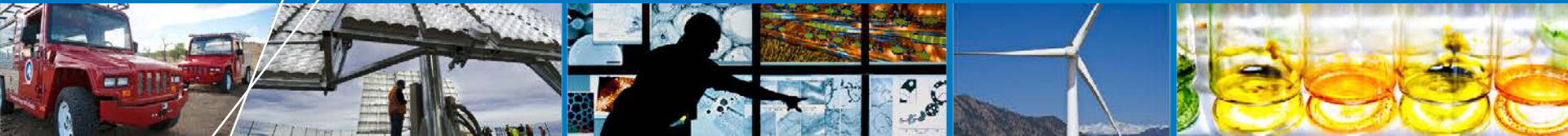


# Analysis Results for ARRA Projects: Enabling Fuel Cell Market Transformation



**2012 DOE Annual Merit Review**

**Jennifer Kurtz, Keith Wipke, Sam Sprik,  
Todd Ramsden, Chris Ainscough,  
Genevieve Saur**

**May 16, 2012**

NREL/PR-5600-54482

**Project ID# H2RA-013**

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

# Overview

## Timeline

Project start date:

August 2009

Project end date:

September 2013\*

Percent complete: 95%

## Barriers

Commercialization of fuel cells in key early markets

## Budget

Total project funding

DOE share: \$1,000k

Contractor share: \$0

Funding received in FY11: \$0k

Funding received in FY09-FY10:

\$1,000k

## Partners

See Collaboration Slide

\*Future evaluations under Technology Validation

# 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.

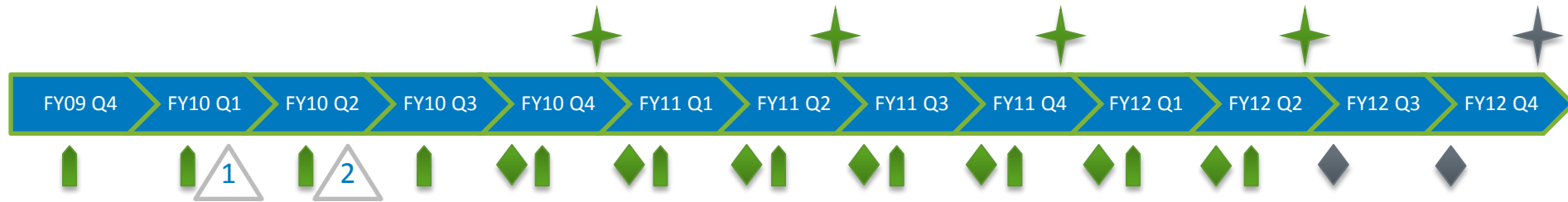
- **Assess Technology**

- Independent technology assessment in real world operation conditions
- Focused 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
- Material handling equipment, backup power, portable power, and stationary power.
- Analysis includes up to 1,000 fuel cell systems deployed with ARRA funds

- **Support Market Growth**

- Analyses and results relevant to the markets' value proposition
- Reporting on technology status to fuel cell and hydrogen communities and other key stakeholders like end users

# Milestones – Approach and Accomplishments

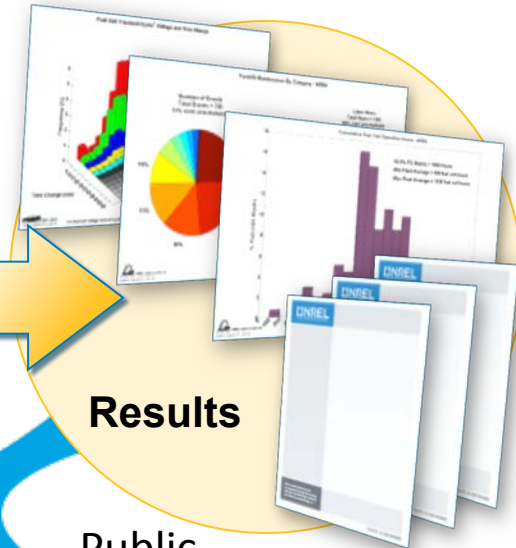
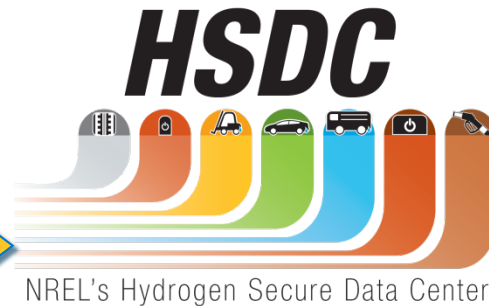


1. Create Early Market FC Analysis website on NREL's technology validation site
2. Finalize data collection and analysis plans through communications with DOE and industry partners
3. Quarterly deployment composite data products
4. Quarterly analysis of operation and maintenance data for fuel cell systems and hydrogen infrastructure
5. Bi-annual technical composite data products
6. Site visits
7. Hydrogen Safety Panel Final Report (FY12 Q4)

# Hydrogen Secure Data Center - Approach

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

Internal analysis completed quarterly



DDPs

Confidential

Results

Public

CDPs

## Detailed Data Products (DDPs)

- Individual data analyses
- Identify individual contribution to CDPs
- Only shared with partner who supplied data every 6 months<sup>1</sup>

## Composite Data Products (CDPs)

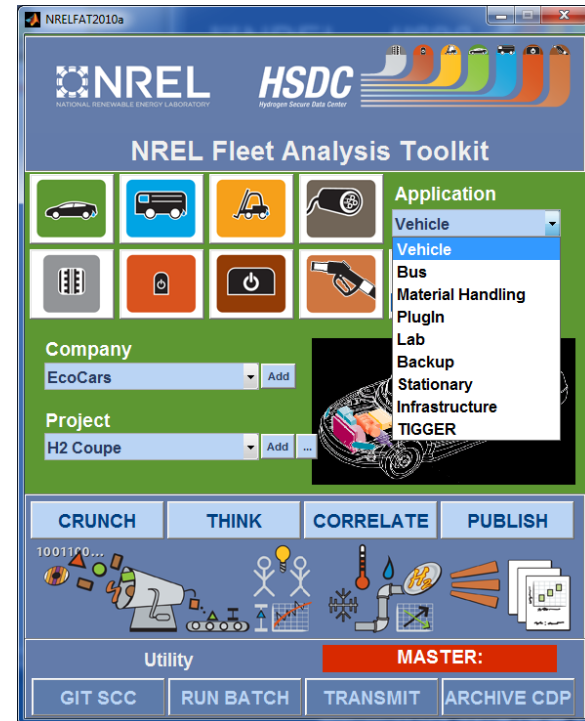
- Aggregated data across multiple systems, sites, and teams
- Publish analysis results without revealing proprietary data every 6 months<sup>2</sup>

1) Data exchange may happen more frequently based on data, analysis, and collaboration

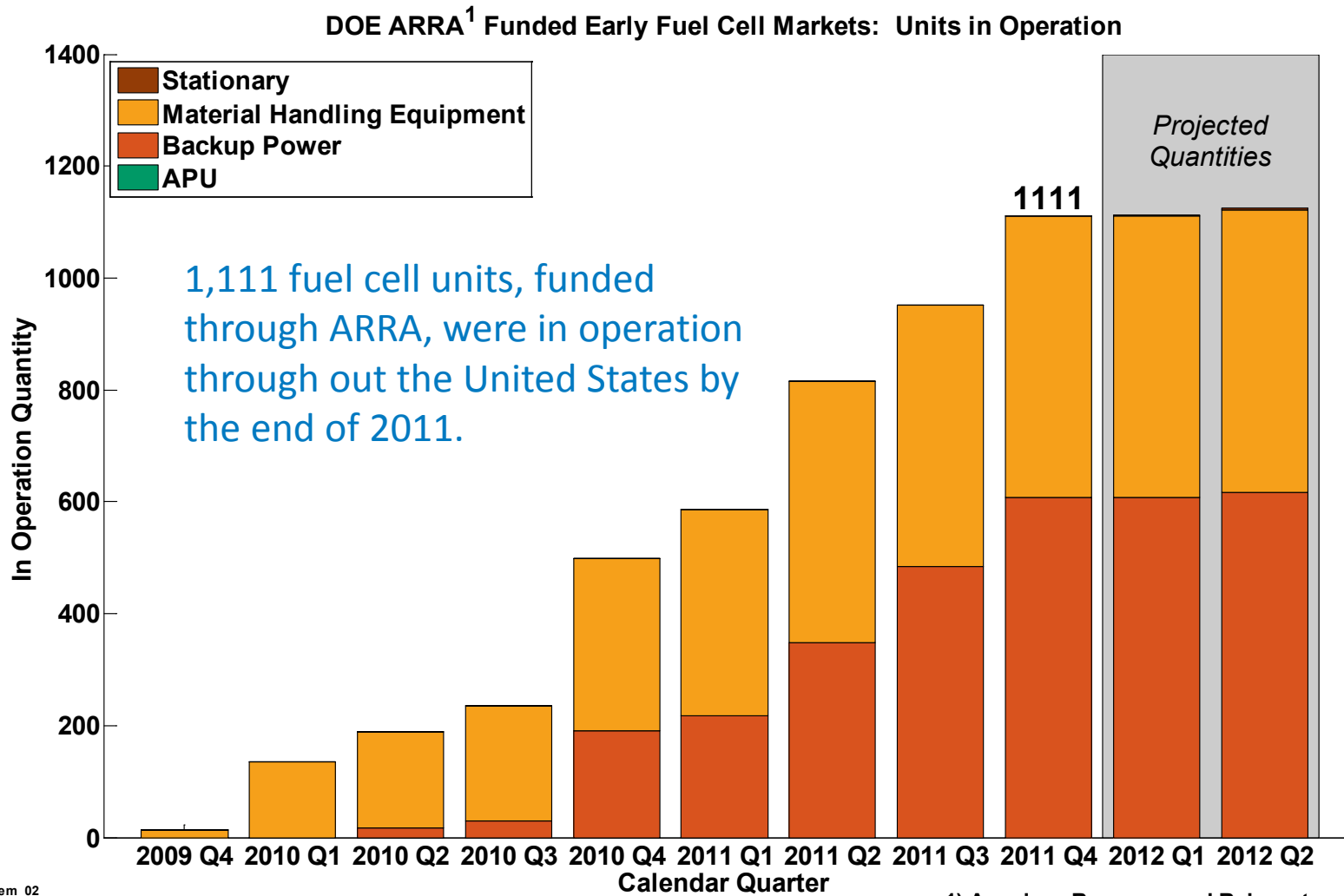
2) Results published via NREL Tech Val website, conferences, and reports

# Analysis – Approach & Accomplishment

- **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



# Deployment Update - Accomplishments



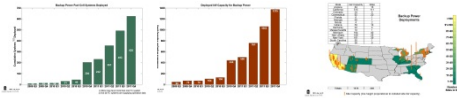
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1) American Recovery and Reinvestment Act

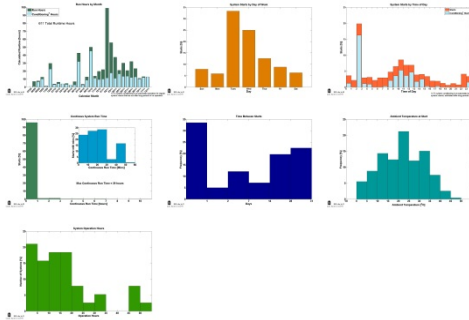
Updated since 05/2011

# 13 Backup Power CDP Count & Category - Accomplishment

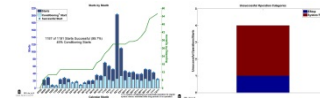
## Deployment (1, 2, 3)



## Fuel Cell Operation (5, 7, 8, 9, 11, 12, 13)



## Fuel Cell Reliability (4, 10)



## Infra. Operation (6)

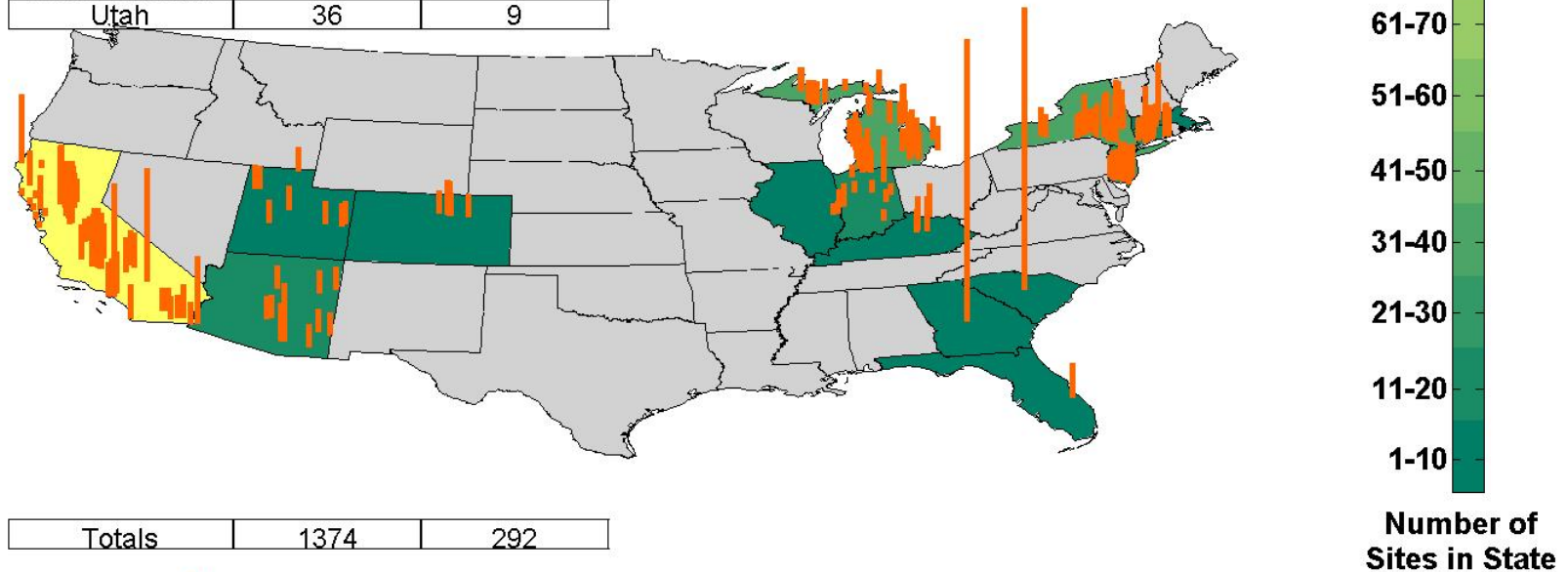




# Backup Power Deployment

State	kW Capacity	Sites
Arizona	84	16
California	515	111
Colorado	24	5
Connecticut	92	20
Florida	6	1
Georgia	50	1
Illinois	4	2
Indiana	50	16
Kentucky	22	4
Massachusetts	10	1
Michigan	164	40
New Jersey	106	26
New York	161	39
South Carolina	50	1
Utah	36	9

06/2010 – 5 sites  
 12/2010 – 85 sites  
 06/2011 – 199 sites  
 12/2011 – 292 sites



Site Capacity (line height proportional to installed site kW capacity)

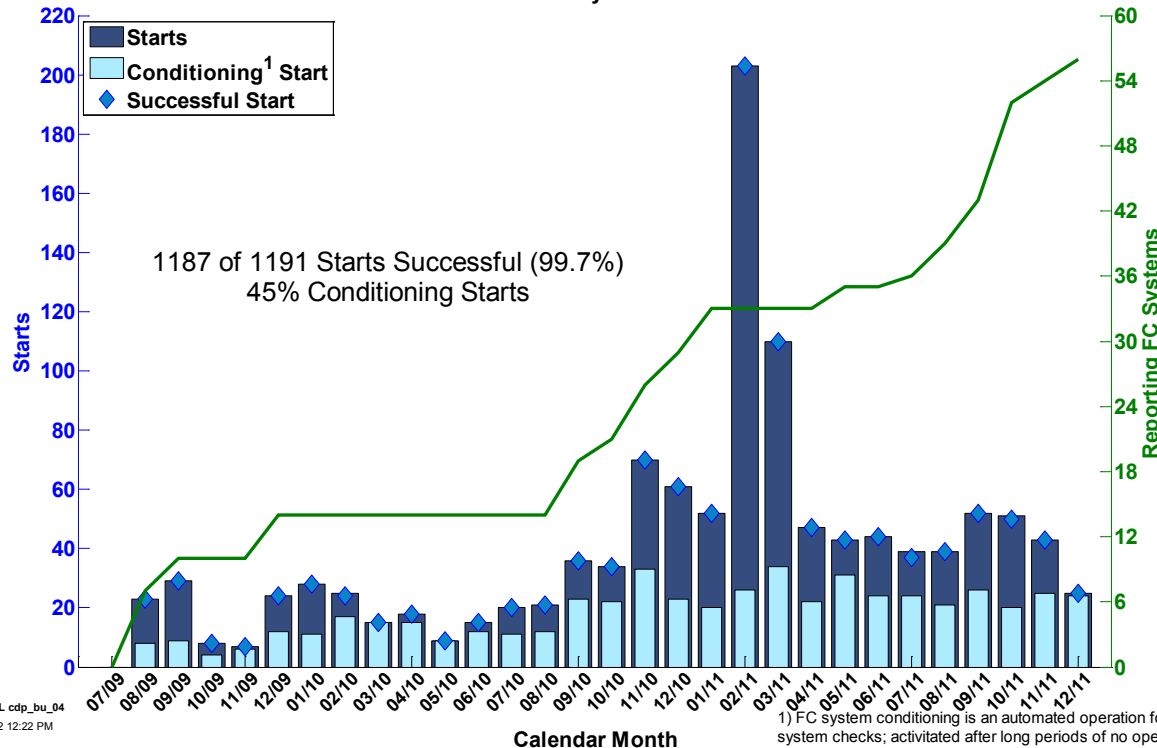
# Summary of Backup Power System Operation

Updated since 05/2011



Sites	292	CDP-BU-#
Deployed Systems	625*	01
Total Successful Starts	1187 (99.7%)*	04
Total Run Time	611 hours*	05
Total Hydrogen	70.7 kg*	06

Starts by Month



Systems are operating reliably in 15 states with 99.7% successful starts. Reasons for unsuccessful starts include an e-stop signal and system failures.

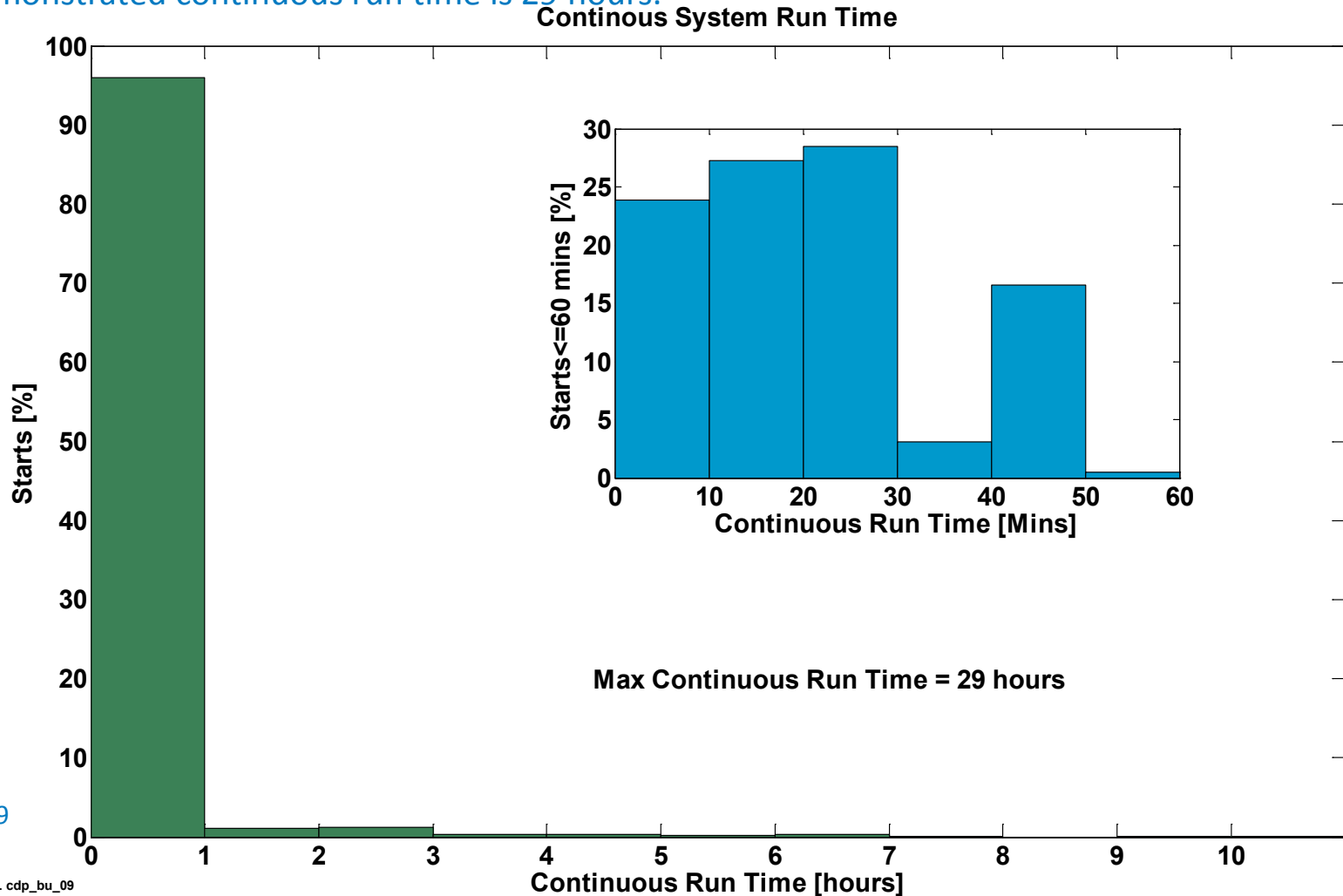
\* Through December 2011

1) FC system conditioning is an automated operation for regular system checks; activated after long periods of no operation.

# Demonstrated FC Backup Continuous Run Time - Accomplishment



Most of the starts operate for less than 1 hour long based on grid stability, interface with site, and conditioning. Conditioning starts account for 45% of all starts and the maximum demonstrated continuous run time is 29 hours.



CDP-BU-09

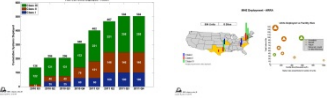
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Updated since 05/2011

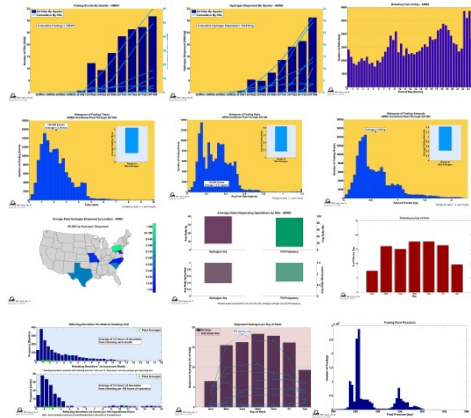
# 63 MHE CDP Count and Category - Accomplishment



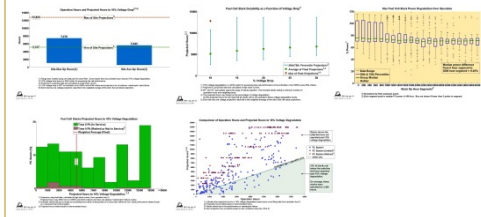
## Deployment & Site Overview (1, 40)



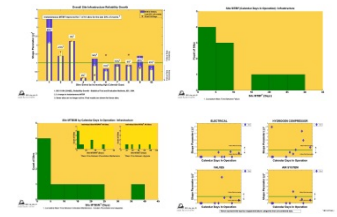
## Infra. Operation (3, 4, 5, 6, 9, 10, 21, 22, 35, 37, 42, 62)



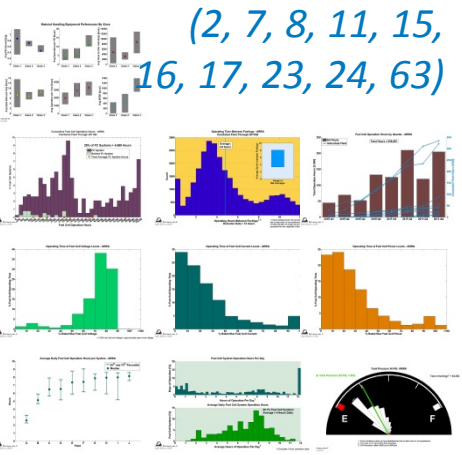
## Fuel Cell Durability (32, 33, 34, 38, 39)



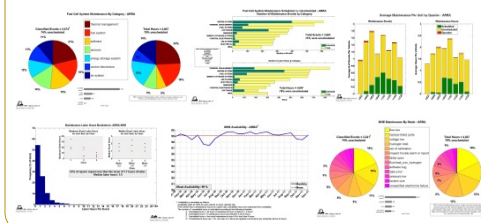
## Infra. Reliability (45, 48, 49, 50)



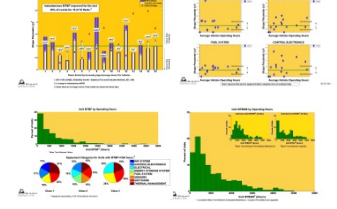
## Fuel Cell Operation (2, 7, 8, 11, 15, 16, 17, 23, 24, 63)



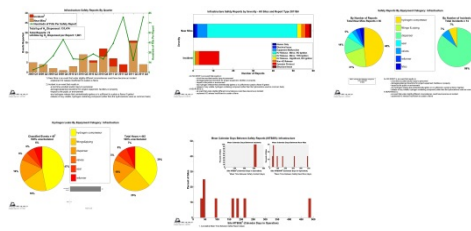
## FC Maintenance (12, 13, 14, 43, 54, 61)



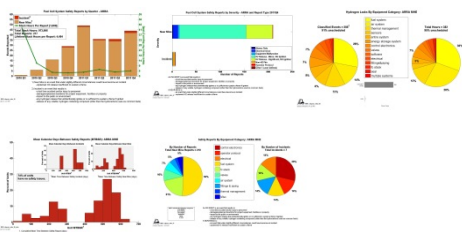
## Fuel Cell Reliability (28, 29, 30, 31)



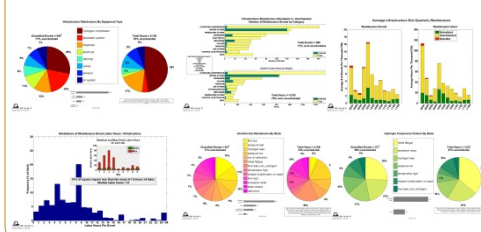
## Infra. Safety (25, 41, 46, 51, 55)



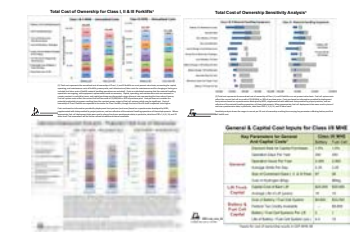
## Fuel Cell Safety (26, 27, 53, 56, 57)



## Infra. Maintenance (18, 19, 20, 44, 47, 52)



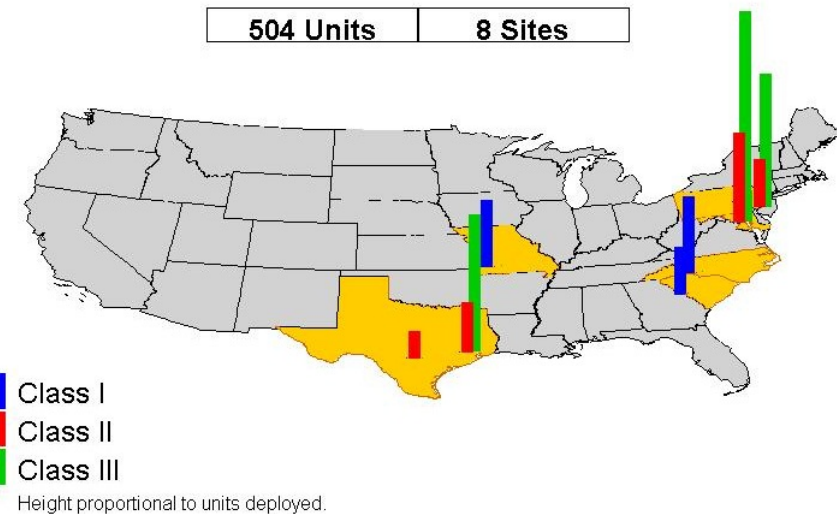
## Cost of Ownership (58, 59, 60, 64)



# MHE Operation Status - Accomplishment



Sites	8	CDPARRA -MHE-#
Units in Operation (100 Class 1, 76 Class 2, 172 Class 3)	504*	01
Hours Accumulated	959,887 hrs*	11
25% of FC Systems	> 4,860 hrs*	02
FC Systems Average > 6 hours Daily	66%*	24
Hydrogen Dispensed	104,916 kg*	04
Hydrogen Fills	148,251*	03
Average Fill Amount	0.6 kg/fill*	10
Average Fill Time	2.2 min/fill*	06
Average Op Time between Fill	4.8 hrs*	08



The majority of sites have delivered liquid hydrogen. 2 of the 8 sites are greenfield sites. 4 sites have more than one class of MHE in operation.

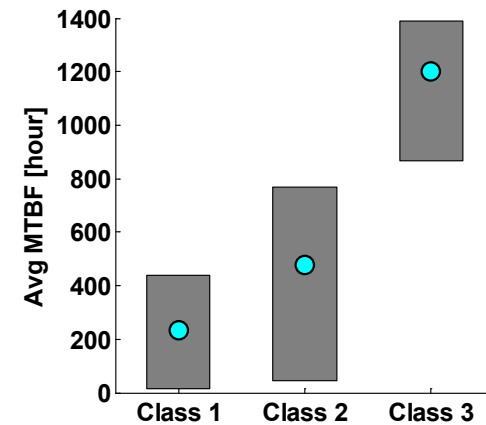
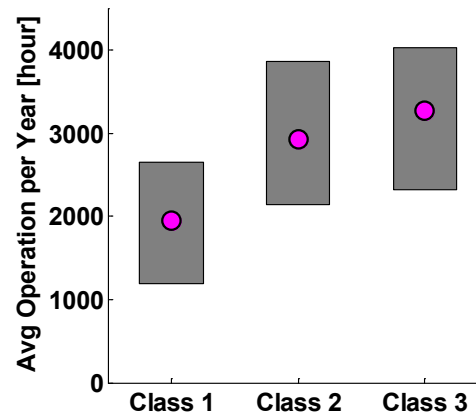
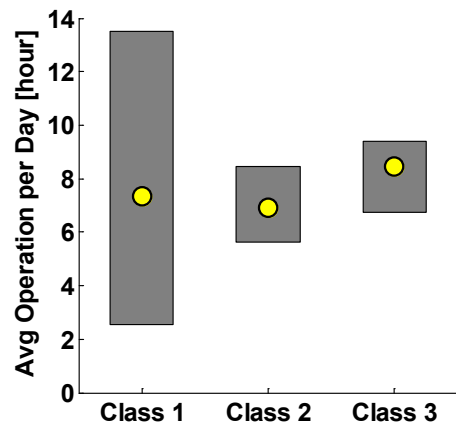
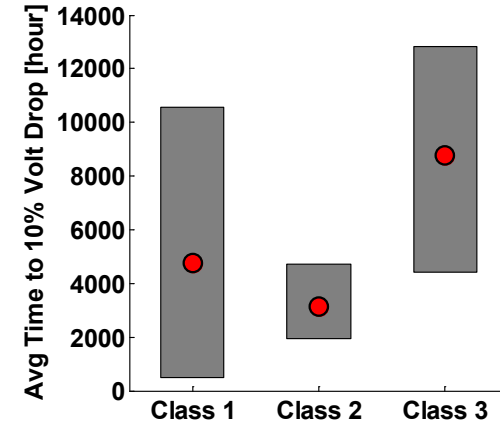
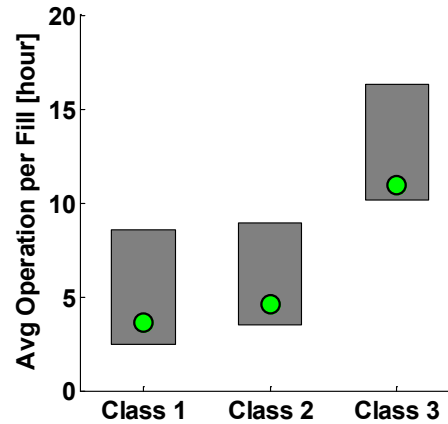
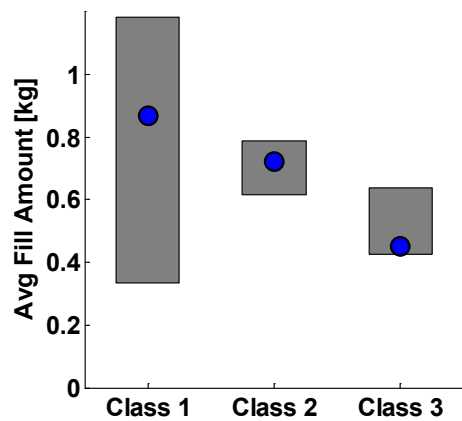
\*Through December 2011

Updated since 05/2011

# Key Performance Areas by MHE Classification - Accomplishment



Key performance areas include fill amount, operation per fill, operation per day, operation per year, mean time between failure, and voltage degradation. Data indicate Class 1 and 2 are similar in operation (and in system specs). One reason for Class 3 systems having higher voltage durability and MTBF is the less strenuous performance needs than Class 1 and Class 2 systems.

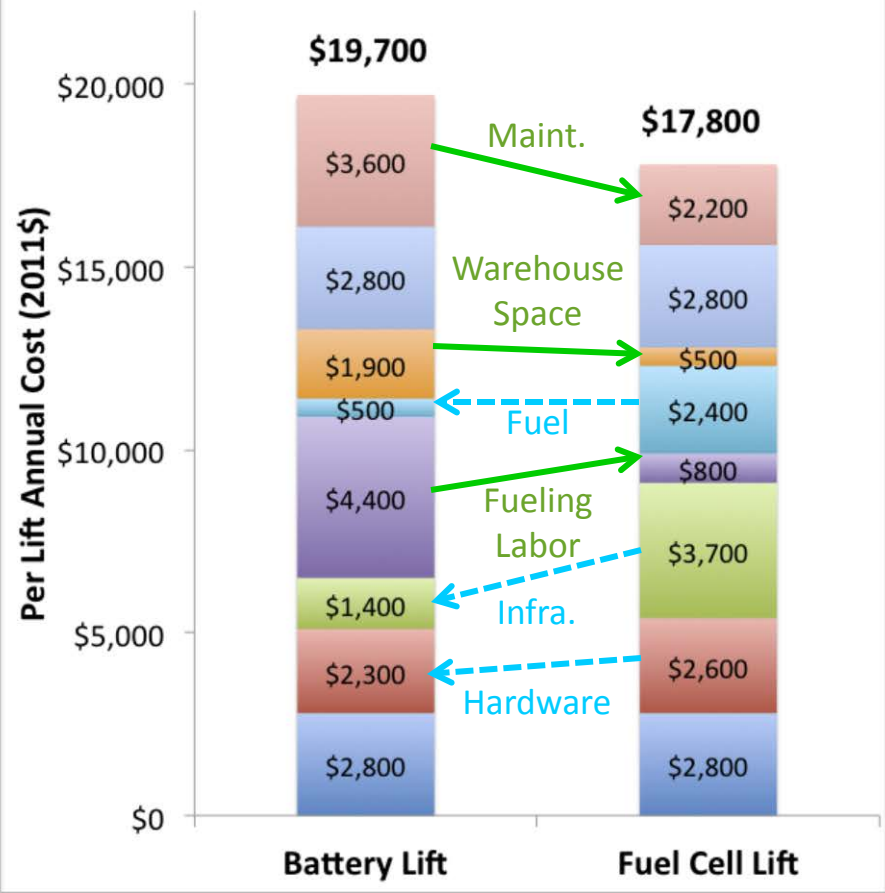


# Annualized Total Cost of Ownership per Unit Identifies Key Cost Advantages are Dependent on Deployment Size - Accomplishment



- Battery / Fuel Cell Maintenance
- Lift Truck Maintenance
- Cost of Infrastructure Warehouse Space
- Cost of Electricity / Hydrogen
- Labor Cost for Battery Charging & H2 Fueling
- Per Lift Cost of Charge/Fuel Infrastructure
- Amortized Cost of Battery / Fuel Cell Packs
- Amortized Cost of Lift

### Class I & II MHE -- Annualized Costs



Analysis inputs are averages per category, some key inputs are:

- 58 FC lifts
- 333 days per year, 2.5 shifts per day (2,100 pedal hours per year)
- 3 min per hydrogen fill & 10 min per battery change out

Class III Annualized Cost

- \$11,700 FC
- \$12,400 Battery

Other results include (#59, 60, & 64)

- Sensitivity
- Intensive deployment scenario (100 lifts and 3,000 pedal hours per year)
- Input values

CDP Ref #: 58

Results assume replacements as needed and do not reflect technology generation improvements or other productivity improvements such as constant power, emissions, and cold environment. FC costs include current tax credit of \$3,000/kW or 30% of purchase price. Data source: ARRA & DLA project partner questionnaire & fuel cell performance data.

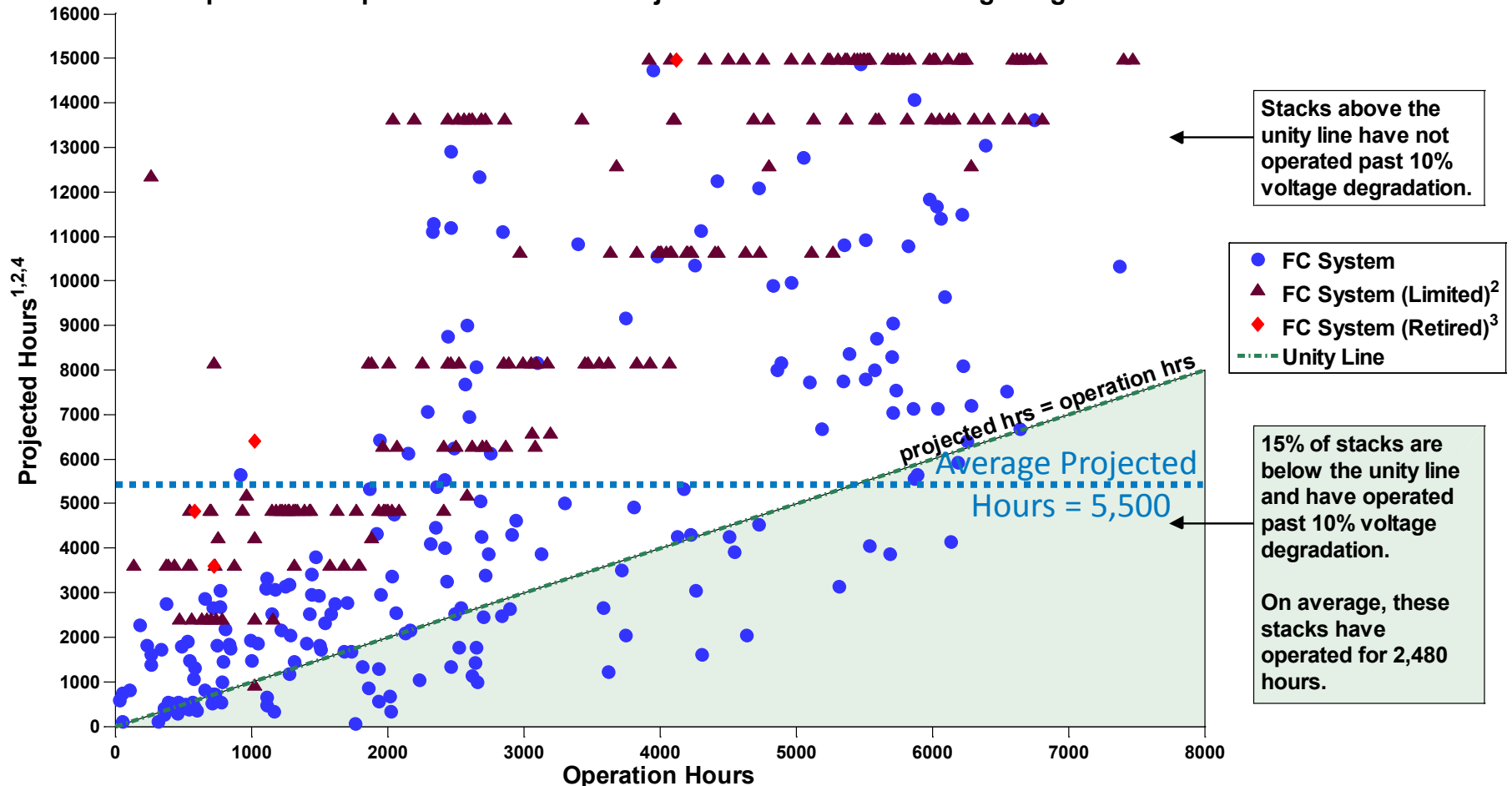
New since 05/2011

# Fuel Cell Voltage Degradation - Accomplishment



Maximum fuel cell accumulated hours is 7,476 and the average projected hours to 10% voltage degradation is 5,500 hours with ~35% of stacks having a projection > 10,500 hours.

Comparison of Operation Hours and Projected Hours to 10% Voltage Degradation



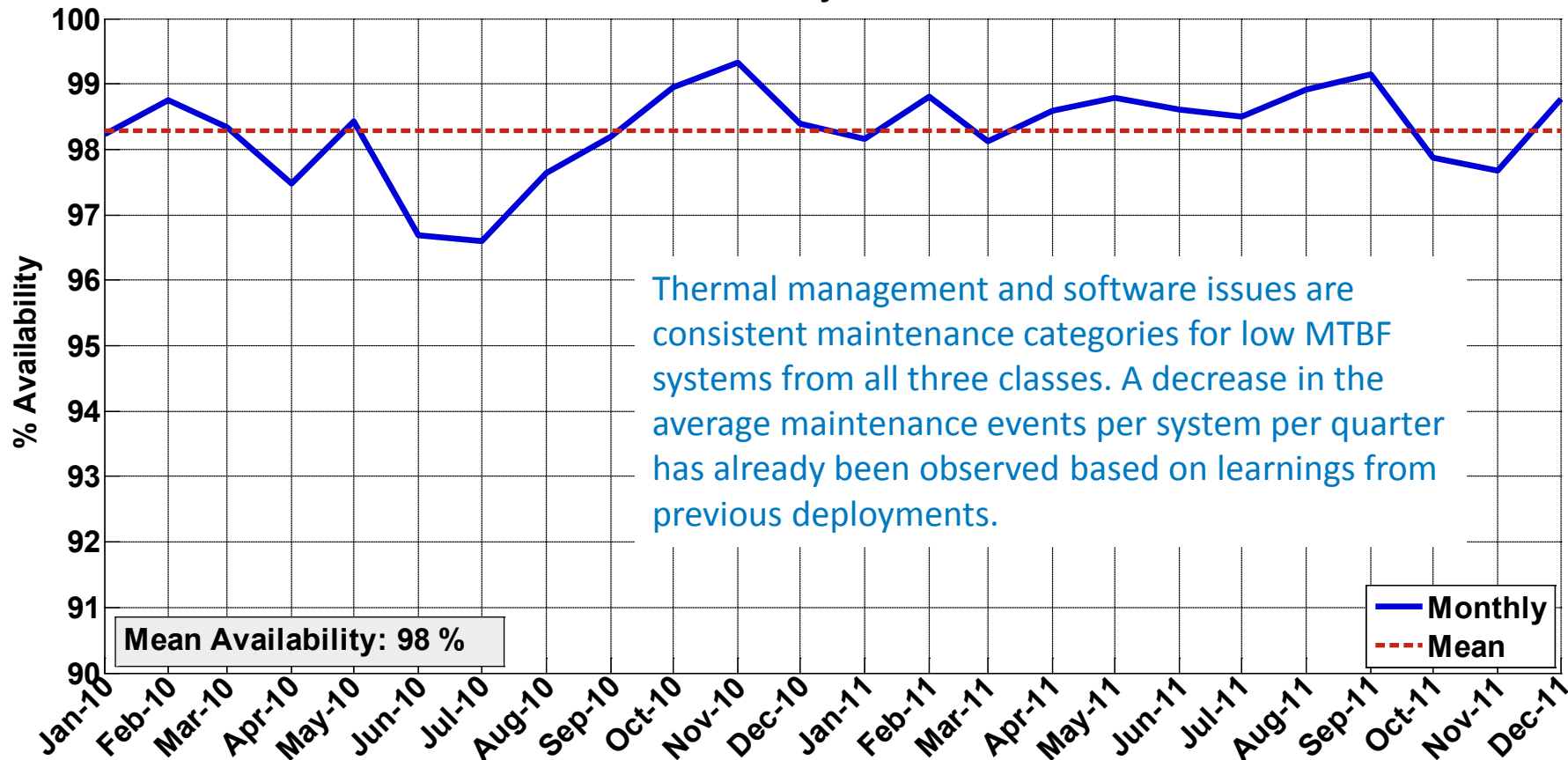


# FC Maintenance Analyses - Accomplishment



The average availability is 98% but ~35% of FC systems have a MTBF of 250 hours or less.

### MHE Availability - ARRA & DLA<sup>1</sup>



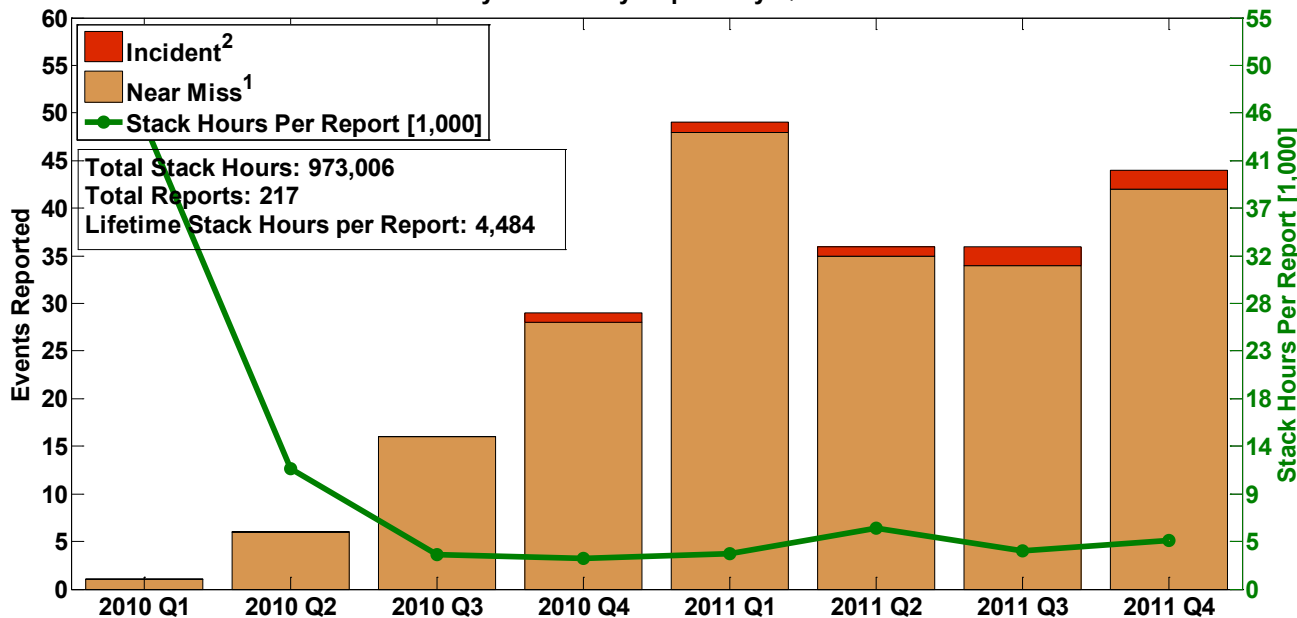
2009 MHE Systems average ~3 maintenance events per unit per quarter.  
2010 MHE Systems average ~1.5 maintenance events per unit per quarter.

# FC MHE Safety Report by Quarter and Classification - Accomplishment

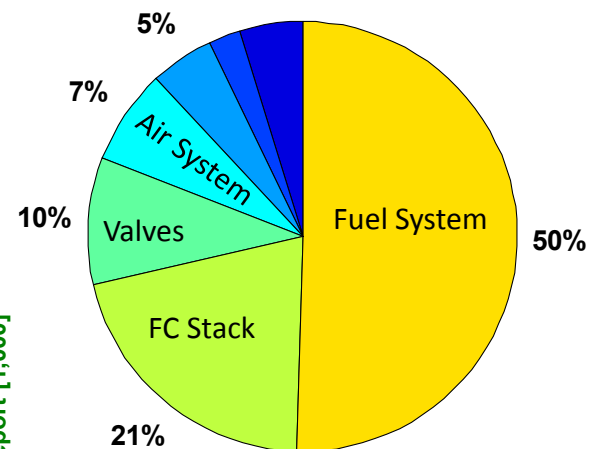


FC Safety: Majority of safety reports are minor hydrogen leaks with an average of 4,480 stack hours per report

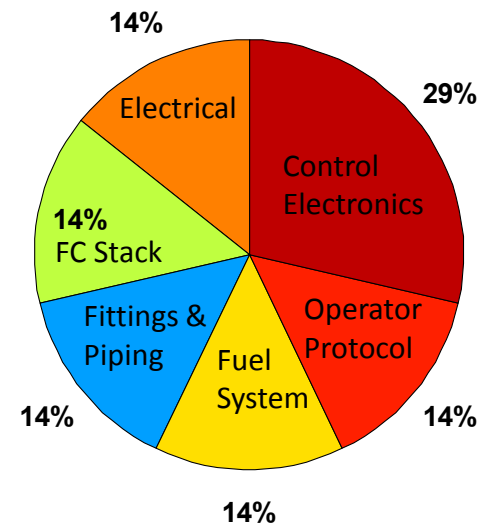
Fuel Cell System Safety Reports by Quarter - ARRA



By Number of Reports  
Total Near Miss Reports = 210  
5%



By Number of Incidents  
Total Incidents = 7



The majority of safety reports were in the on-board Fuel System equipment category. Incident types include non-hydrogen fires, significant hydrogen release without ignition, and operator protocol.

CDP-MHE-26, 27, & 57

Updated & new since 05/2011

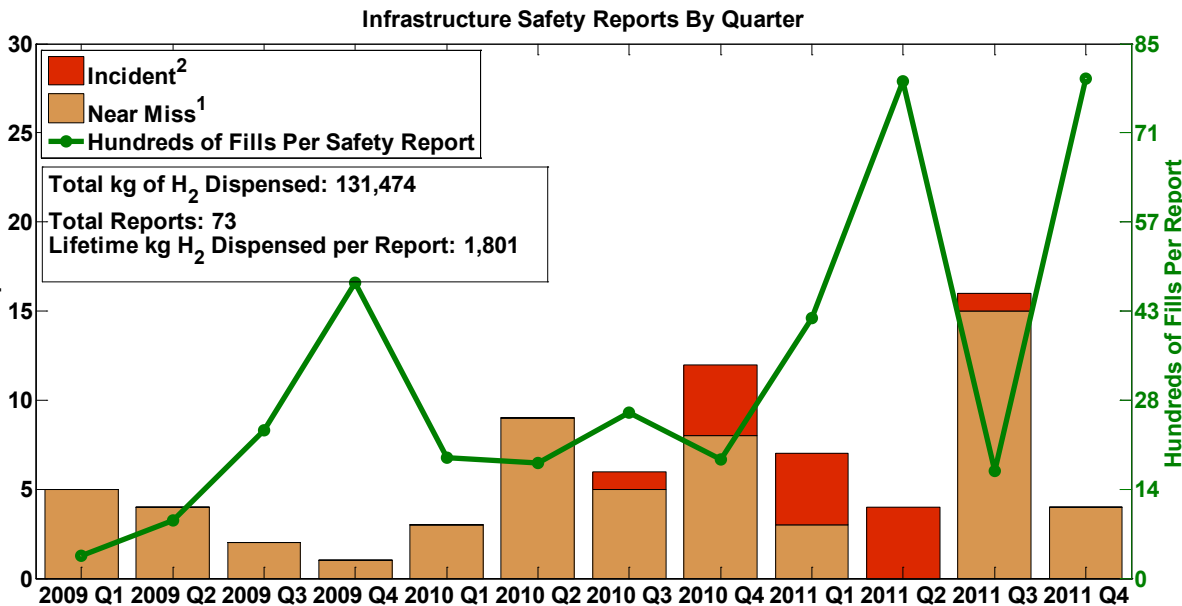
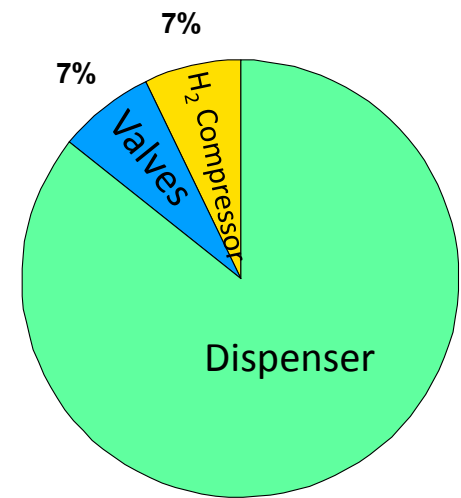
# Infrastructure Safety by Quarter & Classification

## – Accomplishment

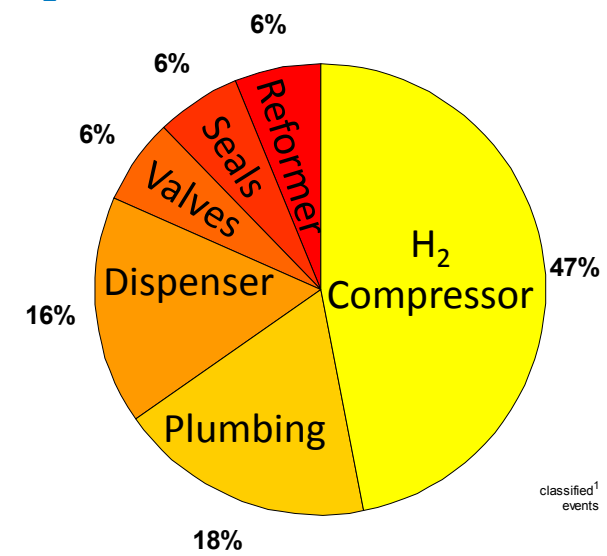


Majority of safety reports are hydrogen leaks primarily from the hydrogen compressor and plumbing.

Incident Categories



H<sub>2</sub> Leak Equipment Categories



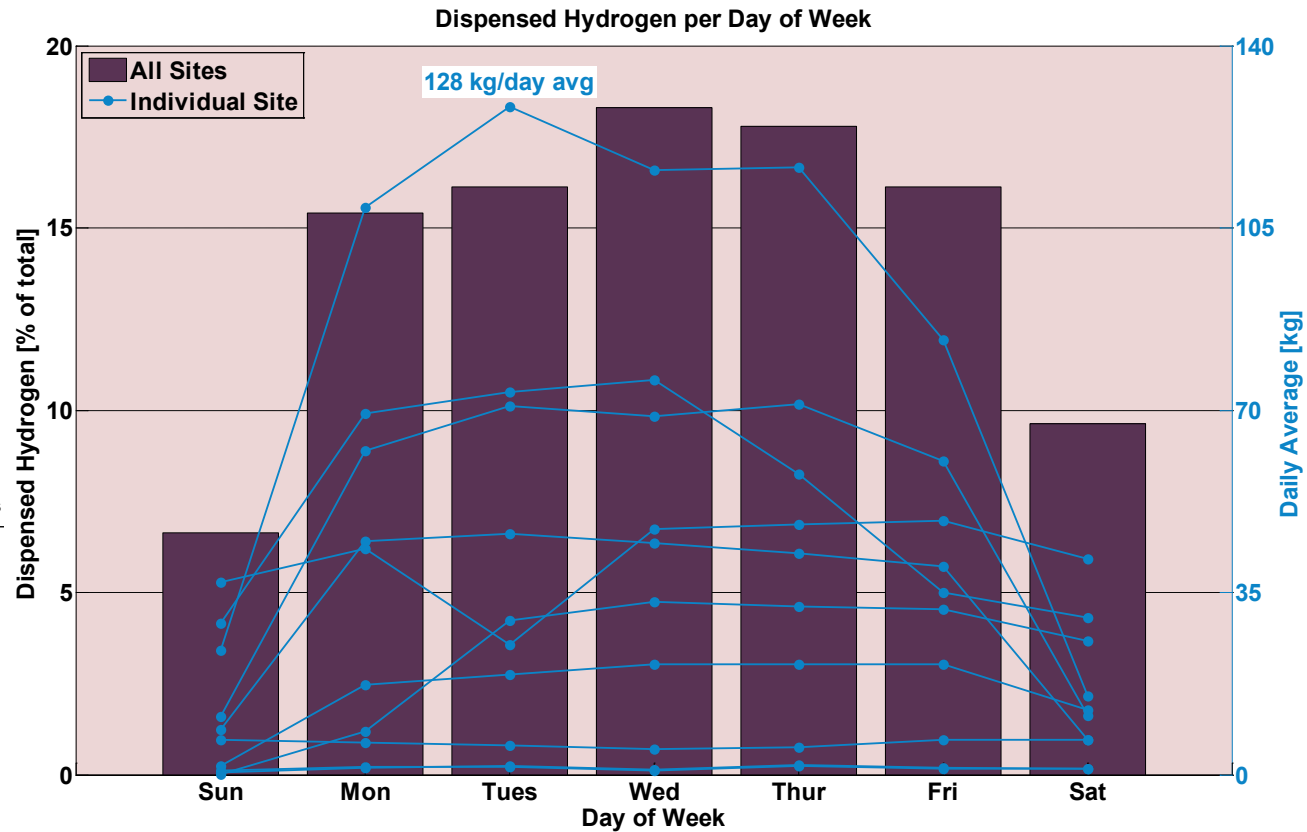
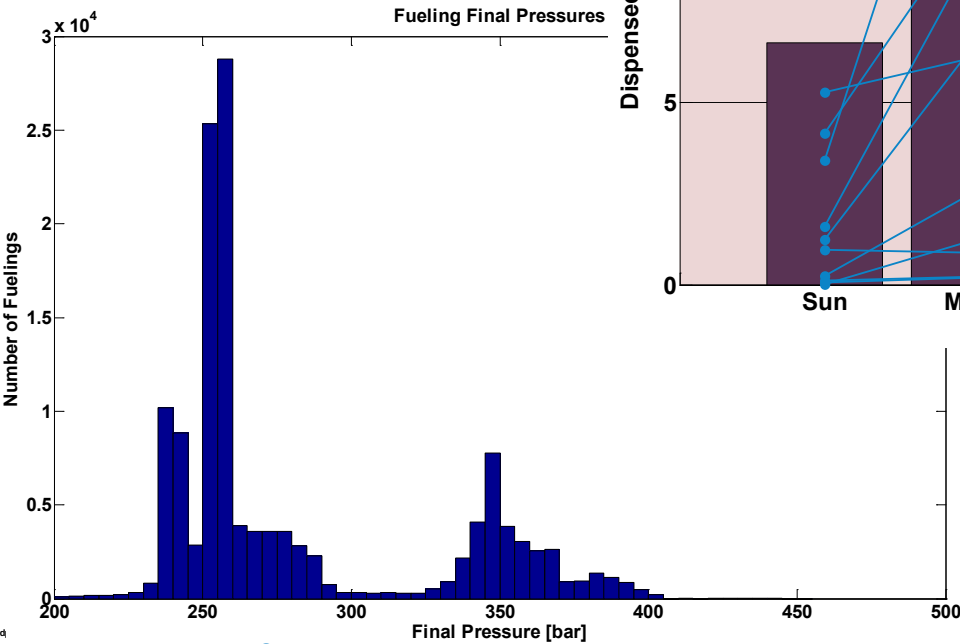
Average of 1,800 kg dispensed per safety report with only 4 incidents. Of the 56 Near Miss safety reports, 27 were from the hydrogen compressor category.

classified<sup>1</sup> events

# Infrastructure Operation - Accomplishment



Infrastructure consistently delivering 250 and 350 bar fills even though the majority of the sites have a MTBF of 10 days or less. One site is delivering more than 115 kg/day on average for 4 days a week.



CDP-MHE-42, 48, & 62

Updated & new since 05/2011

# Collaborations

## *Data Sharing & 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

## *Safety, Codes, and Standards*

- Technical Monitor of Hydrogen Safety Panel reviews of ARRA projects
  - Review of safety plans for each site
  - Conduct safety review site visits for up to 6 sites (3 MHE & 1 Backup site visits completed)
- Quantitative Risk Assessment Data Input
  - Jeff LaChance (Sandia National Lab)
  - Carl Rivkin (NREL)

# Future Work

## ***Remaining FY12 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 2012
  - Update existing set of 74 existing 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
- Conduct 1 hydrogen safety panel site visit
- Support ARRA market impact study through aggregated data sharing

## ***Beyond FY12:***

- Continue quarterly analysis and bi-annual technical CDPs under Technology Validation
- Close collaboration with key stakeholders to identify valuable analyses for technology status updates and metrics important to the value proposition

# Technical Summary – *What We've Learned*



## Fuel Cell Backup Power

- Operating reliability in 15 states with 99.7% successful starts.
- Maximum continuous run time of 29 hours due to an unplanned grid outage.



## Fuel Cell Material Handling Equipment

- Operating with an average availability of >98% at 8 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 cost for refueling labor and infrastructure space but much greater cost for hydrogen infrastructure and fuel.

Aggregated data showcases growth 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.

# 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. Aggregated data for concise reporting on large data sets from multiple project partners.

**Accomplishments:** 4<sup>th</sup> set of technical CDPs published on performance, operation, and safety for MHE and backup power, with 22 new CDPs added. All results and publications available on NREL's technology validation website that also includes monthly highlights.

**Collaborations and Future Work:** Investigate new analyses of importance to supporting market growth and technology advancement (e.g. backup power value proposition analysis) with the close collaboration of the fuel cell and hydrogen developers and end users.



# Reviewer Only

# Response to Reviewer's Comments

“While much data and information is made available, it would be worth brainstorming how it could be “pushed” out to industry more. Many companies and entities might find this useful, but they do not know that it exists or that it could be relevant.”

- We've initiated an update to NREL's technology validation website to showcase highlights and the ability to subscribe for a newsletter for highlights and analyses updates.
- We are investigating other avenues for sharing highlights such as connecting with trade organizations.

“There is a lack of comparable data for the incumbent technologies.”

- A new analysis on the cost of ownership gathered summary information on battery MHE operation from our project partner experience but this is still not data at the quality or amount of data collected for the fuel cell and hydrogen systems.

# Publications and Presentations

(Since FY11 AMR, newest to oldest, key text in Bold)

1. Kurtz, J., Wipke, K., Sprik, S., Ramsden, T., Ainscough, C., Saur, G., “**Spring 2012 – MHE Composite Data Products:** ARRA MHE Composite Data Products for Data Through 2011 Q4,” Golden, CO: National Renewable Energy Laboratory, published October 2012. (presentation)
2. Kurtz, J., Wipke, K., Sprik, S., Ramsden, T., Ainscough, C., Saur, G., “**Spring 2012 – Backup Power Composite Data Products:** Backup Power Composite Data Products for Data Through 2011 Q4,” Golden, CO: National Renewable Energy Laboratory, published October 2012. (presentation)
3. Kurtz, J., Wipke, K., Eudy, L., Sprik, S., Ramsden, T., “Fuel Cell Technology Demonstrations and Data Analysis,” **Chapter in Hydrogen Energy and Vehicle Systems**, Green Chemistry and Chemical Engineering, CRC Press, April 2012. (book chapter)
4. Kurtz, J., Wipke, K., Sprik, S., Ramsden, T., Ainscough, C., Saur, G., “**Early Fuel Cell Market Deployments: ARRA Quarter 4 of 2011** Composite Data Products,” Golden, CO: National Renewable Energy Laboratory, published February 2012. (presentation)
5. Kurtz, J., Wipke, K., Sprik, S., Ramsden, T., Ainscough, C., Saur, G., “**Early Fuel Cell Market Deployments: ARRA Quarter 3 of 2011** Composite Data Products,” Golden, CO: National Renewable Energy Laboratory, published November 2011. (presentation)
6. Kurtz, J., Wipke, K., Sprik, S., Ramsden, T., Ainscough, C., Saur, G., “**Fall 2011 – MHE Composite Data Products:** ARRA MHE Composite Data Products for Data Through 2011 Q2,” Golden, CO: National Renewable Energy Laboratory, published October 2011. (presentation)
7. Kurtz, J., Wipke, K., Sprik, S., Ramsden, T., Ainscough, C., Saur, G., “**Fall 2011 – Backup Power Composite Data Products:** Backup Power Composite Data Products for Data Through 2011 Q2,” Golden, CO: National Renewable Energy Laboratory, published October 2011. (presentation)
8. Kurtz, J., Wipke, K., Sprik, S., Ramsden, T., Ainscough, C., Saur, G., “**Early Fuel Cell Market Deployments: ARRA Quarter 2 of 2011** Composite Data Products,” Golden, CO: National Renewable Energy Laboratory, published August 2011. (presentation)
9. Kurtz, J., Wipke, K., Sprik, S., T., Ramsden, T., Ainscough, C., Saur, G., “Analysis Results for ARRA Projects: Enabling Fuel Cell Market Transformation,” 2011 U.S. DOE Hydrogen Program and Vehicle Technologies Program **Annual Merit Review and Peer Evaluation Meeting**, Washington, D.C, May 2011. (presentation)