Technology Validation: Fuel Cell Bus Evaluations

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NREL
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Overview

Timeline
• Evaluations typically cover 2 years of data
• Start date determined by bus delivery
• International collaboration ongoing

Technology Validation Barriers
• A. Vehicles
• B. Storage
• C. Hydrogen Fueling Infrastructure
• D. Maintenance and Training
• E. Codes and Standards

Budget
• FY 2006: $288K
• FY 2005: $338 K
• FY 2004: $238 K
### Overview: Partners

#### Operating Fleets
- AC Transit
- Santa Clara VTA
- SunLine
- Hickam AFB

#### Manufacturers/Systems Integrators
- Enova Systems
- Gillig/Ballard
- Van Hool/ISE Corp.

#### Fuel Cell Suppliers
- Ballard
- Hydrogenics
- UTC Power

#### H₂ Infrastructure
- Air Products
- Chevron

#### Collaborations

<table>
<thead>
<tr>
<th>U.S.</th>
<th>International</th>
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</thead>
<tbody>
<tr>
<td>FTA</td>
<td>EC</td>
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<tr>
<td>NAVC</td>
<td>PREMIA</td>
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<tr>
<td>HCATT</td>
<td>ECTOS</td>
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<td></td>
<td>CUTE</td>
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<td></td>
<td>STEP</td>
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<td></td>
<td>NRCan</td>
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<td>UNDP-GEF</td>
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</table>
Objectives

• Validate fuel cell and hydrogen technologies in transit applications
  – Provide feedback for HFCIT Program R&D
  – Provide “lessons learned” on implementing next generation fuel cell systems into transit operations

• Harmonize data collection efforts with other fuel cell bus demonstrations worldwide (in coordination with FTA and other U.S. and international partners)
  – Establish a common template for collecting and sharing data between programs
  – Leverage resources by gathering data and comparing a larger statistical set of vehicles (8 - U.S., 30 - Europe)
Approach

• Evaluations
  – Collect and analyze operational data on fuel cell buses in service (using conventional diesel or CNG as baseline):
    • Vehicle specifications, use, and duty-cycle
    • Fluid consumption (fuel, oil, water, etc.)
    • Maintenance records (scheduled and unscheduled)
    • Facility descriptions and costs
    • Fleet experience with buses and infrastructure
    • Detailed data similar to light-duty demonstrations

• International Collaboration
  – International Fuel Cell Bus Working Group
    • Define common data set to collect and share
    • Workshop now an IPHE recognized event
Overview of Technical Accomplishments/Progress

• Evaluations: Working with transit fleets to evaluate fuel cell buses in service
  – Santa Clara VTA: Completed preliminary data report; data collection continues
  – Hickam AFB: Data collection in progress

• International Collaboration
  – Coordinating committee for Working Group
  – 3rd International FCB Workshop; led breakout session on “data sharing sensitivities”
Preliminary Data Results: VTA

Santa Clara Valley Transportation Authority
San Jose, CA
- Currently evaluating 3 prototype fuel cell buses
- Diesel buses used for a baseline

Preliminary results include 8 months of data from March through October 2005

Data collection will continue through June 2006
Preliminary Data Results: VTA

Santa Clara Valley Transportation Authority
San Jose, CA

The fuel cell bus has a non-hybrid fuel cell system by Ballard Power Systems

<table>
<thead>
<tr>
<th>Vehicle System</th>
<th>Cerone Depot</th>
<th>Fuel Cell Buses</th>
<th>Diesel Buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Buses</td>
<td>Three</td>
<td>Five</td>
<td></td>
</tr>
<tr>
<td>Bus Manufacturer and Model</td>
<td>Gillig low-floor</td>
<td>Gillig low-floor</td>
<td></td>
</tr>
<tr>
<td>Model Year</td>
<td>2004</td>
<td>2002</td>
<td></td>
</tr>
<tr>
<td>Length/Width/Height</td>
<td>40 feet/102 in/144 in</td>
<td>40 feet/102 in/120 in</td>
<td></td>
</tr>
<tr>
<td>GVWR/Curb Weight</td>
<td>40,600 lb/34,100 lb</td>
<td>39,600 lb/27,300 lb</td>
<td></td>
</tr>
<tr>
<td>Wheelbase</td>
<td>284 in</td>
<td>284 in</td>
<td></td>
</tr>
<tr>
<td>Passenger Capacity</td>
<td>37 seated or 29 seated and two wheelchairs, five standing</td>
<td>38 seated or 31 seated and two wheelchairs, 43 standing</td>
<td></td>
</tr>
<tr>
<td>Engine Manufacturer and Model</td>
<td>Two Ballard fuel cell modules P5-2</td>
<td>Cummins ISL (8.9 liter)</td>
<td></td>
</tr>
<tr>
<td>Rated Power</td>
<td>150 kW each (300 kW total)</td>
<td>280 bhp @ 2,200 rpm</td>
<td></td>
</tr>
<tr>
<td>Rated Torque</td>
<td>790 lb-ft @ 1,350 rpm (1250 Nm)</td>
<td>900 lb-ft @ 1,300 rpm</td>
<td></td>
</tr>
<tr>
<td>Accessories</td>
<td>Mechanical</td>
<td>Mechanical</td>
<td></td>
</tr>
<tr>
<td>Emissions Equipment</td>
<td>None</td>
<td>Diesel oxidation catalyst</td>
<td></td>
</tr>
<tr>
<td>Fuel Capacity</td>
<td>Approx. 55 kg hydrogen at 5,000 psi</td>
<td>115 gallons</td>
<td></td>
</tr>
</tbody>
</table>
Preliminary Data Results: VTA

In-Use Bus Evaluation

- Comparison of FCBs to conventional diesel baseline
  - 3 model year 2004 buses with non-hybrid FC system
  - 5 model year 2002 diesel buses (Cummins ISL with DPF)
- FCBs limitations
  - Added service (between scheduled diesel buses)
  - During the week only
  - Driver and mechanic availability
- Diesel buses randomly dispatched
- Average speed 14.5 mph
Preliminary Data Results: VTA

Total Miles and Fuel Cell Hour Accumulation

Totals for all 3 FCBs - over 19,000 miles and 1,400 FC hours
Preliminary Data Results: VTA

Average Miles Accumulated per Bus by Month

<table>
<thead>
<tr>
<th>Month</th>
<th>Fuel Cell Bus</th>
<th>Diesel Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar-05</td>
<td>500</td>
<td>3,500</td>
</tr>
<tr>
<td>Apr-05</td>
<td>500</td>
<td>3,500</td>
</tr>
<tr>
<td>May-05</td>
<td>500</td>
<td>3,500</td>
</tr>
<tr>
<td>Jun-05</td>
<td>5,000</td>
<td>3,500</td>
</tr>
<tr>
<td>Jul-05</td>
<td>500</td>
<td>3,500</td>
</tr>
<tr>
<td>Aug-05</td>
<td>500</td>
<td>3,500</td>
</tr>
<tr>
<td>Sep-05</td>
<td>500</td>
<td>3,500</td>
</tr>
<tr>
<td>Oct-05</td>
<td>500</td>
<td>3,500</td>
</tr>
</tbody>
</table>
Preliminary Data Results: VTA

Average Fuel Economy

FCBs have 13% lower energy equivalent fuel economy compared to diesel (FCB = 3.45, Diesel 3.95)
# Preliminary Data Results: VTA

## Preliminary Costs

<table>
<thead>
<tr>
<th></th>
<th>Diesel Buses</th>
<th>Fuel Cell Buses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of Vehicles</strong></td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td><strong>Data Period</strong></td>
<td>3/05-10/05</td>
<td>3/05-10/05</td>
</tr>
<tr>
<td><strong>Fuel Use</strong></td>
<td>41,474 gal</td>
<td>5,469 kg</td>
</tr>
<tr>
<td><strong>Base Fleet Mileage</strong></td>
<td>163,619</td>
<td>16,708</td>
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</tbody>
</table>

### Fuel Costs

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<tr>
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<tbody>
<tr>
<td><strong>Fleet Miles/kg</strong></td>
<td></td>
<td>3.05</td>
</tr>
<tr>
<td><strong>Representative Fleet MPG (energy equiv)</strong></td>
<td>3.95</td>
<td>3.45</td>
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<tr>
<td><strong>Average fuel cost</strong></td>
<td>$2.02/gal</td>
<td>$8.56/kg</td>
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<tr>
<td><strong>Fuel cost per mile</strong></td>
<td>$0.51</td>
<td>$2.80</td>
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</table>

### Maintenance Costs

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</thead>
<tbody>
<tr>
<td><strong>Total maintenance cost per mile</strong></td>
<td>$0.59</td>
<td>$4.26</td>
</tr>
<tr>
<td><strong>Propulsion System Related maintenance cost per mile</strong></td>
<td>$0.21</td>
<td>$3.06</td>
</tr>
</tbody>
</table>

_Warranty costs not included in totals_
Preliminary Data Results: VTA

Reliability: Miles Between Road Calls

- Diesel Buses – 9,019 MBRC total; 11,424 MBRC propulsion related only
- Fuel Cell Buses – 983 MBRC total; 1,044 MBRC propulsion related only

**Definition**: A road call (RC) is a failure of an in-service bus that causes the bus to be replaced on route or results in a significant schedule delay. If the problem can be repaired during a layover and the schedule is not affected, this is not considered a RC. (from the National Transit Database)
Preliminary Data Results: VTA

Cumulative Fueling Rate Histogram: VTA Station

About 55 kg useful fuel on the bus – fast rate required for reasonable fill time

VTA Fueling station:
- Air Products
- Liquid H₂ storage
- Dispenses compressed H₂

DOE Target (light-duty): 1 kg H₂/min
Progress: Ongoing FCB Evaluations

Hickam Air Force Base
Honolulu, HI

• 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
Progress: Ongoing FCB Evaluations

Hickam Air Force Base

Status

– $\text{H}_2$ fueling available in late 2005
– Bus operating on shuttle route around base
– Expect permanent fueling on-site early 2006
– Step van in service as maintenance support vehicle
Progress: International Collaboration

3rd Workshop held in Vancouver, BC, in December 2005:

- Reported status of informational data collection
  - Request sent to 20 cities, 11 responses to date
- Breakout sessions
  - Data sharing sensitivities
  - Policy/business case for FCBs
  - Issues with $H_2$ infrastructure
- Planning 4th International Fuel Cell Bus Workshop for Yokohama, Japan, in October 2006
Future Work

• Remainder of FY 2006
  – Data analysis and draft final report on VTA evaluation
  – Data analysis and draft preliminary data reports on Hickam evaluation
  – Collect more technical data on FCBs and infrastructure to complement DOE Controlled Fleet Demo
  – Report informational data on International FCB demos and finalize list of operational and performance data
Future Work

• FY 2007
  – Publish final report on VTA evaluation
  – Publish preliminary data report on Hickam
  – Feed early results back into HFCIT program R&D
  – Continue collection and analysis of technical data on buses and infrastructure for all fleets
  – Attend 4th International FCB Workshop
  – Begin sharing operational and performance data with international FCB demos
Coordinated FCB Evaluations Under Other Funding

Alameda Contra-Costa Transit Agency
Oakland, CA

- AC Transit is demonstrating 3 Van Hool 40-ft buses with a UTC fuel cell and hybrid system by ISE Corp.
- The hydrogen fueling station was designed and built by Chevron. The station features a natural gas reformer that can produce 150 kg \( H_2 \) per day
- The buses were put into revenue service March 19, 2006; a preliminary data report should be available in late 2006
Coordinated FCB Evaluations Under Other Funding

SunLine Transit Agency, Thousand Palms, CA

- SunLine is demonstrating a Van Hool 40-ft bus with a UTC fuel cell and hybrid system by ISE Corp. The bus started revenue service in December 2005. A preliminary data report should be available in late 2006.

- The hydrogen station features a natural gas reformer by HyRadix.
Summary

• FCBs are all in-service and data collection is ongoing
  – Some preliminary data now available to industry
• Bus duty-cycle allows fast accumulation of miles/FC hours
  – Some buses have accumulated over 17,000 miles
  – On track to achieve well over 1,000 FC hours/bus by end of demo
• Fuel economy results show need for hybridization
• Collecting performance and cost data on conventional technology establishes a baseline for tracking progress
  – Use of prototype FCBs is much less than standard buses
  – High cost for maintaining current generation prototype technology
Response to Previous Year Reviewers’ Comments

• Commitment to data integrity seems absent
  – Raw data carefully processed to ensure accuracy
  – Continue to work with fleets and manufacturers to ensure complete data sets

• Add comparison results
  – Collecting data on conventional buses for baseline comparison (diesel or CNG)
  – Data was not available for previous review

• Document cost information
  – Cost data was part of data collection plan but not available before last review
  – Included in this presentation
Publications and Presentations
(Since FY 2005 Review)

Publications
• L. Eudy, K. Chandler. “VTA, SamTrans Look into Future with Bus Demo,” DOE/GO-102005-2147 (September 2005)

Presentations
Critical Assumptions and Issues

• Assumption
  – Collection of non-proprietary data utilizes existing fleet data.
    • Need assurance that fleet data is accurate and complete.
    • Use proven methods of QA/QC for processing data
    • Working with fleet and manufacturers to ensure data quality

• Issues
  – Budget reduced for FY 2006
    • Supplemental funding received as a grant for this FY
    • Ability to complete work will depend on continued DOE funding
  – Collection of detailed data (similar to light-duty FCV Demo)
    • Although all teams have given verbal consent to share data, legal agreements have not been finalized.
    • Gathering data will depend on ability to build a good relationship with each team.
  – Definition of terms not standard between transit agencies
    • Working with International FCB Working group to establish common definitions to allow accurate comparisons between programs.