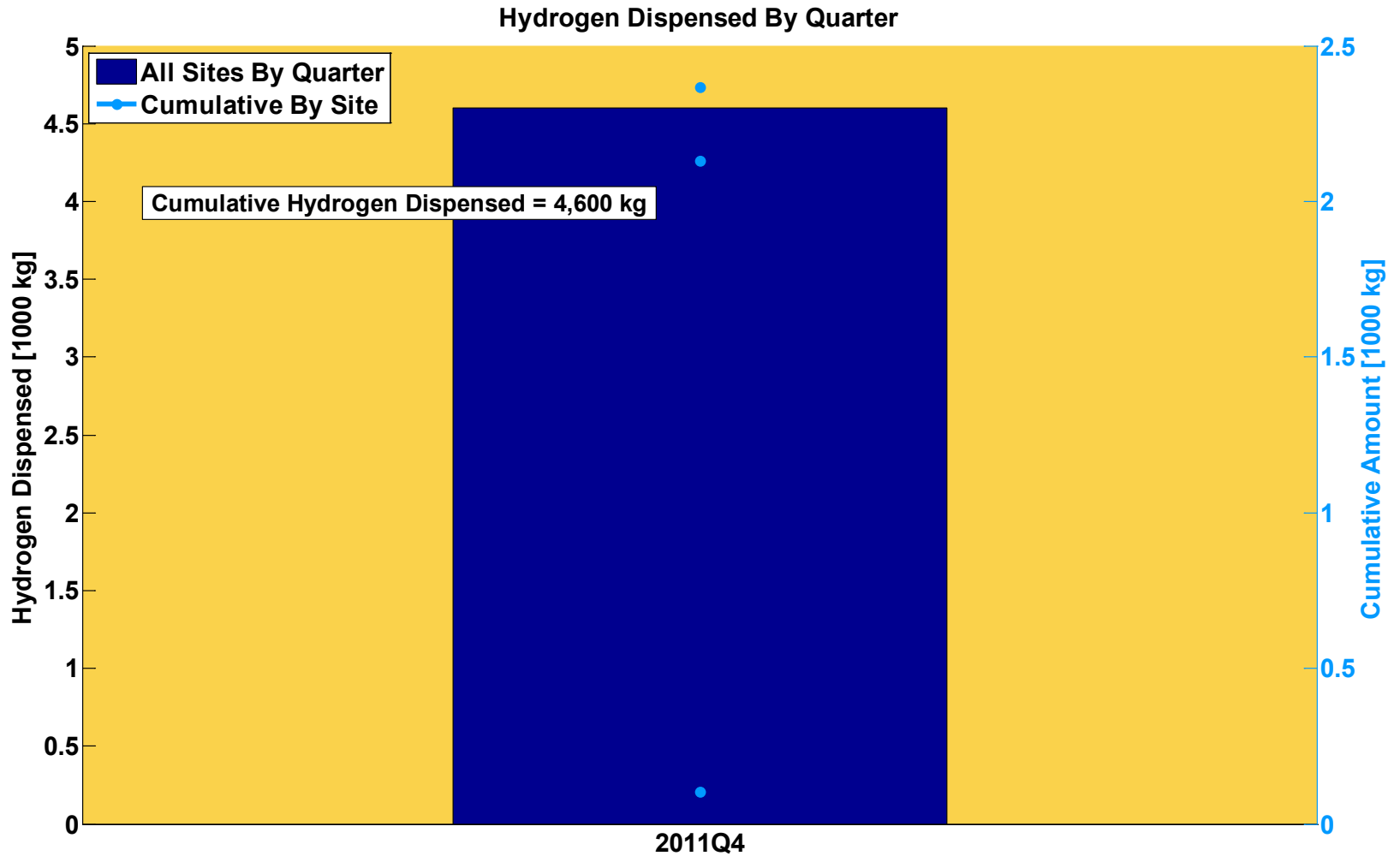


Technical Backup Slides

Previous Spring 2012

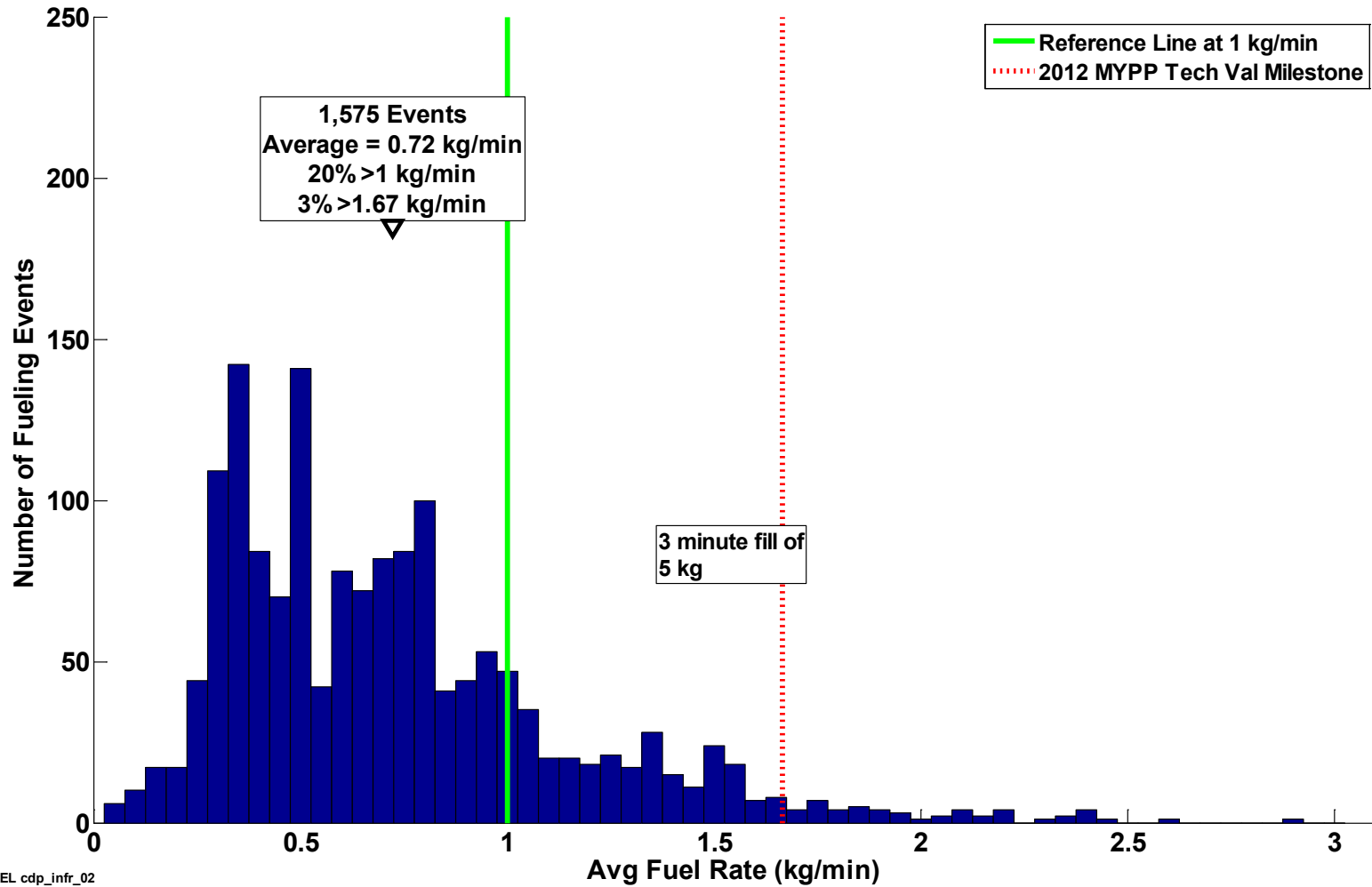
Infrastructure CDPs

Hydrogen Dispensed by Quarter



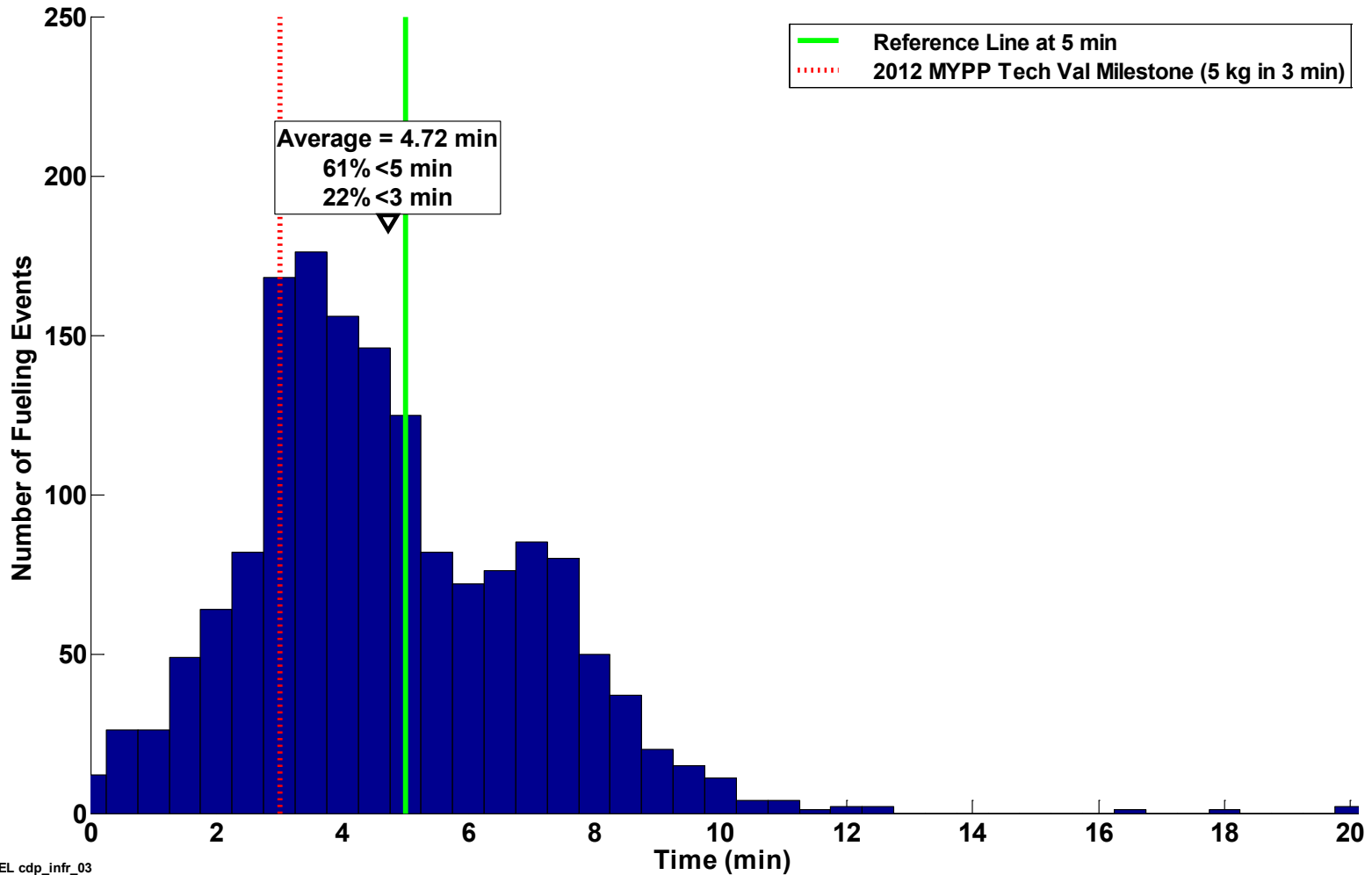
Histogram of Fueling Rates

Histogram of Fueling Rates



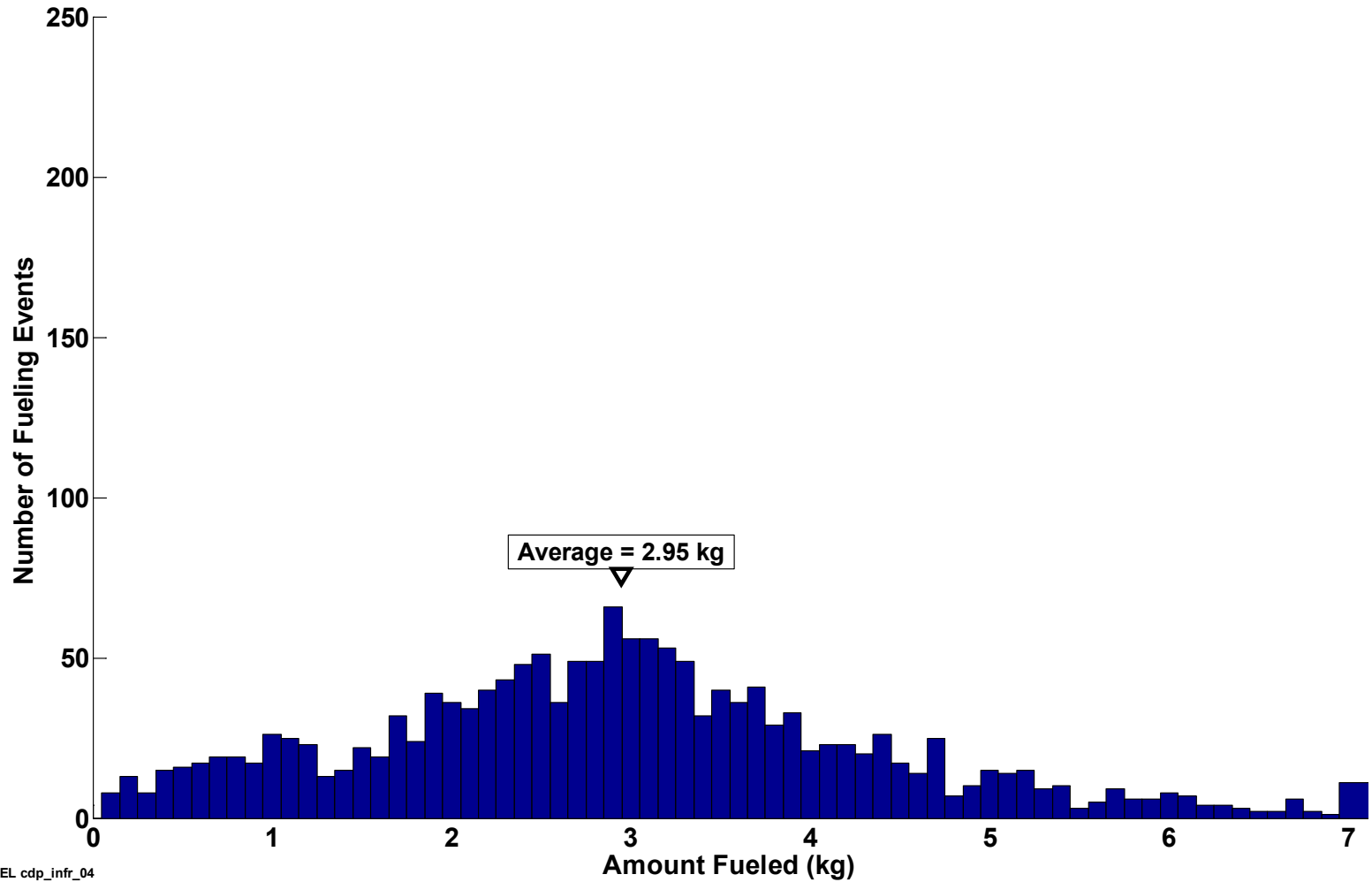
Histogram of Fueling Times

Histogram of Fueling Times

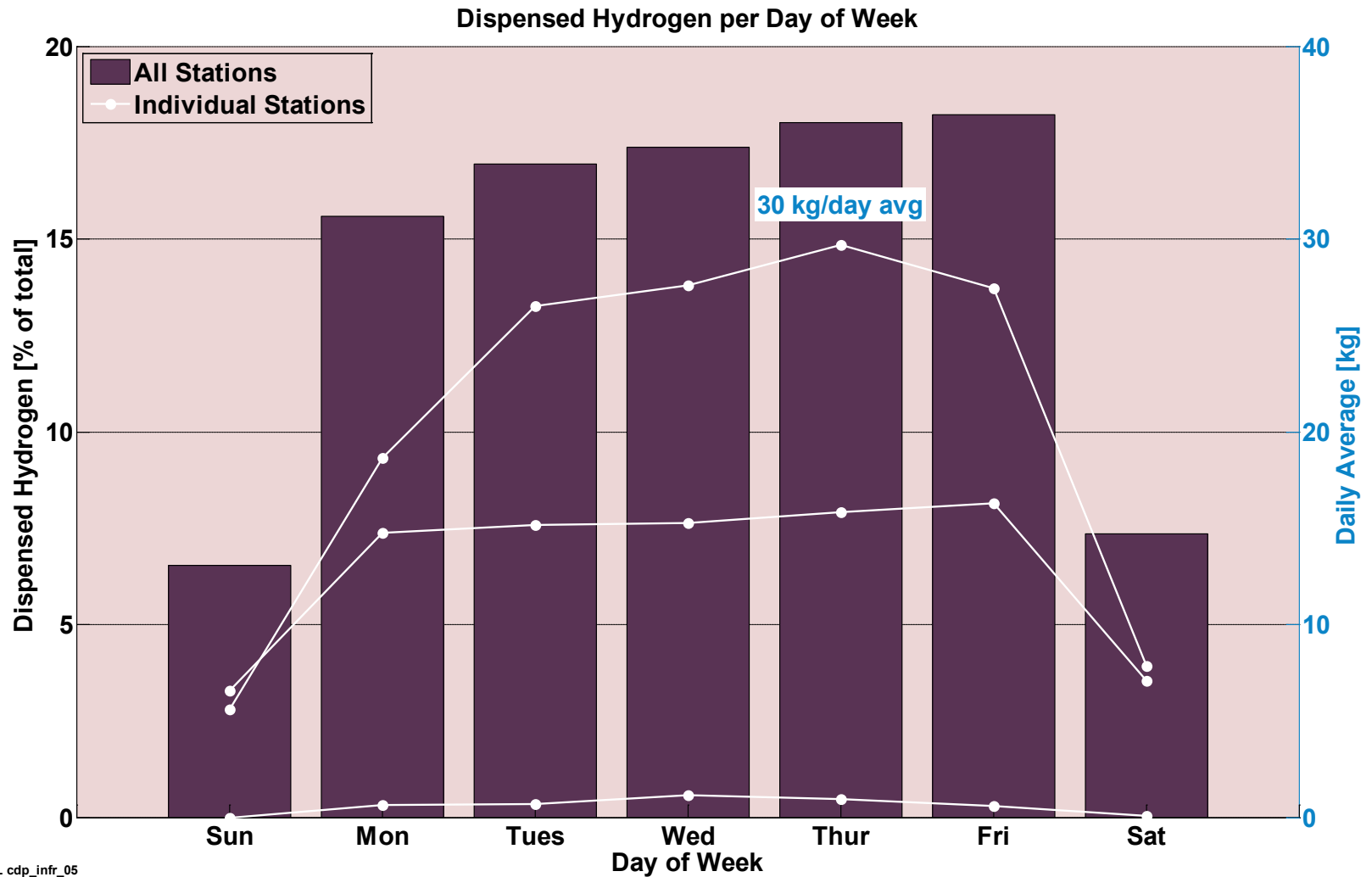


Histogram of Fueling Amounts

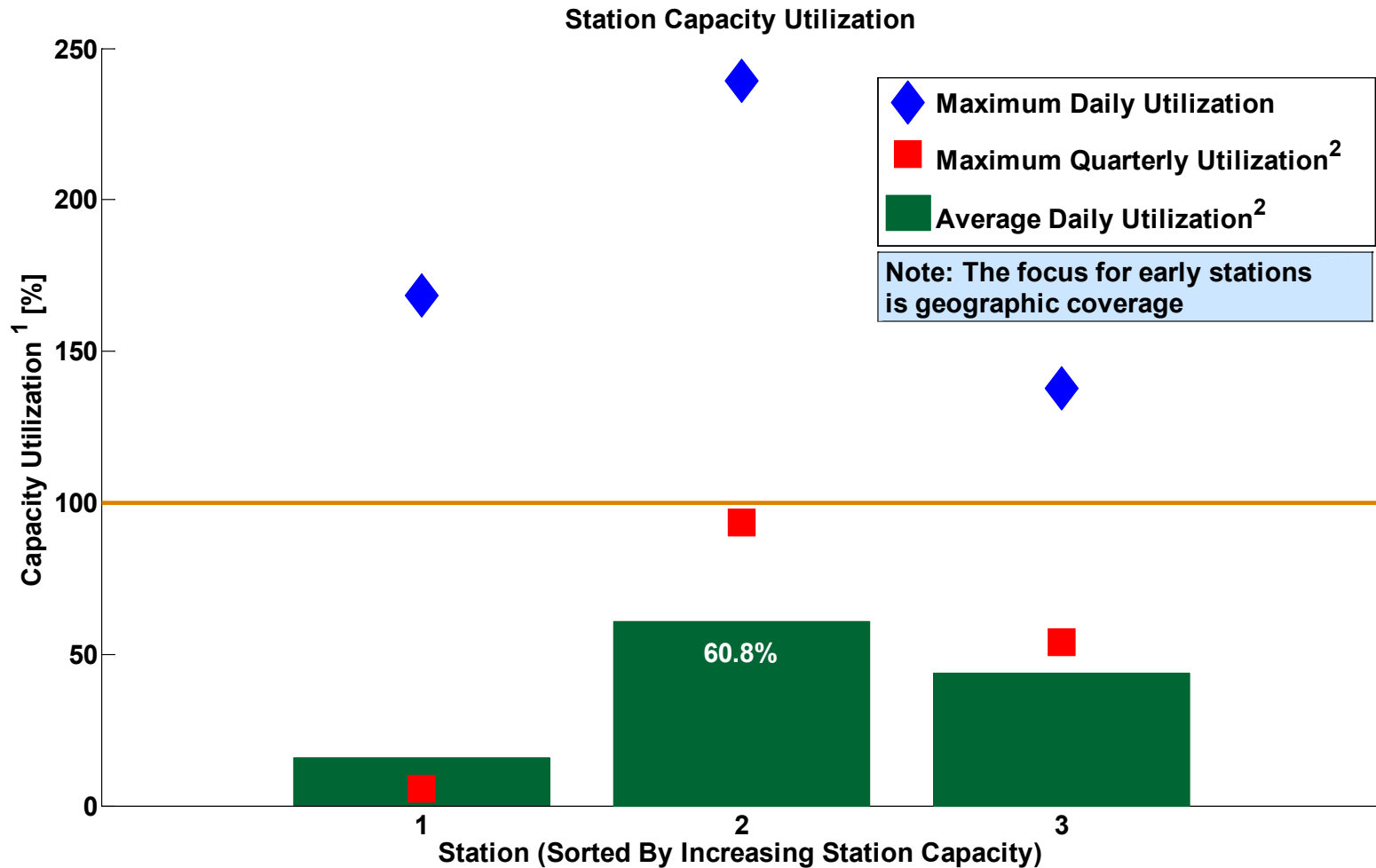
Histogram of Fueling Amounts



Dispensed Hydrogen per Day of Week



Station Capacity Utilization



◆ Maximum Daily Utilization
■ Maximum Quarterly Utilization²
■ Average Daily Utilization²

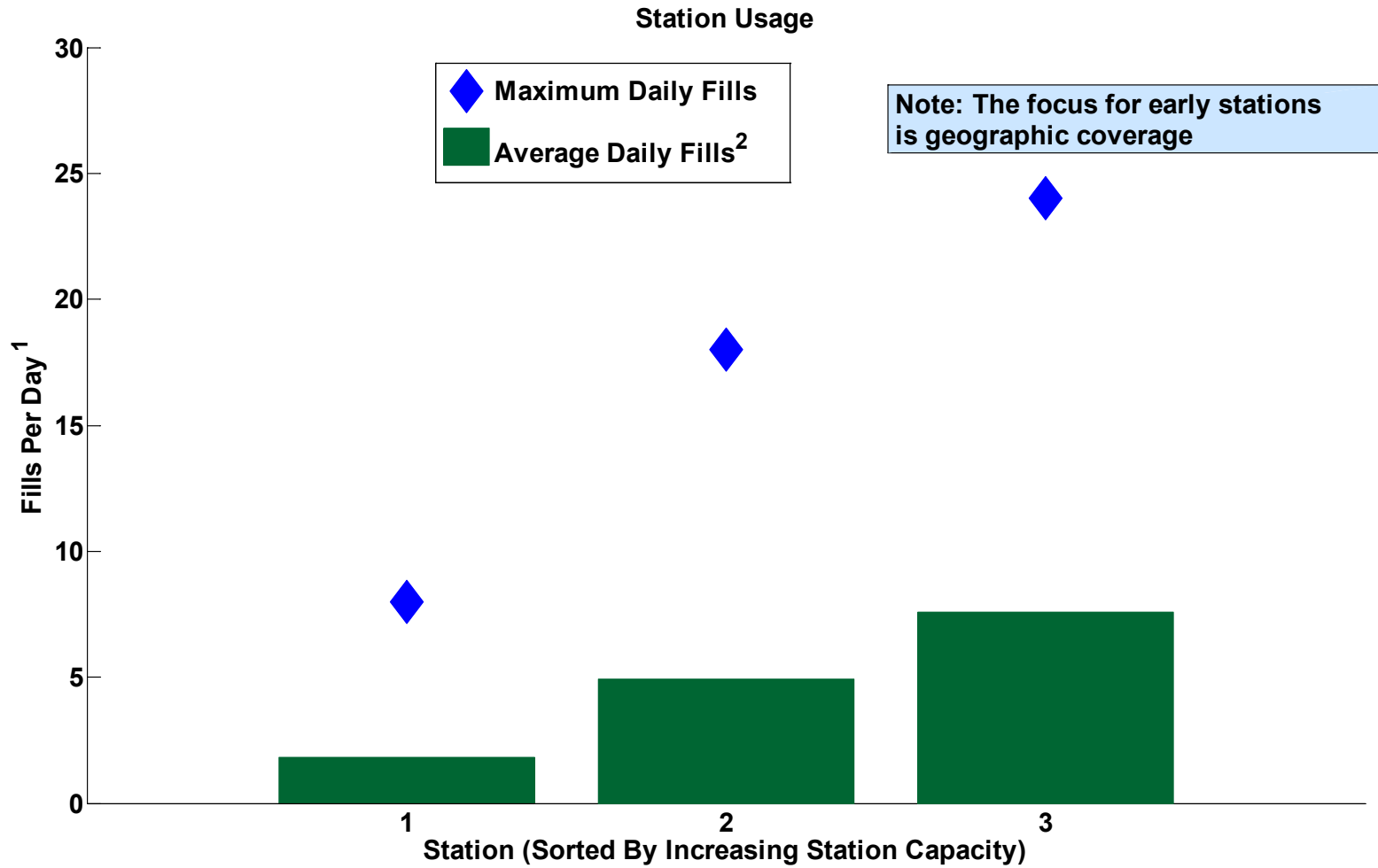
Note: The focus for early stations is geographic coverage

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

CDP-INFR-07

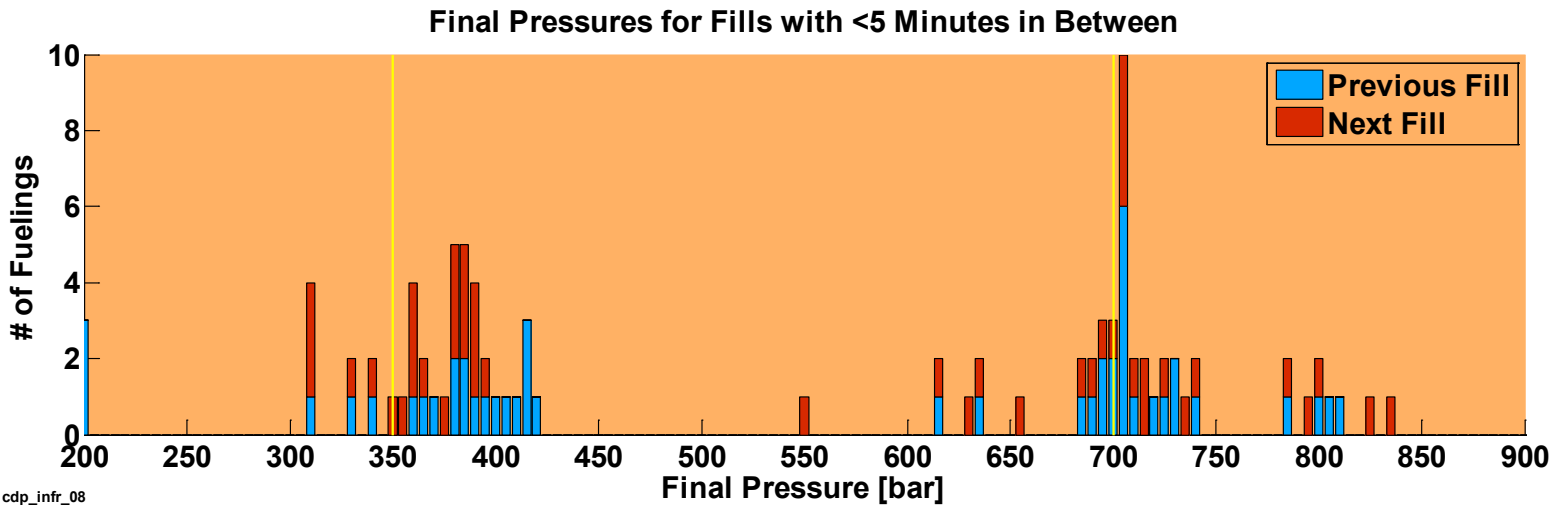
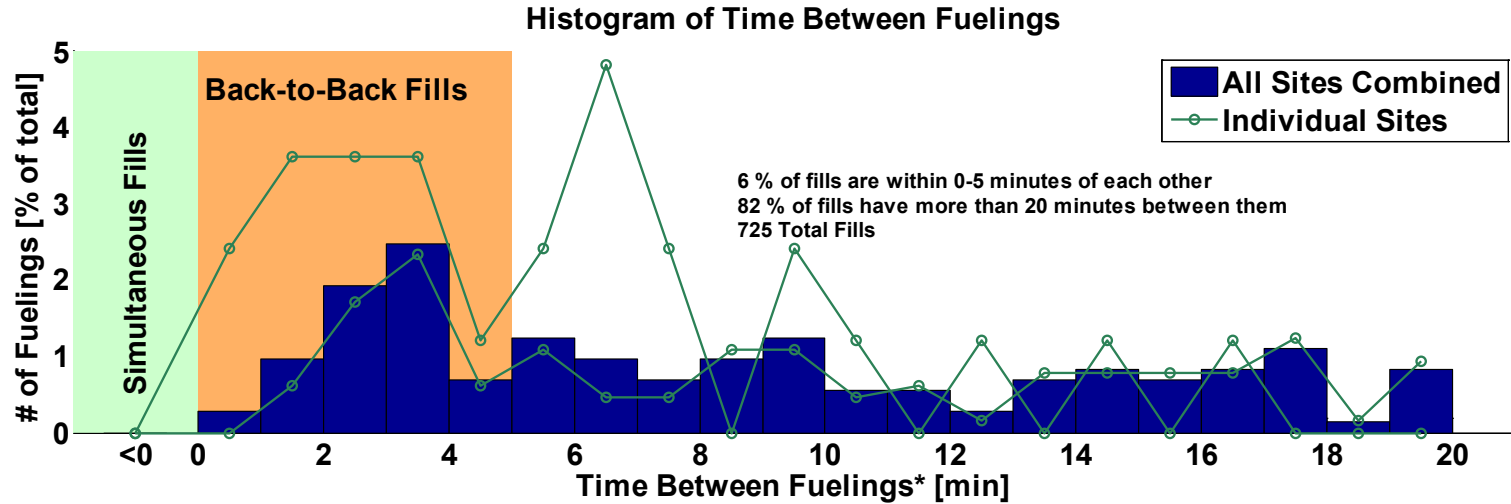
Station Usage



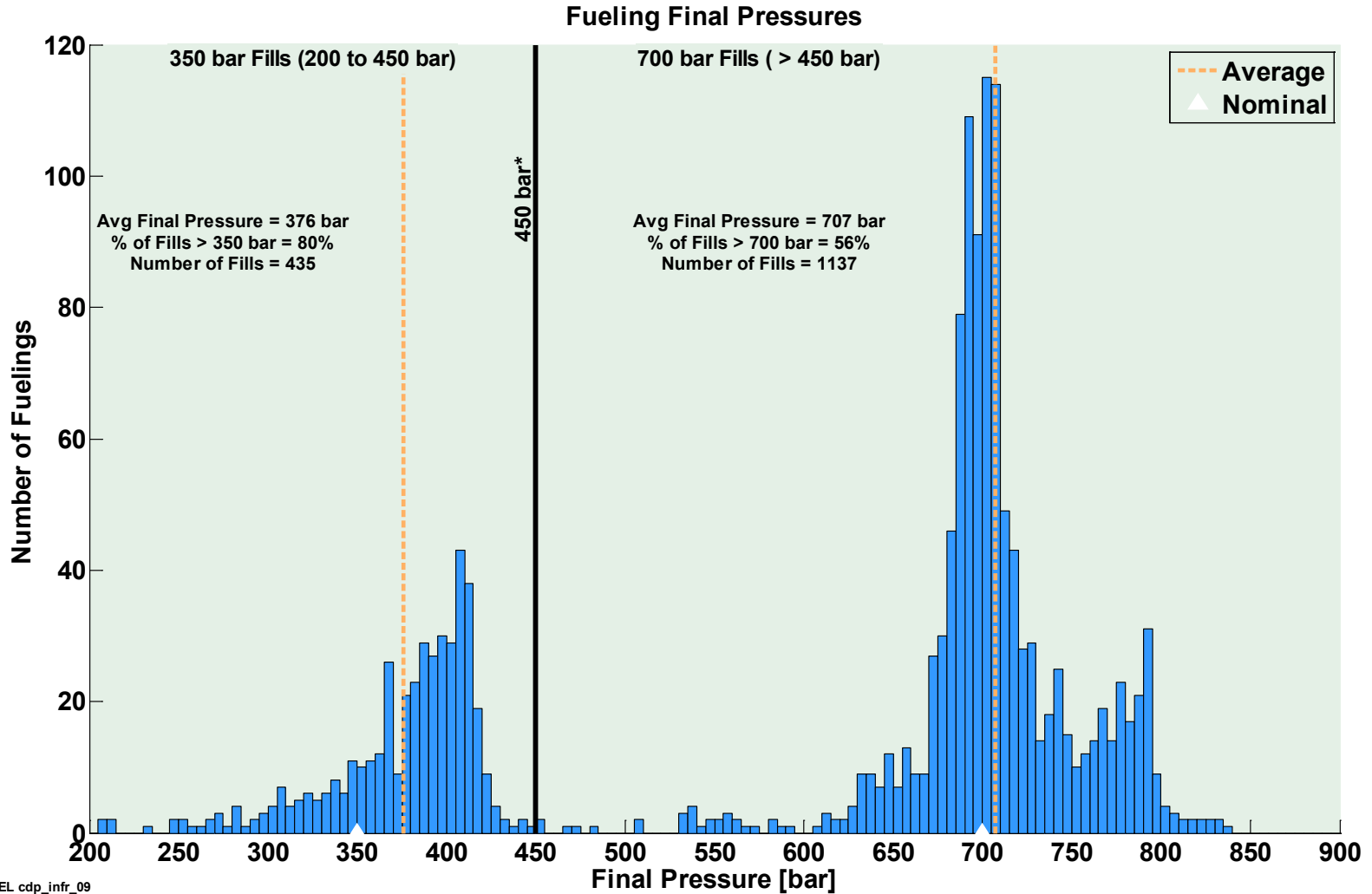
¹Excludes hydrogen fills of < 0.5 kg

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

Time Between Fueling



Fueling Final Pressures

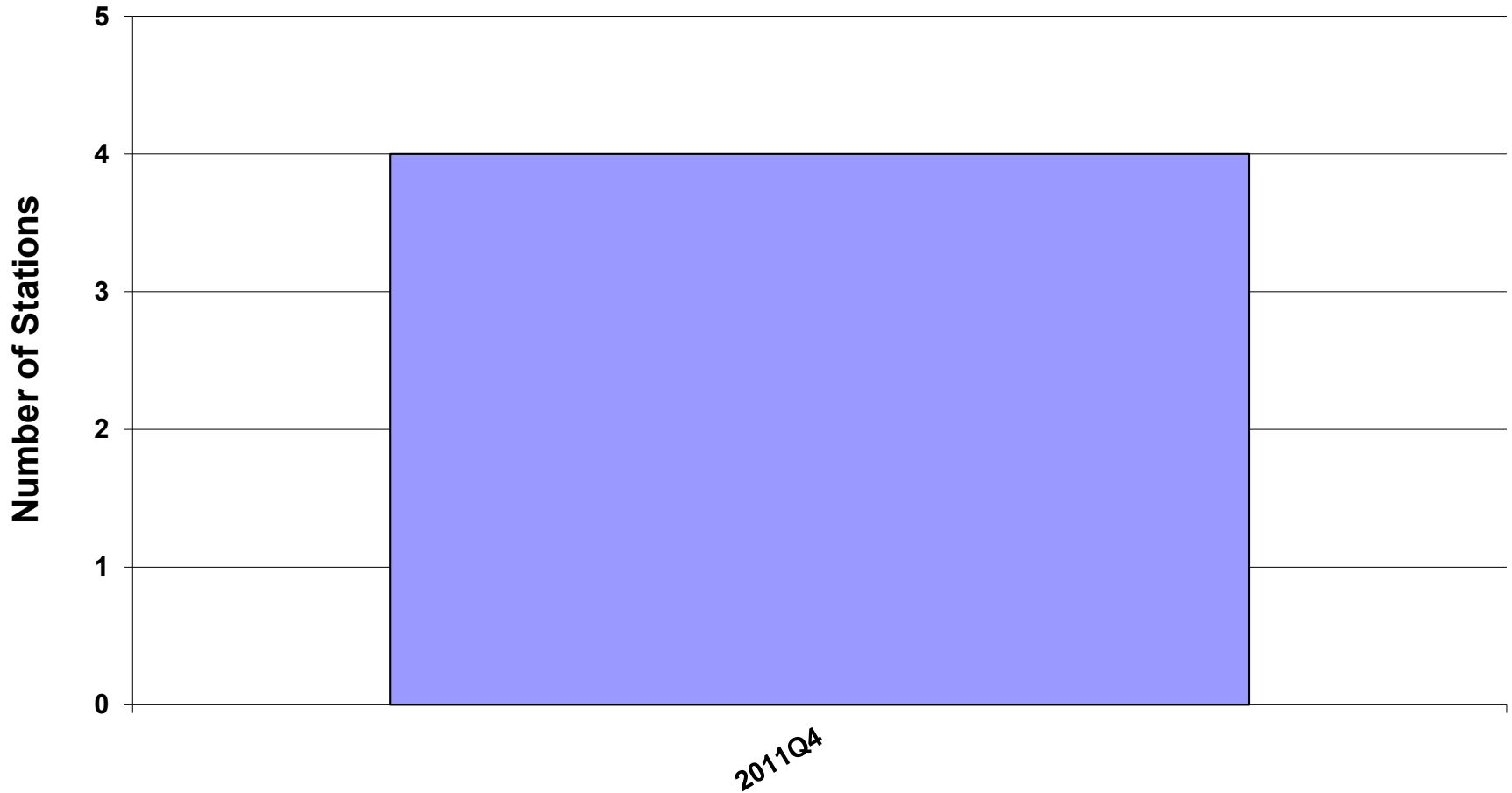


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*The line at 450 bar separates 350 bar fills from 700 bar fills. It is slightly over the allowable 125% of nominal pressure (437.5 bar) from SAE J2601.

Cumulative Number of Stations

Cumulative Stations

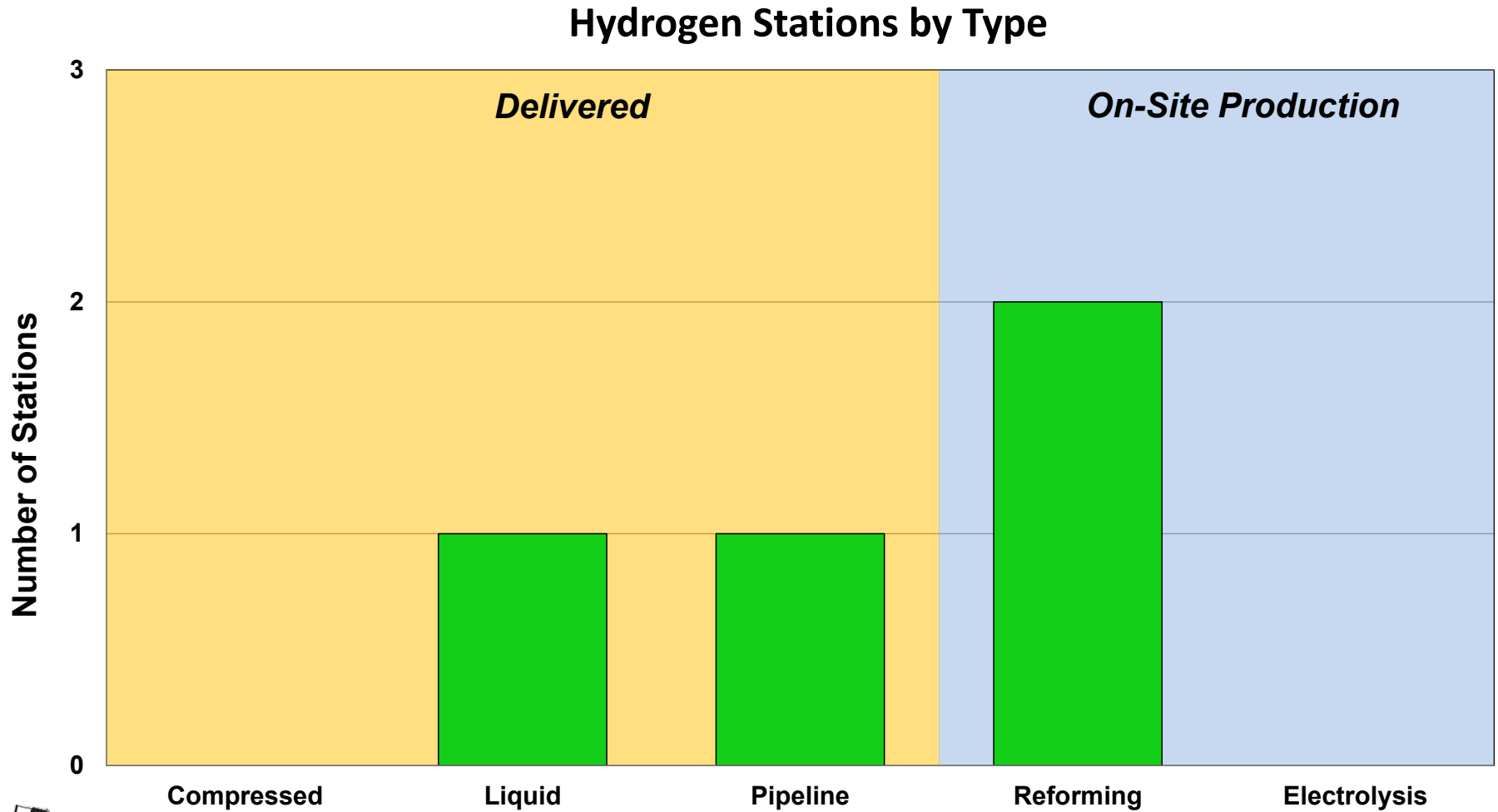


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Reporting Period

Hydrogen Stations by Type



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Fueling Rates 350 vs. 700 bar

