MT004

Direct Methanol Fuel Cell Material Handling Equipment Deployment

2012 DOE Annual Merit Review
Crystal City, VA

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May 16, 2012

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Overview

Timeline

- Start: June, 2010
  - Contract Award February, 2011
- Finish: December, 2012
- 65% Complete

Budget

- Total Project Funding: $2.4M
  - Deployment Project: $2.3M
  - Oorja: $1.4M cost share (60%)
- FY10 Funding: $1M
  - $80K for project mgmt & analysis
- FY11 Funding: $0
- FY12 Funding: $110K
  - For NREL project mgmt & analysis

Barriers Addressed

- Non-technical issues preventing full commercialization of fuel cell systems

Partners

- Oorja Protonics
- Demonstration Sites:
  - Unified Grocers
  - Earp Distribution
  - Testa Produce

Project Overview & Collaborations

- NREL is partnering with Oorja Protonics on a two-year project to deploy and demonstrate direct methanol fuel cells (DMFCs) to provide power for Class III pallet jacks in four commercial wholesale distribution centers
  - Project awarded following competitive solicitation
  - Oorja built and is maintaining DMFC systems for Class III MHE at customer sites and is providing real-world data to NREL
  - NREL providing data analysis and performance assessment
- Lifts are deployed in commercial food distribution warehouses operated by:
  - Unified Grocers
  - Testa Produce
  - Earp Distribution

Photo courtesy of Oorja Protonics

Project Background

- **Fuel cells can offer lower total cost of ownership in material handling applications compared to battery systems**
  - Battelle Early Fuel Cell Markets study found that fuel cells can lower total cost of ownership of MHE compared to batteries
  - DOE and NREL are currently evaluating the use of hydrogen PEM fuel cells in MHE applications
  - Considering all costs, NREL estimates that H2 PEM fuel cell Class III MHE can yield $700 in annual savings per lift compared to traditional battery MHE
- **DMFCs hold promise to deliver many of the same operational benefits of hydrogen PEM fuel cell MHE**
  - Notably, long runtimes, short refueling times, increased productivity
- **Liquid fuels like methanol offer reduced infrastructure costs**

Project Objectives

- Deploy and test fuel cell-powered MHE using methanol in direct methanol fuel cells
- Compile operational data of DMFC fuel cells and validate their performance under real world operating conditions
    - Provide independent technology assessment focusing on fuel cell system and infrastructure performance
    - Validation efforts will help illuminate the market viability of DMFC technologies used in material handling applications
- Longer term: help transform the market for fuel cells in material handling applications and provide information to help replicate successful deployments

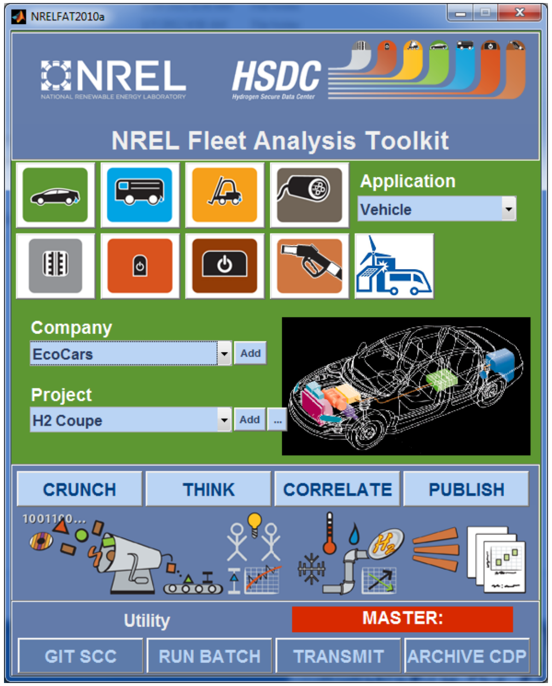
Project Overview

- **Oorja Protonics is operating and maintaining 75 DMFC-based Class III pallet jacks operating in four commercial wholesale distribution centers**
  - 15-month deployment at each site
  - Two shifts per day, 6 days per week
  - Expect 3,500–5,000 total operation hours on each unit
- **Detailed tracking of DMFC system performance**
  - MHE data loggers capture dozens of system parameters 10 times each minute for each DMFC system
  - Data collected by Oorja and compiled by NREL
- **NREL is compiling and analyzing data from the project**
  - Provide a third-party assessment of the performance of DMFCs for material handling equipment

Photo courtesy of Oorja Protonics

Data Analysis Using NRELFAT & HSDC

- **Analyze fuel cell system performance**
  - Data from many systems & operating conditions
- **Establish a baseline of real-world operations**
- **Use NREL's Fleet Analysis Toolkit (NRELFAT) for data processing and analysis capabilities**
  - First developed for FCEVs, restructured for new applications
- **Support FC market growth by analyzing technology and performance relevant to the value proposition**



Project Site Operational Data → **NREL HSDC** Data Processing & Analysis → **Results** Completed Data Analyses

Overview of Accomplishments

- **Oorja Protonics has built, delivered, and is maintaining DMFC-based Class III pallet jacks (and supporting methanol infrastructure)**
  - **Oorja is maintaining DMFC systems & collecting operational data**
- **DMFC lifts have operated for 6-12 months of a total 15 month demonstration**
- **NREL is compiling and analyzing operational data**
  - **Data analysis for operations through Dec 2011 complete**

Photos courtesy of Oorja Protonics

OorjaPac™ DMFC Systems Deployed

- **Oorja built and deployed 75 direct-methanol fuel cell systems on Class III pallet jacks using its OorjaPac Model 3 DMFC power pack**
  - All units deployed as of June 2011
- **OorjaPac is a variant of a PEM fuel cell system that uses an anode catalyst to extract hydrogen from the methanol molecule**
- **OorjaPac Model 3 specifications include:**
  - Power output: 1.5kW
  - Output voltage: 24V/36V/48V
  - Methanol tank volume: 12 liters
  - Energy output: 20kWh per tank

Photo courtesy of Oorja Protonics

- **The OorjaPac acts as an on-board battery charger, allowing:**
  - Grid independence
  - Elimination of battery change-outs and quick refueling
  - Increased autonomy (up to 12-14 hours on single refueling)

Methanol Fueling Infrastructure Deployed

- Indoor dispensing via Oorja's OorjaRig™ methanol dispenser
  - OorjaRig designed for indoor methanol fueling of OorjaPac DMFCs
  - Equipped with methanol storage in two standard 55-gallon drums, pumps, safety connect dispenser nozzle, sensors
  - Cabinet is FM-rated for Class 1 Div 2 operation, meets NFPA code
- Bulk methanol outdoor storage in 2,000 gallon UL-rated, double-walled tanks meeting relevant NFPA codes

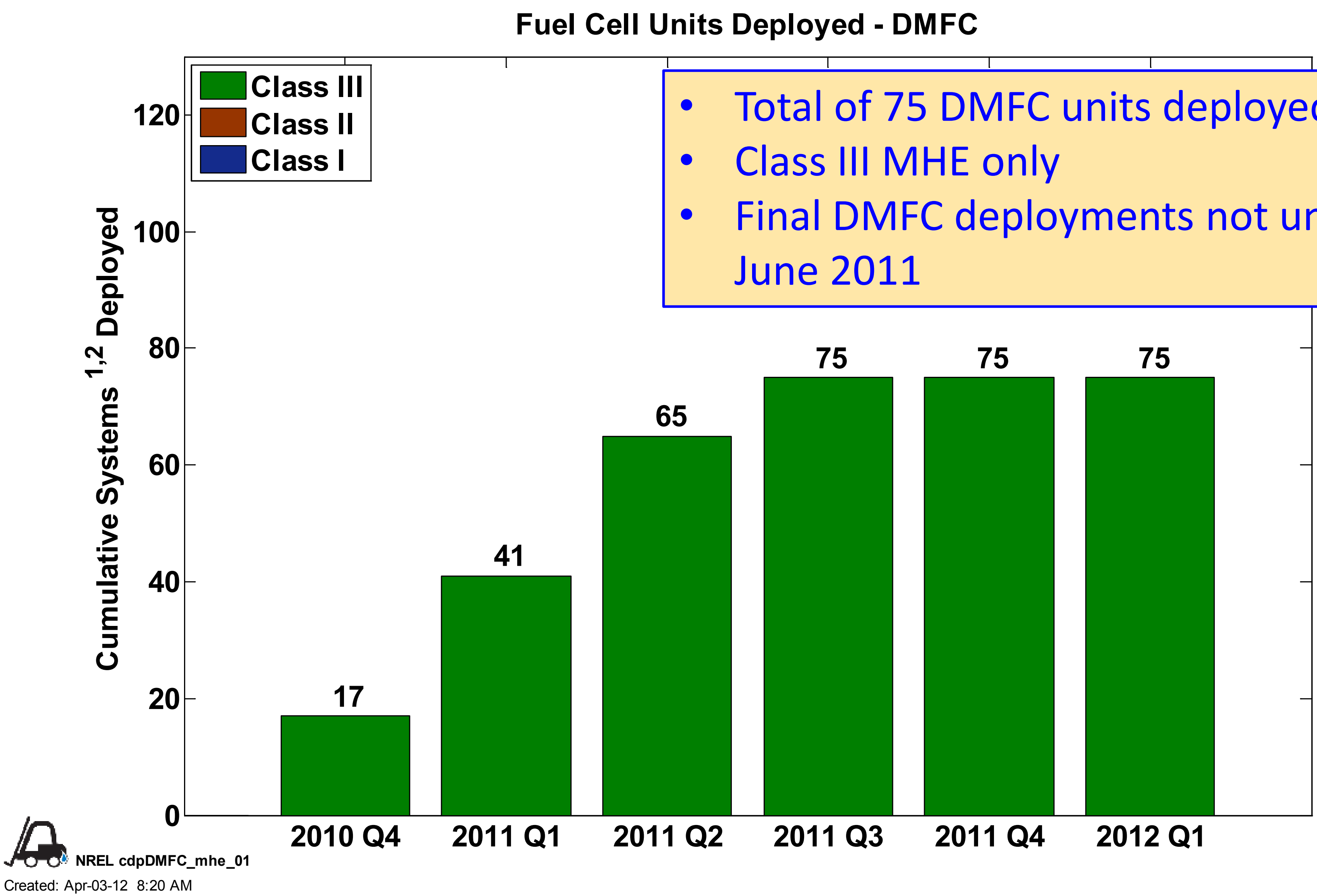
Oorja estimates total infrastructure costs to be about $50K per site[1]

- Hydrogen fueling infrastructure can approach or exceed $1M per site
- NREL analysis of government-funded hydrogen fuel cell MHE deployments found an average annual capital and maintenance cost of $200,000 for hydrogen infrastructure

[1]http://www.oorjaprotonics.com/benefits/ROI.html

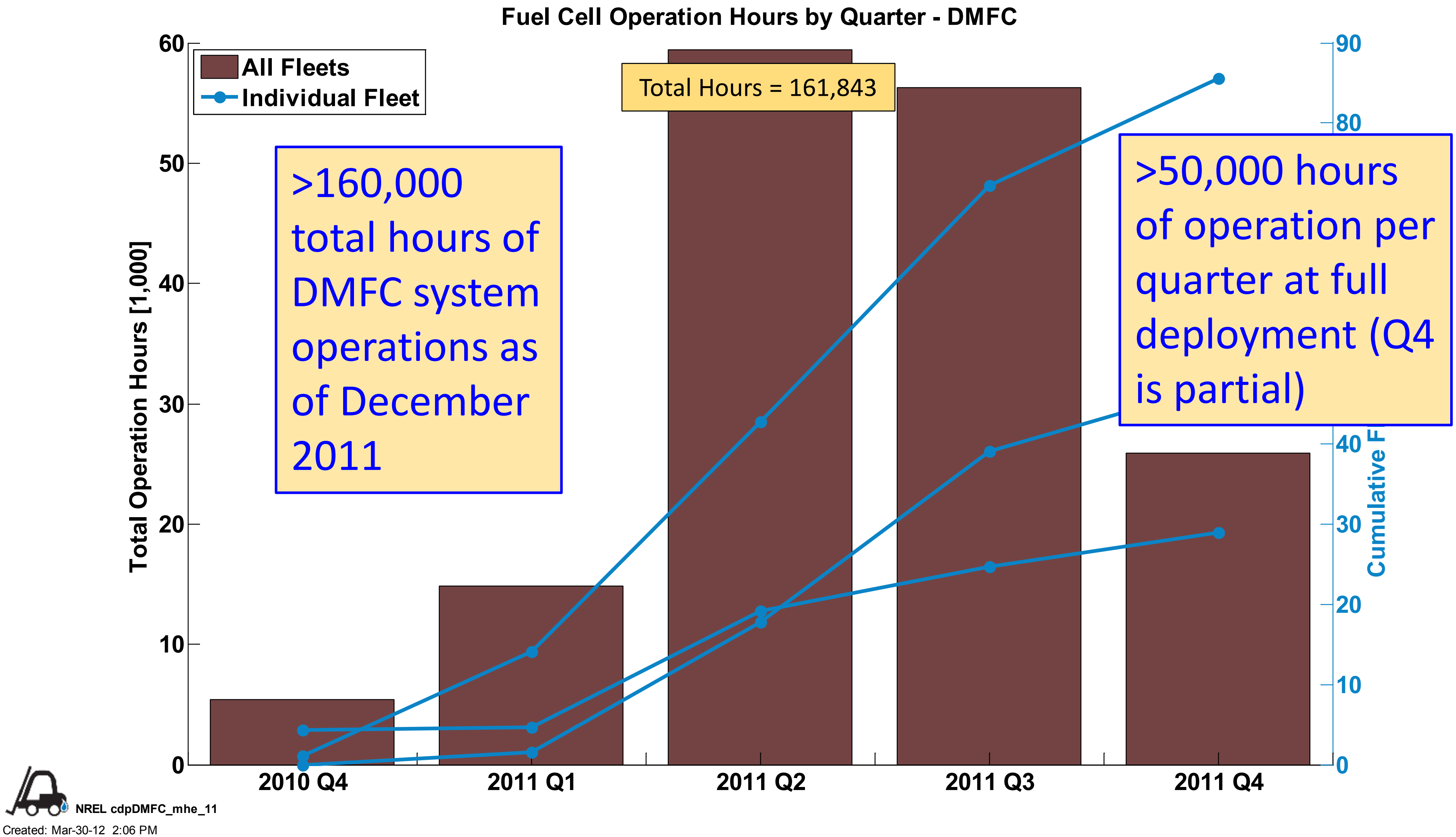
Photo courtesy of Oorja Protonics

Oorja DMFC System Deployments

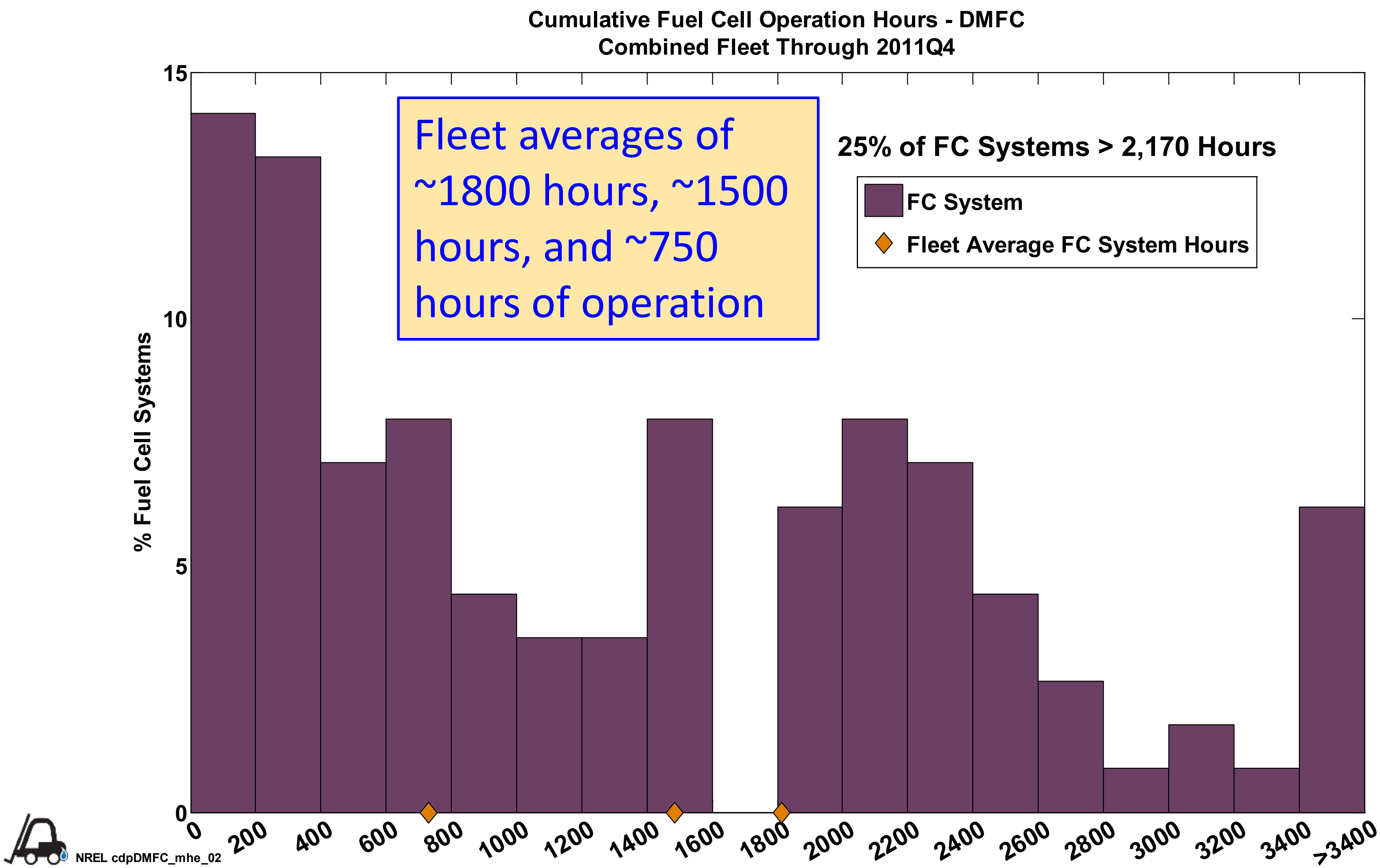


- Total of 75 DMFC units deployed
- Class III MHE only
- Final DMFC deployments not until June 2011

DMFC Operation Hours By Quarter

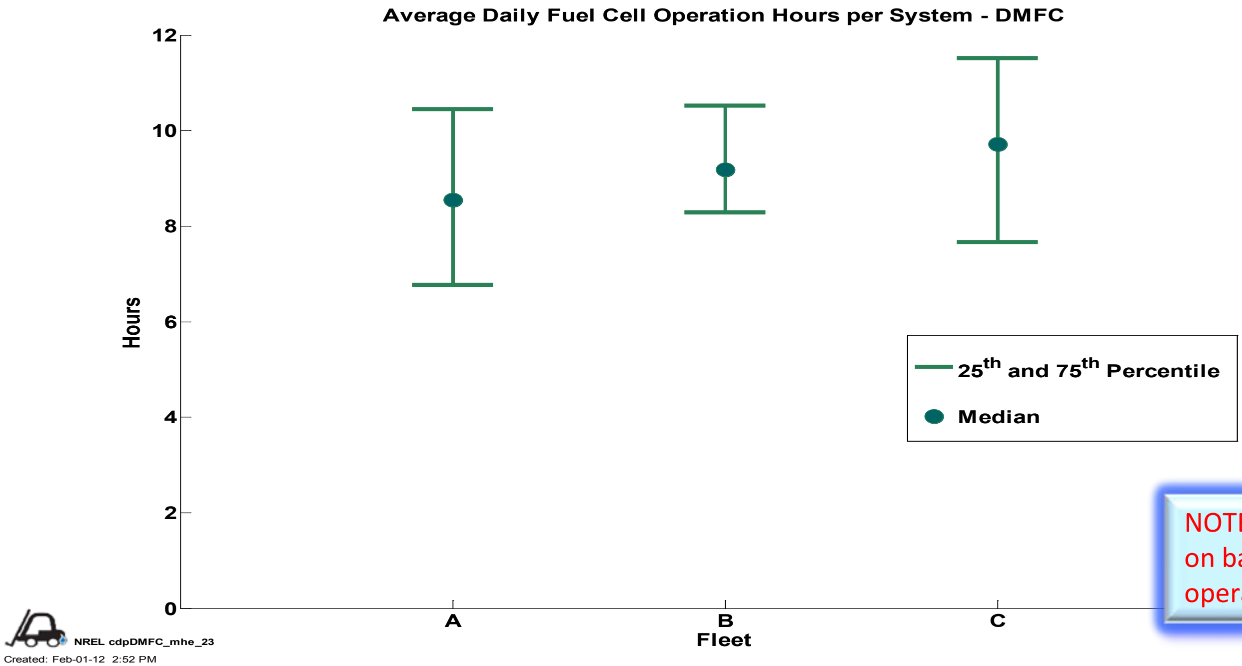


Operation Hours for DMFC Systems



~Half of systems have >1500 hours of operation; 25% of systems >2,170 hours

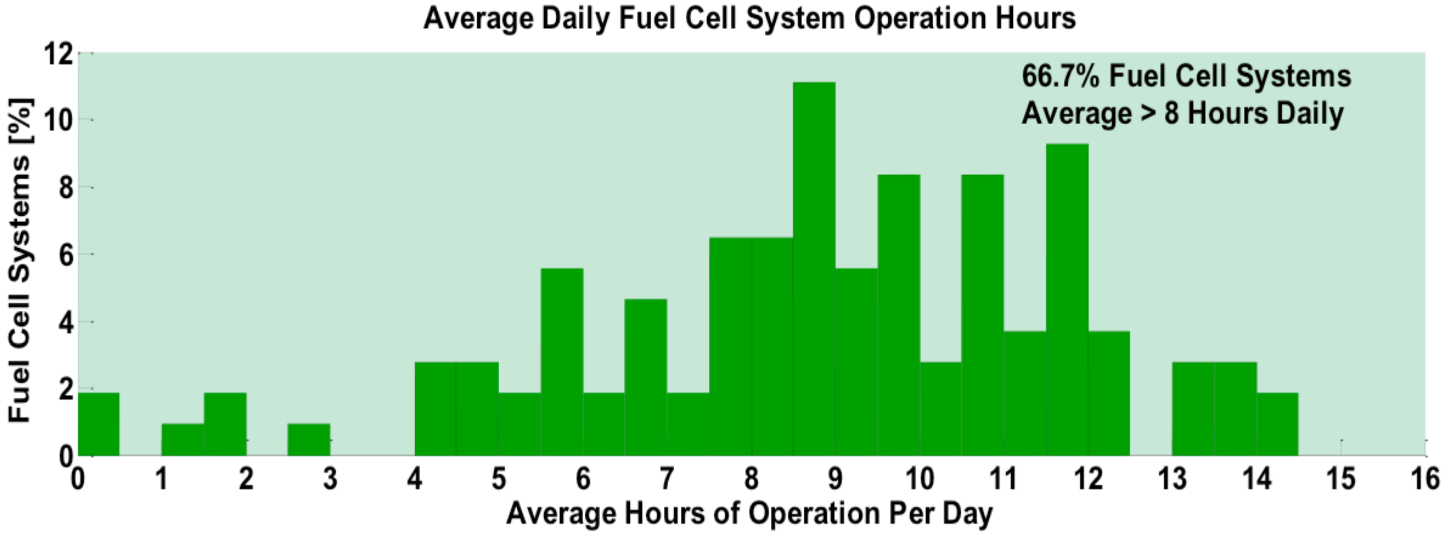
Average Daily DMFC Hours of Operation



- Fleets average 8-10 hours per system per day
- 9.2 hours of DMFC operation per day on average

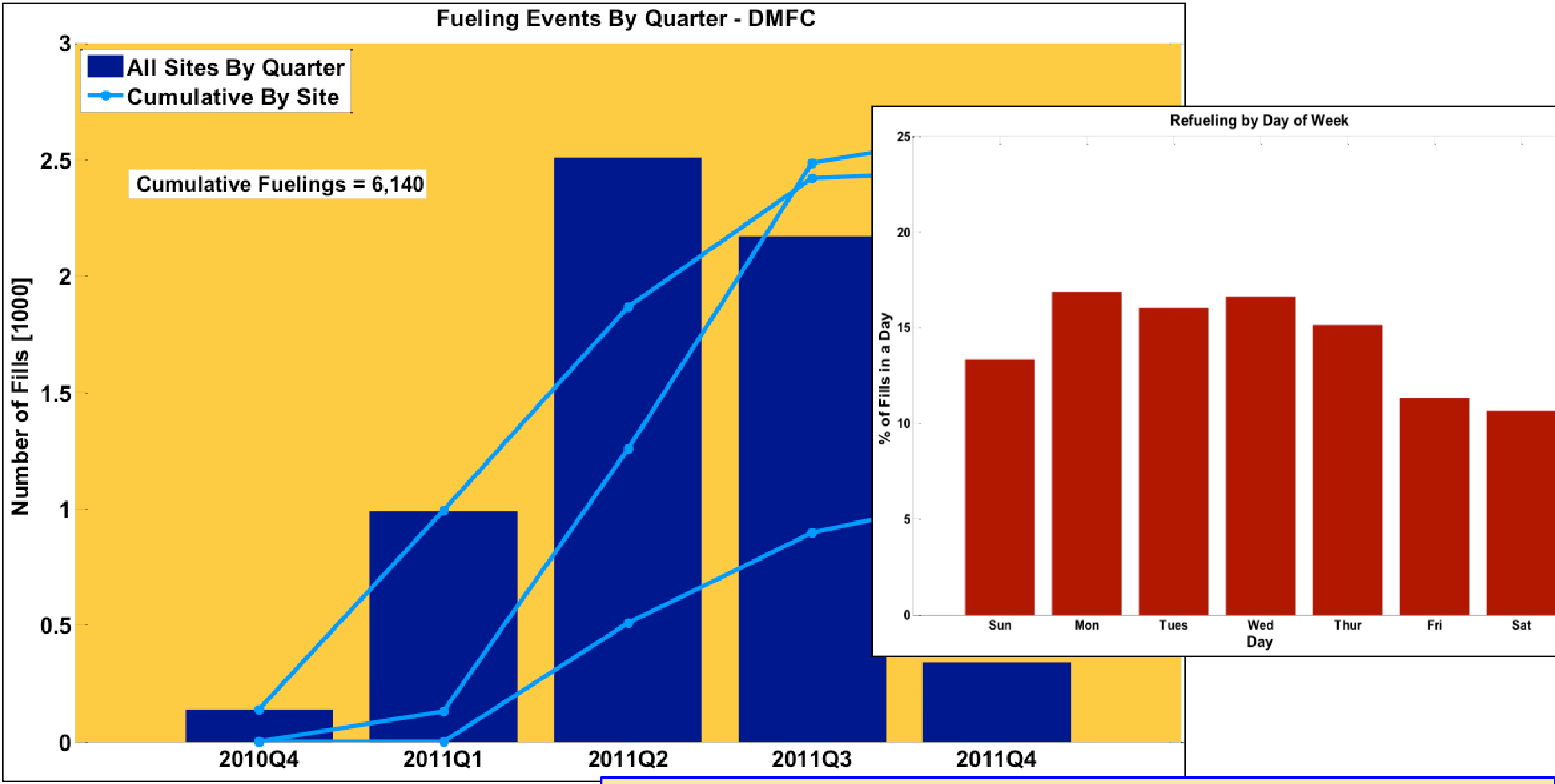
NOTE: DMFC operation time depends on battery state-of-charge; actual MHE operation times may be greater

- 2/3 of DMFC systems average >8 hours/day of operation



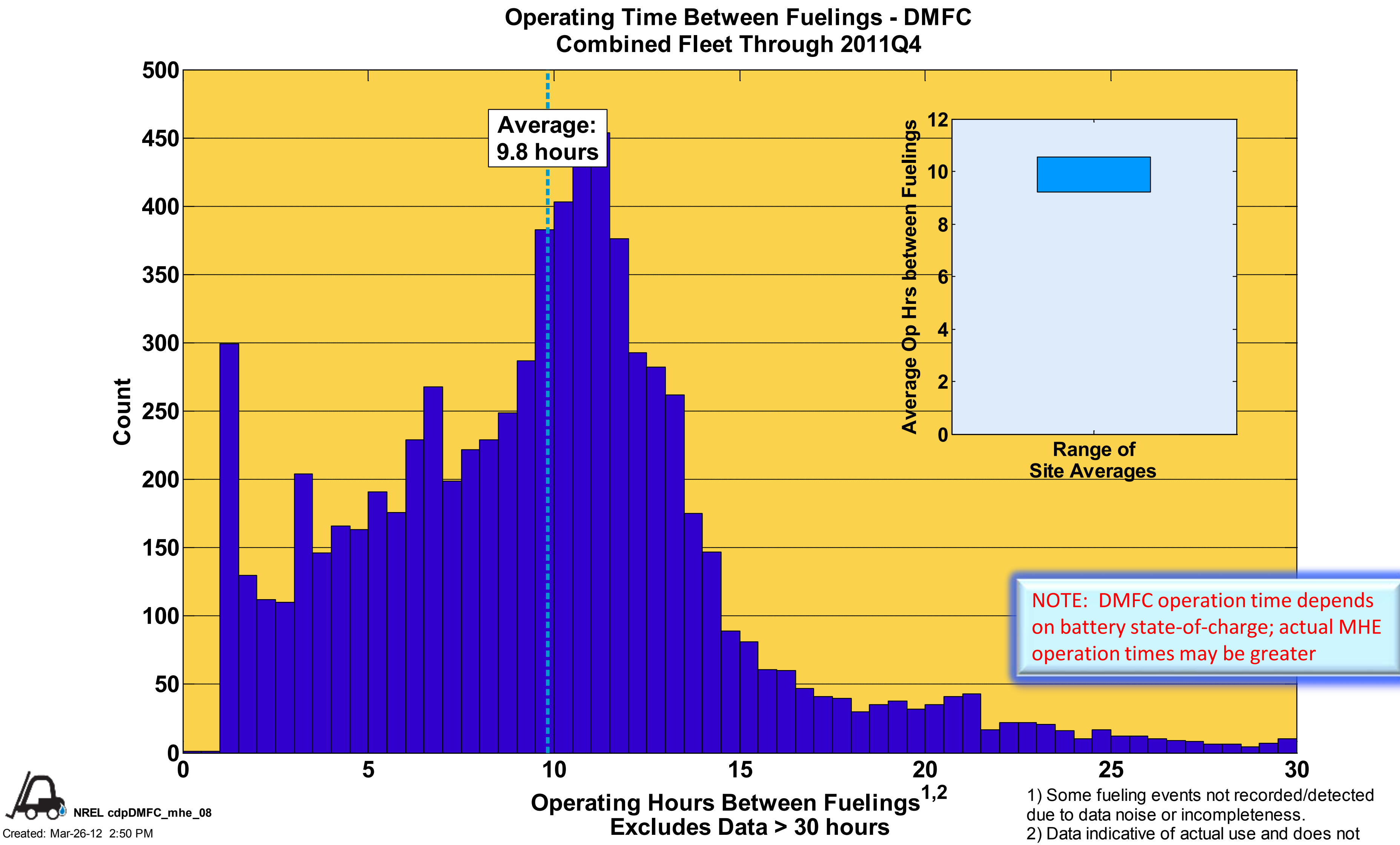
Methanol Fueling

Over 6,000 methanol fills to date; about 700 per month at full deployment



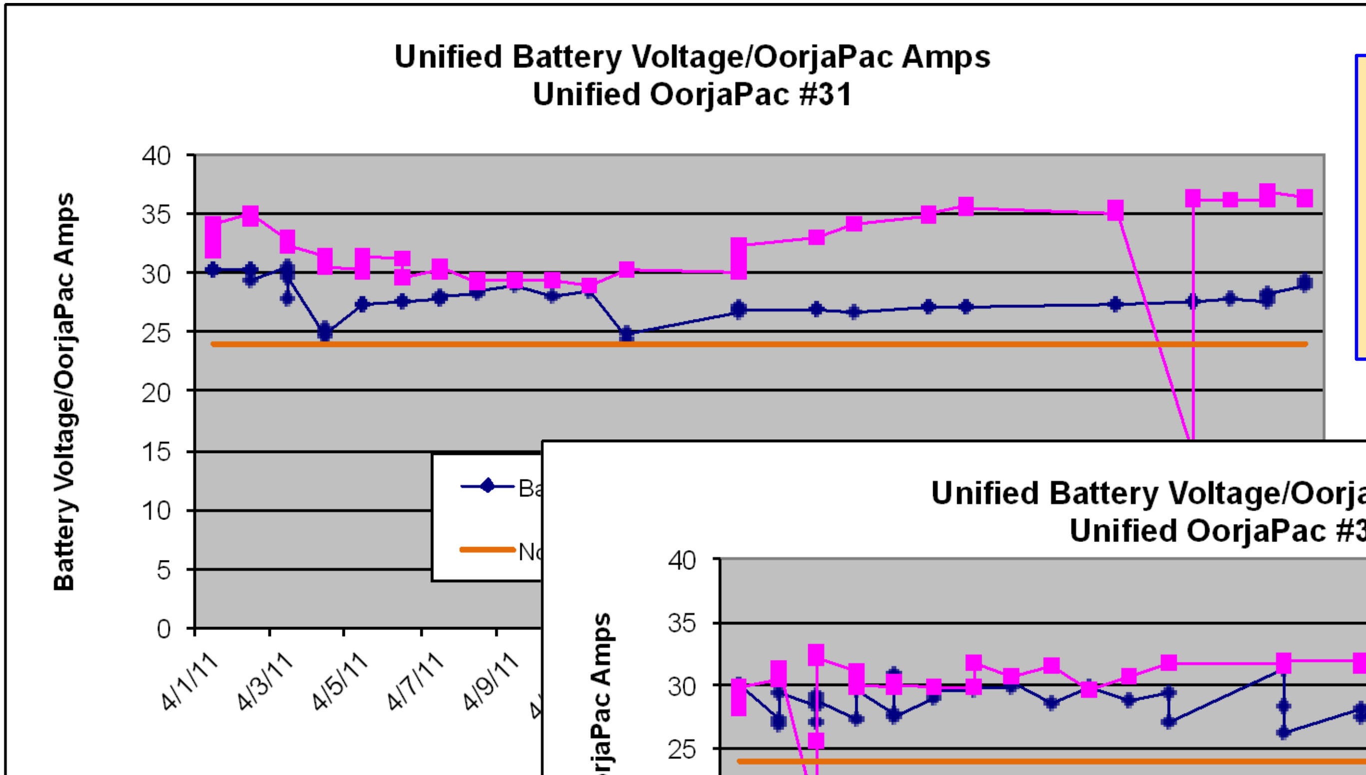
- ~1 methanol fill/day per system
- Methanol filling distributed across the week

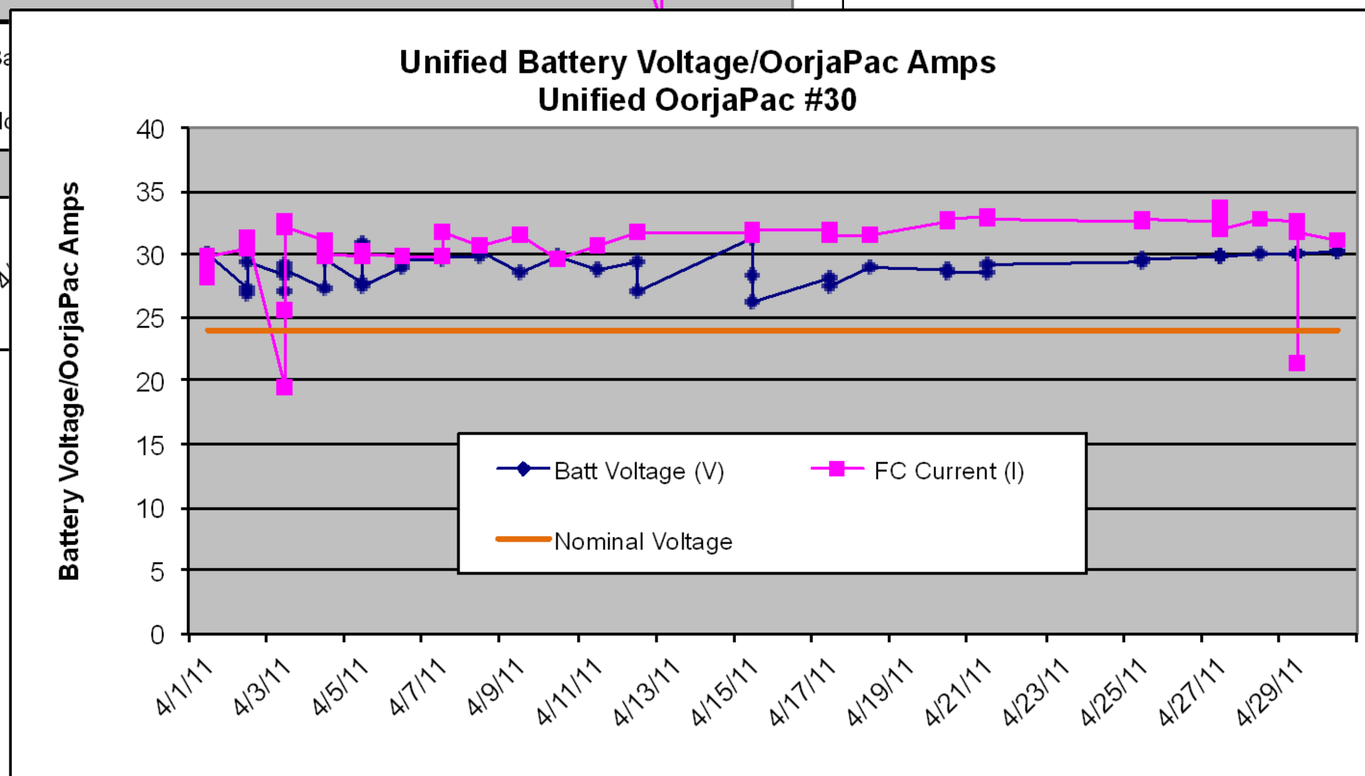
DMFC Operation Hours Between Fuelings



DMFC lifts average ~10 hours between fills; enough for complete shift

Battery System State-of-Charge





Data indicates that DMFC systems avoid deep discharge of battery packs

NOTE: Data and graphics provided by Oorja Protonics

DMFC Maintenance – Common Repairs

Several DMFC system improvements and changes made following analysis of common modes of failure:

- Methanol concentration control
- Balance-of-plant (low FC voltage)
- Temperature control
- Fuel fittings (methanol leaks)
- Electronics

System & technology improvements incorporated following deployment changes from warm/dry warehousing to cold-temperature environments

Maintenance Area	Maintenance Description	Symptom / Fault
Improper Methanol Concentration	Install new methanol concentration sensor	Improper concentration
	Install new methanol pump	Fuel cell low voltage
	Update methanol concentration sensor firmware	
Electronics Failure	Upgrade electronics subsystem	Fuel cell low voltage
Low Fuel Cell Voltage	Install new air pump controller card	Fuel cell low voltage during startup
	Install new methanol concentration sensor	
	Install new solution controller card	Fuel cell low voltage during normal operation
Mixer Temperature	Replace fan on liquid radiator side; install better grills	High Temperature at mixer
	Replace anode and cathode heat exchangers	High temperature at anode loop
Fuel Leak	Replace quick disconnect fitting	Methanol leak from fuel tank

Maintenance Events Before & After System Changes

BEFORE UPGRADES

Total events = 402

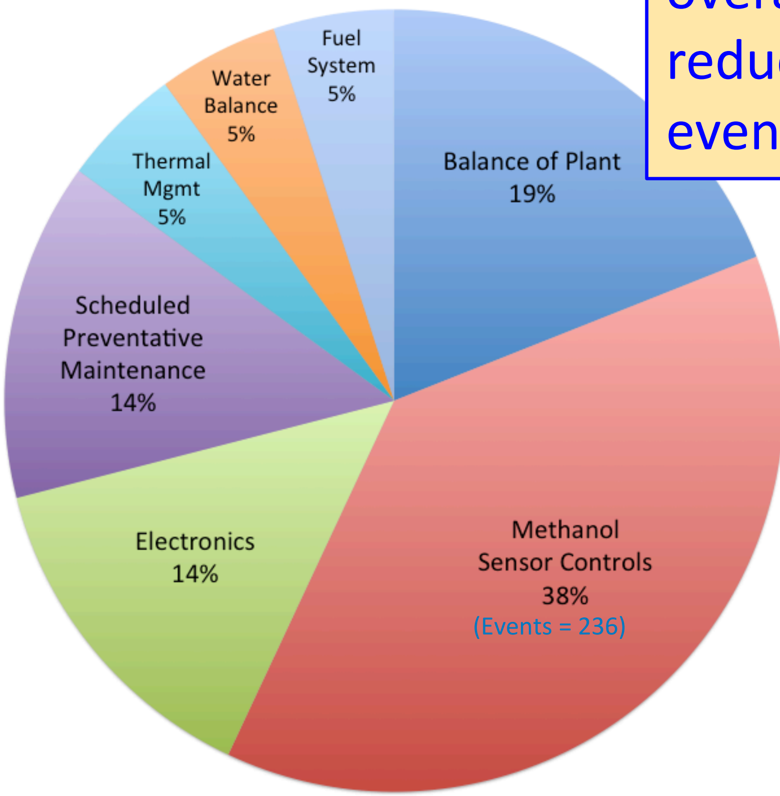
86% Unscheduled

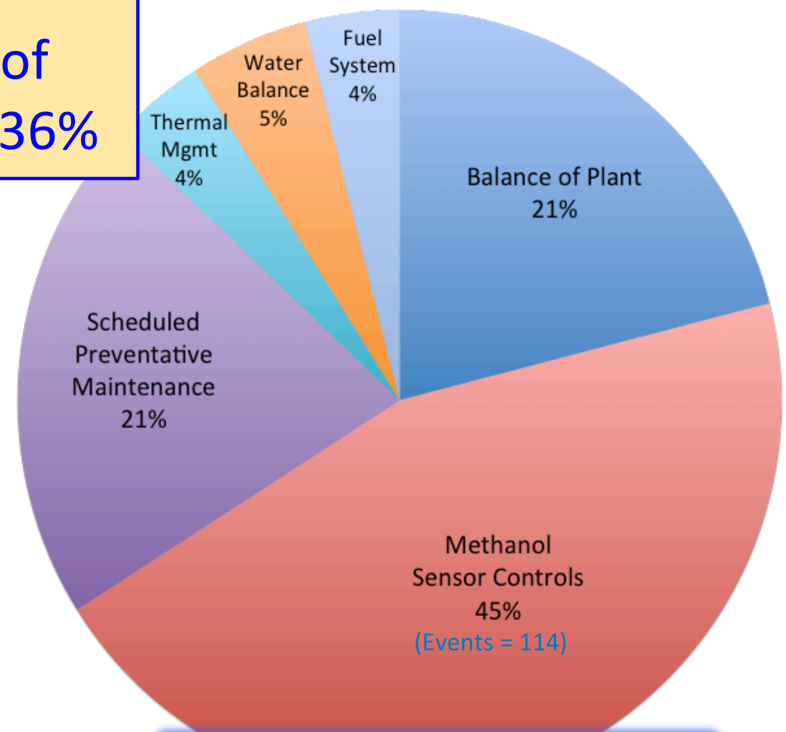
Elimination of electronic failures & overall reduction of events by 36%

AFTER UPGRADES

Total events = 256

79% Unscheduled





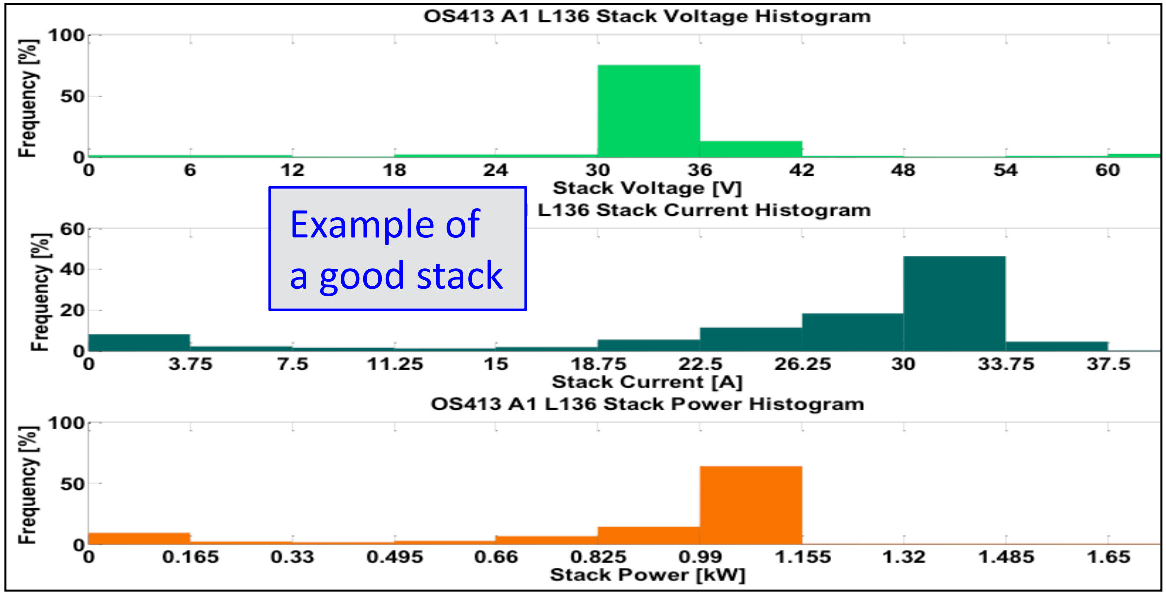
NOTE: Rollout of electronic system upgrades complete; rollout of methanol sensor control in initial phase

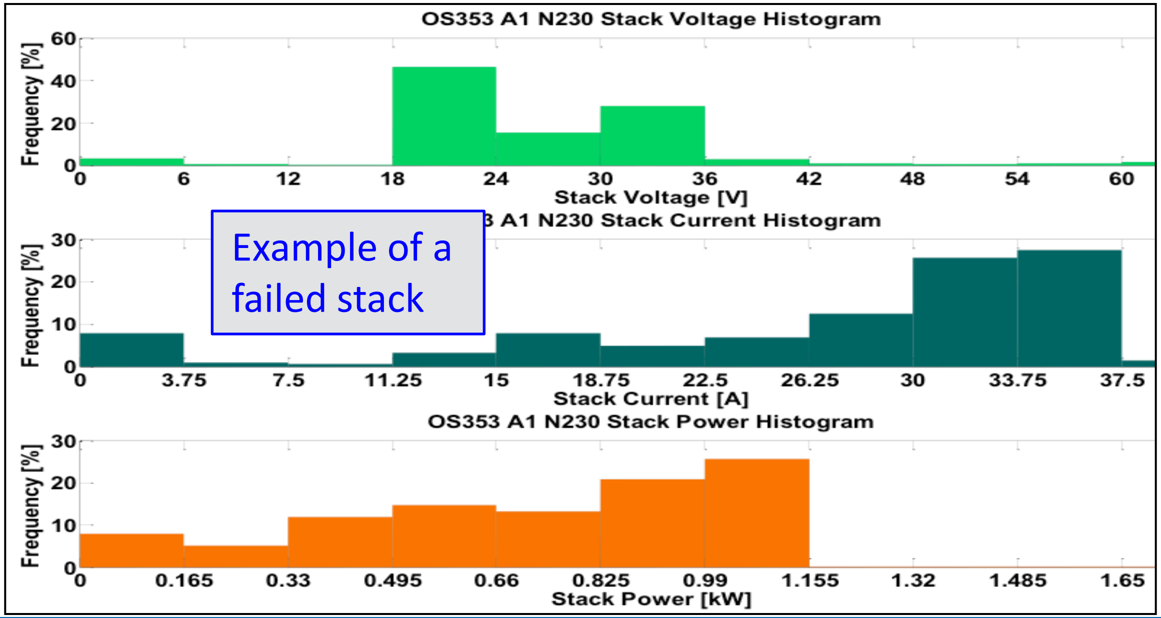
* Data compiled from 20 units before and after over 4-5 month period
* BOP includes Pumps, Valves and Fans

Detailed DMFC Stack Analysis

NREL conducting detailed analyses of all DMFC systems, including healthy stacks and stacks exhibiting early life failures

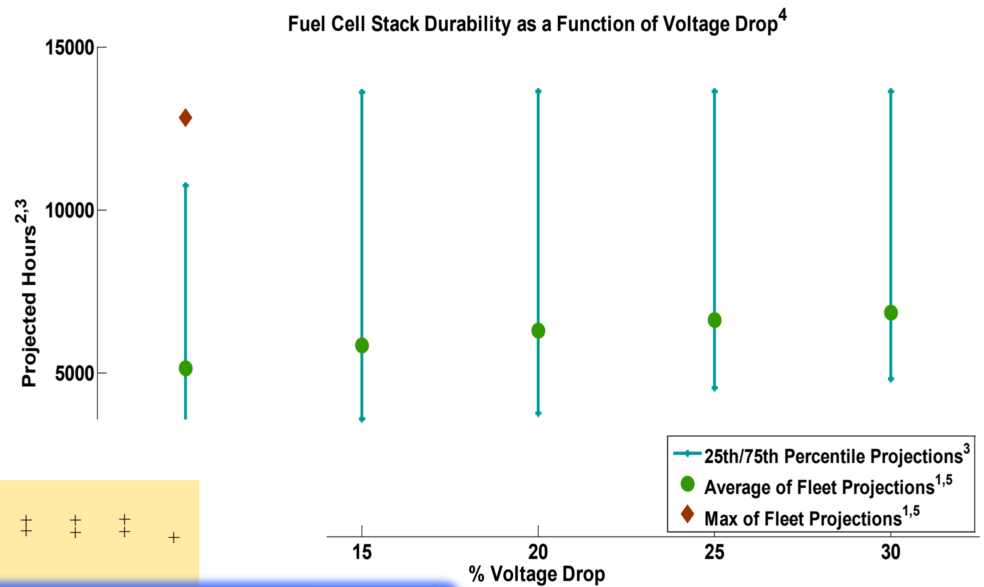
- Healthy stack shows tight operations within 30-36v range & power levels above 1kW
- Failed stack shows more operations below 30v & a wide range of power levels





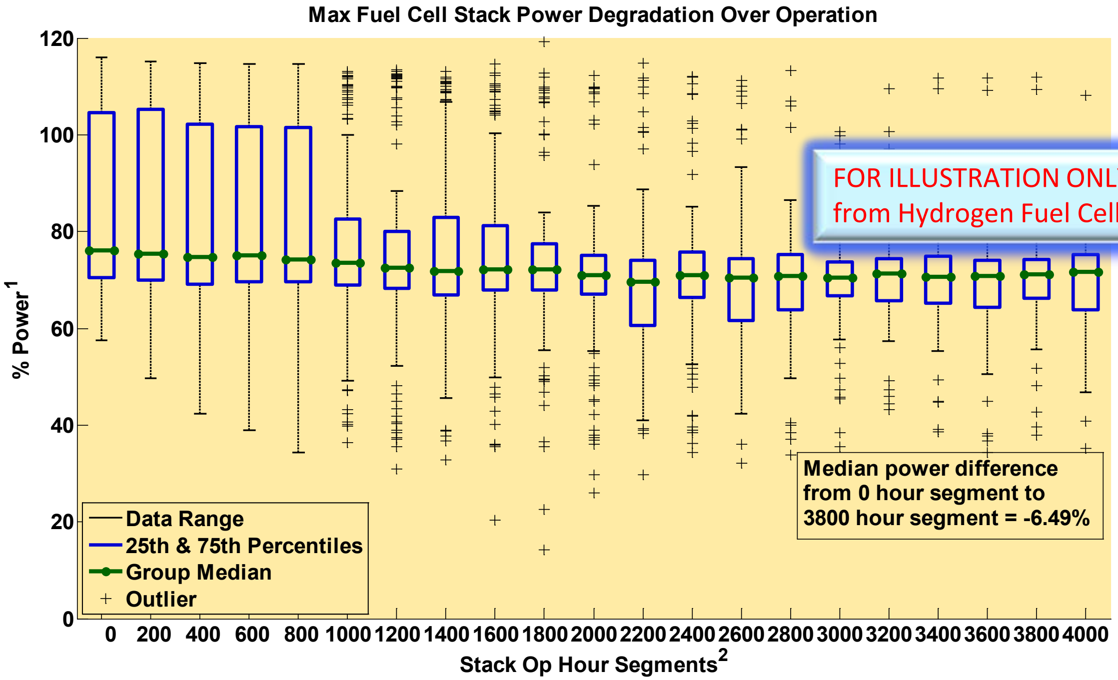
DMFC Voltage & Max Power Degradation

NREL has conducted detailed fleet voltage and power degradation analyses, with results and feedback provided to Oorja and DOE (results are sensitive and not publicly available)



sing fuel cell performance not an indication of an OEM's end-of-life criteria.
ack current.
ojection. The included stacks satisfy a minimum number of
f voltage degradation,
nply that all stacks will (or do) operate to these voltage degradation levels.
ction value that is the weighted average of the site's fuel cell stack projections.

FOR ILLUSTRATION ONLY: Example CDPs from Hydrogen Fuel Cell MHE Project



1) Normalized by fleet maximum power.
2) Each segment point is median FC power (+-100 hrs). Box not drawn if fewer than 3 points in segment.

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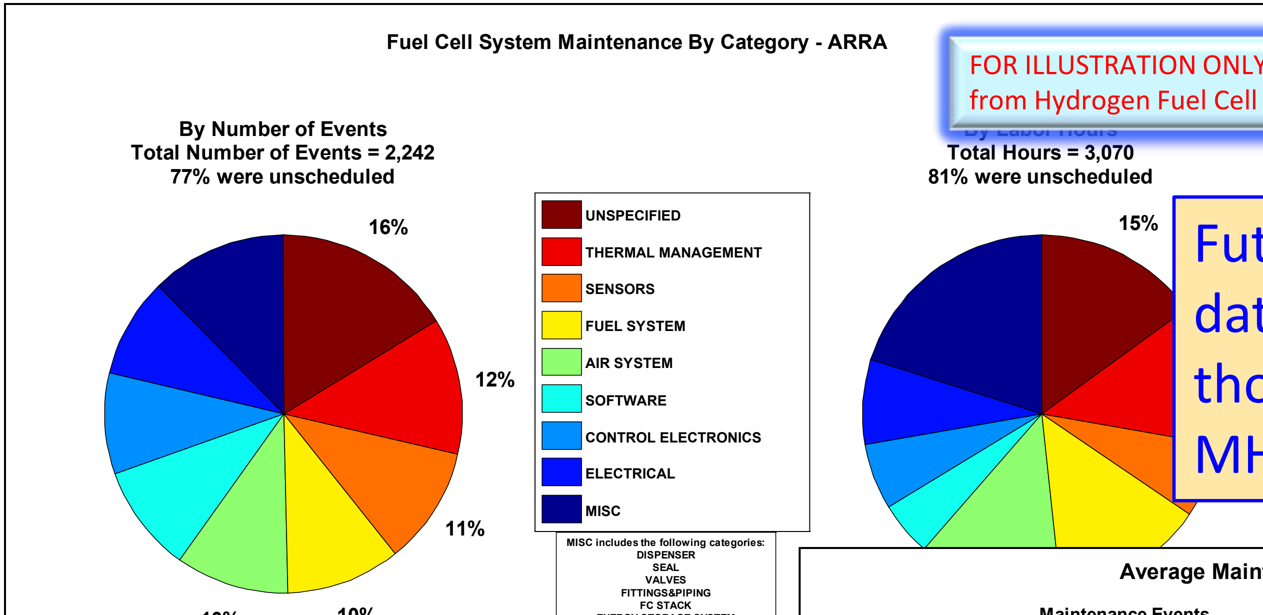
Next Steps & Project Schedule

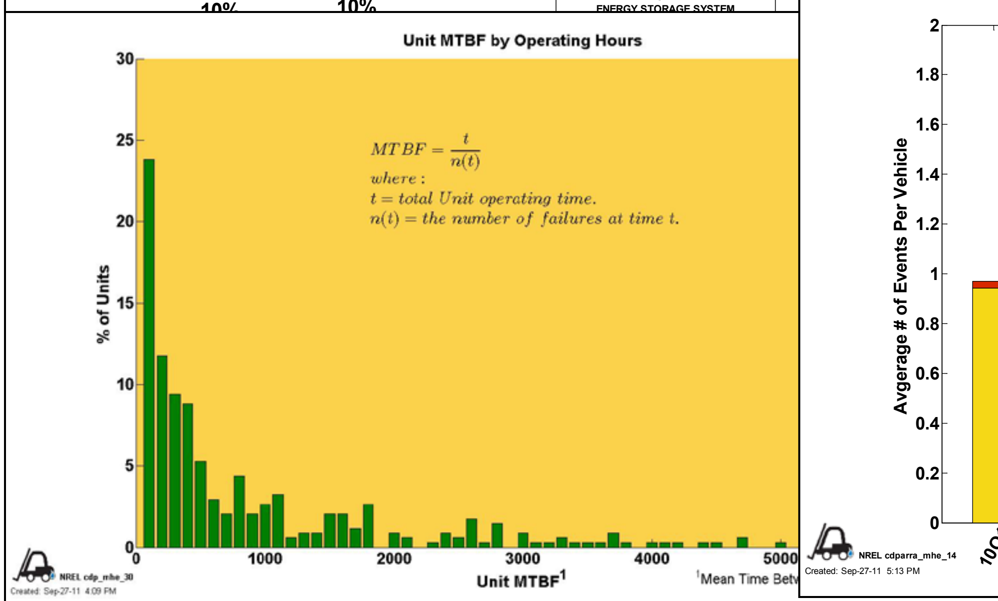
Future Project Work	
3Q-4Q FY2012	**DMFC Deployment & Data Analysis** • DMFC systems operated and maintained • Next round of data analysis from detailed stack data • New data analyses on maintenance & reliability
1Q FY2013	**DMFC Deployment Ends** • DMFC operation and maintenance concludes • Equipment de-commissioning or transfer as needed • Final project data submission
2Q FY2013	**Project Close-Out** • Last round of data analysis and reporting • New analyses on overall cost of ownership • Final project reporting

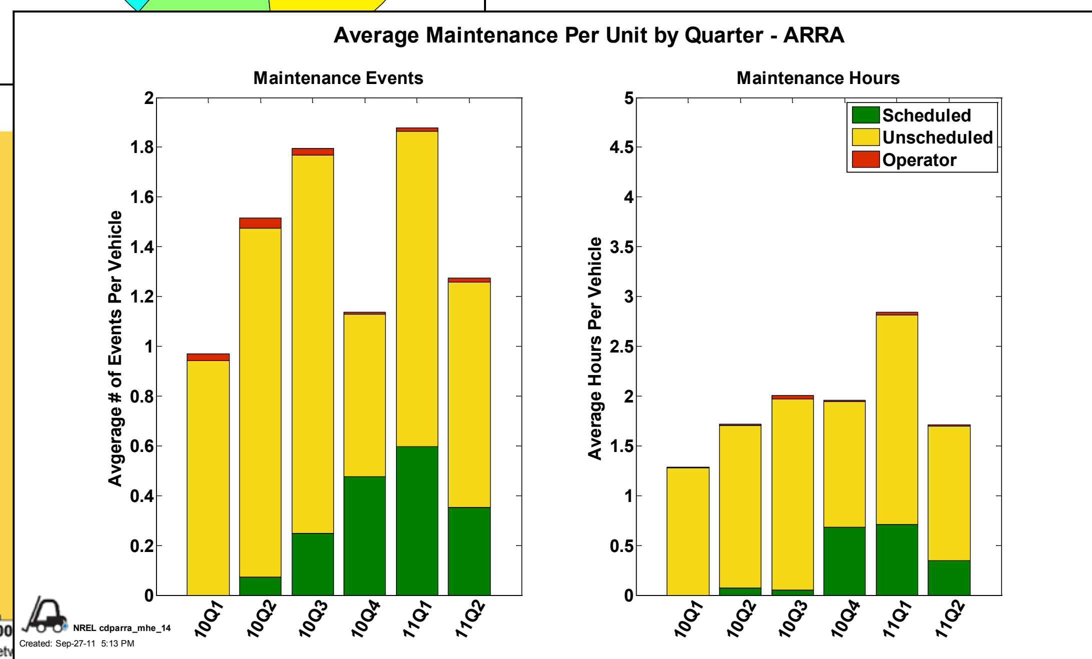
Maintenance & Reliability Analyses

FOR ILLUSTRATION ONLY: Example CDPs from Hydrogen Fuel Cell MHE Project

Future effort will conduct data analyses similar to those done for hydrogen MHE projects



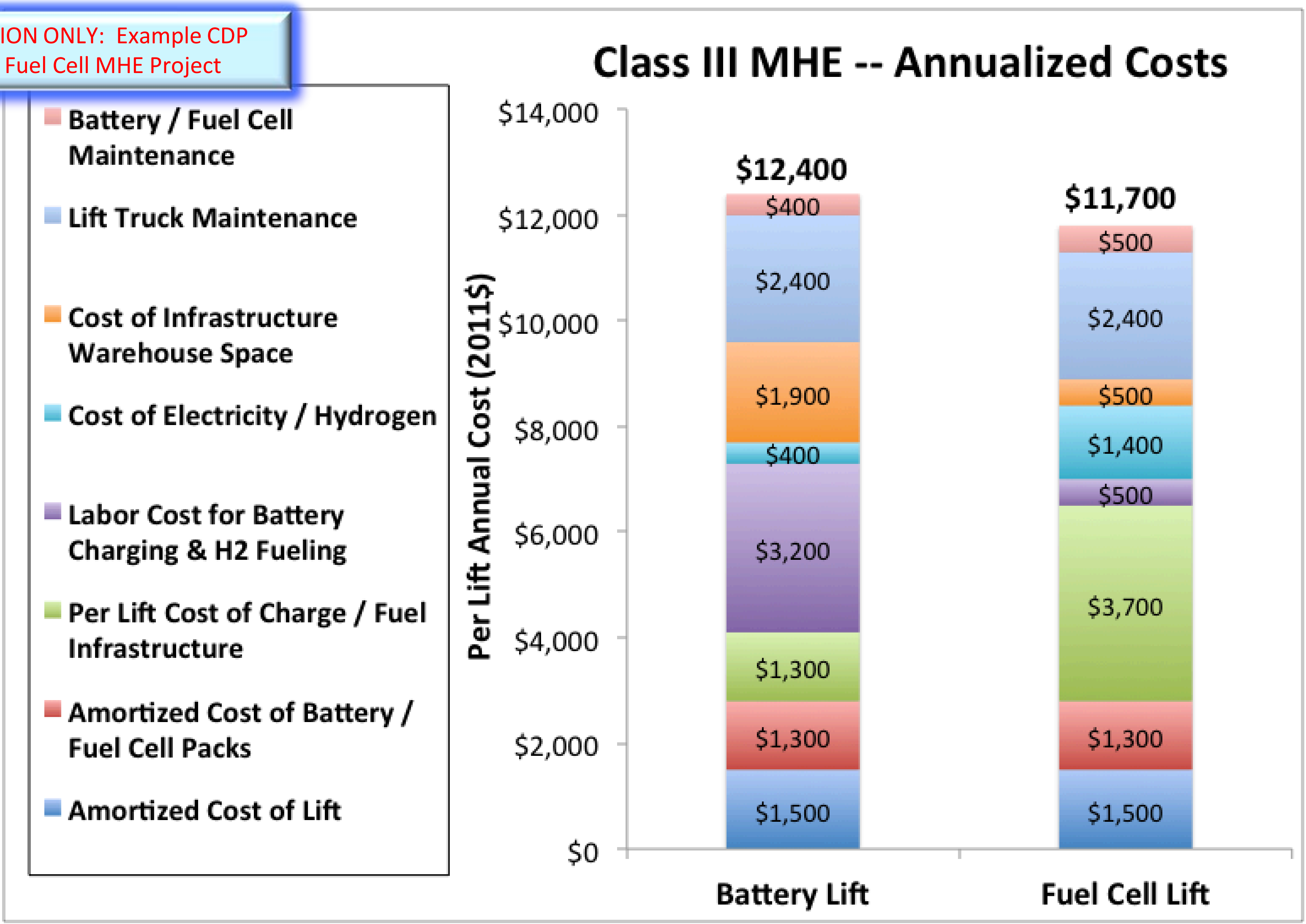




Total Cost of Ownership Analysis

Collect/analyze data to develop and validate cost of ownership

FOR ILLUSTRATION ONLY: Example CDP from Hydrogen Fuel Cell MHE Project



Deployment Summary

Performance Summary	
Site Operations	
Number of Fuel Cell Forklifts in Operation	75
Hours of Operation for the Combined Fleet	160,000
Number of Fueling Events	>6,000
Forklifts	
Hours of Operation Between Fueling	10
Daily Hours of Operation Per System	9.2
Average Methanol Fills Per System Per Day	1
Median DMFC System Hours of Operation	1,500

Project Summary

- **Approach**
  - ~2 year deployment project operating direct methanol fuel cells in Class III material handling equipment in commercial warehouse facilities
  - Collect, compile, and analyze real-world operational data to characterize performance & evaluate the value proposition for DMFCs in MHE applications
- **Relevance**
  - Hydrogen-based fuel cell forklifts a rapid growth market segment for fuel cells; demonstration projects funded by DOE and DOD show total cost benefits
  - DMFC forklifts offer many of the same benefits (long runtimes, short refueling times, increased productivity) with very low fuel infrastructure costs
- **Technical Accomplishments and Progress**
  - 75 DMFC systems deployed in Class III MHE operating in 4 warehouses
  - Over 12 months of operations analyzed; 160,000 hours of DMFC operations
  - Analyses of DMFC operations, methanol fueling, and voltage & power decay
  - Increased reliability and stack durability following DMFC system improvements
- **Collaborations**
  - Subcontract with Oorja Protonics; DMFC MHE deployed at warehouses operated by Unified Grocers, Testa Produce, and Earp Distribution
- **Future Work**
  - Maintenance and reliability analyses
  - Total cost of ownership analysis (validate value proposition)

Questions and Discussion

Thanks!!

Photo courtesy of Oorja Protonics

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