

Technology Validation: Fuel Cell Bus Evaluations

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**Project ID#
TVP2**

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

- Project Start FY03
- First generation FCB complete in FY08
- Second generation FCBs begin 2nd Qtr 2008

Barriers

- A. Lack of fuel cell vehicle performance and durability data
- B. Lack of H₂ fueling infrastructure performance and availability data
- D. Maintenance and training facilities

Budget

- FY 2008: \$288K
- FY 2007: \$288K
- FY 2006: \$288K

Partners

- Fleets: Operational data, fleet experience
- Manufacturers: Vehicle specs, data and review
- Fuel Providers: Fueling data and review

Objectives

- Overall: Validate fuel cell and hydrogen technologies in transit applications
 - Show progress of the technology toward commercialization
 - Provide “lessons learned” on implementing next generation fuel cell systems in transit operations
 - Harmonize data collection efforts with other fuel cell bus demonstrations worldwide (in coordination with FTA and other U.S. and international partners)
- 2008
 - Complete update reports AC Transit and SunLine
 - Begin data collection and analysis for first cold climate site: **CTTRANSIT**
 - Summary of FCB experience and analysis of status

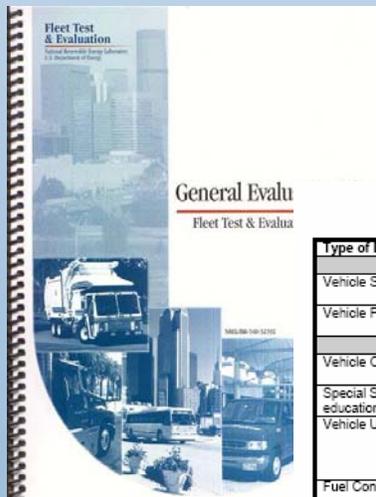
Milestones

- Begin data collection on cold climate sites
 - Hartford, CT: FY07
- Complete evaluations of 1st generation FCBs:
 - Santa Clara VTA: completed FY07
 - AC Transit: FY08
 - SunLine: FY08
 - CTTRANSIT: FY09
- Begin evaluations of 2nd generation FCBs – 2nd Qtr: FY08

Evaluation Approach

Two levels of data collected

- Non-sensitive data
 - Follows existing protocol
 - Data collected mainly from fleet
 - Results are made public after project team review
- Proprietary data
 - Collected from manufacturer
 - Protected in Secure Data Center at NREL
 - Only aggregate data products made public



General Evalu
Fleet Test & Evalua

Table 1. Data Collection Items

| Type of Data | Frequency Recorded | Data Items |
|---|--|--|
| Vehicle Specification and Performance Expectations | | |
| Vehicle System Descriptions | Start of data collection and changes as needed | Data items shown in Appendix C |
| Vehicle Performance Expectations | Start of data collection and changes as needed | Criteria and testing results for performance expectations |
| Vehicle Operation | | |
| Vehicle Operating Cycle | Start of data collection and changes as needed | General description of daily use of vehicles |
| Special Service (Press events, public education, etc.) | Each time vehicle is used for atypical service | Description of event, time out of service. |
| Vehicle Usage in Service | At each time usage is measured | Odometer reading, hours of vehicle and fuel cell operation Daily vehicle assignment GPS data (if needed) |
| Fuel Consumption | Each time a vehicle is fueled | Amount of fuel |

Microsoft Excel - Heavy Vehicles - PowerPlant Parameters Template (Rev A).xls (Road-Only)

Vehicle, Power Plant Parameter Summary
Please confirm data in yellow.

| | | |
|---|-------------------------------------|--------------------------|
| 1 | Report Date | insert report date |
| 2 | Operating Location | insert location |
| 3 | Fleet Site | insert fleet |
| 4 | Bus Chassis Manufacturer | insert bus manufacturer |
| 5 | FC Manufacturer | insert FC manufacturer |
| 6 | FC System Integrator (if different) | insert system integrator |

Vehicle, Power Plant Configuration

| Parameter | Units | Comments | Value |
|--------------|----------------|---------------------|-------|
| veh_CD | dimensionless | Coefficient of drag | |
| veh_PA | m ² | Frontal area | |
| Vehicle Mass | kg | curb weight | |
| 8 Front Axel | kg | | |

On-Road Heavy-Duty Vehicle Performance
Data to be compiled daily for at least one bus at each site.

Preferred method for providing on-road data is a comma other formats (e.g., *.mat, *.mdf, etc) may be acceptable. Information below is clearly identified in the data file and

| Date of Vehicle Trip * | City |
|-------------------------------------|----------------------------------|
| Operating Location | insert operating location |
| Fleet Site | insert fleet name |
| Bus Chassis Manufacturer | insert bus manufacturer |
| FC Manufacturer | insert FC manufacturer |
| FC System Integrator (if different) | insert system integrator |
| Vehicle Number * | insert unique vehicle identifier |

All the above data fields need not be included in each data submission. For ease of reporting, only the fields marked with an asterisk are necessary after the first data transfer on each vehicle.

| Component | N/A | Vehicle | Cumulative Operating Hours | Start/Stop |
|-------------|--|---------------|----------------------------|--|
| Measurement | Time | Vehicle Speed | Hours | Start/Stop |
| Units | Seconds (at least 1 data point per second) | Miles/hour | Hours | 1 = on (from start-up sequ from begins down to |

Evaluation of Hydrogen and Fuel Cell Buses in Five Fleets

Santa Clara VTA, San Jose, CA - completed

Ballard, Gillig: non- hybrid FCB

SunLine, Thousand Palms, CA

UTC Power, ISE Corp: hybrid FCB

ISE Corp: hybrid H₂ ICE

AC Transit, Oakland, CA

UTC Power, ISE Corp: hybrid FCB

CTTRANSIT, Hartford, CT

UTC Power, ISE Corp: hybrid FCB

Hickam AFB, Honolulu, HI

Hydrogenics, Enova: hybrid system



Comparison of Hydrogen and Fuel Cell Buses to Conventional Technology

Targets for assessing the progress toward commercialization

- Performance characteristics
- Bus use
- Fuel economy
- Availability
- Reliability - miles between road call (MBRC)
- Cost - capital, fueling, and maintenance

Fleet Data Summary: AC Transit

Fuel Cell Bus (hybrid system)

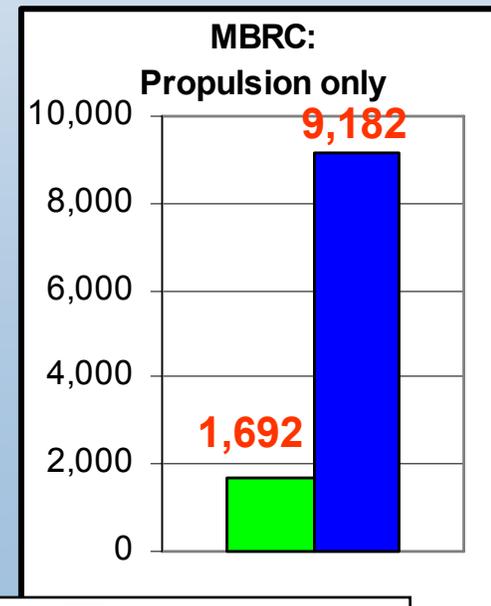
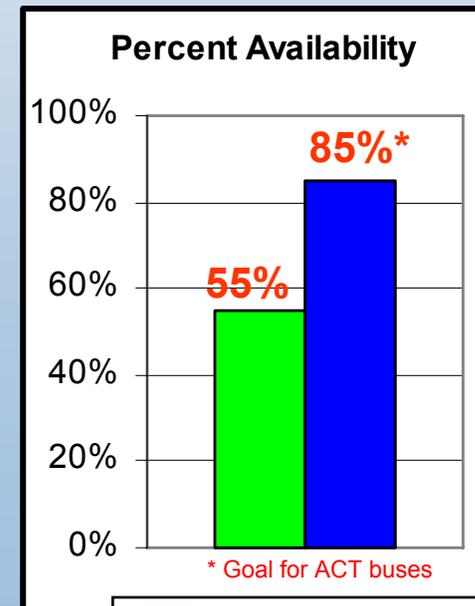
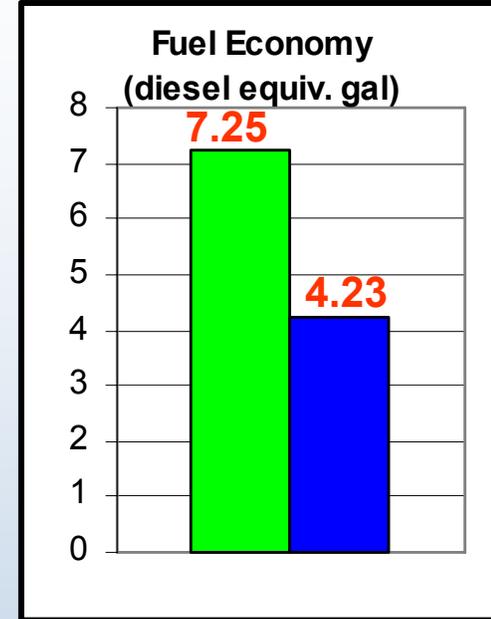


- 24 months operation of 3 FCBs
- Total miles: 82,066
- Total FC system hours: 7,814

Diesel Bus (baseline)



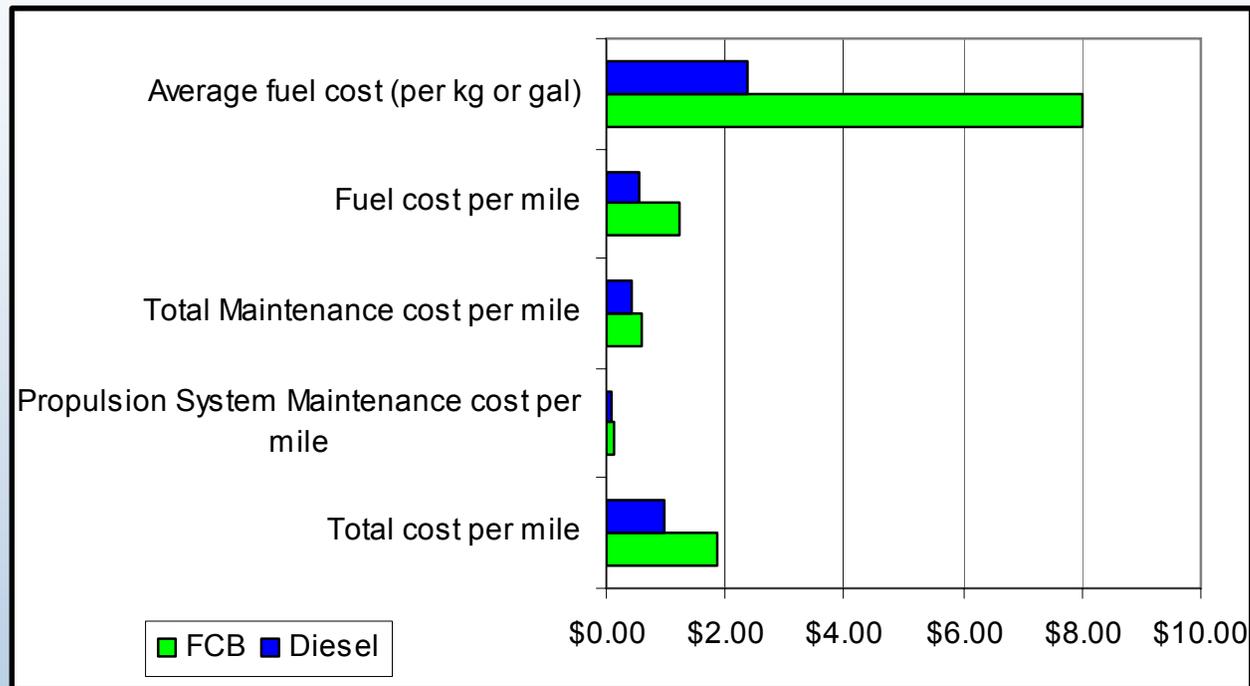
- 24 months operation of 6 diesel buses
- Total miles: 459,096



■ Fuel Cell Bus ■ Diesel Bus

Fleet Data Summary: AC Transit

Summary of Costs



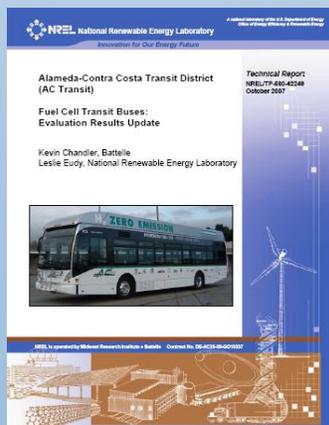
Evaluation Status

- Complete for current generation buses
- Final data report planned for spring
- Data collection will continue under FTA funding (Accelerated testing of current generation)
- Next generation buses arrive 2009 (planned DOE evaluation)

* Warranty data is not included in calculations. Manufacturer staff are conducting most of the system repairs. Costs are expected to increase as fleet takes over these tasks.

Update Report Published 9/07

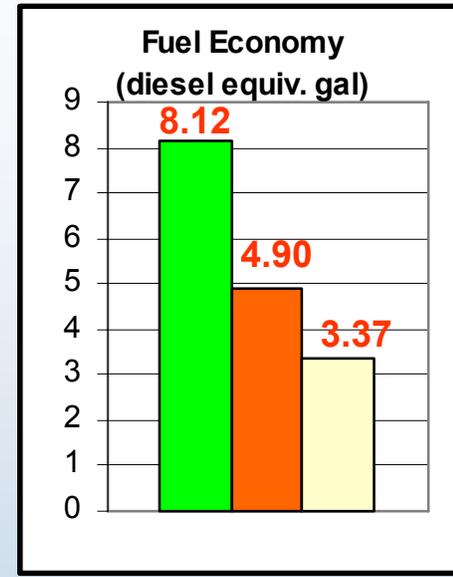
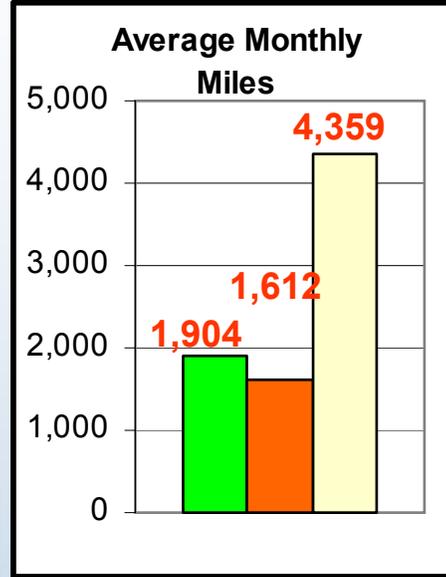
Available online at www.nrel.gov/hydrogen/pdfs/42249.pdf



Fleet Data Summary: SunLine

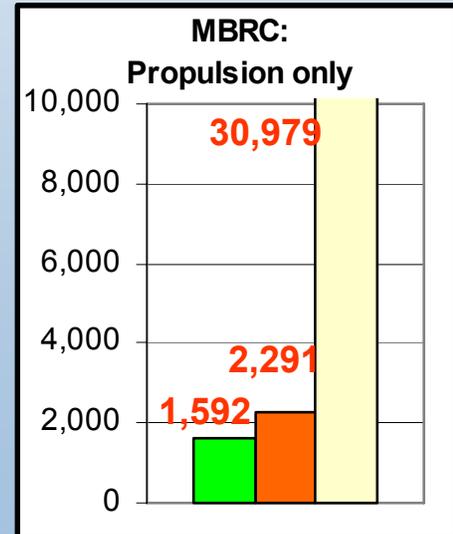
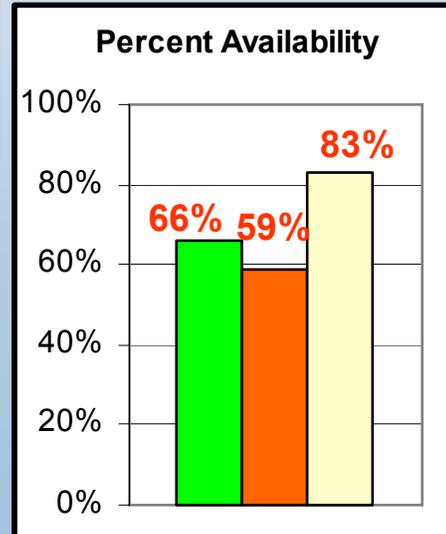
Fuel Cell Bus (hybrid system)

- 27 months operation of 1 FCB
- Total miles: 50,931
- Total FC system hours: 3,918



HHICE Bus

- 27 months operation of 1 HHICE bus
- Total miles: 44,442



CNG Bus

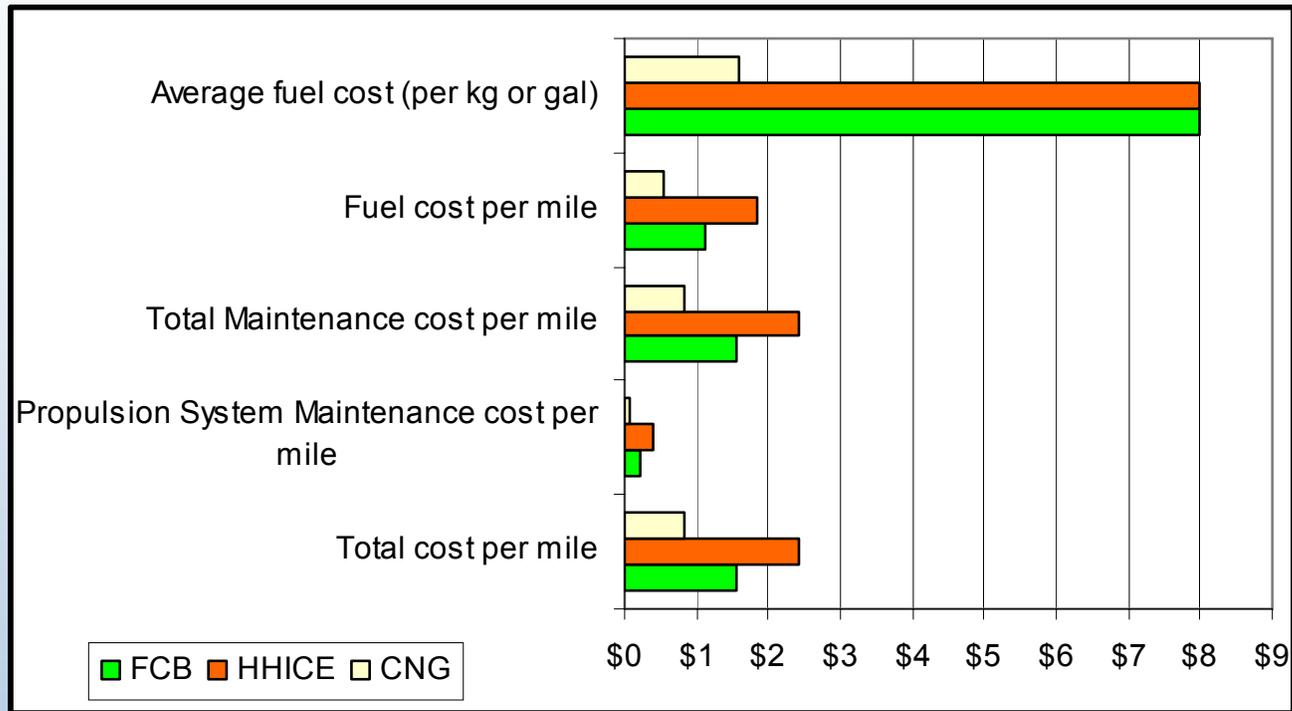
- 21 months operation of 5 CNG buses
- Total miles: 457,654



*HHICE – hybrid H₂ internal combustion engine

Fleet Data Summary: SunLine

Summary of Costs*



* Warranty data is not included in calculations. Manufacturer staff are conducting most of the system repairs. Costs are expected to increase as fleet takes over these tasks.

Evaluation Status

- Data collection on current gen design nearly complete – final report in summer
- Begin data collection on bus with new design FC



Fleet Data Summary: CTTRANSIT

Fuel Cell Bus (hybrid system)

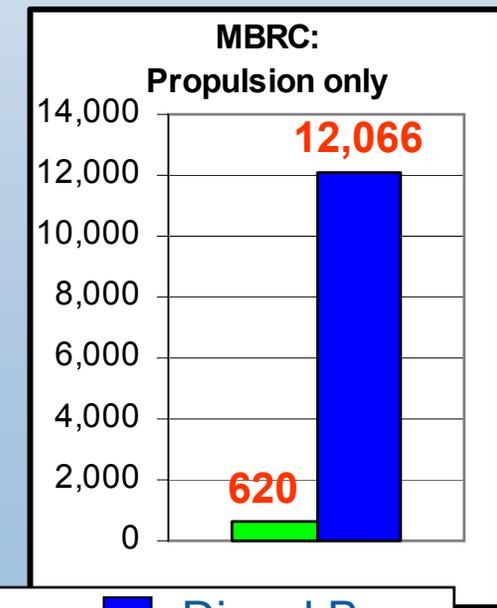
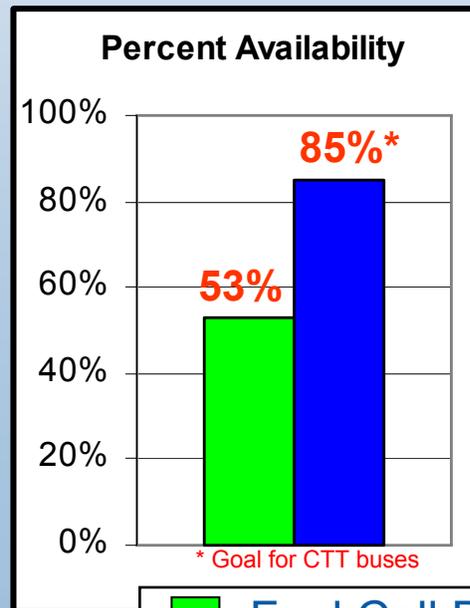
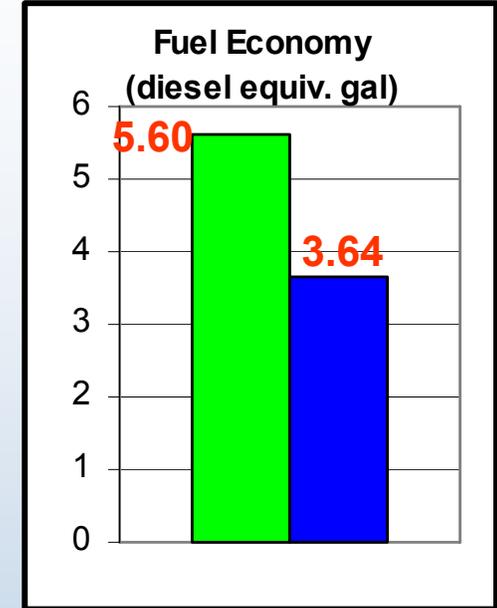


- 12 months operation of 1 FCB
- Total miles: 9,298
- Total FC system hours: 1,596

Diesel Bus (baseline)



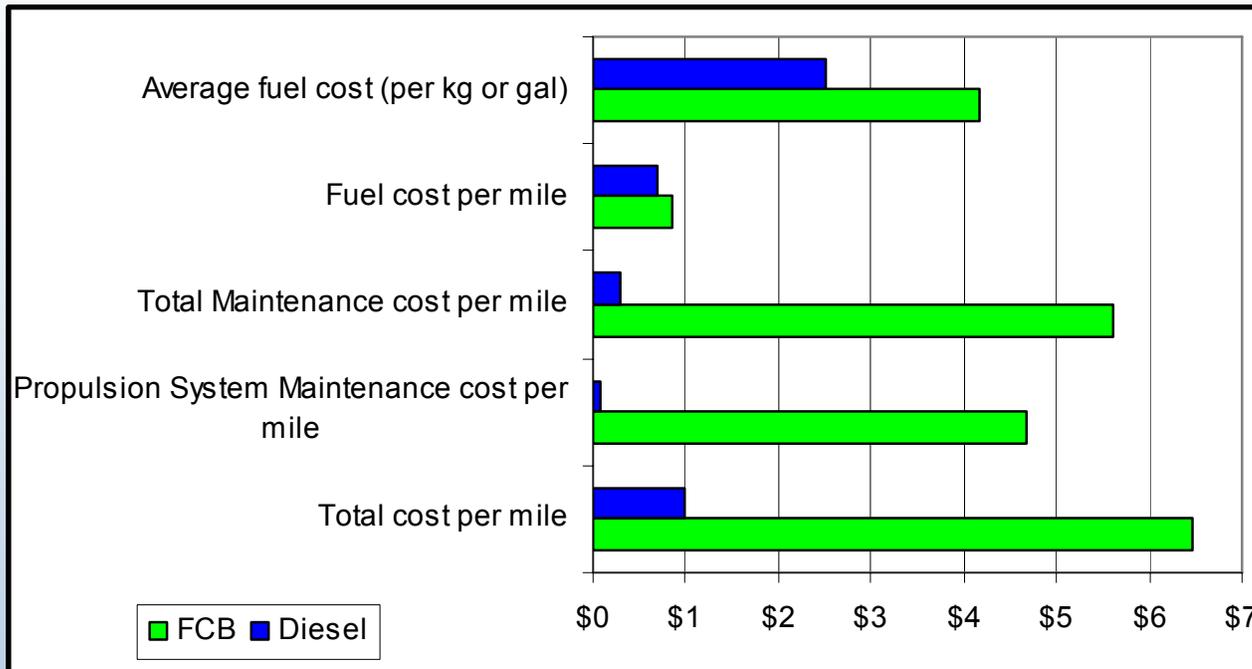
- 8 months operation of 3 diesel buses
- Total miles: 70,236



■ Fuel Cell Bus ■ Diesel Bus

Fleet Data Summary: CTTRANSIT

Summary of Costs*



* Warranty data is not included in calculations. Manufacturer staff are conducting most of the system repairs with assistance from agency staff. Costs are expected to increase as fleet takes over these tasks.

Evaluation Status

- In-Progress
- 1st fleet operating in cold climate
- First data report summer 2008



Fact Sheet Published 2/08

Available online at www.nrel.gov/hydrogen/pdfs/42407.pdf

Infrastructure Data Summary

VTA

- Air Products
- Liquid H₂ storage
- Dispenses compressed H₂
- 32 months data

SunLine

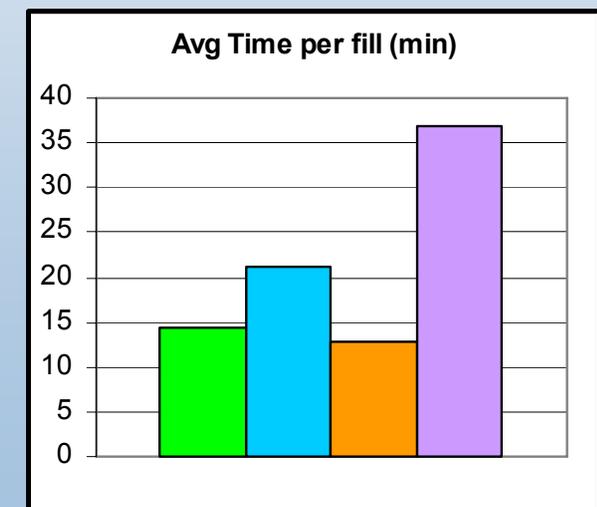
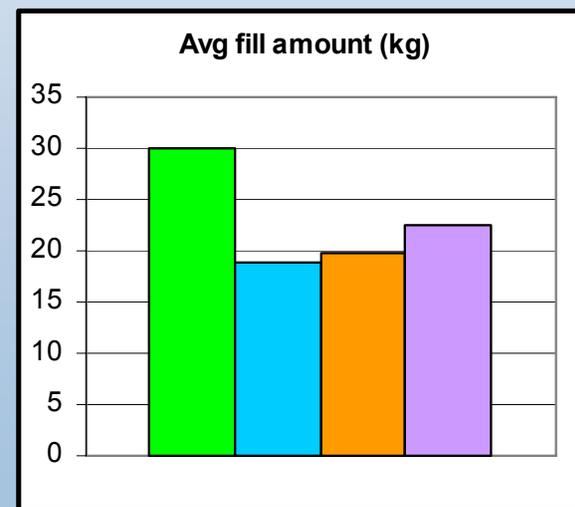
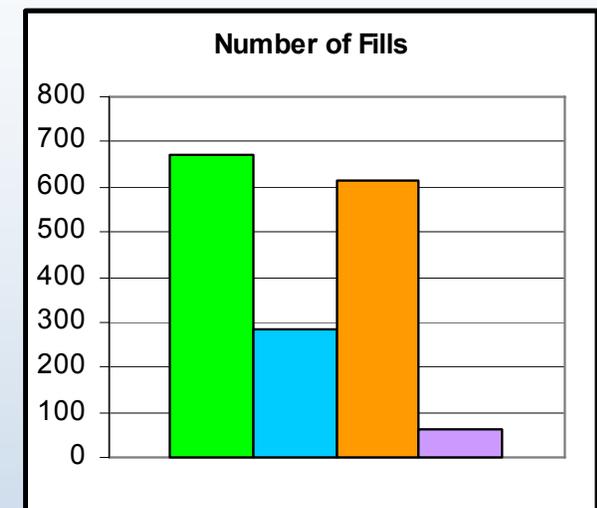
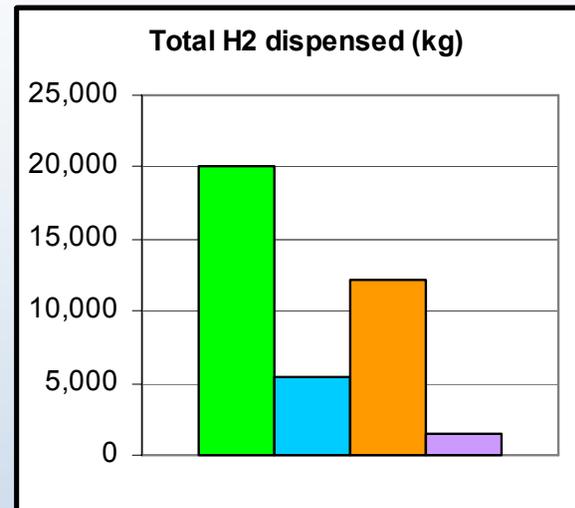
- HyRadix
- Natural gas reformer
- 13 months data

AC Transit

- Chevron
- Natural gas reformer
- 24 months data

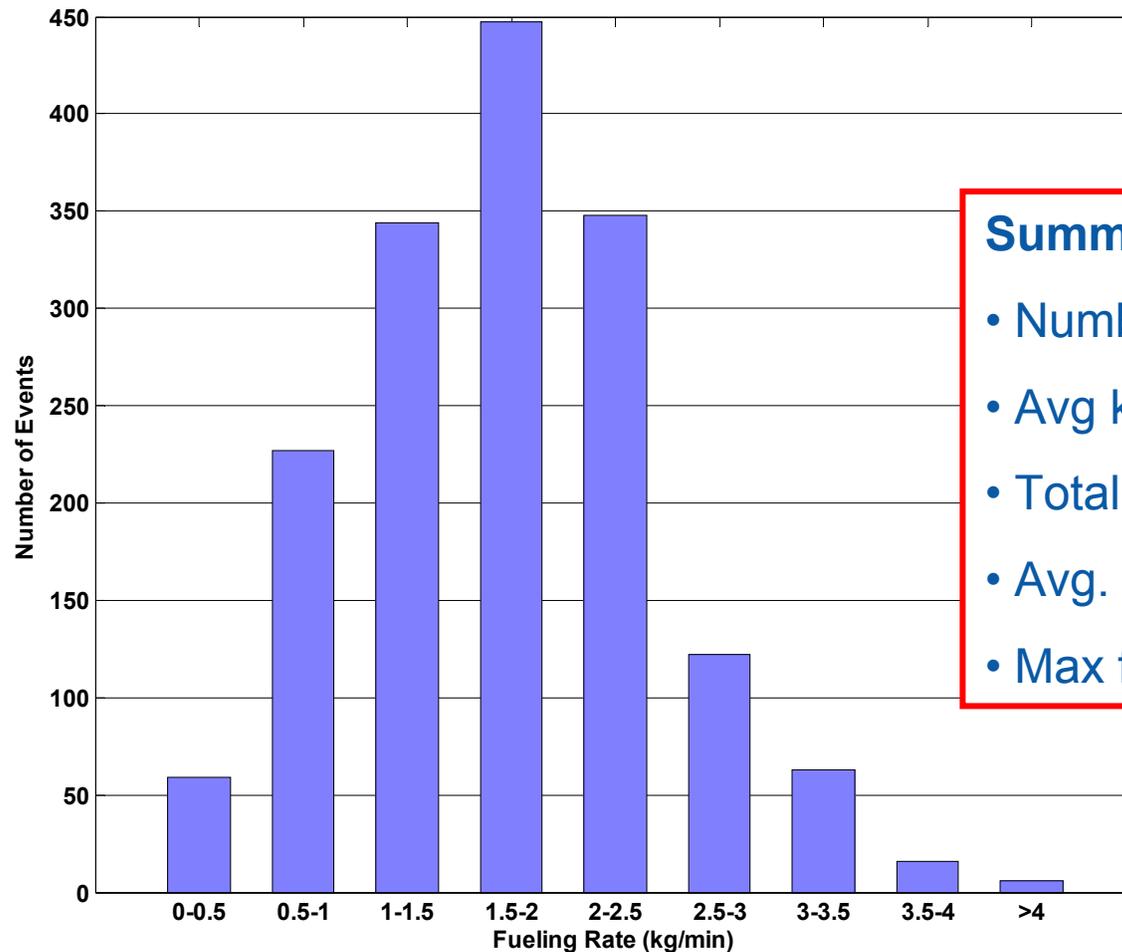
CTTRANSIT

- UTC Power station
- Praxair
- Liquid H₂ storage
- Dispenses compressed H₂
- 9 months data



Infrastructure Data Summary

Fueling Rate Histogram – all fleets



Summary:

- Number of fueling events: 1,632
- Avg kg/fill: 23.9 kg
- Total kg dispensed: 39,077
- Avg. fueling rate: 1.5 kg/min
- Max fill rate: 4.67 kg/min

Future Work

- Remainder of FY 2008
 - Complete data analysis reports on AC Transit and SunLine
 - Initiate data collection on SunLine FCB with next generation fuel cell power system
 - Complete first data analysis report on **CTTRANSIT**
 - Complete update to FCB Summary and Status paper
- FY 2009
 - Complete analysis and final data report on Hickam
 - Complete update data analysis and report on **CTTRANSIT** and SunLine
 - Initiate data collection for second generation design FCBs at AC Transit and VTA
 - Coordinate data collection activities with FTA

Planned FCB Evaluations for DOE and FTA

| Site/Locations | State | Eval. Funding | 2007 | | 2008 | | | | 2009 | | | | 2010 | | | |
|-----------------------------|-------|---------------------------------|------------------------|---|------|---|---|---|------|---|---|---|------|---|---|---|
| | | | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| AC Transit /Oakland | CA | DOE Tech. Validation | HyRoad | | | | | | | | | | | | | |
| AC Transit /Oakland | CA | | AC Transit CA ZEB 2009 | | | | | | | | | | | | | |
| SunLine /Thousand Palms | CA | | FCB/HHICE | | | | | | | | | | | | | |
| SunLine /Thousand Palms | CA | | FCB Ext. Service | | | | | | | | | | | | | |
| SunLine /Thousand Palms | CA | | Advanced FCB Project | | | | | | | | | | | | | |
| CTTRANSIT /Hartford | CT | | CTTRANSIT FCB Demo | | | | | | | | | | | | | |
| Hickam AFB /Honolulu | HI | | Air Force FCV Demo | | | | | | | | | | | | | |
| VTA /San Jose | CA | | VTA CA ZEB 2009 | | | | | | | | | | | | | |
| AC Transit /Oakland | CA | | Accelerated Testing | | | | | | | | | | | | | |
| SunLine /Thousand Palms | CA | American FCB Demo | | | | | | | | | | | | | | |
| CTTRANSIT /Hartford | CT | CT Hybrid FCB Demo | | | | | | | | | | | | | | |
| Columbia /Site 2/ CTTRANSIT | SC/CT | Dual Variable Output Hybrid FCB | | | | | | | | | | | | | | |
| Logan Airport /Boston | MA | MA H2 FCB Fleet | | | | | | | | | | | | | | |
| NFTA /Buffalo | NY | Lightweight FCB Demo | | | | | | | | | | | | | | |
| NFTA /Buffalo | NY | Hydroelectric H2 Powered FCB | | | | | | | | | | | | | | |
| SFMTA /San Francisco | CA | FC APU Hybrid | | | | | | | | | | | | | | |

Demonstration sites are color coded by area:

- California 
- New England 
- Western NY 
- Southeast 
- Hawaii 
- South 

* Detailed data analysis funded by DOE



Summary

- Collected operational, performance, and cost data on 9 hydrogen fueled buses in real-world service at four transit agencies:
 - VTA: 17 months
 - SunLine: 27 months
 - AC Transit: 24 months
 - **CTTRANSIT**: 12 months
- Validated fuel cell bus performance characteristics equal to or better than diesel
 - Drivers report better acceleration and quiet operation
- Demonstrated that bus duty-cycle allows fast accumulation of miles/FC hours
 - Over 220,000 total miles and over 16,000 FC hours
- Collected performance and cost data on conventional technology to establish a baseline for tracking progress
 - Use of prototype FCBs is increasing, but still much less than standard buses
 - High cost for maintaining current generation prototype technology
- Transit agency staff are being trained to handle more of the maintenance repairs
 - For early demonstrations, all propulsion system related maintenance was handled by on-site manufacturer staff
 - Expect costs to rise

Summary (continued)

- Fuel cell bus use less than baseline
 - Beginning to increase as fleets accelerate testing
- Fuel economy
 - Highly dependent on duty-cycle
 - Results show need for hybridization
 - Improvement over conventional technology approaching 2X

