NREL
NATIONAL RENEWABLE ENERGY LABORATORY

# Technology Validation of Fuel Cell Vehicles and Their Hydrogen Infrastructure

## 2013 Fuel Cell Seminar
## Columbus, Ohio


## Sam Sprik, Jennifer Kurtz, Keith Wipke, Genevieve Saur, Chris Ainscough

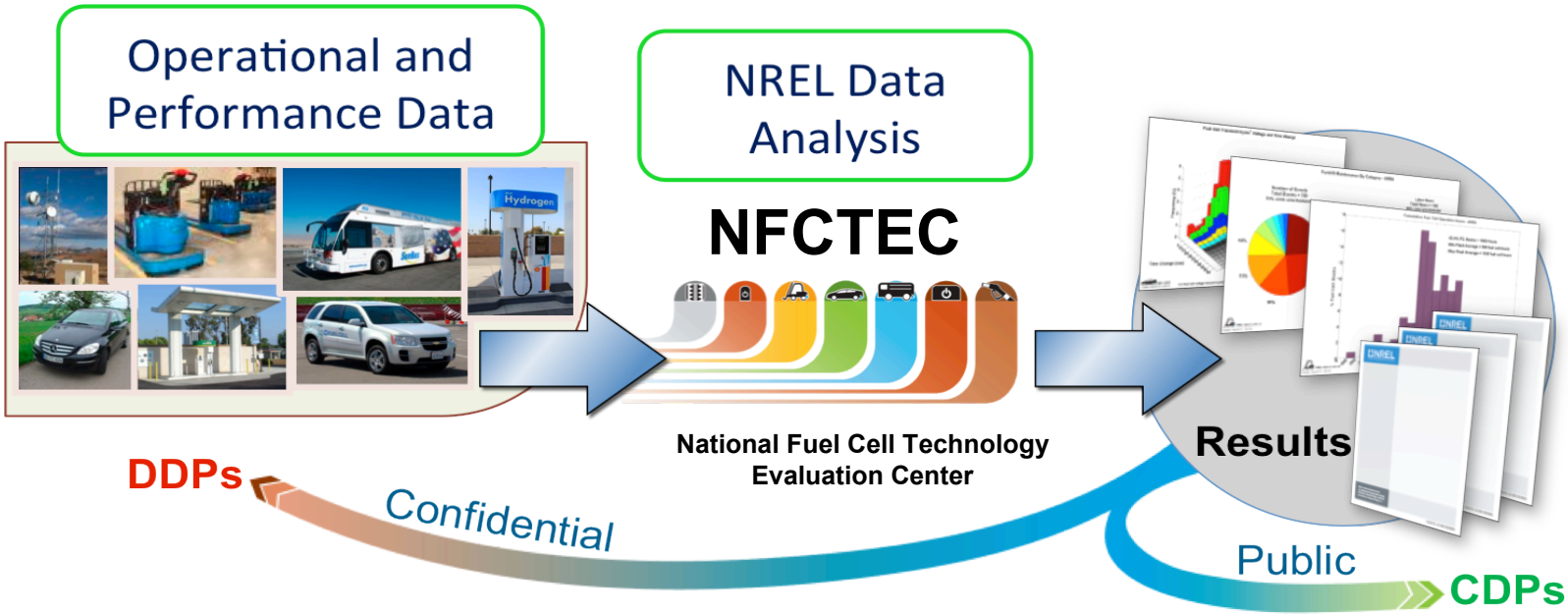

## October 22, 2013


NREL/PR-5400-60876


MOT24

# NFCTEC Analysis Approach

## Analysis and reporting of real-world operation data




### Detailed Data Products (DDPs)

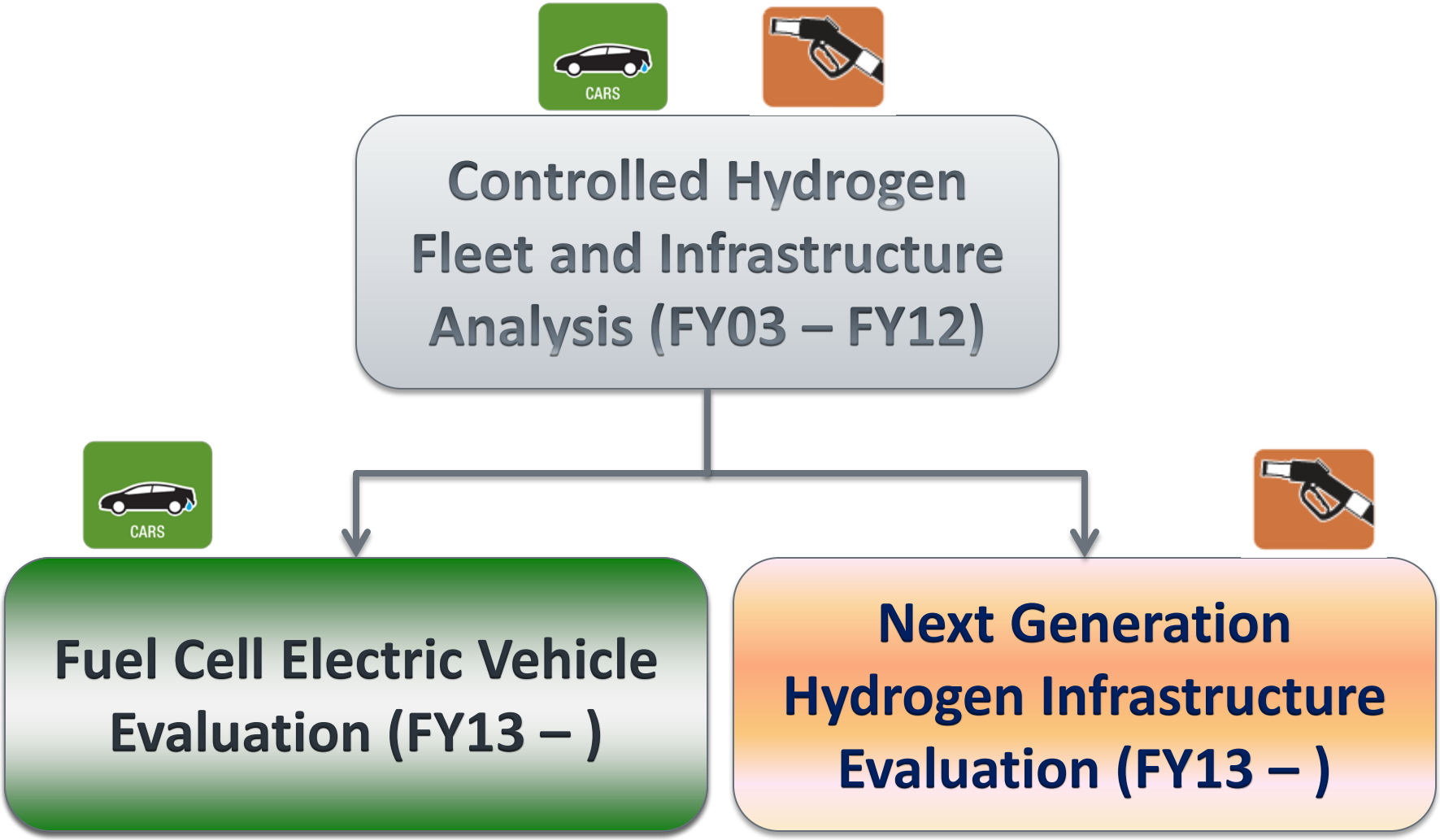
- Individual data analyses, shared only with partner supplying data
- Identify individual contribution to CDPs

### Composite Data Products (CDPs)

- Aggregated data across multiple systems, sites, and teams
- Publicly available analyses, published without revealing proprietary data

***www.nrel.gov/hydrogen/proj_tech_validation.html***

# Relationship of Technology Validation Projects



# Overview and Objectives

- **Validate fuel cell electric vehicles (FCEVs) and hydrogen fueling infrastructure in a real-world setting**
- **Analyze operational data to provide status and feedback**
  - Vehicles: Fuel cell durability, vehicle operation, range, fuel economy, efficiency, reliability
  - Infrastructure: Capacity, utilization, station build time, maintenance/ availability, fueling, geographic coverage
- **Identify current status and evolution of the technology**
- **Objectively assess progress toward targets and market needs**
- **Use metrics to clearly evaluate progress toward challenges**
- **Provide feedback to hydrogen and fuel cell research and development**
- **Publish results for key stakeholder use and investment decisions**

**APC/Shell Pipeline station, Torrance, CA.** Photo: NREL

# Progress Toward Targets

## Objectively assess progress toward targets and market needs

| Key Targets | | |
|---|---|---|
| **Performance Measure** | **Status*** | **Ultimate (2020)** |
| Fuel Cell Stack Durability | 2,500 hours | 5,000 hours |
| Vehicle Range | 254+ miles | 300+ miles |
| Fill Rate | 0.77 kg/min | 1.0 kg/min |
| Efficiency | 59% at 25% Power | 60% at 25% Power |

*As reported in previous Learning Demonstration results

# Infrastructure Challenges and Metrics

## 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…

# Key Vehicle Analysis Topics Identified

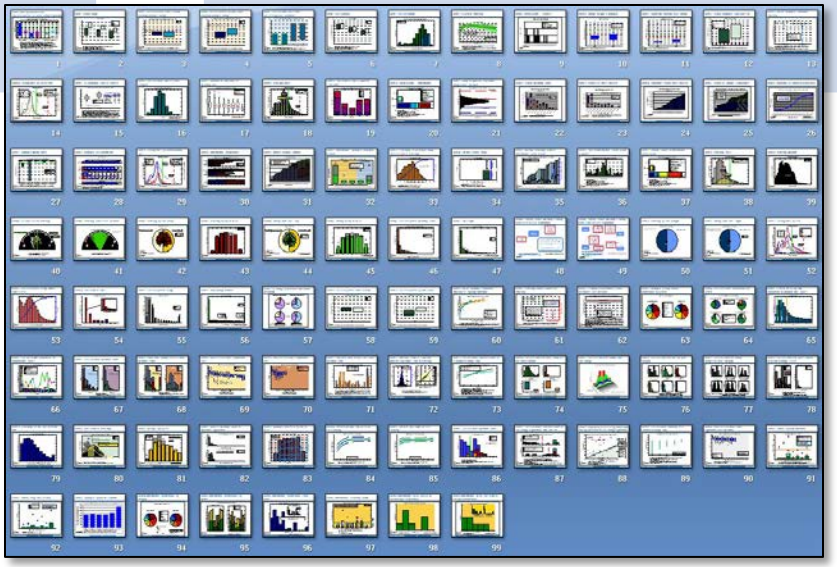
## *Critical*

- FC durability
- Vehicle operation (hours, miles)
- Specs (power density, specific power)
- Range, fuel economy, and efficiency
- Fill performance
- Reliability

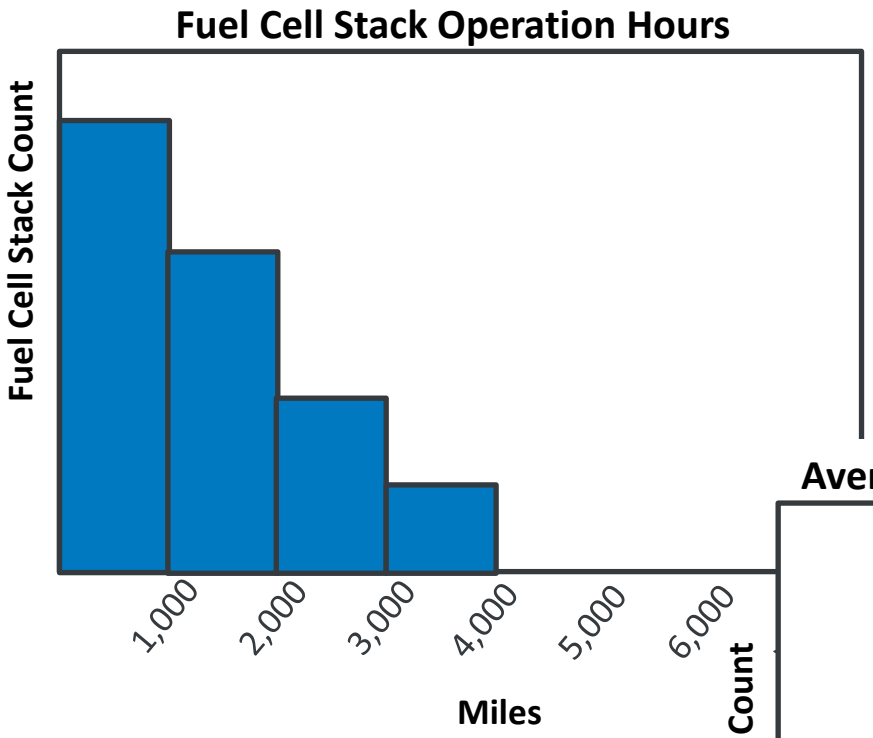
## *Important*

- Drive behaviors
- Fill behaviors
- Power management
- Energy
- Transients
- Comparisons to conventional vehicles

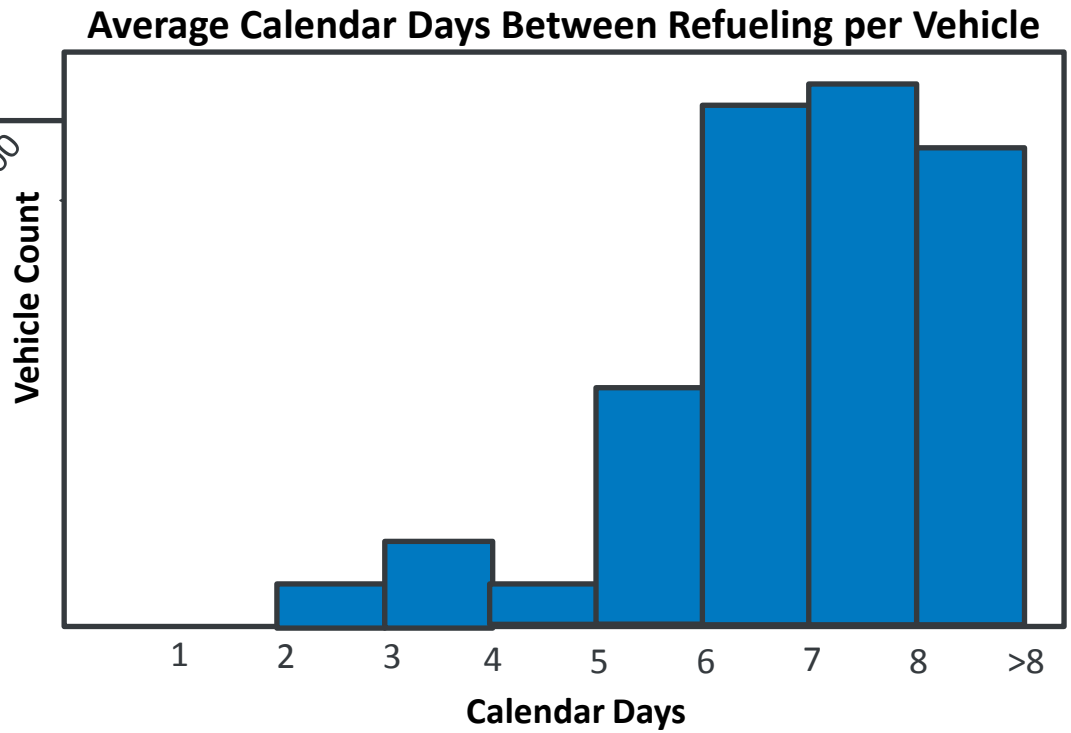
These key topics were selected based on review of past CDPs (99 total), targets, most common referenced topics, and DOE feedback



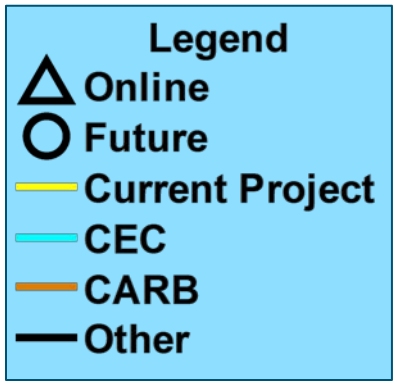
# Sample FCEV CDPs

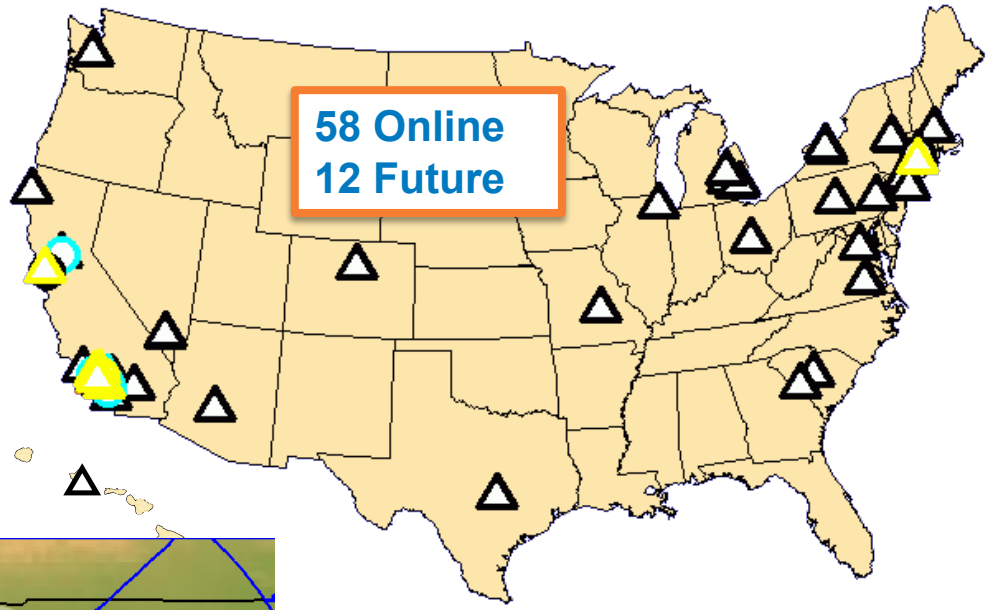


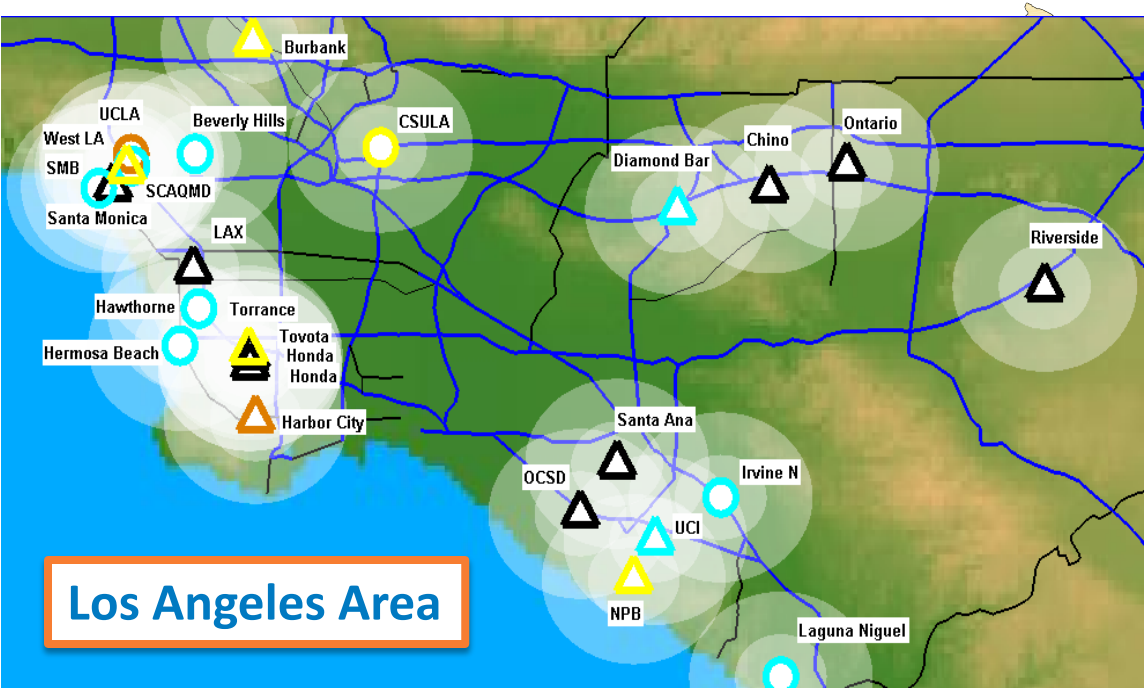

Leverage experience and analysis from the Learning Demonstration (2005–2011)

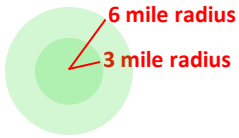


# Station Locations

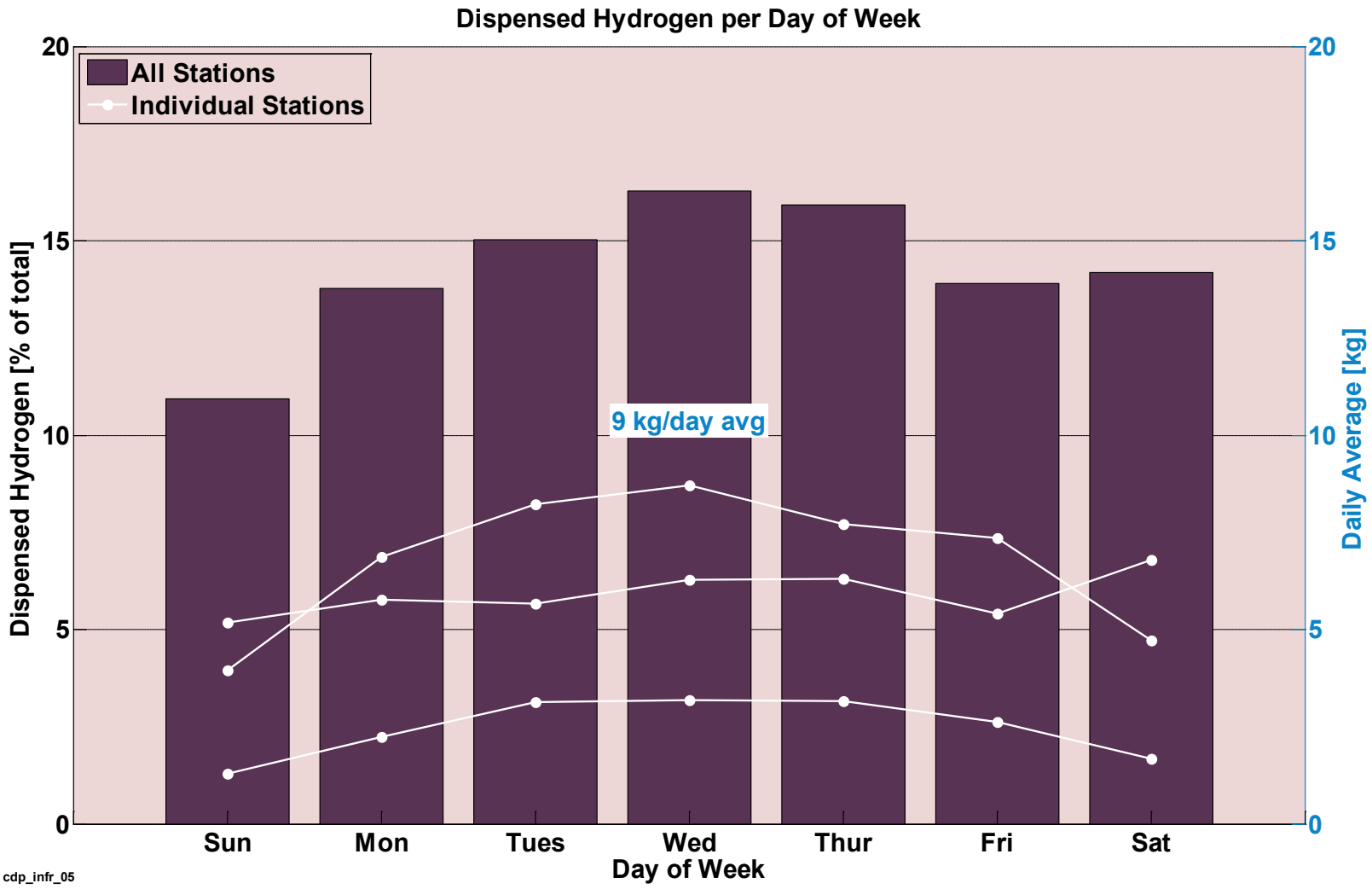


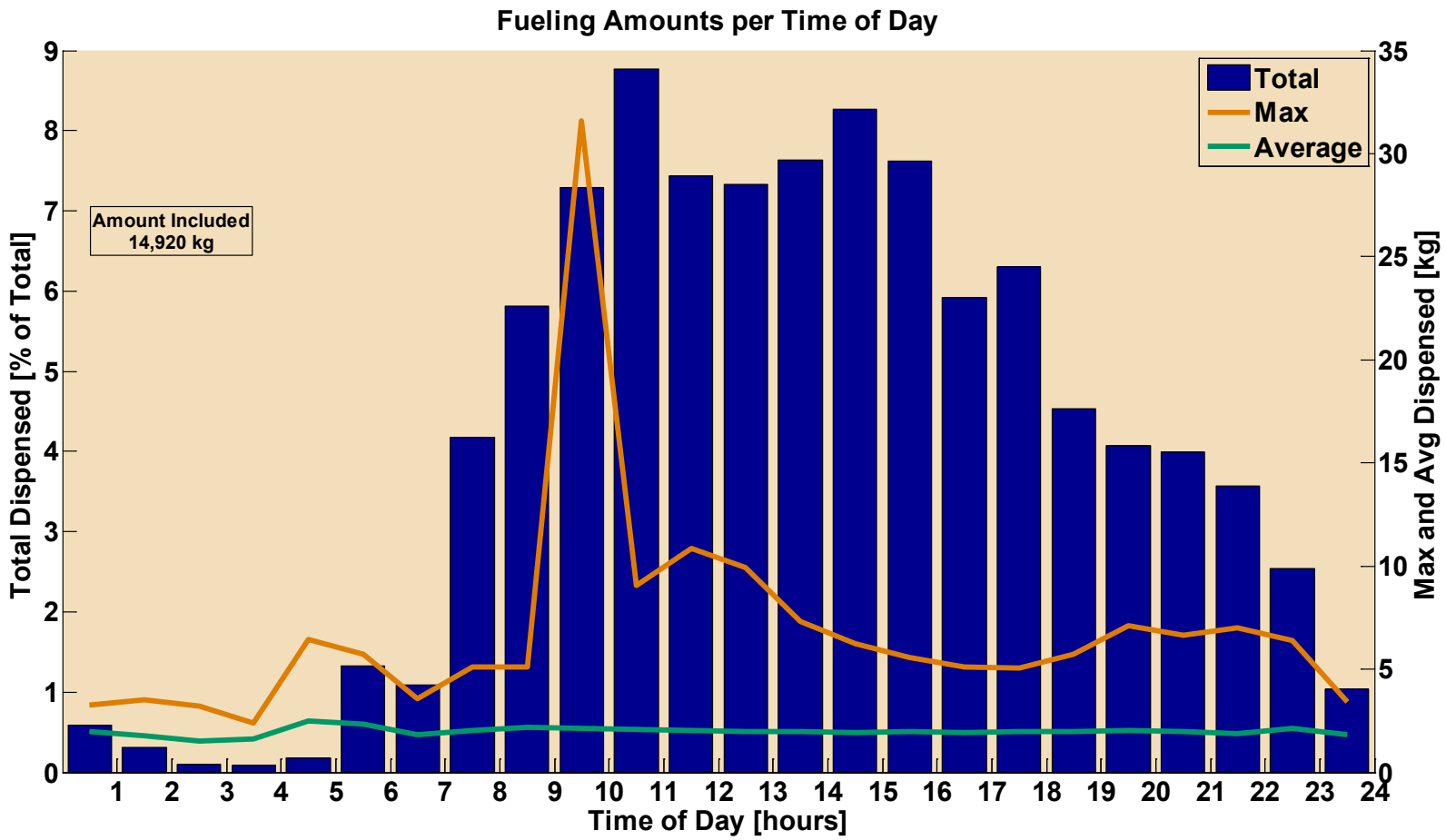



# Dispensed Hydrogen per Day of Week



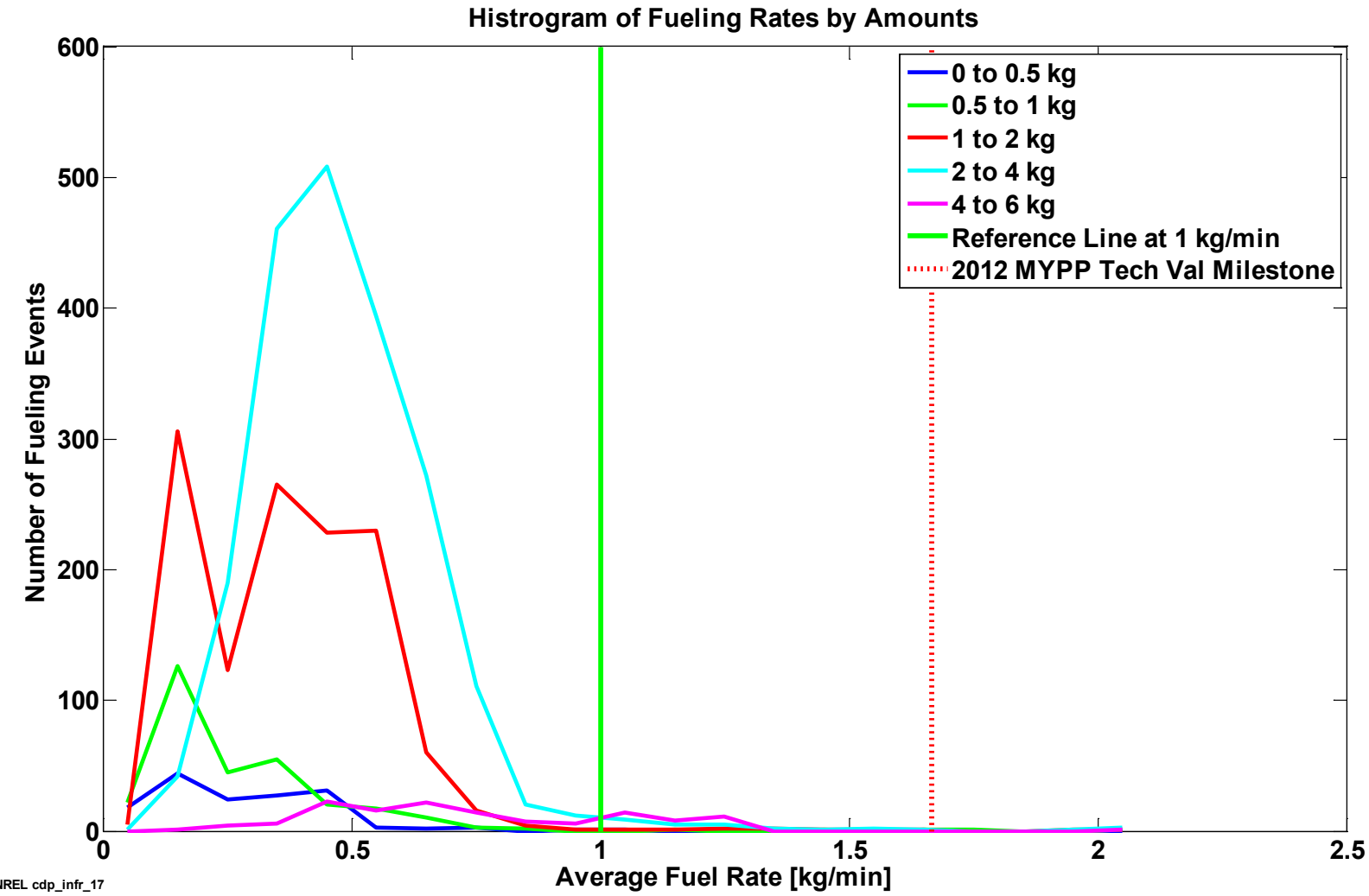

NREL cdp_infr_05
Created: Oct-14-13 4:29 PM | Data Through: 2013Q2

# Fueling Amounts per Time of Day



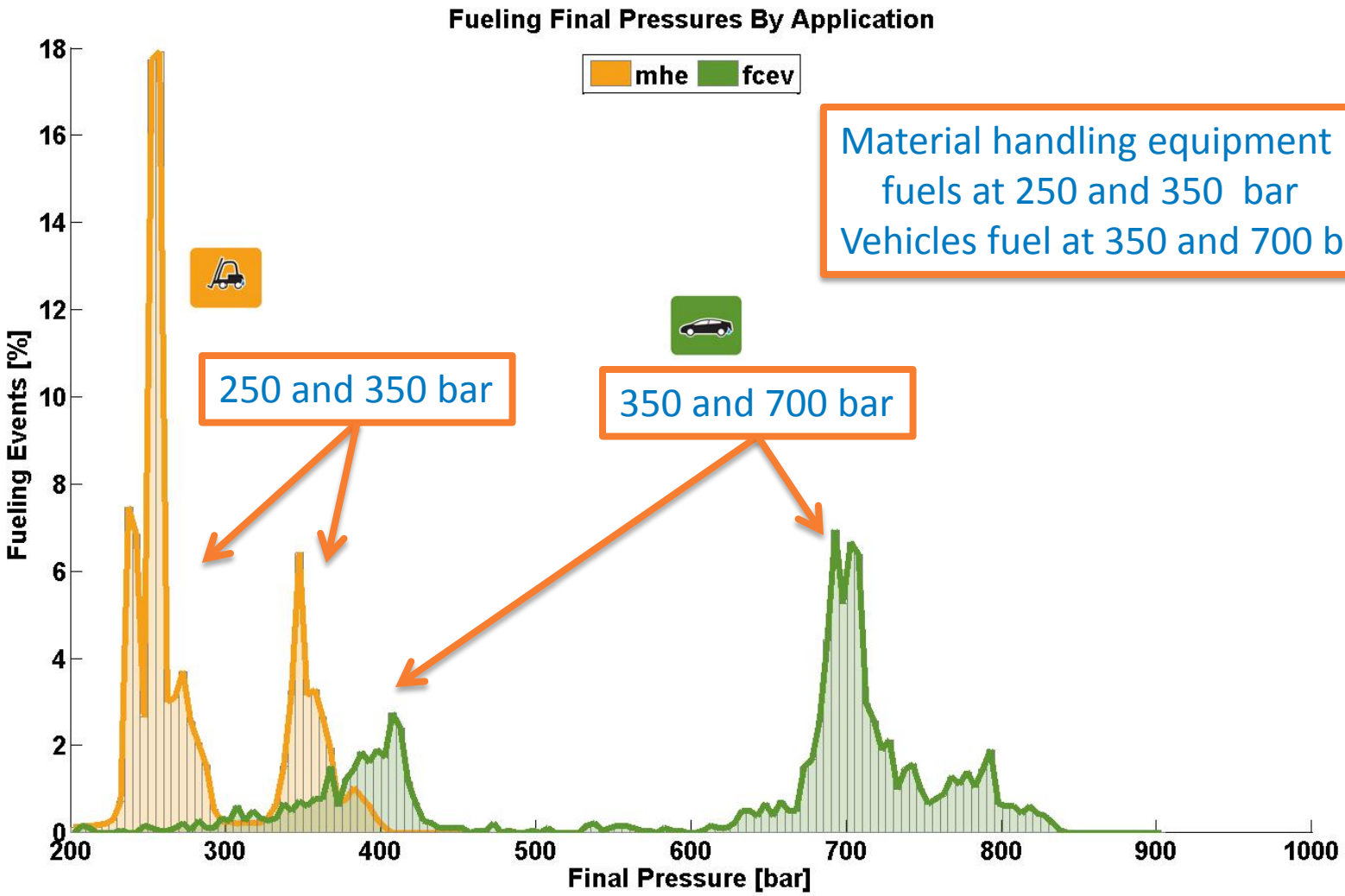

NREL cdp_infr_16
Created: Oct-14-13 4:32 PM | Data Through: 2013Q2

# Fueling Rates by Amount Filled

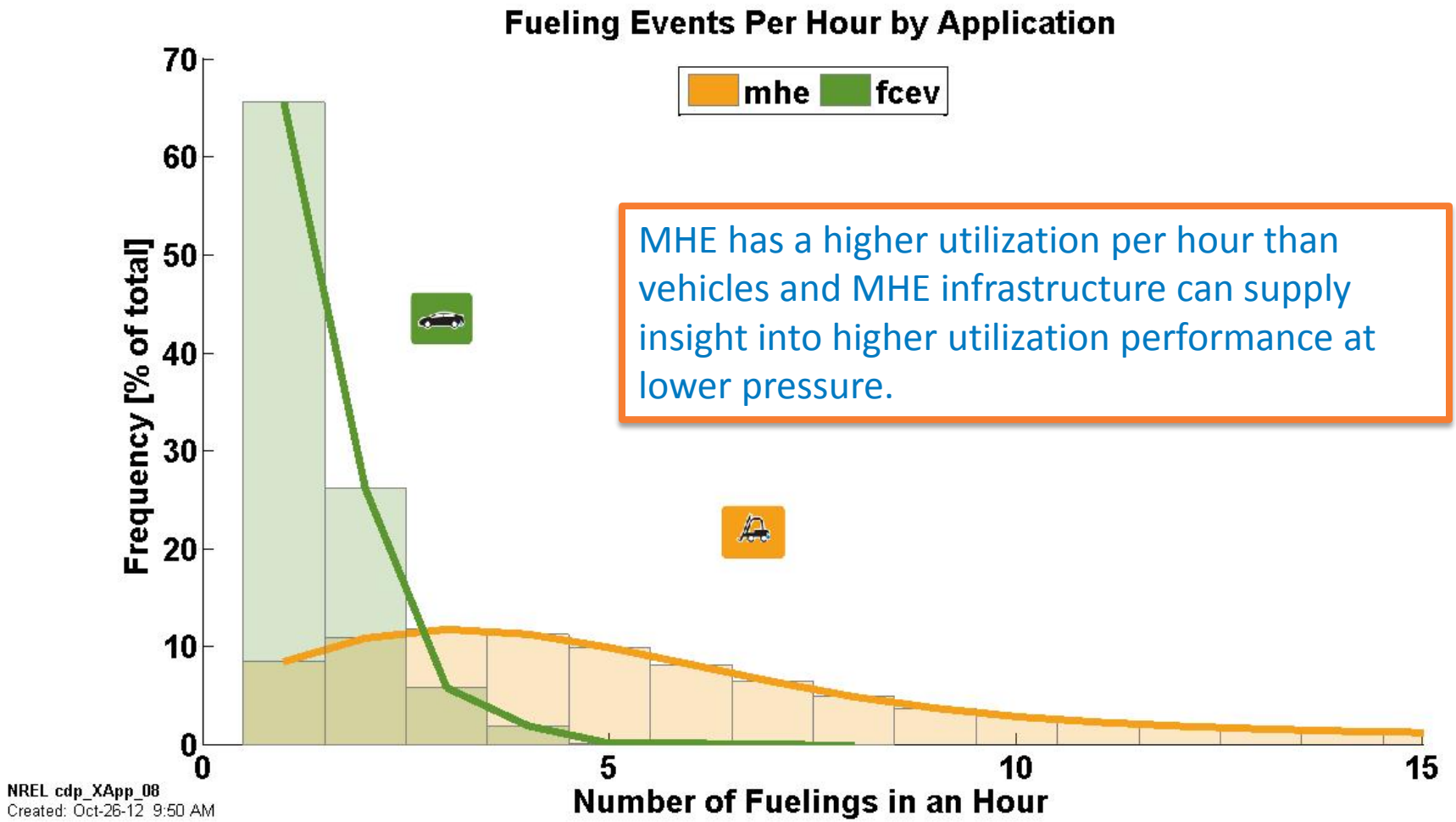



NREL cdp_infr_17
Created: Oct-14-13 4:33 PM | Data Through: 2013Q2

# Fueling Final Pressures by Application

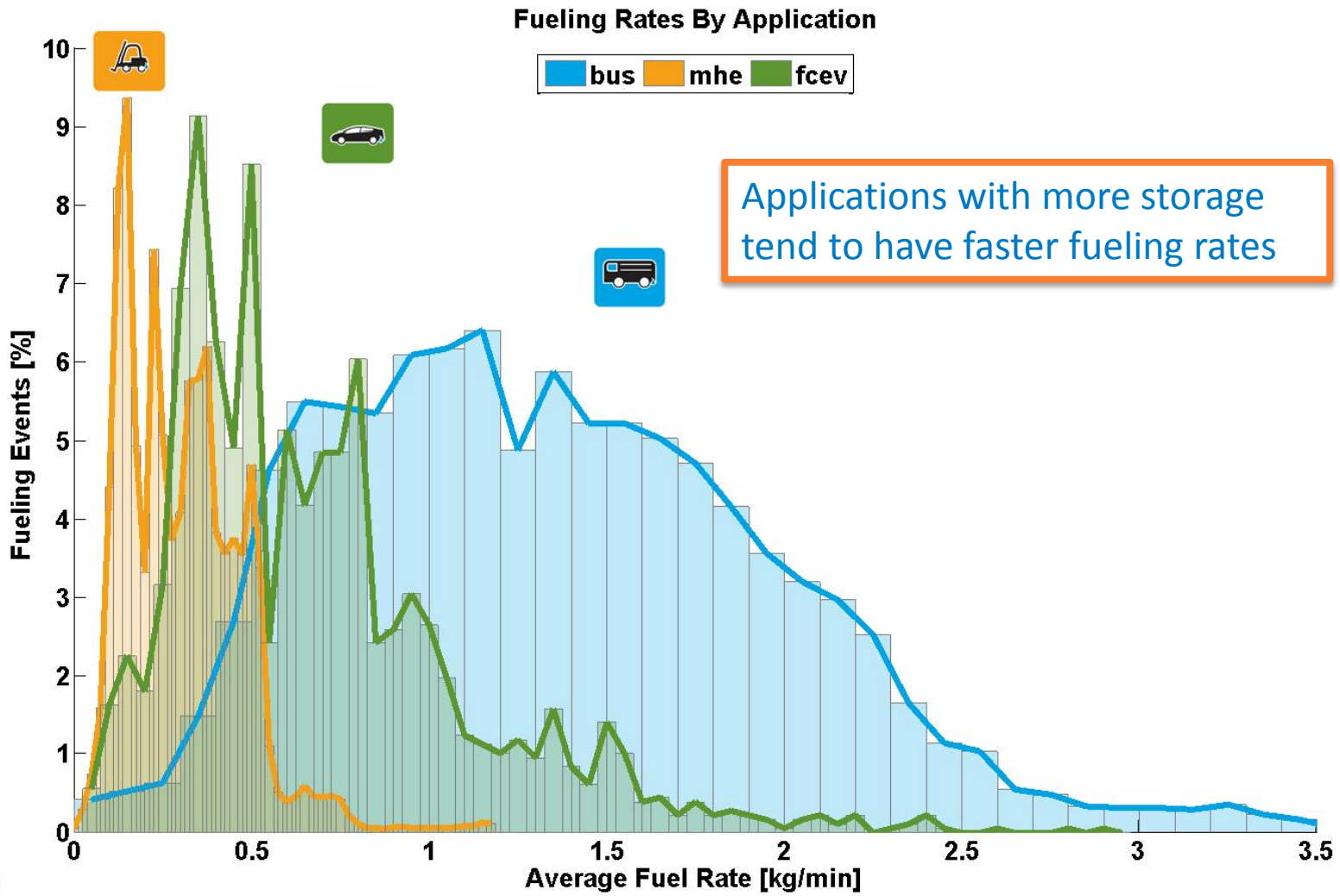


# CDP-XApp-08
# Fueling Events per Hour by Application




MHE has a higher utilization per hour than vehicles and MHE infrastructure can supply insight into higher utilization performance at lower pressure.

# CDP-XApp-04
# Fueling Rates by Application



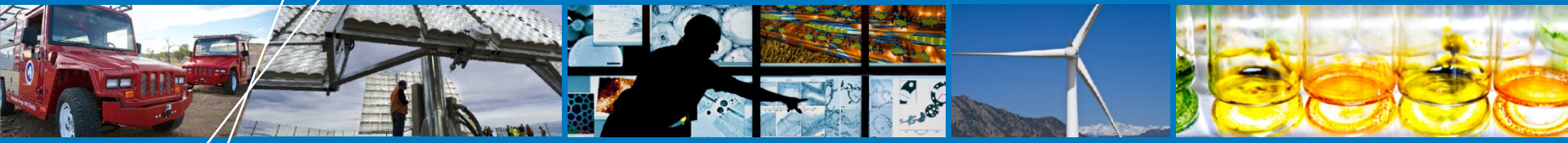

Applications with more storage tend to have faster fueling rates

NREL cdp_XApp_04
Created: Oct-25-12 4:22 PM

# Summary—FCEV and Infrastructure Projects

- **Objectives**
  - Validate FCEV and hydrogen station performance against DOE and industry targets and vehicle needs
- **Approach**
  - Collaborate with industry partners
  - Continue to develop core NFCTEC and analysis capabilities and tools
  - Leverage 7+ years of analysis and experience from the Learning Demonstration
- **Results**
  - Completed data templates and NFCTEC security procedures
  - Prioritized key analysis topics
  - Interacted with auto OEMs on priorities, data sharing, and methods
  - Updated database of stations, held project kickoffs, and completed analysis of current station data
- **Collaborations**
  - Working closely with industry partners to validate methodology, and with other key stakeholders to ensure relevance of results
  - Working with station operators and California organizations
- **Future Work**
  - Identify new opportunities to document fuel cell and hydrogen progress publicly
  - As new stations open and provide data, add them to the analysis to get a good picture of the current state of hydrogen infrastructure

NREL
NATIONAL RENEWABLE ENERGY LABORATORY



# Backup Slides

# Tracking Future Progress Against Previous Demonstration Results

| Vehicle Performance Metrics | Gen 1 Vehicle | Gen 2 Vehicle | 2009 Target | After 2009Q4 |
|---|---|---|---|---|
| ***Fuel Cell Stack Durability*** | | | **2,000 hours** | |
| Max Team Projected Hours to 10% Voltage Degradation | **1,807 hours** | **2,521 hours** | | -- |
| Average Fuel Cell Durability Projection | 821 hours | 1,062 hours | | 1,748 hours |
| Max Hours of Operation by a Single FC Stack to Date | 2,375 hours | 1,261 hours | | 1,582 hours |
| ***Driving Range*** | | | **250 miles** | |
| Adjusted Dyno (Window Sticker) Range | **103-190 miles** | **196-254 miles** | | -- |
| Median On-Road Distance Between Fuelings | 56 miles | 81 miles | | 98 miles |
| Fuel Economy (Window Sticker) | 42 – 57 mi/kg | 43 – 58 mi/kg | no target | -- |
| Fuel Cell Efficiency at ¼ Power | 51% – 58% | 53% – 59% | 60% | -- |
| Fuel Cell Efficiency at Full Power | 30% – 54% | 42% – 53% | 50% | -- |

| Infrastructure Performance Metrics | | | 2009 Target | After 2009Q4 |
|---|---|---|---|---|
| ***$H_2$ Cost at Station (early market)*** | On-Site Natural Gas Reformation **$7.70 – $10.30/kg** | On-Site Electrolysis **$10.00 – $12.90/kg** | **$3/gge** | -- |
| Average $H_2$ Fueling Rate | 0.77 kg/min | | 1.0 kg/min | 0.65 kg/min |

Outside of this project, DOE independent panels concluded at 500 replicate stations/year:
Distributed natural gas reformation at 1,500 kg/day: **$2.75-$3.50/kg** (2006)
Distributed electrolysis at 1,500kg/day: **$4.90-$5.70** (2009)

Outside review panel

# FCEV Data—FOA 625

## DOE Funding Opportunity Announcement (FOA) 625

- **Objectives of FOA**
  - Provide FCEV vehicle data to NREL's NFCTEC for analysis and aggregation
  - Seek to validate improved performance and longer durability from comprehensive set of early FCEVS, including first production vehicles
  - 5-year project duration; two phases
    - "…to collect and submit dynamometer and real-world vehicle performance data to a DOE-sponsored third-party collection and analysis provider to provide statistically valid projections on key metrics including durability of fuel cell system"
- **DOE negotiations in progress with OEM teams**

# Infrastructure Data—FOA 626

## DOE Funding Opportunity Announcement (FOA) 626

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

# FOA-626 Awardees

- **California Air Resources Board (Sacramento, California)**
  - One 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)**
  - One 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)**
  - Five 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)**
  - Two 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)