Fall 2011 Composite Data Products: National FCEV Learning Demonstration

Keith Wipke, Sam Sprik, Jennifer Kurtz, Todd Ramsden, Chris Ainscough, and Genevieve Saur
NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at http://www.osti.gov/bridge
Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/help/ordermethods.aspx

Cover Photos: (left to right) PIX 16416, PIX 17423, PIX 16560, PIX 17613, PIX 17436, PIX 17721

Printed on paper containing at least 50% wastepaper, including 10% post consumer waste.
Fall 2011 Composite Data Products: National FCEV Learning Demonstration

October 5, 2011

Keith Wipke, Sam Sprik, Jennifer Kurtz, Todd Ramsden, Chris Ainscough, Genevieve Saur

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.
# CDP#9: Safety Reports – Vehicles

<table>
<thead>
<tr>
<th>Incident</th>
<th>Number of Reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank Scratch</td>
<td>3</td>
</tr>
<tr>
<td>Traffic Accident</td>
<td>2</td>
</tr>
<tr>
<td>H2 Leak - During Fueling</td>
<td>1</td>
</tr>
<tr>
<td>H2 Alarm - Fuel System</td>
<td>0</td>
</tr>
<tr>
<td>H2 Alarm - Passenger Compartment</td>
<td>0</td>
</tr>
</tbody>
</table>

### Safety Reports - Vehicle Operation

<table>
<thead>
<tr>
<th>Year</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Created: Aug-15-11 1:56 PM
CDP#22: Vehicle Operating Hours

Vehicle Hours: All OEMs, Gen 1 and Gen 2
Through 2011 Q2

Total Vehicle Hours = 146,584

Number of Vehicles

Total Vehicle Hours

In Service
Retired (1)

(1) Retired vehicles have left DOE fleet and are no longer providing data to NREL
Some project teams concluded in Fall/Winter 2009
Vehicle Miles: All OEMs, Gen 1 and 2
Through 2011 Q2

Total Vehicle Miles Traveled = 3,394,302

Number of Vehicles

Total Vehicle Miles

In Service
Retired (1)

(1) Retired vehicles have left DOE fleet and are no longer providing data to NREL.
Some project teams concluded in Fall/Winter 2009
CDP#24: Cumulative Vehicle Miles Traveled

Cumulative Vehicle Miles: All OEMs, Gen 1 and Gen 2
Through 2011 Q2

- Vehicle Miles Traveled
- Through 2011 Q2

Created: Sep-01-11 11:37 AM

National Renewable Energy Laboratory
Innovation for Our Energy Future
CDP#25: Vehicle H2 Storage Technologies

Vehicle Deployment by On-Board Hydrogen Storage Type

(1) Retired vehicles have left DOE fleet and are no longer providing data to NREL
(2) Two project teams concluded in Fall/Winter 2009
CDP#26: Cumulative H2 Produced or Dispensed

Through 2011 Q2

147,500 kg of hydrogen produced or dispensed since project inception

*Some project teams concluded in Fall/Winter 2009
CDP#31: Number of Online Stations

Cumulative Stations

- Continuing Outside of Project
- Retired Stations
- Current Project Stations

Number of Stations

Reporting Period

- 2005 Q2
- 2005 Q3
- 2005 Q4
- 2006 Q1
- 2006 Q2
- 2006 Q3
- 2006 Q4
- 2007 Q1
- 2007 Q2
- 2007 Q3
- 2007 Q4
- 2008 Q1
- 2008 Q2
- 2008 Q3
- 2008 Q4
- 2009 Q1
- 2009 Q2
- 2009 Q3
- 2009 Q4
- 2010 Q1
- 2010 Q2
- 2010 Q3
- 2010 Q4
- 2011 Q1
- 2011 Q2

6
12
7
CDP#32: Infrastructure Hydrogen Production Methods

Learning Demonstration Hydrogen Stations by Type

Delivered

Operating Outside of Project
Operating Within Project
Historical 2005-2009*

On-Site Production

Number of Stations

0 1 2 3 4 5 6 7 8 9

Compressed Liquid Pipeline Reforming Electrolysis

*Some project teams concluded Fall/Winter 2009. Markers show the cumulative stations operated during the 2005-2009 period.
Type of Infrastructure Safety Reports by Quarter Through 2011 Q2

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
CDP#38: Refueling Times

Histogram of Fueling Times
Vehicle and Infrastructure

- Green: 2006 MYPP Tech Val Milestone (5 kg in 5 min)
- Red Dotted: 2012 MYPP Tech Val Milestone (5 kg in 3 min)
- Gray: Through 2009Q4
- Yellow: After 2009Q4

Average = 3.26 min
86% <5 min

Average = 4.47 min
70% <5 min
CDP#39: Refueling Amounts

Histogram of Fueling Amounts
Vehicle and Infrastructure

Through 2009Q4

After 2009Q4

Average = 2.13 kg

Average = 2.67 kg

Amount Fueled (kg)

Number of Fueling Events

0 1 2 3 4 5 6 7

0 100 200 300 400 500 600 700 800 900 1000

Created: Aug-30-11 3:07 PM
CDP#40: H2 Tank Level at Refueling

Median Tank Level (At Fill) = 42%
Median Tank Level (At Fill) = 50%

Total refuelings\(^1\) = 27113
Total refuelings\(^1\) = 9034

1. Some refueling events not recorded/detected due to data noise or incompleteness.
2. The outer arc is set at 20% total refuelings.
3. If tank level at fill was not available, a complete fill up was assumed.
CDP#42: Refueling by Time of Day

1. Fills between 6 AM & 6 PM
2. The outer arc is set at 12% total Fill.
3. Some events not recorded/detected due to data noise or incompleteness.
CDP#43: Refueling by Day of Week

![Bar chart showing refueling by day of week through 2009Q4 and after 2009Q4.](image)

Through 2009Q4

After 2009Q4

% of Fills in a Day

Sun | Mon | Tues | Wed Day | Thur | Fri | Sat
---|---|---|---|---|---|---

Created: Aug-16-11  3:36 PM
CDP#44: Driving Start Time – Day

Driving by Time of Day

% of driving trips b/t 6 AM & 6 PM: 85.3%
% of driving trips b/t 6 AM & 6 PM: 74.5%
% of NHTS trips b/t 6 AM & 6 PM: 81.5%

1. Driving trips between 6 AM & 6 PM
2. The outer arc is set at 12% total Driving.
3. Some events not recorded/detected due to data noise or incompleteness.

2001 NHTS Data Includes Car, Truck, Van, & SUV day trips
ASCII.csv Source: http://nhts.ornl.gov/download.shtml#2001

Total Driving\(^3\) Events = 295222
Total Drive\(^3\) Events = 36839

NREL cdp_fcev_44
Created: Aug-24-11 4:28 PM

Innovation for Our Energy Future
CDP#45: Driving by Day of Week

Driving by Day of Week

% of Trips in a Day

Sun  Mon  Tues  Wed Day  Thur  Fri  Sat

2001 NHTS Data Includes Car, Truck, Van, & SUV day trips
ASCII Source: http://nhts.ornl.gov/download.shtml#2001
CDP#80: Miles Between Refuelings

Distance Driven Between Refuelings: All OEMs

- **Gen1**
  - Refuelings\(^1\) = 18941
  - Median distance between refuelings = 56 Miles

- **Gen2**
  - Refuelings\(^1\) = 6870
  - Median distance between refuelings = 81 Miles

- **Refuelings after 2009Q4**
  - Refuelings\(^1\) = 8964
  - Median distance between refuelings = 96 Miles

---

1. Some refueling events are not detected/reported due to data noise or incompleteness.
2. Distance driven between refuelings is indicative of driver behavior and does not represent the full range of the vehicle.
CDP#81: Average Trip Speed

Histogram of Average Trip Speed

- Average trip speed of 23.2 mph
- Average trip speed of 25.4 mph

1) Excludes trips <= 1 mile (40.9%)

2) 2001 NHTS data includes Car, Truck, Van & SUV day trips

1) Excludes trips <= 1 mile (19.4%)

179,424 trips
29,689 trips
CDP#82: Daily FC Operation Hours in
Automotive Application

Fuel Cell System Operation Hours Per Day

Average Daily Fuel Cell System Operation Hours

9.9% Fuel Cell Systems Average > 30 mins Daily
17.8% Fuel Cell Systems Average > 30 mins Daily
CDP#83: Hydrogen Dispensed by Day of Week

Dispensed Hydrogen per Day of Week

- All Stations
- Individual Stations

Day of Week

Dispensed Hydrogen [% of total]

Average kg

0 3 6 9 12 15 18 21 24 27 30

0 2 4 6 8 10 12 14 16 18 20

0 2 4 6 8 10 12 14 16 18

Sun Mon Tues Wed Thur Fri Sat

National Renewable Energy Laboratory
Innovation for Our Energy Future
CDP#84: Effect of Average Trip Speed on Fuel Economy

Effect of Average Trip Speed on Fuel Economy

(1) Data after 2009Q4. The data has been normalized to the max of the median curve for each fleet. Data binned every 5 mph for calculating median and percentiles.
Effect of Average Trip Length on Fuel Economy

(1) Data after 2009Q4. The data has been normalized to the max of the median curve for each fleet. Data binned every 5 miles for calculating median and percentiles.
CDP#86: Fuel Cell Stack Operation Hours

Fuel Cell Stack Operation Hours

- Stacks that are in service and accumulating operation hours.
- Stacks retired due to low-performance or catastrophic failure.
- 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.
- Only includes systems operating after 2009Q4.

25% of FC Stacks > 920 hours
CDP#87: Fuel Cell Stacks Projected Hours to 10% Voltage Degradation with Two Fits

1) Projection using field data, calculated at high stack current, from operation hour 0 or a steady operation period. 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.

4) Only includes systems operating after 2009Q4.

5) Not all stacks have a steady operation fit which is calculated from data after 200 hr break-in period. The steady operation starting hour is an approximation of the period after initial break-in where degradation levels to a more steady rate.
CDP#88: Comparison of Fuel Cell Operation Hours and Projected Hours to 10% Voltage Degradation

Comparison of Operation Hours and Projected Hours to 10% Voltage Degradation

- Stacks above the unity line have not operated past 10% voltage degradation.
- 24% of stacks are below the unity line and have operated past 10% voltage degradation.
- On average, these stacks have operated for 1,050 hours.

1) Indicates the projected hours to a 10% voltage degradation based upon curve fitting data from operation hour 0.
2) Projected hours limited based on demonstrated hours.
3) Stacks retired due to low-performance or catastrophic failure.
4) Each projection has uncertainty based on the confidence intervals of the fit.
5) Only includes systems operated after 2009Q4.
CDP#89: Fuel Cell Stack Durability as a Function of Voltage Drop

1) 10% Voltage degradation is a DOE metric for assessing fuel cell performance not an indication of an OEM's end-of-life criteria.
2) Projections using field data and calculated at high stack current.
3) 10th and 90th percentiles spans the range of stack projection. The included stacks satisfy a minimum number of operation hours and weighting factor.
4) The projected hours vary based on the percentage of voltage degradation, but the projected hours do not imply that all stacks will (or do) operate to these voltage degradation levels.
5) Each fleet has one voltage projection value that is the weighted average of the fleet's fuel cell stack projections.
6) Only includes systems operated after 2009Q4.
CDP#90: Max Fuel Cell Stack Power Degradation Over Operation

Median power difference from 0 hour segment to 1300 hour segment = -18.4%

1) Normalized by fleet median value at 200 hours.
2) Each segment point is median FC power (+/-50 hrs). Box not drawn if fewer than 3 points in segment.
3) Only includes systems operated after 2009Q4.