Technology Validation: Fuel Cell Bus Evaluations

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May 18, 2007

Presented at the 2007 DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program Review, Washington, DC

This presentation does not contain any proprietary, confidential, or otherwise restricted information
Overview

Timeline
- Evaluations typically cover two years of data
- Start date determined by bus delivery
- International collaboration ongoing

Budget
- FY 2007: $288K
- FY 2006: $288K
- FY 2005: $338K

Barriers
- A. Lack of fuel cell vehicle performance and durability data
- C. Lack of $H_2$ fueling infrastructure performance and availability data
- D. Maintenance and training facilities

Partners
- Fleets: Operational data, fleet experience
- Manufacturers: Vehicle specs, data and review
- Fuel Providers: Fueling data and review
- International: Exchange of results
Objectives

• Overall: Validate fuel cell and hydrogen technologies in transit applications
  – Show progress of the technology toward commercialization
  – Provide “lessons learned” on implementing next generation fuel cell systems in transit operations
  – Harmonize data collection efforts with other fuel cell bus demonstrations worldwide (in coordination with FTA and other U.S. and international partners)

• 2006
  – Complete analysis and reporting on VTA
  – Complete interim analysis and reporting for AC Transit and SunLine
Evaluation Approach

Two levels of data collected

• Non-sensitive data
  – Follows existing protocol
  – Data collected mainly from fleet
  – Results are made public after project team review

• Proprietary data
  – Collected from manufacturer
  – Protected in Secure Data Center at NREL
  – Only aggregate data products made public
### Evaluation of Hydrogen and Fuel Cell Buses in Four Fleets

<table>
<thead>
<tr>
<th>Fleet</th>
<th>Location</th>
<th>System Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santa Clara VTA, San Jose, CA</td>
<td>Ballard FC System: non-hybrid</td>
<td></td>
</tr>
<tr>
<td>AC Transit, Oakland, CA</td>
<td>UTC Power, ISE Corp: hybrid FCB</td>
<td></td>
</tr>
</tbody>
</table>
| SunLine, Thousand Palms, CA | UTC Power, ISE Corp: hybrid FCB  
ISE Corp: hybrid H\textsubscript{2} ICE |
| Hickam AFB, Honolulu, HI | Hydrogenics, Enova: hybrid system |

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*Images of buses from each location.*
Comparison of Hydrogen and Fuel Cell Buses to Conventional Technology

Targets for assessing the progress toward commercialization

- Performance characteristics
- Bus use
- Fuel economy
- Availability
- Reliability - miles between road call (MBRC)
- Cost - capital, fueling, and maintenance
Fleet Data Summary: Santa Clara VTA

Fuel Cell Bus (non-hybrid system)
- 17 months operation of 3 FCBs
- Total miles: 40,208
- Total FC system hours: 3,219

Diesel Bus (baseline)
- 17 months operation of 5 diesel buses
- Total miles: 360,447

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Average Monthly Miles

<table>
<thead>
<tr>
<th>Miles</th>
<th>Fuel Cell Bus</th>
<th>Diesel Bus</th>
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<tr>
<td>0</td>
<td>4,335</td>
<td>809</td>
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<tr>
<td>5,000</td>
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</table>

Fuel Economy (diesel equiv. gal)

<table>
<thead>
<tr>
<th>Mileage</th>
<th>Fuel Cell Bus</th>
<th>Diesel Bus</th>
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<tbody>
<tr>
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<td>3.52</td>
<td>3.98</td>
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<td>5,000</td>
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</tbody>
</table>

Percent Availability

<table>
<thead>
<tr>
<th>Availability</th>
<th>Fuel Cell Bus</th>
<th>Diesel Bus</th>
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</thead>
<tbody>
<tr>
<td>0%</td>
<td>85%</td>
<td>58%</td>
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<tr>
<td>20%</td>
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</tr>
<tr>
<td>40%</td>
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<tr>
<td>60%</td>
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<tr>
<td>80%</td>
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<td></td>
</tr>
<tr>
<td>100%</td>
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</tbody>
</table>

MBRC: Propulsion only

<table>
<thead>
<tr>
<th>MBRC:</th>
<th>Fuel Cell Bus</th>
<th>Diesel Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>11,242</td>
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<td>1,044</td>
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<tr>
<td>2,000</td>
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<td>0</td>
</tr>
</tbody>
</table>

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Fuel Cell Bus: ZERO EMISSIONS FUEL CELL BUS

Diesel Bus: BUS FOR CLEANER LANOS
Fleet Data Summary: Santa Clara VTA

Summary of Costs

- Average fuel cost (per kg or gal)
- Fuel cost per mile
- Total maintenance cost per mile
- Propulsion system maintenance cost per mile
- Total cost per mile

Evaluation Status

- Complete
- Report published

Fleet Data Summary: AC Transit

**Fuel Cell Bus (hybrid system)**
- 8 months operation of 3 FCBs
- Total miles: 27,065
- Total FC system hours: 2,338

**Diesel Bus (baseline)**
- 8 months operation of 6 diesel buses
- Total miles: 102,755

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**Average Monthly Miles**
- Fuel Cell Bus: 2,141
- Diesel Bus: 1,128

**Fuel Economy (diesel equiv. gal)**
- Fuel Cell Bus: 6.22
- Diesel Bus: 4.46

**Percent Availability**
- Fuel Cell Bus: 85%
- Diesel Bus: 77%

**MBRC: Propulsion only**
- Fuel Cell Bus: 8,563
- Diesel Bus: 1,230
Fleet Data Summary: AC Transit

Summary of Costs

- Average fuel cost (per kg or gal)
- Fuel cost per mile
- Total maintenance cost per mile
- Propulsion system maintenance cost per mile
- Total cost per mile

Evaluation Status

- Data collection ongoing
- Interim report published
- Second data report planned for fall 2007

Fleet Data Summary: SunLine

Fuel Cell Bus (hybrid system)
- 11 months operation of 1 FCB
- Total miles: 19,208
- Total FC system hours: 1,345

HHICE Bus
- 11 months operation of 1 HHICE bus
- Total miles: 23,661

CNG Bus
- 5 months operation of 5 CNG buses
- Total miles: 108,540

*HHICE – hybrid H₂ internal combustion engine
Fleet Data Summary: SunLine

Summary of Costs

- Average fuel cost (per kg or gal)
- Fuel cost per mile
- Total maintenance cost per mile
- Propulsion system maintenance cost per mile
- Total cost per mile

![Graph showing cost comparisons for FCB, HHICE, and CNG]

Evaluation Status

- Data collection ongoing
- Interim report published
- Second data report planned for fall 2007

Infrastructure Data Summary: VTA

VTA H₂ Fueling Station

- 460 fills
- Avg kg/fill = 30.9
- Avg rate = 1.93 kg/min
- Total H₂ dispensed = 14,024 kg
Infrastructure Data Summary: AC Transit

Chevron - AC Transit H₂ Energy Station

• 215 fills
• Avg kg/fill = 21.8
• Avg rate = 1.35 kg/min
• Total H₂ dispensed = 4,919

ACT fueling station:
• Chevron Technology Ventures
• Natural gas reformer
• 150 kg H₂ per day
• 366 kg storage
Hickam Air Force Base: Status

Demonstration of two fuel cell vehicles

Vehicles
- 1 ElDorado 30-ft bus
  - Enova battery-dominant hybrid FC system, Hydrogenics 20kW FC
- 1 step van
  - Enova hybrid FC system, Hydrogenics 60kW FC

Status
- H₂ fueling available in late 2006
- Bus operating as visitor shuttle on base and in surrounding area
- Step van in service as maintenance support vehicle
- Interim report scheduled for publication in fall 2007
International Collaboration

4th workshop held in Yokohama, Japan in October 2006

- Overall goal: enhance information sharing and data exchange between international FCB demos

- Group discussion:
  - Developed a list of performance data available to share from all projects
  - Listed concerns and issues that must be solved prior to sharing
  - Established action items and a timeline for accomplishment

- Planning 5th International Fuel Cell Bus Workshop in summer 2008
Future Work

• Remainder of FY 2007
  – Data analysis and draft preliminary data report on Hickam evaluation
  – Complete second data analysis and reports on AC Transit and SunLine
  – Collect more technical data on FCBs and infrastructure to complement DOE Controlled Fleet Demo

• FY 2008
  – Complete analysis and final data report on Hickam
  – Complete final data analysis and reports on SunLine and AC Transit
  – Initiate data collection for additional fleets
Summary

• Collected operational, performance, and cost data on 8 hydrogen fueled buses in real-world service at three transit agencies:
  – VTA: 17 months
  – SunLine: 11 months
  – AC Transit: 8 months

• Validated fuel cell bus performance characteristics equal to or better than diesel
  – Drivers report better acceleration and quiet operation

• Demonstrated that bus duty-cycle allows fast accumulation of miles/FC hours
  – Accumulated over 110,000 total miles and over 6,900 FC hours

• Collected performance and cost data on conventional technology to establish a baseline for tracking progress
  – Use of prototype FCBs is much less than standard buses
  – High cost for maintaining current generation prototype technology
Summary (continued)

- Fuel cell bus use less than baseline
  - Range from 50% below to 81% below standard bus use

- Fuel economy
  - Fuel economy results show need for hybridization
  - Improvement over conventional technology approaching 2X
  - Highly dependent on duty-cycle