# VII.6 Forklift and Backup Power Data Collection and Analysis

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Project End Date: September 2014

## Overall Objectives

- Perform an independent assessment of technology in “real-world” operation conditions, focusing on fuel cell systems and hydrogen infrastructure
- Leverage data processing and analysis capabilities developed under the Fuel Cell Vehicle Learning Demonstration
- Support market growth through reporting on technology status to key stakeholders and performing analyses relevant to the markets’ value proposition
- Study fuel cell systems operating in material handling equipment (MHE), backup power, portable power, and stationary power applications; the project includes approximately 1,000 deployed fuel cell systems

## Fiscal Year (FY) 2013 Objectives

- Conduct quarterly analysis of operation and maintenance data for fuel cell systems and hydrogen infrastructure (x4)
- Prepare bi-annual technical composite data products (x2)
- Publish interim draft report of status and performance of fuel cell MHE and backup power systems
- Complete performance analyses on durability, reliability, and infrastructure utilization

## Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(D) Lack of Hydrogen Refueling Infrastructure Performance and Availability Data

(E) Codes and Standards

## Contribution to Achievement of DOE Technology Validation Analysis Milestones

This project will contribute to achievement of the following DOE milestones from the Technology Validation section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Milestone 4.3: Report safety event data and information from ARRA projects (3Q, 2013)

## FY 2013 Accomplishments

- By December 2012, 1,302 fuel cell systems were in operation throughout the United States, more than double the number of systems that were in operation at the end of 2010. Seven of the eight MHE sites are fully operational (one site completed its project) and the number of fuel cell backup power systems deployed increased more than 18-fold—from 44 to 806—from 2010 to 2012.
- The technical results published in April 2013 [1] include 21 backup power composite data products (CDPs) and 72 MHE CDPs. The results are categorized as deployment, fuel cell operation, infrastructure operation, fuel cell safety, infrastructure safety, fuel cell durability, fuel cell maintenance, infrastructure maintenance, fuel cell reliability, infrastructure reliability, and cost of ownership.
- The basic deployment and use statistics analyzed for MHE are 490 units in operation; 1,445,558 operation hours; average 4.6 hours between fills; 246,997 fills; and 187,426 kilograms of hydrogen dispensed in 2.3 minutes, on average.
- The basic deployment and use statistics analyzed for backup power are 1.86 MW installed capacity; 806 systems in operation; average site capacity between 4 and 6 kW; and a successful start percentage of 99.6% from the 134 systems that reported detailed operation data.
- A continuous run time of 65 hours was demonstrated for at least one backup power system.
- An interim report summarizing the performance status for fuel cell backup power was completed.

- An interim report summarizing the performance status for fuel cell MHE was completed.

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## INTRODUCTION

The U.S. Department of Energy (DOE) designated more than $40 million in American Recovery and Reinvestment Act (ARRA) funds for the deployment of up to 1,000 fuel cell systems. This investment is enabling fuel cell market transformation through development of fuel cell technology, manufacturing, and operation in strategic markets where fuel cells can compete with conventional technologies. The strategic markets include MHE, backup power, stationary power, and portable power, and the majority of the deployed systems are in the MHE and backup power markets. NREL is analyzing operational data from these key deployments to better understand and highlight the business case for fuel cell technologies and report on the technology status.

## APPROACH

The project's data collection plan builds on other technology validation activities. Data (operation, maintenance, and safety) are collected on-site by the project partners for the fuel cell system(s) and infrastructure. NREL receives the data quarterly and stores, processes, and analyzes the data in NREL's Hydrogen Secure Data Center (HSDC). The HSDC is an off-network room with access for a small set of approved users. An internal analysis of all available data is completed quarterly and a set of technical CDPs is published every six months. The CDPs present aggregated data across multiple systems, sites, and teams in order to protect proprietary data and summarize the performance of hundreds of fuel cell systems and thousands of data records. A review cycle is completed before the publication of CDPs. The review cycle includes providing detailed data products (DDPs) of individual system and site performance results to the individual data provider. DDPs also identify the individual contribution to CDPs. The NREL Fleet Analysis Toolkit is an internally developed tool for data processing and analysis structured for flexibility, growth, and simple addition of new applications. Analyses are created for general performance studies as well as application- or technology-specific studies.

## RESULTS

An objective of the ARRA fuel cell project—to deploy approximately 1,000 fuel cell systems in key early markets—was met within two years from the first deployments. Early market end users are operating 1,302 fuel cell units (Figure 1) at 301 sites in 20 states. At the end of 2012, 490 MHE fuel cell units were operating at seven facilities, and 806 backup power fuel cell units were operating at 385 sites.

The data provided a great deal of information regarding deployment numbers, installed capacity, reliability, and operation trends and characteristics. The number of fuel cell backup power systems deployed increased more than

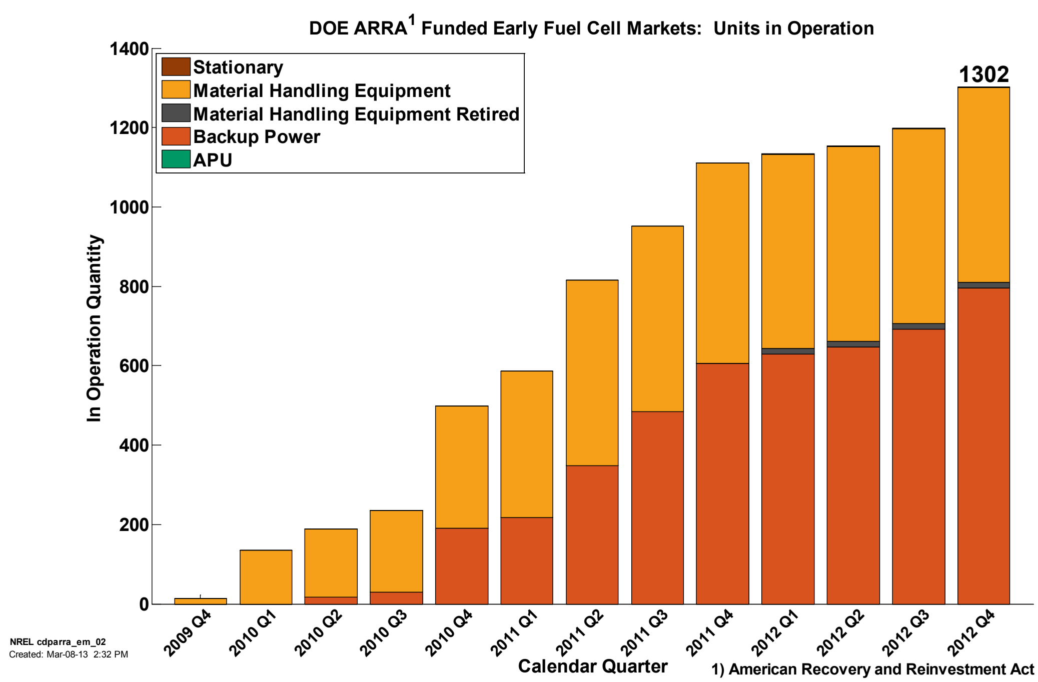


**FIGURE 1.** DOE ARRA-Funded Early Fuel Cell Markets: Units in Operation

18-fold—from 44 to 806—from the beginning to the end of the project. The start reliability of those systems was 99.6%. While system size ranged to greater than 10-kilowatt (kW) systems, 78% of the systems were in the 4–6 kW size range. Modules of smaller fuel cell units could be combined to adjust the system size to the individual site's needs. The fuel cells accumulated more than 1,153 hours of operation time with one unit successfully demonstrating a continuous run time of 65 hours during the data collection period. The average run time was 39 minutes, and the backup fuel cells were typically started less than once a month. The operational data were also used to characterize the interactions with grid outages and how best to use the systems for critical backup power applications.

There were only eight unsuccessful operations during the 2-year monitoring period. The major cause of five unsuccessful starts was system failure. These systems failures vary in cause, some related to the system and integration with the site. Three of the five system failures were related to a software error in certain situations, which was subsequently fixed. This real-world situational feedback is a critical product development step for fuel cell system manufacturers. The other three causes for unsuccessful starts were once for an emergency stop and twice for no fuel. Additional lessons learned here are based on how sites receive low-fuel alarms and training of site personnel. The emergency stop was likely the result of an operator testing the system and not a safety incident.

Many of the operation characteristics are driven by grid outages and stability. In order to better understand this dynamic, we analyzed grid data from a DOE database, the Electric Disturbance Event Annual Summaries [2] from 2002 to 2012. The data were analyzed to show numbers of incidents and average outage time. While the local grid will affect specific backup power unit operation, these national data can help illustrate what systems face. The number of incidents has seen an increasing trend, while the duration has decreased some. Over the 10-year period, the average number of incidents was 118, while the average duration by year was about 42 hours, or 38 hours when averaging per incident.

An animated movie was also developed that shows a visual representation of the grid incidents and the fuel cell operation [3,4]. The major grid outages are overlaid with installation locations and dates as well as operation data for select fuel cell backup power units and synthesized into a time-lapse geographical visualization map. The interactive map allows the user to click or play through the highlighted events to analyze usage patterns in conjunction with major grid outages (Figure 2).

The MHE fuel cell systems accumulated nearly 1.5 million hours by the end of 2012. High operation hours on the 490 systems indicate these systems are successfully performing and making an impact at the high-productivity facilities. These end-user facilities have had experience with

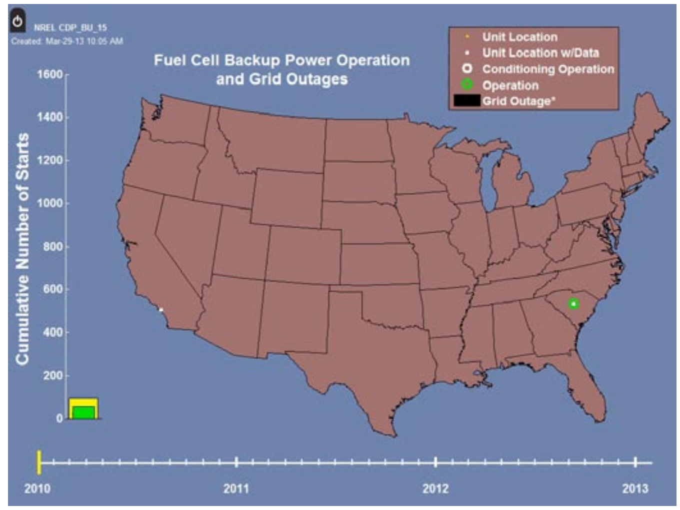


**FIGURE 2.** Snapshot of the Fuel Cell Backup Power Operation and Grid Outages Movie

battery and propane lifts and expected the fuel cell systems to meet and exceed performance expectations in a few key areas for both the retrofit and greenfield sites. These key performance areas include fill amount, operation per fill, operation per day (and year), mean time between failure, and voltage degradation (or fuel cell operation durability). These areas were studied in detail for each system, fleet, and lift classification.

The ultimate durability of fuel cell MHE is still being determined and will continue to be tracked by NREL. This is a key metric to the value proposition—if MHE are unable to meet the expectations of 2–3 times the life of a battery system, the value proposition may be in jeopardy. At least six systems had already demonstrated durability past the interim target of 10,000 hours. However, the majority (60%) of systems are currently projected to experience 10% voltage decay prior to reaching 10,000 hours of operation (Figure 3). It is important to note that the 10% level is a benchmark only and does not necessarily represent end-of-life for the fuel cell stack, and certainly not for the entire power plant, of which the stack is only one part.

The cost of ownership analysis studied the costs for maintenance, equipment, and refueling labor. This analysis compared these costs between fuel cell MHE and battery MHE. On an annualized cost per MHE per year, the fuel cell has approximately 10% savings for a Class I/II MHE. Factors that have a significant impact on the cost of ownership analysis results include deployment size, operation hours, and facility requirements.

Among components related to the infrastructure, hydrogen compressors contributed the highest number of maintenance events and maintenance labor hours, as well as the greatest number of hydrogen leaks. Half of all unscheduled maintenance events and nearly 60% of the repair

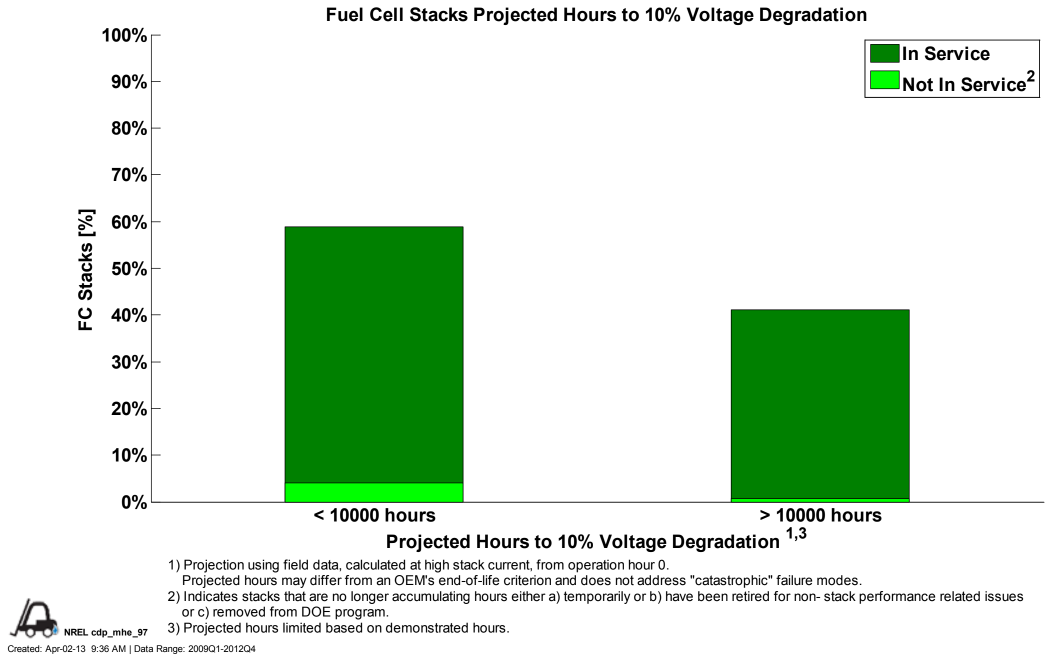


**FIGURE 3.** Study of Fuel Cell MHE Voltage Degradation Against an Interim Metric Of 10,000 Hours

labor hours were attributed to the hydrogen compressor (Figure 4). Some sites, in fact, have redundant compressors because the reliability of the machines is the limiting factor in station reliability, and they are crucial to the station's mission.

Reliability improved for many of the sites over time and allowed fuel cell power module original equipment manufacturers (OEMs) to learn valuable lessons that cannot be learned in a lab setting. These deployments allowed OEMs to improve their products, while giving them a real-world stage on which to prove their value. This ultimately enabled repeat orders from customers in the absence of ARRA funding.

Despite drive-offs, collisions, and even a few (non-hydrogen) fires, the hydrogen systems of the MHE and the infrastructure were never compromised, safety systems worked as intended, and no serious injuries related to the technologies were reported.

## CONCLUSIONS AND FUTURE DIRECTIONS

The results have shown that MHE and backup power are two markets where fuel cells are capable of meeting the operating demands, and these deployments can be leveraged to accelerate fuel cell commercialization. Analysis by NREL of the hydrogen fuel cell MHE and associated infrastructure deployed under ARRA shows that these systems are safe, productive, cost effective, available, durable, and add value to their respective facilities.

The deployment of 1,302 fuel cell units has established a significant data set of successful and safe operation in the hands of end users, has increased fuel cell manufacturing and support capabilities, and has translated lessons learned from the field into improved fuel cell systems for future operation. The aggregated data showcase the significant use and status at end-user sites over the last two years in MHE and backup power applications. The CDPs address a need for published results on the technology status that can be utilized by industry, developers, and end users. The analyses have evolved as the accumulated time and hydrogen dispensed both have increased, providing an insight into market behaviors and expectations. Continued analyses will be covered under Technology Validation and include the following:

- Quarterly analysis of operation data for MHE and backup power systems
- Publication of bi-annual technical CDPs
- Demonstration of a 72-hour continuous run time for a backup power fuel cell system
- Analysis of backup power value proposition

## FY 2013 PUBLICATIONS/PRESENTATIONS

**1.** Ramsden, T., "Fuel Cell-Powered Material Handling Equipment Cost of Ownership Analysis," Golden, CO: National Renewable Energy Laboratory, published April 2013. (report)

**2.** Kurtz, J., Sprik, S., Ainscough, C., Saur, G., Post, M., Peters, M., "ARRA Material Handling Equipment Composite Data Products:

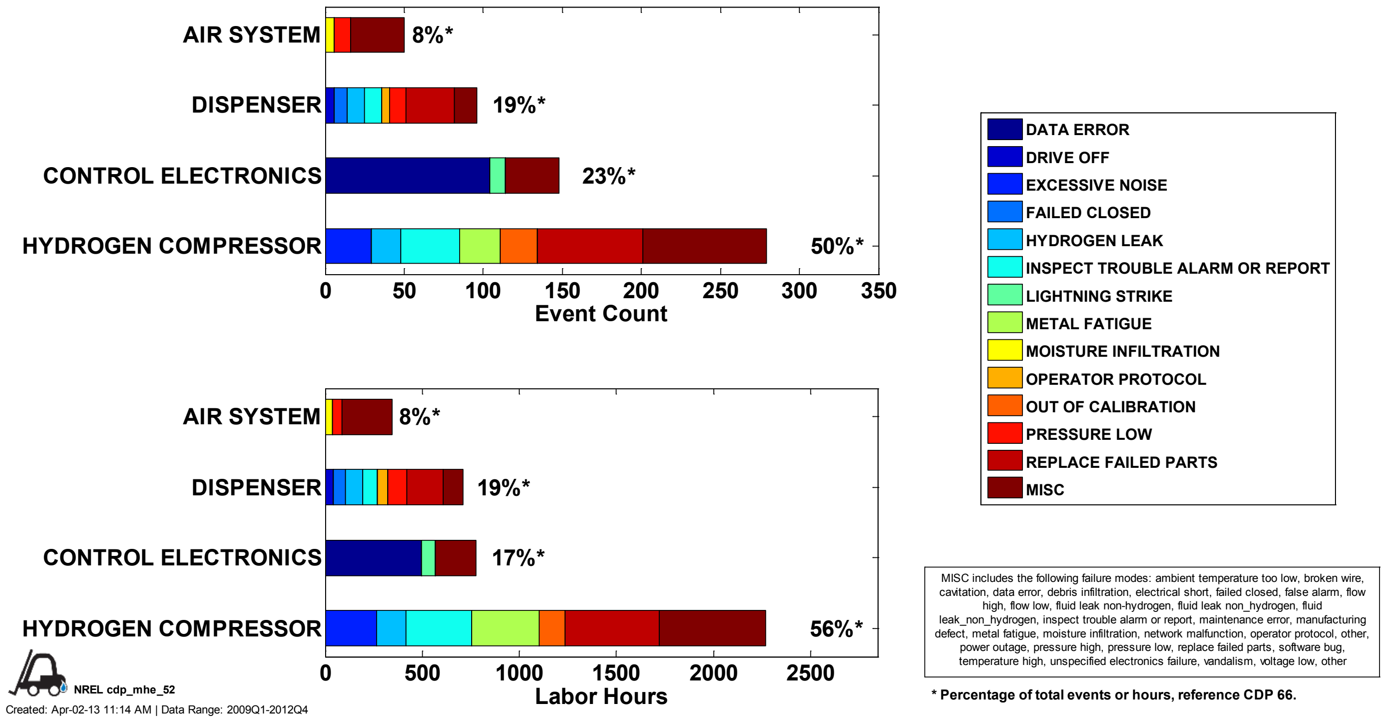


**FIGURE 4.** Breakdown of Failure Modes for the Top Four MHE Infrastructure Maintenance Categories

Data Through Quarter 4 of 2012," Golden, CO: National Renewable Energy Laboratory, published April 2013. Composite data products produced by NREL's early fuel cell market demonstrations team. (report)

**3.** Kurtz, J., Sprik, S., Ainscough, C., Saur, G., Post, M., Peters, M., "Spring 2013 Composite Data Products: Backup Power," Golden, CO: National Renewable Energy Laboratory, published April 2013. Composite data products produced by NREL's early fuel cell market demonstrations team. (report)

**4.** Harrison, K., Rivkin, C., Ainscough, C., Burgess, R., Peters, M., "CSD Safety and Reliability Data," Forecourt CSD Workshop, March 20, 2013. (presentation)

**5.** Kurtz, J., Sprik, S., Ainscough, C., Saur, G., Post, M., Peters, M., "Early Fuel Cell Market Deployments: ARRA and Combined (IAA, DLA, ARRA) – Quarter 4 2012 Composite Data Products," Golden, CO: National Renewable Energy Laboratory, published March 2013. Composite data products produced by NREL's early fuel cell market demonstrations team. (report)

**6.** Kurtz, J., Wipke, K., Sprik, S., Ramsden, T., Ainscough, C., Saur, G., Post, M., "Early Fuel Cell Market Deployments: ARRA and Combined (IAA, DLA, ARRA) - Quarter 3 2012 Composite Data Products," Golden, CO: National Renewable Energy Laboratory, published January 2013. Composite data products produced by NREL's early fuel cell market demonstrations team. (report)

**7.** Kurtz, J., Sprik, S., Ramsden, T., Saur, G., Ainscough, C., "What We've Learned from 2.5 Years of Early Market Fuel Cell Operation," 2012 Fuel Cell Seminar, November 6, 2012. (presentation)

**8.** Kurtz, J., Ainscough, C., Simpson, L., Caton, M., "Hydrogen Storage Needs for Early Motive Fuel Cell Markets," Golden, CO: National Renewable Energy Laboratory, published November 2012. Report on NREL's analyses of hydrogen storage performance needs and technology gaps. (report)

**9.** Kurtz, J., Sprik, S., Ramsden, T., Ainscough, C., Saur, G., "ARRA Material Handling Equipment Composite Data Products: Data Through Quarter 2 of 2012," Golden, CO: National Renewable Energy Laboratory, published October 2012. Composite data products produced by NREL's early fuel cell market demonstrations team. (report)

**10.** Kurtz, J., Sprik, S., Ramsden, T., Saur, G. "Fuel Cell Backup Power Technology Validation," 2012 International Telecommunications Energy Conference, October 1, 2012. (presentation)

**11.** Kurtz, J., Wipke, K., Sprik, S., Ramsden, T., Ainscough, C., Saur, G., "Fall 2012 Composite Data Products: Backup Power," Golden, CO: National Renewable Energy Laboratory, published October 2012. Composite data products produced by NREL's early fuel cell market demonstrations team. (report)

**12.** Kurtz, J., "Secure Data Center," Golden, CO: National Renewable Energy Laboratory, published August 2012. Introductory fact sheet about the Secure Data Center at NREL's Energy Systems Integration Facility. (fact sheet)

**13.** Kurtz, J., Wipke, K., Sprik, S., T., Ramsden, T., Ainscough, C., Saur, G., "Analysis Results for ARRA Projects: Enabling Fuel Cell Market Transformation," 2012 U.S. DOE Hydrogen Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting, Washington, D.C, May 2012. (presentation)

## REFERENCES

**1.** "Early Fuel Cell Market Demonstrations," website, Golden, CO: National Renewable Energy Laboratory, http://www.nrel.gov/hydrogen/proj_fc_market_demo.html.

**2.** Electric Disturbance Events (OE-417) are recorded by DOE's Office of Electricity Delivery & Energy Reliability. Annual summaries are available at http://www.oe.netl.doe.gov/oe417.aspx.

**3.** "Fuel Cell Backup Power Geographical Visualization Map," fact sheet, Golden, CO: National Renewable Energy Laboratory, December 2012, available at http://www.nrel.gov/docs/fy13osti/56740.pdf.

**4.** "Grid Outages and Fuel Cell Usage for Back-up Power," animated movie, Golden, CO: National Renewable Energy Laboratory, available at http://youtu.be/GZBLzP5Ka0Q.