VTA Prototype Fuel Cell Bus Evaluation: Interim Results

APTA Bus and Paratransit Conference
Anaheim, California
May 2, 2006

Leslie Eudy
National Renewable Energy Laboratory

NREL/PR-540-40012
Disclaimer and Government License

This work has been authored by Midwest Research Institute (MRI) under Contract No. DE-AC36-99GO10337 with the U.S. Department of Energy (the "DOE"). The United States Government (the "Government") retains and the publisher, by accepting the work for publication, acknowledges that the Government retains a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for Government purposes.

Neither MRI, the DOE, the Government, nor any other agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any 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 any privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not constitute or imply its endorsement, recommendation, or favoring by the Government or any agency thereof. The views and opinions of the authors and/or presenters expressed herein do not necessarily state or reflect those of MRI, the DOE, the Government, or any agency thereof.
DOE Hydrogen FC Technology Validation Projects

Objectives:

– Validate hydrogen FC vehicles and infrastructure in parallel
– Identify current status of technology and its evolution
– Re-focus hydrogen research and development
Why Fuel Cell Technology?

• Strengthen national energy security
  – Reduce dependence on imported oil
• Reduce greenhouse gas emissions
  – GHGs are thought to be responsible for global climate change
• Improve air quality
  – Reduce smog and harmful particulates
• Increase energy efficiency
  – Fuel cells are inherently more energy efficient than internal-combustion engines
• Reduce noise levels
  – Fuel cell electric drive vehicles can be quieter than conventional vehicles
# Current FCB Evaluations

<table>
<thead>
<tr>
<th>Fleet</th>
<th>Vehicle/Technology</th>
<th>Number</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 in process, interim report published</td>
</tr>
<tr>
<td>U.S. Air Force/Hickam Air Force Base</td>
<td>Shuttle bus: Hydrogenics and Enova, battery-dominant fuel cell hybrid</td>
<td>1</td>
<td>Shuttle bus in operation, data collection will begin once permanent H2 fueling in place.</td>
</tr>
<tr>
<td></td>
<td>Delivery van: Hydrogenics and Enova, fuel cell hybrid</td>
<td>1</td>
<td>Van in service June 2006</td>
</tr>
<tr>
<td>AC Transit and Golden Gate Bridge, Highway, and Transportation District</td>
<td>Van Hool/UTC fuel cell hybrid transit bus integrated by ISE Corp.</td>
<td>3</td>
<td>Buses in service; evaluation in process</td>
</tr>
<tr>
<td>SunLine Transit Agency</td>
<td>Van Hool/UTC fuel cell hybrid transit bus integrated by ISE Corp.</td>
<td>1</td>
<td>Bus in service, evaluation in process</td>
</tr>
<tr>
<td></td>
<td>New Flyer ISE Corp. hydrogen internal combustion engine transit bus</td>
<td>1</td>
<td>Bus in service, evaluation in process</td>
</tr>
</tbody>
</table>
Why Evaluate Prototype Technology?

Demonstrations are a necessary part of the development process, but what do we really hope to accomplish?

• **Show progress toward commercialization**
  – Study the implementation process to document and share lessons learned
  – Provide a real data point in time to document:
    • Vehicle performance in real-world service
    • Comparison to conventional technology (baseline)
    • Costs
    • Effort required

• **Provide a “reality check”**
  – Keep the marketing from getting too far ahead of the progress
VTA/SamTrans: Interim Data Results

Data Period
March – October 2005
Partners/Service Area

• Fleets:
  – Santa Clara Valley Transportation Authority (VTA), San Jose, CA
  – San Mateo County Transit District (SamTrans) in San Carlos, CA

• Manufacturers
  – Ballard Power Systems
  – Gillig

• Infrastructure
  – Air Products & Chemicals
VTA/SamTrans ZEB Program

• CARB ZEB Requirements (for fleets with >200 buses)
  – By Feb 2006, Demonstrate 3 ZEBs and supporting infrastructure (Evaluate feasibility of fuel cell buses)
  – By Jul 2007, Results reports due to CARB
  – Beginning in 2008, 15% of bus purchases must be ZEBs

• Estimated total program cost $18,450,000

• ZEB Program Goals
  – Determine the status of fuel cell technology in transit applications.
  – Identify issues and challenges to overcome.
  – Provide community outreach and educate the public on fuel cell and hydrogen technology.
Fuel Cell Buses at VTA

- Three prototype fuel cell buses
- Diesel buses used for a baseline

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

<table>
<thead>
<tr>
<th>Bus Specifications</th>
<th>Cerone Depot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Buses</td>
<td>Three</td>
</tr>
<tr>
<td>Bus Manufacturer and Model</td>
<td>Gillig low-floor</td>
</tr>
<tr>
<td>Model Year</td>
<td>2004</td>
</tr>
<tr>
<td>Length/Width/Height</td>
<td>40 feet/102 in/144 in</td>
</tr>
<tr>
<td>GVWR/Curb Weight</td>
<td>40,600 lb/34,100 lb</td>
</tr>
<tr>
<td>Wheelbase</td>
<td>284 in</td>
</tr>
<tr>
<td>Passenger Capacity</td>
<td>37 seated or 29 seated and two wheelchairs, five standing</td>
</tr>
<tr>
<td>Engine Manufacturer and Model</td>
<td>Two Ballard fuel cell modules P5-2</td>
</tr>
<tr>
<td>Rated Power</td>
<td>150 kW each (300 kW total)</td>
</tr>
<tr>
<td>Rated Torque</td>
<td>790 lb-ft @ 1,350 rpm (1250 Nm)</td>
</tr>
<tr>
<td>Accessories</td>
<td>Mechanical</td>
</tr>
<tr>
<td>Emissions Equipment</td>
<td>None</td>
</tr>
<tr>
<td>Fuel Capacity</td>
<td>Approx. 55 kg hydrogen at 5,000 psi</td>
</tr>
</tbody>
</table>
Infrastructure at VTA

Hydrogen Fueling Facility

- Facility designed, built and maintained by Air Products
- Liquid hydrogen delivery and storage
- Compressed to 6,000 psi and vaporized for storage in cascade
- Bus fueling capability goal of 8 minute fill with communications
Hydrogen Fueling Experience

Cumulative Fueling Rate Histogram: VTA Station

About 55 kg useful fuel – fast rate required for reasonable fill time
In-Use Bus Evaluation

• Comparison of FCBs to conventional diesel baseline
  – Three MY 2004 buses with non-hybrid FC system
  – Five MY 2002 diesel buses (Cummins ISL with DPF)

• FCBs limitations
  – Extra service (between scheduled diesel buses)
  – During the week only
  – Driver and mechanic availability

• Diesel buses randomly dispatched (7 days/week)
• Average speed 14.5 mph
Average Monthly Mileage per Bus

<table>
<thead>
<tr>
<th>Miles</th>
<th>Mar-05</th>
<th>Apr-05</th>
<th>May-05</th>
<th>Jun-05</th>
<th>Jul-05</th>
<th>Aug-05</th>
<th>Sep-05</th>
<th>Oct-05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cell Bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel Bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend:
- Fuel Cell Bus
- Diesel Bus
Cumulative FCB Mileage per Bus

Total mileage for all 3 FCBs - over 19,000 miles
FC Hour Accumulation by Bus

Total FC hours accumulated for all buses 1,600 hrs.
Average Fuel Economy

Fuel Cell Buses have 13% lower energy equivalent fuel economy compared to diesel (FCB = 3.45, Diesel 3.95)
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)
Summary

• Bus duty-cycle allows fast accumulation of miles/FC hours
  – As of March 2006, highest mileage bus has accumulated over 17,000 miles
  – On-track to achieve 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
Reality Check –
What Was Accomplished?

• Federal Level
  – Current status provided to Federal agencies (DOE, FTA, etc.)
  – Re-focus of R&D and new funding opportunities

• State Level
  – Provided results to State agencies (ARB, CEC, FTA Regional Office)
  – Regulations can be modified to aid in further development of the technology

• Local Level
  – Provided experience to fleet (and project partners)
  – Provided training to local officials (Fire, First Responders, etc.)
  – Increased public awareness – for both transit riders and general population
Special Thanks

• VTA
• SamTrans
• Ballard Power Systems
• Air Products & Chemicals
• U.S. Department of Energy
For More Information

Published Report:
Santa Clara Valley Transportation Authority and San Mateo County Transit District
Fuel Cell Transit Buses: Preliminary Evaluation Results
Report # NREL/TP-540-39365
www.eere.energy.gov/hydrogenandfuelcells/tech_validation/pdfs/vta_prelim_eval_results.pdf

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

Kevin Chandler, Battelle
Phone: 614-424-5127
Email: chandlek@battelle.org