Data Analysis of Early Fuel Cell Market Demonstrations

Fuel Cell Seminar
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# Fuel Cell & Infrastructure Data Collection, Processing, & Analysis

| Demonstrations | Objectives | Methodology | Results |
Government Funded Early Fuel Cell Markets

- Funding sources include DOD Defense Logistics Agency, DOE American Recovery and Reinvestment Act (ARRA), and DOE Interagency Agreement (IAA)
- Diverse collection of early market fuel cell applications, project partners, and end users
- Expected fuel cell deployment: >1,000 units
- Fuel cell applications cover fuel cell forklifts, backup power, micro-CHP, APU, and portable power
Government Funded Fuel Cell Early Market Deployments – Separated by Funding Source & Application

Government Funded Early Market Fuel Cell Count

Projected Quantities Subject to Change

DoD Forklift
ARRA Forklift
IAA Backup
ARRA Backup
ARRA Stationary

FC Count

Install Quarter

0 200 400 600 800 1000 1200 1400

2009 Q1 2009 Q2 2009 Q3 2009 Q4 2010 Q1 2010 Q2 2010 Q3 2010 Q4 2011 Q1

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Government Funded FC Early Market Project Sites

Many site locations to be determined. Quantity and sites are subject to change. DOE is fund source for ARRA & IAA sites.

Project partners include DOE, DoD, FC developers, H₂ suppliers, and end users.
Early Fuel Cell Market Data Analysis Objectives

- Independent technology **assessment**; focused on fuel cell system and hydrogen infrastructure: performance, operation, and safety.
- **Leverage** data processing and analysis capabilities from the fuel cell vehicle Learning Demonstration project and DoD Forklift Demo.
- Establish a **baseline** of real-world fuel cell operation and maintenance data and identify technical/market barriers.
- Support market growth of fuel cell technologies by reporting on technology features relevant to the **value proposition**
- Report on technology to fuel cell and hydrogen communities, R&D, and **stakeholders**

**Detailed Data Products (DDPs)**
- Individual data analyses for each FC system and site
- Identify individual contribution to CDPs
- Only shared with partner who supplied data

**Composite Data Products (CDPs)**
- Aggregated data across multiple systems, sites, and teams
- Publish analysis results without revealing proprietary data
1) Data templates are created for each different application/report and are common to all partners in an application.

2) Data exchange may happen more frequently based on data, analysis, & collaboration

3) Results published via NREL Tech Val website, conferences, and reports
Data Reporting – Fuel Cell Forklift Example

• Fuel cell forklift application represents a significant early market opportunity for fuel cells
• 40 fuel cell forklifts in operation at DLA’s Defense Depot, Susquehanna Pennsylvania
• 9 months of detailed data available, including over 10,000 hydrogen fills
• Available data provides a real-world understanding of fuel cell forklift operations
• Data from this forklift installation and upcoming future installations will be used to develop Composite Data Products on early market deployments of fuel cell forklifts
Data on Deployments and Usage

Vehicle Hours: All OEMs, Gen 1 and Gen 2
Through 2009 Q2

Total Vehicle Hours = 100,284

- In Service
- Retired

Amount of Hydrogen Dispensed (Total = 6169 kg)

Forklift Fueling by Quarter

Total Fuelings = 7931

Number of Fuelings

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Data on Deployments and Usage (cont.)

Time at Fuel Cell Stack Power Levels:

- % Max Fuel Cell Power (Gross)
- Operating Time [%]

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Average Ambient Trip Temperature: DOE Fleet

- Max Op = 140.0 °F
- Min Op = -5.8 °F
- 26.9 % trips above 28 °C
- 1.4 % trips below 0 °C

Segmented Trips/Hour Histogram: DOE Fleet

- Trips/Hour based on 50 hour segments spanning stack operating period

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Data on Fuel Cell Value Proposition

Fuel Cell Vehicle Maintenance Events and Labor Hours

- Fuel Cell Vehicle Events (11075)
  - Vehicle (non-powertrain): 33%
  - Fuel Cell System: 58%
  - Powertrain: 3%
  - Battery: 5%

Fuel Cell Vehicle Labor (11849 hours)
- Vehicle (non-powertrain): 19%
- Fuel Cell System: 49%
- Powertrain: 19%
- Battery: 7%

Fuel Cell System Events (3704)
- Thermal Management: 4%
- Air System: 13%
- Controls, Electronics, Sensors: 38%
- Fuel System: 24%
- Fuel Cell Stack: 11%
- Other: 10%

Time to Fill - Dispenser Data
- Average Time = 3.49 min

Reliability
- 5th & 75th %
- Median
- Outlier

Availability
- 5th & 75th %
- Median
- Outlier

Number of Fills
- Time [min]
- 0 1 2 3 4 5 6 7
- 0 200 400 600 800 1000 1200 1400 1600

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1. Low fuel cell power limit is dependent on the fuel cell vehicle system and is unique to each company in this Learning Demonstration.

2. Acceptable low vehicle performance limit will be determined by retail customer expectations.

3. Power projection method based on the voltage degradation techniques, but uses max fuel cell power instead of voltage at a specific high current.

4. Stacks with less than 200 operation hours are in separate groups because the projection is based on operation data and with operation hours greater than 200 the degradation rate tends to flatten out.
Understanding H2 Tank Cycle Life in FC Forklifts

• Need to better understand expected H2 tank filling cycles in forklift applications
• Data currently being collected can inform that discussion
• Can aggregate data on operating hours per fill and per shift to better predict tank cycling
• Tank life is important factor in business case if shorter than the life of the lift

![Operating Time between Fuelings](image)

Average = 4.1 hours

Excludes Data > 12 hours. Data reflects site operations and not necessarily total available runtime.
Tank Cycling: Forklift Operations Per Shift & Per kg

Histogram of Operating Hours Per Lift

Range of Average Operating Hours Per Lift By Fleet

Accumulated Operating Hours

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Tank Cycling: Real-World Tank Cycles Per Month

- **Range of Tank Cycles By Month**
  - Per Shift/Month: Count
  - Per Month: 0, 20, 40, 60, 80, 100, 120

- **Range of Average Operating Hours Per Lift By Fleet**
  - Per Shift: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
  - Per kg: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Excludes Data > 12 hours. Data reflects site operations and not necessarily total available runtime.
Likely CDPs & Comparable FC Vehicle CDPs

Primary Factors of Infrastructure Safety Reports Through 2009 Q2

- Calibration/Settings/Software Controls
- Design Flaw
- Electrical Power to Site
- Environment (Weather, Power Disruption, Other)
- False Alarm
- Inadequate Training, Protocol
- Inadequate/Non-working Equipment
- Maintenance Required
- Mischief, Vandalism, Sabotage
- New Equipment Materials
- Not Yet Determined
- Operator/Personnel Error
- System Manually Shutdown

An INCIDENT is an event that results in:
- a lost time accident and/or injury to personnel
- damage/unplanned downtime for project equipment, facilities or property
- impact to the public or environment
- any hydrogen release that unintentionally ignites or is sufficient to sustain a flame if ignited
- release of any volatile, hydrogen containing compound (other than the hydrocarbons used as common fuels)

A NEAR-MISS is:
- an event that under slightly different circumstances could have become an incident
- unplanned H2 release insufficient to sustain a flame

Other Likely CDPs
- Durability
- Efficiency
- Power, Voltage, Energy
- Safety
- Reliability
- Maintenance
- Cost (installation and operation)
- Market Application Comparisons

FCV Learning Demo has 72 Data Results

Median Tank Level (At Fill) = 35%

1. Some refueling events not recorded/detected due to data noise or incompleteness.
2. The outer arc is set at 25% total refuelings.
3. Full = 5000 psi

Total refuelings = 7931

Tank Pressures before Refueling

Histogram of Fueling Rates All Light Duty Through 2009Q2

21,854 Events
Average = 0.78 kg/min
24% >1 kg/min
Data Results Reported to Multiple Stakeholders

Data Results

**Government**
Example Results:
- Market Impact
- Environmental Impact

**End User**
Example Result: Value Proposition

**Developer**
Example Result: Stack Durability
### Comparison of Fuel Cell and Battery Powered Forklifts – Cost Metrics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Performance/Cost of Fuel Cell Version Compared to Battery</th>
<th>Fuel Cell Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forklift Vehicle Cost &amp; Life</td>
<td>No Difference</td>
<td>N/A</td>
</tr>
<tr>
<td>Powerpack Cost (FC or Battery)</td>
<td>3x – 6x Higher</td>
<td>-</td>
</tr>
<tr>
<td>Powerpack Life (FC or Battery)</td>
<td>1 – 1.7x Longer</td>
<td>+</td>
</tr>
<tr>
<td># Powerpacks Needed</td>
<td>1/Lift vs 1/Shift/Lift</td>
<td>+</td>
</tr>
<tr>
<td>H2/Electricity Fuel Costs</td>
<td>4x – 6x Higher</td>
<td>-</td>
</tr>
<tr>
<td>H2 Fueling vs Battery Change</td>
<td>3x – 5x Faster</td>
<td>+</td>
</tr>
<tr>
<td>Powerpack Maintenance/Repair</td>
<td>??</td>
<td>TBD</td>
</tr>
<tr>
<td>H2 vs Charger Infrastructure</td>
<td>??</td>
<td>TBD</td>
</tr>
</tbody>
</table>

**Source:** Assessments based on *Identification and Characterization of Near-term Direct Hydrogen Proton Exchange Membrane Fuel Cell Markets* [Batelle Memorial Institute (April 2007)] coupled with forklift manufacturer industry information. Future progress reporting will be based on actual data from DOE and DOD fuel cell forklift demonstrations as reported to NREL.
## Comparison of Fuel Cell Forklifts – Other Performance Metrics

### PEM Fuel Cell Forklift to Conventional Forklift

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Advantage for Fuel Cell vs. Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Operating Temperature Range</td>
<td>+</td>
</tr>
<tr>
<td>Consistent Power Availability Over Shift</td>
<td>+</td>
</tr>
<tr>
<td>Continuous Runtime</td>
<td>+</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>+</td>
</tr>
<tr>
<td>Safety</td>
<td>?</td>
</tr>
</tbody>
</table>

### Parameter Advantage for FC vs. Diesel/Propane

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<tr>
<th>Parameter</th>
<th>Advantage for FC vs. Diesel/Propane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Emissions (Criteria Air Pollutants)</td>
<td>+</td>
</tr>
<tr>
<td>Lifecycle Greenhouse Gas Emissions</td>
<td>+</td>
</tr>
<tr>
<td>Noise</td>
<td>+</td>
</tr>
</tbody>
</table>

*Source: Assessments based on relevant literature coupled with forklift manufacturer industry information. Future progress reporting will be based on actual data from DOE and DOD fuel cell forklift demonstrations as reported to NREL.*