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

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Project Start Date: October 2012
Project End Date: Project continuation and direction determined annually by DOE

## Overall Objectives

- 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
- Perform an independent assessment of technology in "real-world" operation conditions, focusing on fuel cell systems and hydrogen infrastructure
- Support market growth through reporting on technology status to key stakeholders and performing analyses relevant to the markets' value propositions

## Fiscal Year (FY) 2014 Objectives

- Conduct quarterly analysis of operation and maintenance data for fuel cell systems and hydrogen infrastructure
- Prepare bi-annual technical composite data products (CDPs)
- Publish a project completion report of status and performance of fuel cell 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 Milestones

This project contributes to the achievement of the following DOE milestone from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

- Milestone 4.3 Report safety event data and information from ARRA (American Recovery and Reinvestment Act) projects. (3Q 2013)

## FY 2014 Accomplishments

- Created or updated 32 backup power CDPs that were published every six months and included analysis results about deployment, fuel cell operation, fuel cell reliability, infrastructure operation, U.S. grid outage statistics, and cost of ownership.
- Summarized the backup power deployment of 1.99 MW of installed capacity and 852 systems operating in 23 states with an average of 4–6 kW capacity per site.
- Analyzed backup power operation (detailed data analysis of a subset) of 2,578 starts, 99.5% uninterrupted operation rate, 65 hours continuous demonstrated runtime, and 1,749 cumulative operation hours.
- Completed a backup power cost of ownership analysis that included cost estimates for capital, permitting and installation, maintenance, and fuel for multiple runtime scenarios for fuel cell, battery, and diesel systems. In the 72-hour runtime scenario, the cost of ownership of the fuel cell system, without incentives, is approximately 1.2 times higher than that of a diesel generator and more than 5 times lower than that of a battery system. In the same runtime scenario, the cost of ownership of the fuel cell system, with incentives, is approximately equal to that of the diesel generator and more than 6 times lower than that of a battery system.
- Analyzed mean time between interrupted operation (MTBIO) for the fuel cell backup power systems. The majority of systems (94%) did not experience any interrupted operation during the analysis period, and for the systems that experienced one or more of the 13 interrupted starts, the median MTBIO was 465 calendar days.

- Created or updated 75 MHE CDPs that were published every six months and included analysis results about deployment, fuel cell operation, fuel cell reliability, fuel cell safety, fuel cell durability, fuel cell maintenance, infrastructure operation, infrastructure safety, infrastructure maintenance, infrastructure reliability, and cost of ownership.
- Summarized the MHE operation and deployment of 490 units operating for more than 2 million hours and 329,834 hydrogen fills for 275,520 kilograms dispensed.
- Validated fill time to be less than 3 minutes, a key factor in the successful value proposition of fuel cell forklifts.
- Studied MHE durability against a long-term goal of 20,000 hours. Using an interim target of 10,000 hours, more than 50% of the fuel cell stacks have a projected voltage degradation time to 10% loss that is greater than 10,000 hours.
- Reported on the maximum operation hours, greater than 16,600, accumulated by one system.
- Studied MHE infrastructure utilization, which averages between 25% and 40% daily utilization, with maximum daily utilization demonstrated at more than 300 kg of hydrogen.
- Continued to evaluate data voluntarily supplied to the National Fuel Cell Technology Evaluation Center (NFCTEC), although MHE awards have all officially completed.

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## INTRODUCTION

The U.S. Department of Energy designated more than $40 million in 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.

The project includes both end users and system developers: Air Products, FedEx, GENCO, Nuvera Fuel Cells,[1] Plug Power, ReliOn,[1,2] Sprint,[1] and Sysco Houston. The evaluation focused on fuel cell stack durability, reliability, refueling, safety, and value proposition. The deployment partners provided approximately $53 million in industry cost share [1]. In addition to the ARRA co-funded fuel cell backup power demonstrations, DOE supported additional demonstration projects with other federal agencies through Interagency Agreements. The Department of Defense and the Federal Aviation Administration are two agencies with fuel cell backup power demonstrations that also submitted operational and deployment data to NREL. All results covered in this report, unless specified as strictly ARRA, will include both ARRA and Interagency Agreement fuel cell backup power sites. Almost all sites (~98%) were co-funded through ARRA.

[1] Projects have completed, according to the award agreement.
[2] ReliOn was acquired by Plug Power as of April 2014, just before preparation of this report. The brand name is being retained by Plug Power.

## APPROACH

The project's data collection plan builds on other technology validation activities. Operation, maintenance, and safety data for fuel cell system(s) and accompanying infrastructure are collected on site by project partners. NREL receives the data quarterly and stores, processes, and analyzes the data in NREL's NFCTEC. The NFCTEC is an off-network room with access provided to 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. Publications are uploaded to NREL's technology validation website [2] and presented at industry-relevant conferences. 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 CDPs are published. This review cycle includes providing detailed data products (DDPs) of individual system- and site-performance results to the specific data provider. DDPs also identify the individual contribution to the 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

Over approximately a two-year period, 1,330 fuel cell units (Figure 1) were deployed in stationary power, MHE, auxiliary power, and backup power applications with ARRA co-funding awarded through DOE's Fuel Cell Technologies Office. This surpassed an ARRA objective of deploying up to 1,000 fuel cell units.

As of December 2013, 852 fuel cell units were deployed in backup power applications. The prime backup power ARRA awards were to Sprint-Nextel and ReliOn, with a small number of demonstrations to Plug Power. Other project partners included PG&E; AT&T; Robins Air Force Base; Fort

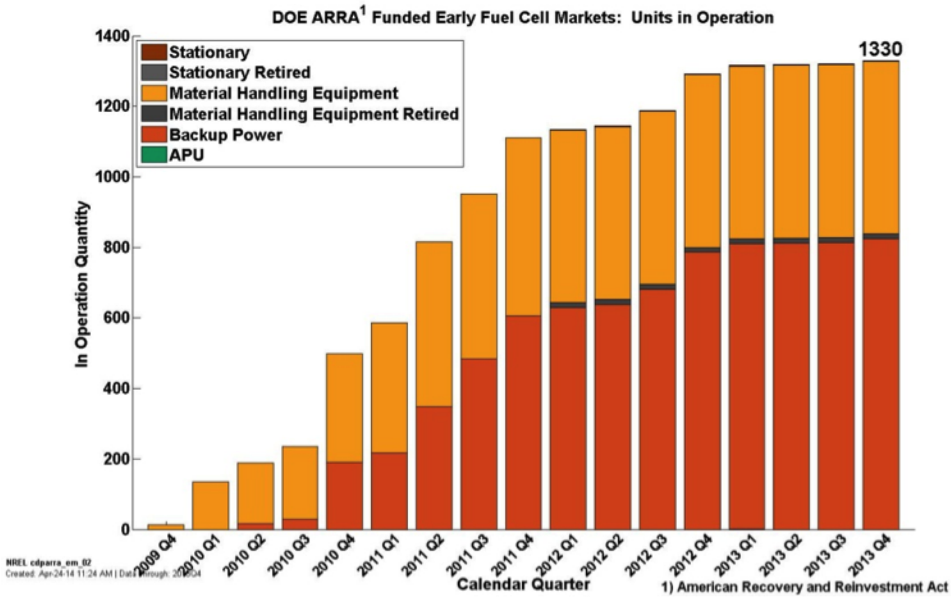



**FIGURE 1.** Early Market Fuel Cell Deployments Funded Through ARRA

Irwin; IdaTech (recently acquired by Ballard); Altergy; Air Products and Chemicals, Inc.; Champion Energy; Ericsson Services, Inc.; A&E Firms; Black & Veatch; and Burns & McDonnell.

Performance in backup power applications is related to the reliability and availability of the fuel cell backup system, the operating characteristics of the fuel cell, and the specific site. Degradation of the fuel cell performance is less of an issue due to the few hours that are accumulated in most backup power applications. These early market deployments did not provide monitoring of the voltage and current to estimate performance degradation; however, voltage degradation is being studied in other early market applications such as material handling and vehicles, and that analysis is expected to provide feedback for other fuel cell applications. The economics of backup power applications has three major factors: 1) the initial capital investment; 2) the opportunity costs of system downtime, which hinge on the reliability and availability of the backup system; and 3) the ongoing operating costs related to ongoing maintenance activities and fuel delivery cost. Other factors that can impact backup system selection are noise, emissions, and environmental issues, especially when considering urban versus rural installations.

The deployed fuel cell backup power units are being used in the field for backup of telecommunication towers, a vital service in emergencies. Detailed operation data are available for 136 of the units participating in the study from August 2009 through December 2013. During that time, the monitored units logged 1,764 hours of runtime. Much of that runtime was conditioning runs, which are used during regular system checks, especially after long periods of no operation, to maintain the health and reliability of the fuel cell. During the monitoring period, there were 2,583 uninterrupted operations and only 13 unsuccessful starts, resulting in a 99.5% availability value. For the purpose of this analysis, an operation is the system operating after a prompt to start. This prompt may either be for a routine system check or because of a grid outage. An interrupted operation is counted if the system did not start when requested or if the system did not complete the full operation period requested. We are not studying operation data on all of the DOE-sponsored deployments in order to keep the cost of data collection logistics to a minimum and the number of units deployed per the funding at a maximum.

An additional way to study the backup power system reliability is with MTBIO. The MTBIO averages all of the operation periods, in calendar days, based on interrupted operation events. As shown in Figure 2, the majority of systems (94%) did not experience an interrupted operation during this evaluation period. Of the 6% of systems that did experience an interrupted operation, the median MTBIO was 465 days. Each system had an MTBIO value, and there was not a weighting based on the total calendar period that the system was installed and operational. That is, a system recently installed may have a low MTBIO because of an early failure.

Backup power is a more intermittent service compared to other applications such as stationary power or vehicle power. The total operating times tend to be very low with long periods of inactivity. However, backup power for key infrastructure elements can aid emergency response during major storms or other devastating events and prevent loss of productivity, time, and money for other grid incidents.

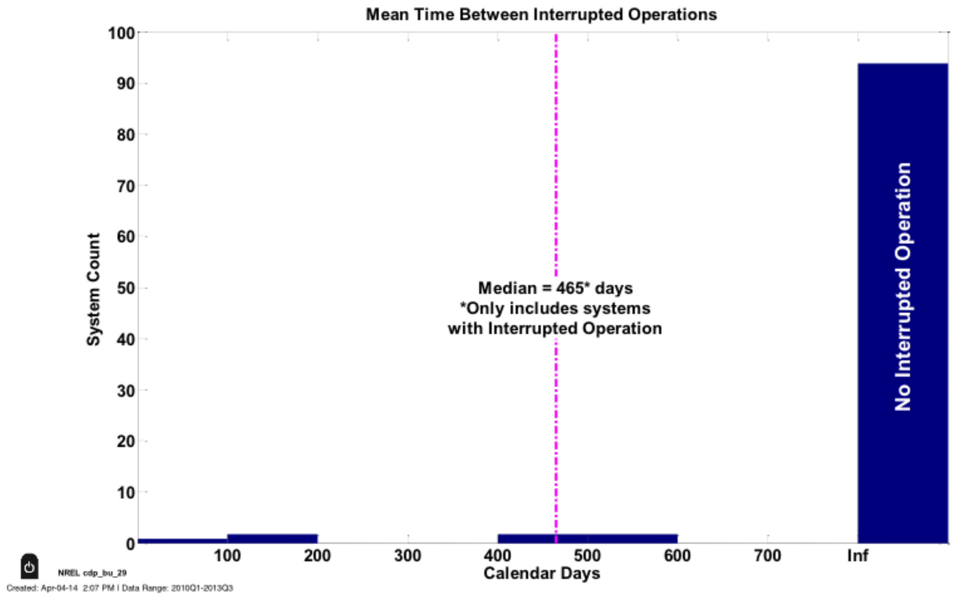



**FIGURE 2.** Mean Time Between Interrupted Operation for Backup Power Systems

The value is in the service backup power provides; however, understanding how the units are operated and needed will help in designing better systems that meet those requirements.

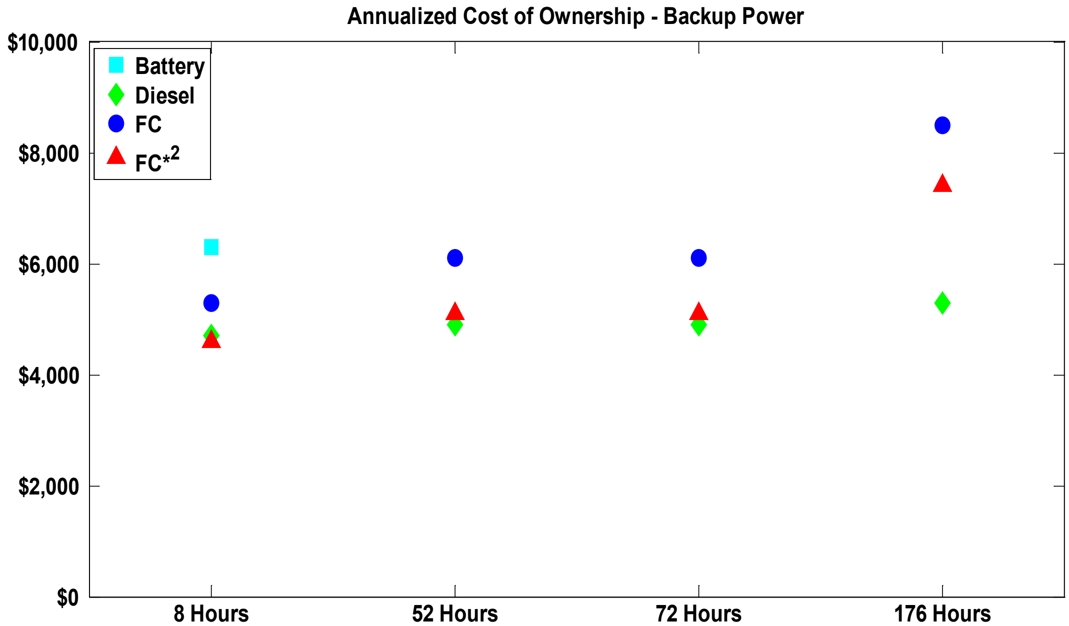
A benefit of fuel cell backup power is the ability for extended run times even if most outages are much shorter. The longest demonstrated continuous run time for a telecommunication tower fuel cell backup unit was 65 hours—close to 3 days; however, the average run time was only 42 minutes. During Hurricane Sandy (10/29/2012 through 11/12/2012), 122 ARRA-installed sites were located in the impact area from the Federal Emergency Management Agency Modeling Task Force analysis [3]. Not all of the systems were submitting detailed operation data to NFCTEC. Of the systems that were reporting data, five sites in New Jersey reported operation during Hurricane Sandy for a total of 112 hours of operation.

General performance metrics for backup power operators are reliability, cost, run time, and emissions. The cost of ownership data request included site description, system description, requirements, capital cost, operating and maintenance cost, and operating lifetime for fuel cells, batteries, and diesel systems. NREL completed a detailed cost of ownership analysis and published the results through CDPs and a report. Backup power operation can vary widely based on region, end user, and site-specific requirements, so a number of assumptions are made to compare three different backup power technologies (diesel, battery, and fuel cell) operating in similar circumstances in four run time scenarios (8, 52, 72, and 176 hours). Each run time scenario assumes the system operates for a specific amount of hours annually; for example. a system in the 72-hour scenario operates for 72 hours a year. The 72 hours could be accumulated through many shorter-run operations or through one continuous operation. It is important to note that the actual use of a telecommunication system is not as simple, nor as prescribed, as these run time scenarios.

Figure 3 displays the annualized cost estimates for each run time scenario and technology. The battery cost of ownership increases significantly with the higher run time scenarios, and this technology is unlikely to be a truly stand-alone solution for situations that require high run times. The fuel cell system with incentives[3] (denoted FC* in figures) is cost-competitive with the diesel generator, particularly in the 8-hour, 52-hour, and 72-hour run time scenarios. The fuel cell system has a higher efficiency and less frequent maintenance schedule than the diesel generator does, and the incentives offset the higher capital and installation costs.

As of December 2013, 490 fuel cell forklifts were in operation with one project (14 fuel cell forklifts) having completed the demonstration period. The prime forklift ARRA awards were to FedEx Freight East, GENCO, Nuvera Fuel Cells, and Sysco of Houston. The MHE fuel cell systems accumulated more than 2 million hours by the end of 2013. 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 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

[3] "The credit is equal to 30% of expenditures, with no maximum credit. However, the credit for fuel cells is capped at $1,500 per 0.5 kilowatt (kW) of capacity. Eligible property includes fuel cells with a minimum capacity of 0.5 kW that have an electricity-only generation efficiency of 30% or higher" [4].




| | 8 Hours | 52 Hours | 72 Hours | 176 Hours |
|---|---|---|---|---|
| Battery | $6300 | $24800 | $31300 | $67200 |
| Diesel | $4700 | $4900 | $4900 | $5300 |
| FC | $5300 | $6100 | $6100 | $8500 |
| FC*2 | $4600 | $5100 | $5100 | $7400 |

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1) Refer to the report for complete analysis details and assumptions (http://www.nrel.gov/docs/fy14osti/60732.pdf).
2) Fuel cell system with incentives (FC*), calculated as 30% of expenditures and capped at $3,000/kW of system capacity.

**FIGURE 3.** Annualized Cost-of-Ownership Technology Comparison for Multiple Run Time Scenarios (battery cost is only plotted for the 8-hour scenario)

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 (3,000–5,000 hours), the value proposition may be in jeopardy. The majority of systems are currently projected to experience 10% voltage decay past 10,000 hours of operation. 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.

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. The next three categories that lead in unscheduled maintenance events are control electronics, dispenser, and air system. Figure 4 depicts the maintenance labor hours per month for these four categories. Over a three-year period, maintenance hours for compressors and dispensers are fairly consistent. Over this same period, the control electronics and air system maintenance hours are most sporadic. This analysis has helped set up the NFCTEC analysts for a future review that looks more closely at these maintenance trends, possible reasons for the trends, and identification of research and development gaps.

## CONCLUSIONS AND FUTURE DIRECTIONS

- The ARRA co-funded deployment of early-market systems has enabled a significant amount of industry growth and lessons learned. The deployment of 1,330 fuel cell units, the majority in the backup power and forklift applications, exceeded the ARRA target of 1,000 fuel cell units. Additionally, the deployment vitalized the industry in several ways, including quantification and validation of fuel cell systems. The successful deployments show the technical viability of a cleaner, efficient, and effective alternative to the incumbent backup power technologies.
- A reduction in capital and installation costs will result in a stronger value proposition for fuel cell systems as backup power solutions. The cost and difficulty

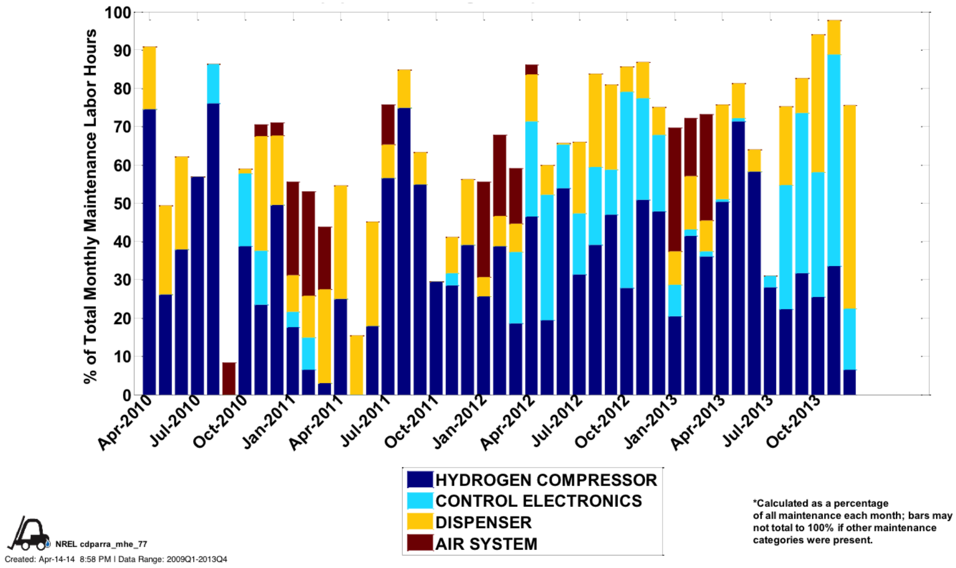


**FIGURE 4.** Maintenance Labor Hours per Month for Four Categories

associated with the permitting of hydrogen systems are other areas that require development for widespread deployment of fuel cell systems. These permitting challenges can vary greatly across the country and can be addressed by the consistent implementation of codes and standards.

## FY 2014 PUBLICATIONS/PRESENTATIONS

**1.** Kurtz, J.; Sprik, S.; Ainscough, C.; Saur, G. "Backup Power Cost of Ownership Analysis and Incumbent Technology Comparison." Golden, CO: National Renewable Energy Laboratory, expected in August 2014. (report)

**2.** Kurtz, J.; Sprik, S.; Post, M., Peters, M. "Forklift and Backup Power Data Collection and Analysis." 2014 DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Office Annual Merit Review and Peer Evaluation Meeting, June 2014. (poster presentation)

**3.** Kurtz, J.; Sprik, S.; Ainscough, C.; Saur, G.; Post, M.; Peters, M. "ARRA Material Handling Equipment Composite Data Products: Data Through Quarter 4 of 2013." Golden, CO: National Renewable Energy Laboratory, June 2014. (CDP report)

**4.** Kurtz, J.; Sprik, S.; Ainscough, C.; Saur, G.; Post, M.; Peters, M. "Spring 2014 Composite Data Products: Backup Power." Golden, CO: National Renewable Energy Laboratory, June 2014. (CDP report)

**5.** Kurtz, J.; Sprik, S. "National Fuel Cell Technology Evaluation Centers." DOE webinar, March 11, 2014. (presentation)

**6.** Kurtz, J.; Sprik, S.; Ainscough, C.; Saur, G.; Post, M.; Peters, M. "ARRA Material Handling Equipment Composite Data Products: Data Through Quarter 2 of 2013." Golden, CO: National Renewable Energy Laboratory, November 2013. (CDP report)

**7.** Kurtz, J.; Sprik, S.; Ainscough, C.; Saur, G.; Post, M.; Peters, M. "Fall 2013 Composite Data Products: Backup Power." Golden, CO: National Renewable Energy Laboratory, December 2013. (CDP report)

**8.** Kurtz, J.; Sprik, S.; Ainscough, C.; Saur, G.; Post, M.; Peters, M. "U.S. Department of Energy-Funded Performance Validation of Fuel Cell Material Handling Equipment." UK Hydrogen and Fuel Cell Association webinar, November 27, 2013. (presentation)

**9.** Kurtz, J.; Sprik, S.; Ainscough, C.; Saur, G.; Post, M.; Peters, M. "Hydrogen Fuel Cell Performance in Key Early Markets of MHE and Backup Power." 2013 Fuel Cell Seminar, October 23, 2013. (presentation)

**10.** Kurtz, J. "National Fuel Cell Technology Evaluation Center." Golden, CO: National Renewable Energy Laboratory, September 2013. (fact sheet)

## REFERENCES

**1.** *Highlights from U.S. Department of Energy's Fuel Cell Recovery Act Projects*. Washington, DC: U.S. Department of Energy, February 2014. http://energy.gov/eere/fuelcells/downloads/highlights-us-department-energys-fuel-cell-recovery-act-projects.

**2.** "Fuel Cell and Hydrogen Technology Validation." Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/hydrogen/proj_tech_validation.html.

**3.** "FEMA MOTF Hurricane Sandy Impact Analysis." FEMA Modeling Task Force Web Map, 2014. http://fema.maps.arcgis.com/home/webmap/viewer.html?webmap=307dd522499d4a44a33d7296a5da5ea0.

**4.** "Database of State Incentives for Renewables and Efficiency." U.S. Department of Energy, 2014. http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F&re=1&ee=1.