NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Technology Validation: Fuel Cell Bus Evaluations

2011 DOE Annual Merit Review

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Overview

Timeline

- Project started in FY03
- First-generation FCBs completed in FY10
- Second-generation FCBs began in Q4 FY09

Budget

- Pre-FY2010 Funding
  - DOE share: $1.777 M (7 yr)
- FY 2011: $300K
- FY 2010: $200K
- Additional funding from DOT/Federal Transit Admin.

Tech. Val. Barriers

A. Lack of fuel cell vehicle performance and durability data

C. 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 – Relevance

Overall: Validate fuel cell technologies in transit applications

- Analyze fuel cell bus (FCB) performance and cost compared to conventional technologies to measure progress toward commercialization
- Provide “lessons learned” on implementing fuel cell systems in transit operations to address barriers to market acceptance
- Harmonize data collection efforts with other FCB demonstrations worldwide (in coordination with FTA and other U.S. and international partners)

2011

- Complete analysis and report results on first-generation FCBs
- Document FC hours more than 8,000 and 2x fuel economy compared to baseline technology
- Continue data collection and analysis for next-generation fuel cell buses at Burbank, SunLine, and AC Transit
- Conduct crosscutting analysis of FCB status at all sites

Evaluation Approach

- Data collection & analysis at transit sites
  - Follows standard protocol
  - Uses cost-effective process with data already collected by agency
  - Includes data on baseline vehicles in same service
  - Builds database of evaluations/results
- Annual FCB Status report
  - Includes summary of data across all sites
  - Assesses progress and needs for continued success
- Expansion of data collected and analyzed as resources allow

Approach - Milestones

- Complete evaluations of first-generation FCBs
  - Santa Clara VTA: completed in FY07
  - AC Transit: completed in FY09
  - SunLine: completed in FY09
  - **CT**TRANSIT: completed in FY10
  - Overall assessment of first-generation FCBs: September FY10

- Begin evaluations of second-generation FCBs
  - SunLine: May 2010
  - AC Transit: June 2010
  - City of Burbank: April 2011
  - Other FTA-funded FCBs

- Key Q2FY11 DOE milestone for FCBs: Document FC hours >8,000 and 2x fuel economy compared to baseline: Mar 2011

Performance Targets for FCBs

Comparison of FCBs to baseline technology

- Performance characteristics: match or exceed conventional bus technology
- Bus use: monthly miles > 3,000
- Fuel economy: exceed conventional buses by at least 2X
- Availability: better than 85%
- Reliability: miles between roadcall (MBRC):
  - > 4,000 miles for all roadcalls
  - > 10,000 miles for propulsion related roadcalls
  - FC system 20,000 to 30,000 hours
- Costs: capital, fueling, and maintenance

Summary for Early Gen FCBs

Site	VTA	AC Transit	SunLine	CTTRANSIT	
Technology	Ballard/Gillig (non-hybrid)	UTC Power/Van Hool/ISE	UTC Power/Van Hool/ISE	UTC Power/Van Hool/ISE	
Project Status	Complete, Buses Retired	Complete, Buses Retired	In operation	In operation	Totals
Data period	3/05 - 7/06	4/06 - 7/10	1/06 - 1/11	4/07 - 1/11	
Number of buses	3	3	1	1	8
Number months	17	52	61	47	
Total miles	40,208	253,166	119,889	51,715	464,978
Total hours	3,219	25,244	9,230	8,094	45,787
Hydrogen used (kg)	12,904	41,317	16,706	10,629	81,556
Average speed (mph)	12.6	10	13	6.4	
Fuel economy mi/kg	3.12	6.12	7.18	4.83	
Fuel economy mi/DGE	3.52	6.92	8.11	5.46	
Baseline technology	diesel	diesel	CNG	diesel	
Fuel economy difference	-12%	65%	134%	41%	

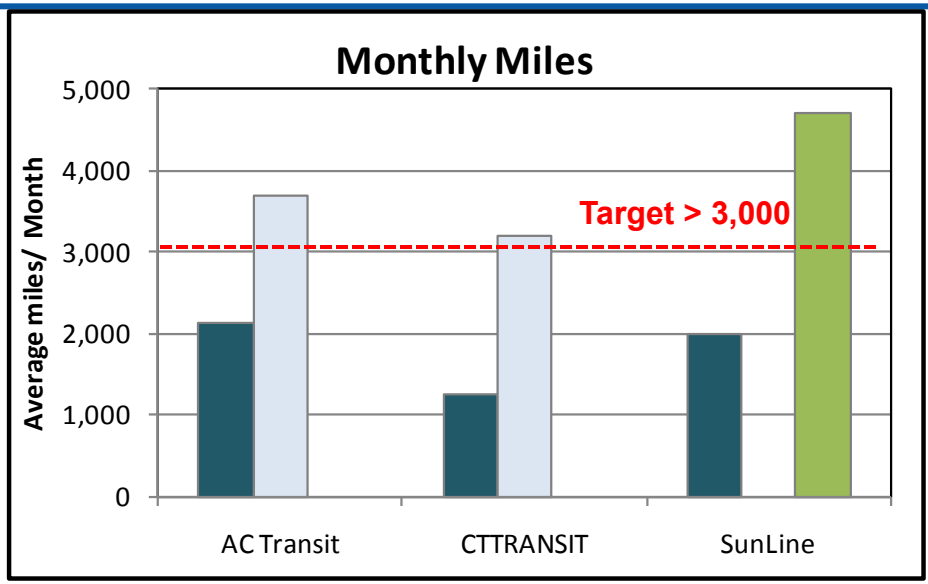
Note: Blue shaded columns indicate completed projects – data are final

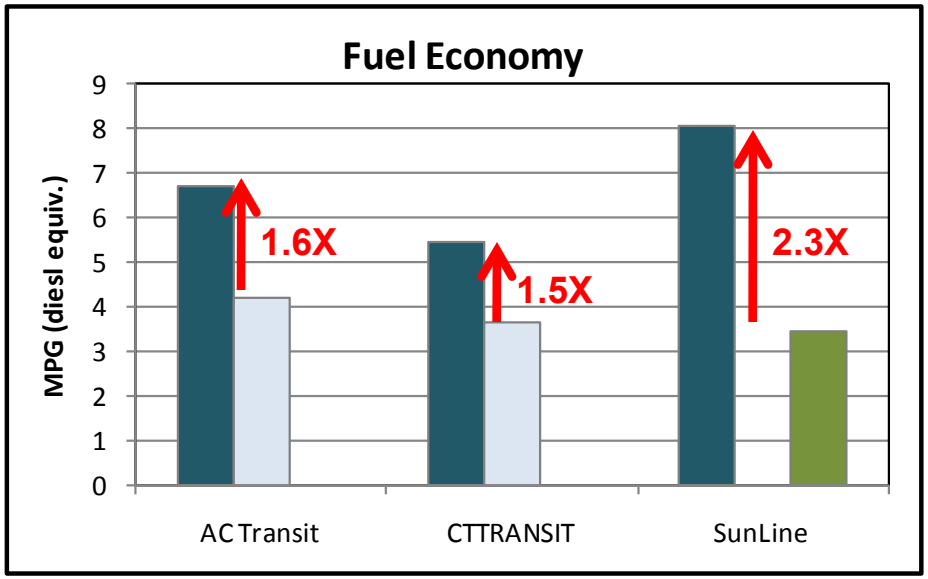
Same FCB Technology at these three locations

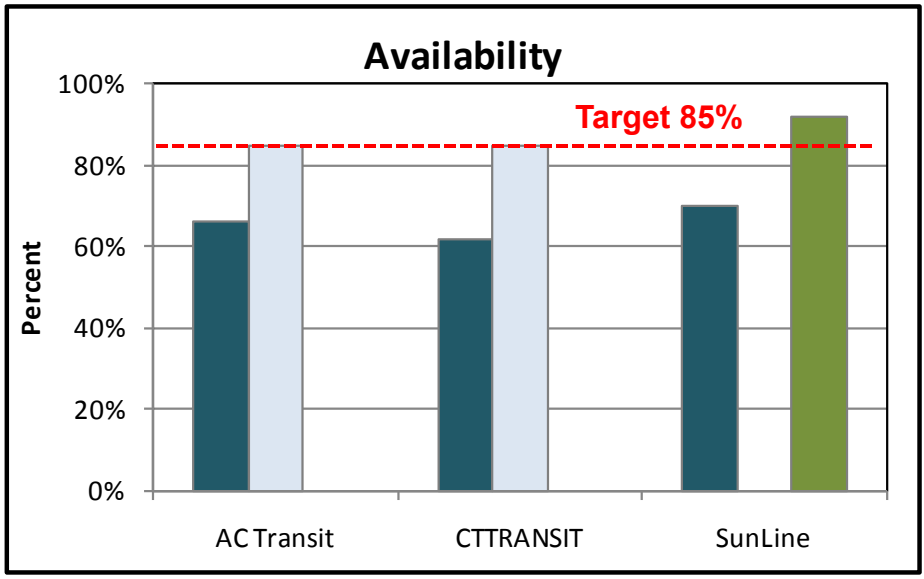
Data Summary: Baseline Comparison

Data from UTC Power/Van Hool buses in service at 3 sites

- Buses went into service in 2006
- UTC Power used early results to optimize FC system
- In 2008, a new version of FC system was installed on all 5 buses
- Data presented on new FC systems

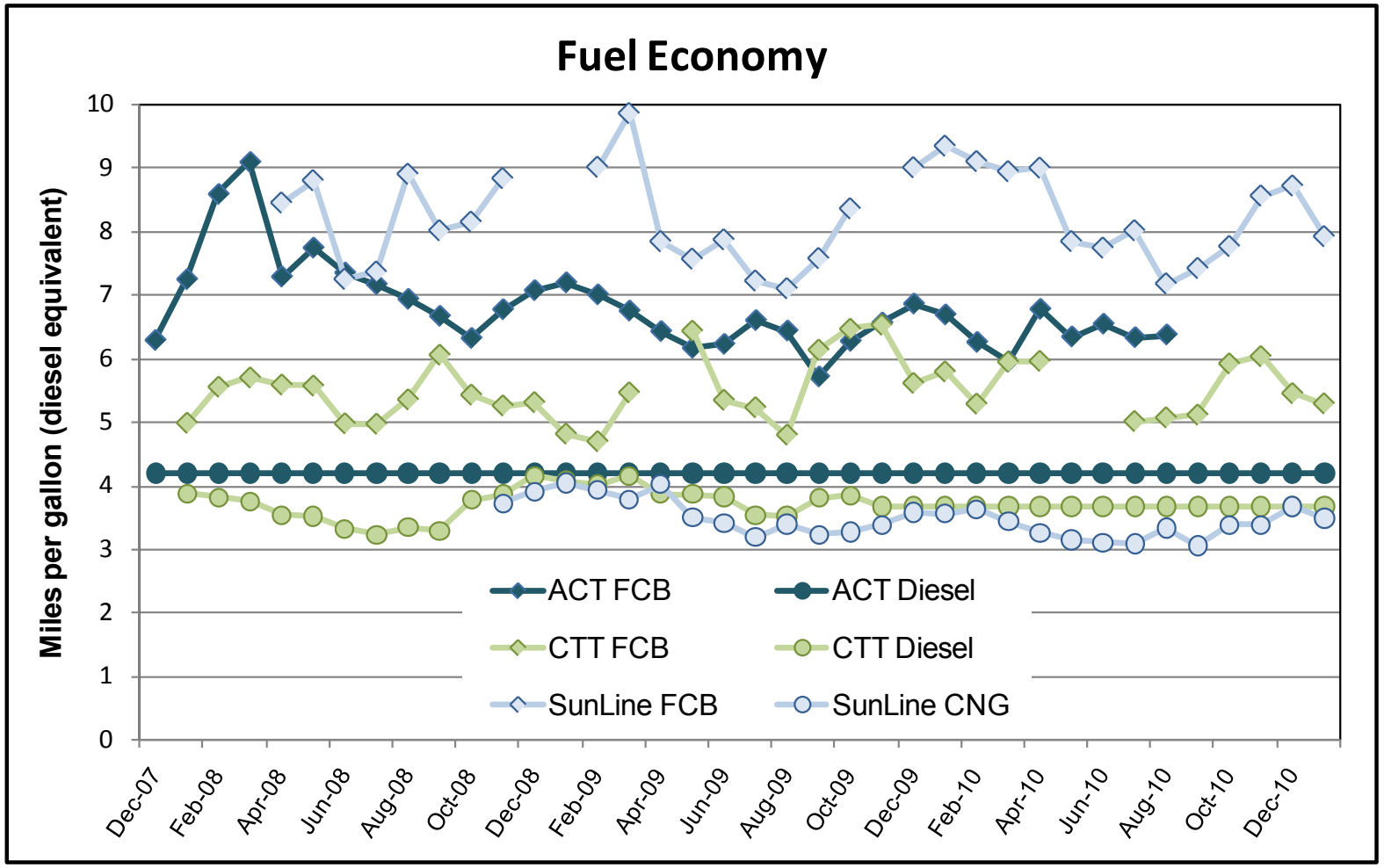






FCB Diesel CNG

Data Summary: Baseline Comparison



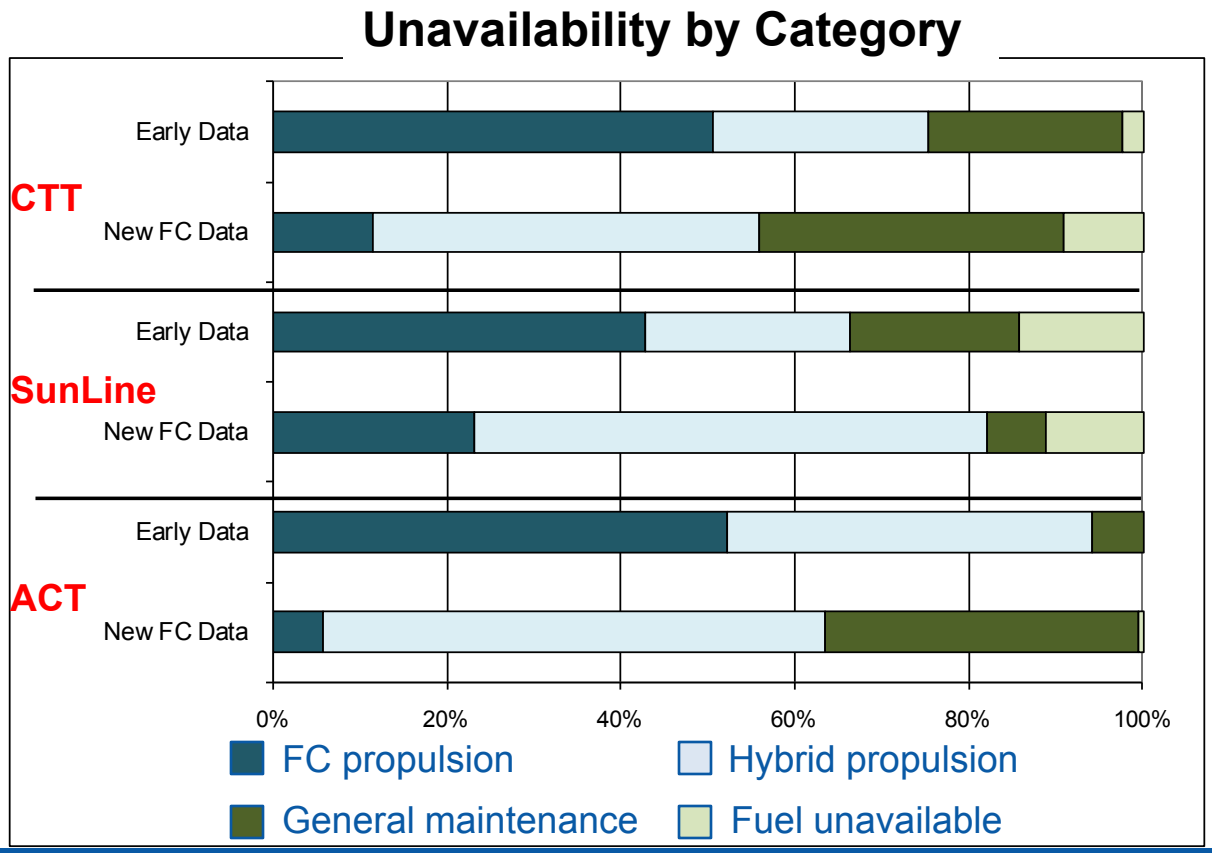
- FCBs have consistently achieved higher fuel economies than baseline buses
- Fuel economy is highly dependent on duty cycle:
  Average speed for SunLine – 13 mph; AC Transit – 10 mph; CTTRANSIT – 6 mph
- Monthly data show seasonal variations due to A/C use

Data Summary: FC System Comparison

Site	Period	Months	No. of Buses	Planned Days	Days Avail.	% Avail.
Early FC System Results						
AC Transit	4/06-10/07	19	3	1,246	720	58
SunLine	1/06-3/08	27	1	653	432	66
CTTRANSIT	4/07-12/07	10	1	192	87	45
New FC System Results						
AC Transit	11/07-4/10	~27	3	1,857	1,226	66
SunLine	4/08-7/10	28	1	746	500	67
CTTRANSIT	1/08-7/10	31	1	707	446	63

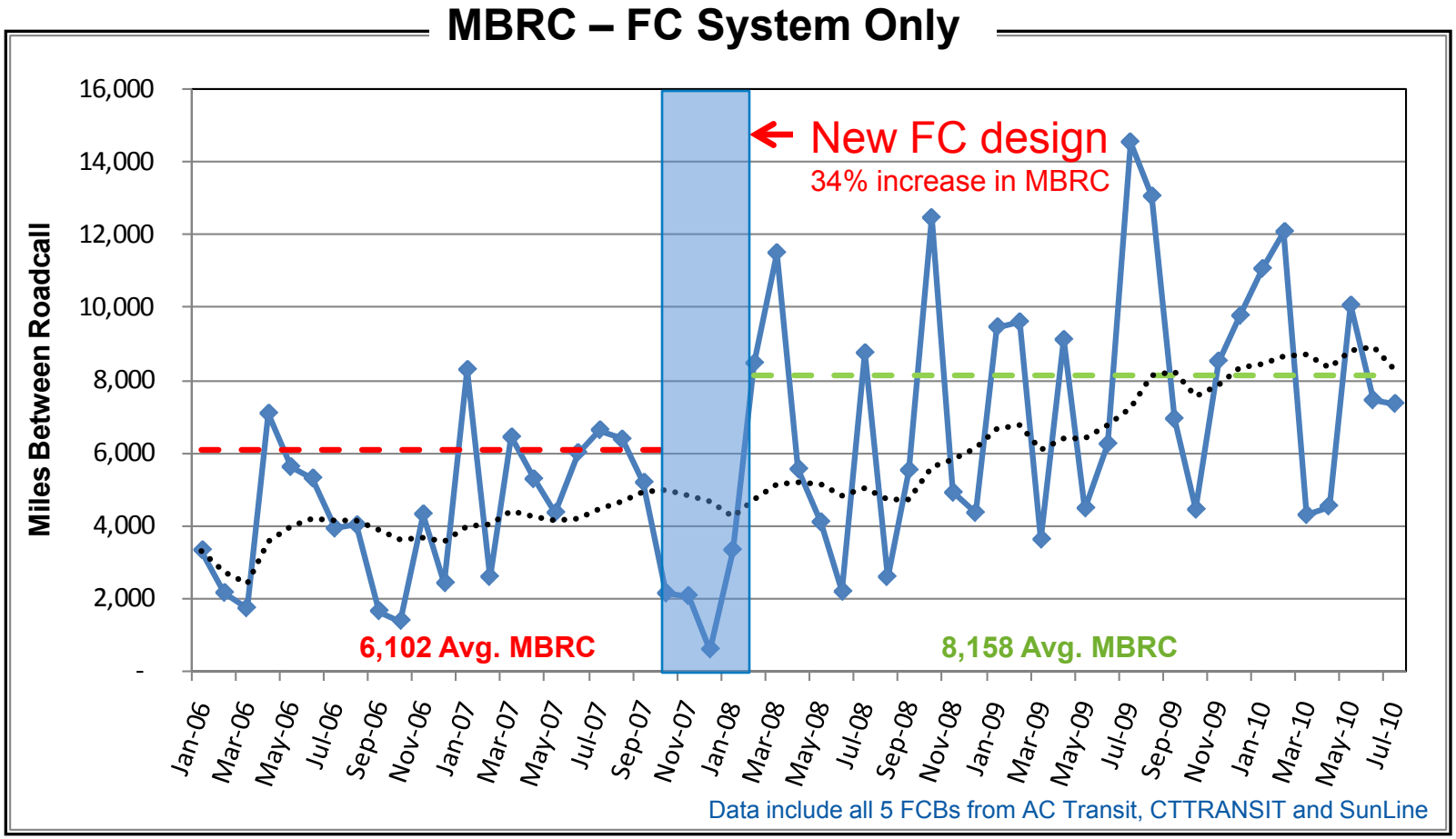
Availability is a measure of bus reliability.

Availability = Planned operation days compared to actual operation days



- Availability of new FC system shows an increase
- Unavailability not typically due to fuel cell issues
- Traction battery and hybrid issues most common reasons for unavailability

Data Summary: FC System Comparison



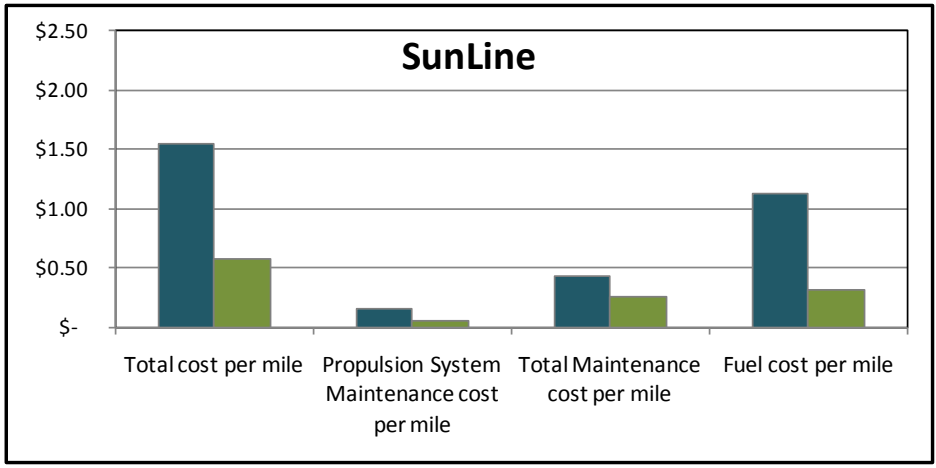
- Chart shows the monthly MBRC for the FC system only and highlights the increase over time
- 34% increase in average since new FC systems were installed
- Black dotted line shows running 12-month average FC MBRC

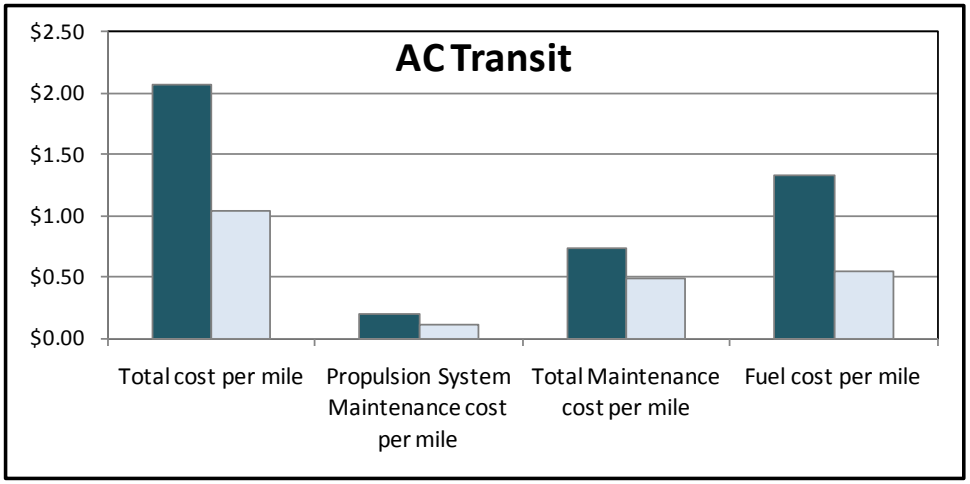
Data Summary: Costs

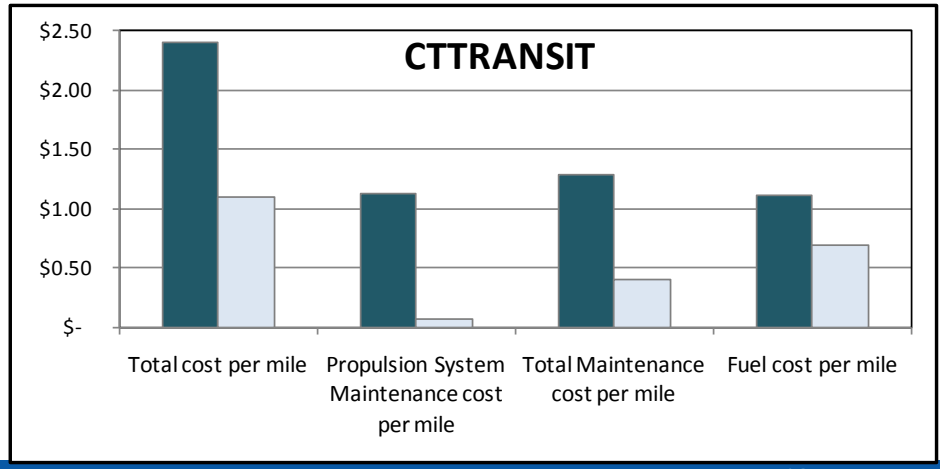
- Capital costs of buses dropping; larger quantity orders should help
  - First-generation $3.2M
  - Next-generation $2.27M
- Fuel costs remain higher
- Operational costs still higher

Fuel Costs (per kg or gallon)

ACT H2	$8.00
ACT Diesel	$2.29
CTT H2	$5.29
CTT Diesel	$2.70
SL H2	$8.00
SL CNG	$1.07





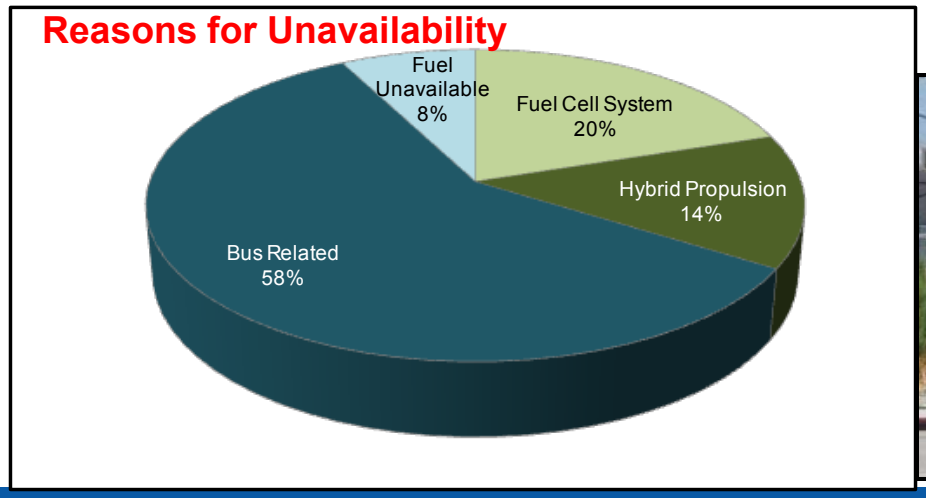


FCB Diesel CNG

Data Summary: Next-Generation FCBs

SunLine — Palm Springs, California Status: in progress

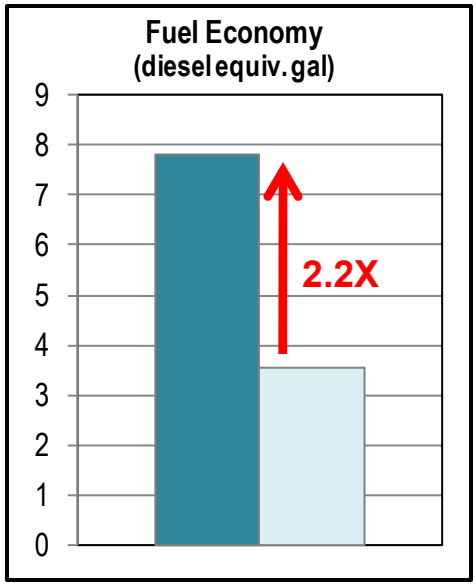
- New Flyer/Bluways bus with Ballard fuel cell system
- Same design as the BC Transit 20-bus fleet
- Bus went into service May 27th
- More than 9,600 miles accumulated, >800 fuel cell hours
- Average hours/day: 7.37
- Max hours in one day: 14.4
- 5.75 mi/kg, 6.5 mi/DEG: 2 times CNG baseline buses
- First report published in March 2011

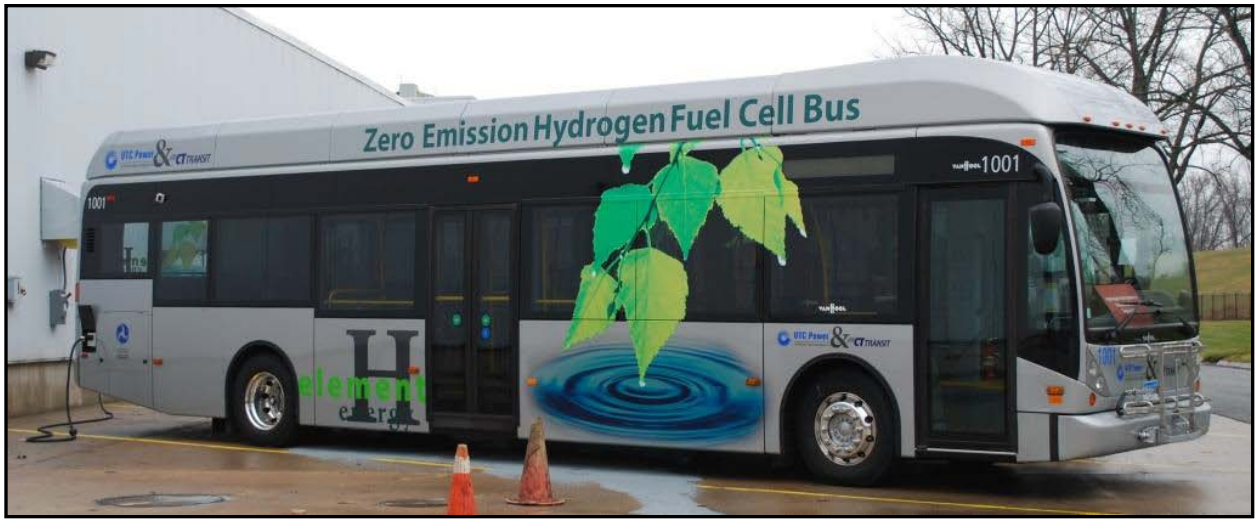


Data Summary: Next-Generation FCBs

CTTRANSIT — Hartford, Connecticut Status: in progress

- Next generation, 40-ft Van Hool/UTC Power
- Fuel cell dominant hybrid system
- Four buses delivered and in operation
- Will provide cold weather data on system
- Buses have logged more than 11,000 miles
- 858 total FC hours
- 6.92 mi/kg; 7.82 mi/DGE at 13.7 mph average speed





National Fuel Cell Bus Program

Data Summary: Next Gen FCBs

AC Transit — Oakland, California

- Zero Emission Bay Area (ZEBA) demonstration led by AC Transit
- Next-generation, 40-ft Van Hool/UTC Power
- 7 of 12 buses delivered
- 3 first generation buses retired. Two of those fuel cell power systems were transferred into new buses (one > 8,500 hrs.)

BurbankBus — Burbank, California

- CARB funded development and demonstration project
- Proterra FCB, battery dominant, plug-in hybrid
- Hydrogenics fuel cells and lithium titanate batteries

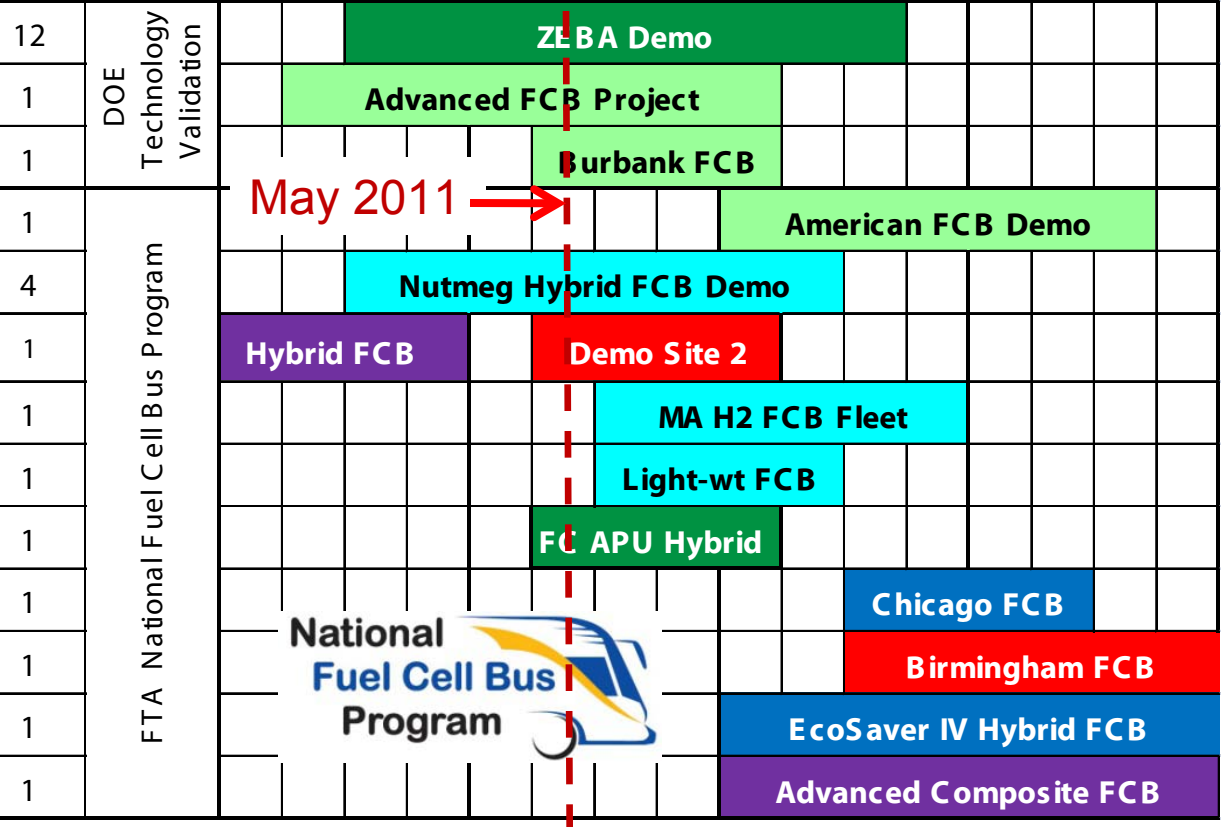
Collaborations

- Transit agencies provide data on buses, fleet experience and training, and review reports
  - California: AC Transit, BurbankBus, Golden Gate Transit, Santa Clara VTA, SamTrans, SunLine, San Francisco MTA
  - Connecticut: CTTRANSIT
  - South Carolina: Central Midlands RTA, USC
- Manufacturers provide some data on buses and review reports
  - Bus OEMs: Proterra, Van Hool, New Flyer
  - FC OEMs: Ballard, Hydrogenics, UTC Power
  - Hybrid system OEMs: BAE Systems, Bluways
- Other organizations share information and data
  - National: CARB, NAVC, CTE, Calstart
  - International: Various organizations from Germany, Iceland, Brazil, Canada, China, Japan, England, Australia

Planned FCB Evaluations for DOE and FTA

NREL Hydrogen Evaluations for DOE and FTA

Site/Locations	State	# Buses	Eval. Funding
AC Transit /SF Bay Area	CA	12	DOE Technology Validation
SunLine /Thousand Palms	CA	1	DOE Technology Validation
City of Burbank/Burbank	CA	1	DOE Technology Validation
SunLine /Thousand Palms	CA	1	FTA National Fuel Cell Bus Program
CTTRANSIT /Hartford	CT	4	FTA National Fuel Cell Bus Program
USC, CMRTA /Columbia UT, Cap Metro/Austin	SC TX	1	FTA National Fuel Cell Bus Program
Logan Airport /Boston	MA	1	FTA National Fuel Cell Bus Program
Albany /NY	NY	1	FTA National Fuel Cell Bus Program
SFMTA /San Francisco	CA	1	FTA National Fuel Cell Bus Program
CTA/Chicago	IL	1	FTA National Fuel Cell Bus Program
BJCTA/Birmingham	AL	1	FTA National Fuel Cell Bus Program
Ohio State/Columbus	OH	1	FTA National Fuel Cell Bus Program
USC, CMRTA /Columbia	SC	1	FTA National Fuel Cell Bus Program



Demonstration sites color coded by geographic area:

- Northern California
- Northeast
- South
- Southern California
- Southeast
- Midwest

- Estimate of NREL data collection/evaluation schedule
- Schedule subject to change based on progress of each project

Future Work

- Remainder of FY 2011
  - Continue data collection on next-generation FCBs at AC Transit, SunLine, and City of Burbank
  - Continue data collection on FCBs developed under the FTA program
  - Complete first crosscutting analysis of next-generation FCBs at all sites
- FY 2012
  - Analyze data and report on new FCBs at Burbank, SunLine, and AC Transit
  - Complete annual crosscutting analysis across sites
  - Continue coordinating data collection activities with FTA

Summary

- Completed data collection and analysis of early generation FCBs in real-world service at three transit agencies
- Documented progress achieved including:
  - Fuel economy improvement over conventional technology > 2 times (depending on duty cycle)
  - Planned service increasing: buses operating up to 19 hrs/day, 7 days/week
  - Durability: FC hours over 8,500
  - Reliability: MBRC increase of 34% for FC system shows significant improvement
- Provided results to stakeholders/industry: published 4 reports and 3 fact sheets since the last AMR
- Documented remaining challenges for the industry including:
  - Increase durability of FC
  - Optimization of hybrid system & reliability of components (batteries, converters, software)
  - Training/transition of all maintenance to transit staff
  - Ramp up of fueling to supply larger fleets
  - Cost reduction: capital and operating