ARRA Material Handling Equipment Composite Data Products

Data through Quarter 2 of 2012

J. Kurtz, S. Sprik, T. Ramsden, C. Ainscough, and G. Saur
Fuel Cell MHE Systems Deployed

Fuel Cell Units Deployed - ARRA

- Class III
- Class II
- Class I
- Retired Class II

Cumulative Systems Deployed

Year and Quarter:
- 2010 Q1
- 2010 Q2
- 2010 Q3
- 2010 Q4
- 2011 Q1
- 2011 Q2
- 2011 Q3
- 2011 Q4
- 2012 Q1
- 2012 Q2
Cumulative Fuel Cell Operation Hours - ARRA
Combined Fleet Through 2012Q2

25% of FC Systems > 5,260 Hours

- FC System
- Retired FC System
- Fleet Average FC System Hours

Fuel Cell Operation Hours

% Fuel Cell Systems

FC System

NREL cdparra_mhe_02
Created: Oct-04-12 12:42 PM
CDPARRA-MHE-03
Fueling Events by Quarter

Cumulative Fuelings = 197,991
Hydrogen Dispensed by Quarter

Cumulative Hydrogen Dispensed = 141,500 kg
Histogram of Fueling Times
ARRA Combined Fleet Through 2012Q2

186,876 Events
Average = 2.26 min

Fill data for class 1, 2, and 3 trucks
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.
Operating Time between Fueling

Operating Time Between Fuelings - ARRA
Combined Fleet

Average: 4.7 hours

Operating Hours Between Fuelings
Excludes Data > 12 hours

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

186,876 Events
Average = 0.32 kg/min

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

ARRA Combined Fleet

Average = 0.63 kg

Fill data for class 1, 2, and 3 trucks
Fuel Cell Operation Hours by Quarter

Fuel Cell Operation Hours by Quarter - ARRA

Total Hours = 1,248,384

Cumulative Fleet Hours [1000]

All Fleets
Individual Fleet

Total Operation Hours [1,000]


0 50 100 150 200 250 300 350 400 450 500

Created: Sep-21-12 9:11 AM
Operating Time at Fuel Cell Voltage Levels

1) 100% max fuel cell voltage is approximately open-circuit voltage
Operating Time at Fuel Cell Current Levels - ARRA

% Fuel Cell Operating Time

% Rated Max Fuel Cell Current

Created: Sep-21-12 9:12 AM
Operating Time at Fuel Cell Power Levels - ARRA
Infrastructure Maintenance by Category

**Infrastructure Maintenance By Equipment Type**

- Hydrogen compressor: 31%
- Feedwater system: 15%
- Dispenser: 14%
- Air system: 18%
- Electrical: 14%
- Control electronics: 9%
- Valves: 9%
- Reformer: 7%

**Miscellaneous**

- Hydrogen compressor: 31%
- Feedwater system: 15%
- Dispenser: 14%
- Air system: 18%
- Electrical: 14%
- Control electronics: 9%
- Valves: 9%
- Reformer: 7%

**Total Events = 1,126**
- 70% unscheduled

**Total Hours = 6,357**
- 66% unscheduled

**Event Count**

- Classified events: 781
- Multiple systems: 201
- Misc: 128
- Entire system: 16

*MISC includes the following failure modes: actuators, safety, seal, unspecified, software, thermal management, fuel system, fittings&piping, sensors, other.*
Infrastructure Scheduled & Unscheduled Maintenance by Category

**Infrastructure Maintenance Scheduled vs. Unscheduled**

Number of Maintenance Events by Category

**Total Events = 1,126**

71% were unscheduled

**Number of Labor Hours by Category**

**Total Hours = 6,357**

65% were unscheduled
Average Infrastructure Site Quarterly Maintenance

Maintenance Events

- Average # of Events Per Thousand Fills

09Q1 09Q2 09Q3 10Q1 10Q2 10Q3 10Q4 11Q1 11Q2 11Q3 11Q4 12Q1 12Q2

Maintenance Hours

- Average Hours Per Thousand Fills

09Q1 09Q2 09Q3 10Q1 10Q2 10Q3 10Q4 11Q1 11Q2 11Q3 11Q4 12Q1 12Q2

Scheduled
Unscheduled
Operator
Average Daily Hydrogen Dispensed by Location

141,027 kg Hydrogen Dispensed
CDPARRA-MHE-22

Average Daily Dispensing Operations by Site

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

Average Daily Fuel Cell Operation Hours per System - ARRA

Fleet

Hours

25th and 75th Percentile
Median

Created: Oct-05-12 12:07 PM
Average Daily Fuel Cell Operation Hours per System

Fuel Cell System Operation Hours Per Day

Hours of Operation Per Day

Days of Operation [%]

Average Daily Fuel Cell System Operation Hours

54.8% Fuel Cell Systems Average > 6 Hours Daily

Average Hours of Operation Per Day

Fuel Cell Systems [%]

1) Excludes 0 hour operation days
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
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
CDPARRA-MHE-42
Amount of Hydrogen Dispensed by Day of Week

Dispensed Hydrogen per Day of Week

Dispensed Hydrogen [% of total]

Daily Average [kg]

Sun Mon Tues Wed Thur Fri Sat

108 kg/day avg

Dispensed Hydrogen per Day of Week

All Sites
Individual Site

Created: Oct-04-12 12:19 PM
Breakdown of Maintenance Event Labor Hours: Infrastructure

51% of repairs require less than the mean of 7.4 hours of labor.
Median labor hours: 7.1
CDP-MHE-45
Infrastructure Reliability Growth


2. % change in instantaneous MTBF
Safety Reports By Equipment Category: Infrastructure

By Number of Reports
Total Near Miss Reports = 61

- 46% hydrogen compressor
- 23% fittings & piping
- 16% dispenser
- 5% seal
- 6% valves
- 6% reformer
- 6% Misc

By Number of Incidents
Total Incidents = 16

- 88% Misc

MISC includes the following categories:
- 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 = 1,126¹
71% unscheduled

Total Hours = 6,357
65% unscheduled

Infrastructure Maintenance By Mode

flow low: 5%
presence high: 6%
hydrogen leak: 6%
replace failed parts: 6%
pressure low: 6%
out of calibration: 6%
metal fatigue: 6%
fluid leak_non_hydrogen: 10%
data error: 12%
inspect trouble alarm or report: 8%
temperature high: 8%
flow high: 8%
excessive noise: 10%
failed closed: 8%
operator protocol: 5%

MISC includes the following failure modes: animal damage, cavitation, debris infiltration, vandalism, voltage low, power outage, cleanup device failed, electrical short, maintenance error, manufacturing defect, network malfunction, broken wire, ambient temperature too low, drive off, unspecified electronics failure, failed open, software bug, lightning strike, moisture infiltration, other
1. Cumulative Mean Time Between Failure

Site MTBF (Calendar Days In Operation): Infrastructure

Count of Sites

Site MTBF\(^1\) (Days)

0 25 50 75 100 125 150 175

0 1 2 3 4 5 6 7

CDP-MHE-48
Infrastructure Mean Time Between Failures
1. Cumulative Mean Time Between Scheduled Maintenance. Includes Preventative and Upgrades
These represent the top four equipment failure categories from all combined data.
Infrastructure Hydrogen Leaks by Equipment Type

Total Events = 48
100% unscheduled

- Hydrogen compressor: 43%
- Fittings & piping: 6%
- Valves: 19%
- Seals: 19%
- Reformers: 6%
- Dispensers: 6%
- Miscellaneous: 6%

Total Hours = 447
100% unscheduled

- Hydrogen compressor: 36%
- Fittings & piping: 25%
- Valves: 20%
- Seals: 5%
- Reformers: 8%
- Dispensers: 7%
- Miscellaneous: 1%

Event Count:
- Classified events: 47
- Misc: 1
Infrastructure Failures by Mode

Failure Modes for Top Four Infrastructure Equipment Categories

- **AIR SYSTEM**: 11%*
- **CONTROL ELECTRONICS**: 12%*
- **DISPENSER**: 22%*
- **HYDROGEN COMPRESSOR**: 47%*

*MISC includes the following failure modes: ambient temperature too low, broken wire, cavitation, debris infiltration, failed closed, flow high, flow low, fluid leak_non_hydrogen, inspect trouble alarm or report, maintenance error, manufacturing defect, metal fatigue, moisture infiltration, network malfunction, operator protocol, other, pressure high, software bug, vandalism, voltage low, other

* Percentage of total events or hours, reference CDP 66.
CDP-MHE-55

Infrastructure Mean Time Between Safety Events

Mean Calendar Days Between Safety Reports (MTBSR): Infrastructure

Mean Calendar Days Between Incidents

Mean Calendar Days Between Near Miss

1. Cumulative Mean Time Between Safety Report (days)

Site MTBSE\textsuperscript{1} (Calendar Days in Operation)

Site MTBSI\textsuperscript{2} (Calendar Days in Operation)

Site MTBSNM\textsuperscript{3} (Calendar Days in Operation)
Final Pressure of Hydrogen Fills

- **250 bar Fills (200 to 315 bar)**
  - Avg Final Pressure = 256 bar
  - % of Fills > 250 bar = 74%
  - Number of Fills = 122275

- **350 bar Fills (315 bar)**
  - Avg Final Pressure = 355 bar
  - % of Fills > 350 bar = 55%
  - Number of Fills = 47672

*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.*
Details of Back-to-Back Fills

Histogram of Time Between Fuelings

- 36% of fills are within 0-5 minutes of each other
- 23% of fills have more than 20 minutes between them
- 193171 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 = 759
- **Hydrogen compressor**: 47%
- **Dispenser**: 12%
- **Control electronics**: 11%
- **Air system**: 16%
- **Sensors**: 22%

61% unscheduled

Total Hours = 5,243
- **Hydrogen compressor**: 55%
- **Dispenser**: 6%
- **Control electronics**: 8%
- **Air system**: 8%
- **Sensors**: 20%

61% unscheduled

MISC includes the following failure modes: seal, fuel system, safety, thermal management, electrical, software, fittings & piping, valves, other

Event Count:
- Classified events: 472
- Multiple systems: 195
- Misc: 76
- Entire system: 16

Creation Date: Sep-21-12 2:59 PM
Fill Counts per Hours

Number of Fuelings Per Hour - ARRA

Average: 7.4 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

Amount Fueled in an Hour [kg]