National Renewable Energy Laboratory
Innovation for Our Energy Future

Technology Validation: Fuel Cell Bus Evaluations

2009 DOE Annual Merit Review

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Overview

Timeline

- Project started in FY03
- First-generation FCB completed in FY09
- Second-generation FCBs begin 3rd Qtr 2009

Budget

- FY 2009: $205K
- FY 2008: $300K
- FY 2007: $288K

Barriers

A. Lack of fuel cell vehicle performance and durability data

B. Lack of H_2 fueling infrastructure performance and availability data

D. Need for maintenance and training facilities

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
  - Measure 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)
- 2009
  - Complete data reports on **CT**TRANSIT and SunLine
  - Begin data collection and analysis for next-generation fuel cell buses at Burbank and AC Transit
  - Crosscutting analysis of FCB status at all sites

Planned FCB Evaluations for DOE and FTA

NREL Hydrogen Bus Evaluations for DOE and FTA

Site/Location	State	Eval. Funding	2008				2009				2010				2011			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
AC Transit/ SF Bay Area	CA	DOE Technology Validation							CA ZEB Advanced Demo									
SunLine/ Thousand Palms	CA		FCB Extended Testing															
SunLine/ Thousand Palms	CA								Advanced FCB Project									
CTTRANSIT/ Hartford	CT		CTTRANSIT FCB Demo															
City of Burbank/ Burbank	CA								Burbank									
AC Transit/ Oakland	CA	FTA National Fuel Cell Bus Program	Accelerated Testing															
SunLine/ Thousand Palms	CA										American FCB Demo							
CTTRANSIT/ Hartford	CT									Nutmeg Hybrid FCB Demo								
Columbia / Site 2/ **CT**TRANSIT	SC/ CT								Dual Variable Output Hybrid FCB									
Logan Airport / Boston	MA										MA H2 FCB Demo							
TBD / NY	NY										Lightweight FCB Demo							
TBD / NY	NY										NYPA H2 Powered FCB							
SFMTA / San Francisco	CA										FC APU Hybrid							

National Fuel Cell Bus Program

Demonstration sites color coded by geographic area:

- Northern California
- New England
- Southeast
- Southern California
- New York
- South

Milestones

- Begin data collection on buses at cold climate sites – Hartford, CT: FY07
- Complete evaluations of 1st generation FCBs:
  - Santa Clara VTA: completed in FY07
  - AC Transit: completed in FY09
  - SunLine: FY09
  - **CT**TRANSIT: FY09
- Begin evaluations of 2nd generation FCBs
  - City of Burbank: FY09
  - AC Transit: FY09

Evaluation Approach

- Data collection & analysis at separate transit sites
  - Follows existing, standard protocol
  - Cost-effective process utilizing data already collected by agency
  - Includes data on baseline vehicles in same service
  - Builds database of evaluations
- Annual crosscutting analysis measuring progress toward commercialization
  - Includes summary of data across all sites
  - Assessment of progress and needs for continued success
- Continual assessment of data collection process
  - Investigate opportunities to expand data collected and analyzed as resources allow

Comparison of Fuel Cell Buses to Conventional Technology Baseline

Metrics for assessing progress toward commercialization

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

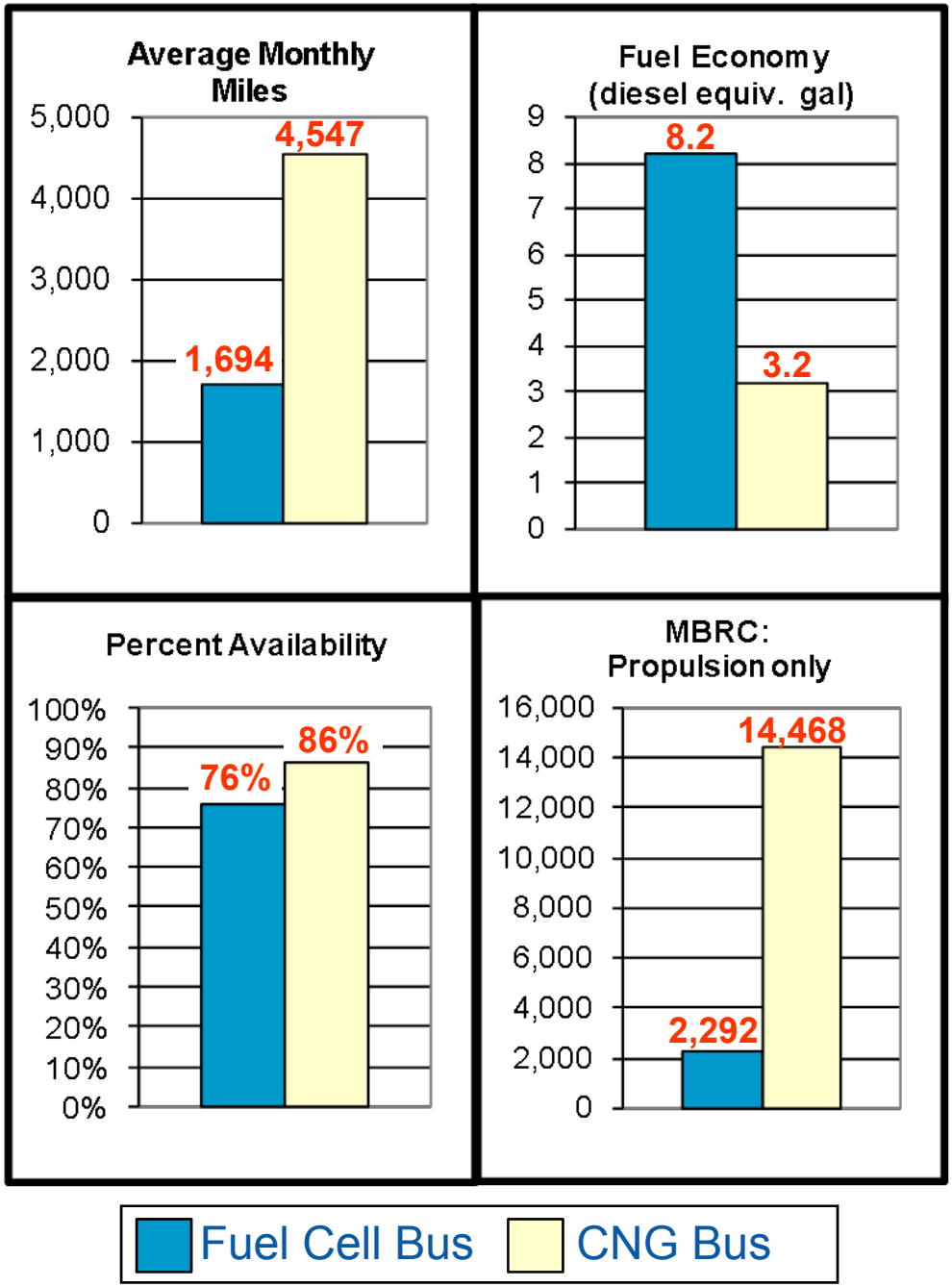
Fleet Data Summary: SunLine

Fuel Cell Bus (hybrid system)

- 7 months operation of 1 FCB
- Total miles: 11,461
- New, updated version of fuel cell installed
- Total FC system hours: 885

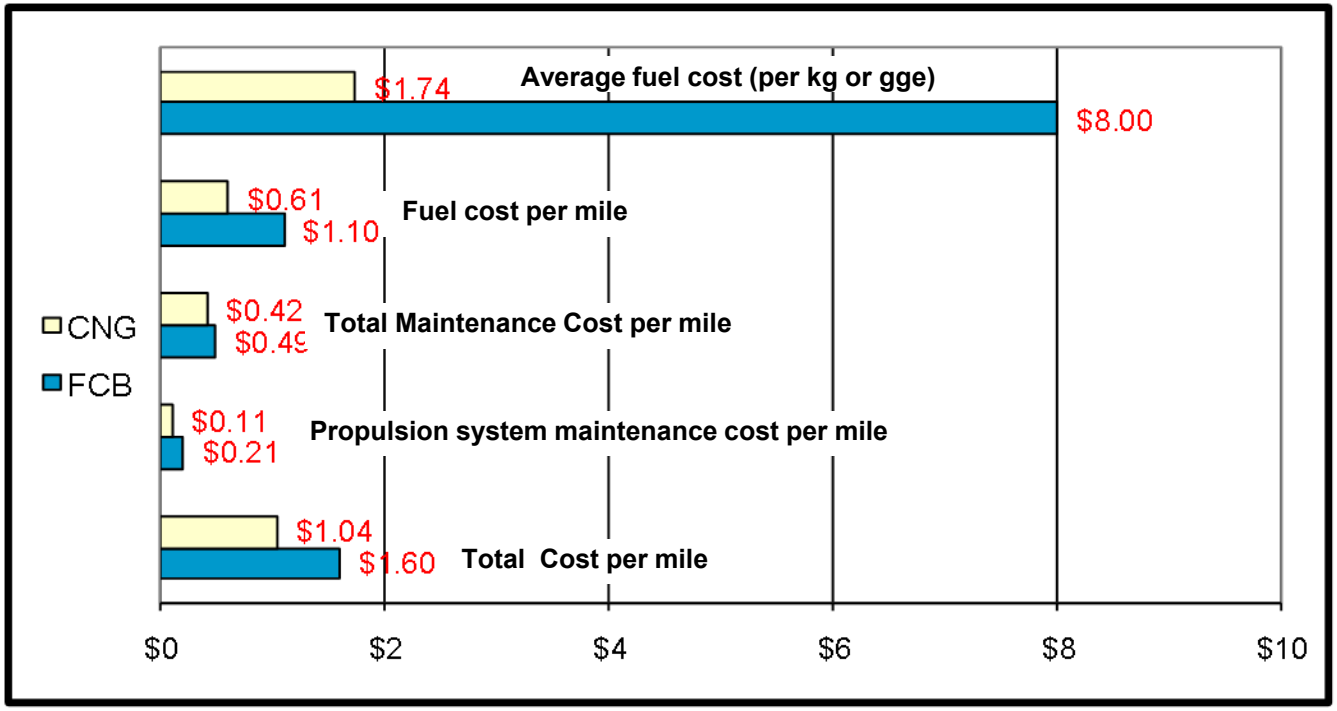
CNG Bus

- 7 months operation of 5 CNG buses
- Total miles: 159,150



Fleet Data Summary: SunLine

Summary of Costs*



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

Evaluation Status

- Completed data collection on current-gen. design: report, June 08
- Began data collection on bus with new design FC: report, Jan. 09

Report published 1/09
Available online at www.nrel.gov/hydrogen/pdfs/44646-1.pdf

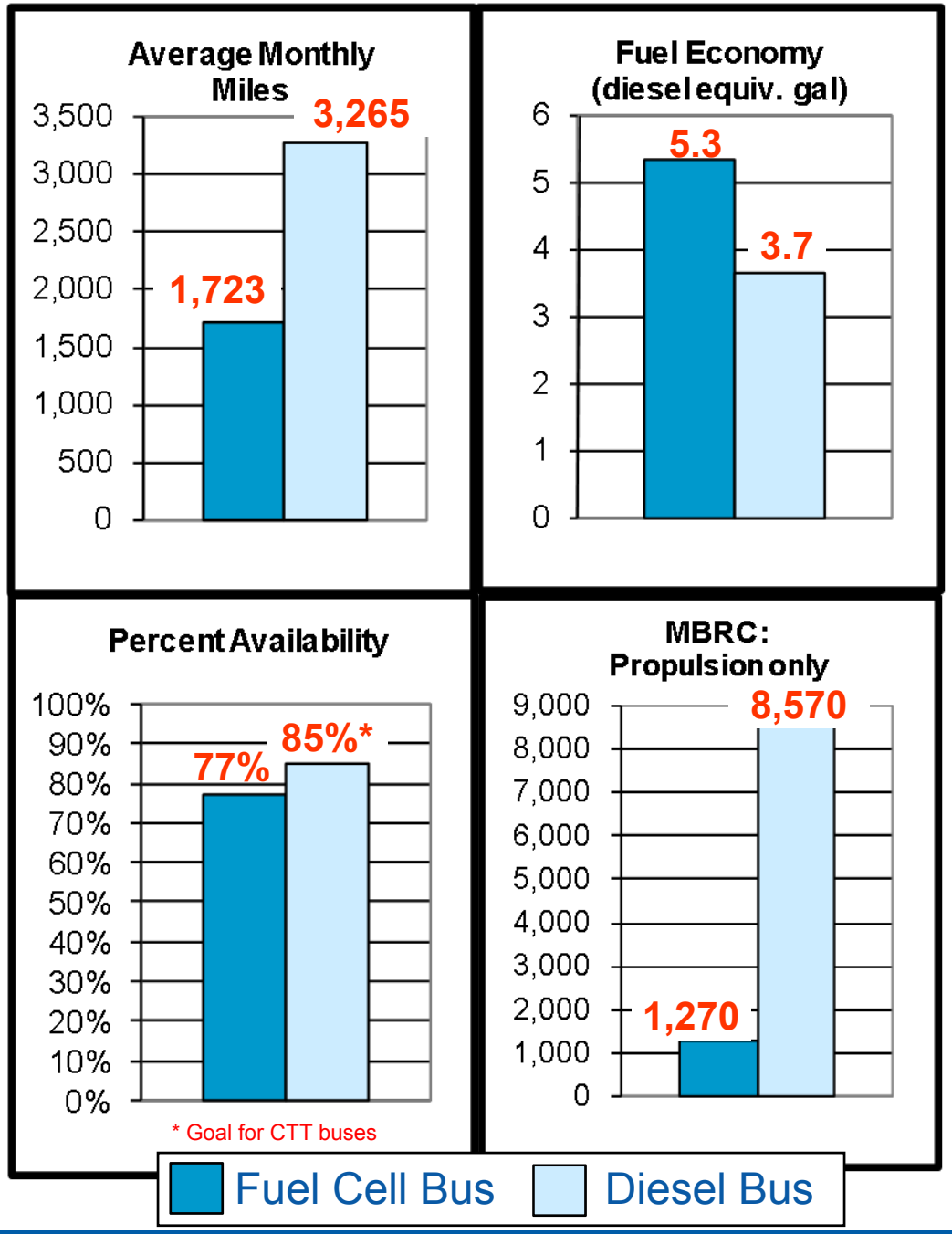
Fleet Data Summary: CTTRANSIT

Fuel Cell Bus (hybrid system)

- 14 months operation of 1 FCB
- Total miles: 24,127
- Updated version of fuel cell installed
- Total FC system hours: 3,544

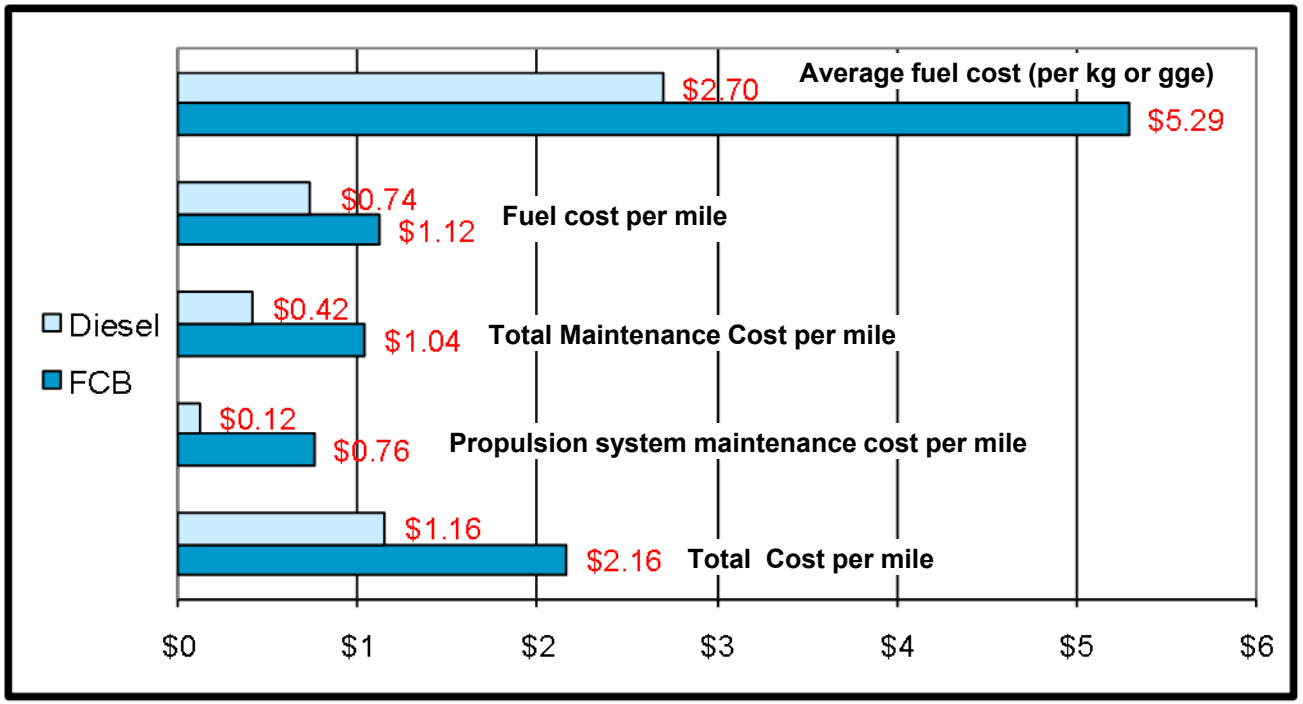
Diesel Bus (baseline)

- 14 months operation of 3 diesel buses
- Total miles: 137,127



Fleet Data Summary: CTTRANSIT

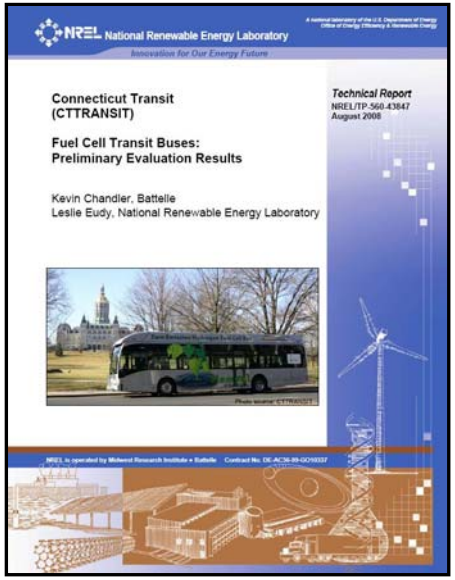
Summary of Costs*



* Warranty data are not included in calculations. Manufacturer's 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
- First fleet operating in cold climate
- 1st report, Oct. 08
- 2nd report, May 09



Report published 10/08
Available online at www.nrel.gov/hydrogen/pdfs/43847.pdf

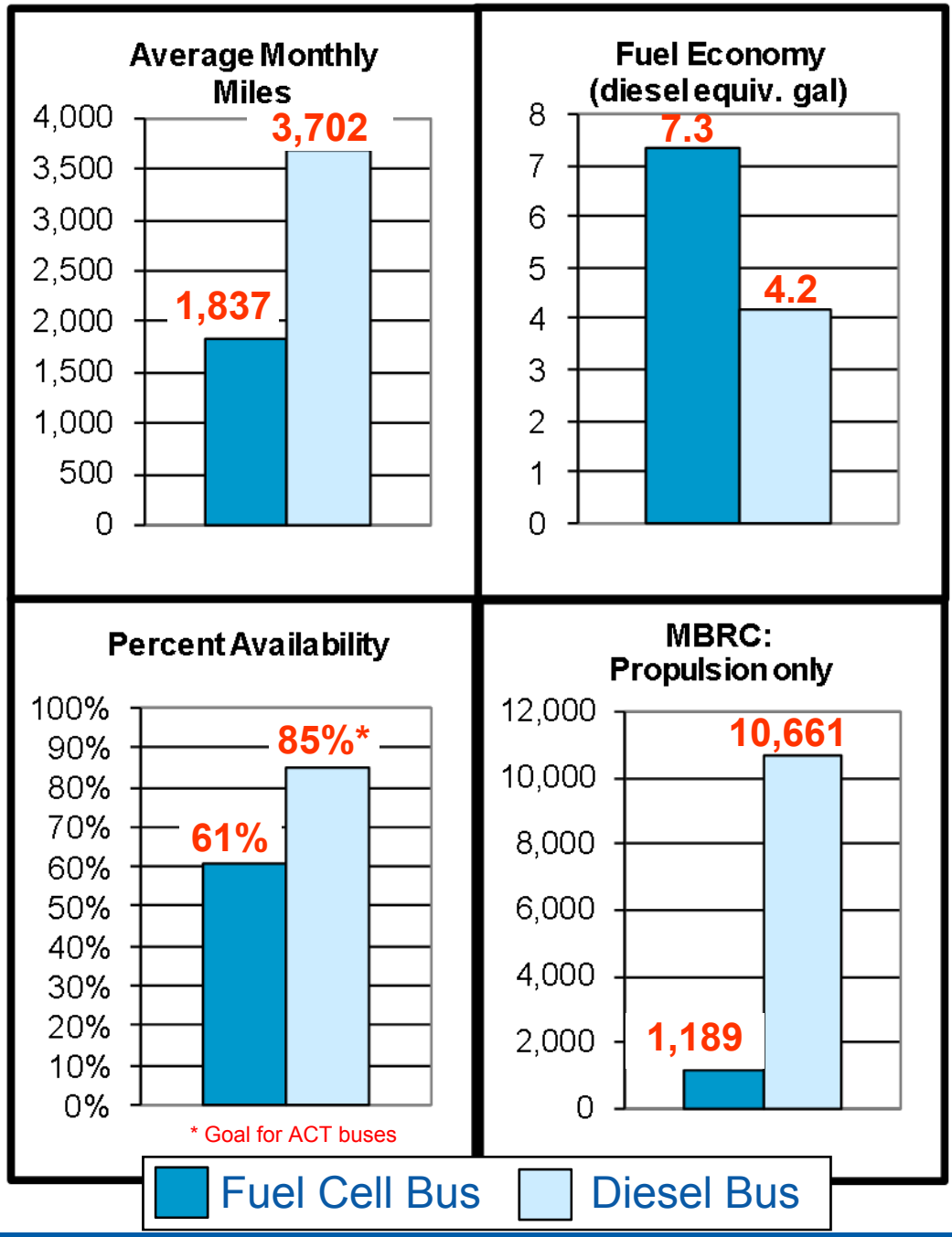
Fleet Data Summary: AC Transit

Fuel Cell Bus (hybrid system)

- ~9 months operation of 3 FCBs
  (Clean point with new FC systems)
- Total miles: 49,600
- Total FC system hours: 4,957

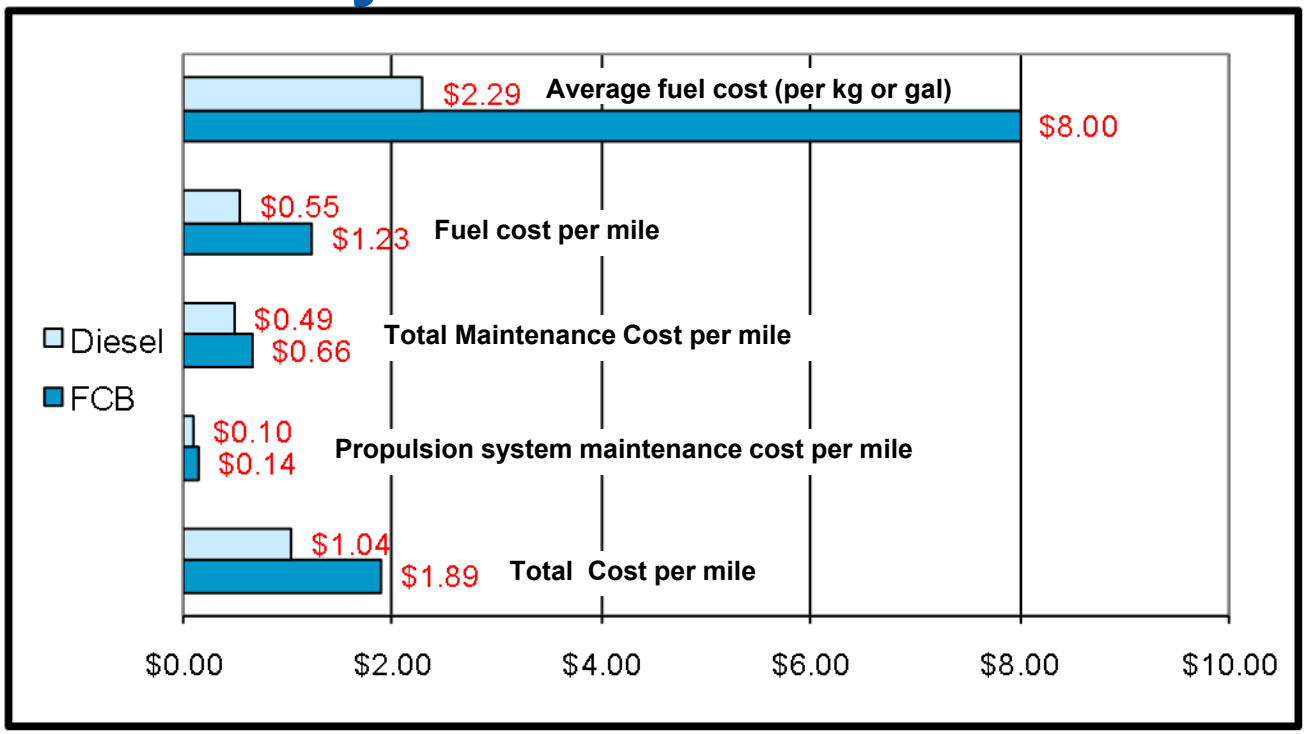
Diesel Bus (baseline)

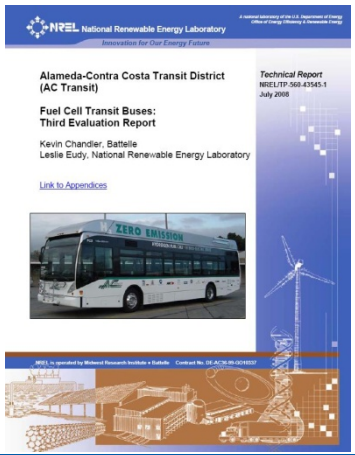
- 12 months operation of 6 diesel buses
- Total miles: 266,514



Fleet Data Summary: AC Transit

Summary of Costs*





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Update report published 7/08
Available online at www.nrel.gov/hydrogen/pdfs/43545.pdf

Evaluation Status

- Complete for current-generation buses – report, 7/08
- Data collection continues under FTA funding (accelerated testing of current generation)
- Next-generation buses arrive 2009 (planned DOE evaluation)

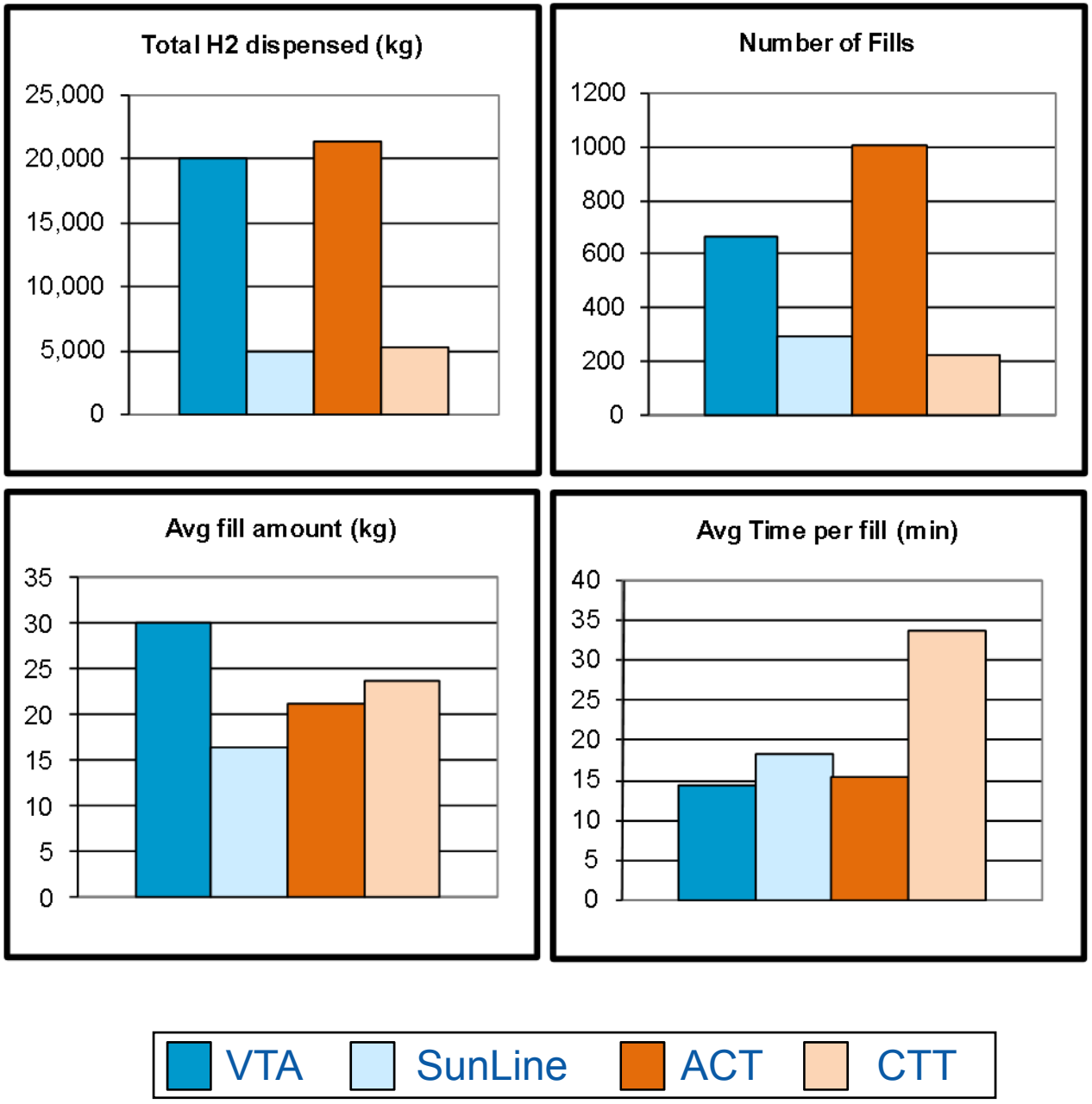
Infrastructure Data Summary

VTA
- Air Products
- Liquid H_2 storage
- Dispenses compressed H_2
- 32 months of data

SunLine
- HyRadix
- Natural gas reformer
- 24 months of data

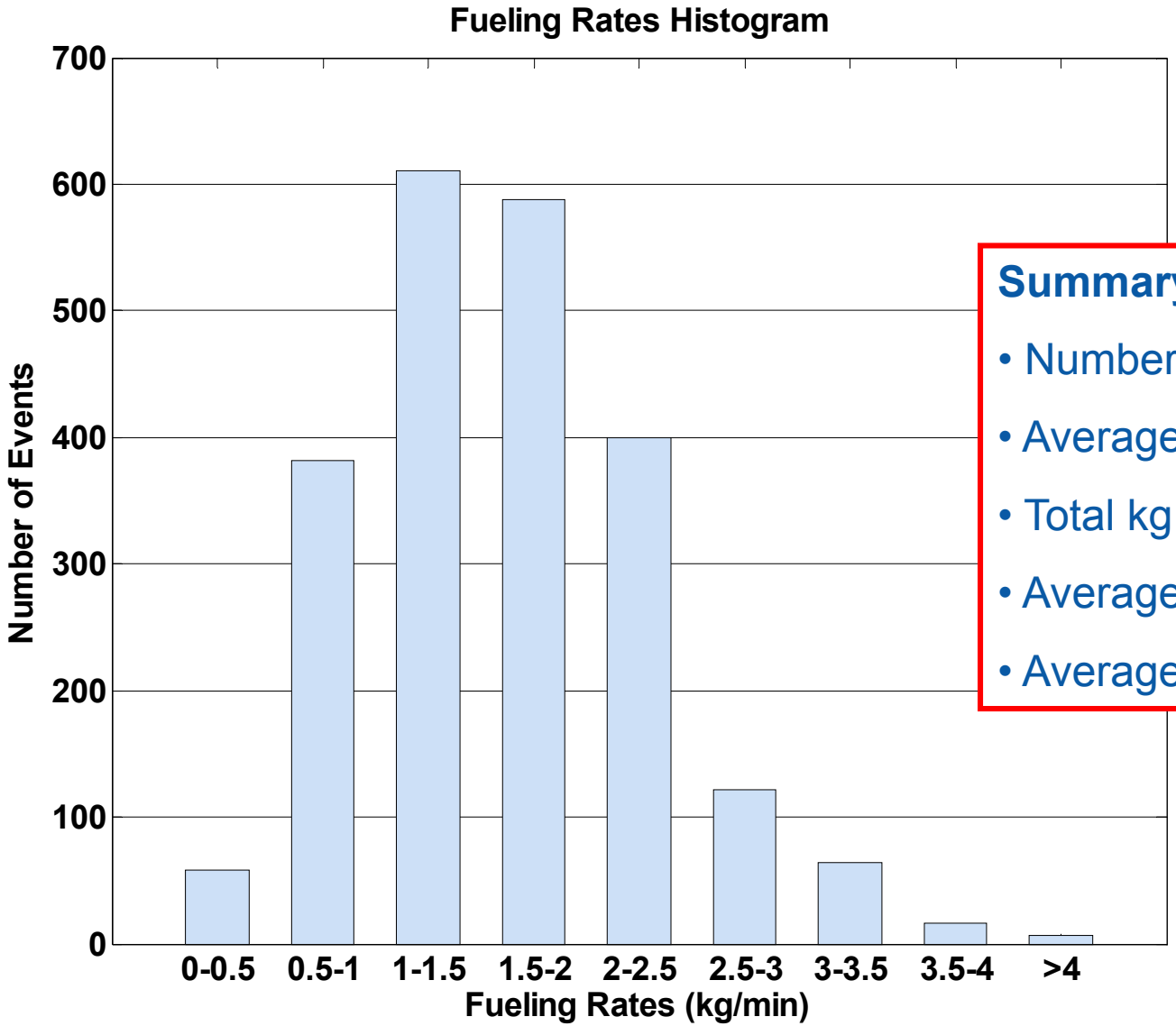
AC Transit
- Chevron
- Natural gas reformer
- 34 months of data

CTTRANSIT
- UTC Power station
- Praxair
- Liquid H_2 storage
- Dispenses compressed H_2
- 20 months of data



Infrastructure Data Summary

Fueling Rate Histogram



Summary:

- Number of fueling events: 2,469
- Average kg/fill: 23.6 kg
- Total kg dispensed: 58,179
- Average fueling rate: 1.4 kg/min
- Average fill time: 16.5 min

Future Work

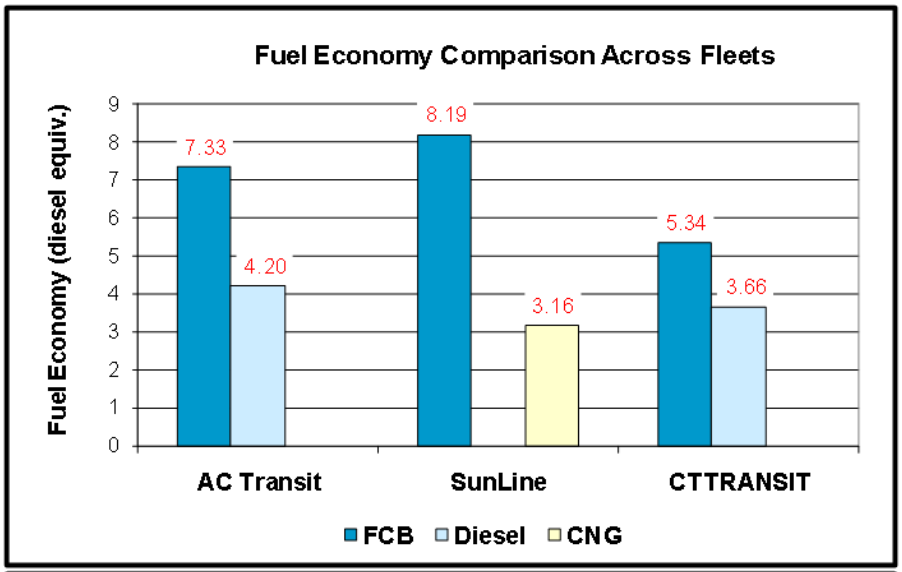
- Remainder of FY 2009
  - Complete data analysis reports on **CT**TRANSIT and SunLine
  - Initiate data collection on next-generation fuel cell buses at AC Transit and City of Burbank
  - Initiate detailed data collection on first FCBs developed under the FTA program
  - Complete annual crosscutting analysis across sites
- FY 2010
  - Complete data analysis and reports on **CT**TRANSIT, City of Burbank, and AC Transit
  - Initiate detailed data collection on additional FCBs developed under the FTA program
  - Continue coordinating data collection activities with FTA

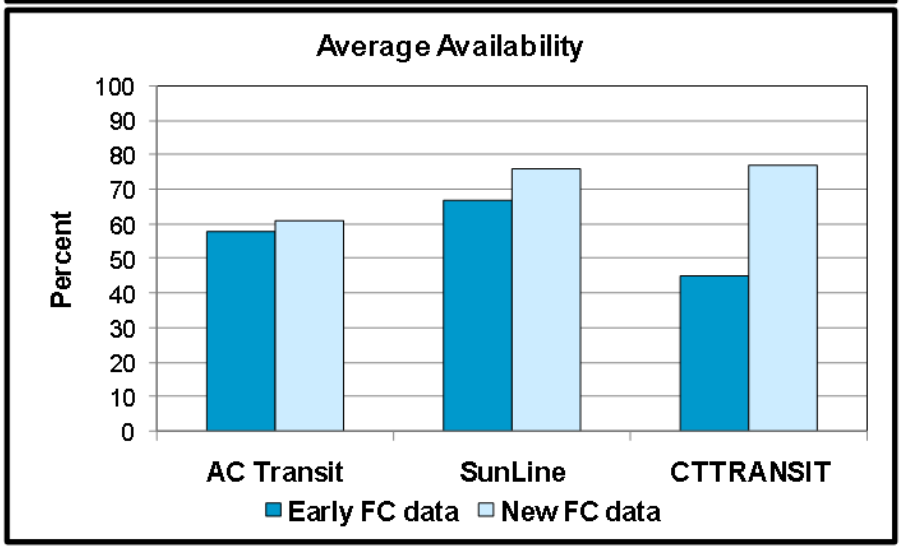
Summary

Progress

- Continued data collection & analysis of five FCBs in real-world service at three transit agencies
- Agencies working to maximize service of buses: Operating up to 19 hours/day, 7 days/week
- Fuel economy improvement over conventional technology as high as 2 times (depending on duty cycle)
- Manufacturer has modified FC based on early results. New version installed in all 5 buses beginning in late 2007
- Biggest improvement seen in availability with new fuel cell system
- Results show improvements in reliability

Agency	Total		Clean Point	
	Miles	FC hours	Miles	FC hours
AC Transit	142,176	13,819	77,332	7,821
SunLine	68,438	5,255	16,102	1,228
CTTRANSIT	29,284	4,451	24,127	3,544





Summary (continued)

OEMs working through early issues

- Fuel cell durability
  - Early versions were showing more degradation than expected
  - Modifications were made to address issues
- Energy storage issues
  - Issues encountered with ZEBRA batteries
  - Manufacturers have been investigating problems, solutions include software modifications
- Issues to be addressed in next generation
  - Investigating new energy storage solution
  - Modifications to reduce height and weight of bus will eliminate need for current speed limitations
  - Increase training levels to transfer more maintenance work to transit staff