Fuel Cell Bus Evaluation Results

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Leslie Eudy, NREL

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Hydrogen Fuel Cell Technology Validation

Objectives:
– Validate H₂ fuel cell vehicles and infrastructure in parallel
– Identify current status and evolution of the technology
  • Assess progress toward technology readiness
  • Provide feedback to H₂ research & development and policy decision makers
  • Provide “lessons learned” on implementing next generation fuel cell systems into bus operation
DOE/NREL Technology Validation

Light-Duty Vehicle/Infrastructure Learning Demonstration Project

Fuel Cell/Hydrogen Bus Evaluations
## Current NREL FCB Evaluation Status

<table>
<thead>
<tr>
<th>Fleet</th>
<th>Vehicle/Technology</th>
<th>Number of buses</th>
<th>Evaluation Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>VTA and SamTrans</td>
<td>Gillig/Ballard fuel cell transit bus</td>
<td>3</td>
<td>Evaluation complete; report Nov 06</td>
</tr>
<tr>
<td>U.S. Air Force/</td>
<td>Shuttle bus: Hydrogenics and Enova, battery-dominant fuel cell hybrid</td>
<td>1</td>
<td>Shuttle bus in operation, data collection in process; Report Oct 07</td>
</tr>
<tr>
<td>Hickam Air Force Base</td>
<td>Delivery van: Hydrogenics and Enova, fuel cell hybrid</td>
<td>1</td>
<td>Van in service, data collection in process; Report Oct 07</td>
</tr>
<tr>
<td>AC Transit</td>
<td>Van Hool/UTC Power fuel cell hybrid transit bus integrated by ISE Corp.</td>
<td>3</td>
<td>Buses in service; evaluation in process; Reports Mar &amp; Oct 07</td>
</tr>
<tr>
<td>CTTRANSIT</td>
<td>Van Hool/UTC Power fuel cell hybrid transit bus integrated by ISE Corp.</td>
<td>1</td>
<td>Buses in service; evaluation in process</td>
</tr>
<tr>
<td>SunLine Transit Agency</td>
<td>Van Hool/UTC Power fuel cell hybrid transit bus integrated by ISE Corp.</td>
<td>1</td>
<td>Bus in service, evaluation in process, Reports Feb &amp; Sep 07</td>
</tr>
<tr>
<td></td>
<td>New Flyer ISE Corp. hybrid hydrogen internal combustion engine transit bus</td>
<td>1</td>
<td>Bus in service, evaluation in process, Interim report Feb &amp; Sep 07</td>
</tr>
</tbody>
</table>
FTA/NREL Fuel Cell Bus Evaluations

• Evaluate fuel cell buses developed under the National Fuel Cell Bus Program
  – Up to 14 FCBs in service around the U.S.
  – Niagara, NY; Hartford, CT; Boston, MA; Columbia, SC; Birmingham, AL; San Francisco, Oakland, Palm Springs, CA
  – Four different fuel cell manufacturers represented: Ballard, Hydrogenics, Nuvera, UTC Power

• Support to national and international FCB work groups to collaborate and share data
Why Evaluate Prototype Technology?

• Measure progress toward FCB commercialization

• Provide credible and consistent data collection & analysis for comparison

• Provide information to the transit industry and government

• Provide a “reality check”
AC Transit: Data Results

Data Period:
April 2006 – August 2007
AC Transit: Partners/Service Area

- Fleets:
  - AC Transit in Oakland, CA
  - Golden Gate Transit in San Rafael, CA
- Manufacturers
  - UTC Power
  - ISE Corp.
  - Van Hool
- Infrastructure
  - Chevron Technology Ventures
AC Transit: Study Buses

Evaluation Period: April 2006 - Aug 2007 (17 months)

• Buses
  – 3 fuel cell buses
  – 6 diesel buses (baseline)

• Mileage accumulation
  – FCB: 54,404 miles total, fuel cell system hours: 4,938
  – Diesel: 277,408 miles total

• Average monthly miles
  - FCB: 1,067 miles/month
  - Diesel: 2,720 miles/month
AC Transit: Infrastructure

Hydrogen Fueling Facility

- Chevron Technology Ventures
- Natural gas reformer
- 150 kg H₂ per day
- 366 kg storage
AC Transit: Infrastructure

Chevron – AC Transit Hydrogen Energy Station
Cumulative Fueling Rate Histogram (Apr 06 – Aug 07)

Summary
• 215 fills
• Avg fill = 21.8 kg
• Avg rate = 1.35 kg/min
• Total H₂ dispensed = 4,919 kg
AC Transit: Fuel Economy

Fuel economy Summary:
- FCBs: 6.17 mi/kg, 6.97 mpdeg, 33.7 L/100km
- Diesel buses: 4.03 mpg, 58.4 L/100km
AC Transit: Availability

Availability during evaluation period: 61%
- Buses were available 655 out of a possible 1,087 days

Availability by Category:

Reasons for unavailability:
AC Transit: Reliability

Miles Between Road Calls

- Diesel Buses – 4,474 MBRC total; 10,670 MBRC propulsion related only
- Fuel Cell Buses – 1,395 MBRC total; 1,649 MBRC propulsion related only
SunLine: Data Results

Data Period:
SunLine: Partners/Service Area

• Fleet
  – SunLine Transit Agency, Thousand Palms, CA

• Manufacturers
  – UTC Power
  – ISE Corp.
  – Van Hool
  – Ford
  – New Flyer

• Infrastructure
  – HyRadix
SunLine: Study Buses

Evaluation Period:  
Jan 2006 - Jun 2007 (18 months)

• Buses  
  – 1 fuel cell bus  
  – 1 HHICE bus  
  – 5 CNG buses (baseline)

• Mileage accumulation  
  – FCB: 37,005 miles, fuel cell system hours: 2,822  
  – HHICE: 38,853 miles  
  – CNG: 265,107 miles total

• Average monthly miles  
  – FCB: 2,056 miles/month  
  – HHICE: 2,159 miles/month  
  – CNG: 4,418 miles/month
SunLine: Infrastructure

Hydrogen Fueling Facility

- Hyradix
- Natural gas reformer
- 9 kg $\text{H}_2$ per hour max
- 180 kg storage
SunLine: Infrastructure

Cumulative Fueling Rate Histogram (Mar – Jun 2007*)

Summary
- 111 fills
- Avg fill = 19 kg
- Avg rate = 0.97 kg/min
- Total H₂ dispensed = 2,358 kg

* Prior to March 2007, this data was not available
SunLine: Fuel Economy

Summary:
FCB: 7.37 mi/kg, 8.33 mpdge
HHICE: 4.39 mi/kg, 4.96 mpdge
CNG: 2.95 mpg, 3.29 mpdge
# SunLine: Availability

<table>
<thead>
<tr>
<th>Category</th>
<th>Fuel Cell Bus</th>
<th>HHICE Bus</th>
<th>CNG Buses</th>
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<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Percent</td>
<td>Number</td>
</tr>
<tr>
<td>Planned Work Days</td>
<td>449</td>
<td></td>
<td>465</td>
</tr>
<tr>
<td>Days Available</td>
<td>293</td>
<td>65</td>
<td>357</td>
</tr>
<tr>
<td>Available</td>
<td>293</td>
<td>100</td>
<td>357</td>
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<tr>
<td>On-Route</td>
<td>283</td>
<td>97</td>
<td>334</td>
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<tr>
<td>Event/Demonstration</td>
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<td>1</td>
<td>6</td>
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<tr>
<td>Training</td>
<td>6</td>
<td>2</td>
<td>13</td>
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<tr>
<td>Not Used</td>
<td>2</td>
<td>0</td>
<td>4</td>
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<tr>
<td><strong>Unavailable</strong></td>
<td>156</td>
<td>100</td>
<td>108</td>
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<td>Fuel Cell Propulsion</td>
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<td>29</td>
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<td>Hybrid Propulsion</td>
<td>9</td>
<td>6</td>
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<td>ZEBRA Battery</td>
<td>29</td>
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<td>Air Conditioning</td>
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<td>Headsign</td>
<td>7</td>
<td>4</td>
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<tr>
<td>SunLine Maintenance</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Fueling Unavailable</td>
<td>31</td>
<td>20</td>
<td>31</td>
</tr>
</tbody>
</table>
SunLine: Reliability

Miles Between Road Calls

- CNG Buses – 10,604 MBRC total; 37,872 MBRC propulsion related only
- Fuel Cell Bus – 1,194 MBRC total; 1,322 MBRC propulsion related only
- HHICE Bus – 2,428 MBRC total; 2,775 MBRC propulsion related only
Achievements

• Successful demonstration of FCBs in several locations
• \( \text{H}_2 \) Fueling
  – More than 14,000 kg \( \text{H}_2 \) safely dispensed
• Technology progress
  – Lessons learned with bus and \( \text{H}_2 \) station are being incorporated into the next designs
• Information Dissemination
  – Results shared with industry
  – Training for fire officials and first responders
  – Public awareness
Industry’s Needs for Continued Successful FCB Implementation

- **Costs**: optimize the initial cost for buses and infrastructure
- **Performance & Reliability**: further optimize systems and increase availability
- **Durability**: control maintenance costs by addressing durability and analyze overall operational costs
- **Fleet Personnel Training**: focus on full fleet integration and training of staff
- **Continued Data Collection & Analysis**: more data is needed to fully understand all aspects and costs
For More Information

Contact: Leslie Eudy, NREL
Phone: 303-275-4412
Email: leslie_eudy@nrel.gov

NREL Hydrogen Technology Validation web page:
www.nrel.gov/hydrogen/proj_tech_validation.html