Technology Validation: Fuel Cell Bus Evaluations

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Overview

Timeline

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

Budget

- FY 2006: $288K
- FY 2005: $338 K
- FY 2004: $238 K

Technology Validation Barriers

- A. Vehicles
- B. Storage
- C. Hydrogen Fueling Infrastructure
- D. Maintenance and Training
- E. Codes and Standards

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

H_2 Infrastructure
Air Products
Chevron

Collaborations

U.S.

FTA
NAVC
HCATT
CaFCP
University of Hawaii

International

EC
PREMIA
ECTOS
CUTE
STEP
NRCan
UNDP-GEF

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

Bus Specifications

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

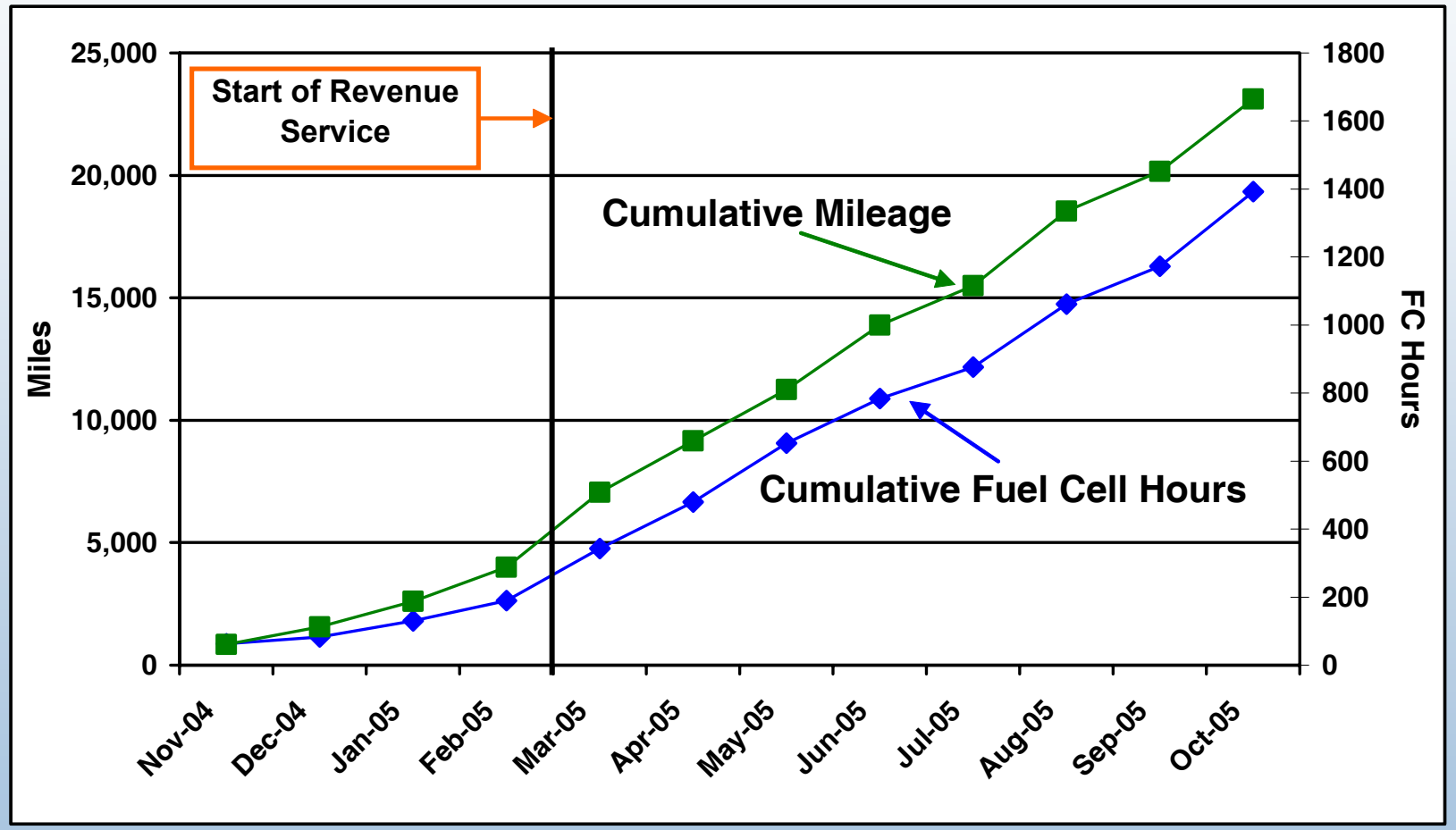
Preliminary Data Results: VTA

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

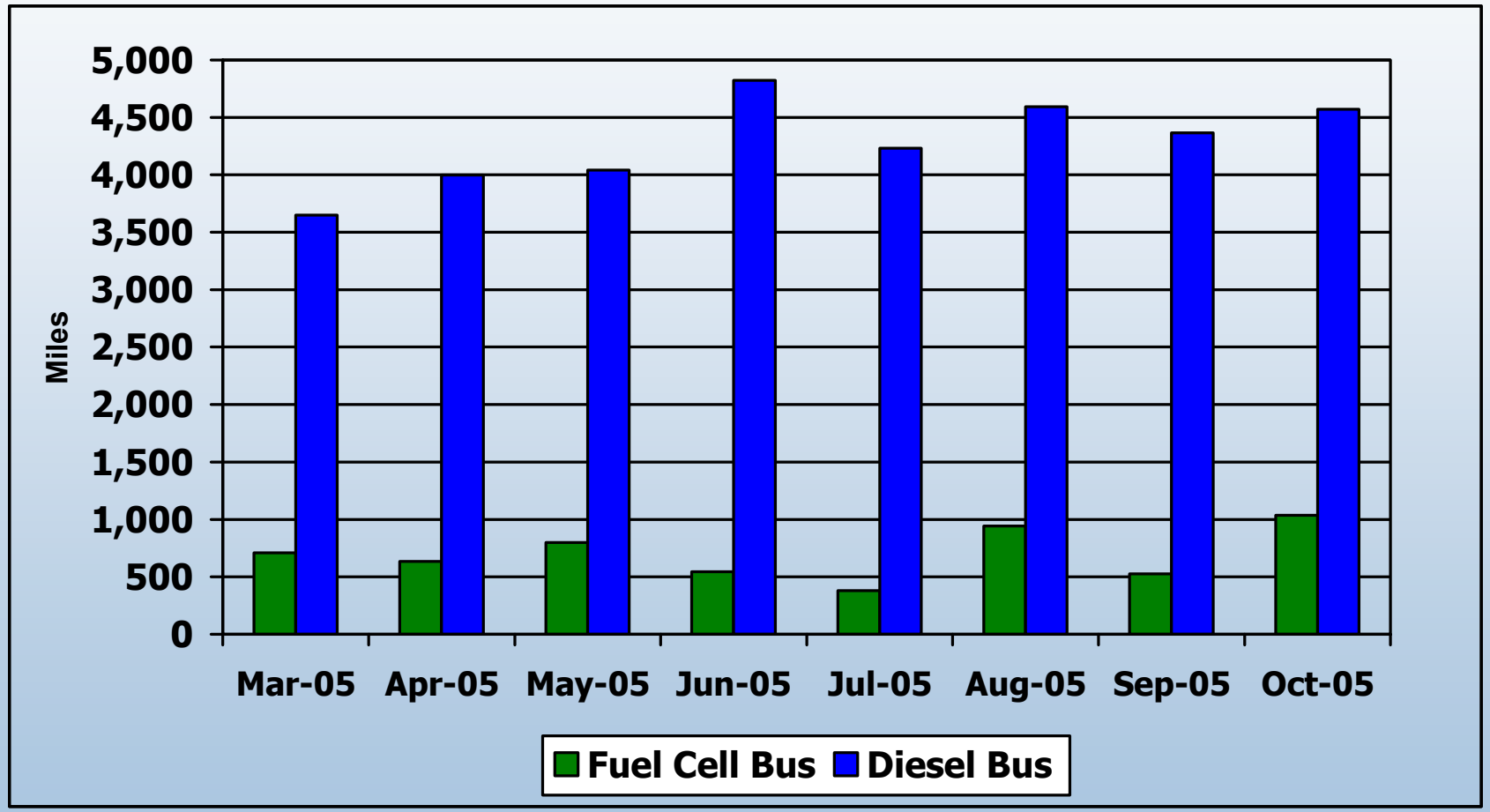
Total Miles and Fuel Cell Hour Accumulation



Totals for all 3 FCBs - over 19,000 miles and 1,400 FC hours

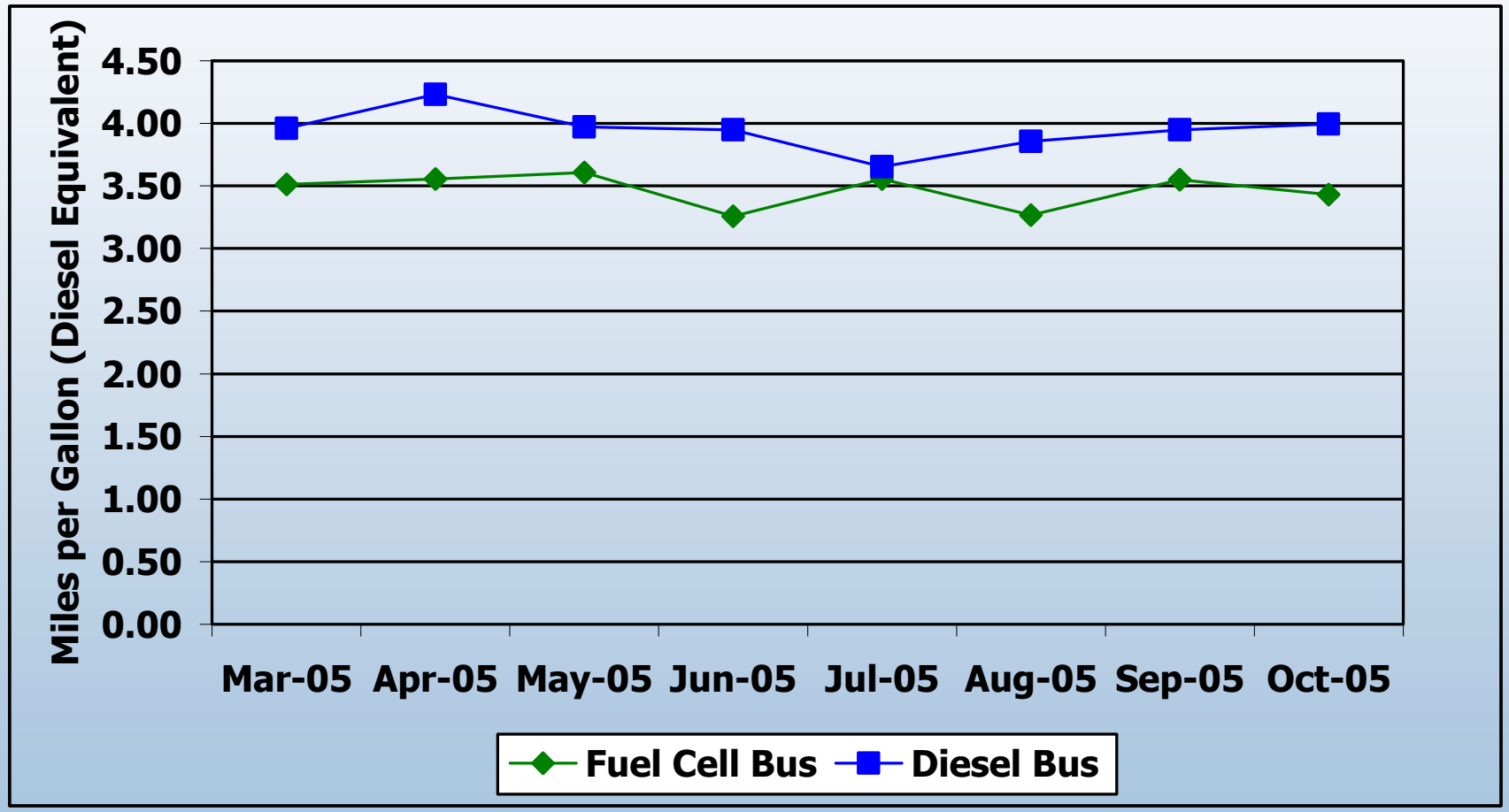
Preliminary Data Results: VTA

Average Miles Accumulated per Bus by Month



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

	Diesel Buses	Fuel Cell Buses
Number of Vehicles	5	3
Data Period	3/05-10/05	3/05-10/05
Fuel Use	41,474 gal	5,469 kg
Base Fleet Mileage	163,619	16,708
Fuel Costs		
Fleet Miles/kg		3.05
Representative Fleet MPG (energy equiv)	3.95	3.45
Average fuel cost	$2.02/gal	$8.56/kg
Fuel cost per mile	$0.51	$2.80
Maintenance Costs		
Total maintenance cost per mile	$0.59	$4.26
Propulsion System Related maintenance cost per mile	$0.21	$3.06

Warranty costs not included in totals

Preliminary Data Results: VTA

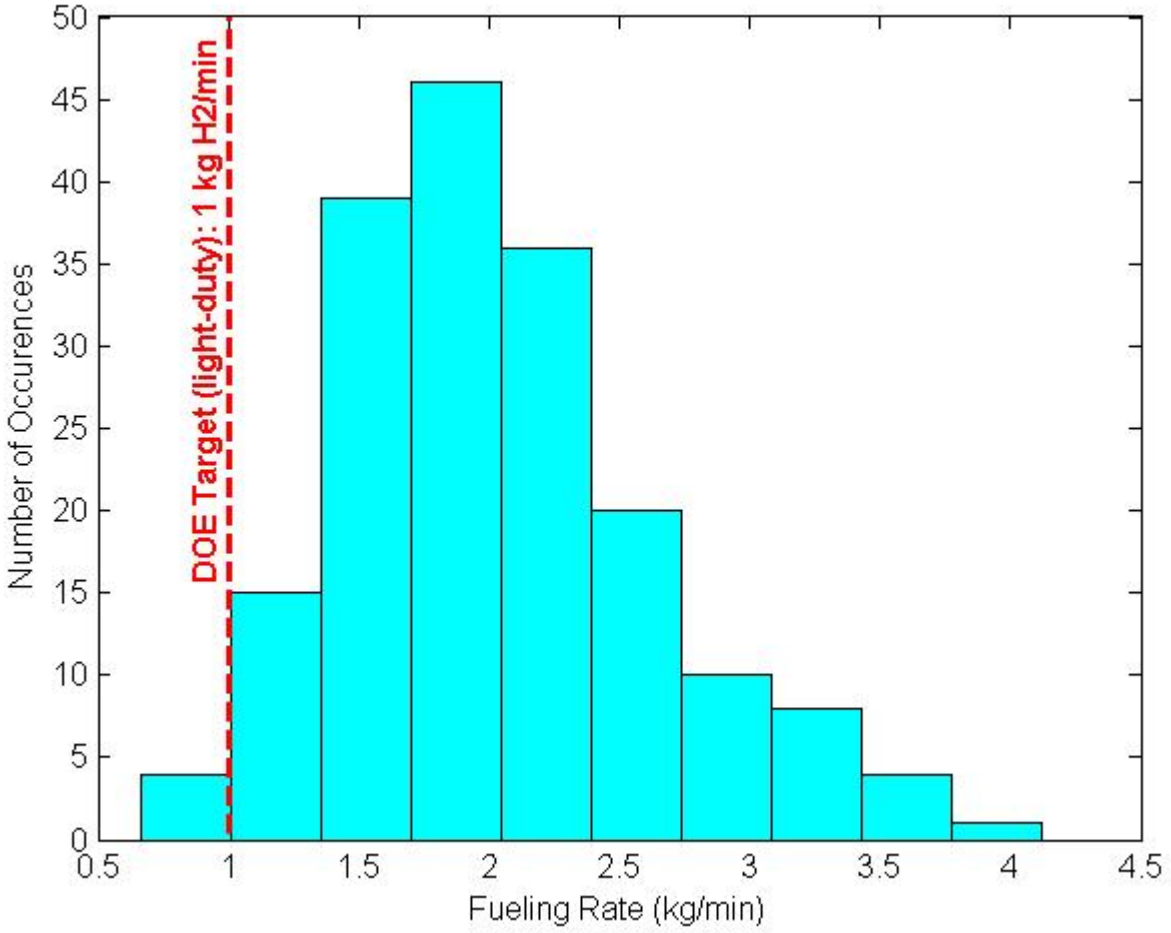
Reliability: Miles Between Road Calls

- 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



VTA Fueling station:

- Air Products
- Liquid H_2 storage
- Dispenses compressed H_2

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

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

- 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

IPHE Recognized Event

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

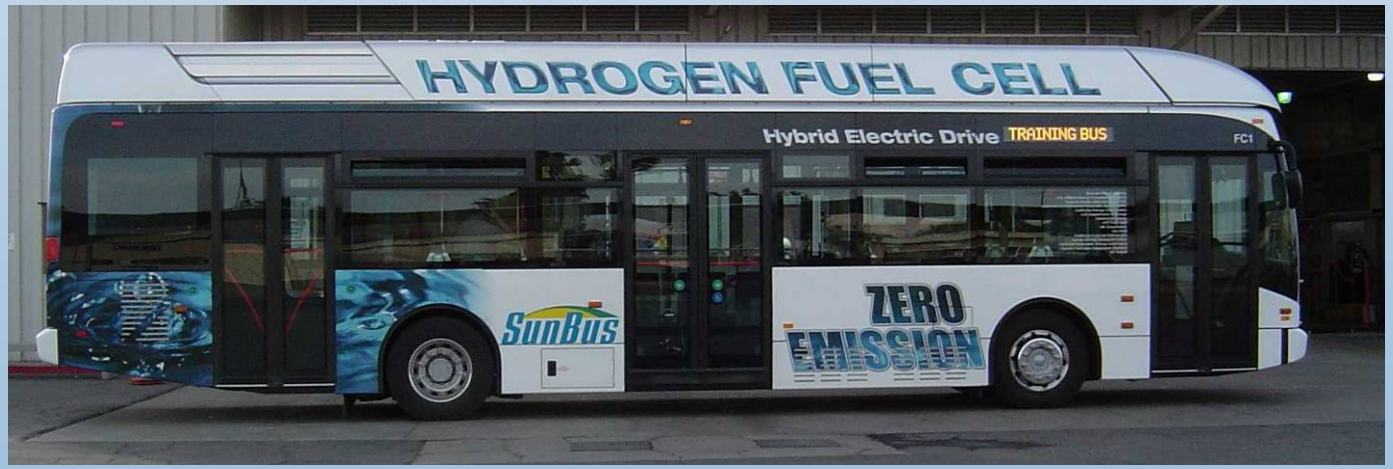
Oakland, CA

- 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. "Santa Clara Valley Transportation Authority and San Mateo County Transit District, Fuel Cell Transit Buses: Preliminary Evaluation Results," NREL/TP-540-39365 (March, 2006)
- L. Eudy, K. Chandler. "VTA, SamTrans Look into Future with Bus Demo," DOE/GO-102005-2147 (September 2005)

Presentations

- L. Eudy. "Data Sharing Sensitivities," International Fuel Cell Bus Workshop, Vancouver, Canada (December 2005).
- L. Eudy. "Preliminary Results from FCB Evaluations," 2006 American Public Transportation Association Bus and Paratransit Conference, Anaheim, California (May 2006)

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.