ARRA Material Handling Equipment Composite
Data Products

Data through Quarter 2 of 2013

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Printed on paper containing at least 50% wastepaper, including 10% post consumer waste.
25% of FC Systems > 6,870 Hours
Max Stack Hours = 16,610
Average Stack Hours = 4,720
Fueling Events by Quarter

Cumulative Fuelings = 291,114
Hydrogen Dispensed by Quarter

Cumulative Hydrogen Dispensed = 232,551 kg
Histogram of Fueling Times

ARRA Combined Fleet

255,493 Events
Average = 2.31 min

Number of Fueling Events [1,000]

Time (min)

Fill data for class 1, 2, and 3 trucks
Median Tank Pressure (At Fill) = 26%

1. Some refueling events not recorded/detected due to data noise or incompleteness.
2. The outer arc is set at 30% total refuelings.
3. Full Pressure is either 3600 psi or 5000 psi.
Operable Time Between Fuelings - ARRA
Combined Fleet

Average: 4.4 hours

Operating Hours Between Fuelings
Excludes Data > 12 hours

Site Averages

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.
Histogram of Fueling Rates

ARRA Combined Fleet

255,493 Events
Average = 0.33 kg/min

Fill data for class 1, 2, and 3 trucks
Histogram of Fueling Amounts

ARRA Combined Fleet

Average = 0.68 kg

Fill data for class 1, 2, and 3 trucks
1) 100% max fuel cell voltage is approximately open-circuit voltage
Operating Time at Fuel Cell Current Levels

The graph illustrates the operating time at various fuel cell current levels. The y-axis represents the percentage of fuel cell operating time, while the x-axis shows the percentage of rated max fuel cell current. The data is labeled as "Operating Time at Fuel Cell Current Levels - ARRA." The data range is from 2009Q4 to 2013Q2.
Operating Time at Fuel Cell Power Levels

% Rated Max Fuel Cell Power

% Fuel Cell Operating Time

NREL cdparra_mhe_17
Created: Sep-30-13  9:59 AM | Data Range: 2009Q4-2013Q2
Infrastructure Maintenance by Category

Total Events = 1,697
69% unscheduled

- Total Hours = 9,928
66% unscheduled

- hydrogen compressor: 40%
- dispenser: 16%
- control electronics: 14%
- feedwater system: 6%
- air system: 9%
- electrical: 11%
- valves: 6%
- miscellaneous: 5%
- classified: 13%
- multiple systems: 8%
- misc: 17%
- entire system: 11%

MSC includes the following failure modes: actuators, seal, storage, unspecified, thermal management, safety, software, fuel system, fittings&piping, reformer, sensors, other.
Infrastructure Maintenance Scheduled vs. Unscheduled
Number of Maintenance Events by Category

Total Events = 1,697
70% were unscheduled

Number of Labor Hours by Category

Total Hours = 9,928
66% were unscheduled
Average Infrastructure Site Quarterly Maintenance

Maintenance Events

Average # of Events Per Thousand Fills

Maintenance Hours

Average Hours Per Thousand Fills

Scheduled
Unscheduled
Operator
Average Daily Hydrogen Dispensed by Location

232,038 kg Hydrogen Dispensed
Average Daily Dispensing Operations by Site - ARRA

Shaded areas represent the min and max site average hydrogen use and fill frequency.
Average Daily Fuel Cell Operation Hours per Fleet - ARRA

Fleet
A  B  C  D  E  F  G  H  I  J  K  L

Average Daily Fuel Cell Operation Hours per System - ARRA

25th and 75th Percentile
Median
Average Daily Fuel Cell Operation Hours per System

Fuel Cell System Operation Hours Per Day

Average Daily Fuel Cell System Operation Hours

49.8% Fuel Cell Systems Average > 6 Hours Daily

1) Excludes 0 hour operation days
CDP-MHE-25

Infrastructure Safety Reports by Quarter

Infrastructure Safety Reports By Quarter

Total kg of H₂ Dispensed: 259,103
Total Reports: 90
Lifetime kg H₂ Dispensed per Report: 2,879

1) Near Miss is an event that under slightly different circumstances could have become an incident
   - unplanned H₂ release insufficient to sustain a flame

2) 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 uses as common fuels)
Refuel Events by Day of Week

Refueling by Day of Week

Day

% of Fills in a Day

Sun
Mon
Tues
Wed
Thur
Fri
Sat
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
Amount of Hydrogen Dispensed by Day of Week

Dispensed Hydrogen per Day of Week

- All Sites
- Individual Site

86 kg/day avg

Dispensed Hydrogen [% of total]

Daily Average [kg]

All Sites

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Breakdown of Maintenance Event Labor Hours: Infrastructure

50% of repairs require less than the mean of 7.0 hours of labor. Median labor hours: 7.0
Overall Site Infrastructure Reliability Growth: ARRA

Instantaneous MTBF improved for 2 of 6 sites for the last 20% of events.

Sites sorted by Increasing Age (Calendar Days)


2. % change in instantaneous MTBF
MISC includes the following categories:
- STORAGE
- FUEL SYSTEM
- OTHER

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
Infrastructure Maintenance by Mode

Total Events = 1,697
70% unscheduled

- 14% data error
- 13% replace failed parts
- 12% inspect trouble alarm or report
- 10% flow low
- 8% metal fatigue
- 7% out of calibration
- 6% hydrogen leak
- 6% pressure high
- 6% pressure low
- 5% temperature high
- 4% fluid leak_non_hydrogen
- 4% flow high
- 3% excessive noise

Total Hours = 9,928
66% unscheduled

- 16% data error
- 15% replace failed parts
- 15% inspect trouble alarm or report
- 12% flow low
- 10% metal fatigue
- 9% out of calibration
- 8% hydrogen leak
- 7% pressure high
- 6% pressure low
- 5% temperature high
- 4% fluid leak_non_hydrogen
- 4% flow high
- 3% excessive noise

MISC includes the following failure modes: animal damage, cavitation, debris infiltration, false alarm, fluid leak non_hydrogen, vandalism, voltage low, cleanup device failed, electrical short, maintenance error, network malfunction, fluid leak non-hydrogen, broken wire, manufacturing defect, ambient temperature too low, power outage, unspecified electronics failure, failed open, software bug, lightning strike, drive off, moisture infiltration, operator protocol, failed closed, other.
CDP-MHE-48
Infrastructure Mean Time Between Failures

Site MTBF (Calendar Days In Operation): Infrastructure

1. Cumulative Mean Time Between Failure
NREL cdp_mhe_49
Created: Sep-26-13  9:47 AM | Data Range: 2009Q1-2013Q2

1. Cumulative Mean Time Between Scheduled Maintenance. Includes Preventative and Upgrades
These represent the top four equipment failure categories from all combined data.

*IEC 61164 β
**CDP-MHE-51**

Infrastructure Hydrogen Leaks by Equipment Type

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**Total Events = 59**

100% unscheduled

- 47% hydrogen compressor
- 5% dispenser
- 5% fittings&piping
- 21% valves
- 5% seal
- 16% reformer
- 5% storage
- 5% misc

**Total Hours = 531**

100% unscheduled

- 42% hydrogen compressor
- 21% dispenser
- 21% fittings&piping
- 6% valves
- 6% seal
- 6% reformer
- 1% misc

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1 Event Count

- classified events: 58
Failure Modes for Top Four Infrastructure Equipment Categories

- **AIR SYSTEM**: 10%*
- **CONTROL ELECTRONICS**: 19%*
- **DISPENSER**: 20%*
- **HYDROGEN COMPRESSOR**: 51%*

* Percentage of total events or hours, reference CDP 66.

MISC includes the following failure modes: ambient temperature too low, broken wire, cavitation, data error, debris infiltration, electrical short, failed closed, false alarm, flow high, flow low, fluid leak non-hydrogen, fluid leak non_hydrogen, fluid leak_non_hydrogen, inspect trouble alarm or report, maintenance error, manufacturing defect, metal fatigue, moisture infiltration, network malfunction, operator protocol, other, power outage, pressure high, pressure low, replace failed parts, software bug, unspecified electronics failure, vandalism, voltage low, other.

* Percentage of total events or hours, reference CDP 66.
Mean Calendar Days Between Safety Reports (MTBSR): Infrastructure

Mean Calendar Days Between Incidents

Mean Calendar Days Between Near Miss

Site MTBSI² (Calendar Days in Operation)
²Mean Time Between Safety Incident (days)

Site MTBSNM³ (Calendar Days in Operation)
³Mean Time Between Safety Near Miss (days)

Site MTBSE¹ (Calendar Days in Operation)
¹Cumulative Mean Time Between Safety Report (days)
CDPARRA-MHE-62
Final Pressure of Hydrogen Fills

Fueling Final Pressures

- 250 bar Fills (200 to 315 bar)
  - Avg Final Pressure = 255 bar
  - % of Fills > 250 bar = 69%
  - Number of Fills = 149644

- 350 bar Fills (> 315 bar)
  - Avg Final Pressure = 355 bar
  - % of Fills > 350 bar = 52%
  - Number of Fills = 64138

*The line at 315 bar separates 250 bar fills from 350 bar fills. It is slightly over the allowable 125% of nominal pressure (312.5 bar) from SAE J2601.
CDPARRA-MHE-65
Details of Back-to-Back Fills

**Histogram of Time Between Fuelings**

- 34% of fills are within 0-5 minutes of each other.
- 25% of fills have more than 20 minutes between them.
- 266085 Total Fills

**Final Pressures for Fills with <5 Minutes in Between**

*Time is from end of fill to start of next fill.
Delivered Hydrogen Infrastructure Maintenance By Equipment Type

Total Events = 1,330
63% unscheduled

- 51% hydrogen compressor
- 20% dispenser
- 19% control electronics
- 10% air system

Total Hours = 8,814
62% unscheduled

- 58% hydrogen compressor
- 18% dispenser
- 14% control electronics

Miscellaneous (MISC) includes the following failure modes: seal, fuel system, thermal management, storage, electrical, fittings & piping, safety, software, valves, sensors, other.

Event Count:
- Classified events 1: 841
- Multiple systems: 272
- Misc: 142
- Entire system: 75

Created: Sep-26-13  9:47 AM | Data Range: 2009Q1-2013Q2
Fill Counts per Hour

Average: 6.8 per hour
Median: 5.0 per hour
Max: 39.0 per hour
Fill Amount per Hour

Hydrogen Dispensed Per Hour - ARRA

Average: 4.7 kgs per hour
Median: 3.5 kgs per hour
Max: 52.5 kgs per hour
Station Usage

Station Usage

Maximum Daily Fills
Average Daily Fills

Station (Sorted By Increasing Max Daily Amount)

Fills Per Day

1Average daily fills considers only days when at least one fill occurred
Station Capacity Utilization

Station Capacity Utilization

Station (Sorted By Increasing Max Daily Amount)

<table>
<thead>
<tr>
<th>Station</th>
<th>Max Daily Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20 kg</td>
</tr>
<tr>
<td>2</td>
<td>25 kg</td>
</tr>
<tr>
<td>3</td>
<td>73 kg</td>
</tr>
<tr>
<td>4</td>
<td>99 kg</td>
</tr>
<tr>
<td>5</td>
<td>102 kg</td>
</tr>
<tr>
<td>6</td>
<td>135 kg</td>
</tr>
<tr>
<td>7</td>
<td>293 kg</td>
</tr>
<tr>
<td>8</td>
<td>358 kg</td>
</tr>
</tbody>
</table>

1 Maximum quarterly utilization considers all days; average daily utilization considers only days when at least one filling occurred.
2 100% represents maximum daily amount dispensed for each individual site.

NREL cdparra_mhe_71
Created: Sep-26-13 10:23 AM | Data Range: 2009Q4-2013Q2
CDPARRA-MHE-72
Component Mean Time Between Failures

MTBF by Equipment Category: Infrastructure (Delivered H₂ Only)

- Median Site
- Lowest Site

MTBF (Days)

- AIR SYSTEM
- CONTROL ELECTRONICS
- DISPENSER
- FITTINGS & PIPING
- HYDROGEN COMPRESSOR
- SENSORS
- VALVES

Created: Sep-26-13 10:24 AM | Data Range: 2010Q1-2013Q2
CDPARRA-MHE-76
Component Repair Time

Equipment Category Repair Time: Infrastructure (Delivered H₂ Only)

Repair Labor Time (Hours)

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Created: Sep-28-13 10:08 AM | Data Range: 2010Q10-2013Q2

75% Percentile
Mean
Median
25% Percentile
CDPARRA-MHE-77

Equipment Percentage of Monthly Repair Labor Hours

*Calculated as a percentage of all maintenance each month; bars may not total to 100% if other maintenance categories were present.
Projected Hours to 10% Voltage Degradation

- **In Service**
- **Not In Service**

1) Projection using field data, calculated at high stack current, from operation hour 0. Projected hours may differ from an OEM's end-of-life criterion and does not address "catastrophic" failure modes.

2) Indicates stacks that are no longer accumulating hours either a) temporarily or b) have been retired for non-stack performance related issues or c) removed from DOE program.

3) Projected hours limited based on demonstrated hours.

Created: Sep-28-13 12:46 PM | Data Range: 2009Q1-2013Q2