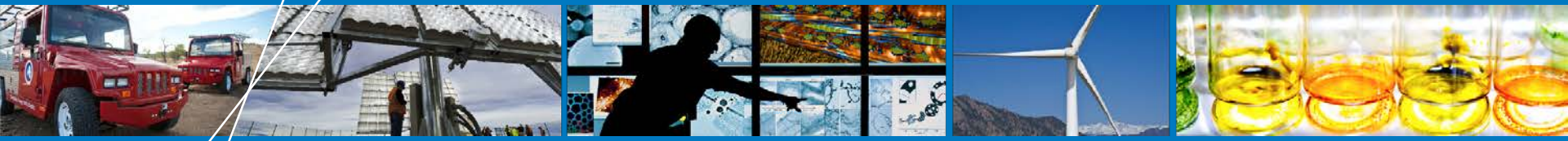
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Material Handling Equipment Data Collection and Analysis



Chris Ainscough, P.E., Jennifer Kurtz
NREL
June 10th, 2015

Project ID #TV021

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

Overview

Timeline

- **Project start date: Oct. 2012**
- **Project end date: Oct. 2015***

Barriers

- **Barriers addressed**
  - Commercialization of fuel cells in key early markets

Budget

- **Total DOE funds received to date: $865**
- **FY14 DOE funding: $100k**
- **FY15 planned DOE funding: $70k**

Partners

- **Interactions/collaborations**
- **Project lead: NREL**
- **See collaborations slide**

***Project continuation & direction determined annually by DOE.**

Relevance: Objectives

FORKLIFTS

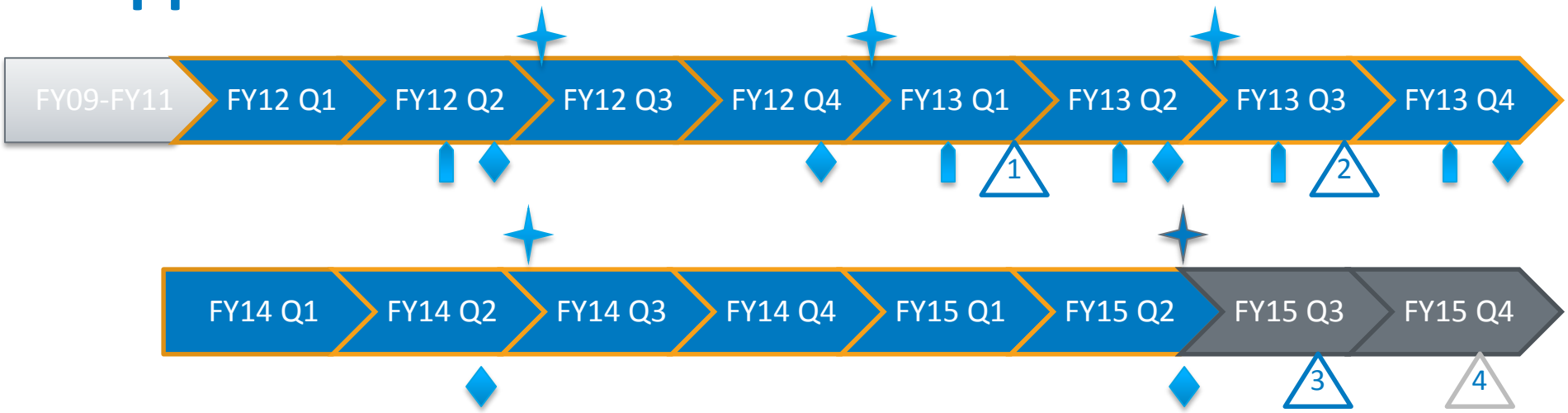
Assess the technology status in real-world operations, establish performance baselines, report on fuel cell and hydrogen technology, and support market growth by evaluating performance relevant to the markets' value proposition.

- **Assess technology**
  - Perform independent technology assessment in real-world operation conditions
  - Focus on fuel cell system performance, and operation
  - Leverage data processing and analysis capabilities developed under the fuel cell vehicle Learning Demonstration project
  - Evaluate material handling equipment (MHE) and backup power
  - Analysis includes up to 1,000 fuel cell systems deployed with ARRA funds plus over 200 deployed privately.
- **Support market growth**
  - Provide analyses and results relevant to the markets' value proposition
  - Report on technology status to fuel cell and hydrogen communities and other key stakeholders like end users

Approach

- The design and manufacture of fuel cell MHE continues to evolve, and we need to keep updated status on developments
- ARRA project data collection has come to an end but…
- The ARRA phase collected data on hundreds of MHE units, with over 2-million total vehicle operation hours
- Leverage the massive amount of data collected under ARRA (1.7 TB, 13-million analysis & data files) to continue status monitoring of MHE on a voluntary basis with OEMs.
- We will continue producing updated data products with ARRA as a backdrop.

Approach: Milestones



- Deployment composite data products
- Analysis of operation data for fuel cell systems
- Technical composite data products
- 1 Hydrogen Safety Panel Final Report (FY13 Q1)
- 2 Interim draft report of status and performance of fuel cell MHE and backup power systems
- 3 Final report of status and performance of fuel cell backup power
- 4 Annual report of status and performance of fuel cell MHE*

*Gray markers indicate future work

Approach: NFCTEC Analysis and Reporting of Real-World Operation Data

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

Internal analysis completed quarterly in NFCTEC

National Fuel Cell Technology Evaluation Center

Results

DDPs

Confidential

Public

CDPs

Detailed Data Products (DDPs)

- Individual data analyses
- Identify individual contribution to CDPs
- Shared every six months only with the partner who supplied the data

Composite Data Products (CDPs)

- Aggregated data across multiple systems, sites, and teams
- Publish analysis results every six months without revealing proprietary data

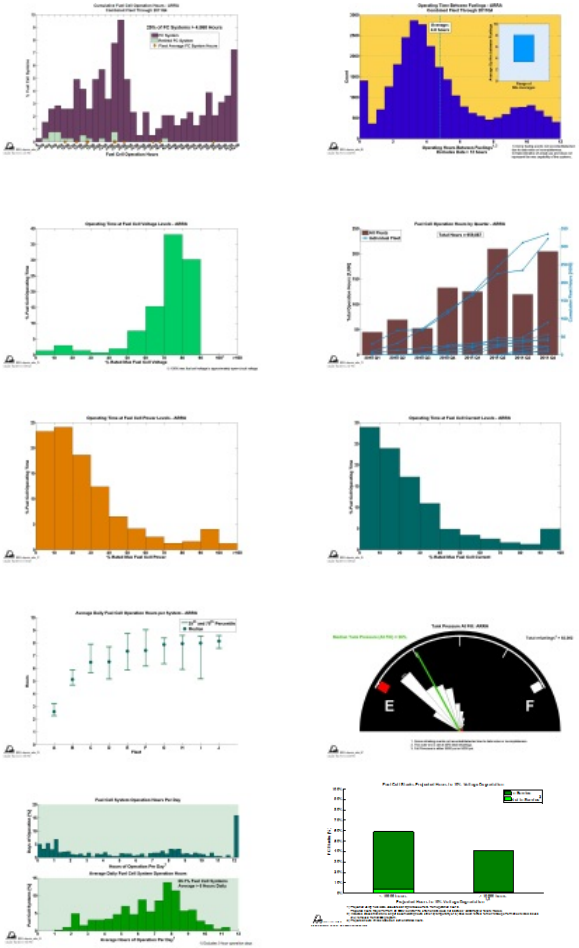
www.nrel.gov/hydrogen/proj_tech_validation.html

Accomplishment

FORKLIFTS

Operation & Durability

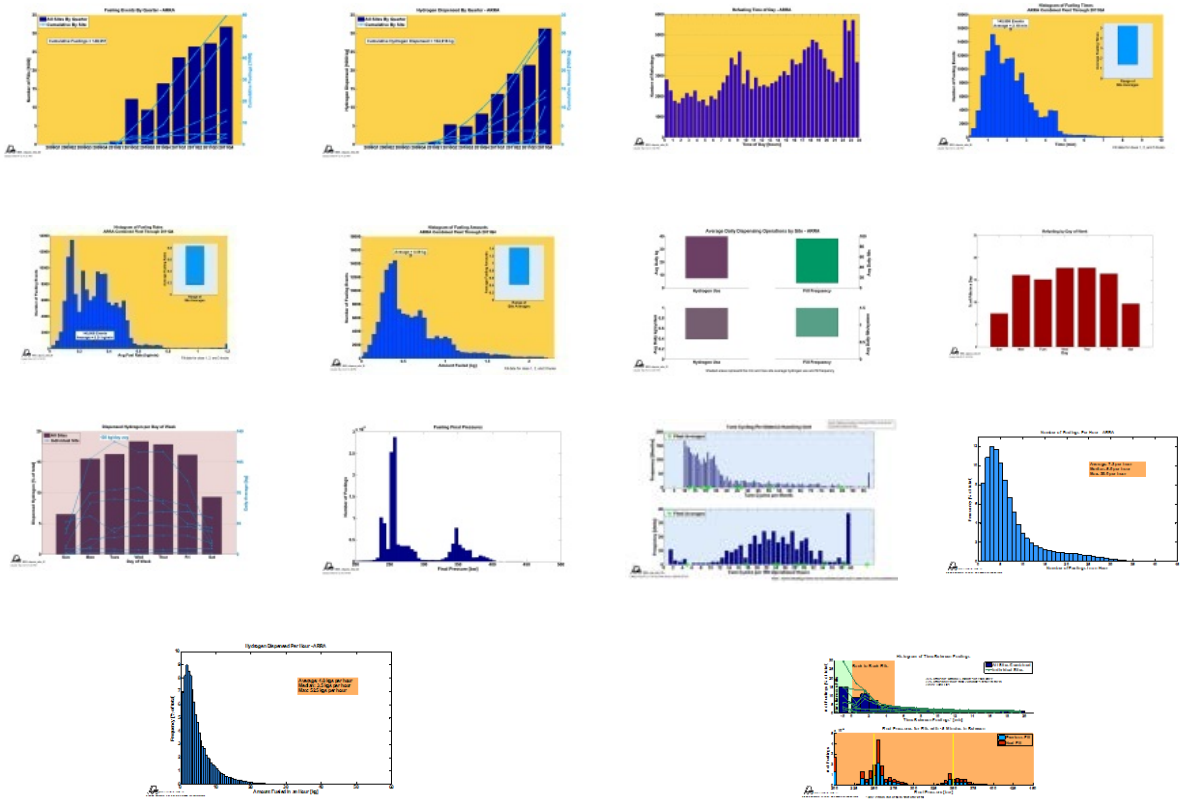
(97, 102, 107, 108, 111, 115, 116, 117, 123, 124)



24 Updated MHE & Infrastructure CDPs

Infrastructure Operation

(103, 104, 105, 106, 109, 110, 122, 135, 136, 142, 162, 165, 168, 169)



Accomplishments: MHE Operation Summary 2009 Q4 – 2014 Q3

FORKLIFTS

Validation of MHE is based on real-world operation data from high-use facilities.

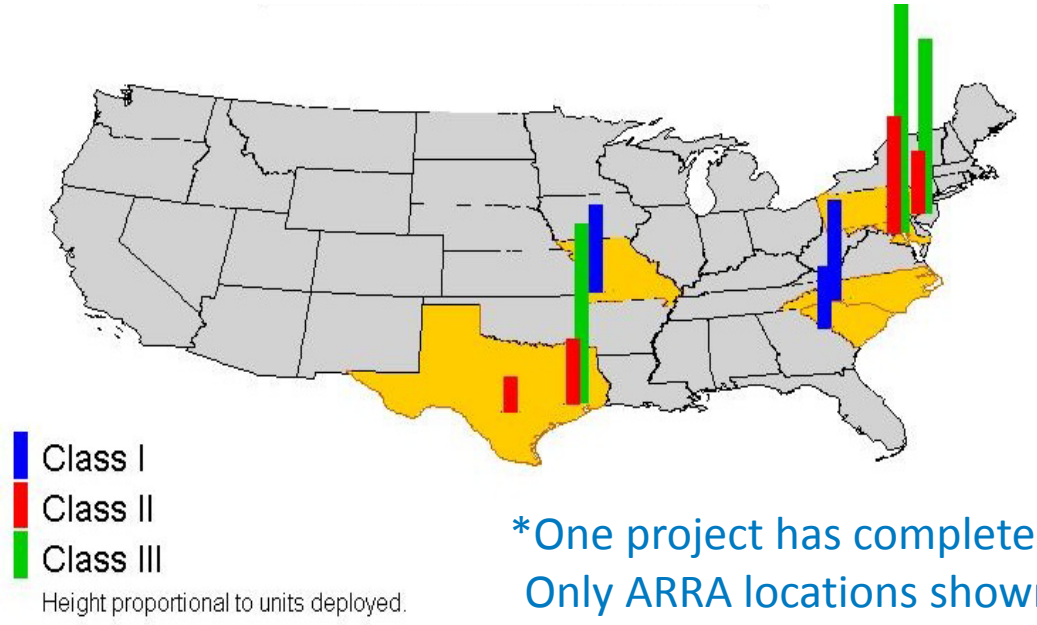
2,683,567
Operation hours

352,527
Hydrogen fills

720
Units in operation*

3.7
Average operation hours between fills

287,967
Hydrogen dispensed in kg



*One project has completed. Only ARRA locations shown

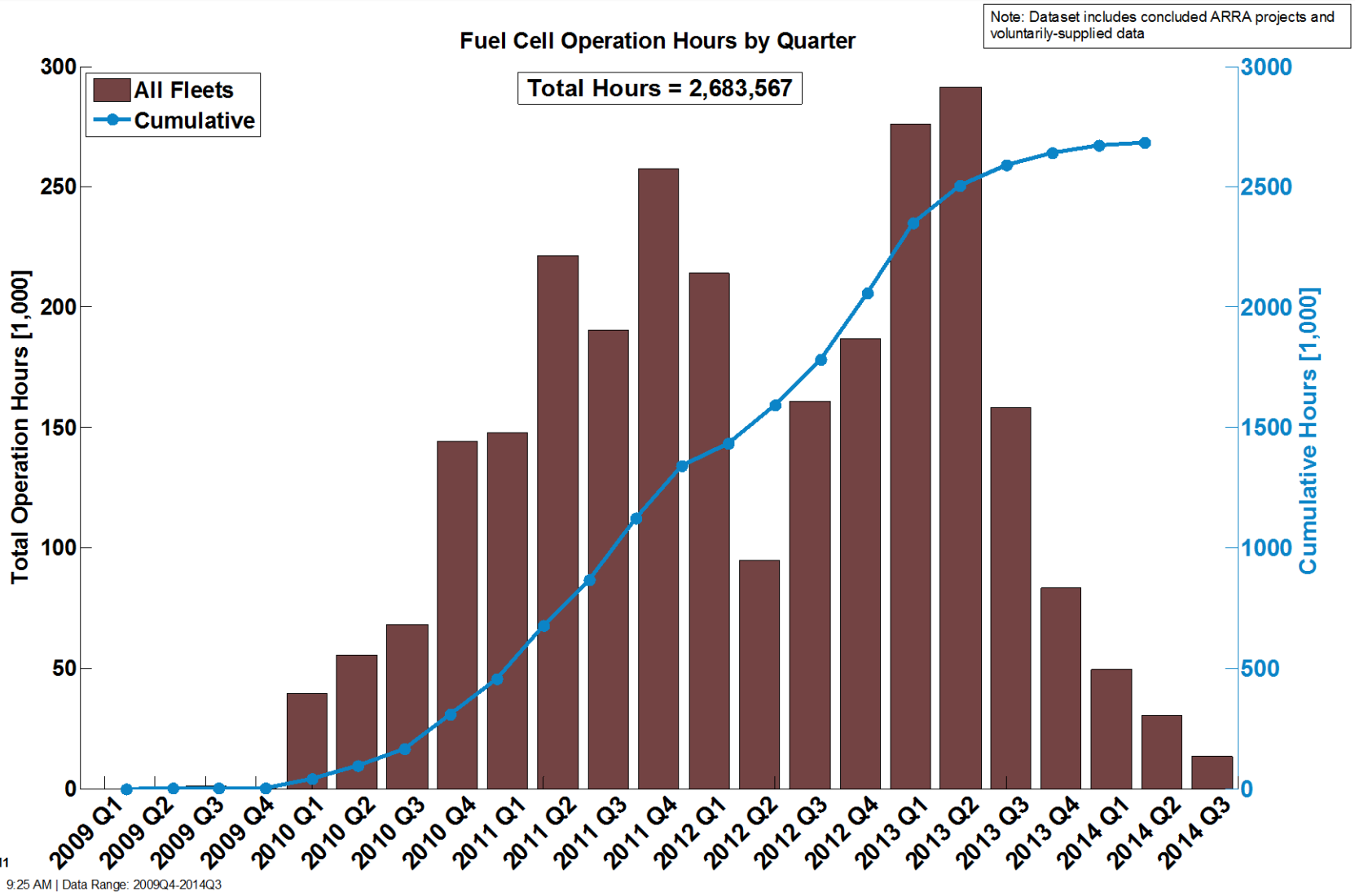
0.7
Average fill amount in kg

2.5
Average fill time in minutes

Accomplishments: Study of FC Operation Hours

FORKLIFTS

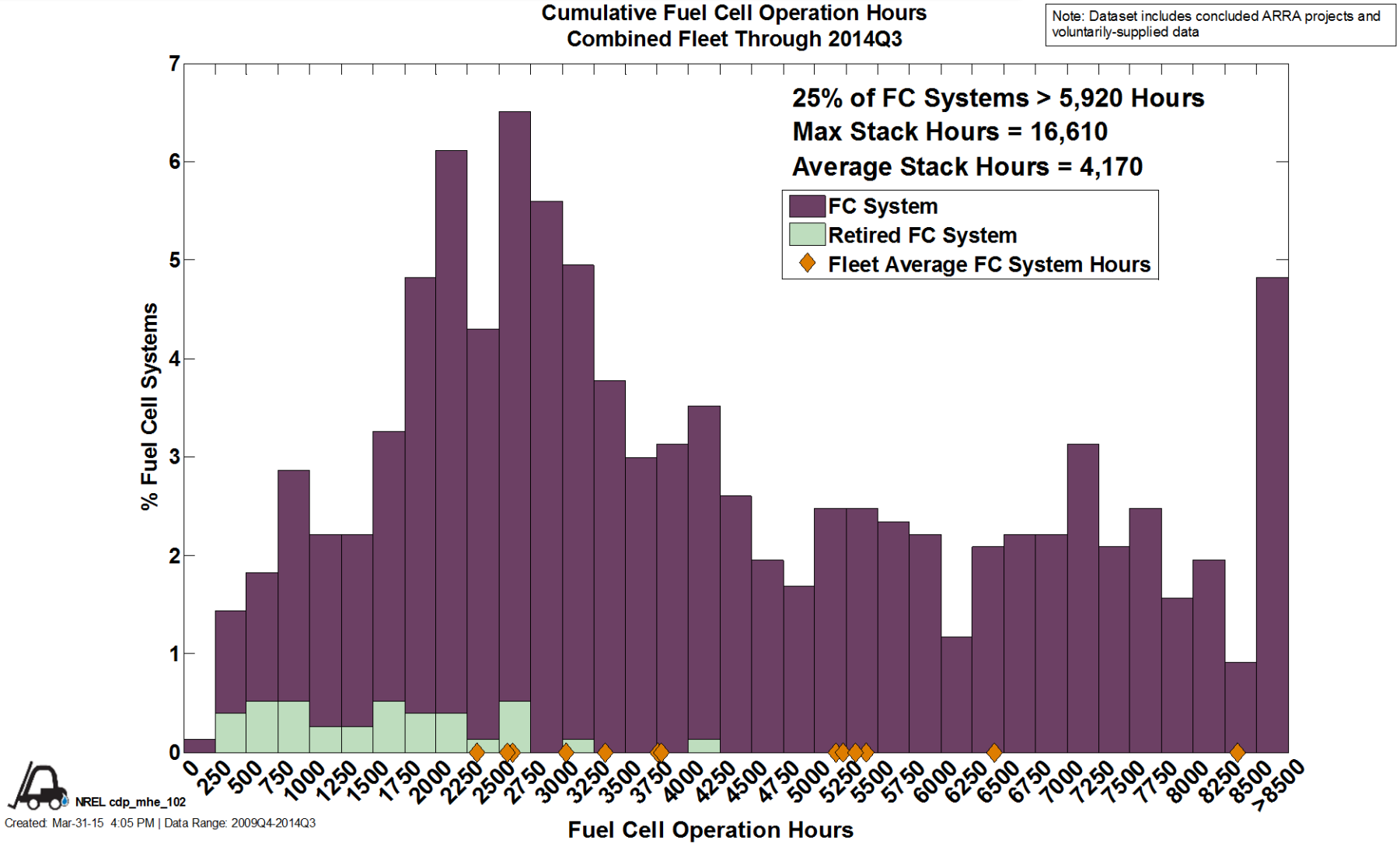
Nearly 2.7-millon vehicle hours. New data represent a >30% increase in operational hours. 2014 decline does not represent less usage, just projects no longer reporting.



Accomplishments: Study of FC Operation Hours

FORKLIFTS

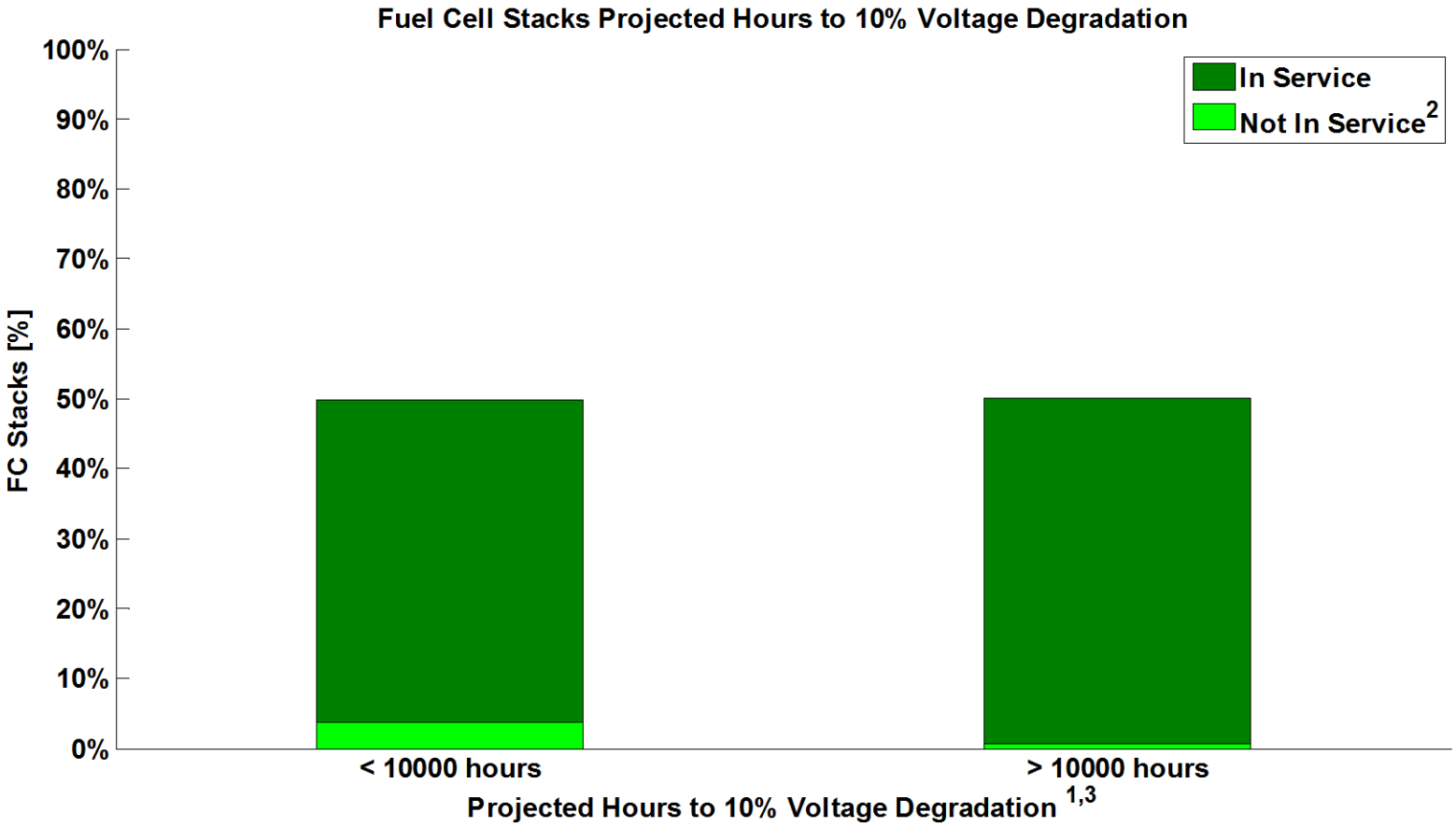
New data have reduced the bi-modal peak at ~7000 hours.
Mean reduced from 4700 to 4100 hours



Accomplishments: Study of FC Voltage Degradation Against 10,000 Hours

FORKLIFTS

~50% of stacks have projected hours to 10% voltage degradation > 10,000 hours.



1) Projection using field data, calculated at high stack current, from operation hour 0.
Projected hours may differ from an OEM's end-of-life criterion and does not address "catastrophic" failure modes.
2) Indicates stacks that are no longer accumulating hours either a) temporarily or b) have been retired for non- stack performance related issues or c) removed from DOE program.
3) Projected hours limited based on demonstrated hours.

NREL cdp_mhe_97

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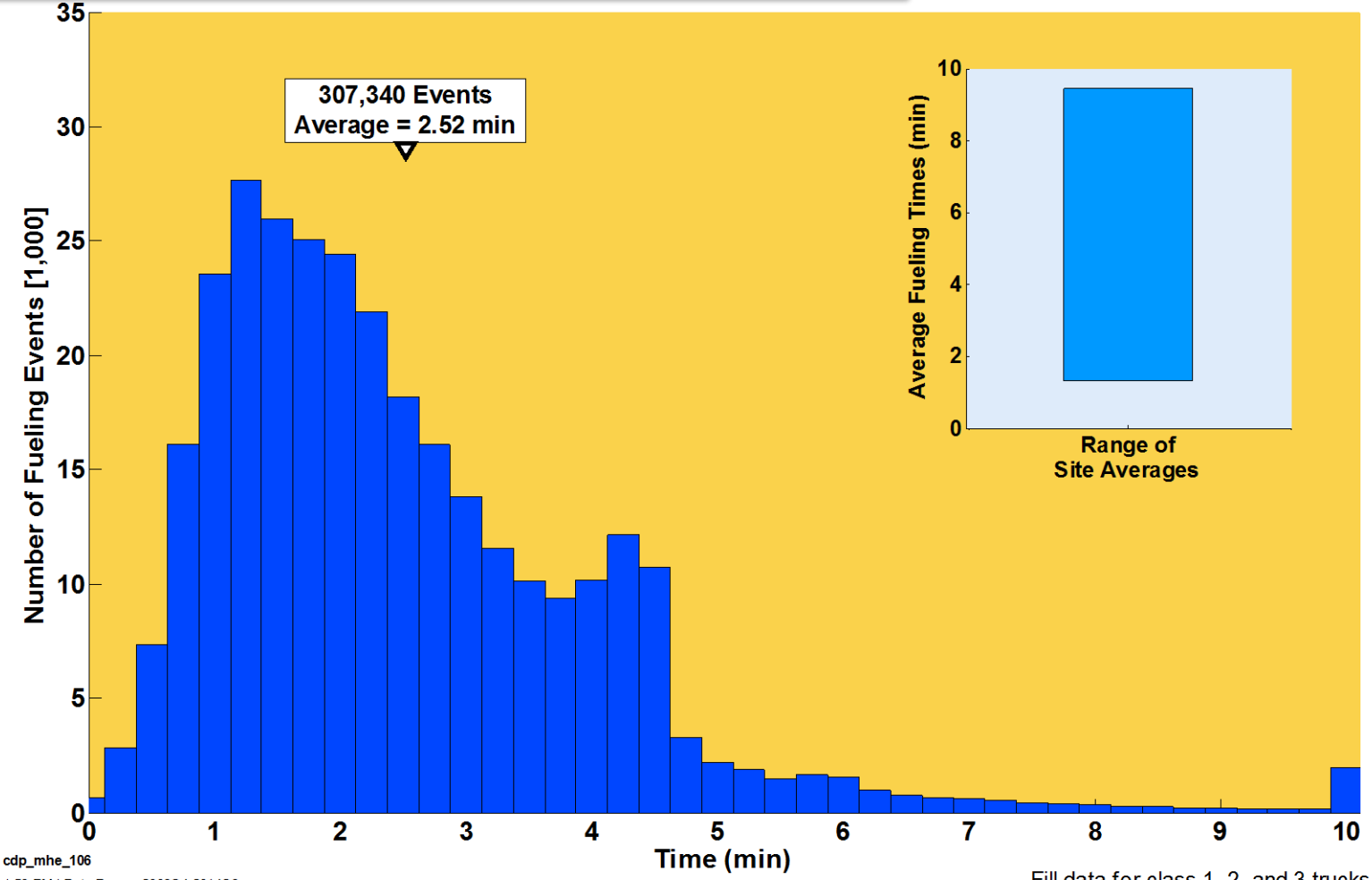
Accomplishments: Study of Fueling Times

FORKLIFTS

Fast fueling times (under three minutes) are key to the value proposition for fuel cell MHE.

Note: Dataset includes concluded ARRA projects and voluntarily-supplied data

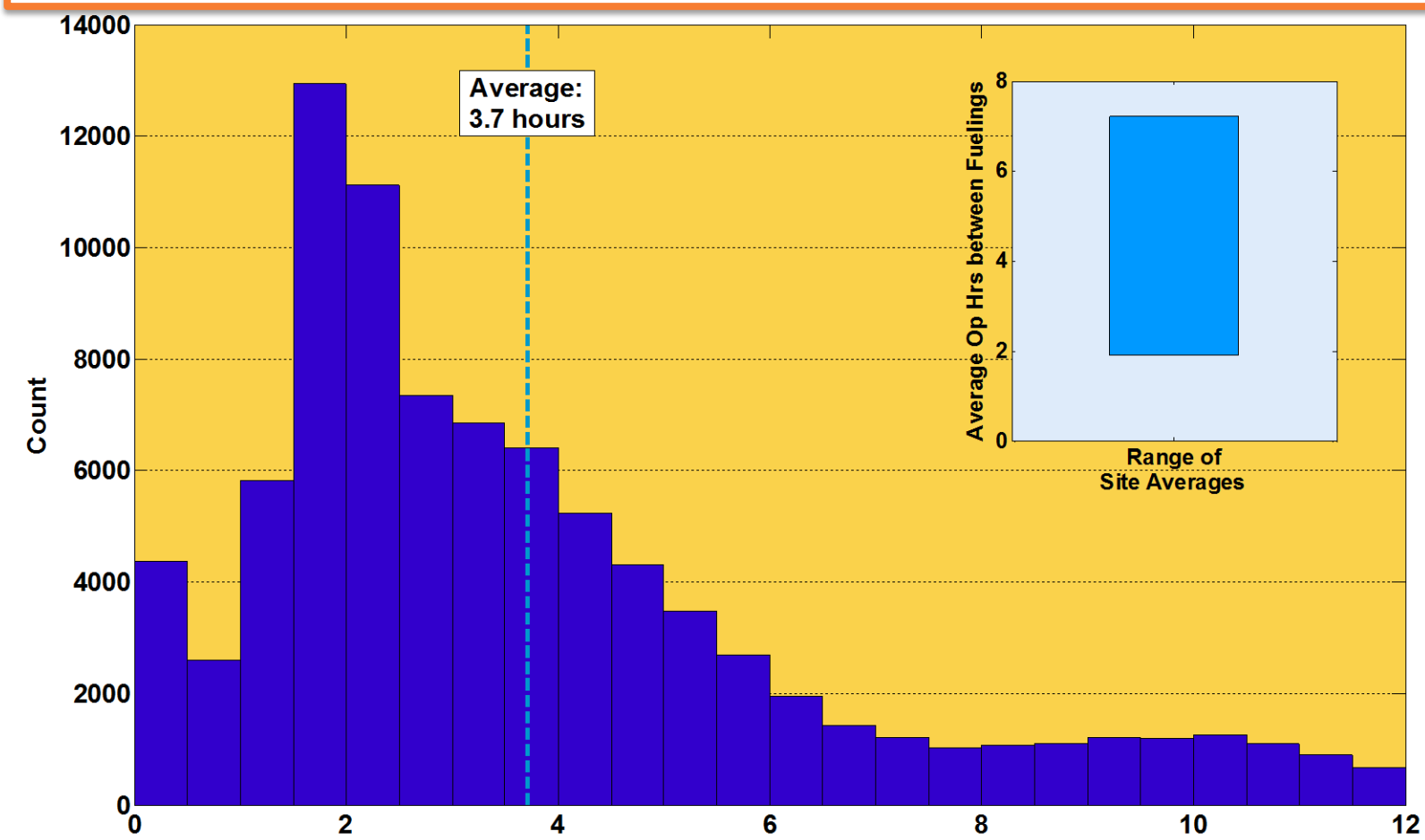


Fill data for class 1, 2, and 3 trucks

Accomplishments: Study of Operation Times

FORKLIFTS

On average MHE is fueled more than once in an 8-hour shift.
NOTE: Indicative of actual use and does not represent vehicle maximum capability.



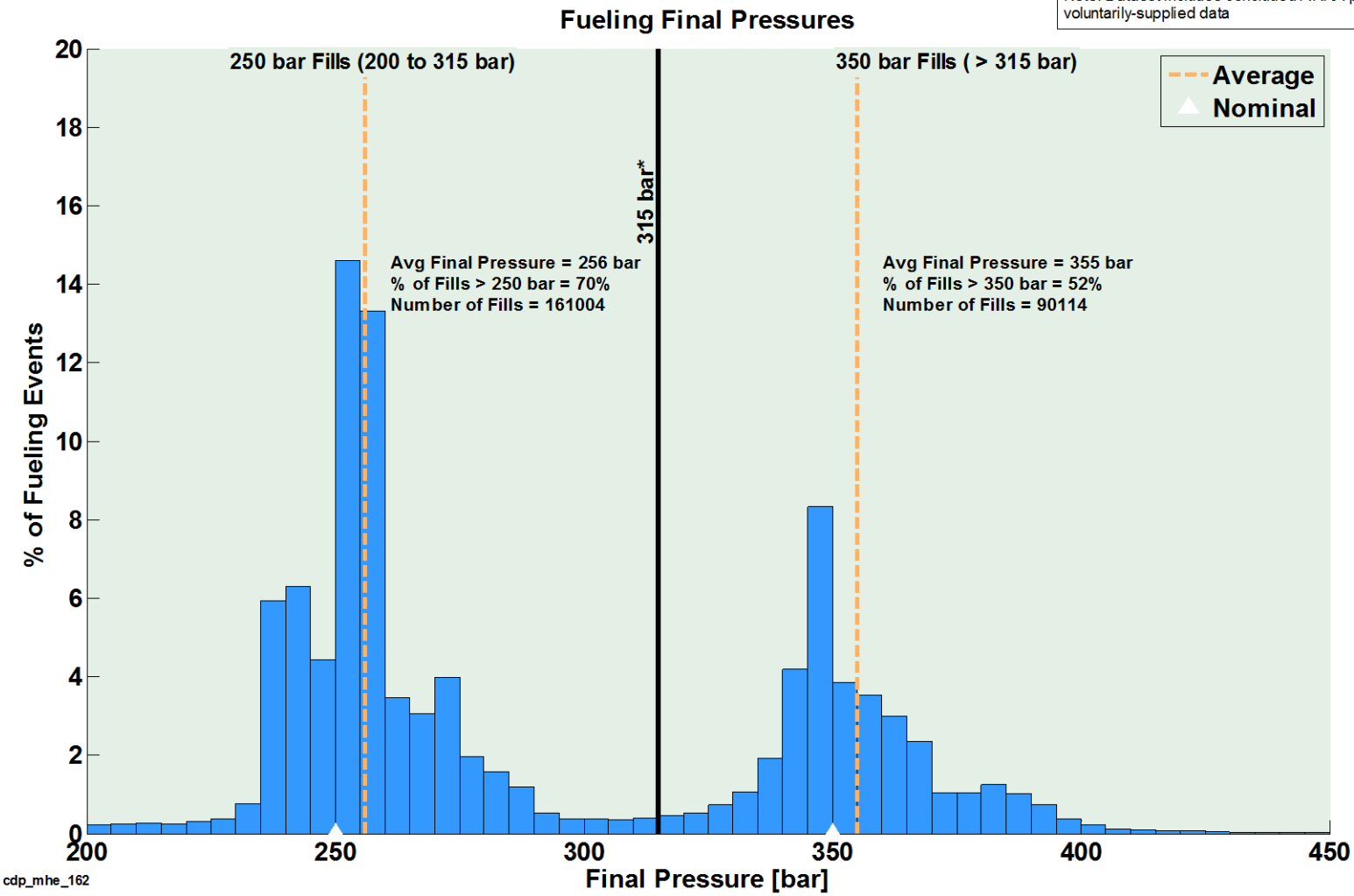
1) Some fueling events not recorded/detected due to data noise or incompleteness.
2) Data indicative of actual use and does not represent the max capability of the systems.

Accomplishments: Study of Fueling Pressure

FORKLIFTS

Market continues move to 350-bar fueling.

Note: Dataset includes concluded ARRA projects and voluntarily-supplied data



NREL cdp_mhe_162

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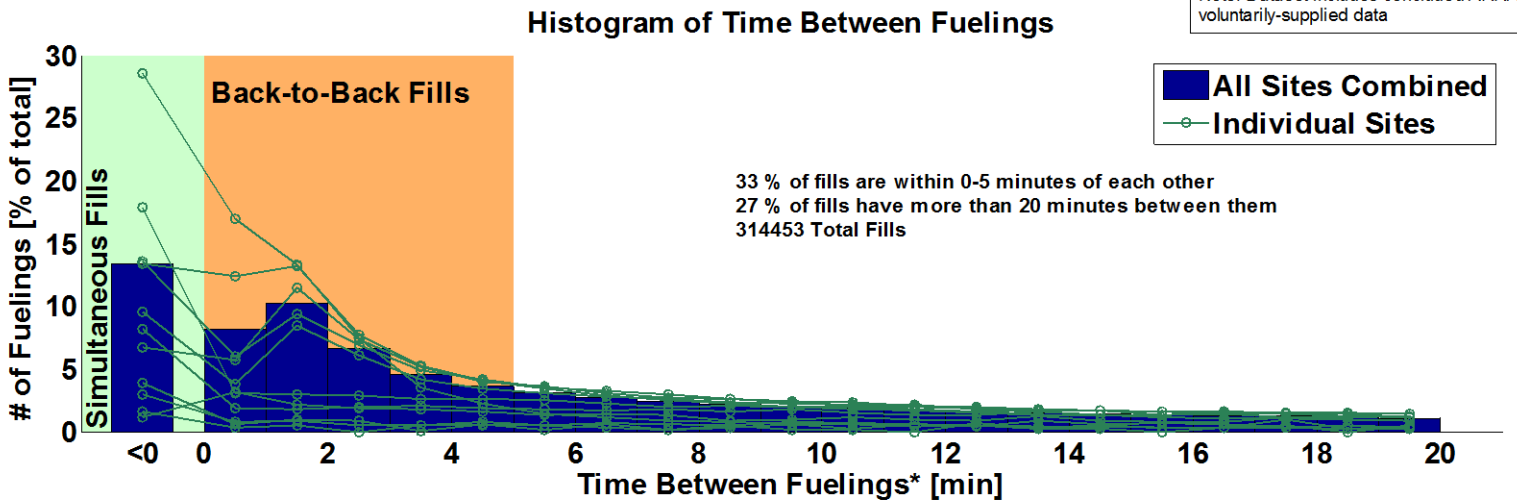
*The line at 315 bar separates 250 bar fills from 350 bar fills. It is slightly over the allowable 125% of nominal pressure (312.5 bar) from SAE J2601.

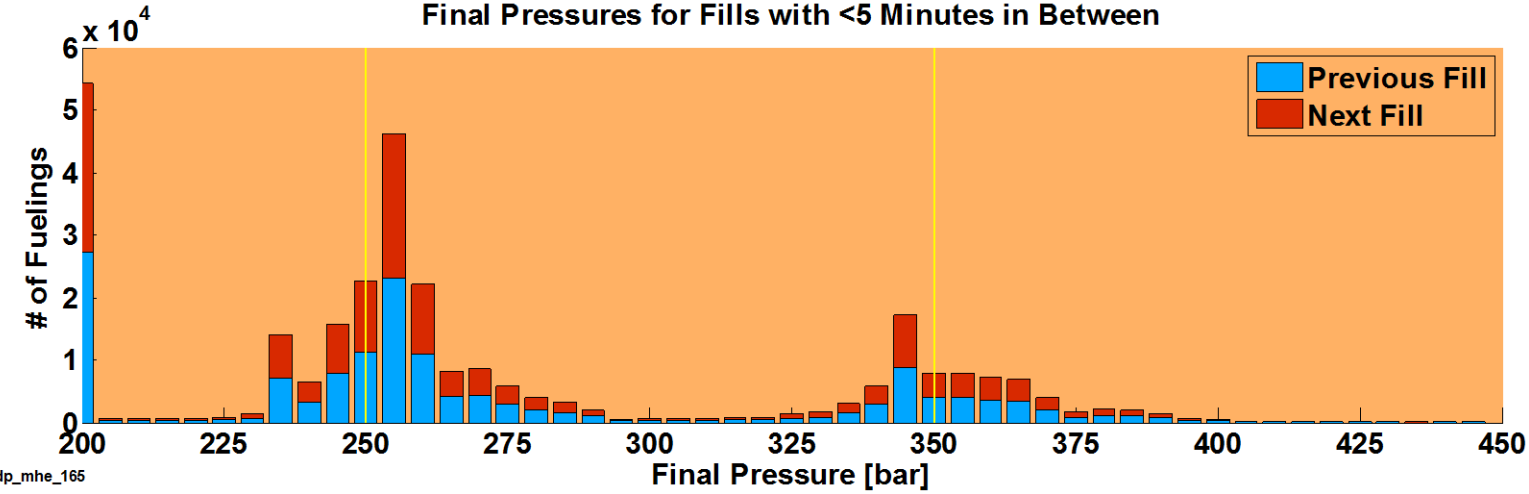
Accomplishments: Study of Fueling Behavior

FORKLIFTS

About 1/3 of fills are back-to-back (within 5 min.) 60% within 20 minutes of each other.

Note: Dataset includes concluded ARRA projects and voluntarily-supplied data





NREL cdp_mhe_165

Created: Mar-31-15 5:53 PM | Data Range: 2009Q4-2014Q3

*Time is from end of fill to start of next fill.

Accomplishments: Response to Previous Year Reviewer's Comments

"…[W]hile measuring … data is of great importance, projects that fundamentally advance actual deployment of fuel cells … may have an advantage…"

- This project is the data collection and analysis part of actual deployment projects. Through the ARRA projects, a new market was created that industry has continued to develop over tenfold from the DOE investment. This is evidenced by the fact that non-ARRA sites continue to provide data.

"…little discussion detailed the collaborators' roles"

- Partners play a key role in developing CDPs that are valuable to industry. They provide data, review results in a multi-step process, and suggest new analyses.

"It is recommended that DOE and NREL investigate whether industry would continue to provide data voluntarily on operations of MHE…"

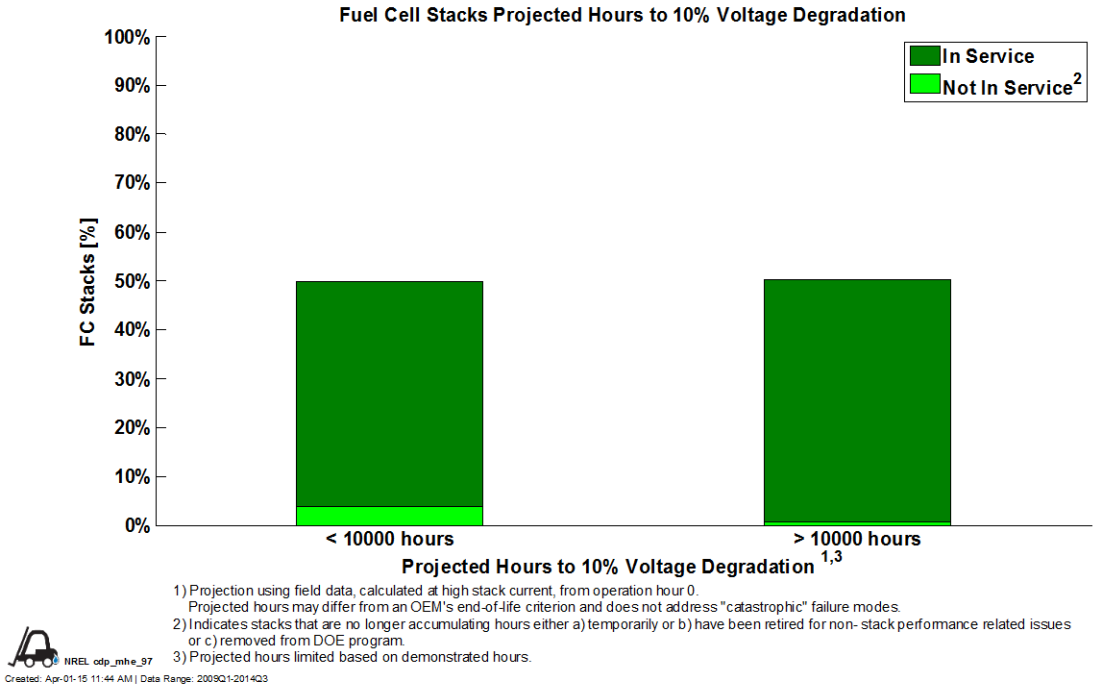
- We were able to leverage the large dataset and strong relationships with industry to continue the project for MHE through voluntary submissions.

Collaborations

Data Sharing and Analysis Partners	
Air Products	Plug Power
FedEx	ReliOn
GENCO	Sprint
Nuvera Fuel Cells	Sysco Houston
Company Name Redacted	

Remaining Challenges and Barriers

- **Improvements need to be made in stack durability so that substantially more than 50% of stacks have more than 10,000 hours projected to 10% decay.**



Future Work

Remaining FY15 tasks:

- Complete annual report on MHE status and progress (August)
- Work with partners to access a MUCH larger data set including many, non-ARRA sites.
- Provide value-added analysis back to industrial partners
- Evaluate whether sufficient data can be shared to continue the project.

Project Summary

***Relevance*: Assess the technology status in real world operations, establish performance baselines, report on fuel cell and hydrogen technology, and support market growth by evaluating performance relevant to the markets' value proposition for early fuel cell markets.**

***Approach*: Leverage capabilities established under other technology validation activities (NRELFAT) and industry collaborations. Aggregate data for concise reporting on large data sets from multiple project partners.**

***Accomplishments*: Published the ninth set of technical CDPs on performance, operation, and safety for MHE, with 24 updated results. All results and publications are available on NREL's technology validation website that also includes monthly highlights.**

***Collaborations and Future Work*: Continue MHE validation with voluntarily supplied data with the close collaboration of the fuel cell and hydrogen developers and end users.**

NFCTEC Contacts

Website

http://www.nrel.gov/hydrogen/proj_tech_validation.html

Email

techval@nrel.gov

Chris.Ainscough@nrel.gov

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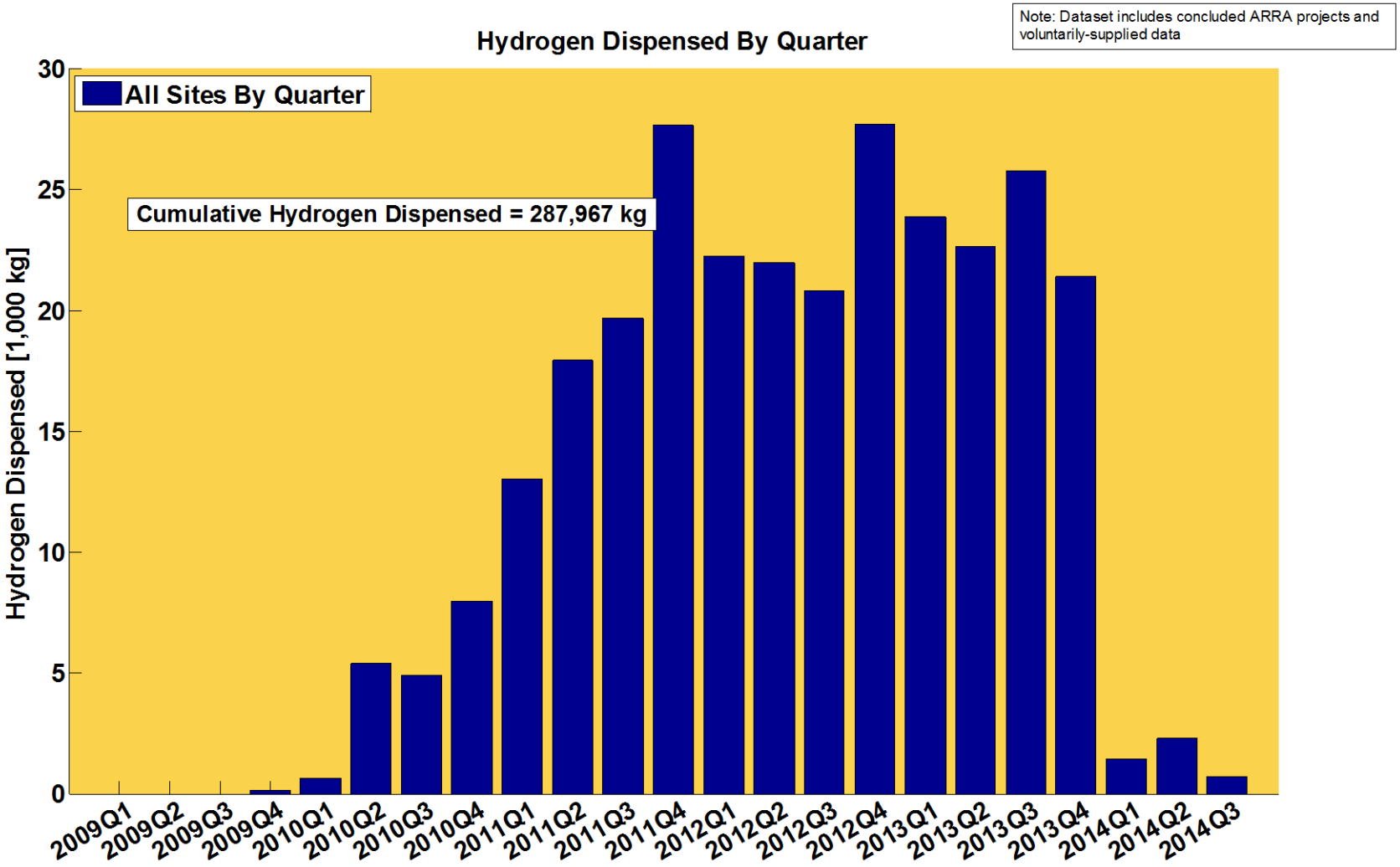
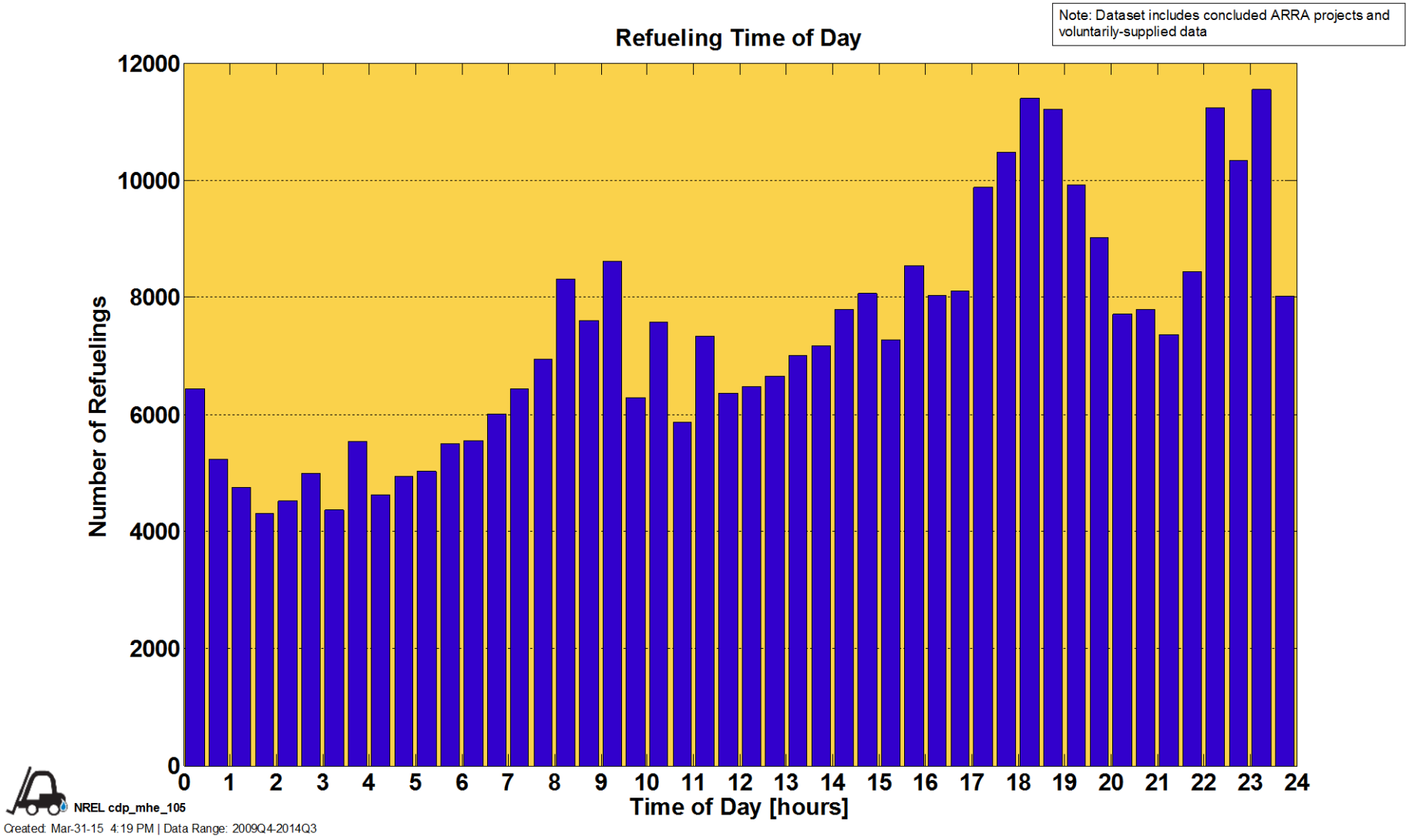
Technical Back-Up Slides

CDP-MHE-104
Hydrogen Dispensed by Quarter



CDP-MHE-105
Refueling Time of Day



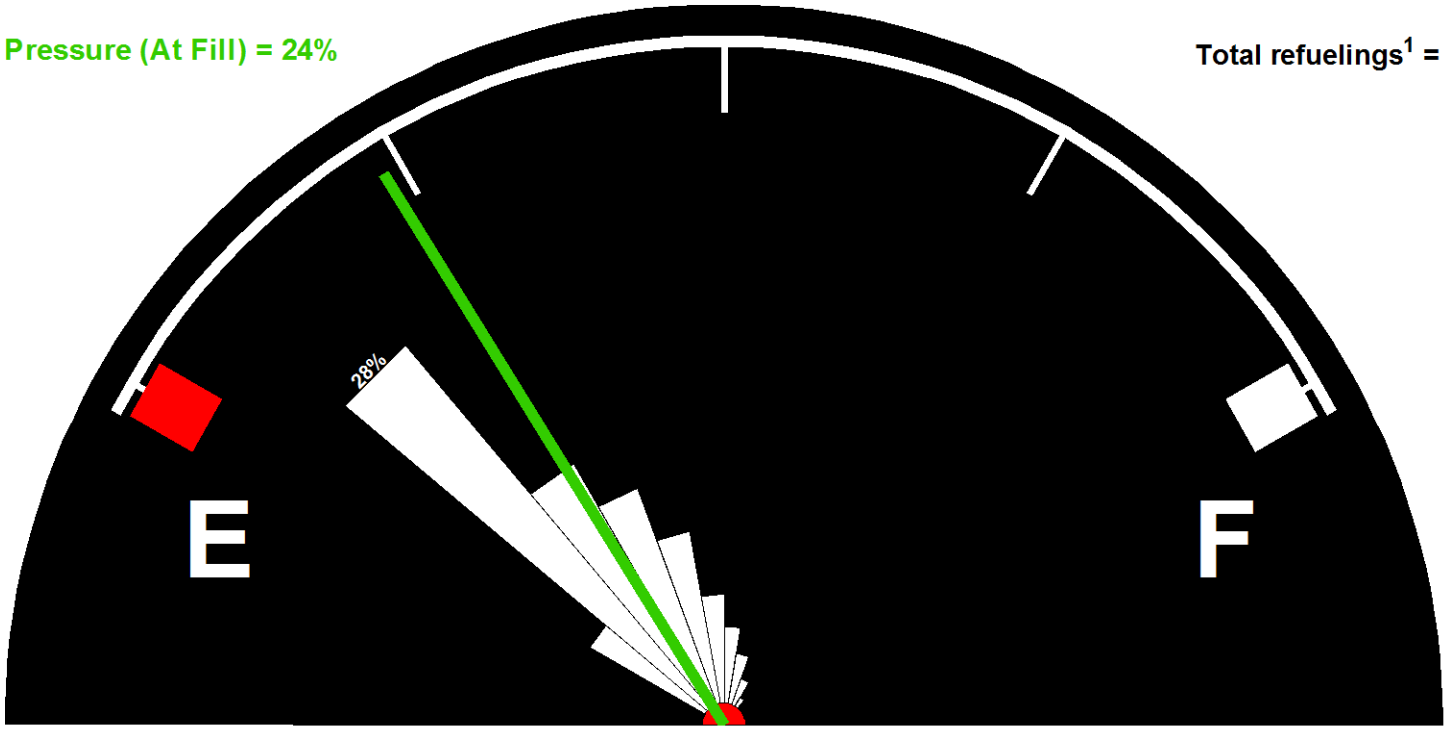
CDP-MHE-107
Tank Pressure Level at Fueling

Note: Dataset includes concluded ARRA projects and voluntarily-supplied data

Tank Pressure At Fill:

Median Tank Pressure (At Fill) = 24%

Total refuelings[1] = 139,881



1. Some refueling events not recorded/detected due to data noise or incompleteness.
2. The outer arc is set at 40% total refuelings.
3. Full Pressure is either 3600 psi or 5000 psi.

NREL cdp_mhe_107

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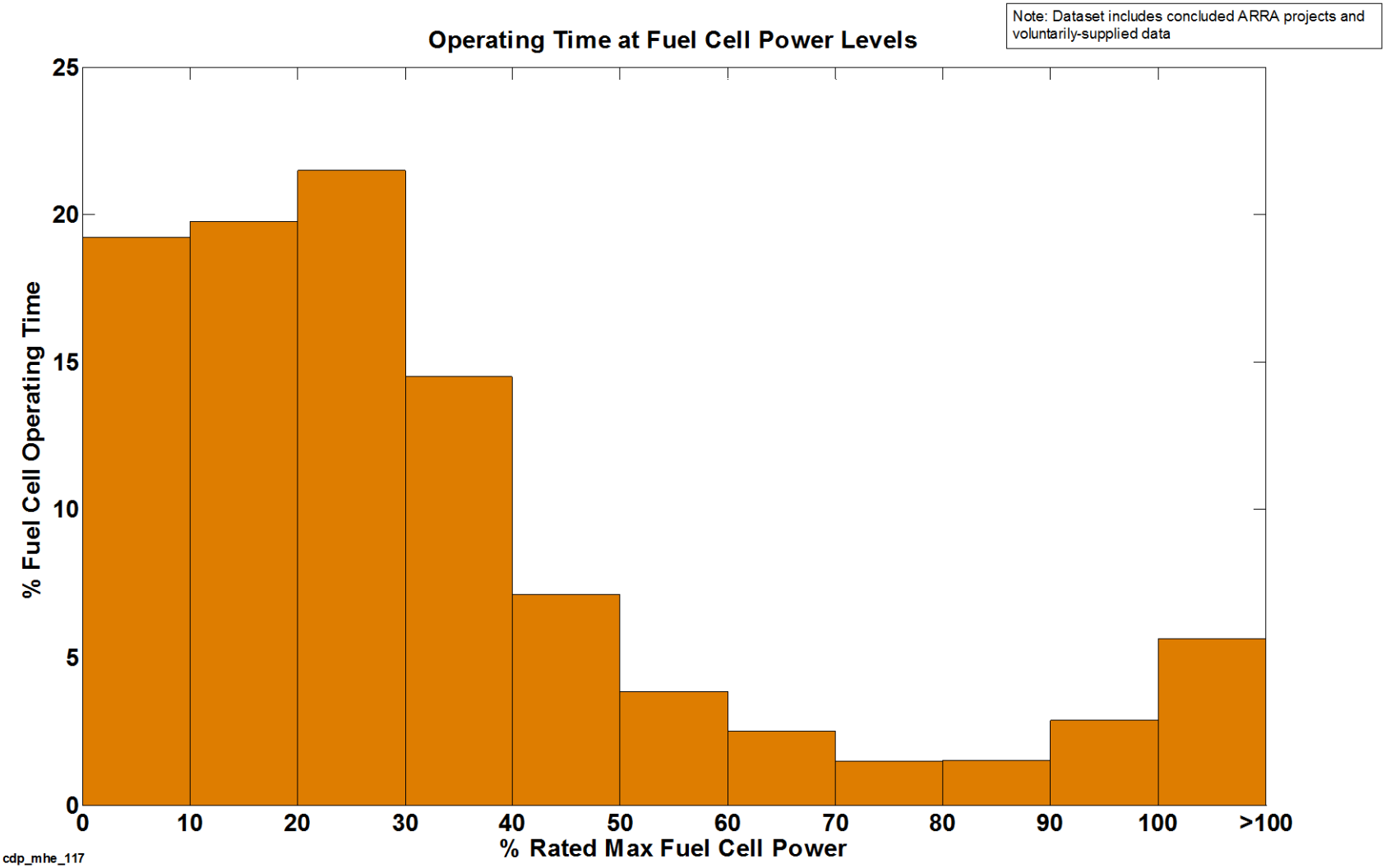
CDP-MHE-117
Operating Time at Fuel Cell Power Levels



CDP-MHE-123

Average Daily Fuel Cell Operation Hours per Fleet