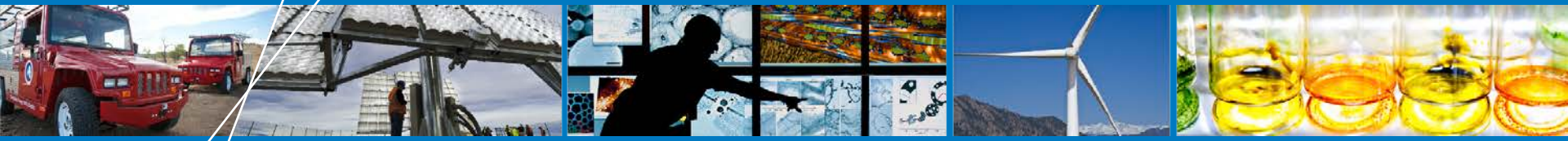
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

MT004

Direct Methanol Fuel Cell Material Handling Equipment Deployment



2013 DOE Annual Merit Review, Crystal City, VA

Todd Ramsden, Mike Ulsh, Sam Sprik, Jennifer Kurtz, Chris Ainscough

May 15, 2013

Overview

Timeline

- Start: June, 2010
  - Contract Award February, 2011
- Finish: June, 2013*
- 98% Complete

Budget

- Total Project Funding: $2.58M
  - Oorja cost share: $1.4M (60%)
  - DOE share for deployment: $920K
  - NREL project management & analysis (FY10-FY13): $255K

*Sub-contract deployment completed in December 2012

Barriers Addressed

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

Collaborators

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

Project Objectives

Oorja Protonics:

- Deploy and operate DMFC powered MHE and methanol infrastructure
- Compile operational and maintenance data and deliver to NREL

NREL:

- Validate performance under real world conditions and provide independent technology assessment
  - Reliability and durability of fuel cell systems
  - Performance of infrastructure
  - Overall value proposition
- Support the market for fuel cells in material handling applications by providing relevant results for the key stakeholders

Project Overview

Oorja Protonics:

- Operate and maintain 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
- Target 3,500–5,000 total operation hours on each unit
- Use data loggers to provide detailed tracking of DMFC system performance

NREL:

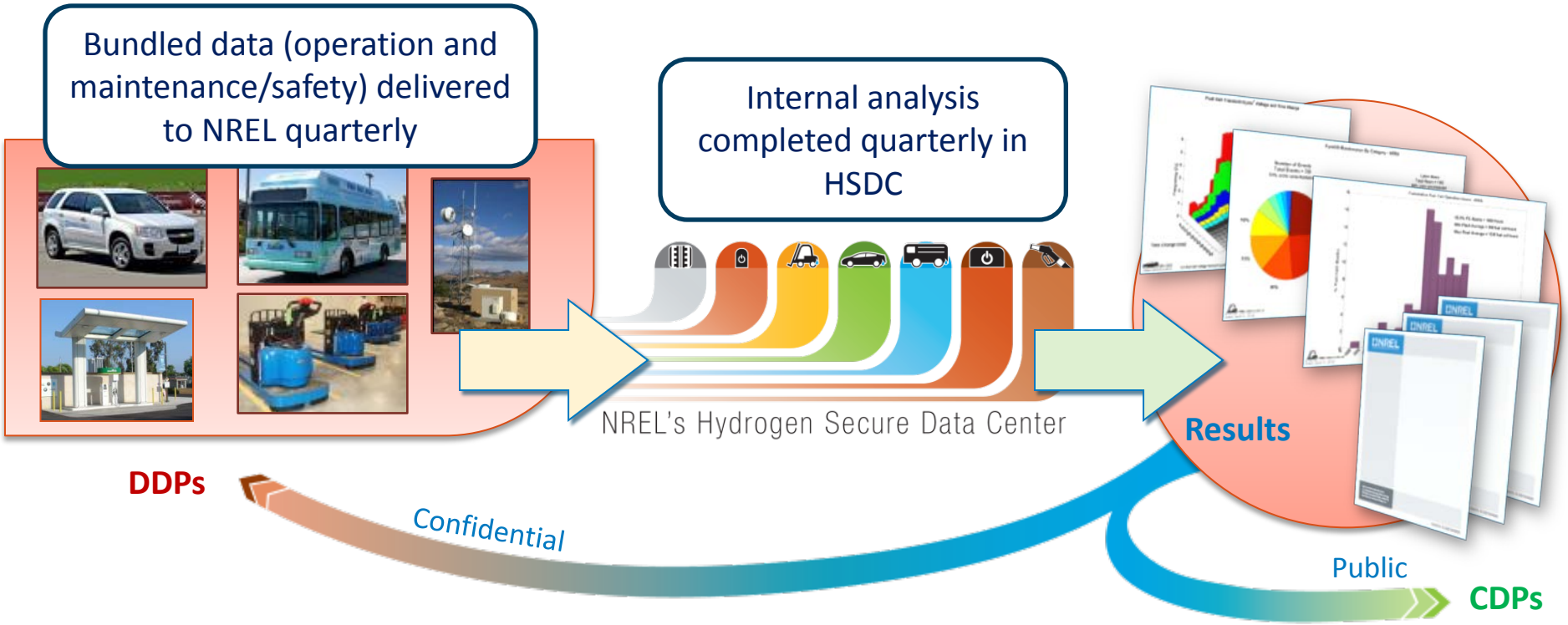
- Manage competitive solicitation and subcontract
- Validate performance of systems and infrastructure
- Assess value proposition

Photo courtesy of Oorja Protonics

Incorporation of Learnings

- As reported last year, initial deployment of 75 units experienced failures due to methanol sensors and other design issues
- As a result, many learnings were gained and new system designs were implemented
  - However, the project budget did not allow for complete overhaul of the initial 75 units
  - In a follow-on commercial order, a second fleet of systems was deployed, which incorporated the design updates resulting from the initial 75 unit deployment
    - **Fleet of 35+ units at separate end-user distribution site**

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)

Collaborations

- **Oorja Protonics:**
  - Built and maintained DMFC Class III MHE systems for customer sites
  - Provided operational data to NREL
- **Commercial food distribution warehouses:**
  - Unified Grocers
  - Testa Produce
  - Earp Distribution
- **Fourth end-user agreed to provide data from separate deployment**

Photo courtesy of Oorja Protonics

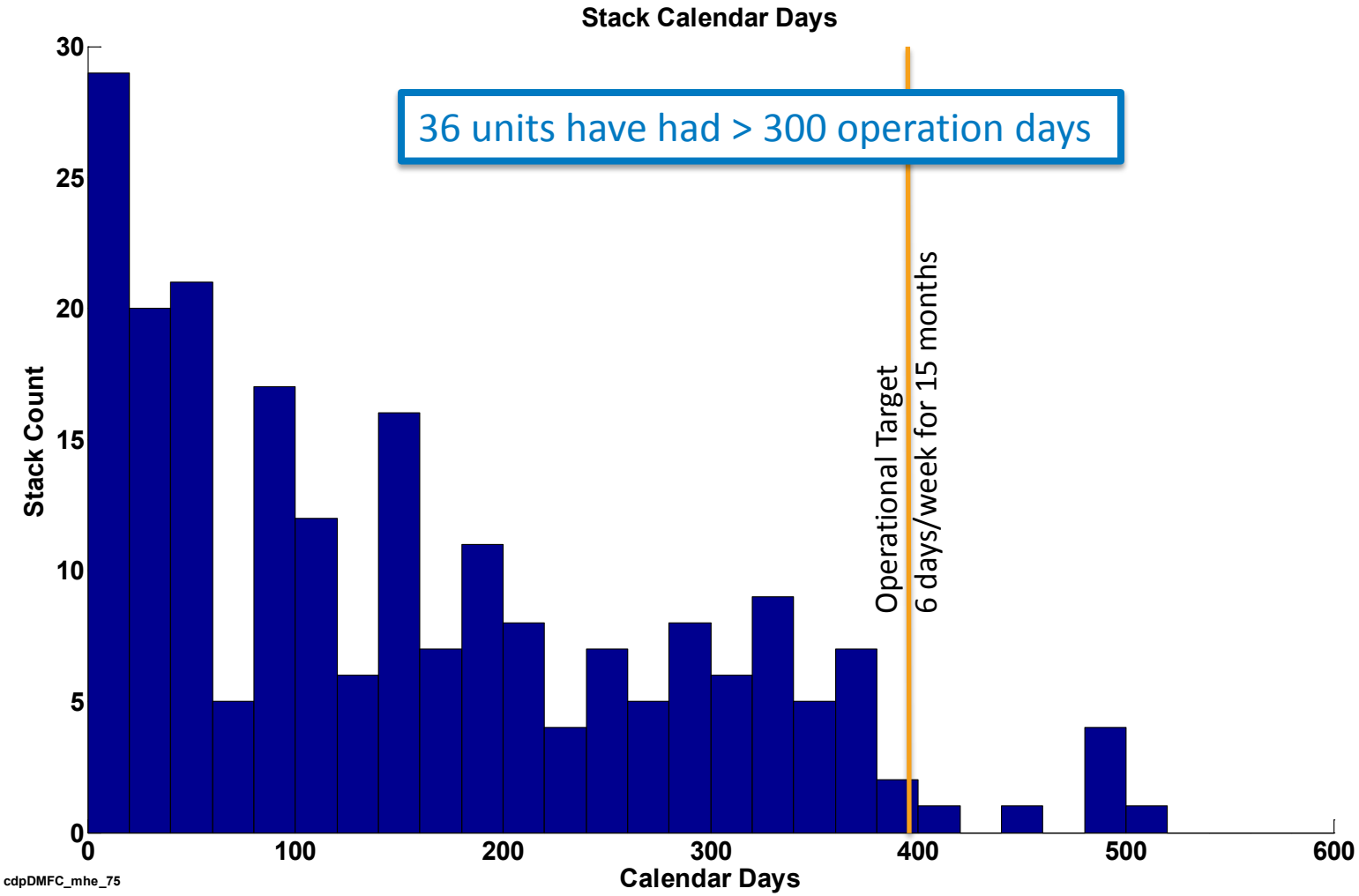
Methanol Fueling Infrastructure Deployed

- **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**

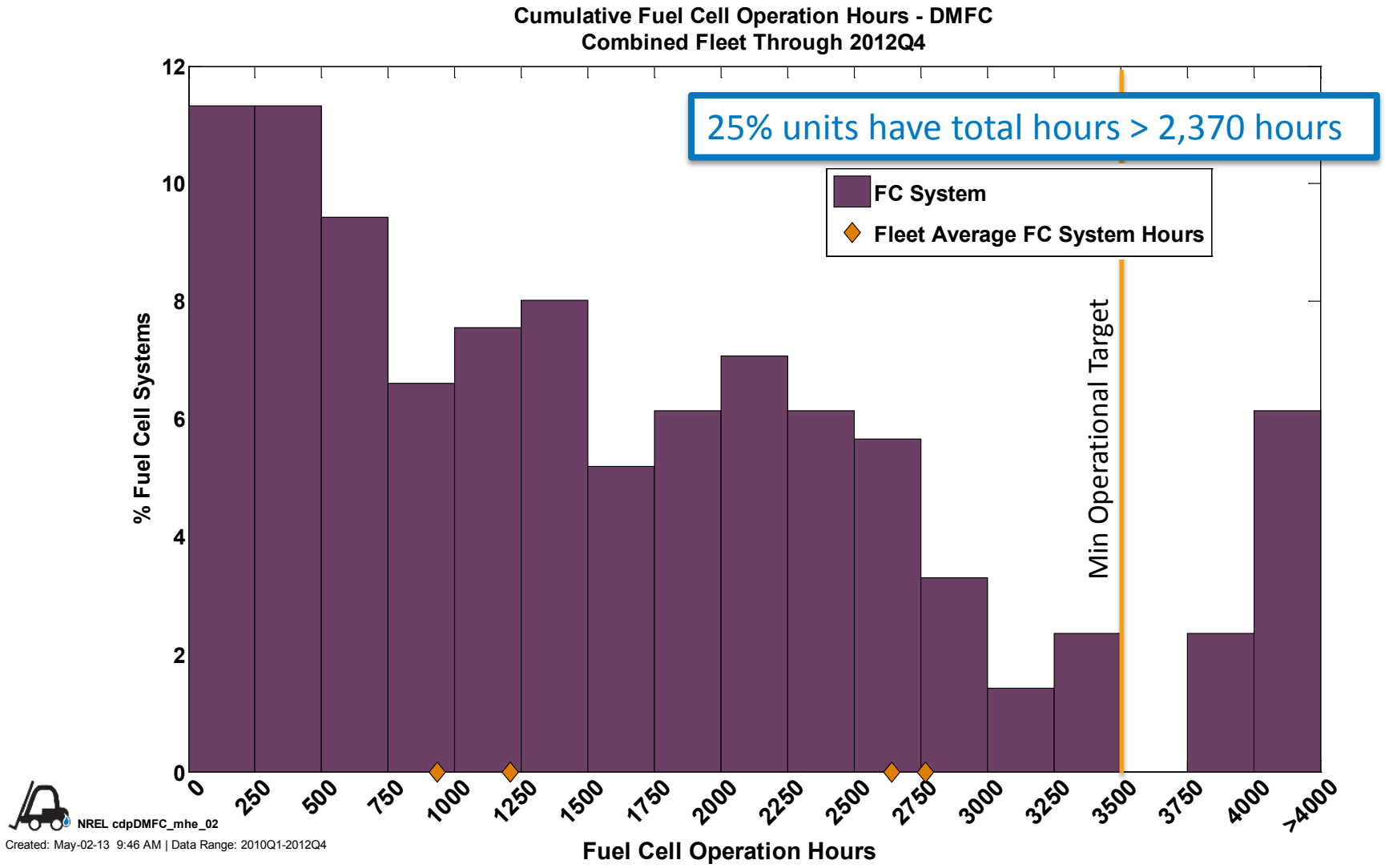
Photo courtesy of Oorja Protonics

Data previously shown

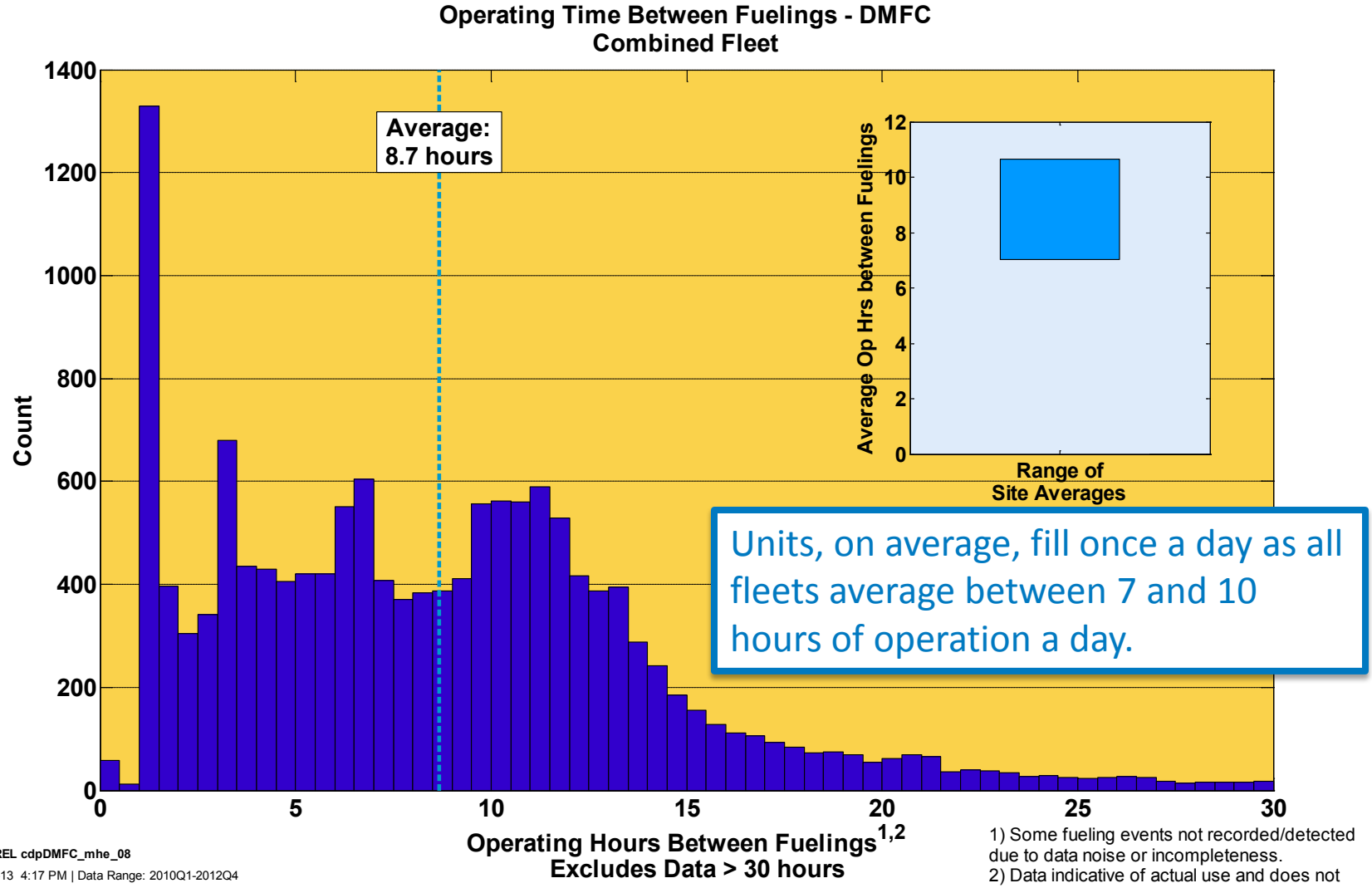
Fuel Cell Unit Elapsed Calendar Days of Operation



Fuel Cell Unit Operational Hours



Fuel Cell Unit Operation Time Between Fills



Units, on average, fill once a day as all fleets average between 7 and 10 hours of operation a day.

NREL cdpDMFC_mhe_08

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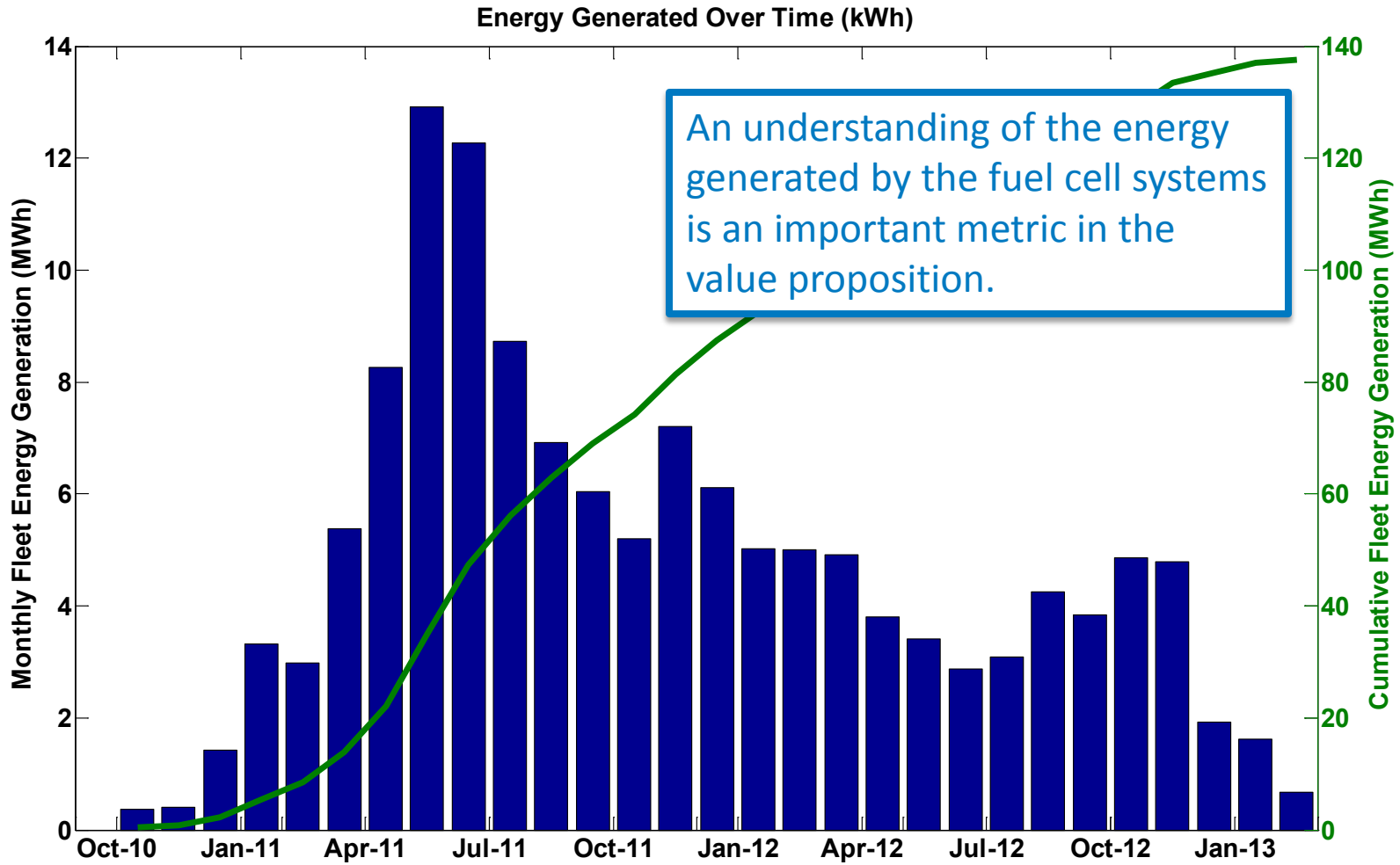
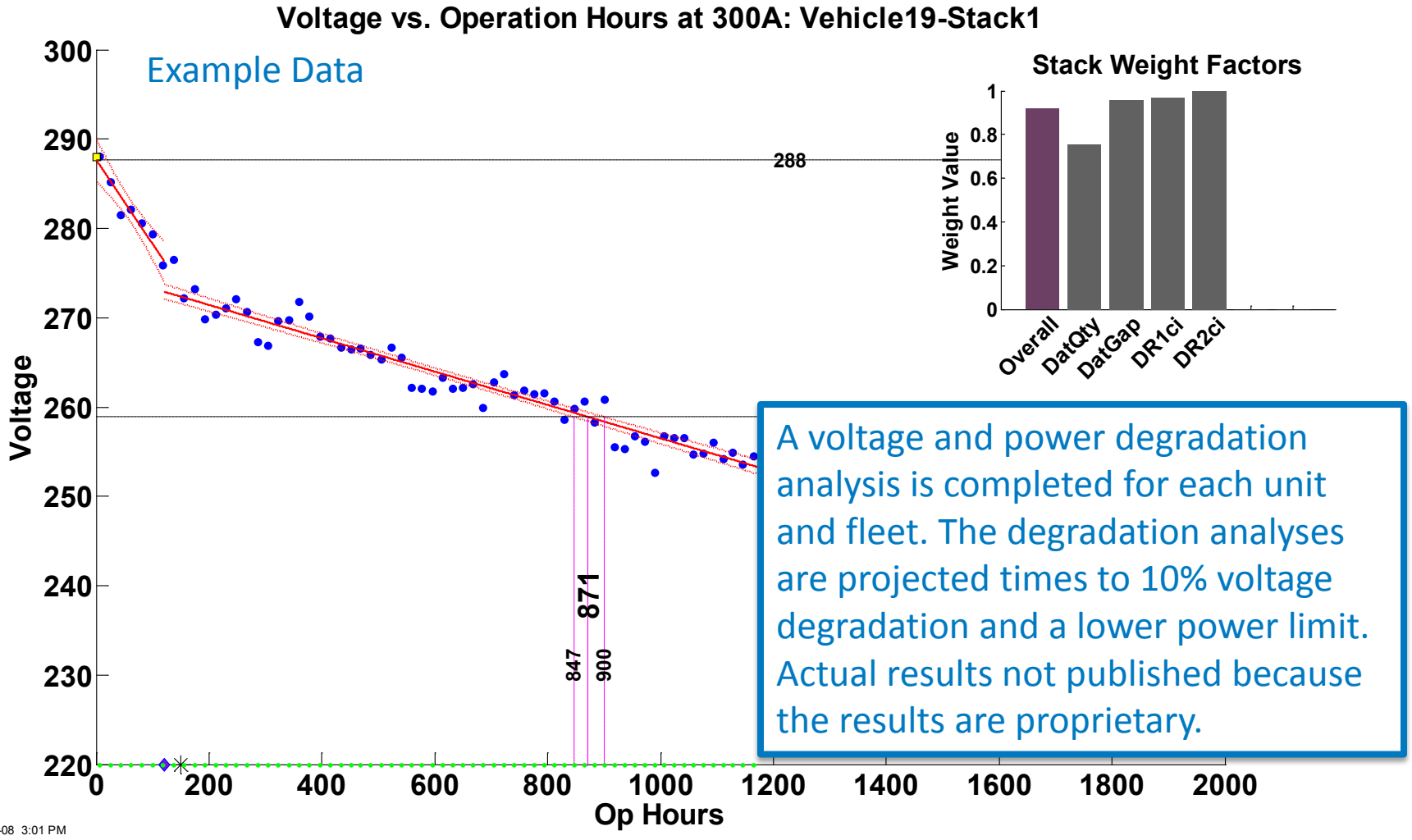
1) Some fueling events not recorded/detected due to data noise or incompleteness.
2) Data indicative of actual use and does not represent the max capability of the systems.

Fuel Cell Unit MWh Generated



Fuel Cell Voltage Degradation Analysis



A voltage and power degradation analysis is completed for each unit and fleet. The degradation analyses are projected times to 10% voltage degradation and a lower power limit. Actual results not published because the results are proprietary.

DMFC Maintenance Data

- **Summary of maintenance data provided by Oorja Protonics in FY11-12**

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	Intall 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 exhangers	High temperature at anode loop
Fuel Leak	Replace quick disconnect fitting	Methanol leak from fuel tank

Data previously shown

Summary

Performance Summary	
Sites	5
Number of fuel cell forklift power units analyzed	131
Total hours of operation	251,000
Total methanol fueling events	>14,000
Average hours of operation between fueling	~9
Average daily hours of operation per system	8-10
Average daily methanol fills per system	~1
Median DMFC system hours of operation	1391

Validation:

- **Technology Durability – Analysis completed**
- **Technology Reliability – Not yet completed due to insufficient data**
- **MHE Value Proposition – Not yet completed due to insufficient data**
- **Re-design performance benchmark – In progress**

Proposed Next Steps

- **Demonstration completed in December, 2012**
- **Project close-out and final reporting between NREL, Oorja, and DOE**
- **Maintenance data to be provided by Oorja for FY12-13**
- **Pending sufficient data and continued project funding, evaluations on**
  - Value proposition
  - Reliability
  - Safety
  - Benchmark system re-design performance

Questions and Discussion

Thanks!!

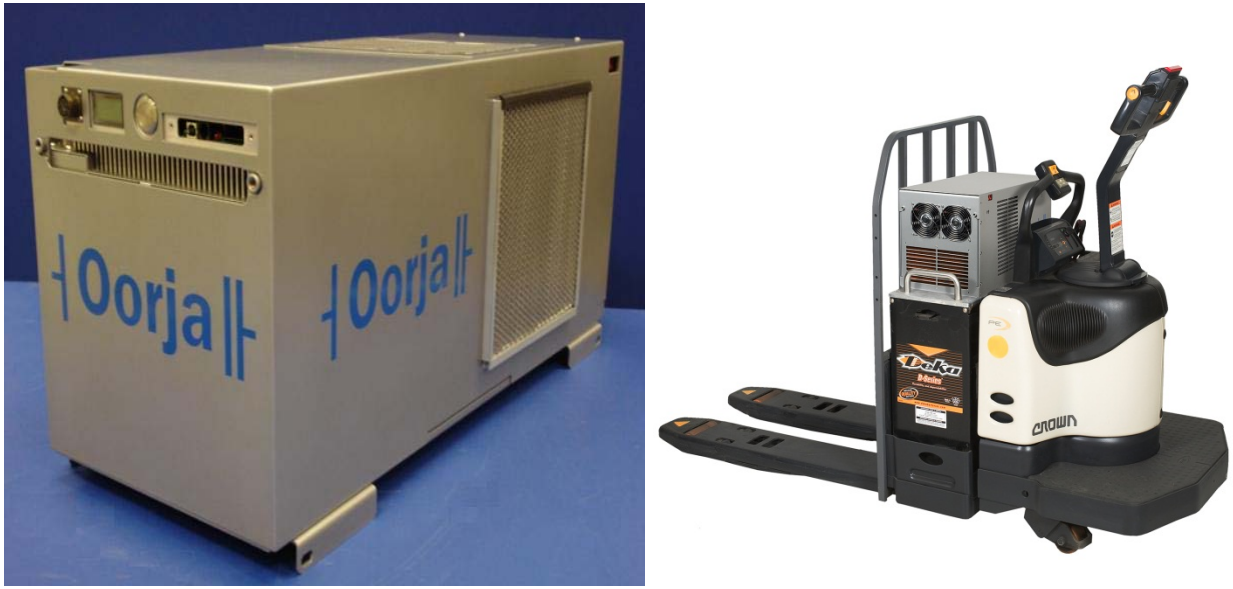


Photo courtesy of Oorja Protonics

Backup Slides

Relevance: 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**

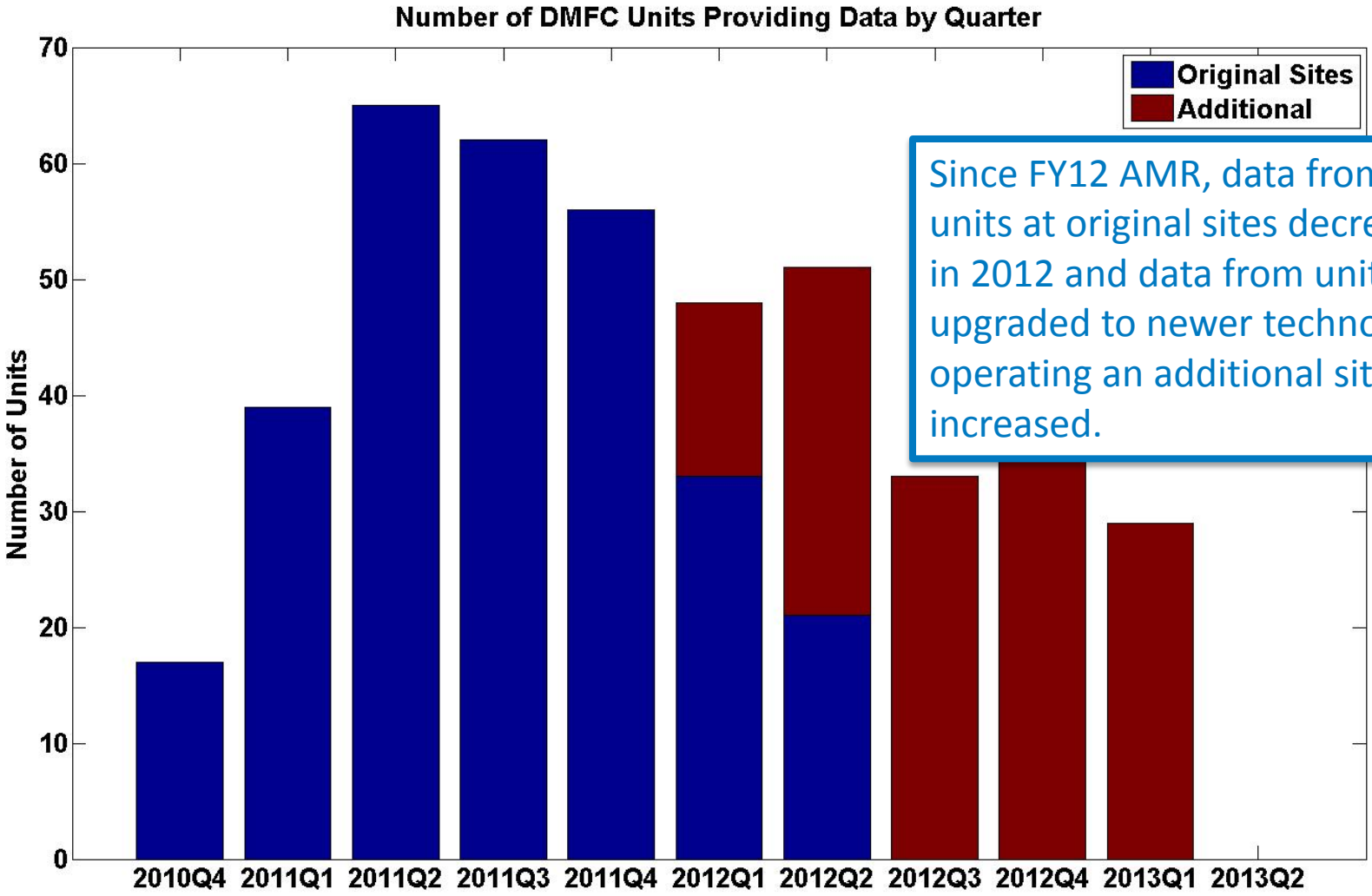
OorjaPac™ DMFC Systems Deployed

- 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)

Fuel Cell Units Providing Data



Since FY12 AMR, data from units at original sites decreased in 2012 and data from units upgraded to newer technology operating an additional site increased.

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Units not reporting data does not necessarily indicate a retired system.