Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project –

Progress Update

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March 13, 2006
National Hydrogen Association Meeting

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Outline

- Project Overview and Industry Partners
- Data Collection and Processing
- Analysis Methodology
- First Public Results Now Available: Composite Data Products
Project Objectives and Targets

- Objectives
  - Validate H₂ FC Vehicles and Infrastructure in Parallel
  - Identify Current Status of Technology and its Evolution
  - Re-Focus H₂ Research and Development
  - Support Industry Commercialization Decision by 2015

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>2009*</th>
<th>2015**</th>
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</thead>
<tbody>
<tr>
<td>Fuel Cell Stack Durability</td>
<td>2000 hours</td>
<td>5000 hours</td>
</tr>
<tr>
<td>Vehicle Range</td>
<td>250+ miles</td>
<td>300+ miles</td>
</tr>
<tr>
<td>Hydrogen Cost at Station</td>
<td>$3/gge</td>
<td>$2-3/gge</td>
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</tbody>
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* To verify progress toward 2015 targets
** Subsequent projects to validate 2015 targets
Teams are Fielding Four Main* Types of Vehicles

*Validation also includes FCV Sprinter vans

*Validation also includes Kia Sportage FCVs
Sample Hydrogen Refueling Infrastructure

DTE/BP Power Park, Southfield, MI

LAX refueling station

Hydrogen and gasoline station, WA DC

Chino, CA

Photos: DTE

Photo: Shell Hydrogen

Photo: H2CarsBiz
Refueling Stations from All Four Teams
Creating Regional Networks

Northern California
- Additional Planned Stations
  - Ford & BP (3)
  - DaimlerChrysler & BP (TBD)
  - General Motors & Shell (1)

SE Michigan
- Additional Planned Stations
  - DaimlerChrysler & BP (2)
  - Ford (1)
  - Chevron & Hyundai/Kia (1)

Mid-Atlantic
- Additional Planned Stations
  - General Motors & Shell (2)

Southern California
- Additional Planned Stations
  - DaimlerChrysler & BP (2)
  - General Motors & Shell (2)
  - Chevron & Hyundai/Kia (2)

Florida

Legend
- Chevron & Hyundai/Kia
- DaimlerChrysler & BP
- Ford & BP
- General Motors & Shell
- Other Companies
## Data Collection: Overview

<table>
<thead>
<tr>
<th>Key Vehicle Data</th>
<th>Key Infrastructure Data</th>
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<tbody>
<tr>
<td>Stack Durability</td>
<td>Conversion Method</td>
</tr>
<tr>
<td>Fuel Economy (Dyno &amp; On-Road) and Vehicle Range</td>
<td>Production Emissions</td>
</tr>
<tr>
<td>Fuel Cell System Efficiency</td>
<td>Maintenance, Safety Events</td>
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<td>Maintenance, Safety Events</td>
<td>Hydrogen Purity/Impurities</td>
</tr>
<tr>
<td>Top Speed, Accel., Grade</td>
<td>Refueling Events, Rates</td>
</tr>
<tr>
<td>Max Pwr &amp; Time at 40C</td>
<td>$H_2$ Production Cost</td>
</tr>
<tr>
<td>Freeze Start Ability (Time, Energy)</td>
<td>Conversion, Compression, Storage and Dispensing Efficiency</td>
</tr>
<tr>
<td>Continuous Voltage and Current (or Power) from Fuel Cell Stack, Motor/Generator, Battery &amp; Key Auxiliaries: (Dyno &amp; On-Road)</td>
<td></td>
</tr>
</tbody>
</table>
Project Now Well Underway
Current Status of Data Reporting to the Hydrogen Secure Data Center at NREL

On-Road Data Received -- Running Totals

- # files
- Data Size (MB)

Graph showing the number of files and data size over time, with a significant increase in both from September 2004 to January 2006.
Vehicle Data Analysis: Automated Process from CD/DVD Delivery to Results

Data is delivered to NREL’s Hydrogen Secure Data Center (HSDC) on CD/DVDs

Data protected in HSDC for 5 years after data developed under EPACT 2005, Sec. 810

On-Road Fuel Economy: All Vehicles

Weighted Average Fuel Economy = 47.6 miles/kg H2

All trip lengths included in calculations

Range Histogram: Vehicle 1

Maximum range bw refuelings = 175 miles

Current (A) vs. Voltage (V)

Vpred = 427.9 - 15.78*\( \log(current) \) - 0.3370*current

10.0 hours of data per curve fit
12000 data points per curve fit

Operating Time (hrs) vs. Predicted Voltage (V)

Actual
CurveFit
95% CI: Observation
95% CI: CurveFit

@Current = 50A
@Current = 100A
@Current = 150A
@Current = 200A
@Current = 250A

Data is delivered to NREL’s Hydrogen Secure Data Center (HSDC) on CD/DVDs

Data protected in HSDC for 5 years after data developed under EPACT 2005, Sec. 810
Analysis Controlled by New NREL-Developed GUI: Fleet Analysis Toolkit (FAT)
FAT GUI Includes TripView to Dive Deeper and Investigate Individual Trips and Refuelings
On-Road Voltage Degradation Analysis: Polarization Curve Fitting, Piecewise in Time

Stack Degradation Analysis: Vehicle16-Stack2

2400 data points per curve fit
Time (stack oper hrs) = 164

Predicted (Curve Fit) Voltage vs. time for Vehicle16-Stack2

Not Real Data
Voltage Degradation Analysis: Individual-Stack Methodology

Voltage vs. Operating Hours at 300A: Vehicle16-Stack2

Nominal V @ zero hrs = 207V

Threshold for 10% drop = 186V

13 mV/hr

938 hrs

95.1%

1560 hrs

Created: 28-Feb-2006

Not Real Data
Voltage Degradation Analysis: Multiple-Stack-Average Methodology

Voltage vs. Operating Hours at 300A: All Stacks

- Nominal V @ zero hrs = 206V
- Threshold for 10% drop = 185V
- 11 mV/hr

Vehicle15-Stack1
Vehicle16-Stack2
Vehicle17-Stack1

Not Real Data
Composite Data Products are Main Output to Public and Hydrogen Community

A. Critical Program Metrics:

1. Fuel Cell Durability, Actual vs. DOE Targets, All OEM’s
2. Vehicle Ranges, Actual vs. DOE Targets, All OEM’s
3. H2 Production Cost. Actuals/Projections vs. DOE Targets

B. Composite Performance Tracking:

Vehicles

4. Reliability (FC System & Powertrain, MTEF)
5. Start Times vs. DOE Target
6. Fuel Economy: Dyno, On-Road
7. Normalized Vehicle Fuel Economy
8. Fuel Cell System Efficiency
9. Safety Incidents - Vehicle Operation
10. Weight % Hydrogen
11. Energy Density of Hydrogen Storage
12. Vehicle Hydrogen Tank Cycle Life

Hydrogen Infrastructure

13. H2 Production Efficiency vs. Process
15. H2 Production Cost vs. Process
16. H2 Purity vs. Production Process
17. Hydrogen Impurities - Range for Production Process A
18. Histogram: Refueling Rate
19. Average Maintenance Hours - Scheduled and Unscheduled
20. Safety Incidents - Infrastructure

C. High Level Program Progress:

Vehicles

21. Range of Actual Ambient Temperatures During Vehicle Operation – All Vehicle Teams
22. Histogram: # Vehicles vs. Operating Hours to Date
23. Histogram: # Vehicles vs. Miles Traveled to Date
24. Cumulative Vehicle Miles Traveled - All Teams
25. Progression of Low to High Pressure On-board H2 Storage

Hydrogen Infrastructure

26. Cumulative Hydrogen Production – All Teams
Accomplishment: Baseline Vehicle Chassis Dynamometer Testing Completed by All 4 Teams

- One vehicle per team per geographic region
- 11 vehicles tested using SAE J2572
- Some teams may elect to use test results for EPA certification
Dynamometer and On-Road Fuel Economy

(1) One data point for each make/model. Combined City/Hwy fuel economy per DRAFT SAEJ2572.
(2) Adjusted combined City/Hwy fuel economy (0.78 x Hwy, 0.9 x City).
(3) Excludes trips < 1 mile. One data point for on-road fleet average of each make/model.
(4) Calculated from on-road fuel cell stack current or mass flow readings.
Vehicle Range Based on Dyno Results and Usable H2 Fuel Stored On-Board

Vehicle Range

- 2015 Target
- 2009 Target

Vehicle Range (miles)

0 50 100 150 200 250 300

Data indicate improved H2 storage technologies capable of being packaged in a vehicle are necessary to meet range targets.

(1) Calculated from combined City/Hwy fuel economy (dyno test) per DRAFT SAE J2572 and usable fuel on board.

Created: 21-Feb-2006
Strong vehicle safety record indicates very few start-up issues, and no fundamental safety problems with the vehicles.
Safety Incidents – Infrastructure

Data indicate a strong infrastructure safety record; Station robustness to external forces and false alarms could be improved.
Vehicle H2 Storage Technologies Include 350 bar, 700 bar, and Liquid H2

First generation vehicle fleet still being deployed; Fleet is now largest H2 FC vehicle fleet in the world.

On-Board Hydrogen Storage Methods

- 5,000 psi tanks
- 10,000 psi tanks
- Liquid H2
Compressed and liquid H2 tanks meet durability and short term weight %, but don’t meet long-term weight % or volumetric capacity targets for vehicles.

Technical Status of On-Board H2 Storage Technologies Being Validated

Some near-term targets have been achieved with compressed and liquid tanks. Emphasis is on advanced materials-based technologies.
Hydrogen Purity Sampled from Stations Meets Target Majority of the Time

Hydrogen Purity Sampled from Stations\(^{(1)}\)

- **Range of Reported Data**
- **ISO FDTS 14687-2 Target**

Created: 21-Feb-2006

(1) Includes sampling from both electrolysis and reforming
Hydrogen Impurities Sampled from All Stations – Includes On-Site Reformation, Electrolysis, and Delivered H2

H₂ Impurities

- **Particulates**
  - Range of Reported Data
  - ISO FDTS 14687-2 Max
  - Reported Detection Limit

- **(N₂ + He + Ar)**

- **NH₃**

- **Total S Compounds**
  - *Includes SO₂, COS, and H₂S.*

- **CO**

- **CO₂**

- **O₂**

- **Total HC**

- **H₂O**

Created: 23-Feb-2006

Improved sampling technologies are necessary to improve low-concentration sensitivities.
Actual Vehicle Refueling Rates: Measured by Stations or by Vehicles

Histogram of Vehicle Refueling Rates

- 2006 Tech Val Milestone
- 2010 MYPP Adv Storage Materials Target

5 minute fill of 5 kg at 350 bar

3 minute fill of 5 kg at 350 bar

Future analyses could compare impact of communication and non-communication fills on fill rates and completeness of fill

Created: 21-Feb-2006
Fuel cell vehicles are currently able to operate in extreme conditions. Future tests will determine capability of starting in cold temperatures.
Vehicle Operating Hours and Miles Traveled Distribution

**Vehicle Hours: All OEM’s Combined through Q4 2005**

- Total Vehicle Hours = 7,831

**Vehicle Miles: All OEM’s Combined through Q4 2005**

- Total Vehicle Miles Traveled = 196,405

Data reflect youthful nature of current fleet

Created: 16-Feb-2006

Created: 28-Feb-2006
Rate of mileage accumulation increasing as initial fleets approach full deployment

Current deployment of new H2 refueling stations for this project is about 20% complete
Summary

• First year of the 5-year project completed
  – 59 vehicles now in fleet operation
  – Several new refueling stations opened
  – No major safety problems encountered

• Project has identified current technical status relative to program targets
  – Will track improvements from 2nd generation stacks/vehicles introduced mid-way through project

• Future public results will include:
  – FC durability, reliability, efficiency, and start-up times
  – H2 production cost, efficiency, and maintenance
Questions and Discussion

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