Technology Validation: Fuel Cell Bus Evaluations

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**Project ID#
TV10**

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

Overview

Timeline

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

Budget

- FY 2007: $288K
- FY 2006: $288K
- FY 2005: $338 K

Barriers

A. Lack of fuel cell vehicle performance and durability data

C. Lack of H_2 fueling infrastructure performance and availability data

D. Maintenance and training facilities

Partners

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

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)

- 2006
  - Complete analysis and reporting on VTA
  - Complete interim analysis and reporting for AC Transit and SunLine

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
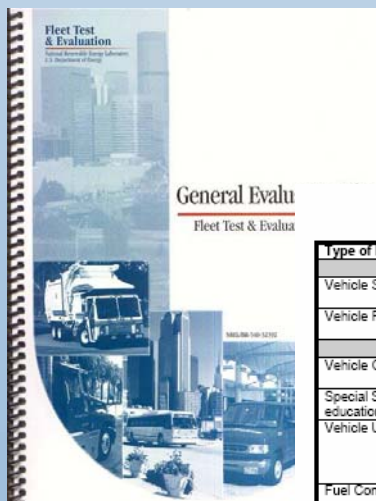 - Only aggregate data products made public

Evaluation of Hydrogen and Fuel Cell Buses in Four Fleets

Santa Clara VTA, San Jose, CA

Ballard FC System: non-hybrid

AC Transit, Oakland, CA

UTC Power, ISE Corp: hybrid FCB

SunLine, Thousand Palms, CA

UTC Power, ISE Corp: hybrid FCB

ISE Corp: hybrid H_2 ICE

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: Santa Clara VTA

Fuel Cell Bus (non-hybrid system)

- 17 months operation of 3 FCBs
- Total miles: 40,208
- Total FC system hours: 3,219

Diesel Bus (baseline)

- 17 months operation of 5 diesel buses
- Total miles: 360,447

Average Monthly Miles

- Fuel Cell Bus: 809
- Diesel Bus: 4,335

Fuel Economy (diesel equiv. gal)

- Fuel Cell Bus: 3.52
- Diesel Bus: 3.98

Percent Availability

- Fuel Cell Bus: 58%
- Diesel Bus: 85%

MBRC: Propulsion only

- Fuel Cell Bus: 1,044
- Diesel Bus: 11,242

Legend: Fuel Cell Bus | Diesel Bus

Fleet Data Summary: Santa Clara VTA

Summary of Costs

Chart legend: FCB (green), Diesel (blue)

Categories (top to bottom):
- Average fuel cost (per kg or gal)
- Fuel cost per mile
- Total maintenance cost per mile
- Propulsion system maintenance cost per mile
- Total cost per mile

X-axis: $0.00, $2.00, $4.00, $6.00, $8.00, $10.00
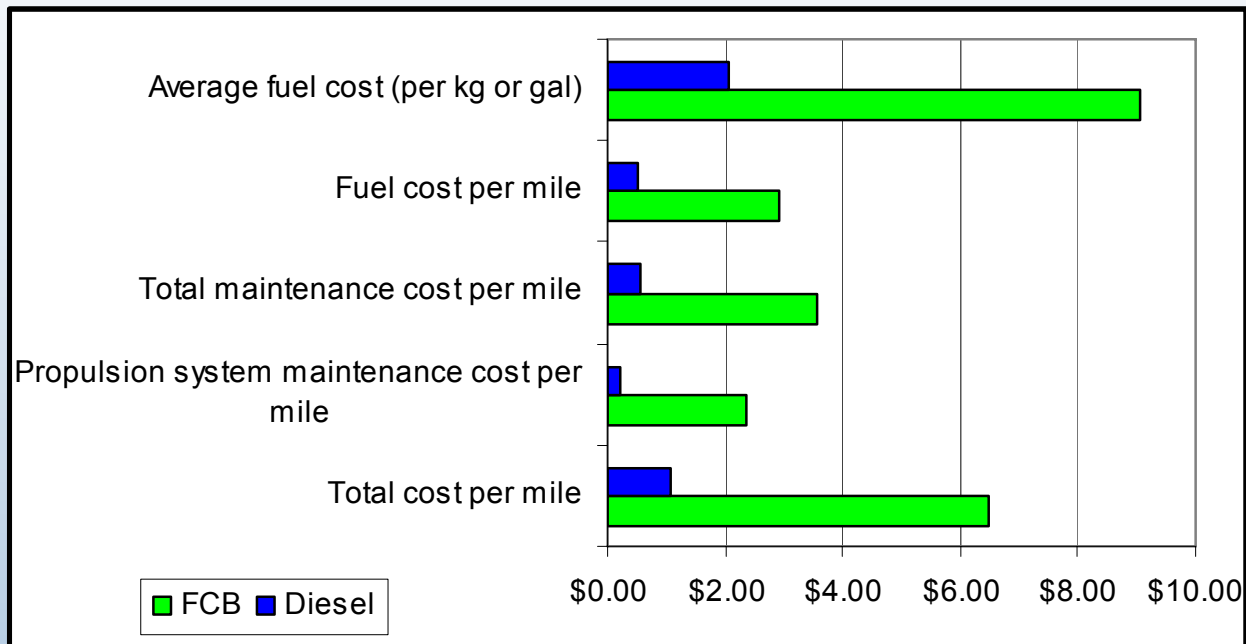
Evaluation Status

- Complete
- Report published
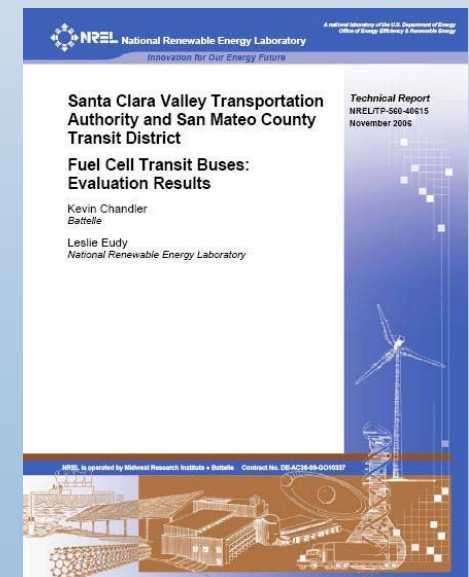
Report available online at
www.nrel.gov/hydrogen/pdfs/40615.pdf

NREL National Renewable Energy Laboratory
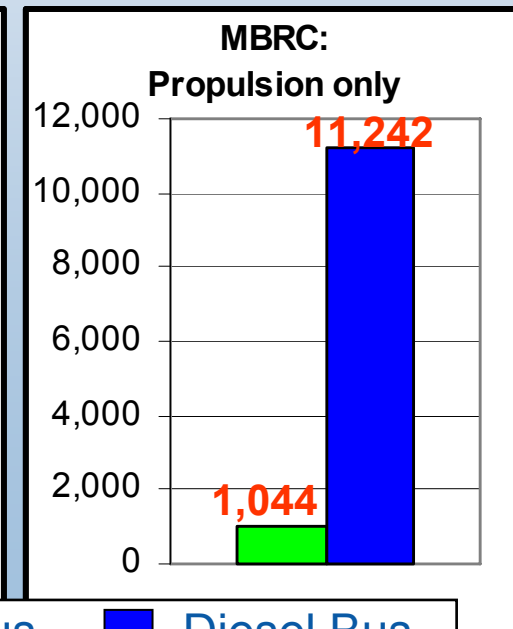
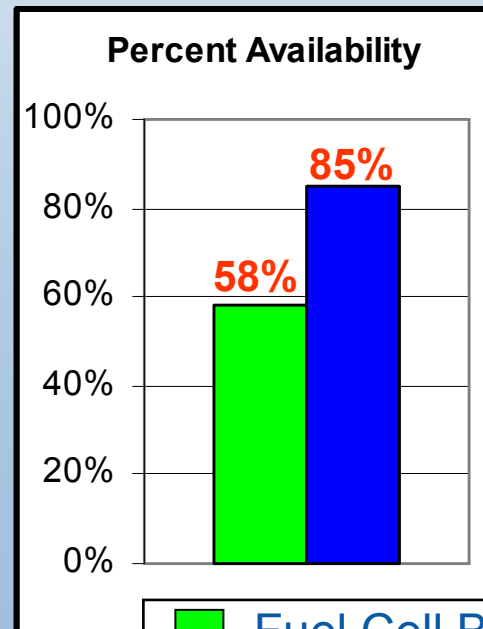# Fleet Data Summary: AC Transit
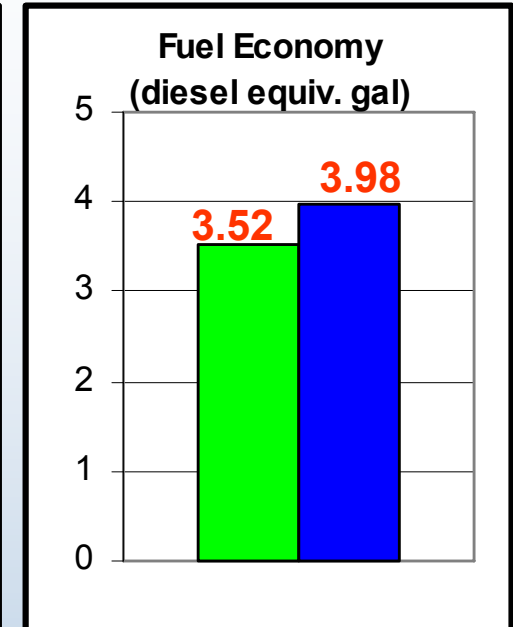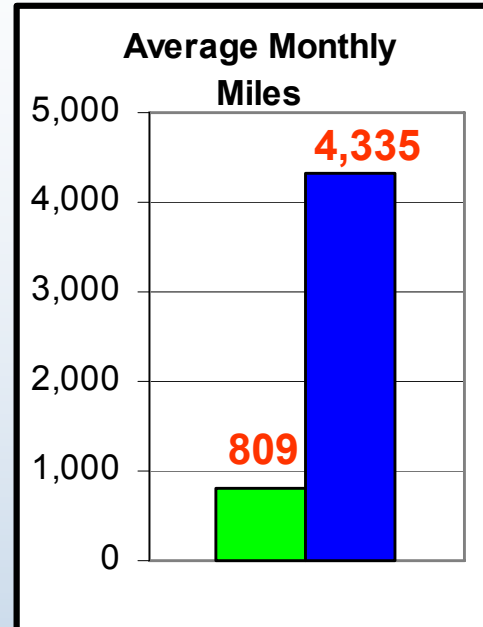
Fuel Cell Bus (hybrid system)

- 8 months operation of 3 FCBs
- Total miles: 27,065
- Total FC system hours: 2,338

Diesel Bus (baseline)

- 8 months operation of 6 diesel buses
- Total miles: 102,755

Average Monthly Miles

- 1,128 (Fuel Cell Bus)
- 2,141 (Diesel Bus)

Fuel Economy (diesel equiv. gal)

- 6.22 (Fuel Cell Bus)
- 4.46 (Diesel Bus)

Percent Availability

- 77% (Fuel Cell Bus)
- 85% (Diesel Bus)

MBRC: Propulsion only

- 1,230 (Fuel Cell Bus)
- 8,563 (Diesel Bus)
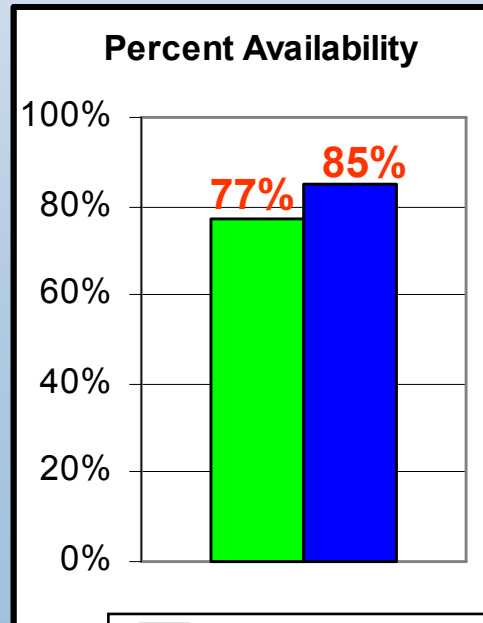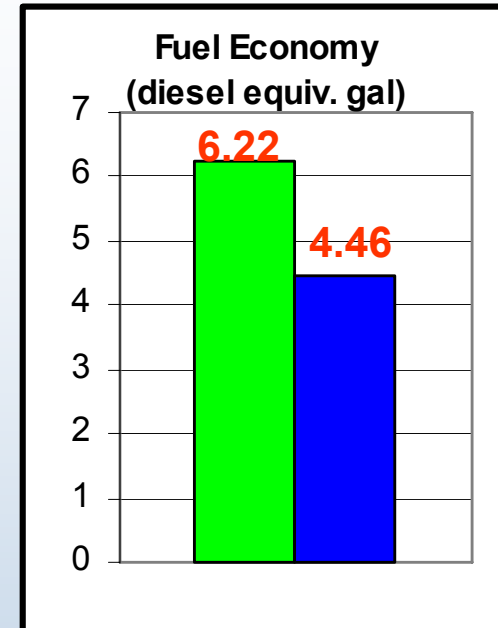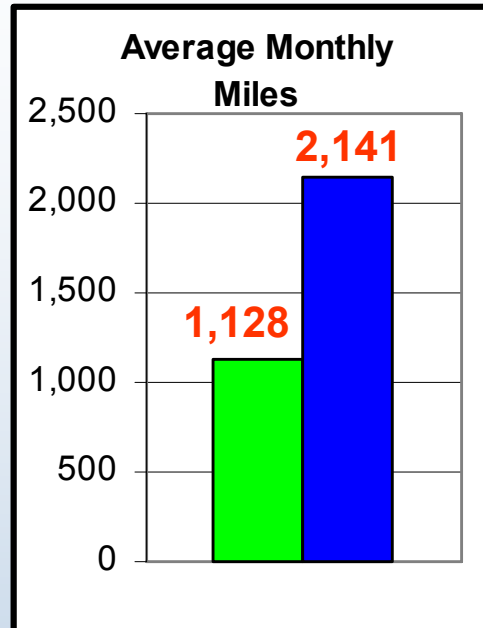
Legend: Fuel Cell Bus | Diesel Bus

Fleet Data Summary: AC Transit

Summary of Costs
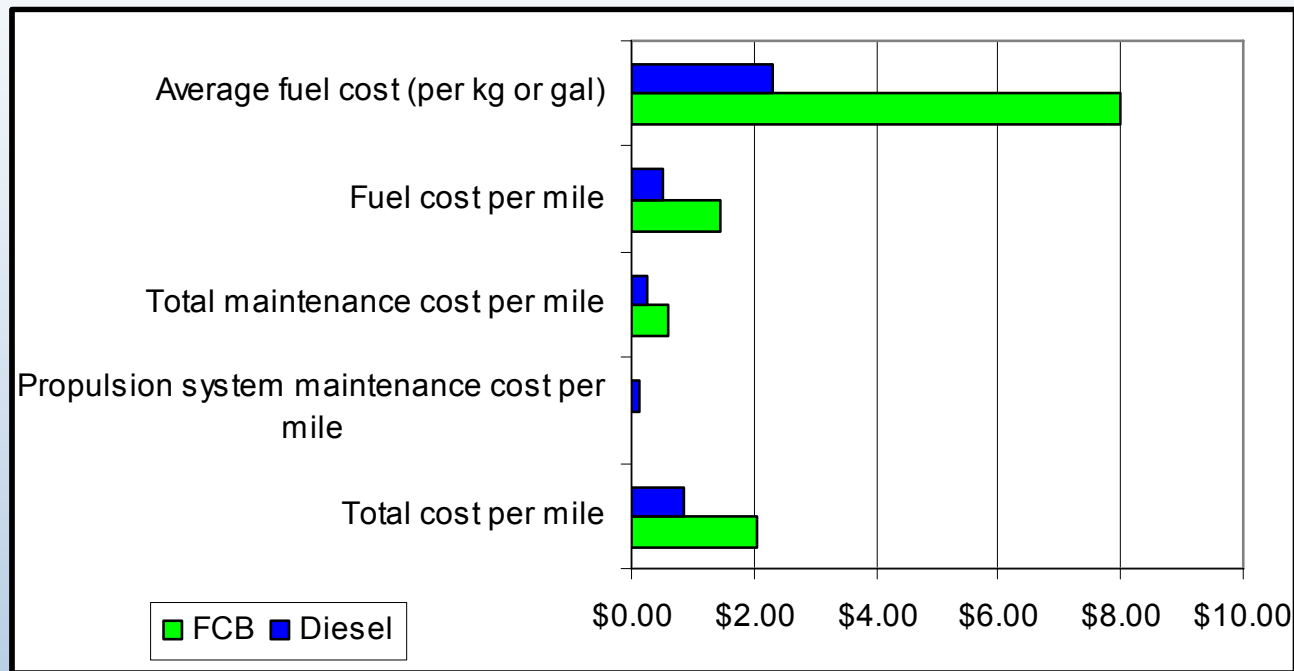
Chart categories (top to bottom):
- Average fuel cost (per kg or gal)
- Fuel cost per mile
- Total maintenance cost per mile
- Propulsion system maintenance cost per mile
- Total cost per mile

Legend: ■ FCB ■ Diesel

X-axis: $0.00 $2.00 $4.00 $6.00 $8.00 $10.00

Evaluation Status

- Data collection ongoing
- Interim report published
- Second data report planned for fall 2007

National Renewable Energy Laboratory

Alameda-Contra Costa Transit District (AC Transit) Fuel Cell Transit Buses

Technical Report
NREL/TP-560-41041
March 2007

Preliminary Evaluation Results

K. Chandler
Battelle

L. Eudy
National Renewable Energy Laboratory

Report available online at
www.nrel.gov/hydrogen/pdfs/41041.pdf

NREL National Renewable Energy Laboratory
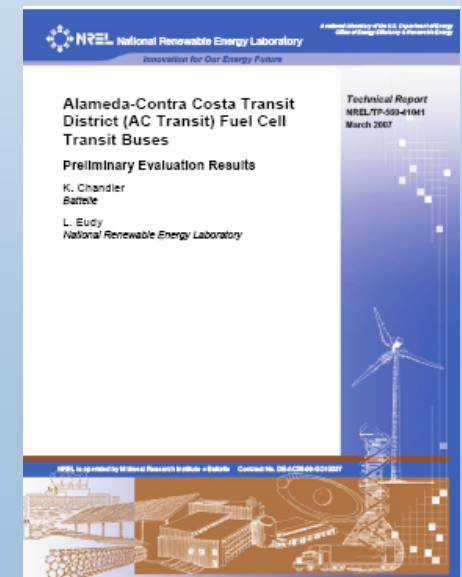
Fleet Data Summary: SunLine

Fuel Cell Bus (hybrid system)

- 11 months operation of 1 FCB
- Total miles: 19,208
- Total FC system hours: 1,345
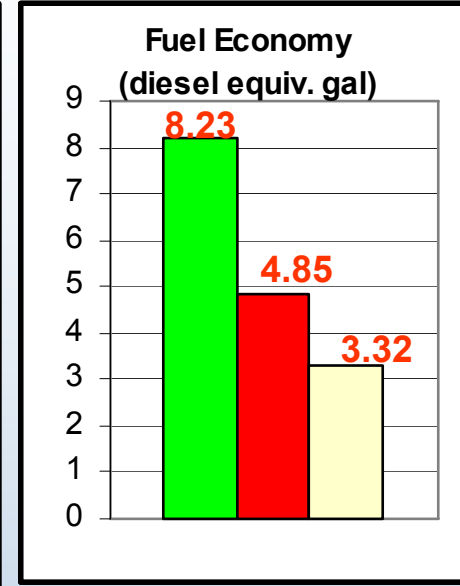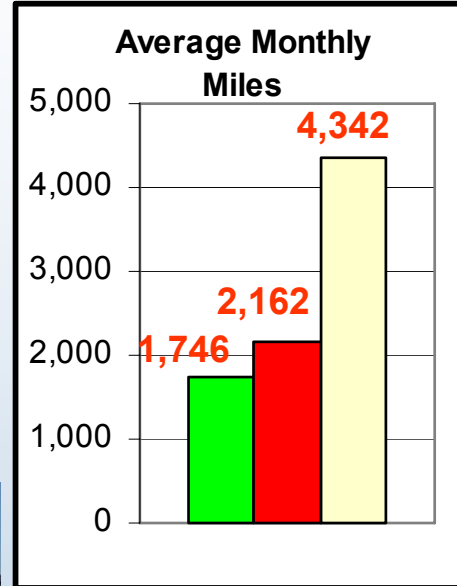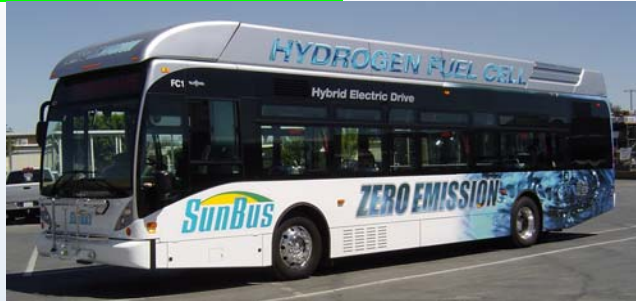
HHICE Bus

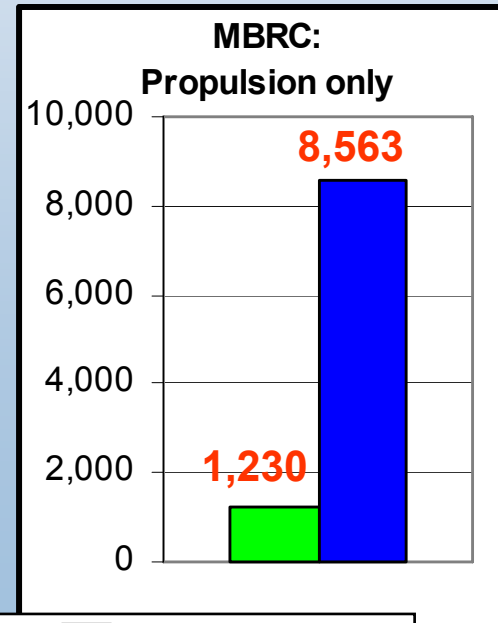- 11 months operation of 1 HHICE bus
- Total miles: 23,661
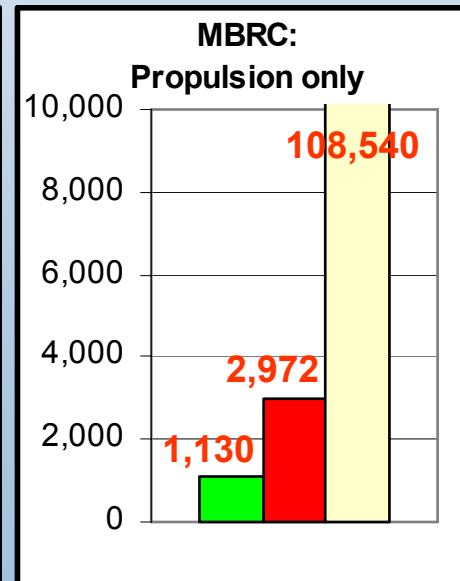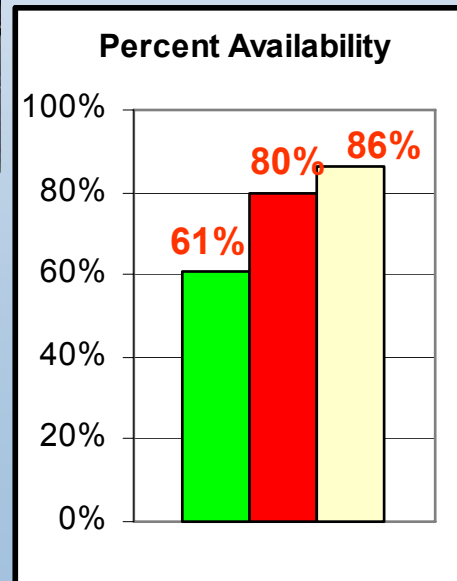
CNG Bus

- 5 months operation of 5 CNG buses
- Total miles: 108,540

Average Monthly Miles
- 1,746
- 2,162
- 4,342

Fuel Economy (diesel equiv. gal)
- 8.23
- 4.85
- 3.32

Percent Availability
- 61%
- 80%
- 86%

MBRC: Propulsion only
- 1,130
- 2,972
- 108,540

Legend: Fuel Cell Bus | HHICE bus | CNG Bus

*HHICE – hybrid H_2 internal combustion engine

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Fleet Data Summary: SunLine

Summary of Costs
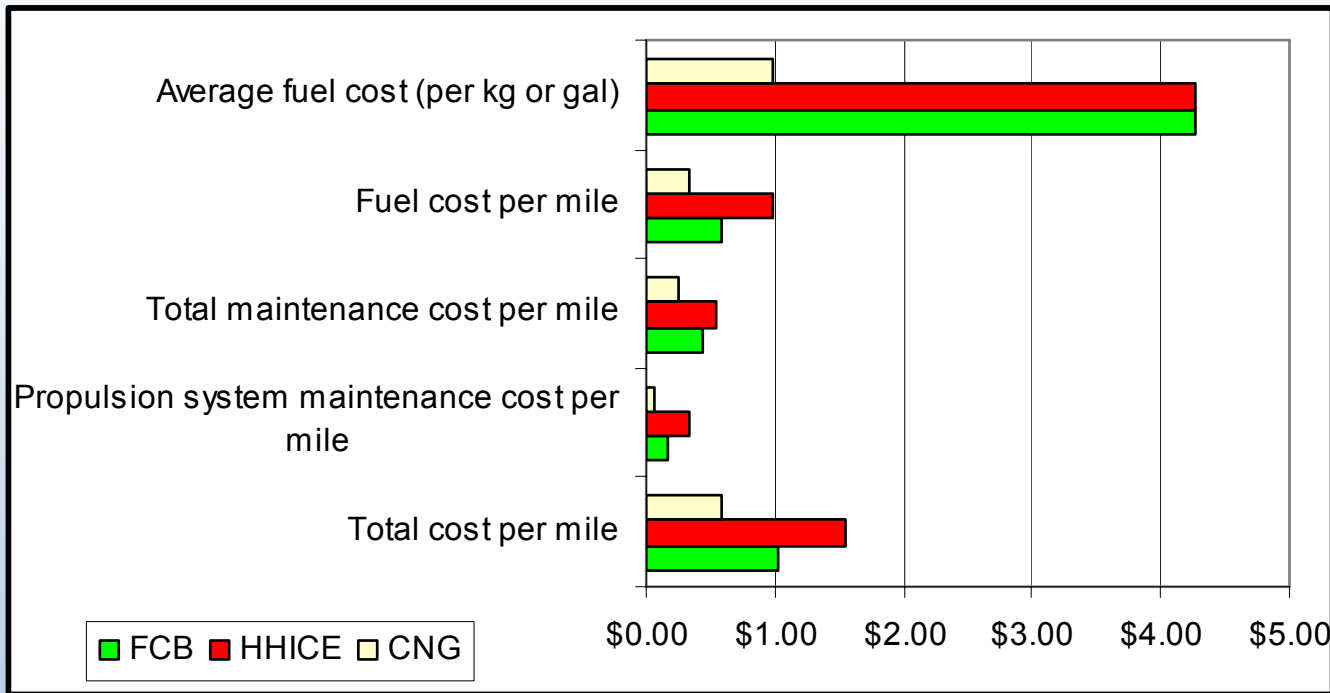
Chart legend: FCB (green), HHICE (red), CNG (yellow)

Categories:
- Average fuel cost (per kg or gal)
- Fuel cost per mile
- Total maintenance cost per mile
- Propulsion system maintenance cost per mile
- Total cost per mile

X-axis: $0.00, $1.00, $2.00, $3.00, $4.00, $5.00

Evaluation Status

- Data collection ongoing
- Interim report published
- Second data report planned for fall 2007

SunLine Transit Agency
Hydrogen-Powered Transit Buses:
Preliminary Evaluation Results

Technical Report
NREL/TP-560-41001
February 2007

K. Chandler
Battelle

L. Eudy
National Renewable Energy Laboratory
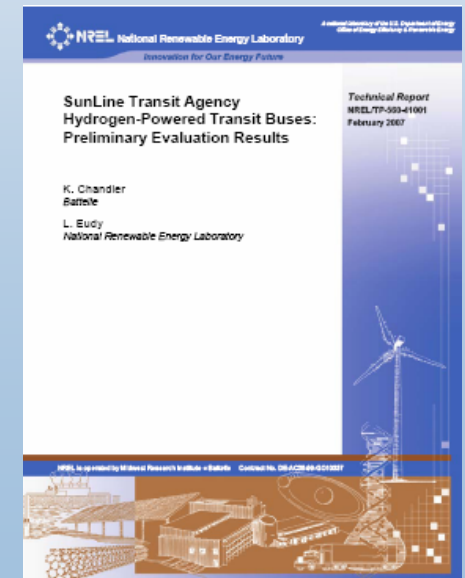
Report available online at
www.nrel.gov/hydrogen/pdfs/41001.pdf

Infrastructure Data Summary: VTA

VTA H$_2$ Fueling Station

Cumulative Fueling Rate Histogram

- 460 fills
- Avg kg/fill = 30.9
- Avg rate = 1.93 kg/min
- Total H$_2$ dispensed = 14,024 kg
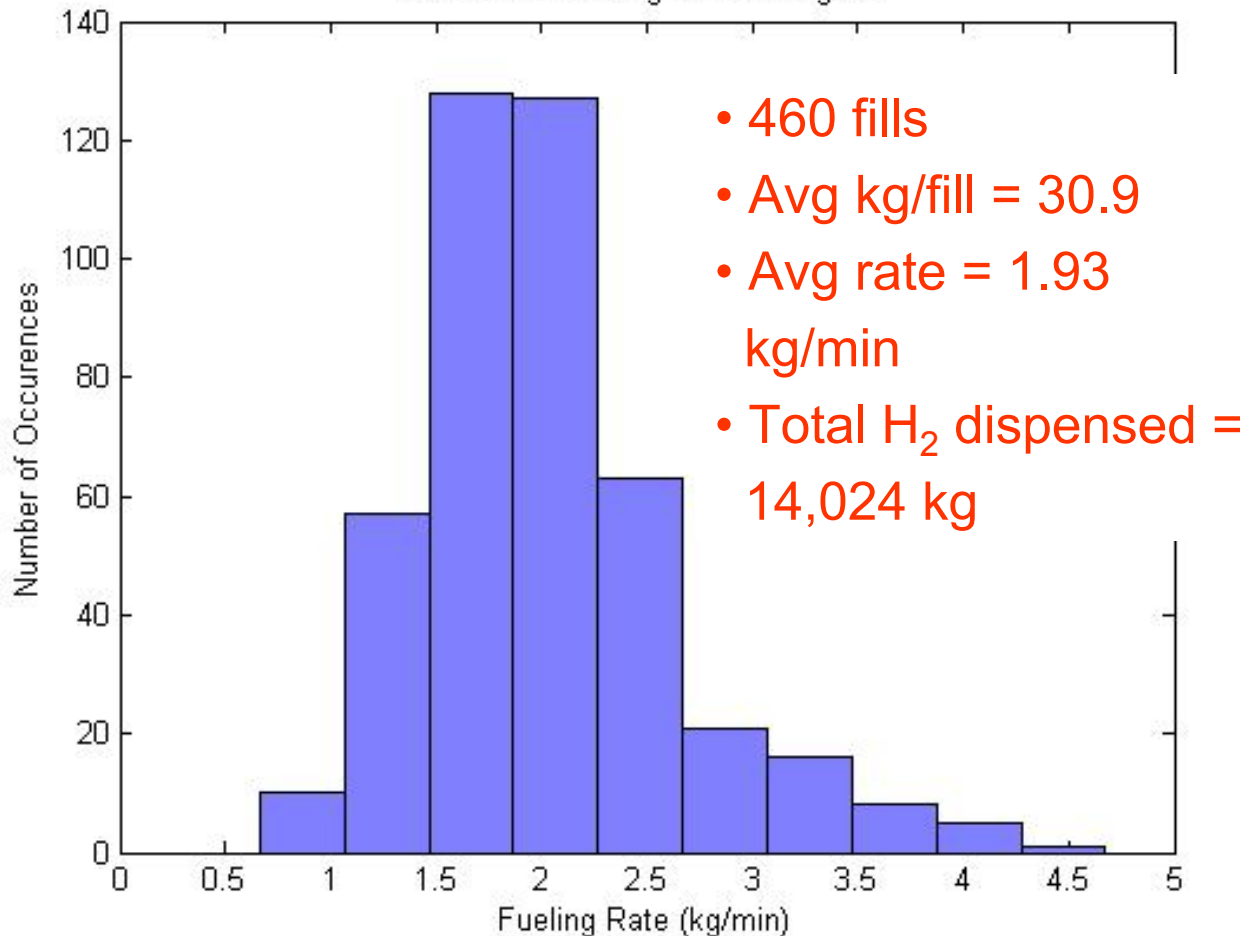
VTA fueling station:
- Air Products
- Liquid H$_2$ storage
- Dispenses compressed H$_2$

Chevron - AC Transit H_2 Energy Station

Cumulative Fueling Rate Histogram - Chevron - AC Transit H2 Energy Station (Bus only)

- 215 fills
- Avg kg/fill = 21.8
- Avg rate = 1.35 kg/min
- Total H_2 dispensed = 4,919

ACT fueling station:

- Chevron Technology Ventures
- Natural gas reformer
- 150 kg H_2 per day
- 366 kg storage
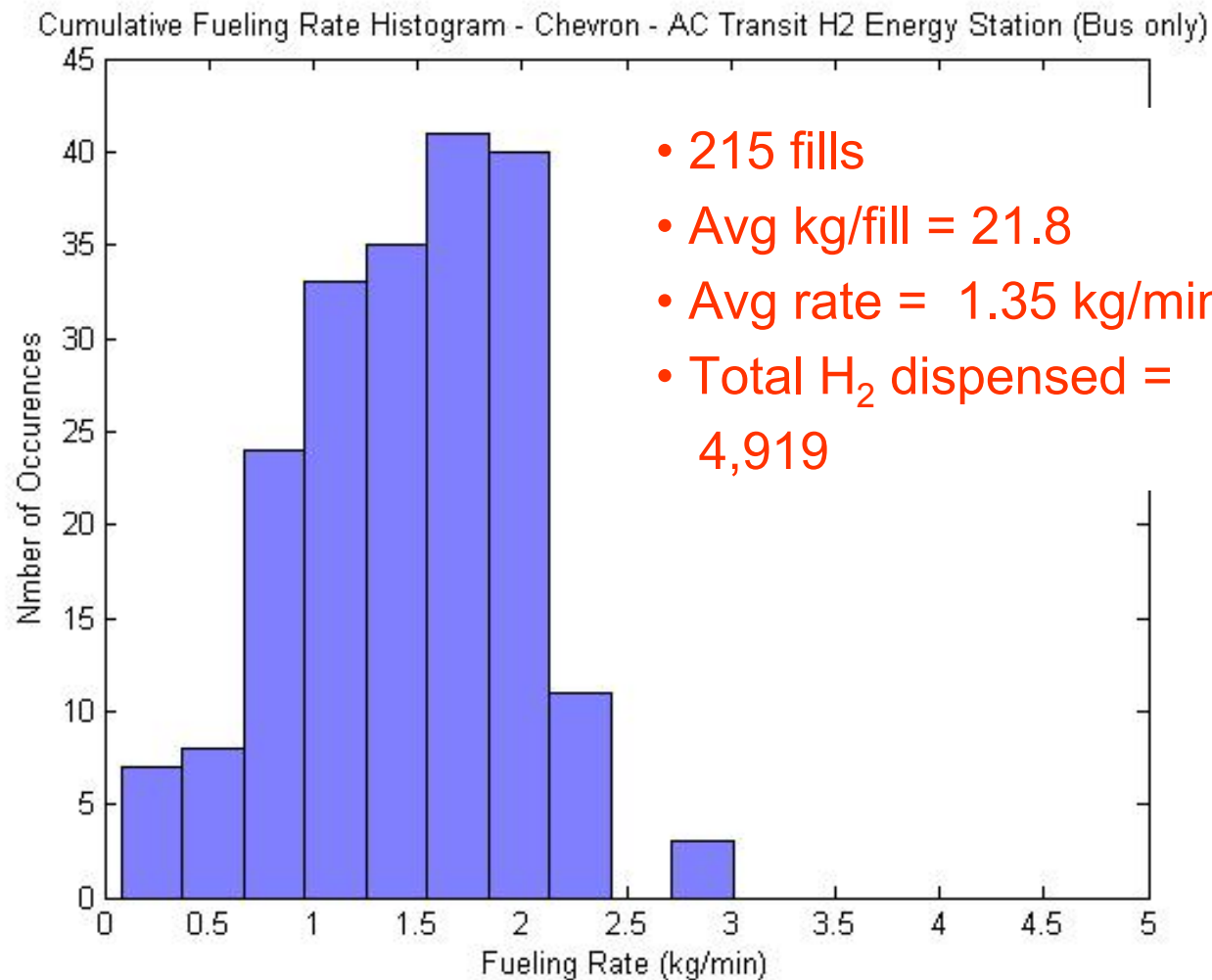
Hickam Air Force Base: Status

Demonstration of two fuel cell vehicles

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

Status

- H_2 fueling available in late 2006
- Bus operating as visitor shuttle on base and in surrounding area
- Step van in service as maintenance support vehicle
- Interim report scheduled for publication in fall 2007

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International Collaboration

4th workshop held in Yokohama, Japan in October 2006

- Overall goal: enhance information sharing and data exchange between international FCB demos

- Group discussion:
  - Developed a list of performance data available to share from all projects
  - Listed concerns and issues that must be solved prior to sharing
  - Established action items and a timeline for accomplishment

- Planning 5th International Fuel Cell Bus Workshop in summer 2008

IPHE
Recognized
Event

Future Work

- Remainder of FY 2007
  - Data analysis and draft preliminary data report on Hickam evaluation
  - Complete second data analysis and reports on AC Transit and SunLine
  - Collect more technical data on FCBs and infrastructure to complement DOE Controlled Fleet Demo
- FY 2008
  - Complete analysis and final data report on Hickam
  - Complete final data analysis and reports on SunLine and AC Transit
  - Initiate data collection for additional fleets

Summary

- Collected operational, performance, and cost data on 8 hydrogen fueled buses in real-world service at three transit agencies:
  - VTA: 17 months
  - SunLine: 11 months
  - AC Transit: 8 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
  - Accumulated over 110,000 total miles and over 6,900 FC hours

- Collected performance and cost data on conventional technology to establish a baseline for tracking progress
  - Use of prototype FCBs is much less than standard buses
  - High cost for maintaining current generation prototype technology

Summary (continued)

- Fuel cell bus use less than baseline
  - Range from 50% below to 81% below standard bus use
- Fuel economy
  - Fuel economy results show need for hybridization
  - Improvement over conventional technology approaching 2X
  - Highly dependent on duty-cycle

Monthly Mileage Comparison

Average Monthly Mileage (VTA, SunLine, AC Transit)

Legend: Fuel Cell Bus, Diesel Bus, CNG, HHICE Bus

Fuel Economy: Percent difference from Baseline

Non-hybrid system with Diesel baseline

Hybrid systems with CNG baseline

Hybrid system with Diesel baseline

(VTA, SunLine FCB, SunLine HHICE, AC Transit)