Analysis Results of ARRA Fuel Cell Early Market Projects

Hydrogen + Fuel Cells 2011
May 17, 2011

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

NREL Data Analysis Objectives

Overview of ARRA Fuel Cell Projects

Deployment and Performance Results

Backup Power

Material Handling Equipment
Objectives

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
Hydrogen Secure Data Center

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

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

1) Data exchange may happen more frequently based on data, analysis, and collaboration
2) Results published via NREL Tech Val website, conferences, and reports
ARRA Early Market Fuel Cell Project – Evaluating deployments in many applications, sites, and regions

Enabling Fuel Cell Market Transformation
Accelerate the commercialization of fuel cells, manufacturing, installation, maintenance, and support service through 12 awards

Deploy up to 1,000 FC Units

<table>
<thead>
<tr>
<th>COMPANY</th>
<th>APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delphi Automotive</td>
<td>Auxiliary Power</td>
</tr>
<tr>
<td>FedEx Freight East</td>
<td>Specialty Vehicle</td>
</tr>
<tr>
<td>GENCO</td>
<td>Specialty Vehicle</td>
</tr>
<tr>
<td>Jadoo Power</td>
<td>Backup Power</td>
</tr>
<tr>
<td>MTI MicroFuel Cells</td>
<td>Portable</td>
</tr>
<tr>
<td>Nuvera Fuel Cells</td>
<td>Specialty Vehicle</td>
</tr>
<tr>
<td>Plug Power, Inc. (1)</td>
<td>CHP</td>
</tr>
<tr>
<td>Plug Power, Inc. (2)</td>
<td>Backup Power</td>
</tr>
<tr>
<td>Univ. of N. Florida</td>
<td>Portable</td>
</tr>
<tr>
<td>ReliOn Inc.</td>
<td>Backup Power</td>
</tr>
<tr>
<td>Sprint Comm.</td>
<td>Backup Power</td>
</tr>
<tr>
<td>Sysco of Houston</td>
<td>Specialty Vehicle</td>
</tr>
</tbody>
</table>
ARRA Fuel Cell Units in Operation Current and Projected Quantities

DOE ARRA\(^1\) Funded Early Fuel Cell Markets: Units in Operation

<table>
<thead>
<tr>
<th>Calendar Quarter</th>
<th>APU</th>
<th>Backup Power</th>
<th>Material Handling Equipment</th>
<th>Stationary</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009 Q4</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
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<td>2010 Q1</td>
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<td></td>
<td></td>
<td>200</td>
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<tr>
<td>2010 Q2</td>
<td></td>
<td></td>
<td></td>
<td>400</td>
</tr>
<tr>
<td>2010 Q3</td>
<td></td>
<td></td>
<td></td>
<td>600</td>
</tr>
<tr>
<td>2010 Q4</td>
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<td></td>
<td></td>
<td>800</td>
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<tr>
<td>2011 Q1</td>
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<td></td>
<td></td>
<td>1000</td>
</tr>
<tr>
<td>2011 Q2</td>
<td></td>
<td></td>
<td></td>
<td>1200</td>
</tr>
<tr>
<td>2011 Q3</td>
<td></td>
<td></td>
<td></td>
<td>1400</td>
</tr>
<tr>
<td>2011 Q4</td>
<td></td>
<td></td>
<td></td>
<td>1600</td>
</tr>
</tbody>
</table>

1) American Recovery and Reinvestment Act
ARRA Early Fuel Cell Market Deployment Sites

16 States

Some site locations TBD
Some site location not yet in operation

- Material Handling Equipment (8 Sites and 504 FC Units)
- Backup Power (96 Sites and 228 FC Units)
- Stationary (1 Site and 6 FC Units)
- APU (1 Site and 1 FC Unit)

Number of FC Units in State/Site

NREL cdparra_em_03
Created: May-04-11 10:09 AM
FC Backup Power 10 CDPs

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
Site Location and Capacity

9 states with backup power sites

Backup Power Deployments

<table>
<thead>
<tr>
<th>State</th>
<th>kW Capacity</th>
<th>Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona</td>
<td>40</td>
<td>9</td>
</tr>
<tr>
<td>California</td>
<td>146</td>
<td>23</td>
</tr>
<tr>
<td>Colorado</td>
<td>24</td>
<td>5</td>
</tr>
<tr>
<td>Florida</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Illinois</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Indiana</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>Michigan</td>
<td>102</td>
<td>25</td>
</tr>
<tr>
<td>South Carolina</td>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td>Utah</td>
<td>36</td>
<td>9</td>
</tr>
</tbody>
</table>

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

Totals 432 85

Number of Sites in State

NREL cdp_bu_03
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Summary of Backup Power System Operation

<table>
<thead>
<tr>
<th>Sites</th>
<th>85</th>
<th>CDP-BU-#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployed Systems</td>
<td>189*</td>
<td>01</td>
</tr>
<tr>
<td>Total Successful Starts</td>
<td>408 (99.8%)*</td>
<td>04</td>
</tr>
<tr>
<td>Total Run Time</td>
<td>218 hours*</td>
<td>05</td>
</tr>
<tr>
<td>Total Hydrogen</td>
<td>32.3 kg*</td>
<td>06</td>
</tr>
</tbody>
</table>

Key Performance Metrics
Reliability
Low Emissions
Low Noise
Ease of Use
Remote Monitoring

* Through December 2010

1) FC system conditioning is an automated operation for regular system checks; activated after long periods of no operation.
>90% start operations last <60 minutes
Most of the starts are 20 minutes or less & 59% of the starts are for conditioning (Ref: CDP-BU-04)
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 the ARRA MHE Sites

- **468 Units**
- **8 Sites**

### MHE Deployment - ARRA

- **Units Deployed vs Facility Size**
- **Operation**
  - **Shifts per Day**
    - 0,26,72: 2
    - 0,14,0: 2
    - 35,0,0: 3
    - 25,0,0: 1-2
    - 45,14,2: 3
    - 0,36,100: 2
    - 40,0,0: 2
    - 0,25,70: 3
  - **Hours per Shift**
    - 8-10
    - 9.5
    - 8
    - 10
    - 8
    - 8-10
    - 8
  - **Days per Week**
    - 6
    - N/A
    - N/A
    - 7
    - 7
    - 6
    - 6

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

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

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

*Through December 2010
Daily Fuel Cell Operation Hours

Average Daily Fuel Cell Operation Hours per System - ARRA

- 25th and 75th Percentile
- Median

Range of Fleet Average Daily System Hours = 2 – 8 hours

48.7% of Systems Average > 6 hours a day

Average Daily Fuel Cell System Operation Hours

48.7% Fuel Cell Systems Average > 6 Hours Daily
Average Daily Dispensing Operations by Site

Range of Fleet Average Daily kgs/System = 0.2 – 0.7

Range of Fleet Average Daily Fills/System = 0.5 – 0.9

Shaded areas represent the min and max site average hydrogen use and fill frequency
Fuel Cell Voltage Durability Analysis

Operation Hours and Projected Hours to 10% Voltage Drop$^{(2-4)}$

- **Max of Site Projections**: 9519 hours
- **Ave of Site Projections**: 3002 hours

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

(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.
Fuel Cell Stack Power Degradation over Time

Little max power degradation over 4,000 operation hours (median drop ~12%)
Refueling Trends by Day of Week and Site

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

- **Total Hours:** 614,031
  - 49,272
  - 114,290
  - 450,251
- **Total Hours:** 547,653
  - 614,031
- **Total Miles:** 3,420,186
  - 2,872,533
- **Total Miles:** 3,420,186
  - 547,653
- **Total Hydrogen Amount:** 226,660
  - 96,286
  - 90,865
  - 39,477
  - 32
- **Total Hydrogen Fills:** 108,135
  - 4,541
  - 28,230
  - 75,364
- **99.8% Successful Starts**
- **189 units at 85 sites**
- **368 units at 7 sites**
  - > 450,200 Hours
  - > 90,800 H₂ kgs

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Contact Information & Website

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303-275-4061


Early Fuel Cell Market Demonstrations
Early fuel cell market demonstrations are focused primarily on using fuel cell technologies for material handling, backup power, and prime-power applications. The Department of Energy-sponsored demonstration projects support fuel cell market transformation activities and help foster the growth of fuel cell markets. In addition, the Department of Defense funds early fuel cell demonstration projects.

NREL receives operational data from these early market fuel cell demonstrations, analyzes, and reports on these data. By aggregating data across numerous industry teams and sites, NREL develops composite data products (CDPs), which provide relevant data results on the technology status and fuel cell performance without revealing proprietary data. These publicly available CDPs will help the development community understand the state of fuel cell technologies, identify areas for continued improvement, and provide data metrics that are important to the business case for these fuel cell markets.

This page provides the following resources:

- Composite Data Products
- Presentations and Publications
- Presentations Containing All CDPs

Composite Data Products
The public technical analysis results are generated in the form of composite data products. The following CDPs can be sorted by title, category, CDP number, and date updated. Download the CDPs as PowerPoint or JPEG files using the links in the two columns on the right. Download the current presentation containing all CDPs (PowerPoint 2.7 MB) or see the archived presentations containing all CDPs.