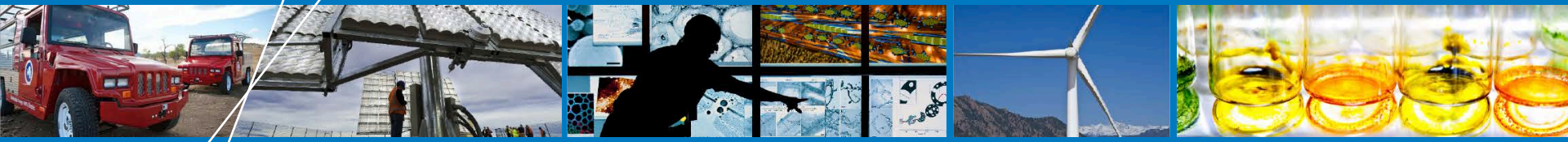
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Forklift and Backup Power Data Collection and Analysis



2013 DOE Annual Merit Review

Jennifer Kurtz, Keith Wipke, Sam Sprik, Todd Ramsden, Chris Ainscough, Genevieve Saur, Matt Post, Mike Peters

May 16, 2013

Project ID# TV021

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

Overview

Timeline

Project start date: October 2012*

Project end date: June 2014

Percent complete: 60%

Barriers

Commercialization of fuel cells in key early markets

Budget

Total project funding

DOE share: $270k

Contractor share: $0

Funding received in FY12: $325k

Partners

Air Products

FedEx

GENCO

Nuvera Fuel Cells

Plug Power

ReliOn

Sprint

Sysco Houston

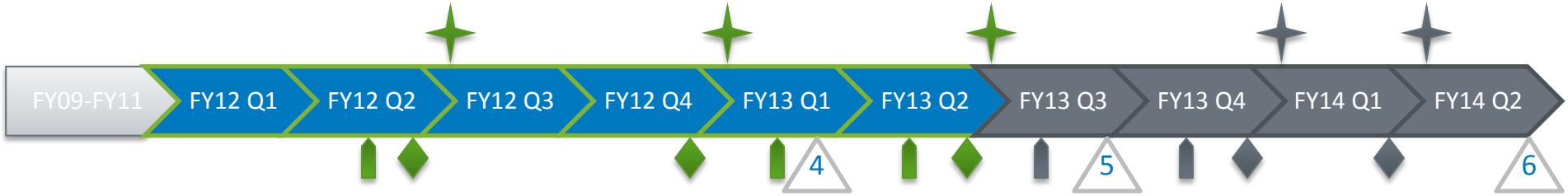
*Previous evaluations funded with ARRA ($1,000k FY09 – FY11)

Objectives - 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.

- **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 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 like end users

Approach: Milestones



1.* Quarterly deployment composite data products

2.* Quarterly analysis of operation and maintenance data for fuel cell systems and hydrogen infrastructure

3.* Bi-annual technical composite data products

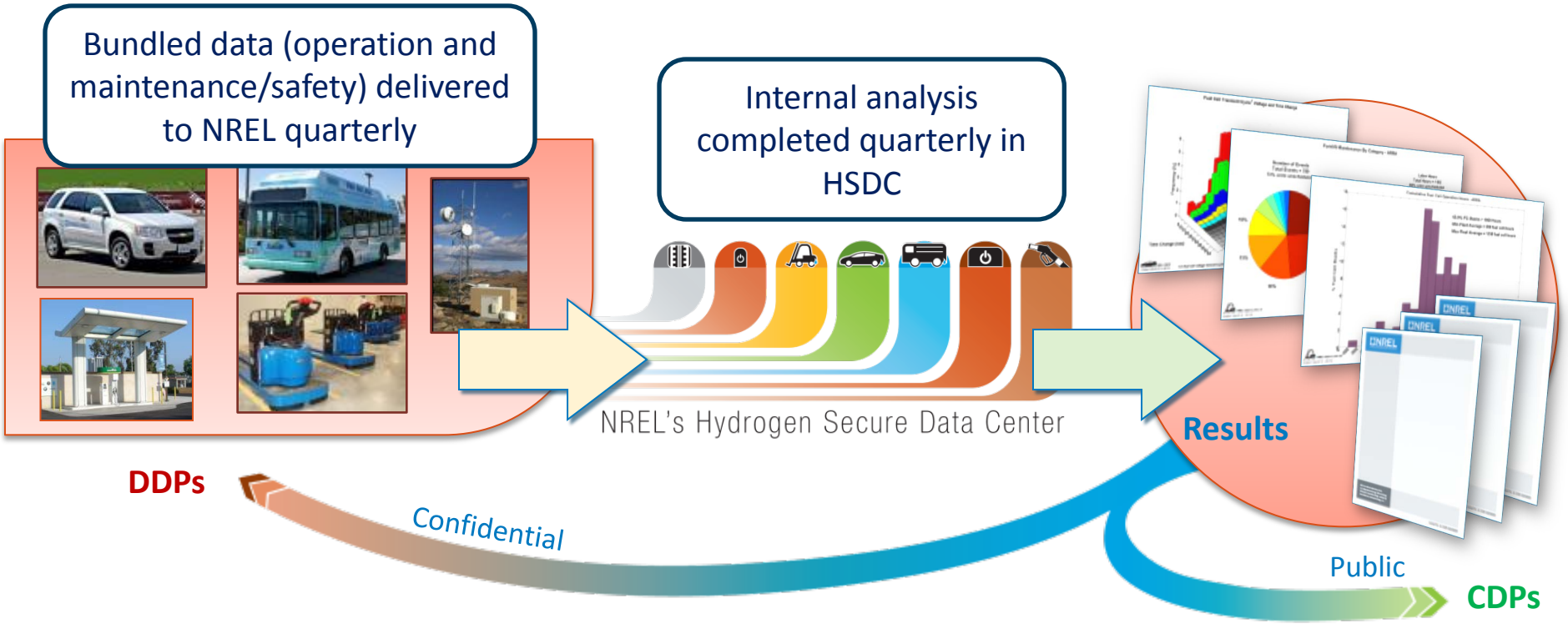
4. Hydrogen Safety Panel Final Report (FY13 Q1)

5. Interim draft report of status and performance of fuel cell MHE and backup power systems

6. Final report of status and performance of fuel cell MHE and backup power for project close-out

*Gray markers indicate future work

Approach: Analysis and Reporting of Real-World Operation Data



Detailed Data Products (DDPs)

- Individual data analyses
- Identify individual contribution to CDPs
- Shared every six months only with the partner who supplied the data[1]

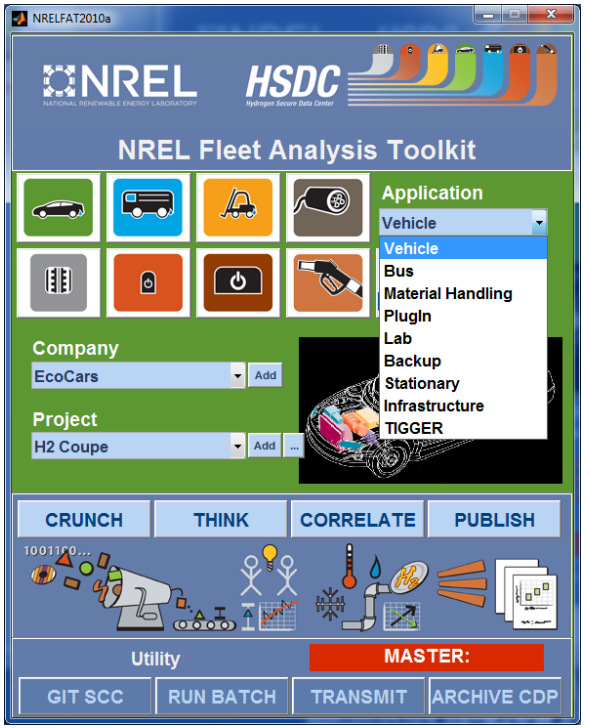
Composite Data Products (CDPs)

- Aggregated data across multiple systems, sites, and teams
- Publish analysis results every six months without revealing proprietary data[2]

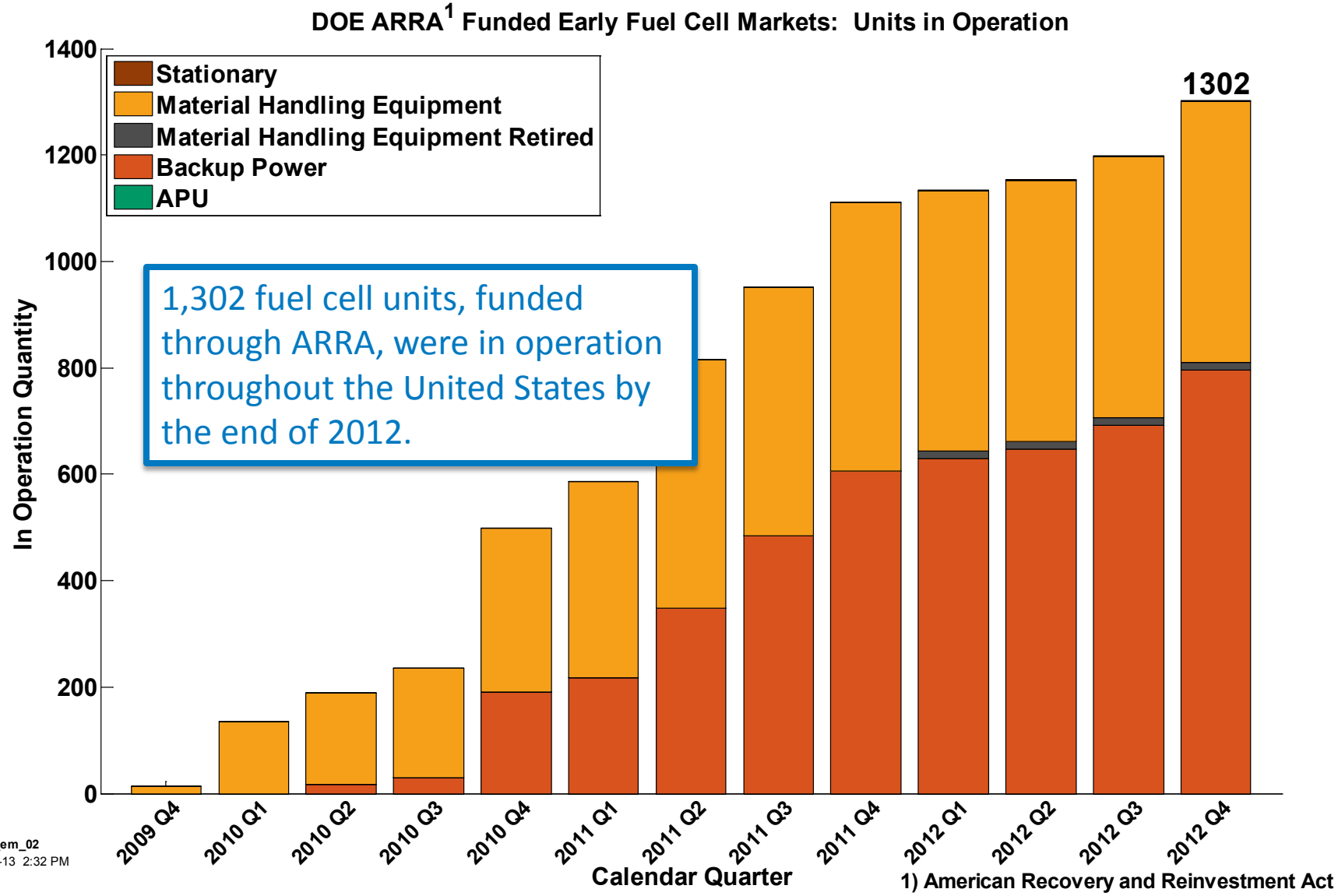
1) Data exchange may happen more frequently
2) Results published via NREL technology validation website, conferences, and reports (http://www.nrel.gov/hydrogen/proj_learning_demo.html)

Approach: Analysis Tools

- **NREL Fleet Analysis Toolkit (NRELFAT)**
  - Developed first under fuel cell vehicle Learning Demonstration
  - Expanded to include material handling, backup power, and stationary power
  - Restructured architecture and interface to effectively handle new applications and projects and for flexible analysis
- **Analysis important to an application**
  - Leverage Learning Demonstration analyses already created
  - Create new application-specific analyses
- **Publish results**
  - Detailed and Composite results
  - Target key stakeholders such as fuel cell and hydrogen developers and end users



Accomplishments: Deployment Update



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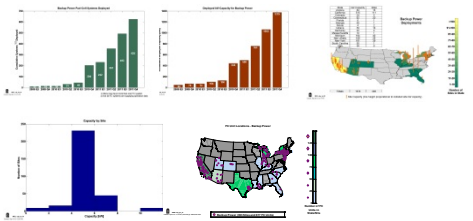
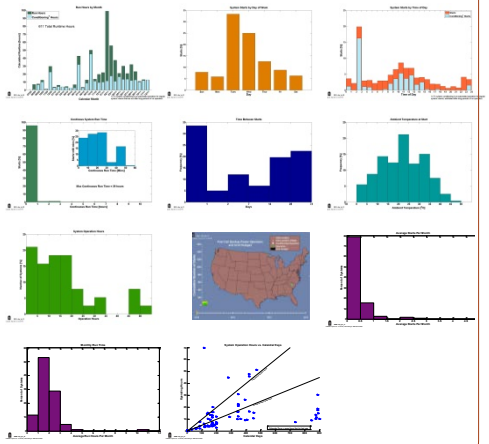
Accomplishments: 21 Backup Power CDPs – Count and Category

BACKUP POWER

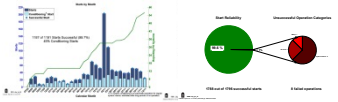
Deployment
(1, 2, 3, 14, 19)



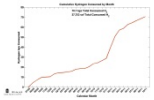
Fuel Cell Operation
(5, 7, 8, 9, 11, 12, 13, 15, 16, 17, 21)



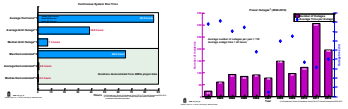
Fuel Cell Reliability
(4, 10)



Infra. Operation
(6)



U.S. Grid Outage Stats
(18, 20)



Since 05/2012:
8 new & 13 updated

Accomplishments: Backup Power Operation Summary 2009 Q1 – 2012 Q4

BACKUP POWER

1.86
Installed capacity in MW

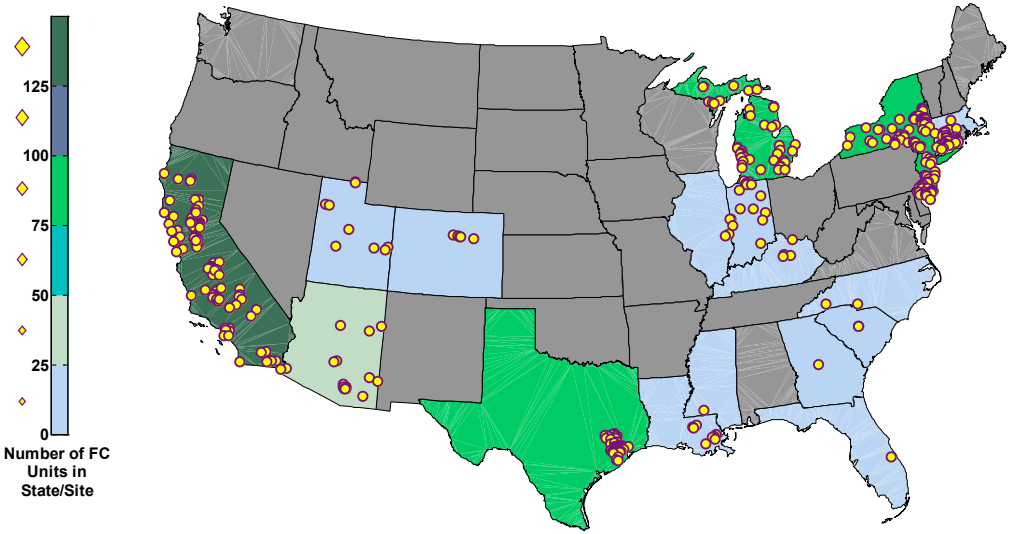
Systems are operating reliably in 19 states. Reasons for unsuccessful starts include an e-stop signal, no fuel, and other system failures.

99.6%
Successful starts

806
Systems in operation*

4-6
Average site capacity in kW

1,796
Start attempts



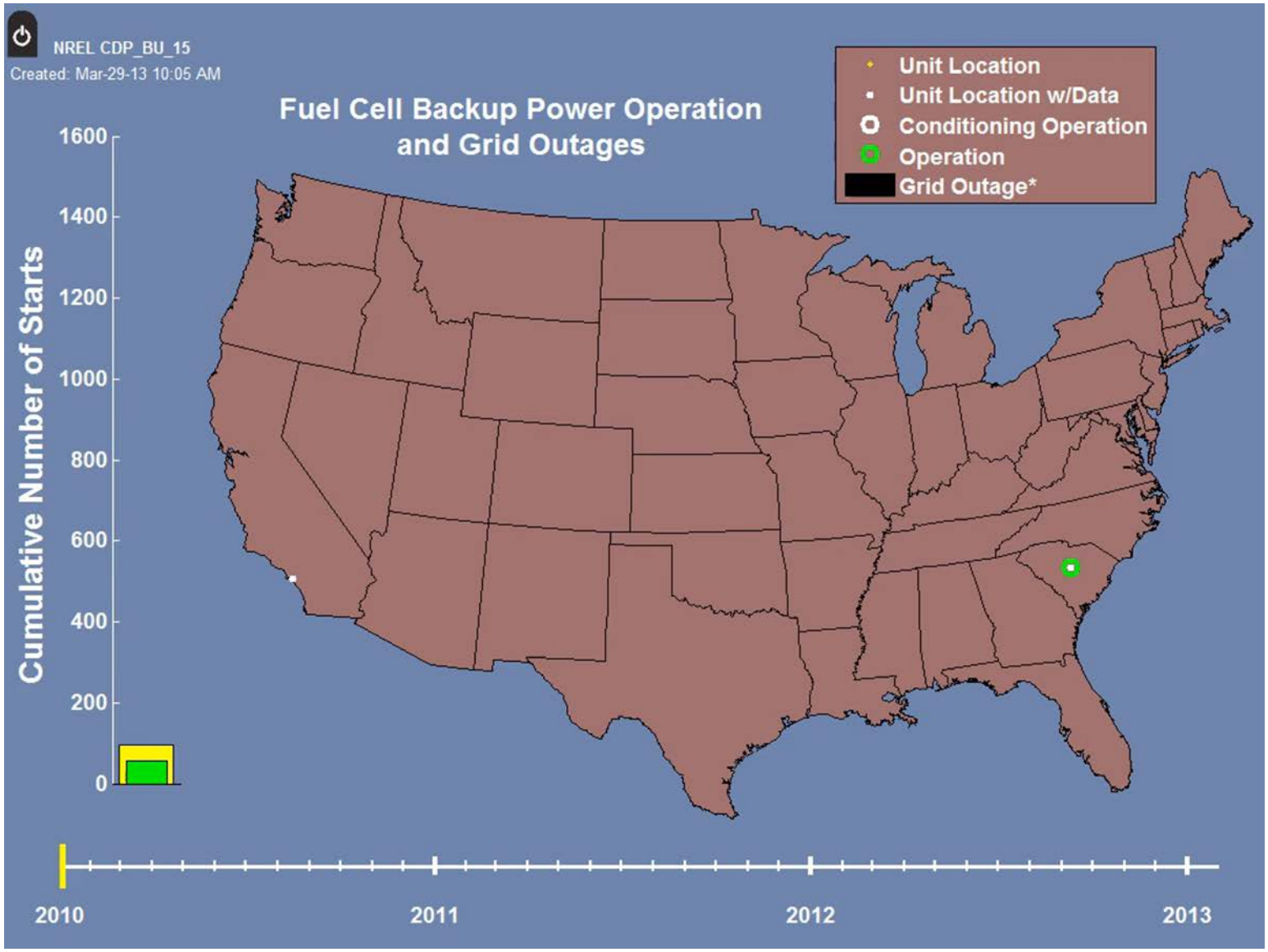
65
Continuous run hours demonstrated

1,153
Operation hours

*Not all systems have detailed data reporting to NREL

Accomplishments: Analysis of Fuel Cell Backup Power Operation with U.S. Grid Outage

BACKUP POWER

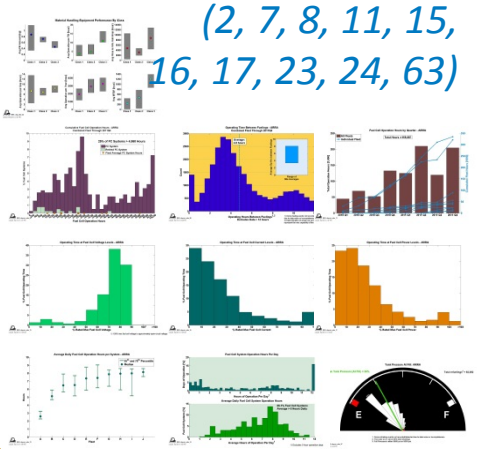


Accomplishments: 72 MHE CDP Count and Category

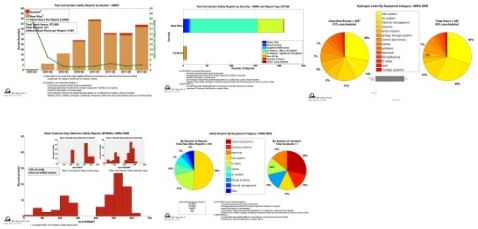
FORKLIFTS

Deployment & Site Overview *(1, 40)*

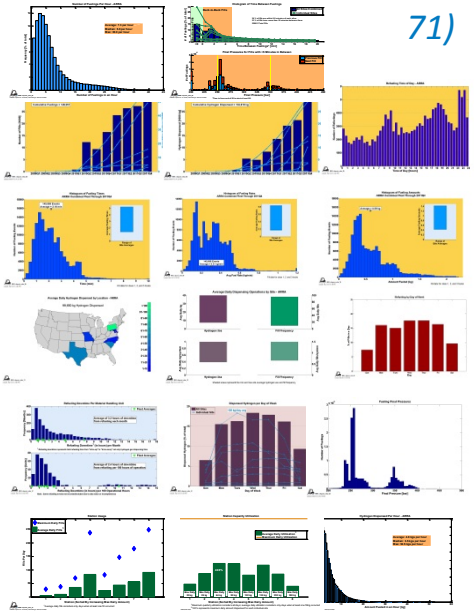
Fuel Cell Operation *(2, 7, 8, 11, 15, 16, 17, 23, 24, 63)*



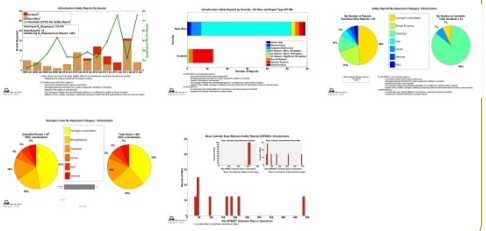
Fuel Cell Safety *(26, 27, 53, 56, 57)*



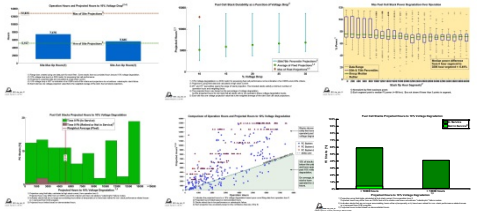
Infra. Operation *(3, 4, 5, 6, 9, 10, 21, 22, 35, 37, 42, 62, 65, 68, 69, 70, 71)*



Infra. Safety *(25, 41, 46, 51, 55)*

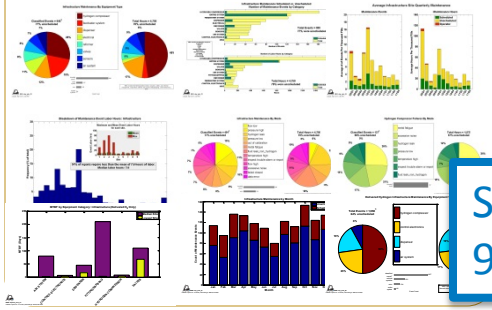


Fuel Cell Durability *(32, 33, 34, 38, 39, 73)*

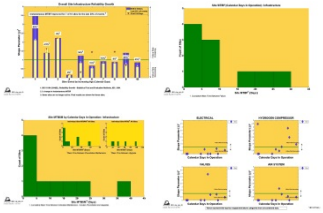


FC Maintenance *(12, 13, 14, 43, 54, 61)*

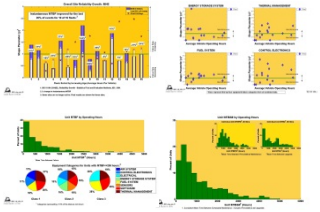
Infra. Maintenance *(18, 19, 20, 44, 47, 52, 66, 67, 72)*



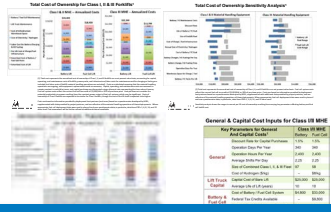
Infra. Reliability *(45, 48, 49, 50)*



Fuel Cell Reliability *(28, 29, 30, 31)*



Cost of Ownership *(58, 59, 60,64)*



Since 05/2012:
9 new & 45 updated

Accomplishments: MHE Operation Summary 2009 Q4 – 2012 Q4

FORKLIFTS

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

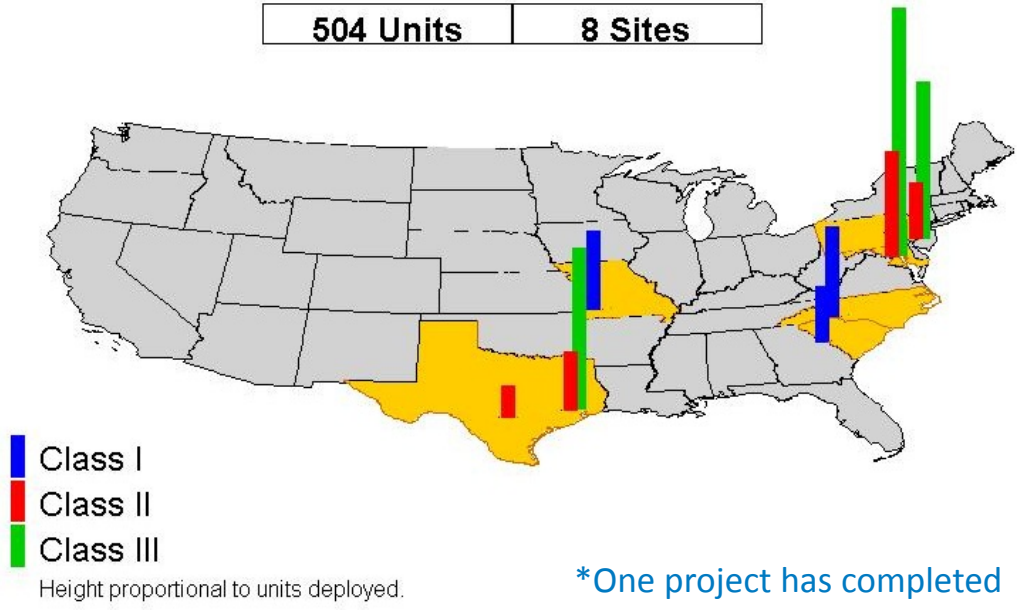
1,445,558
Operation hours

246,997
Hydrogen fills

490
Units in operation*

4.6
Average operation hours between fills

187,426
Hydrogen dispensed in kg



0.6
Average fill amount in kg

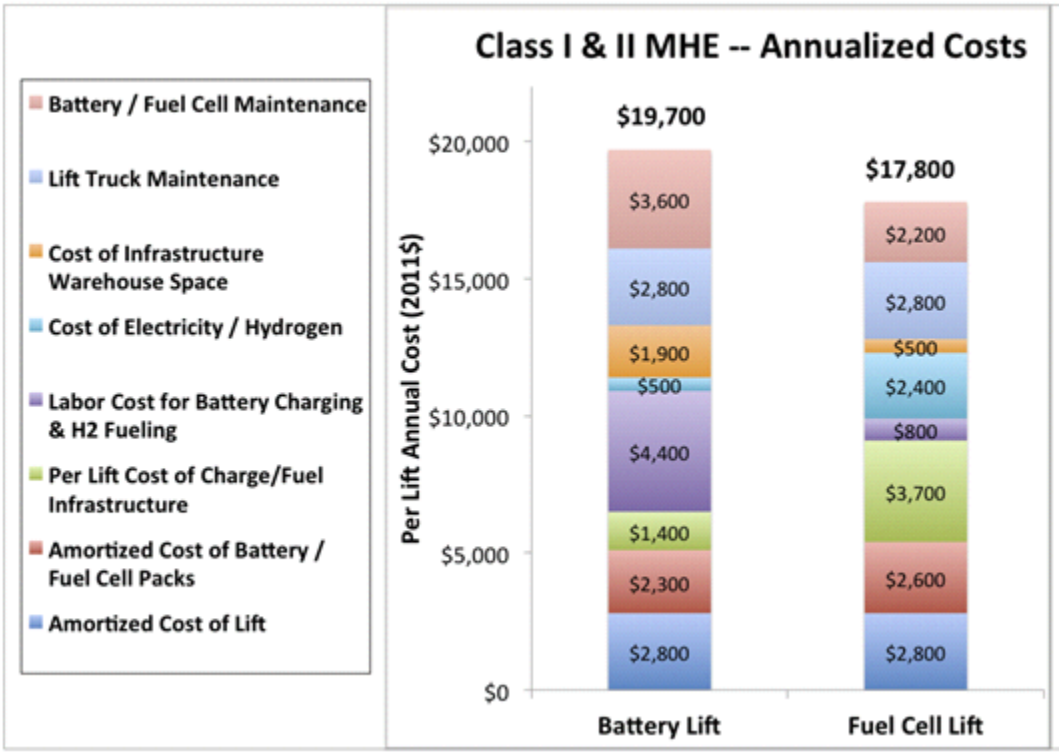
2.3
Average fill time in minutes

*One project has completed

Accomplishments: Completed 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

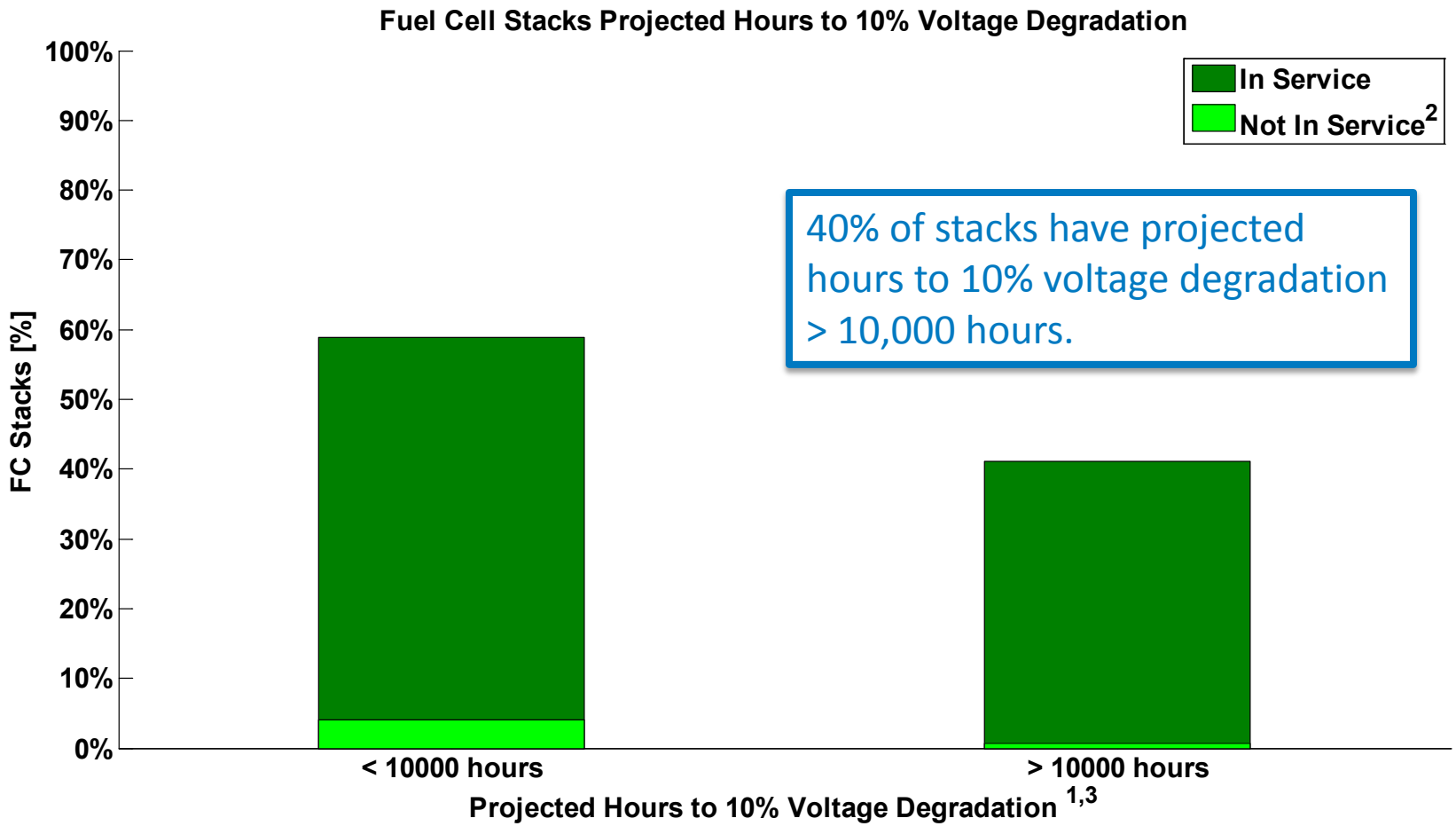
Report Sections

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

*Publication expected 04/2013

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

FORKLIFTS



40% 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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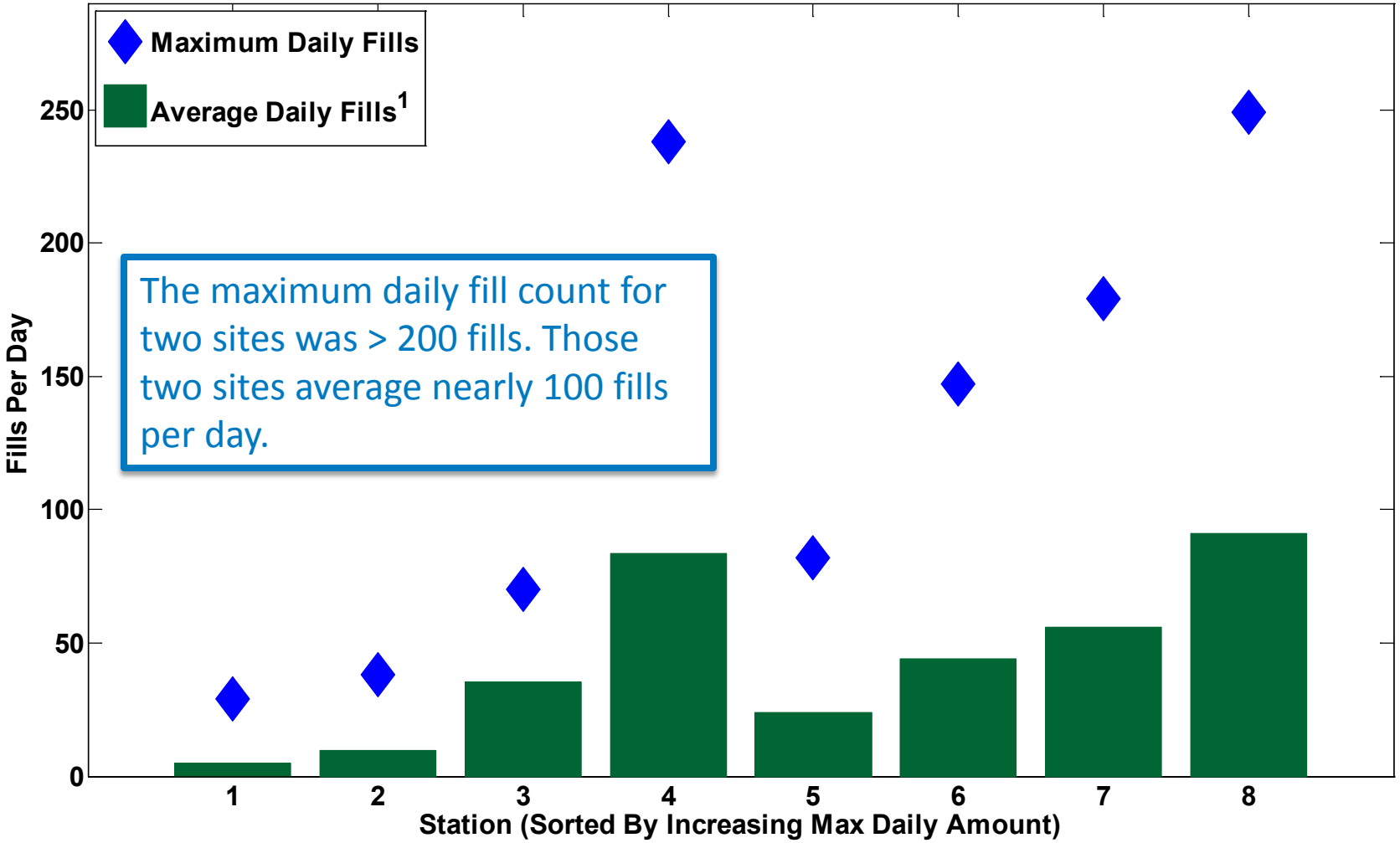
Accomplishments: Study of Infrastructure Usage by Daily Fills

FORKLIFTS



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

NREL cdparra_mhe_70

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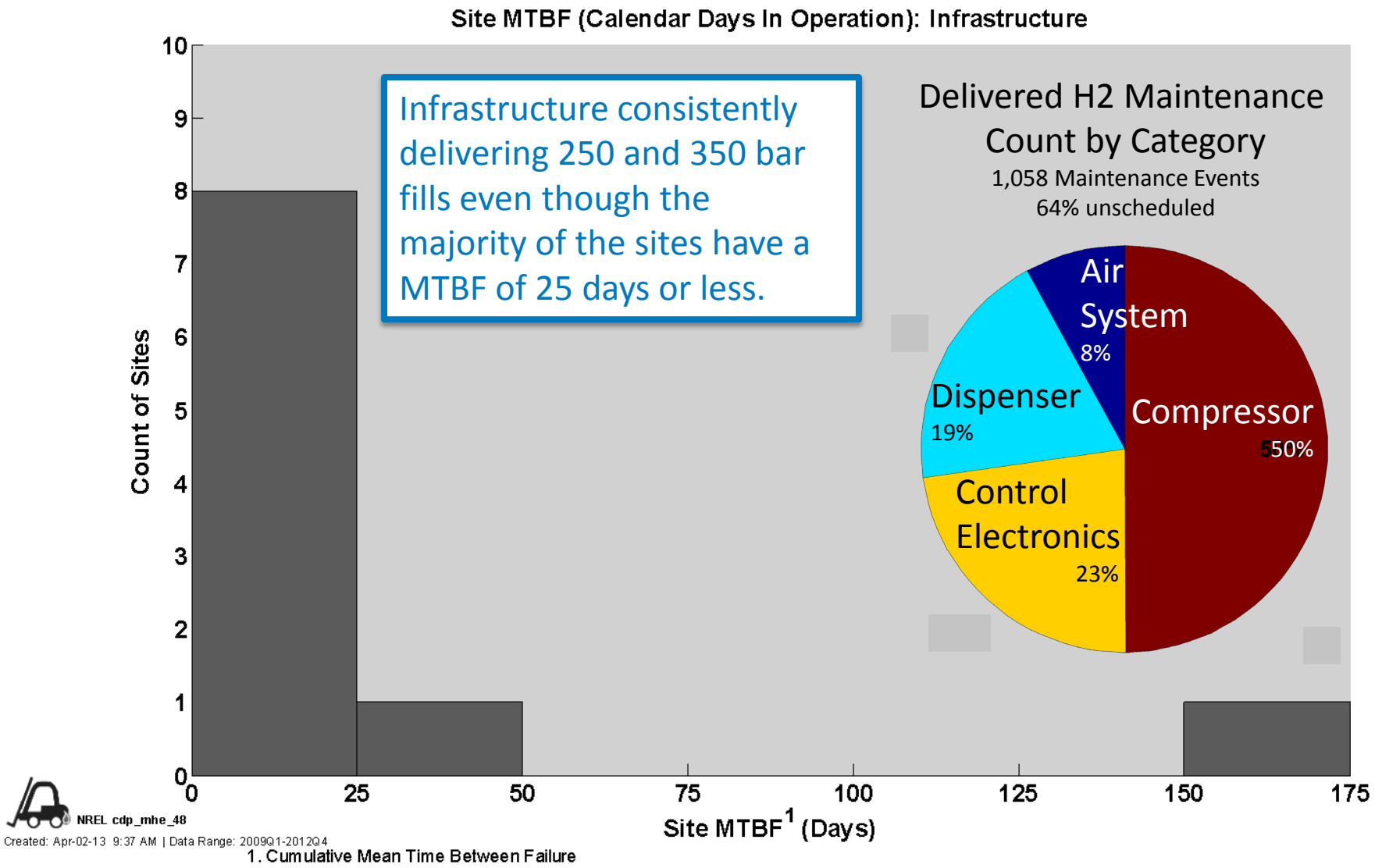
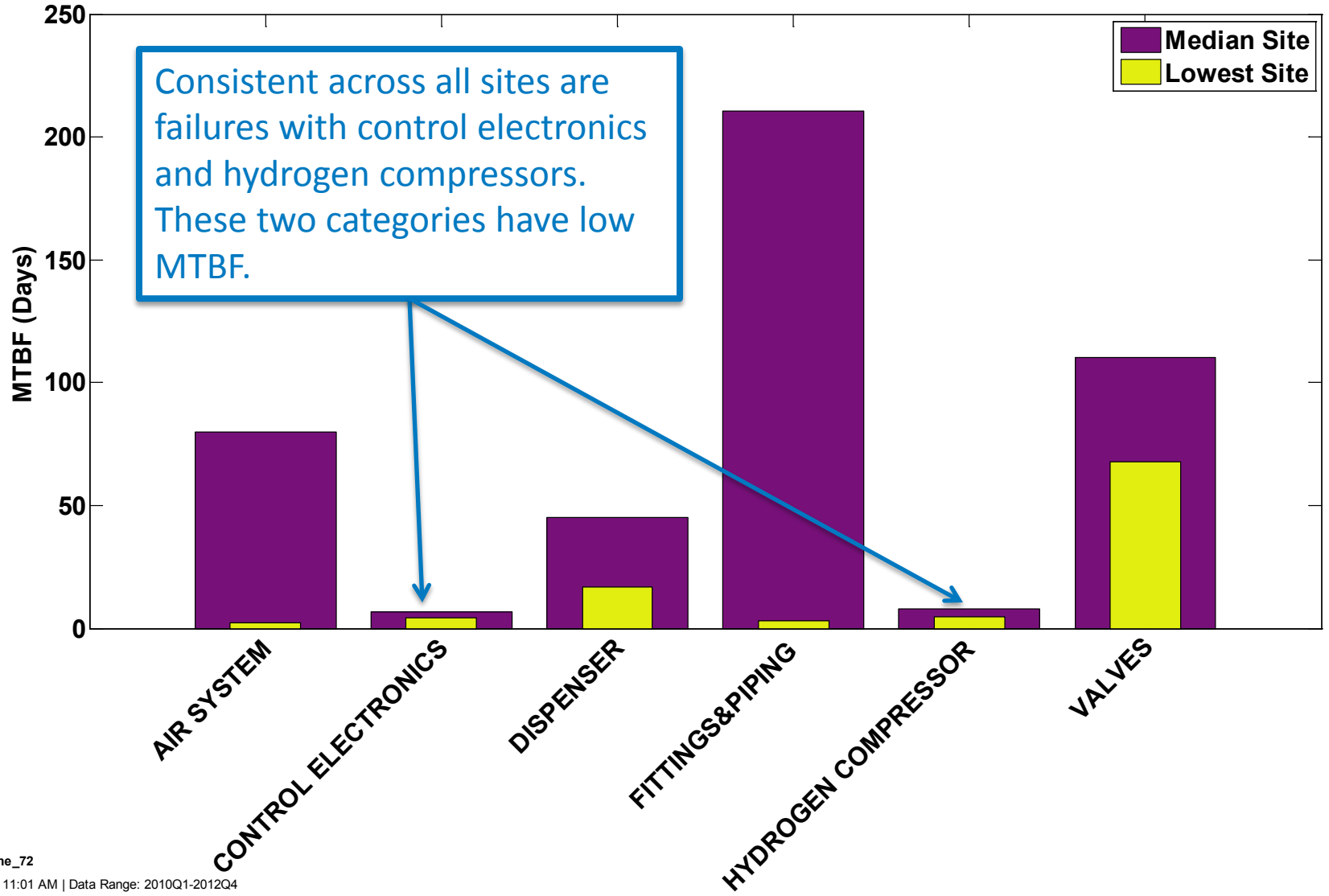
Accomplishments: Infrastructure Reliability Analysis



Accomplishments: Breakdown of MTBF by Key Delivered Hydrogen Infrastructure Categories

FORKLIFTS



NREL cdparra_mhe_72

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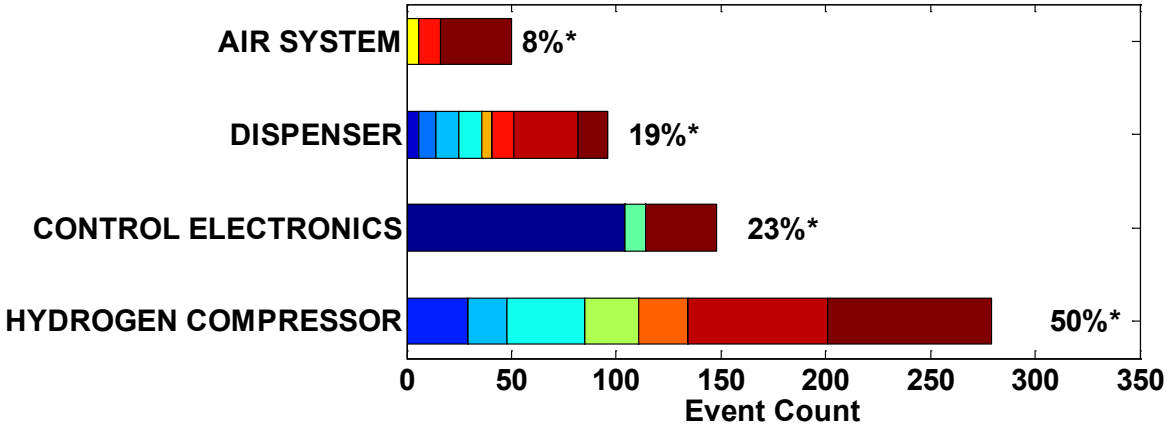
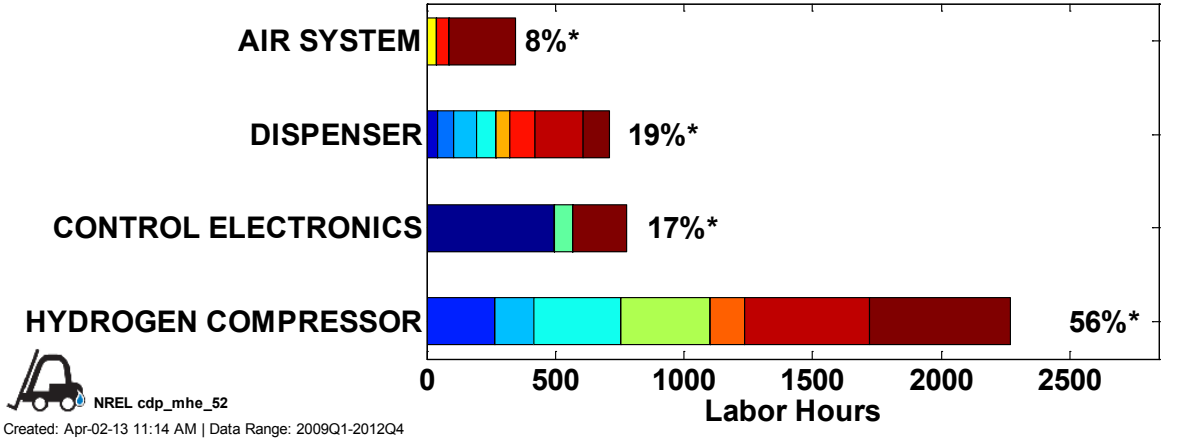
Accomplishments: Breakdown of Failure Modes for Top Four Maintenance Categories for Infrastructure

FORKLIFTS

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, temperature high, unspecified electronics failure, vandalism, voltage low, other

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

NREL cdp_mhe_52

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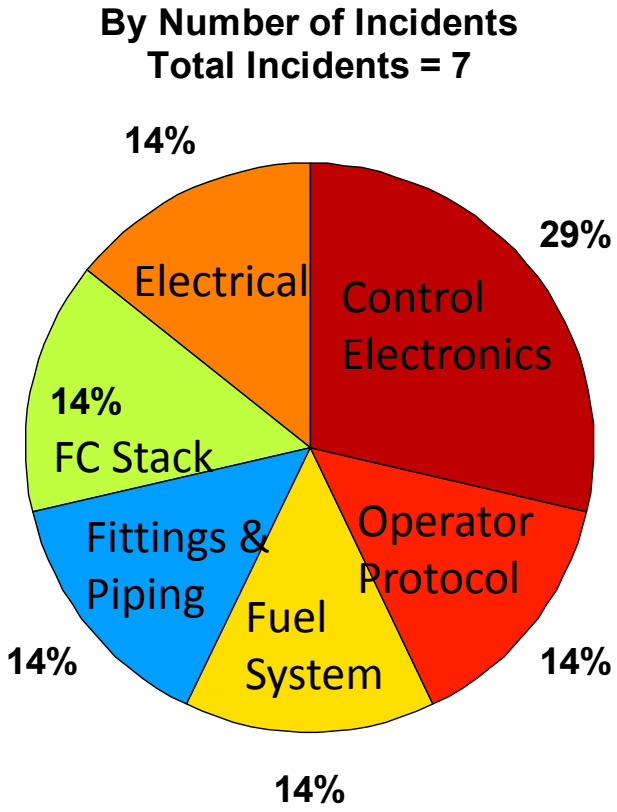
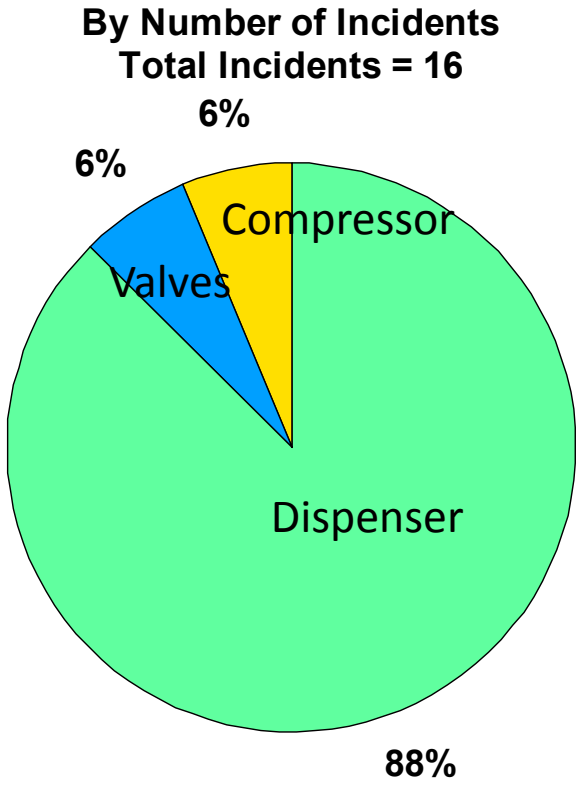
Accomplishments: MHE and Infrastructure Safety Report Analyses

FORKLIFTS

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
(3,587 kg dispensed per report)



Collaborations

Data Sharing and Analysis Partners

- Air Products
- FedEx
- GENCO
- Nuvera Fuel Cells*
- Plug Power
- ReliOn*
- Sprint
- Sysco Houston

ARRA Market Impact Study

Other collaboration activities include site visits and detailed analysis discussions

*Project completed

Other

- Hydrogen Safety Panel
  - Site visits and data discussion
- Quantitative Risk Assessment & Process Hazard Assessment Data Input
  - Carl Rivkin (NREL)
- Hydrogen production & delivery
  - Data shared for RD&D needs workshop
- Market transformation
  - Data shared for MHE and backup power fact sheets

Future Work

Remaining FY13 tasks:

- Quarterly analysis of operation and maintenance data for fuel cell systems and hydrogen infrastructure (2 cycles)
- Backup power value proposition & reliability analyses
- Bi-annual technical composite data products for data through June 2013
  - Update existing set of CDPs
  - Add to the CDPs pertaining to the market value proposition performance metrics
- Detailed data sharing with individual project partners for identification of successes and gaps with the early market technology validation
- Interim draft report of status and performance for fuel cell MHE and backup power systems

FY14:

- Complete final quarterly analysis and technical CDPs (data through 09/2013)
- Complete final report of status and performance for fuel cell MHE and backup power systems for project close out

Technical Summary – *What We've Learned*

Fuel Cell Backup Power

- Operating reliability in 19 states with 99.6% successful starts.
- Maximum continuous run time of 65 hours due to an unplanned grid outage.

Fuel Cell Material Handling Equipment

- 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 indicates an annual cost savings primarily from refueling labor and infrastructure space even with an increase in cost for hydrogen infrastructure and fuel.

Published results track performance status over the last two years in MHE and backup power.

Data analyses develop based on the key performance areas for each market.

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.

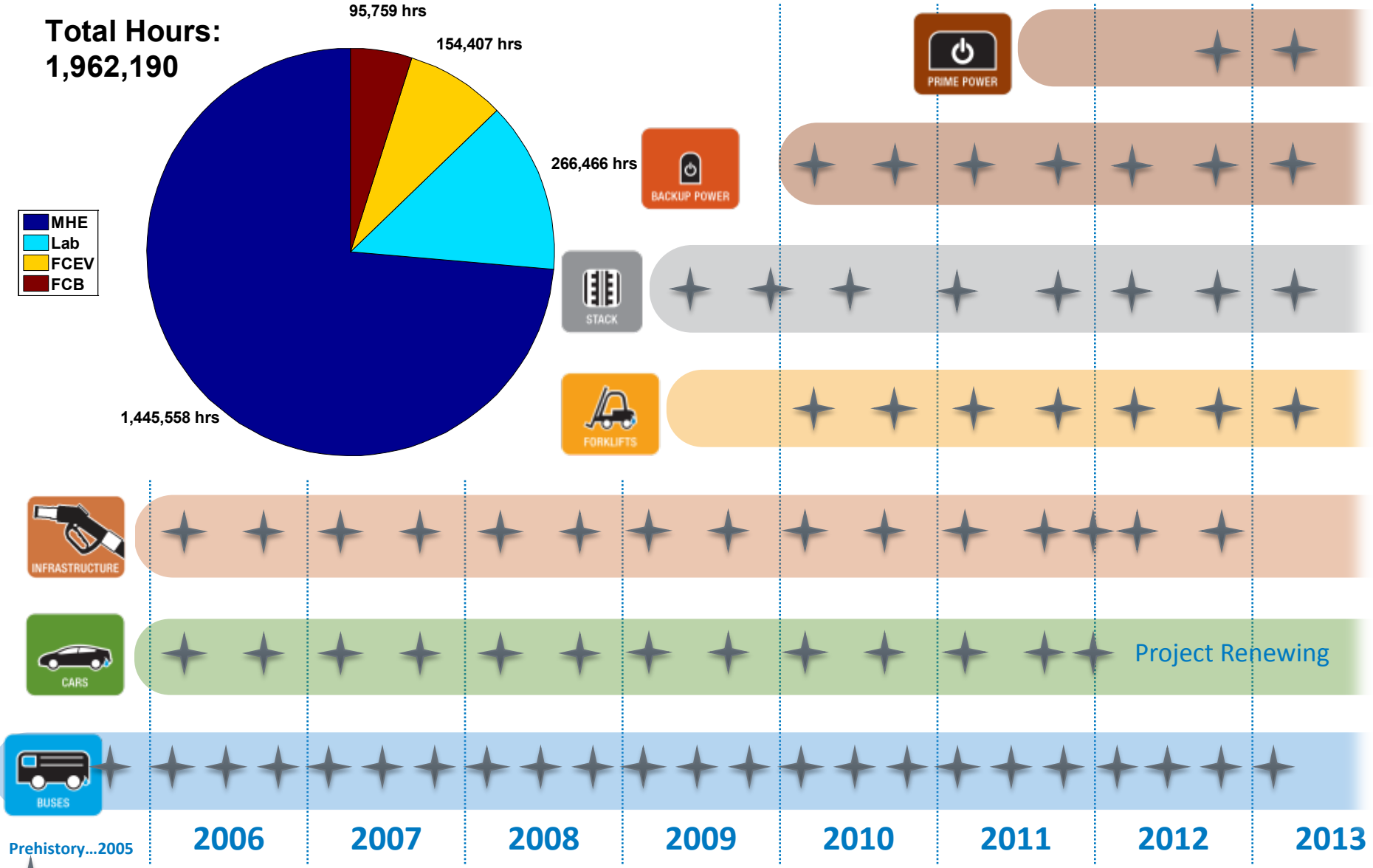
***Approach*:** Leverage capabilities established under other technology validation activities (NRELFAT) and industry collaborations. Aggregate data for concise reporting on large data sets from multiple project partners.

***Accomplishments*:** Sixth set of technical CDPs published on performance, operation, and safety for MHE and backup power, with 22 new CDPs added. All results and publications are available on NREL's technology validation website that also includes monthly highlights.

***Collaborations and Future Work*:** Prepare for project close out in FY14 through a two-stage report with close collaboration of the fuel cell and hydrogen developers and end users.

Technical Backup

Approach: Leveraging Data Process and Analysis Capabilities Across Technology Validation Projects



Cost of Ownership: Backup power

BACKUP POWER

Gathering data on:

- Site description
- System description
- System requirements
- Capital cost
- Operating & maintenance cost
- Operating lifetime for fuel cells, batteries, and generators

	Fuel Cell*	Diesel	Battery
Reliability	+	o	+
Capital Cost ($/kW)	-	+	++
Extended Run Time	++	++	--
Emissions	++	-	++
Noise	+	+	++
Environmental	~	-	~
Weight	+	-	-
Efficiency	+	-	++
Annual Fuel Cost	+	-	++
Annual Maintenance Cost	+	-	++
Maintenance Frequency	++	-	~
Refurbishment	+	+	--
Conditioning Tests	+	-	~
Operation Lifetime	+	++	--

*Tax credit $3,000/kW or 30% total

++	Much better
+	Better
o	No difference
-	Worse
--	Much worse
~	Details unknown