NREL
NATIONAL RENEWABLE ENERGY LABORATORY

U.S. Department of Energy-Funded Performance Validation of Fuel Cell Material Handling Equipment

UK Hydrogen and Fuel Cell Association Webinar

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FCMHE Validation Overview

- U.S. DOE enabling early fuel cell markets
- National Fuel Cell Technology Evaluation Center objectives
- FCMHE performance status

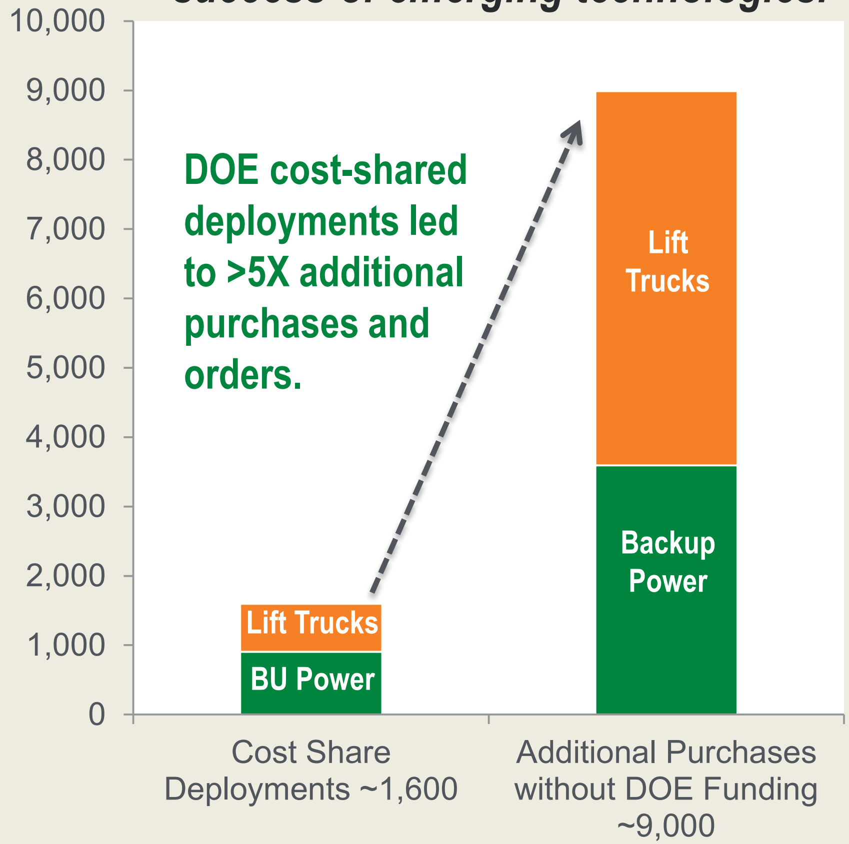
Enabling Early Markets

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Deployments help catalyze market penetration and ensure continued technology utilization growth while providing data and lessons learned.

Leveraging DOE Funds:

Government as "catalyst" for market success of emerging technologies.



~9,000 ADDITIONAL FUEL CELL LIFT TRUCKS AND BACKUP POWER UNITS PLANNED OR INSTALLED **with NO DOE funding**

Examples of industry* sectors in DOE ARRA projects

- Telecommunications (e.g., AT&T, PG&E, Sprint, etc.)
- Distribution Centers/Warehouses (e.g., FedEx, Genco, Sysco, Wegmans, Whole Foods, etc.)

*Provided as examples and not intended as endorsement

DOE FCTO Fall 2013
http://www1.eere.energy.gov/hydrogenandfuelcells/presentations.html

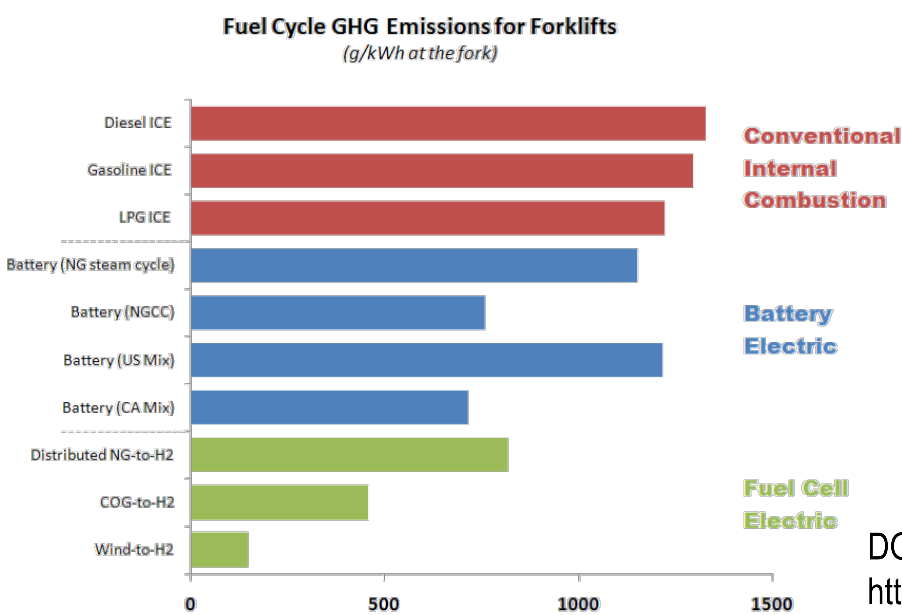
The Case for Fuel Cell Forklifts

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Fuel cell forklifts offer several advantages compared to conventional fork lift technology

Preliminary Analysis

- **Compared to conventional forklifts, fuel cell forklifts have:**
- **1.5 X lower maintenance cost**
- **8 X lower refueling/recharging labor cost**
- **2 X lower net present value of total system cost**



Preliminary Analysis: Comparison of PEM Fuel Cell- and Battery-Powered Forklifts

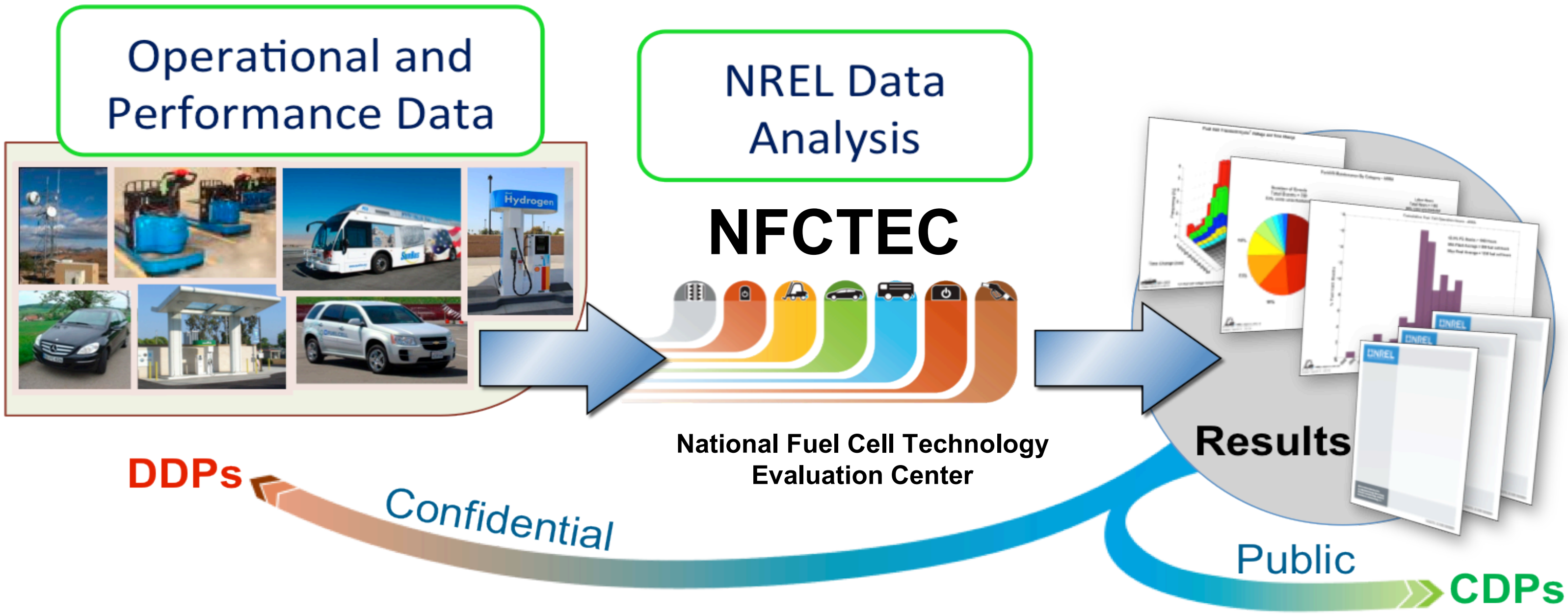
Time for Refueling/ Changing Batteries	4-8 min/day	45-60 min/day (for battery change-outs) 8 hours (for battery recharging & cooling)
Labor Cost of Refueling/Recharging	$1,100/year	$8,750/year
NPV of Capital Costs	$12,600 ($18,000 w/o incentives)	$14,000
NPV of O&M Costs (including fuel)	$52,000	$128,000

Published Fact Sheets & Case Studies

DOE FCTO Fall 2013
http://www1.eere.energy.gov/hydrogenandfuelcells/presentations.html

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

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

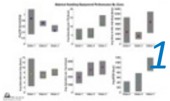
- **Assess technology**
  - Perform independent technology assessment in real world operation conditions
  - Focus on fuel cell system and hydrogen infrastructure: performance, operation, and safety
  - Leverage data processing and analysis capabilities developed under the fuel cell vehicle Learning Demonstration project
  - Evaluate material handling equipment (MHE) and backup power
  - Analysis includes up to 1,000 fuel cell systems deployed with American Recovery and Reinvestment Act (ARRA) funds
- **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 such as end users

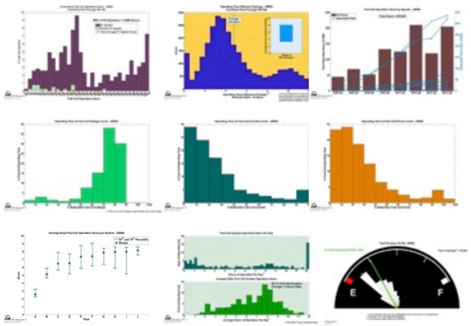
74 MHE CDPs—Count and Category

Deployment & Site Overview *(1, 40)*

Fuel Cell Operation

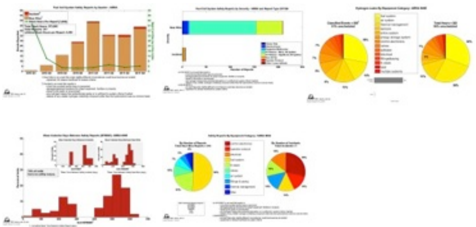
(2, 7, 8, 11, 15, 16, 17, 23, 24, 63)





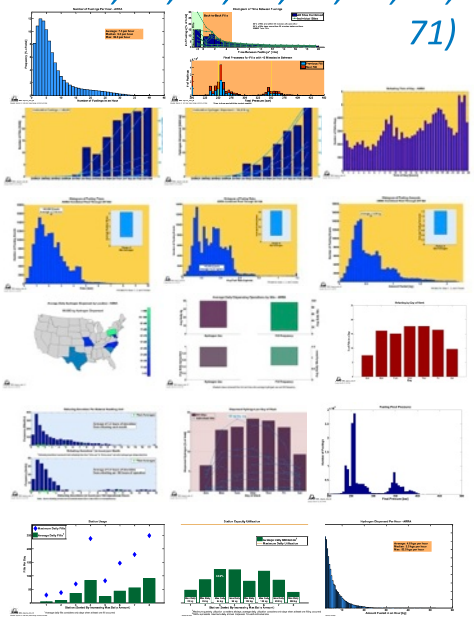
Fuel Cell Safety

(26, 27, 53, 56, 57)



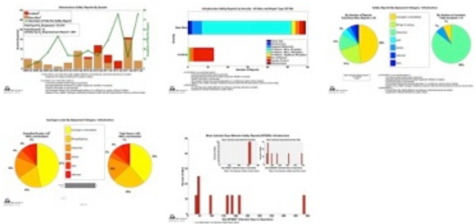
Infra. Operation

(3, 4, 5, 6, 9, 10, 21, 22, 35, 37, 42, 62, 65, 68, 69, 70, 71)



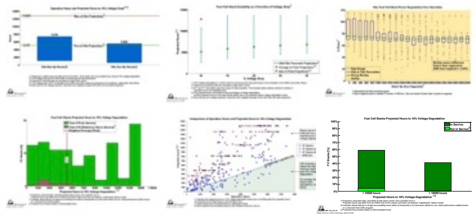
Infra. Safety

(25, 41, 46, 51, 55)



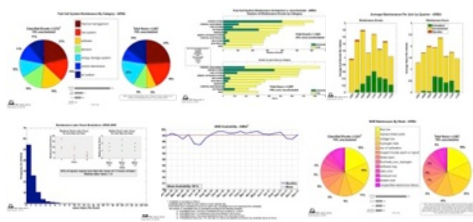
Fuel Cell Durability

(32, 33, 34, 38, 39, 73)



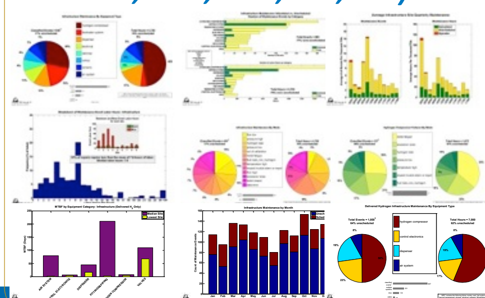
FC Maintenance

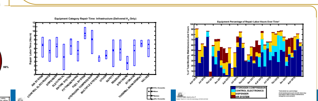
(12, 13, 14, 43, 54, 61)



Infra. Maintenance

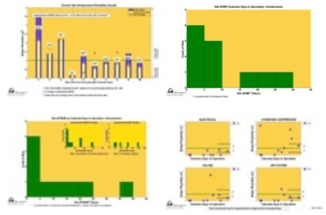
(18, 19, 20, 44, 47, 52, 66, 67, 72,76,77)





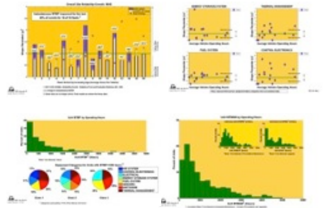
Infra. Reliability

(45, 48, 49, 50)



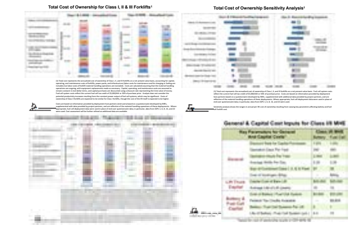
Fuel Cell Reliability

(28, 29, 30, 31)



Cost of Ownership

(58, 59, 60,64)



MHE Operation Summary
2009 Q4–2013 Q2

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

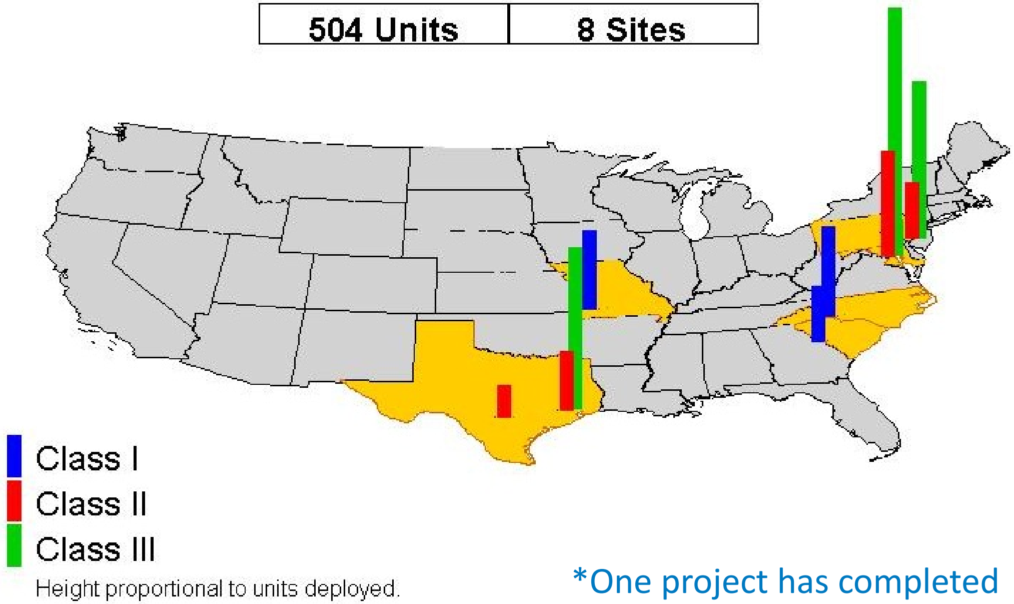
1,859,616
Operation hours

291,114
Hydrogen fills

490
Units in operation*

4.4
Average operation hours between fills

232,551
Hydrogen dispensed in kg

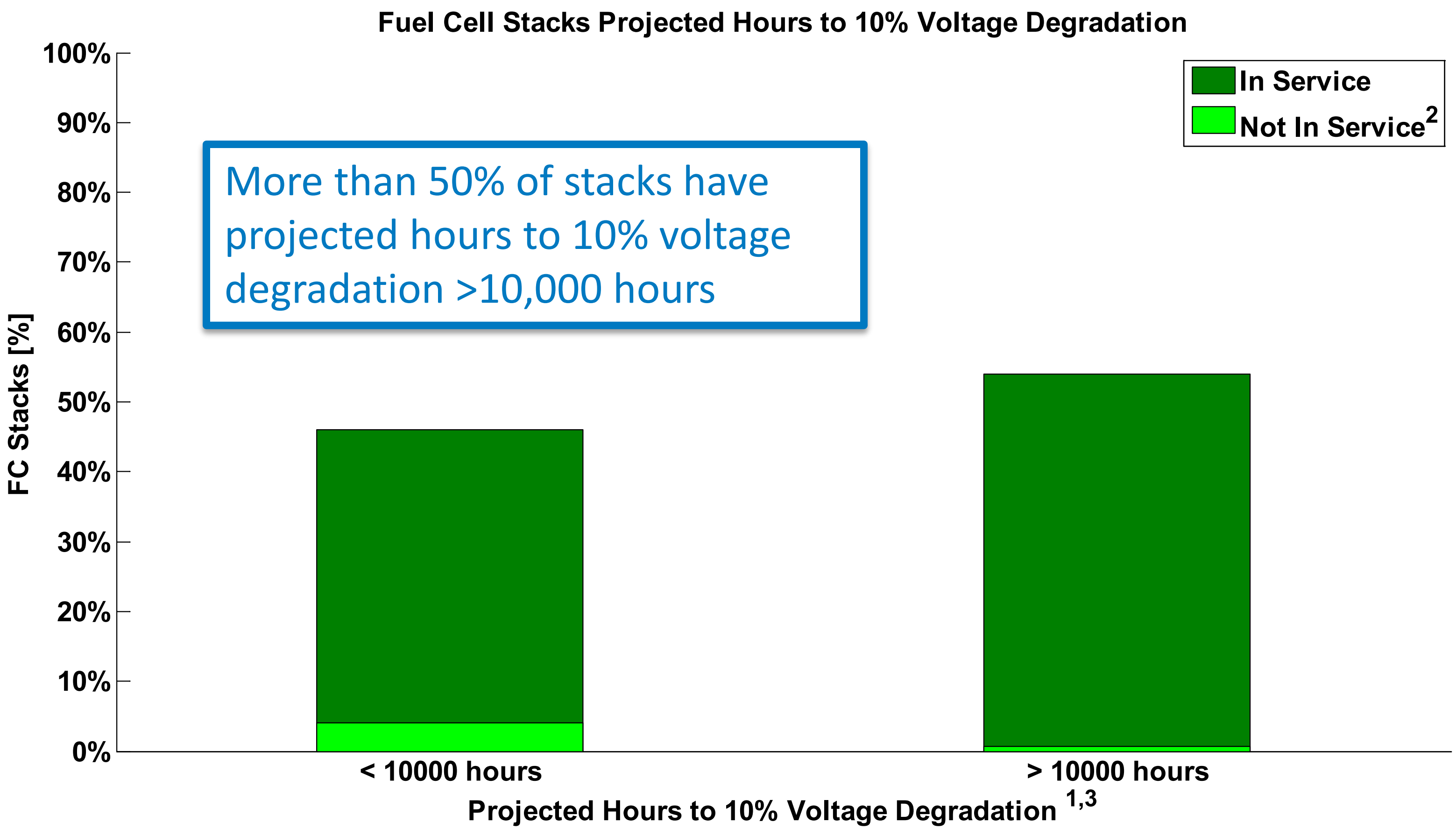


0.6
Average fill amount in kg

2.3
Average fill time in minutes

*One project has completed

Study of FC Voltage Degradation Against 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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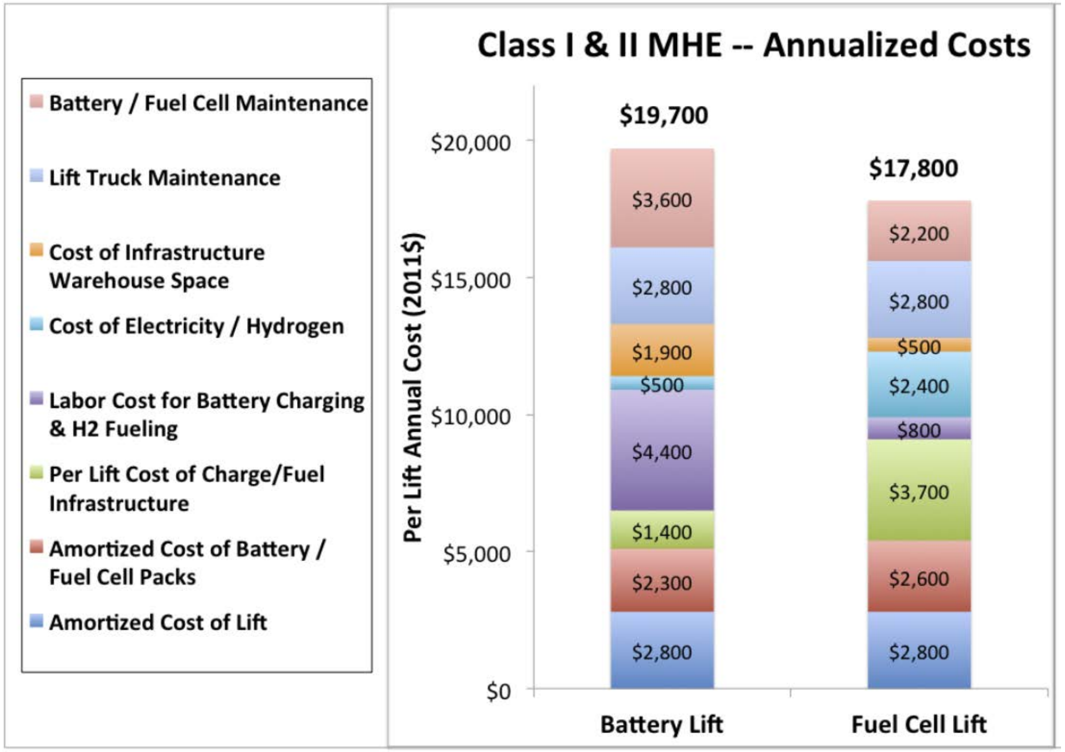
Published MHE Cost of Ownership Report

FORKLIFTS

Cost advantage per unit is ~$2,000/year for the average high-use facility with Class I and II fuel cell lift trucks analyzed by NREL



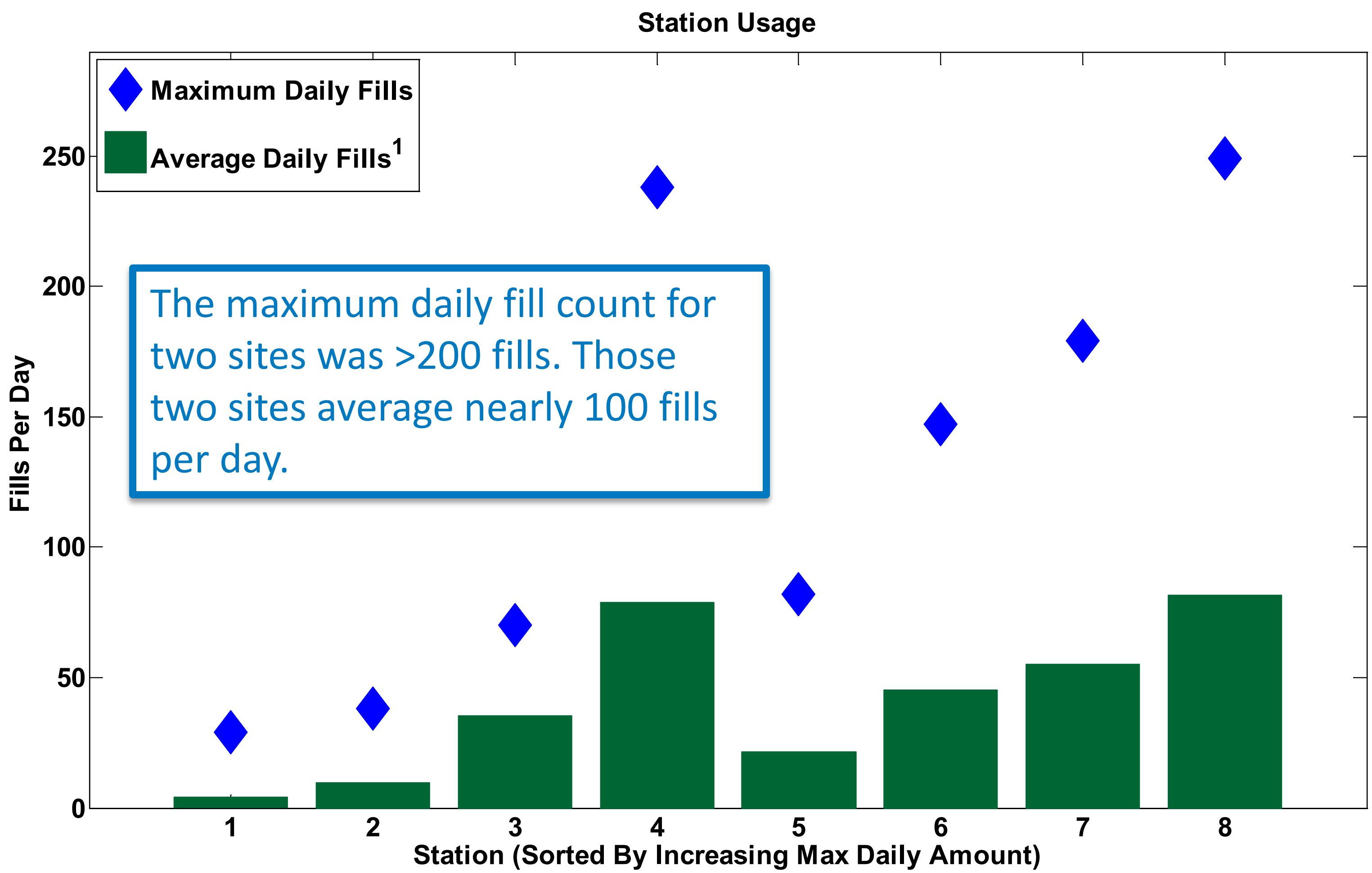
Key Findings

- Cost advantages dependent on deployment size and use (i.e., multi-shift operation per day)
- H_2 fuel cell cost advantages in maintenance, warehouse infrastructure space, and refueling labor cost
- H_2 fuel cell cost disadvantages in infrastructure and fuel cell cost and hydrogen cost

Report Sections

- Inputs, assumptions, and results for Class I/II and Class III
- Sensitivity study
- Intensive deployment scenario

Study of Infrastructure Usage by Daily Fills



NREL cdparra_mhe_70

[1]Average daily fills considers only days when at least one fill occurred

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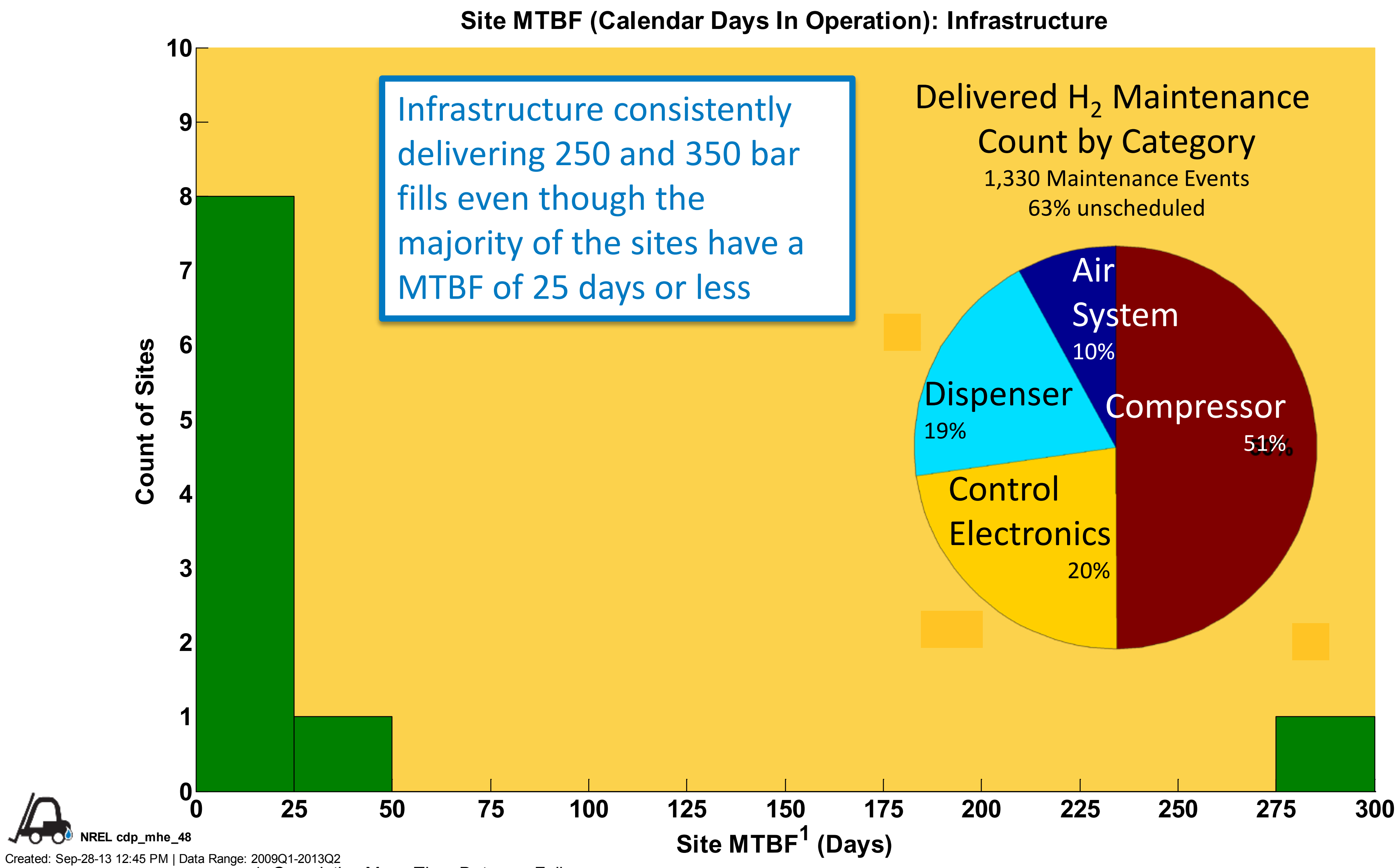
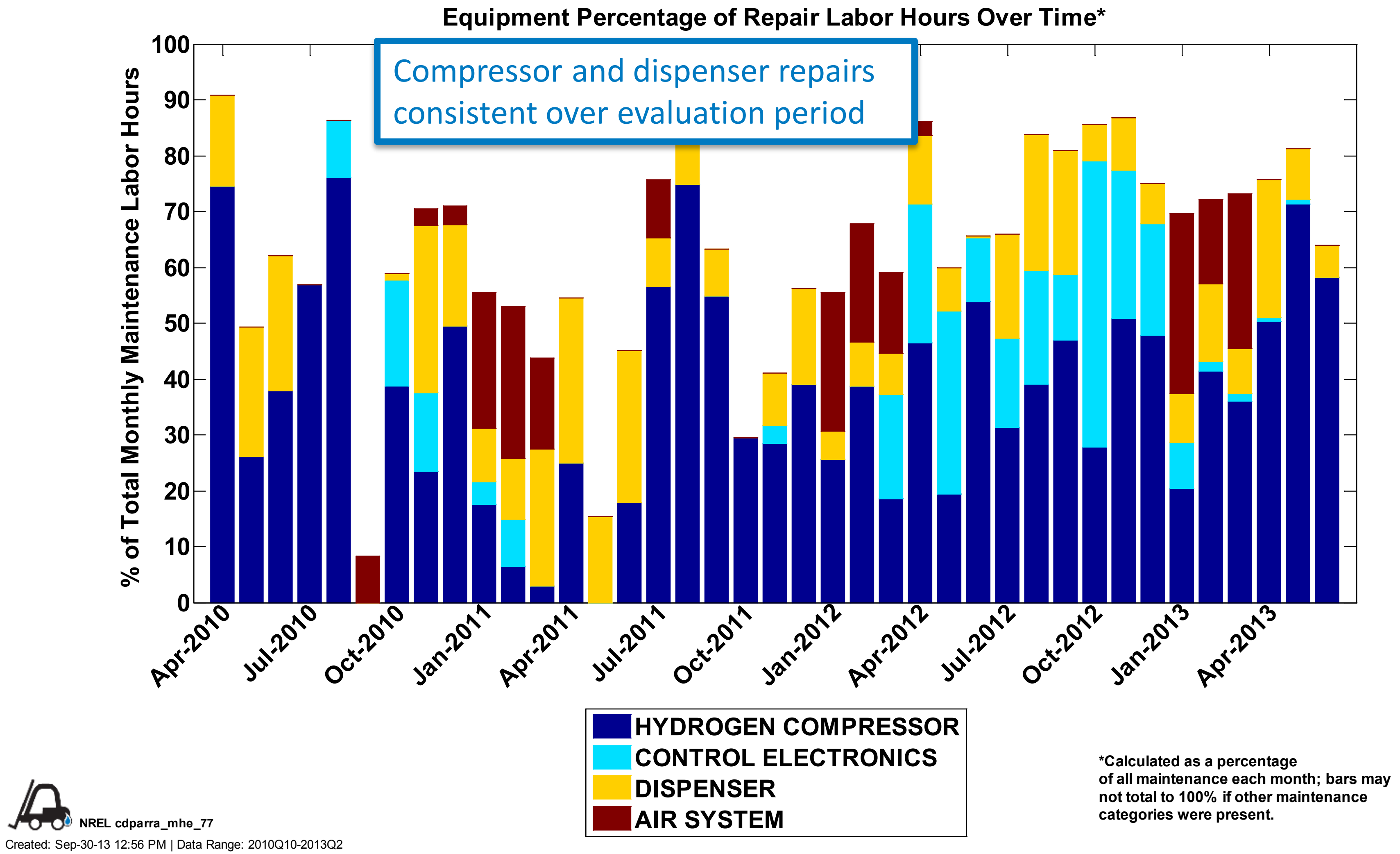
Infrastructure Reliability Analysis



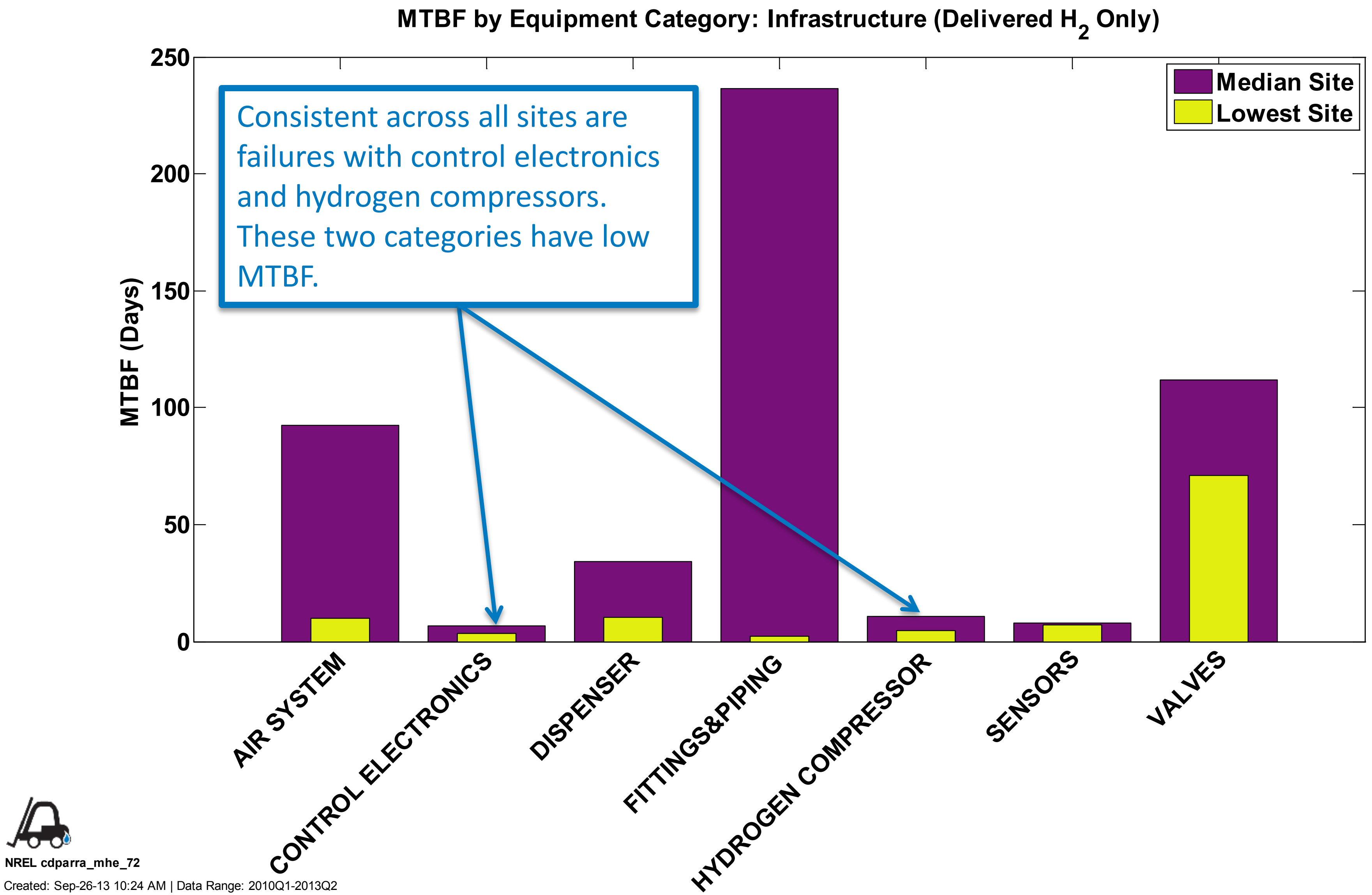
1. Cumulative Mean Time Between Failure

Equipment Percentage of Monthly Repair Labor Hours



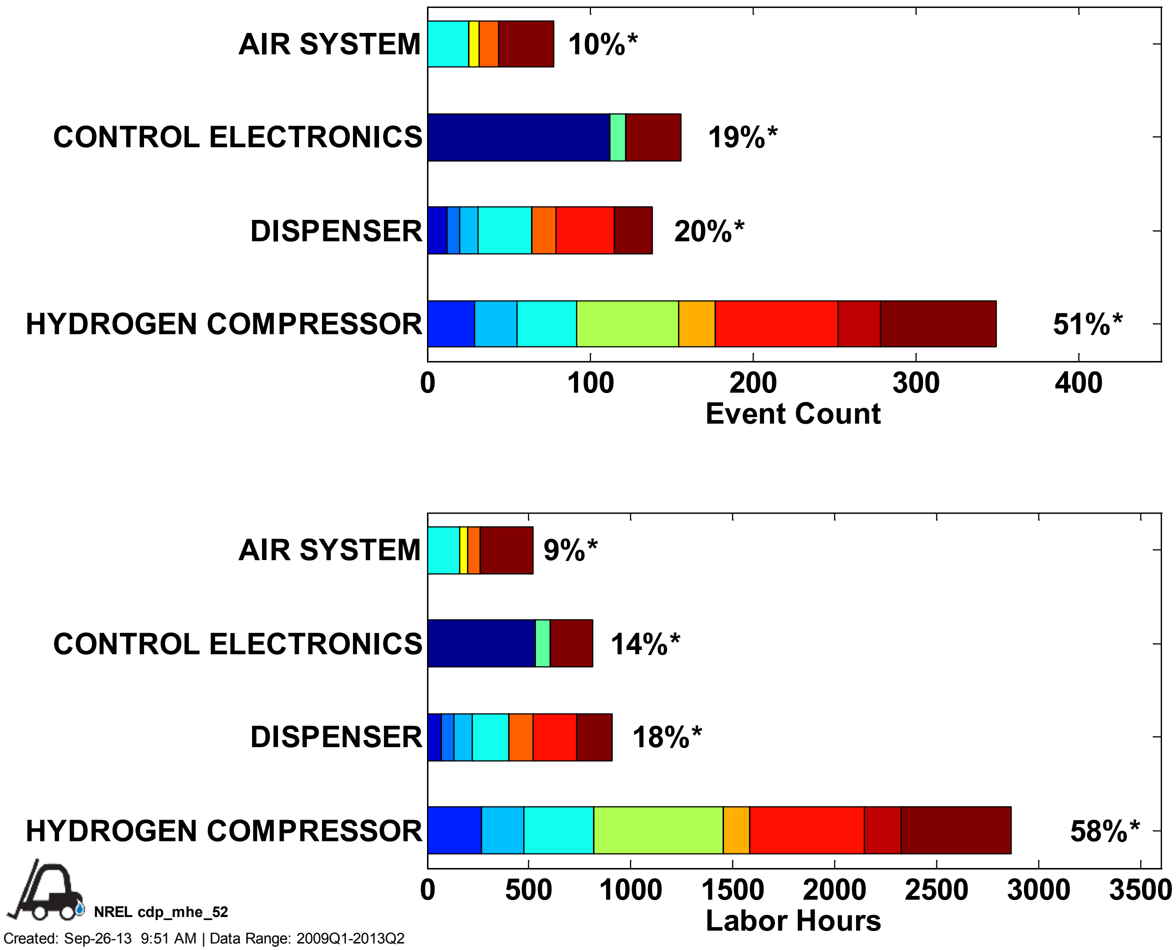
*Calculated as a percentage of all maintenance each month; bars may not total to 100% if other maintenance categories were present.

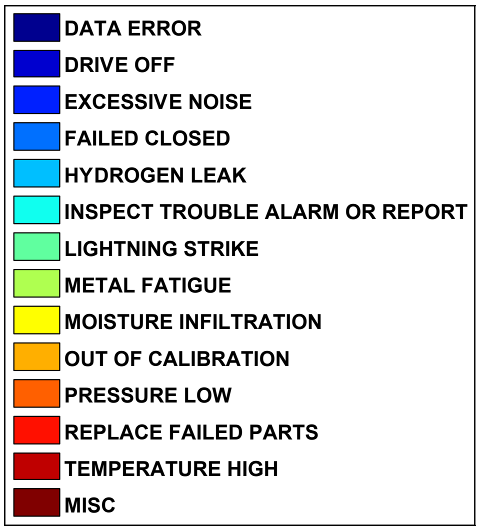
Breakdown of MTBF by Key Delivered Hydrogen Infrastructure Categories



Breakdown of Failure Modes for Top Four Maintenance Categories for Infrastructure

There are many different failure modes for the top four categories and these modes provide insight for RD&D needs



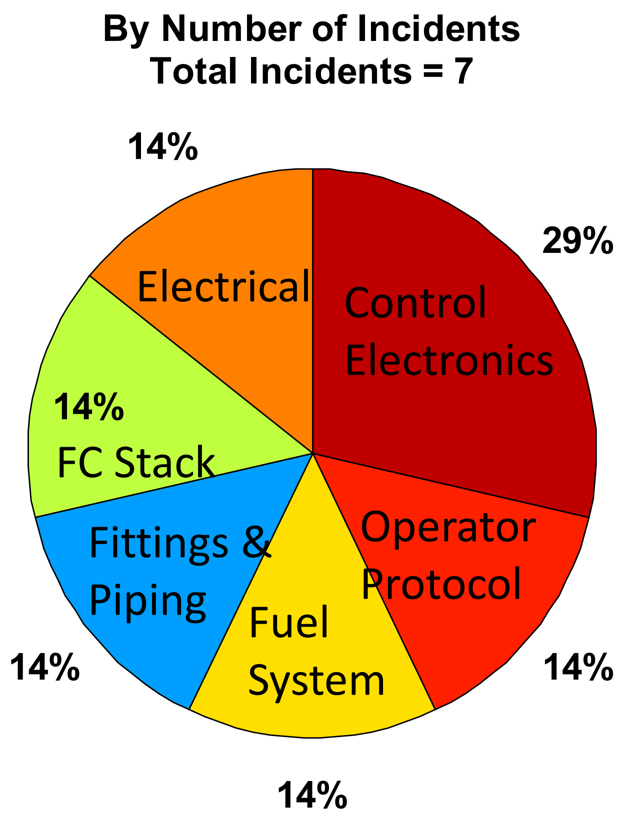


MISC includes the following failure modes: ambient temperature too low, broken wire, cavitation, data error, debris infiltration, electrical short, failed closed, false alarm, flow high, flow low, fluid leak non-hydrogen, fluid leak non_hydrogen, fluid leak_non_hydrogen, inspect trouble alarm or report, maintenance error, manufacturing defect, metal fatigue, moisture infiltration, network malfunction, operator protocol, other, power outage, pressure high, pressure low, replace failed parts, software bug, unspecified electronics failure, vandalism, voltage low, other

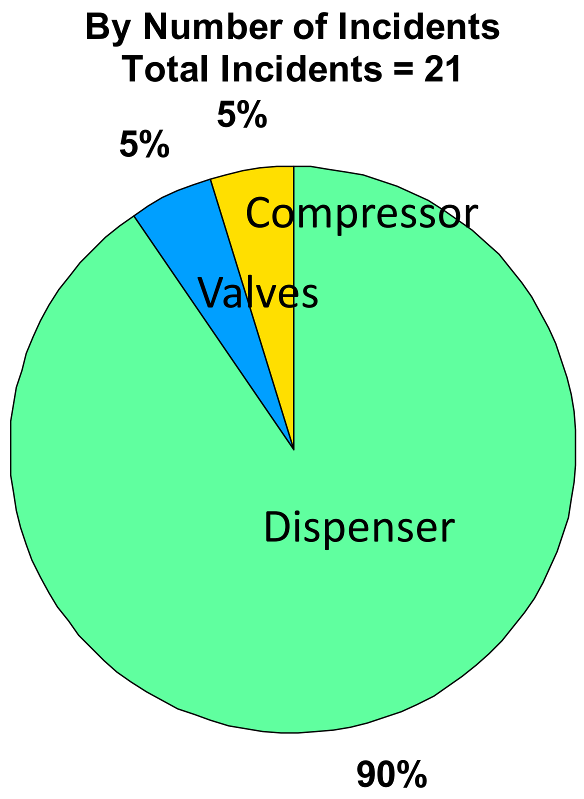
*** Percentage of total events or hours, reference CDP 66.**

MHE and Infrastructure Safety Report Analyses

Majority of MHE safety reports (217) are minor hydrogen leaks
(4,480 stack hours per report)



Majority of infrastructure safety reports (82) are hydrogen leaks primarily from the hydrogen compressor and plumbing
(2,879 kg dispensed per report)



Technical Summary—*What We've Learned*

- Operating with an average availability of ~98% at eight end-user facilities.
- Most systems operate at least 6 hours a day.
- Cost of ownership comparison between fuel cell and battery MHE indicate significant cost savings for refueling labor and infrastructure space but much greater cost for hydrogen infrastructure and fuel.
- MHE infrastructure can provide insight into infrastructure performance for the light duty vehicle application.

Aggregated data showcase performance over the last two years in MHE and backup power.

Performance results address a need for published results on the technology status.

Data analyses develop as systems operate and based on the key performance areas in the markets.

This project is supported by the U.S. Department of Energy Fuel Cell Technologies Office EERE, Jason Marcinkoski, Sara Dillich, and Pete Devlin

Photo by Jennifer Kurtz, NREL 18347

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