VTA Prototype Fuel Cell Bus Evaluation:

*Interim Results*

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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,</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>Highway, and Transportation District</td>
<td></td>
<td></td>
<td></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

### Bus Specifications

<table>
<thead>
<tr>
<th>Vehicle System</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>
</tr>
<tr>
<td>Bus Manufacturer and Model</td>
<td>Gillig low-floor</td>
<td>Gillig low-floor</td>
</tr>
<tr>
<td>Model Year</td>
<td>2004</td>
<td>2002</td>
</tr>
<tr>
<td>Length/Width/Height</td>
<td>40 feet/102 in/144 in</td>
<td>40 feet/102 in/120 in</td>
</tr>
<tr>
<td>GVWR/Curb Weight</td>
<td>40,600 lb/34,100 lb</td>
<td>39,600 lb/27,300 lb</td>
</tr>
<tr>
<td>Wheelbase</td>
<td>284 in</td>
<td>284 in</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>
</tr>
<tr>
<td>Engine Manufacturer and Model</td>
<td>Two Ballard fuel cell modules P5-2</td>
<td>Cummins ISL (8.9 liter)</td>
</tr>
<tr>
<td>Rated Power</td>
<td>150 kW each (300 kW total)</td>
<td>280 bhp @ 2,200 rpm</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>
</tr>
<tr>
<td>Accessories</td>
<td>Mechanical</td>
<td>Mechanical</td>
</tr>
<tr>
<td>Emissions Equipment</td>
<td>None</td>
<td>Diesel oxidation catalyst</td>
</tr>
<tr>
<td>Fuel Capacity</td>
<td>Approx. 55 kg hydrogen at 5,000 psi</td>
<td>115 gallons</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

- **Mar-05**: 3,500 miles (Fuel Cell Bus)
- **Apr-05**: 4,000 miles (Fuel Cell Bus)
- **May-05**: 4,200 miles (Fuel Cell Bus)
- **Jun-05**: 4,500 miles (Fuel Cell Bus)
- **Jul-05**: 4,000 miles (Fuel Cell Bus)
- **Aug-05**: 4,000 miles (Fuel Cell Bus)
- **Sep-05**: 4,000 miles (Fuel Cell Bus)
- **Oct-05**: 4,000 miles (Fuel Cell Bus)

- **Mar-05**: 3,000 miles (Diesel Bus)
- **Apr-05**: 3,000 miles (Diesel Bus)
- **May-05**: 3,000 miles (Diesel Bus)
- **Jun-05**: 4,000 miles (Diesel Bus)
- **Jul-05**: 4,000 miles (Diesel Bus)
- **Aug-05**: 4,000 miles (Diesel Bus)
- **Sep-05**: 4,000 miles (Diesel Bus)
- **Oct-05**: 4,000 miles (Diesel Bus)

- **Fuel Cell Bus**
- **Diesel Bus**
Cumulative FCB Mileage per Bus

Total mileage for all 3 FCBs - over 19,000 miles
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

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