NREL National Renewable Energy Laboratory

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Technology Validation: Fuel Cell Bus Evaluations

Leslie Eudy • National Renewable Energy Laboratory • May 17, 2006 • Project ID # TVP-7

Overview

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

Budget
- FY06: $288 K
- FY05: $338 K
- FY04: $238 K

Technology Validation Barriers
A. Vehicles
B. Storage
C. Hydrogen fueling infrastructure
D. Maintenance and training
E. Codes and standards

Partners

Operating Fleets
AC Transit
Santa Clara VTA
SunLine
Hickam AFB

Manufacturers/ Systems Integrators
Enova Systems
Gillig/Ballard
Van Hool /ISE Corp

FC Suppliers
Ballard Hydrogenics
UTC Power

H_2 Infrastructure
Air Products Chevron

Collaborations

United States
FTA CaFCP
NAVC Unviersity of Hawaii
HCATT

International
EC ECTOS NRCan
Premia CUTE UNDP-GEF
STEP

Objectives

- Validate FC and hydrogen technologies in transit applications
  - Provide feedback for HFCIT Program R&D
  - Provide "lessons learned" on implementing next generation FC systems into transit operations
- Harmonize data collection efforts with other FC 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 (eight - U.S., 30 - Europe)

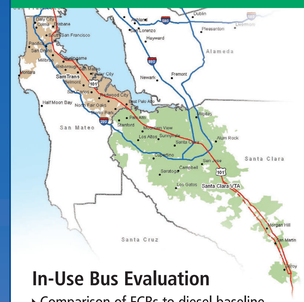
Approach

- Evaluations
  - Collect and analyze operational data on FCBs in service (using 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 FCB 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 FCBs 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
  - Third International FCB Workshop; led breakout session on "data sharing sensitivities"

Preliminary Data Results: Santa Clara VTA – San Jose, CA



In-Use Bus Evaluation
- Comparison of FCBs to diesel baseline
  - Three model year 04 buses with non-hybrid FC system by Ballard Power Systems
  - Five model year 02 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

Reliability: Miles Between Road Calls
- Diesel buses – 9,019 MBRC total; 11,424 MBRC propulsion related only
- FCBs – 983 MBRC total; 1,044 MBRC propulsion related only

VTA Fueling Station
- Air Products
- Liquid H_2 storage
- Dispenses compressed H_2

Preliminary Costs

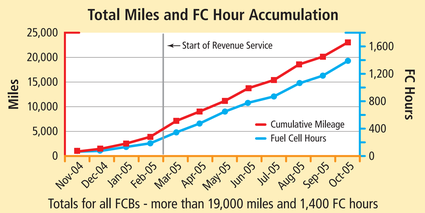
	FCBs	Diesel Buses
Number of Vehicles	Three	Five
Data Period	3/05-10/05	3/05-10/05
Fuel Use	5,469 kg	41,474 gal
Base Fleet Mileage	16,708	163,619
Fuel Costs		
Fleet Miles/kg	3.05	
Representative Fleet MPG (energy equiv)	3.45	3.95
Average Fuel Cost	$8.56/kg	$2.02/gal
Fuel Cost per Mile	$2.80	$0.51
Maintenance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

Warranty costs not included in totals

Bus Specifications

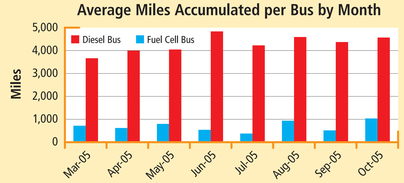
Vehicle System	Cerone Depot	
	FCBs	Diesel Buses
Number of Buses	Three	Five
Bus Manufacturer and Model	Gillig low-floor	Gillig low-floor
Model Year	2004	2002
Length/Width/Height	40 ft/102 in/144 in	40 ft/102 in/120 in
GVWR/Curb Weight	40,600 lb/34,100 lb	39,600 lb/27,300 lb
Wheelbase	284 in	284 in
Passenger 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 FC 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 gal

Total Miles and FC Hour Accumulation

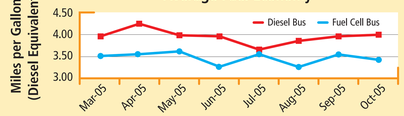


Totals for all FCBs - more than 19,000 miles and 1,400 FC hours

Average Miles Accumulated per Bus by Month

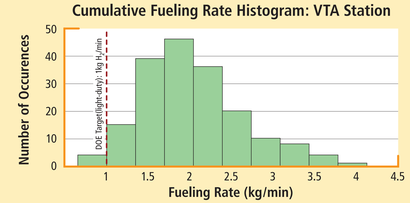


Average Fuel Economy



FCBs have 13% lower energy equivalent fuel economy compared to diesel (FCB 3.45, Diesel 3.95)

Cumulative Fueling Rate Histogram: VTA Station



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

*Preliminary results in the above graphs include eight months of data from March through October 2005

Progress

Ongoing FCB Evaluations
Hickam AFB, Honolulu, HI
- Vehicles
  - One ElDorado 30-ft bus
    - Enova battery-dominant hybrid FC system, Hydrogenics 20kW FC
  - One step van
    - Enova hybrid FC system, Hydrogenics 60kW FC
- Status
  - Hydrogen fueling available in late 2005
  - Bus operating on shuttle route around base
  - Expect permanent fueling onsite in early 2006
  - Step van in service as maintenance support vehicle

International Collaboration
Third workshop held in Vancouver, BC, 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 Fourth International FCB Workshop for Yokohama, Japan, October 2006
- Workshop now an IPHE recognized event

Coordinated FCB Evaluations Under Other Funding

SunLine Transit Agency Thousand Palms, CA
- SunLine is demonstrating a Van Hool 40-ft bus with a UTC FC and an ISE Corp hybrid system. 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.

Alameda Contra-Costa Transit Agency, Oakland, CA
- AC Transit is demonstrating three Van Hool 40-ft buses with a UTC FC and an ISE Corp hybrid system
- 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 in March 2006. A preliminary data report should be available in late 2006

Future Work

Remainder of FY06
- Data analysis and draft final report on VTA evaluation
- Data analysis and draft preliminary data report on Hickam AFB 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

FY07
- Publish final report on VTA evaluation
- Publish preliminary data report on Hickam AFB
- Feed early results back into HFCIT Program R&D
- Continue collection and analysis of technical data on buses and infrastructure for all fleets
- Attend Fourth International FCB Workshop
- Begin sharing operational and performance data with international FCB demos

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