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Analysis Results for ARRA Projects: Enabling Fuel Cell Market Transformation

2011 DOE Annual Merit Review

J. Kurtz, K. Wipke, S. Sprik, T. Ramsden, C. Ainscough, G. Saur

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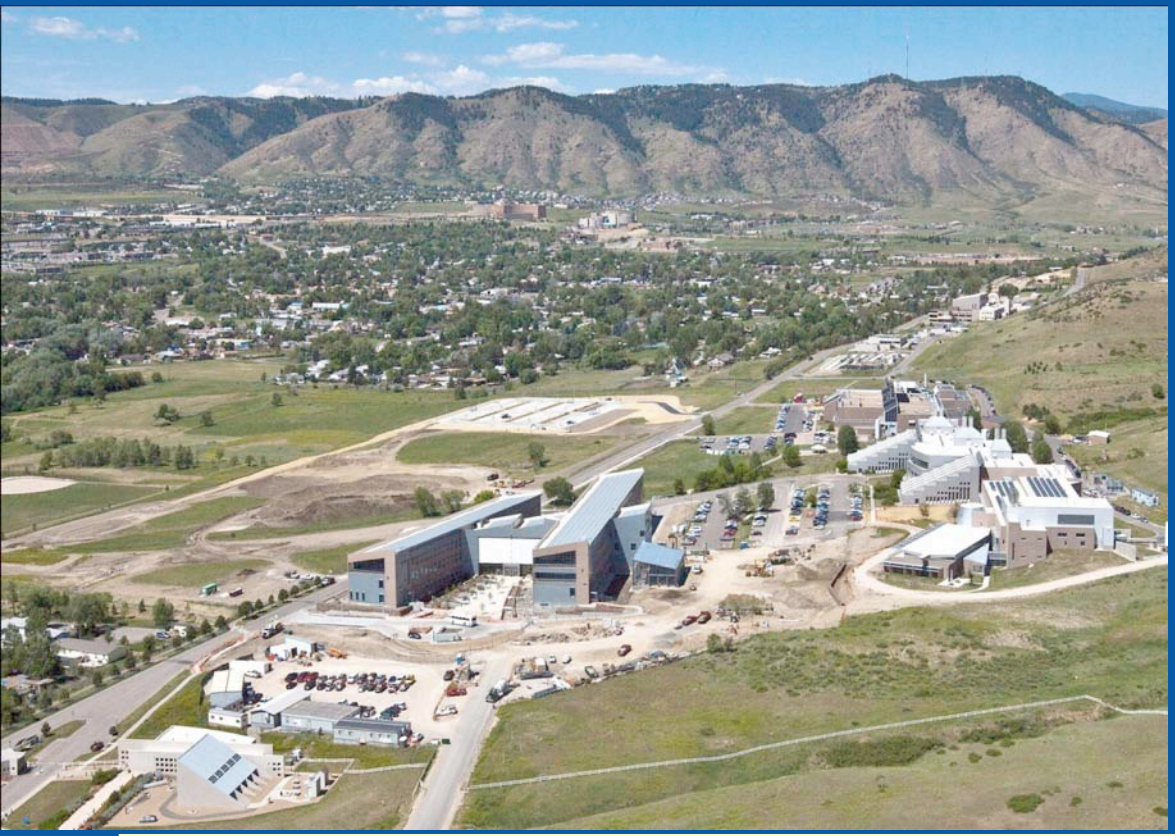
Analysis Results for ARRA Projects: Enabling Fuel Cell Market Transformation



2011 DOE Annual Merit Review

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

5/12/2011

Project ID: H2RA013

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Overview

Timeline

Project Start Date: August 2009

Project End Date: October 2011*

Percent Complete: 75%

Barriers

Commercialization of fuel cells in key early markets.

Budget

Total Project Funding

DOE share: $1,000k

Contractor share: $287k

Funding Received in FY09: $260k

Funding Received in FY10: $740k

Funding Received in FY11: $0k

Partners

See Collaboration slide

*Project continuation and direction determined annually by DOE

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 for early fuel cell markets.

- 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
- 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
- Early Fuel Cell Markets
  - Material handling equipment, backup power, portable power, and stationary power.
  - Analysis includes up to 1,000 fuel cell systems deployed with ARRA funds

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

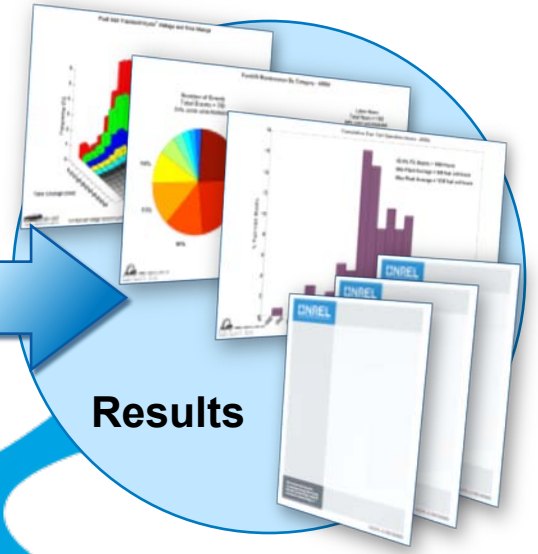
Hydrogen Secure Data Center - Approach

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

Internal analysis completed quarterly

HSDC

NREL's Hydrogen Secure Data Center



DDPs

CDPs

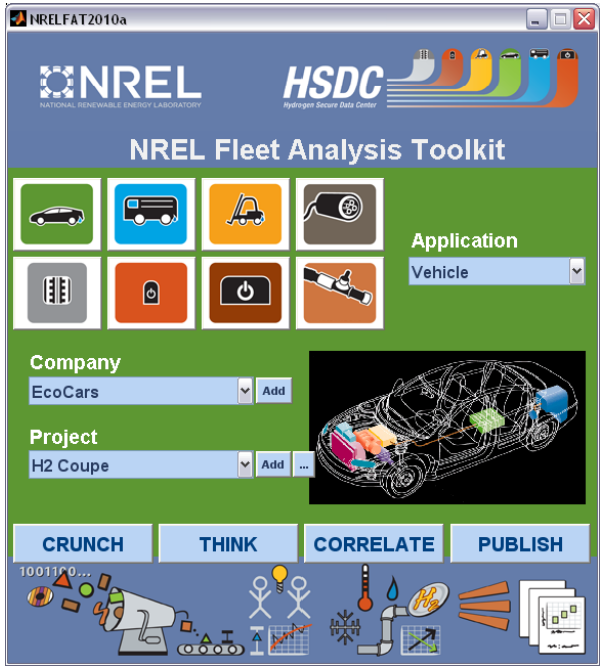
Detailed Data Products (DDPs)
- Individual data analyses
- Identify individual contribution to CDPs
- Only shared with partner who supplied data every 6 months[1]

Composite Data Products (CDPs)
- Aggregated data across multiple systems, sites, and teams
- Publish analysis results without revealing proprietary data every 6 months[2]

1) Data exchange may happen more frequently based on data, analysis, and collaboration
2) Results published via NREL Tech Val website, conferences, and reports

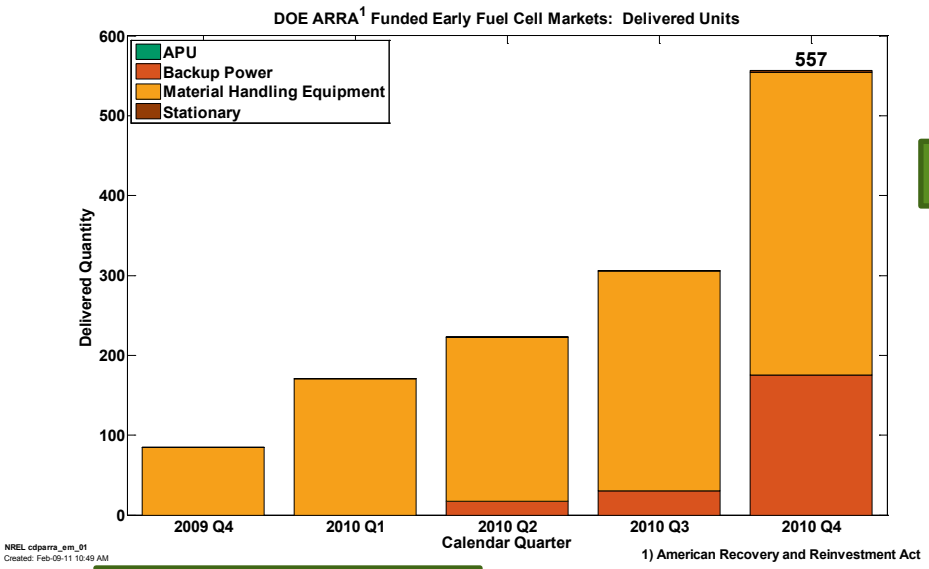
Analysis – Approach & Accomplishment

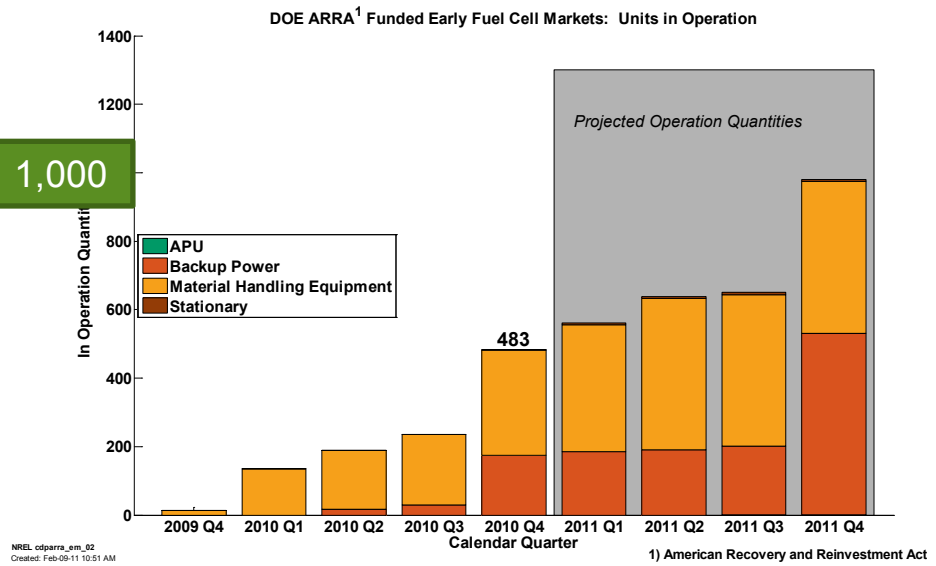
- NREL Fleet Analysis Toolkit (NRELFAT)
  - Developed first under fuel cell vehicle Learning Demonstration
  - Expanded to include material handling, backup power, and stationary power
  - Restructured architecture and interface to effectively handle new applications and projects and for analyses flexibility



- 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 community and end users

Deployment CDPs Updated Quarterly - Accomplishment

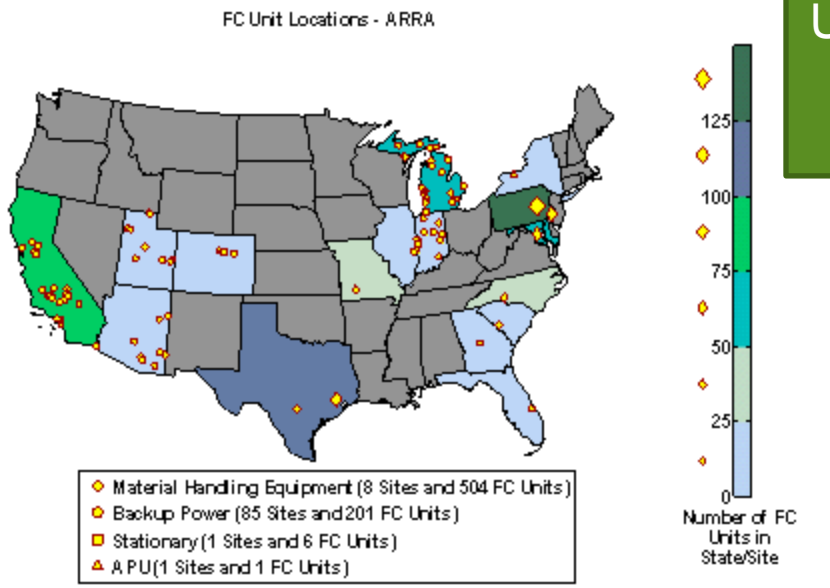




Delivered Units by Quarter & Application

Units in Operation by Quarter & Application

Location by application & unit count



FCMHE 42 CDPs - Accomplishment

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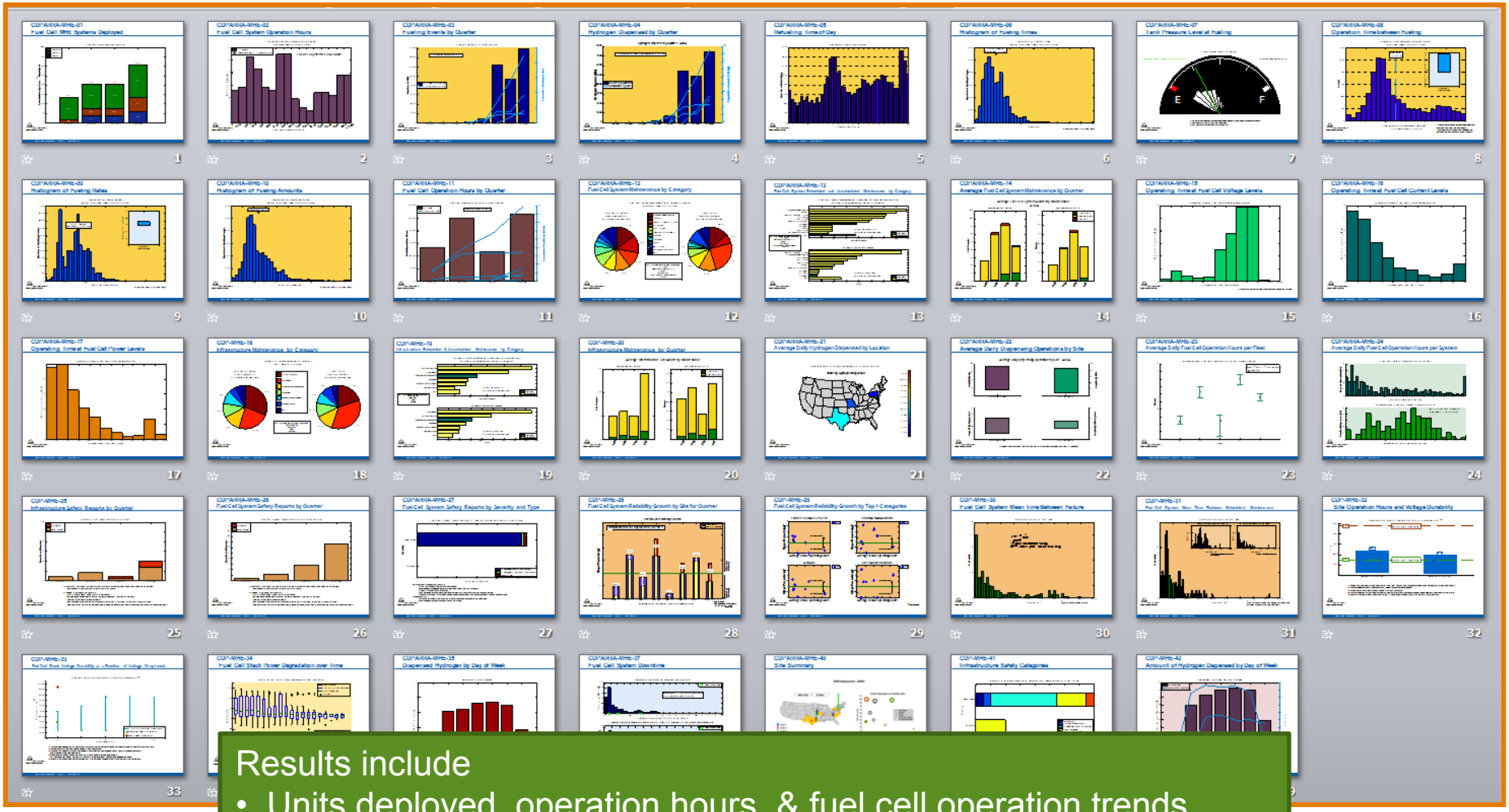


Results include

- Units deployed, operation hours, & fuel cell operation trends
- Hydrogen fill count, amount, time, & rate
- Tank level at fill & downtime from fill
- Fuel cell durability & reliability
- Fuel cell and infrastructure maintenance events & safety reports

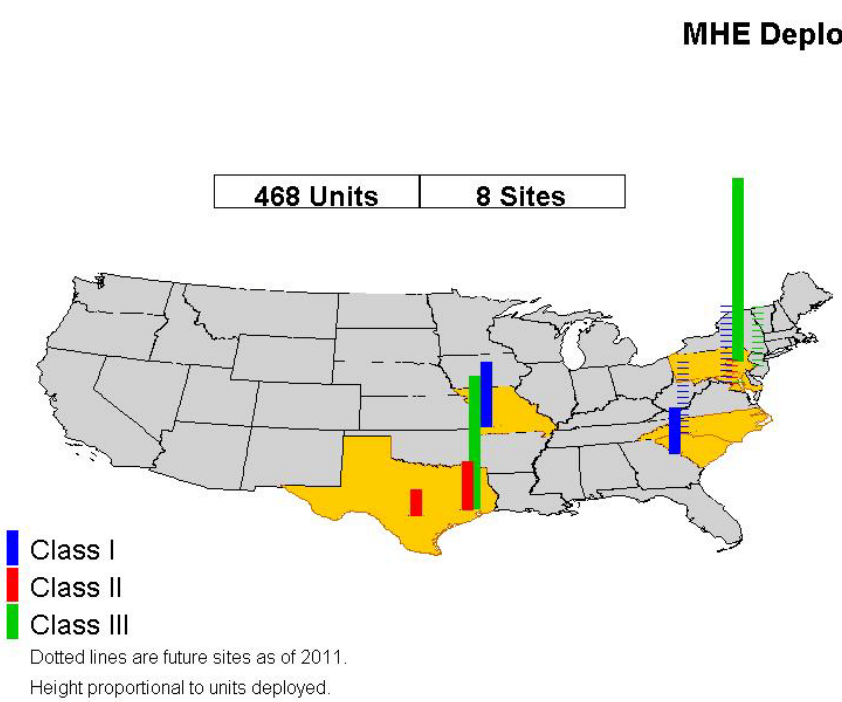
Summary of FC MHE Operation - Accomplishment

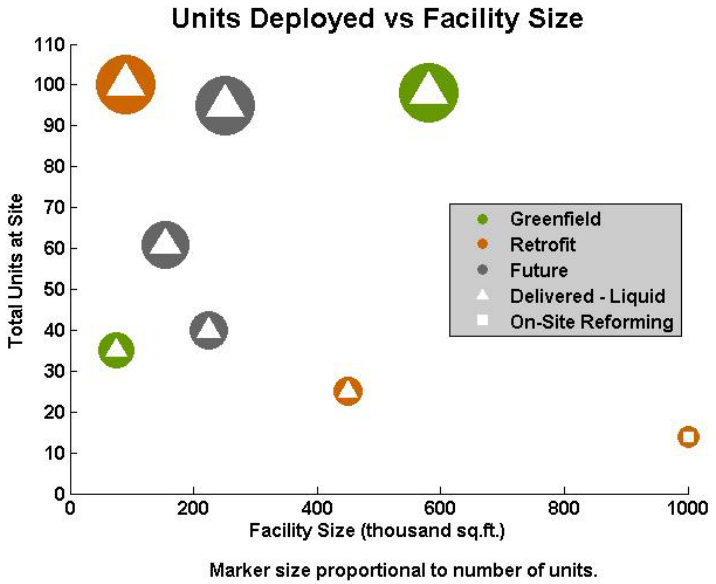
Sites	5	CDPARRA-MHE-#
Units in Operation (60 Class 1, 76 Class 2, 172 Class 3)	308*	01
Hours Accumulated	307,433 hrs*	11
FC Systems > 2360 hrs	25%*	02
Hydrogen Dispensed	18,597 kg*	04
Hydrogen Fills	38,863*	03
Average Fill Amount	0.48 kg/fill*	10
Average Fill Time	1.8 min/fill*	06

FCMHE operating at end user facilities, accumulating many hours and hydrogen fills safely, and already showing productivity improvements.

*Through December 2010

Summary of the ARRA MHE Sites - Accomplishment





Forklift Units (I,II,III)	0,26,72	0,14,0	35,0,0	25,0,0	45,14,2	0,36,100	40,0,0	0,25,70
Operation								
Shifts per Day	2	2	3	1-2	3	2	2	3
Hours per Shift	8-10	9.5	8	10	8	8-10	8	8
Days per Week	6	N/A	N/A	7	7	6	6	6

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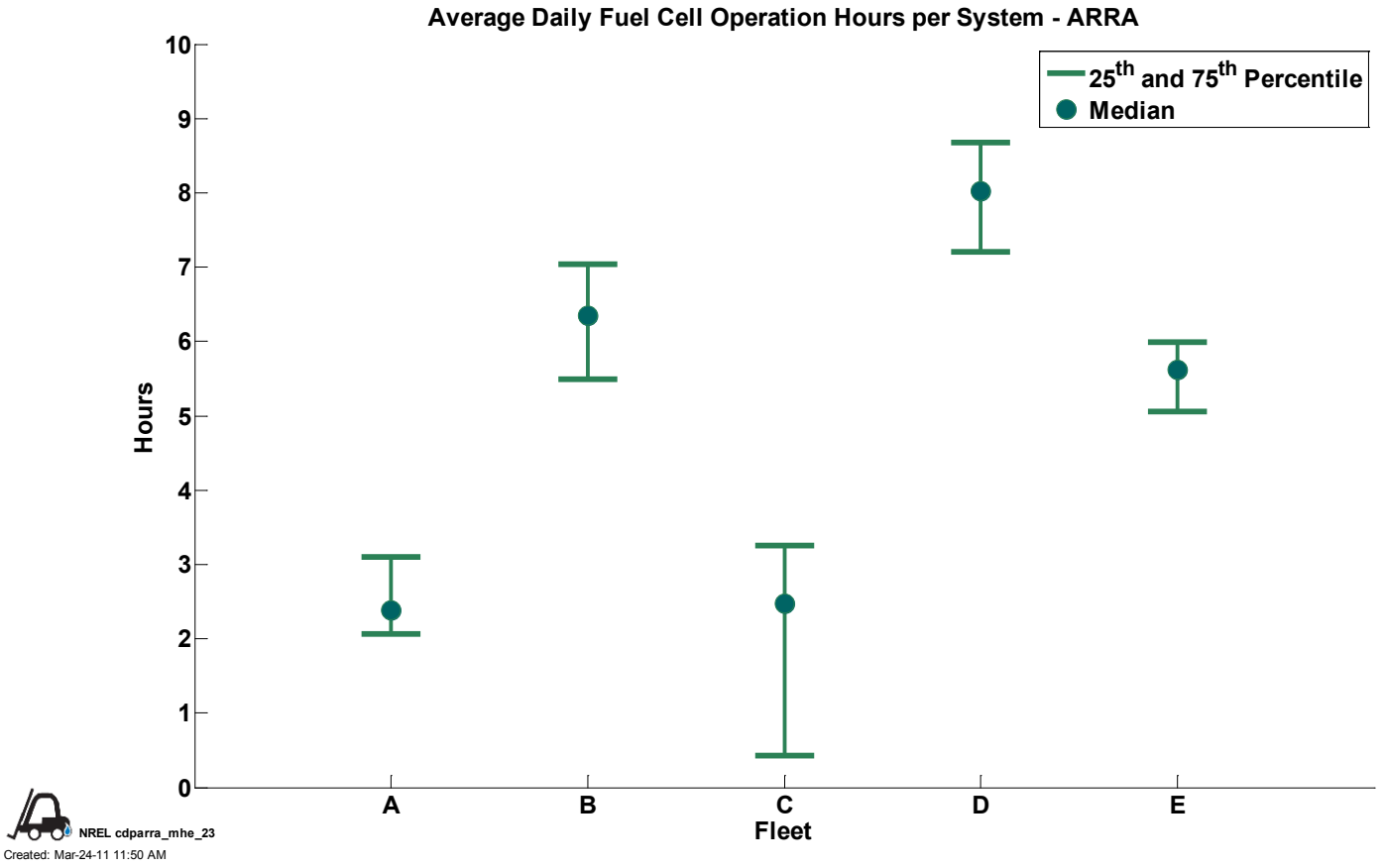
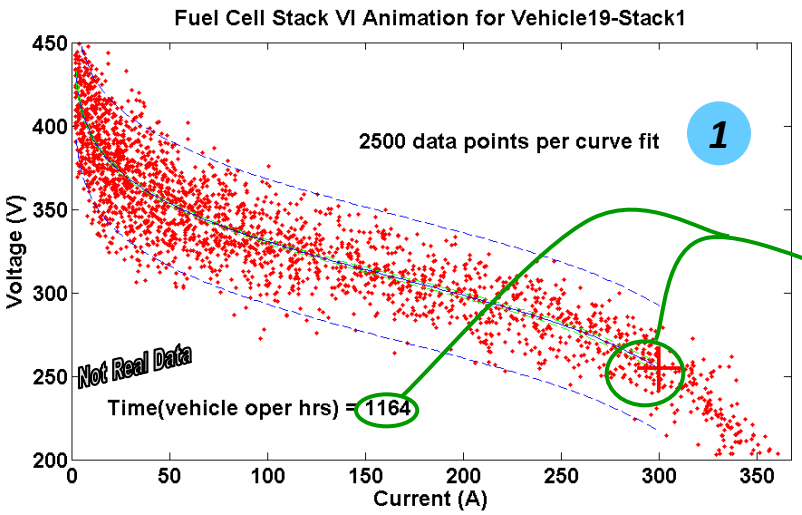
Of the 8 sites
- Most use delivered liquid hydrogen
- Mix of greenfield and retrofit sites
- Some utilize more than one class of truck

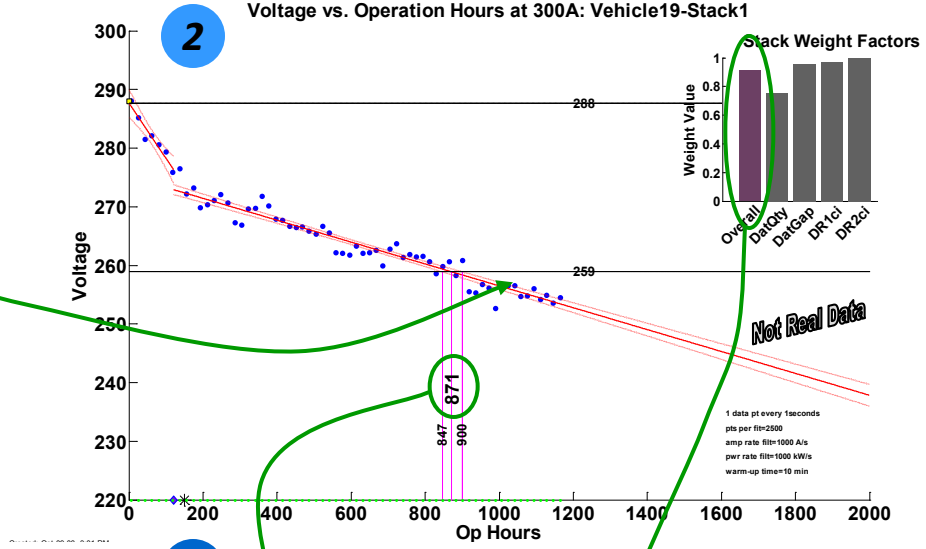
Study of Site Specific Operation Trends - Accomplishment

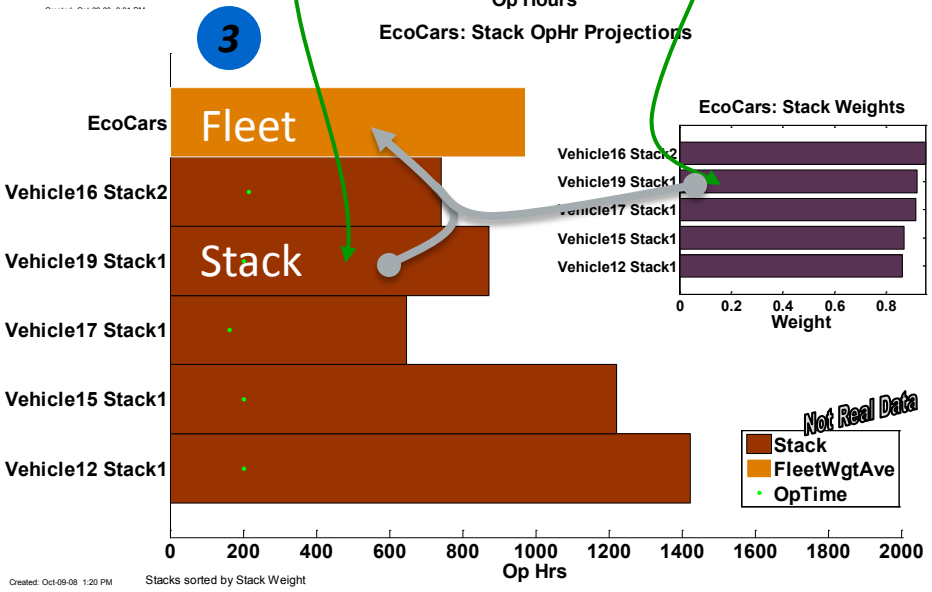


- Range of average daily operation hours per system per fleet is 2-8
- Average demonstrated operation time between fills is 5 hours (Ref: CDPARRA-MHE-08)
- Average daily fills per system per fleet is 0.5 – 0.9 (Ref: CDPARRA-MHE-22)

Method for Calculating Projected Time to 10% Voltage Drop for Stack and Fleet - Approach





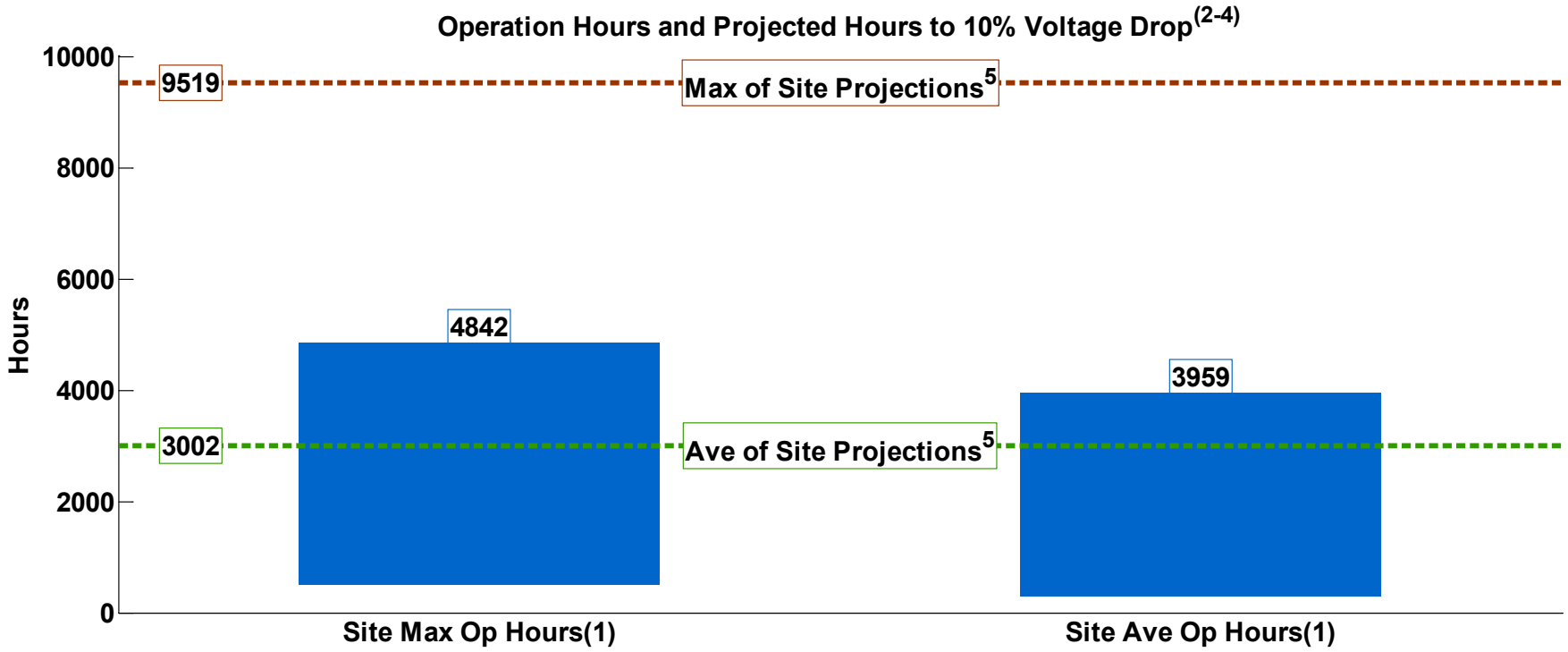


1. ***FC Stack*** voltage & current polarization fit
2. ***FC Stack*** voltage decay estimate using an adaptable **segmented linear fit** instead of linear fit (follows non-linear decay trends & early voltage decay)
3. ***Fleet*** weighted average using FC Stack operating hour projections and weights (based on data and confidence in fit)

Note, 10% voltage drop is a DOE metric, not an indicator of end-of-life

Consistent analysis method applied to all data

Analysis of Voltage Durability - Accomplishment



(1) Range bars created using one data point for each fleet. Some stacks have accumulated hours beyond 10% voltage degradation.
(2) 10% voltage drop level is a DOE metric for assessing fuel cell performance.
(3) Projections using field data and calculated at a high stack current.
(4) 10% voltage drop is NOT an indication of an OEM's end-of-life criteria and projections do not address catastrophic stack failure.
(5) Each site has one voltage projection value that is the weighted average of the site's fuel cell stack projections.

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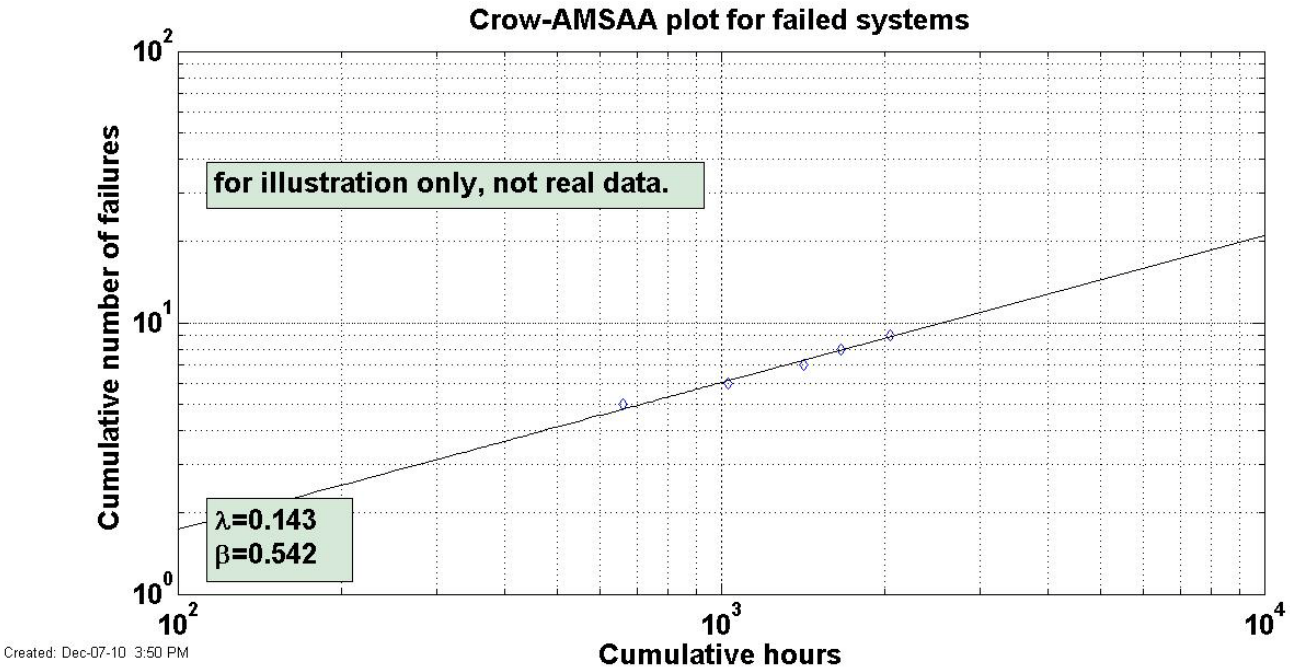
Each site has a weight average time to 10% voltage drop
- Average of the sites is 3002 hours
- Maximum of the sites is 9519 hours

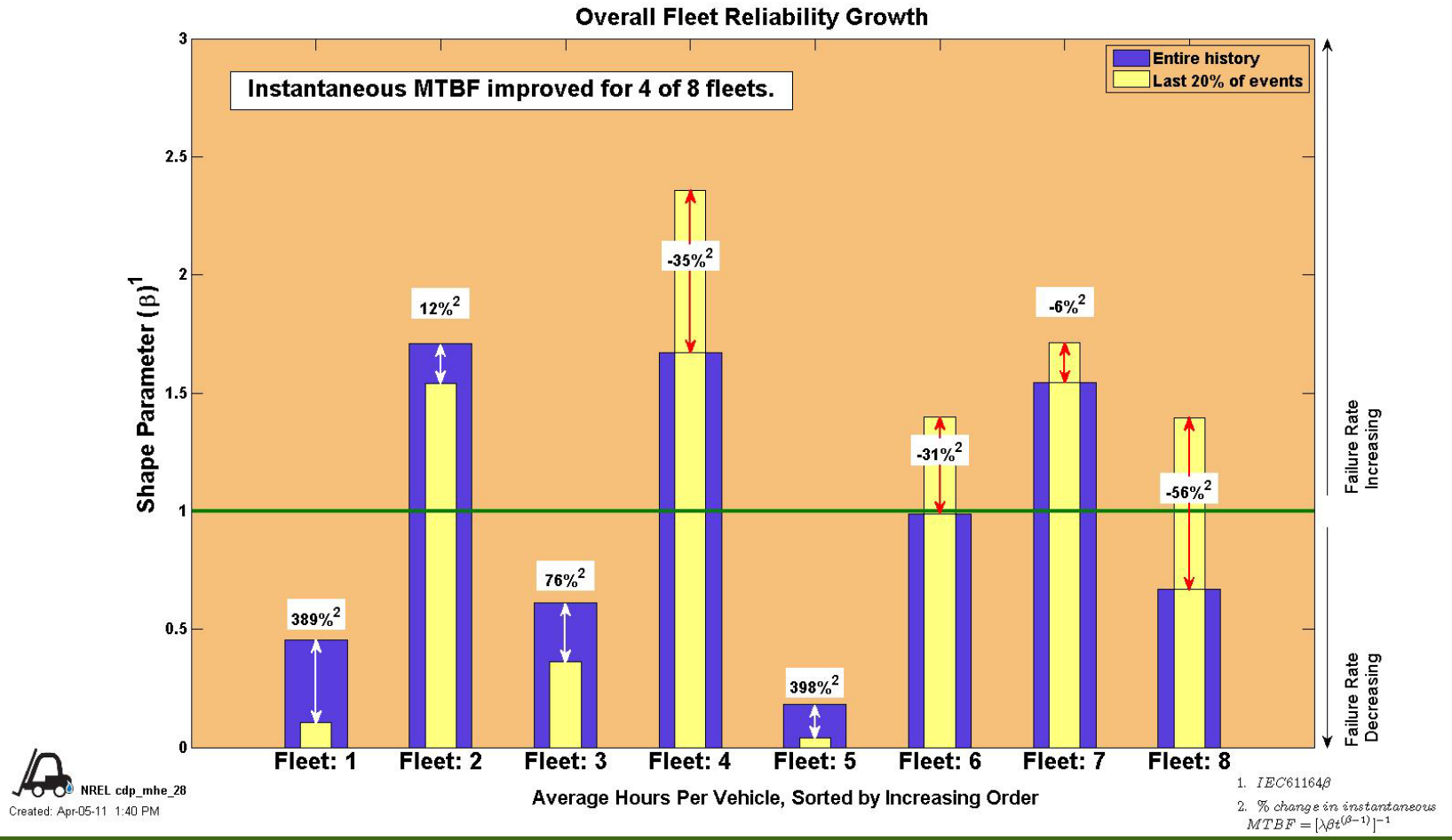
Fuel Cell System Reliability Analysis - Approach

- Failure events (i.e. unscheduled maintenance records) are tracked per unit and per fleet
- Crow-AMSAA analysis method[1,2]
- Study failure rates (e.g Shape Parameter > 1 is an increasing failure rate)
- Highlight common failures per category and unit
- Tracks progress and reliability predictions



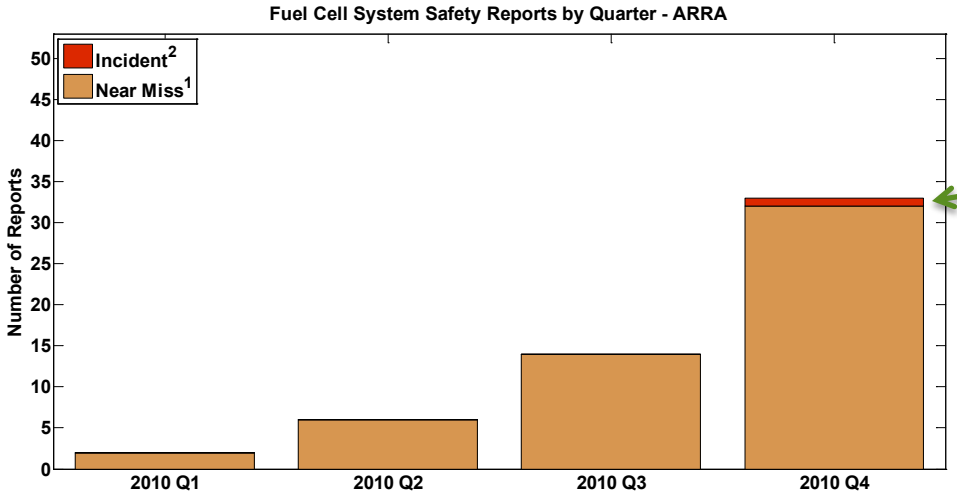
1. *The New Weibull Handbook*, 5th ed., Robert Abernethy, (2007)
2. *IEC 61164:2004, Reliability Growth – Statistical Estimation Methods*, International Electrotechnical Commission, (2004)

Site Reliability Growth - Accomplishment



- 5 Fleets have a steady or decreasing failure rate overall, but 2 of those fleets have experienced an increasing failure rate for the last 20% of events.
- Failure rate is also studied by failure category (Ref: CDP-MHE-29)
- 25% of the systems have a MTBF of <= 100 hours (Ref: CDP-MHE-30)

Tracking Safety Reports - Accomplishment



1) Near Miss is an event that under slightly different circumstances could have become an incident
-unplanned H2 release insufficient to sustain a flame

2) Incident is an event that results in:
-a lost time accident and/or injury to personnel
-damage/unplanned downtime for project equipment, facilities or property
-impact to the public or environment
-any hydrogen release that unintentionally ignites or is sufficient to sustain a flame if ignited
-release of any volatile, hydrogen containing compound (other than the hydrocarbons uses as common fuels)

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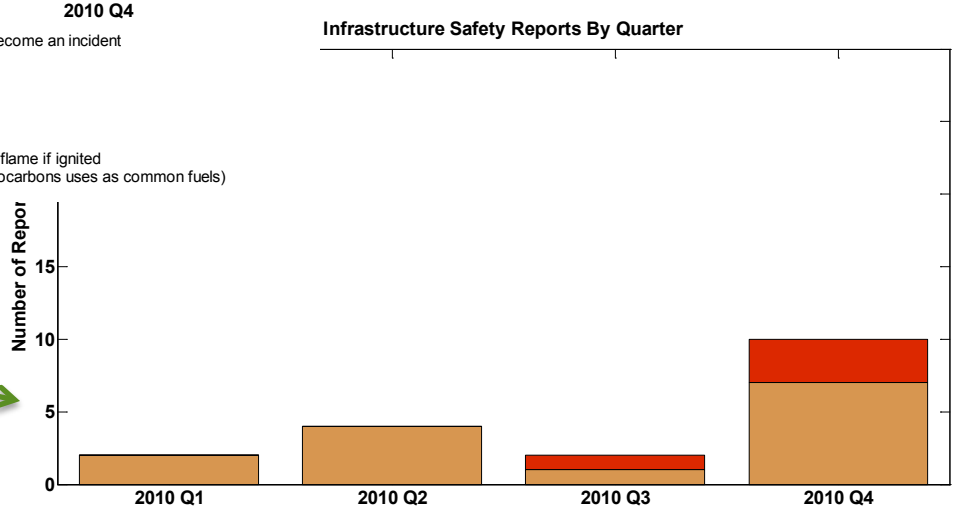
- 308 systems, 307,433 operation hours with 54 safety reports categorized as Near Miss and 1 Incident
- 94% of safety reports are classified as Minor Hydrogen Release (Ref: CDPARRA-MHE-27)
- 1 Incident classified as Significant Hydrogen Release – No Ignition

- 75,364 fills (ARRA & DLA projects) with 18 safety reports categorized as Near Miss
- 4 safety incidents are classified as Non-Hydrogen Release (Ref: CDP-MHE-41)



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-any hydrogen release that unintentionally ignites or is sufficient to sustain a flame if ignited
-release of any volatile, hydrogen containing compound (other than the hydrocarbons uses as common fuels)

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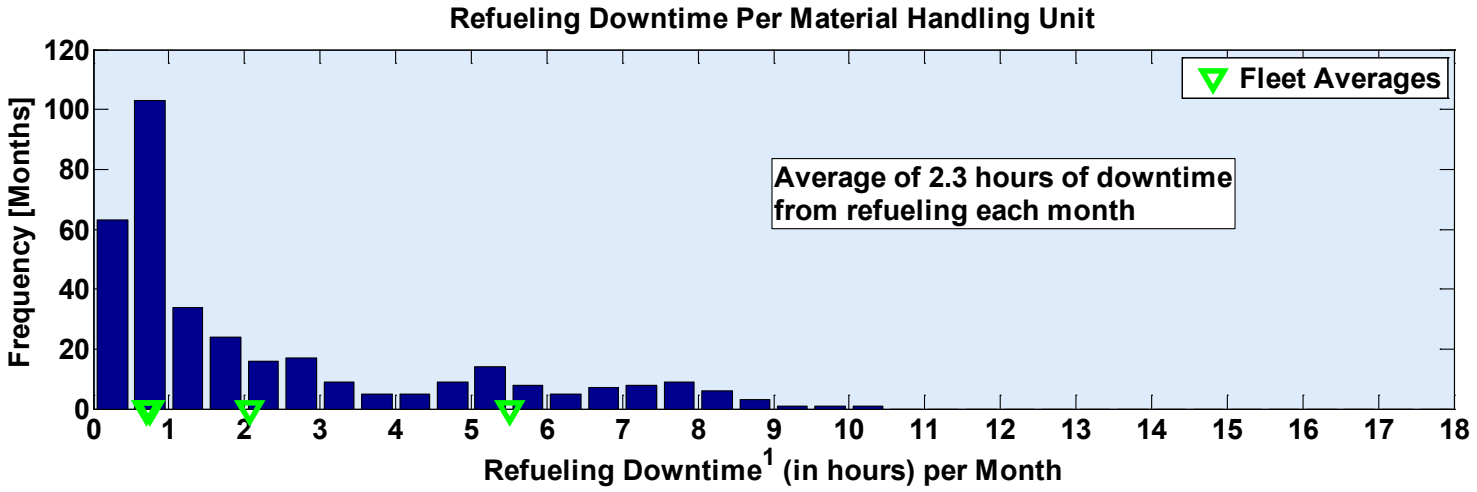
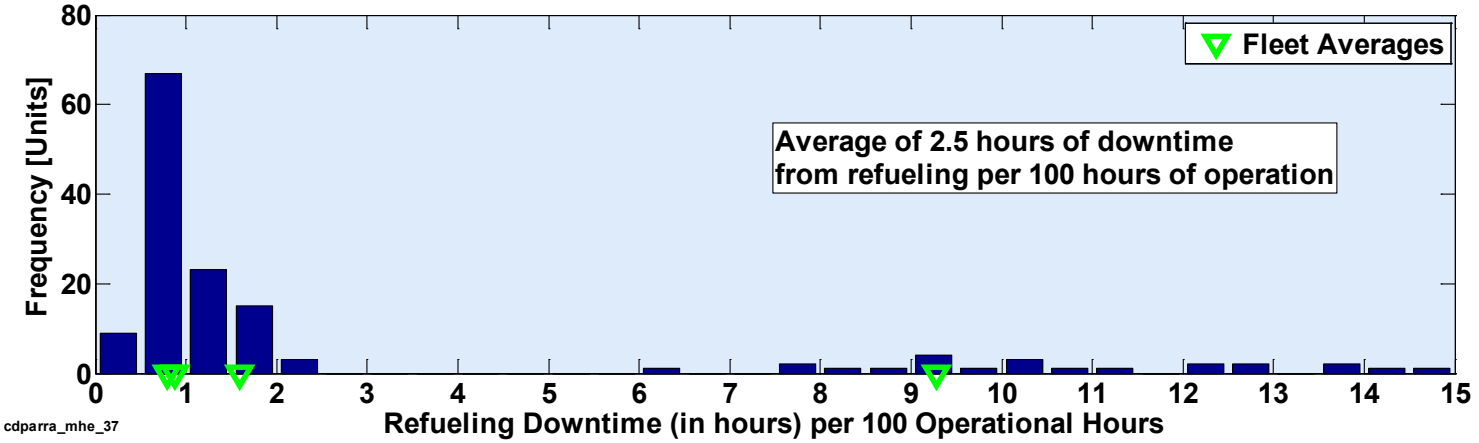
Demonstrated Refueling Downtime per Month and 100 Hours of Operation - Accomplishment

- Studied refueling downtime per month and per 100 hours of operation
- Average 2.3 hours each month or 2.5 hours per 100 op hrs
- Downtime represents time from “drive-up” to “drive-away”



[1] Refueling downtime represents total refueling time from "drive-up" to "drive-away" not only hydrogen gas dispensing time



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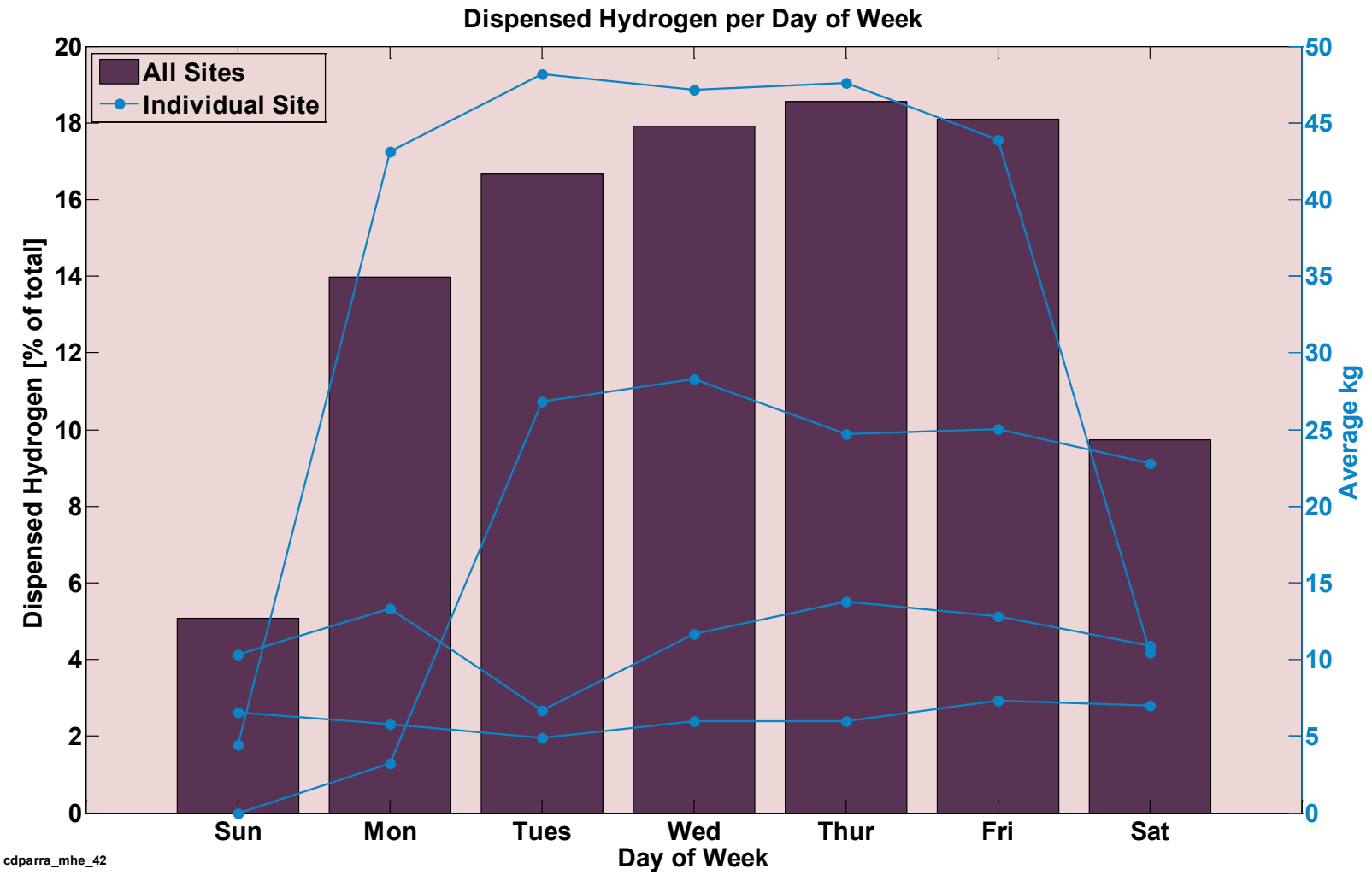
Note: Some refueling events not recorded/included due to data noise or incompleteness

Refueling Trends by Day of Week and Site - Accomplishment



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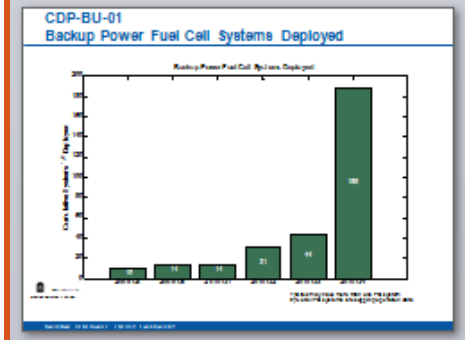
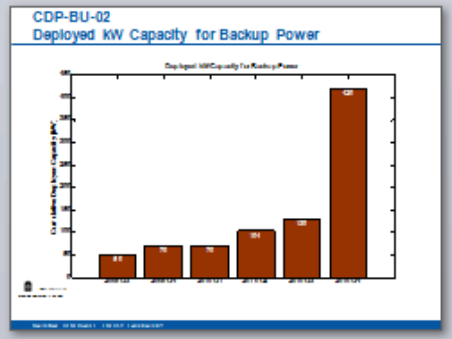
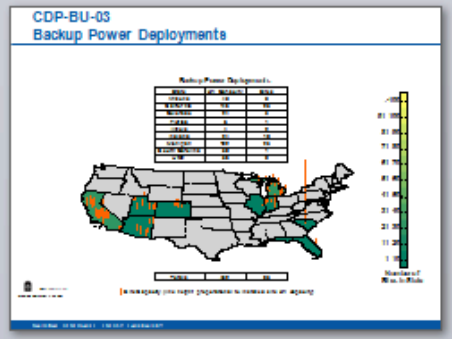
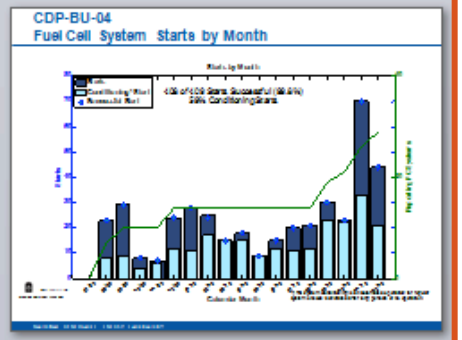
- Most of the dispensed hydrogen is Monday – Friday
- Individual site dispensing is fairly consistent Monday - Friday

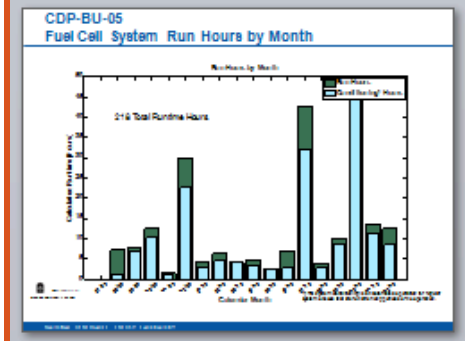
FC Backup Power 10 CDPs - Accomplishment

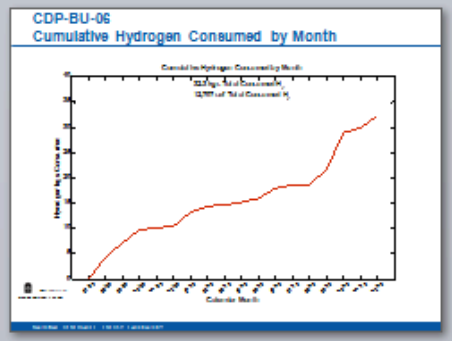


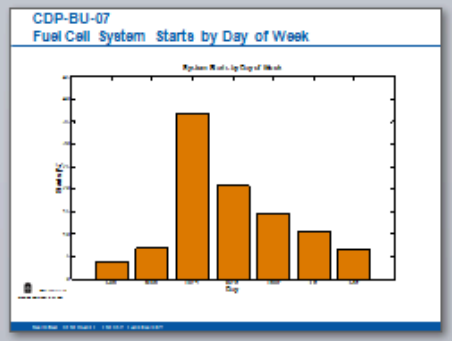


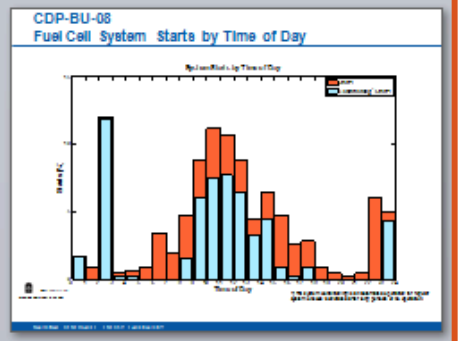


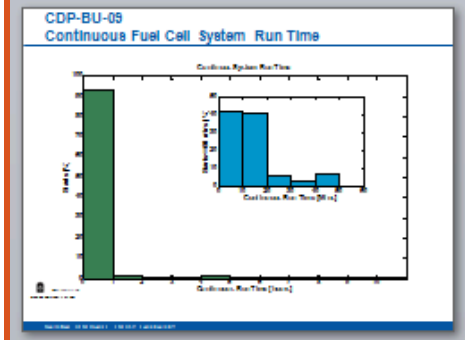


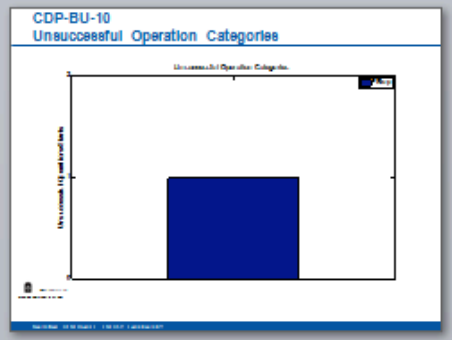












Results include

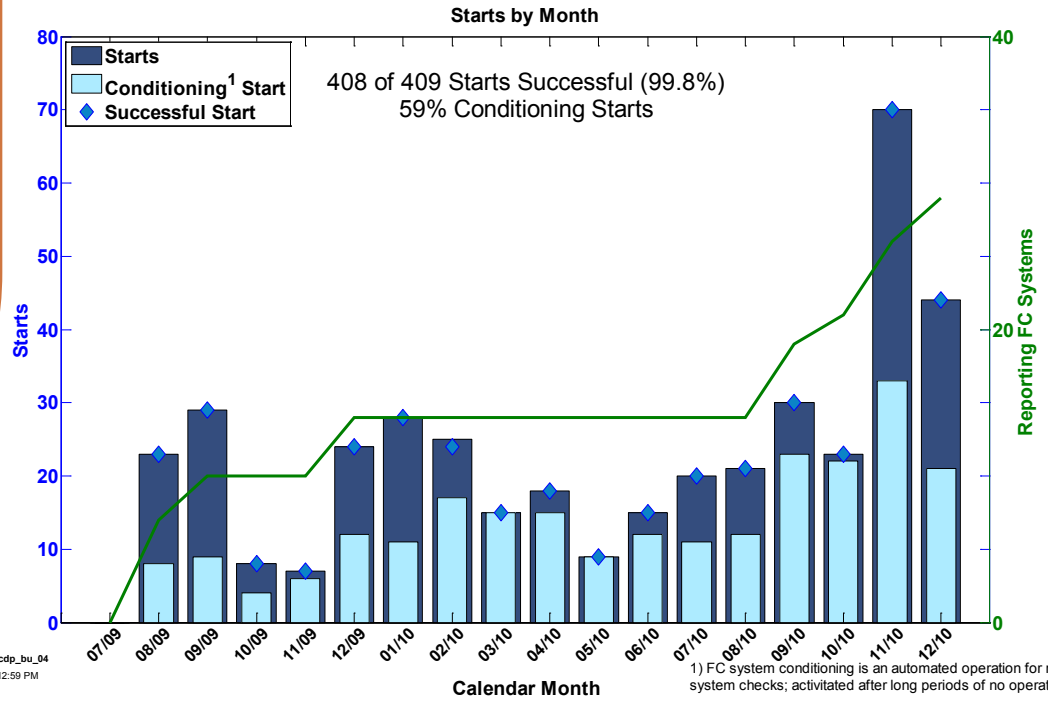
- Units deployed & deployed kW capacity
- Starts, hours, & continuous runtime
- Reasons for unsuccessful starts
- Hydrogen consumed
- Start trends by day of week & time of day

Summary of Backup Power System Operation - Accomplishment

Sites	*85*	*CDP-BU-#*
Deployed Systems	189*	01
Total Successful Starts	408 (99.8%)*	04
Total Run Time	218 hours*	05
Total Hydrogen	32.3 kg*	06

Key Performance Metrics

Reliability
Low Emissions
Low Noise
Ease of Use
Remote Monitoring



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

* Through December 2010

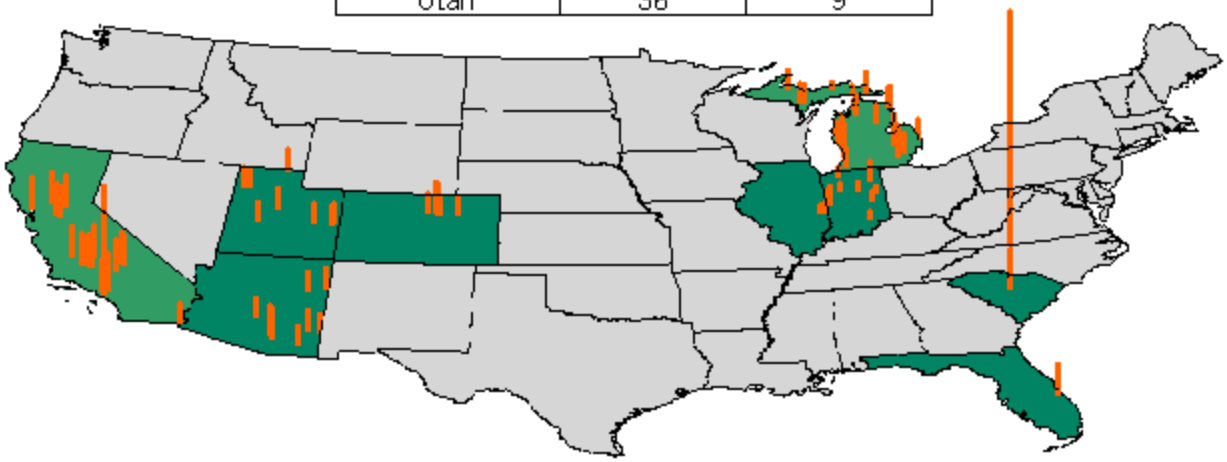
Site Location and Capacity - Accomplishment

BACKUP POWER

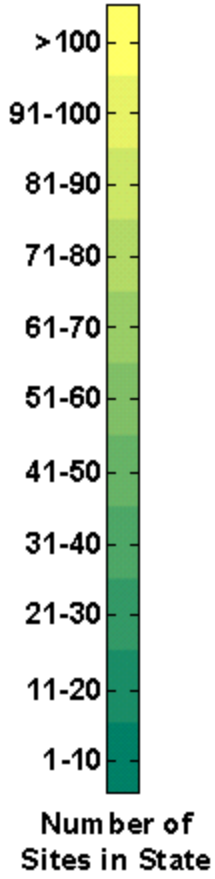
9 states with backup power sites

Backup Power Deployments

State	kW Capacity	Sites
Arizona	40	9
California	146	23
Colorado	24	5
Florida	6	1
Illinois	4	2
Indiana	24	10
Michigan	102	25
South Carolina	50	1
Utah	36	9



Totals	432	85



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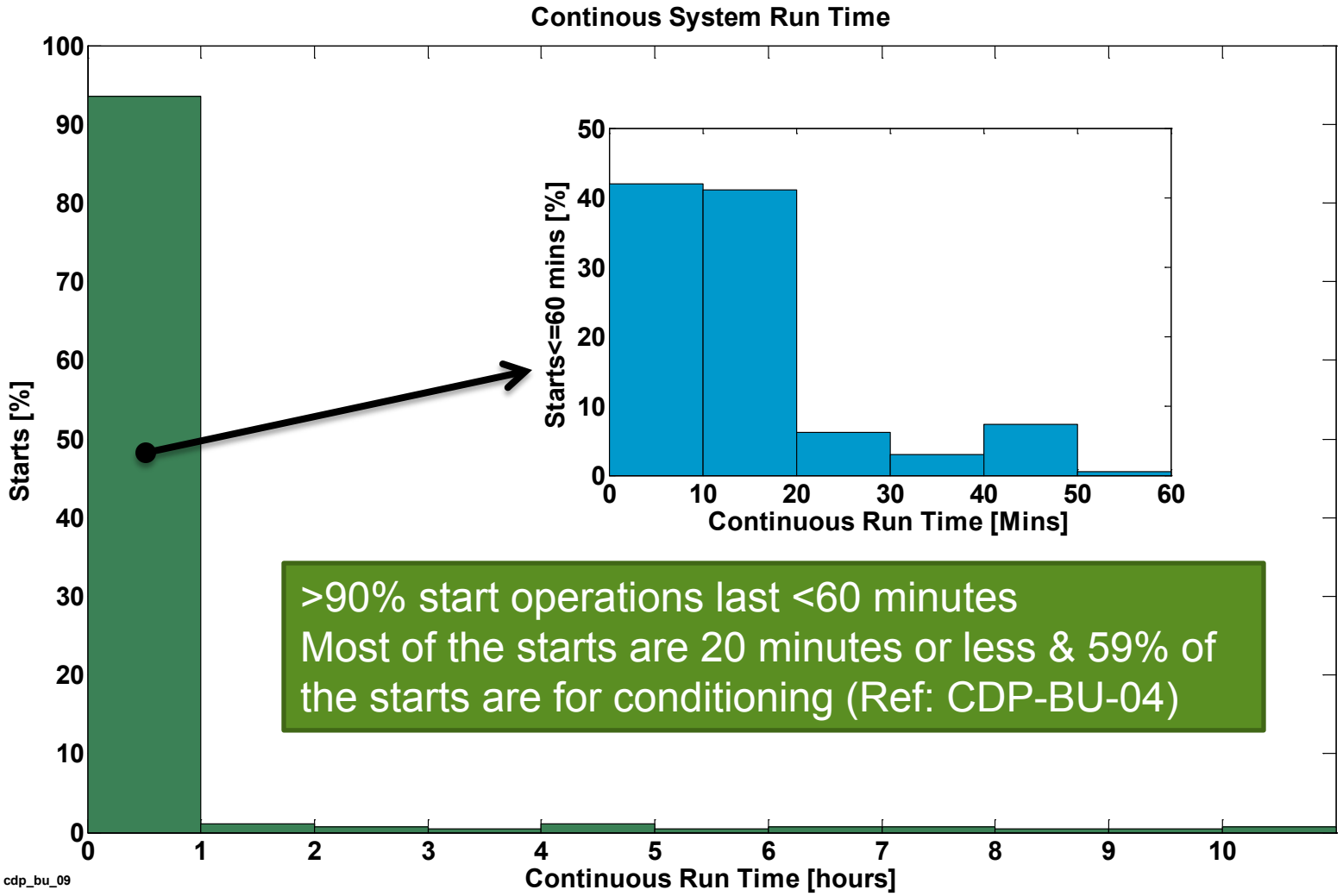
Site Capacity (line height proportional to installed site kW capacity)

Demonstrated Continuous Run Time - Accomplishment



Collaborations

Data Sharing & Analysis Partners

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

Other collaboration activities include site visits and detail 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 (2 MHE site visits completed)
- Quantitative Risk Assessment Data Input
  - Carl Rivkin (NREL)
  - Jeff LaChance (Sandia National Lab)

Future Work

Remaining FY11 tasks:

- Quarterly deployment composite data products (2 cycles)
- Quarterly analysis of operation and maintenance data for fuel cell systems and hydrogen infrastructure (2 cycles)
- Bi-annual technical composite data products for data through June 2011
  - Update existing set of 42 existing CDPs
  - Add to the CDPs pertaining to the market value proposition performance metrics
- Conduct 2 hydrogen safety panel site visits

Beyond FY11:

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

Summary

- Deployment CDPs (3) updated quarterly
- Two cycles of technical CDPs for material handling and backup power
  - 42 MHE specific CDPs
  - 10 Backup Power specific CDPs
- Conducted 2 safety panel site visits, 3 site visits, and 2 partner facility visits
- New, application specific analysis include continuous runtime, reliability, downtime, and durability
- All of the published results can be found at:

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

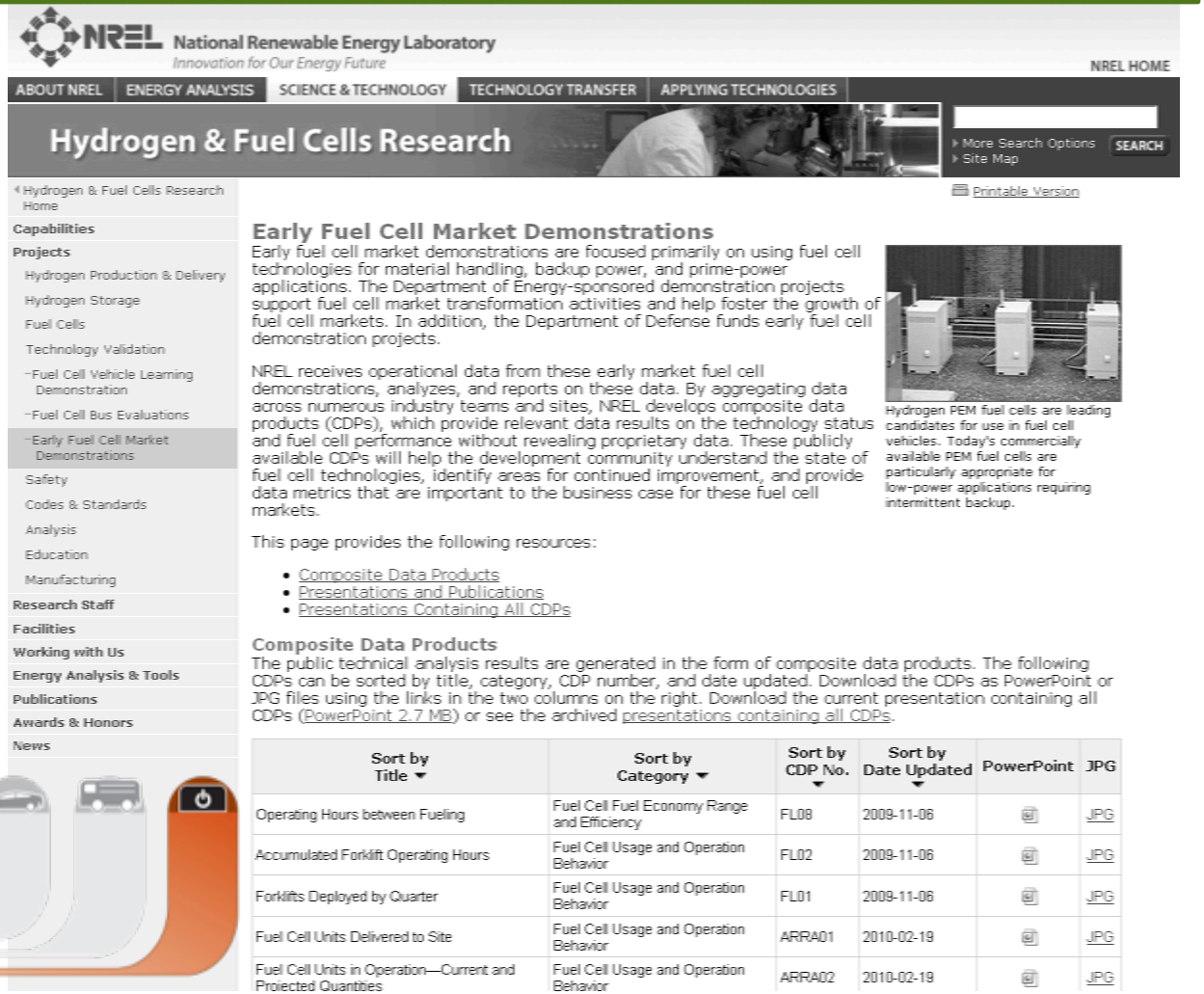
BACKUP POWER **Sites**	**85**	**CDP-BU-#**
Deployed Systems	189*	01
Total Successful Starts	408 (99.8%)*	04
Total Run Time	218 hrs*	05
Total Hydrogen	32.3 kg*	06

FORKLIFTS **Sites**	**5**	**CDPARRA-MHE-#**
Units in Operation (60 Class 1, 76 Class 2, 172 Class 3)	308*	01
Hours Accumulated	307,433 hrs*	11
FC Systems > 2360 hrs	25%*	02
Hydrogen Dispensed	18,597 kg*	04
Hydrogen Fills	38,863*	03
Average Fill Amount	0.48 kg/fill*	10
Average Fill Time	1.8 min/fill*	06

* Through December 2010

Contact Information & Website

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



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