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

Cumulative Systems Deployed

Class III
Class II
Class I
Retired Class II


136 206 206 172 308 402 467 504 504 504 504

122 40 40 76 121 146 221 258 258 258 258

14 35 35 60 60 100 100 100 100 100 100

Cumulative Systems Deployed

NREL cdparra_mhe_01
Created: Oct-04-12 12:31 PM
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

0.25 0.5 0.75 1.0 1.25 1.5 1.75 2.0 2.25 2.5 2.75 3.0 3.25 3.5 3.75 4.0 4.25 4.5 4.75 5.0 5.25 5.5 5.75 6.0 6.25 6.5 6.75 7.0 7.25 7.5 7.75 8.0

0 1 2 3 4 5 6 7

Cumulative Fuel Cell System Operation Hours - ARRA
Combined Fleet Through 2012Q2
Fueling Events by Quarter

Cumulative Fuelings = 197,991
CDPARRA-MHE-04
Hydrogen Dispensed by Quarter

Hydrogen Dispensed By Quarter - ARRA

Cumulative Hydrogen Dispensed = 141,500 kg
Refueling Time of Day - ARRA

Number of Refuelings

Time of Day [hours]
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
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.

Total refuelings$^1 = 81,892$
CDPARRA-MHE-08
Operation 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

Number of Fueling Events

Amount Fueled (kg)

Average Fueling Amounts (kg)

Range of Site Averages

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

Total Hours = 1,248,384

Comparison of Total Hours for All Fleets and Individual Fleet.
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

% Rated Max Fuel Cell Current

% Fuel Cell Operating Time

0 10 20 30 40 50 60 70 80 90 100

25 20 15 10 5 0

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

% Fuel Cell Operating Time

% Rated Max Fuel Cell Power

Operating Time at Fuel Cell Power Levels - ARRA

Created: Sep-21-12 9:13 AM
Infrastructure Maintenance by Category

Total Events = 1,126
70% unscheduled

- 31% hydrogen compressor
- 15% feedwater system
- 14% dispenser
- 9% air system
- 9% electrical
- 8% control electronics
- 7% valves
- 7% reformer

Total Hours = 6,357
66% unscheduled

- 50% hydrogen compressor
- 18% feedwater system
- 9% dispenser
- 9% air system
- 7% electrical
- 7% control electronics
- 6% valves
- 5% reformer

MISC includes the following failure modes: actuators, safety, seal, unspecified, software, thermal management, fuel system, fittings&piping, sensors, other

Event Count
- classified events: 781
- multiple systems: 201
- misc: 128
- entire system: 16

Created: Sep-21-12 2:51 PM
Infrastructure Maintenance Scheduled vs. Unscheduled
Number of Maintenance Events by Category

- **Total Events = 1,126**
- **71% were unscheduled**

- **MISC** includes the following categories:
  - ACTUATORS
  - SAFETY
  - SEAL
  - OTHER
  - UNSPECIFIED
  - SOFTWARE
  - THERMAL MANAGEMENT
  - FUEL SYSTEM
  - MULTIPLE SYSTEMS
  - FITTINGS&PIPING

Number of Labor Hours by Category

- **Total Hours = 6,357**
- **65% were unscheduled**
Average Daily Hydrogen Dispensed by Location - ARRA

141,027 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 System - ARRA

Fleet

Average Daily Fuel Cell Operation Hours per System - ARRA

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

Average Daily Fuel Cell System Operation Hours

54.8% Fuel Cell Systems Average > 6 Hours Daily

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 used as common fuels)
Refuel Events by Day of Week

Refueling by Day of Week

% of Fills in a Day

Sun  Mon  Tues  Wed Day  Thur  Fri  Sat

Created: Sep-20-12  3:42 PM
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

- All Sites
- Individual Site

108 kg/day avg

Dispensed Hydrogen [% of total]

Daily Average [kg]

Sun Mon Tues Wed Thur Fri Sat

0 5 10 15 20 30 60 90 120

108 kg/day avg

Created: Oct-04-12 12:19 PM
51% of repairs require less than the mean of 7.4 hours of labor. Median labor hours: 7.1
Overall Site Infrastructure Reliability Growth

Instantaneous MTBF improved for 1 of 6 sites for the last 20% of events.

2. % change in instantaneous MTBF
By Number of Reports
Total Near Miss Reports = 61

- Hydrogen compressor: 46%
- Fittings & piping: 23%
- Dispenser: 16%
- Seal: 5%
- Valves: 6%
- Reformer: 6%
- Misc: 23%

By Number of Incidents
Total Incidents = 16

- Hydrogen compressor: 6%
- Fittings & piping: 88%

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 = 1,126
71% unscheduled

Infrastructure Maintenance By Mode

- flow low: 10%
- pressure high: 8%
- hydrogen leak: 8%
- replace failed parts: 8%
- pressure low: 7%
- out of calibration: 7%
- metal fatigue: 6%
- fluid leak_non_hydrogen: 6%
- data error: 6%
- inspect trouble alarm or report: 5%
- temperature high: 5%
- flow high: 5%
- excessive noise: 5%
- failed closed: 5%
- operator protocol: 5%
- classified events: 4%
- preventative maintenance: 3%
- misc: 3%
- upgrade: 1%

Total Hours = 6,357
65% unscheduled

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
Site MTBF (Calendar Days In Operation): Infrastructure

1. Cumulative Mean Time Between Failure
Site MTBSM by Calendar Days In Operation: Infrastructure

1. Cumulative Mean Time Between Scheduled Maintenance. Includes Preventative and Upgrades

1. Site MTBSM \(^1\) (Days)

2. Site MTBPM \(^2\) (Days)

3. Site MTBU \(^3\) (Days)

Individual Site MTBPM \(^2\) All Sites

Individual Site MTBU \(^3\) All Sites

Mean Time Between Preventative Maintenance

Mean Time Between Upgrade

Count of Sites

Created: Sep-21-12  2:56 PM
These represent the top four equipment failure categories from all combined data.
Hydrogen Leaks By Equipment Category: Infrastructure

- Hydrogen compressor: 43%
- Fittings & piping: 19%
- Dispenser: 6%
- Valves: 6%
- Seal: 6%
- Reformer: 5%
- Miscellaneous: 7%

Total Events = 48
Total Hours = 447

Event Count:
- Miscellaneous: 1
- Classified: 47

100% unscheduled
Failure Modes for Top Four Infrastructure Equipment Categories

**AIR SYSTEM**
- DATA ERROR: 8%
- DRIVE OFF: 11%
- ELECTRICAL SHORT: 10%
- EXCESSIVE NOISE: 9%
- FAILED CLOSED: 5%
- HYDROGEN LEAK: 5%
- INSPECT TROUBLE ALARM OR REPORT: 5%
- LIGHTNING STRIKE: 3%
- METAL FATIGUE: 3%
- MOISTURE INFILTRATION: 3%
- OPERATOR PROTOCOL: 3%
- PRESSURE LOW: 3%
- REPLACE FAILED PARTS: 3%
- TEMPERATURE HIGH: 3%
- UNSPECIFIED ELECTRONICS FAILURE: 2%
- SOFTWARE BUG: 2%
- VANDALISM: 2%
- VOLTAGE LOW: 2%
- OTHER: 1%

**CONTROL ELECTRONICS**
- DATA ERROR: 8%
- DRIVE OFF: 11%
- ELECTRICAL SHORT: 10%
- EXCESSIVE NOISE: 9%
- FAILED CLOSED: 5%
- HYDROGEN LEAK: 5%
- INSPECT TROUBLE ALARM OR REPORT: 5%
- LIGHTNING STRIKE: 3%
- METAL FATIGUE: 3%
- MOISTURE INFILTRATION: 3%
- OPERATOR PROTOCOL: 3%
- PRESSURE LOW: 3%
- REPLACE FAILED PARTS: 3%
- TEMPERATURE HIGH: 3%
- UNSPECIFIED ELECTRONICS FAILURE: 2%
- SOFTWARE BUG: 2%
- VANDALISM: 2%
- VOLTAGE LOW: 2%
- OTHER: 1%

**DISPENSER**
- DATA ERROR: 8%
- DRIVE OFF: 11%
- ELECTRICAL SHORT: 10%
- EXCESSIVE NOISE: 9%
- FAILED CLOSED: 5%
- HYDROGEN LEAK: 5%
- INSPECT TROUBLE ALARM OR REPORT: 5%
- LIGHTNING STRIKE: 3%
- METAL FATIGUE: 3%
- MOISTURE INFILTRATION: 3%
- OPERATOR PROTOCOL: 3%
- PRESSURE LOW: 3%
- REPLACE FAILED PARTS: 3%
- TEMPERATURE HIGH: 3%
- UNSPECIFIED ELECTRONICS FAILURE: 2%
- SOFTWARE BUG: 2%
- VANDALISM: 2%
- VOLTAGE LOW: 2%
- OTHER: 1%

**HYDROGEN COMPRESSOR**
- DATA ERROR: 8%
- DRIVE OFF: 11%
- ELECTRICAL SHORT: 10%
- EXCESSIVE NOISE: 9%
- FAILED CLOSED: 5%
- HYDROGEN LEAK: 5%
- INSPECT TROUBLE ALARM OR REPORT: 5%
- LIGHTNING STRIKE: 3%
- METAL FATIGUE: 3%
- MOISTURE INFILTRATION: 3%
- OPERATOR PROTOCOL: 3%
- PRESSURE LOW: 3%
- REPLACE FAILED PARTS: 3%
- TEMPERATURE HIGH: 3%
- UNSPECIFIED ELECTRONICS FAILURE: 2%
- SOFTWARE BUG: 2%
- VANDALISM: 2%
- VOLTAGE LOW: 2%
- OTHER: 1%

*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.
Mean Calendar Days Between Safety Reports (MTBSR): Infrastructure

1. Cumulative Mean Time Between Safety Report (days)
2. Mean Time Between Safety Incident (days)
3. Mean Time Between Safety Near Miss (days)
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 = 122,275

- **350 bar Fills (> 315 bar)**
  - Avg Final Pressure = 355 bar
  - % of Fills > 350 bar = 55%
  - Number of Fills = 47,672

*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

36% of fills are within 0-5 minutes of each other
23% of fills have more than 20 minutes between them
193171 Total Fills

*Time is from end of fill to start of next fill.
CDP-MHE-66
Infrastructure Maintenance for Delivered Hydrogen

Delivered Hydrogen Infrastructure Maintenance By Equipment Type

Total Events = 759¹
61% unscheduled

- hydrogen compressor: 47%
- dispenser: 11%
- control electronics: 12%
- air system: 22%
- sensors: 8%

Total Hours = 5,243
61% unscheduled

- hydrogen compressor: 55%
- dispenser: 11%
- control electronics: 8%
- air system: 20%

¹ 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

Created: Sep-21-12 2:59 PM
Infrastructure Maintenance by Month

- Unscheduled
- Scheduled

Count of Maintenance Events by Month:
- January: 110
- February: 90
- March: 130
- April: 100
- May: 120
- June: 110
- July: 40
- August: 50
- September: 60
- October: 70
- November: 80
- December: 90

Created: Sep-21-12 3:00 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
Hydrogen Dispensed Per Hour - ARRA

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