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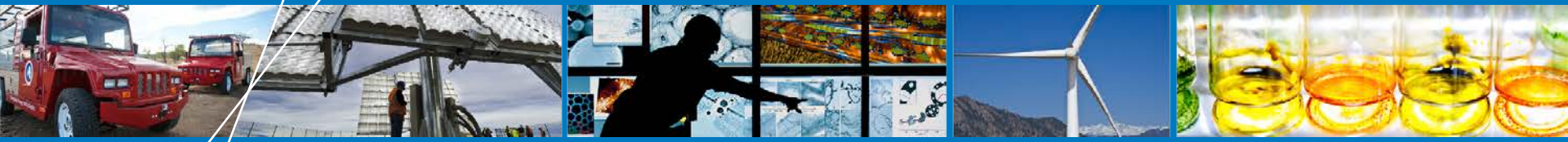
Technology Validation: Fuel Cell Bus Evaluations



2012 DOE Annual Merit Review

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Project ID# TV-008

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

Overview

Timeline

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

Budget

- Pre-FY 2011 funding
  - DOE share: $1.977 M (8 yr)
- FY 2011: $300K
- Planned FY 2012: $300K
- 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 electric bus (FCEB) 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 FCEB demonstrations worldwide (in coordination with FTA and other U.S. and international partners)

2012

- Document more than 10,000 FC hours and 2x fuel economy compared to baseline technology (diesel and natural gas buses)
- Continue data collection and analysis for 2nd generation fuel cell buses at Burbank, SunLine, AC Transit
- DOT/FTA collaboration – collect data on sites for National Fuel Cell Bus Program (NFCBP)
- Conduct crosscutting analysis/comparison of FCEB status at all sites

Milestones

- **Eight 1st gen buses operated by four transit agencies were evaluated between FY05 and FY10:**
  - Santa Clara VTA, San Jose, CA: 3 buses
  - AC Transit, Oakland, CA: 3 buses
  - SunLine, Thousand Palms, CA: 1 bus
  - CTTRANSIT, Hartford, CT: 1 bus
- **Evaluate 2nd generation FCEBs:**

Transit Agency	Project	Location	No. buses	Start-up date
SunLine	Adv. Tech FCEB	Thousand Palms, CA	1	May 2010 *
AC Transit	ZEBA	Emeryville, CA	12	June 2010 *
CTTRANSIT	NFCBP: Nutmeg	Hartford, CT	4	Aug 2010 *
SunLine	NFCBP: AFCB	Thousand Palms, CA	1	Jan 2012
SFMTA	NFCBP: Bus 2010	San Francisco, CA	1	Jun 2012
Cap Metro	NFCBP: Proterra	Austin, TX	1	April 2012

* Data included in this presentation

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 (diesel, CNG, diesel hybrid)
- Builds database of evaluations/results

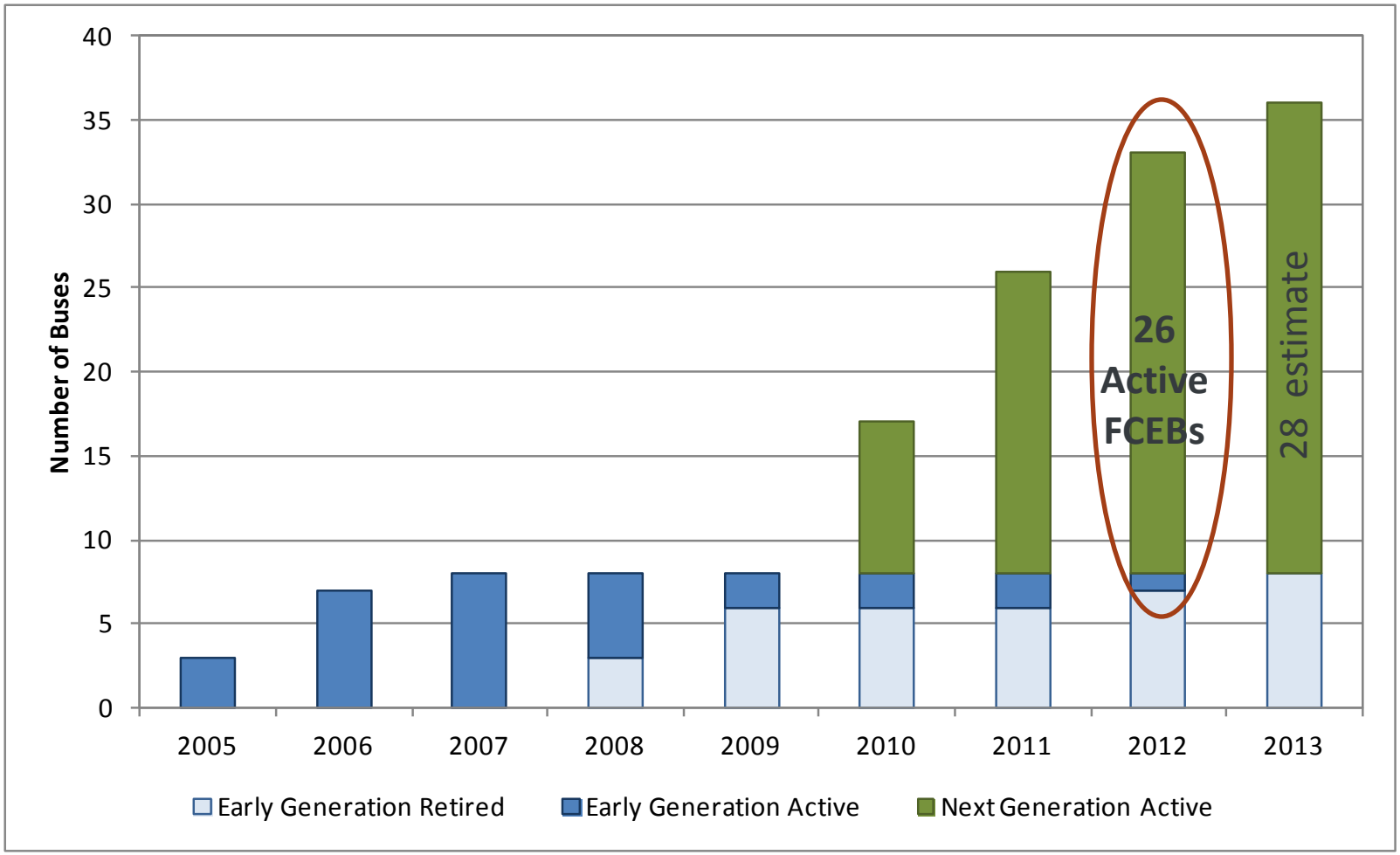
Annual FCEB status report / crosscutting analysis

- Includes summary of data across all sites
- Crosscutting analysis comparing FCEB results from all sites
- Assesses progress and needs for continued success

Expansion of data collected and analyzed as resources allow

U.S. FCEB Numbers Continue to Grow

Data being collected on increasing number of FCEBs (includes FTA NFCBP buses)



Estimate 26 active FCEBs by the end of 2012; 28 by the end of 2013

FCEB Design Strategies

FCEB Design	Strategy	Advantages	Disadvantages
Fuel Cell Dominant	Charge sustaining hybrid bus – FC charges batteries	- Excellent performance - No range issues - Zero-emission	- Higher cost
Battery Dominant	Charge depleting electric bus – FC acts as a range extender	- Good performance - Smaller FC is less expensive - Zero-emission	- Still needs to be plugged in for best performance - Infrastructure for two energy sources: hydrogen and electricity
Diesel Hybrid w/ FC for accessories	Charge sustaining hybrid bus – FC handles all electric accessories and some motive power	- Excellent performance - Smaller FC is less expensive - Hybrid design is commercial product	- Need to deal with two fuels - Not zero-emission

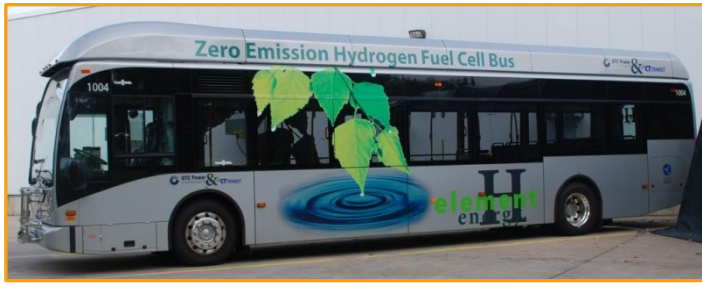
FCEB OEM Partners

Bus OEM	Fuel Cell System	Hybrid System	Design Strategy	Energy Storage	Transit Agency
Van Hool 40-ft	UTC Power	Siemens ELFA	Fuel cell dominant	Lithium-based batteries	AC Transit, Oakland, CA; CTTRANSIT, Hartford, CT
ElDorado 40-ft	Ballard	BAE Systems	Fuel cell dominant	Lithium-based batteries	SunLine, Thousand Palms, CA; Chicago Transit Authority
New Flyer 40-ft	Ballard	Siemens ELFA	Fuel cell dominant	Lithium-based batteries	SunLine, Thousand Palms, CA
Proterra 35-ft	Hydrogenics or Ballard	Proterra integration	Battery dominant	Lithium-based batteries	Capital Metro, Austin, TX
DesignLine 35-ft	Ballard	DesignLine integration	Battery dominant	Lithium-based batteries	University of Ohio, Columbus
Ebus 22-ft	Ballard	Ebus integration	Battery dominant	Nickel cadmium	University of Delaware, Newark
EVAmerica	Ballard	EVAmerica integration	Battery dominant	Lithium-based batteries	BJCTA, Birmingham, AL
Daimler (Orion)	Hydrogenics	BAE Systems	Diesel Hybrid w/ FC	BAE Systems	San Francisco MTA

Data Summary for 2nd Gen Buses

Data summary includes two types of fuel cell dominant, 2nd gen FCEBs at three transit sites:

- AC Transit, Oakland, CA
  - 40-foot Van Hool buses with UTC Power FC
- CTTRANSIT, Hartford, CT
  - 40-foot Van Hool buses with UTC Power FC
- SunLine, Thousand Palms, CA
  - 40-foot New Flyer bus with Ballard FC and Bluways hybrid system



Performance Targets for FCEBs

To meet commercialization targets, FCEBs need to meet or exceed performance of baseline conventional technology: diesel, CNG

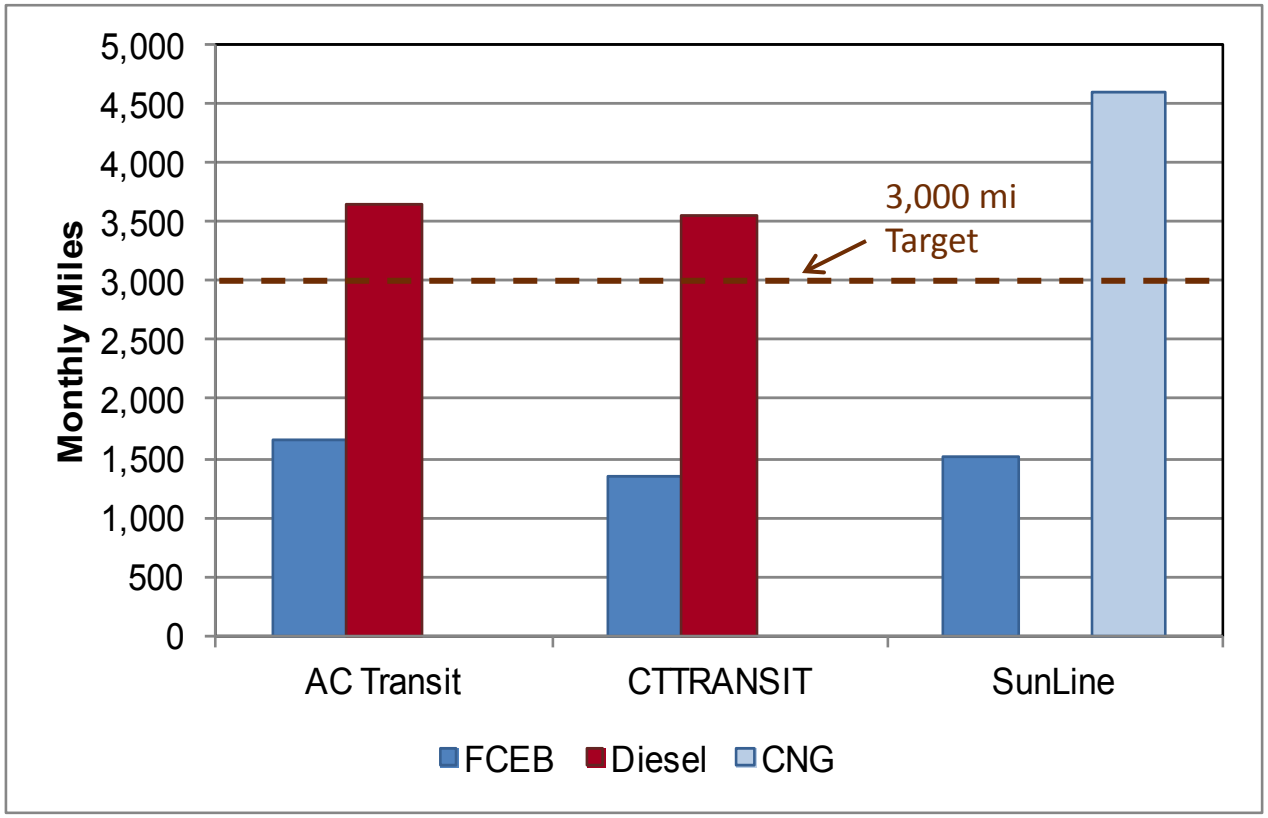
Current Performance Targets*

	Units	Commercialization Target
Bus Lifetime	Years / miles	12 / 500,000
Powerplant Lifetime	Years / hours	6 / 25,000
Bus Use	Miles per month	3,000
Bus Availability	%	90
Fuel Economy	Miles per diesel gallon equivalent	8
Road call frequency (All/powerplant)	Miles between road call	4,000/10,000

*All performance, cost, and durability targets summarized in draft DOE/DOT record

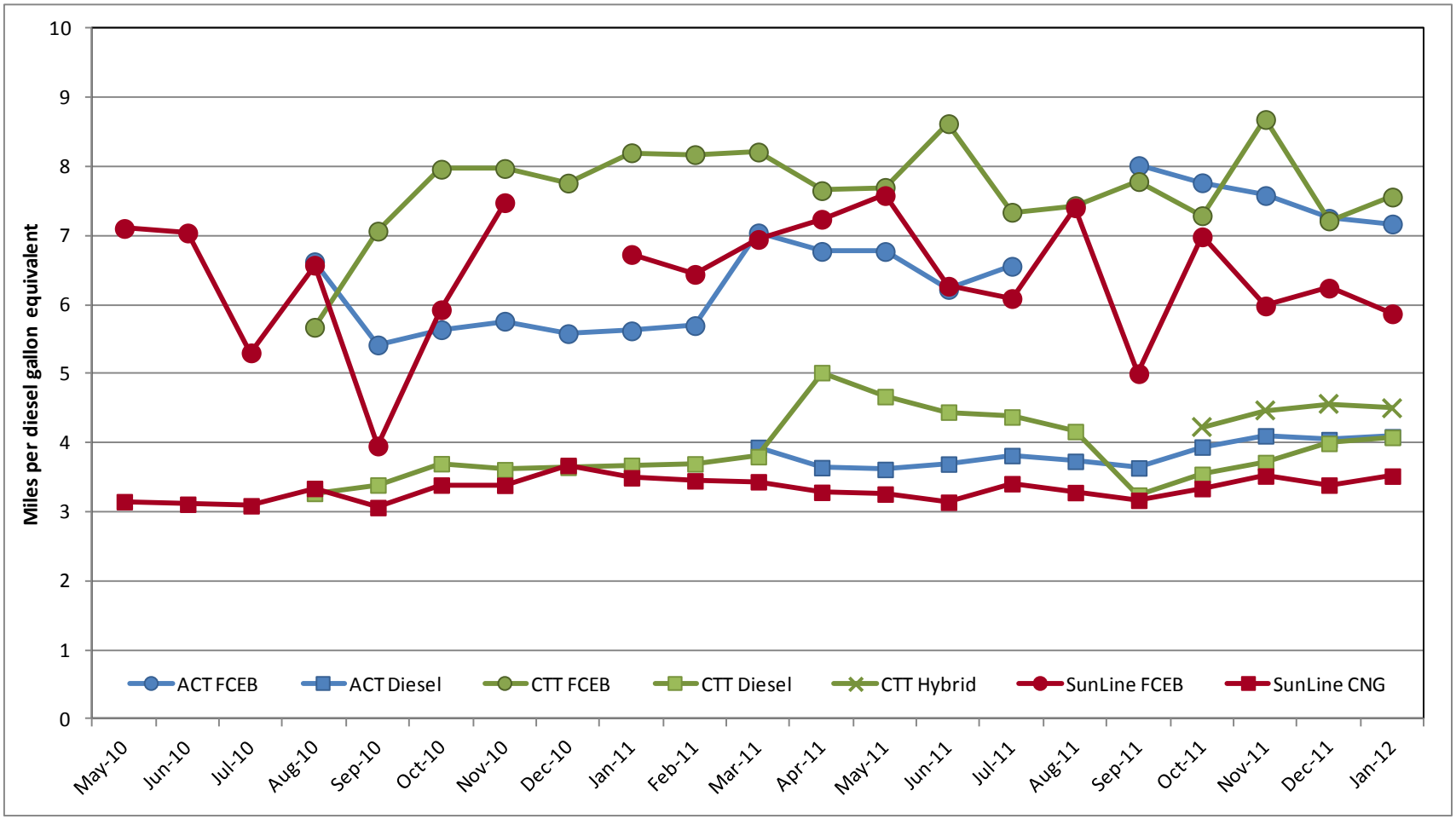
Accomplishments

2nd Gen FCEB Mileage Accumulation at 1,500 miles/month



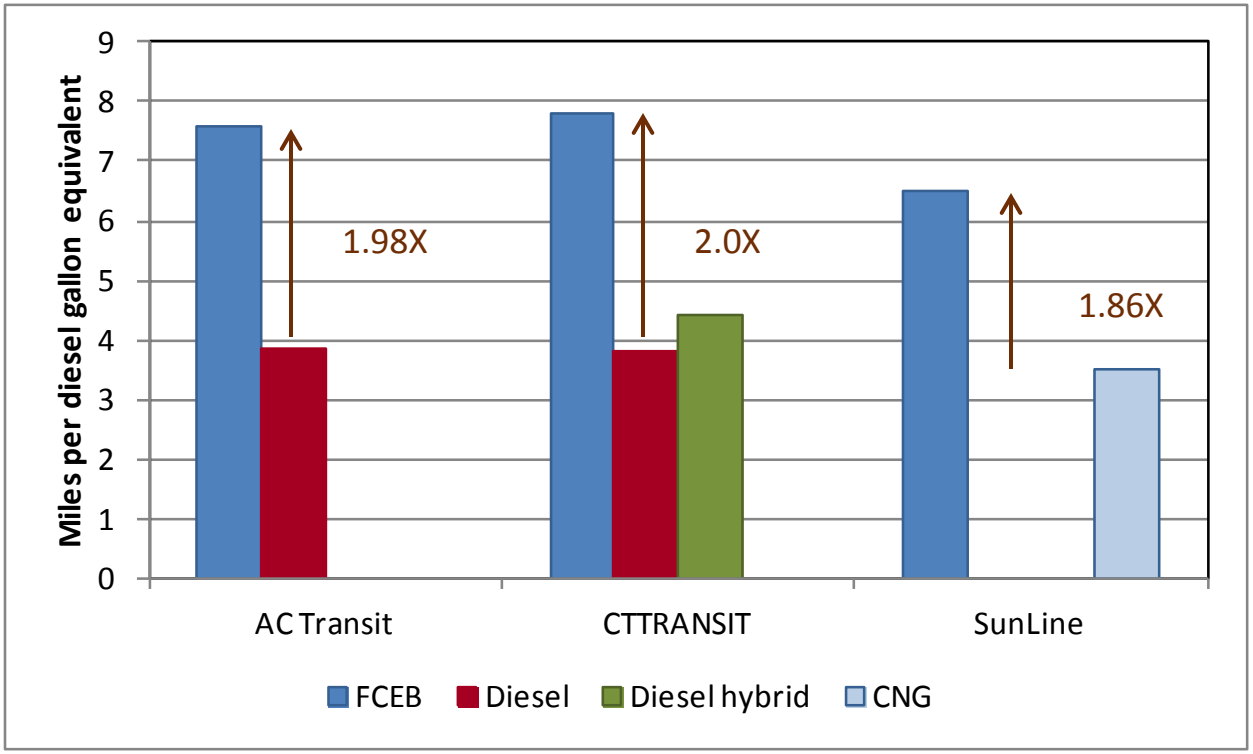
Transit agencies are increasing the number of scheduled miles per day:
Buses operating as many as 19 hours/day with some weekend service

FCEB Fuel Economy Consistently Higher than Baseline



Fuel economy is highly dependent on duty cycle:
Average speed for SunLine – 13 mph; AC Transit – 9.9 mph; CTTRANSIT – 13.6 mph

2nd Gen FCEB Designs Approach 2x Fuel Economy

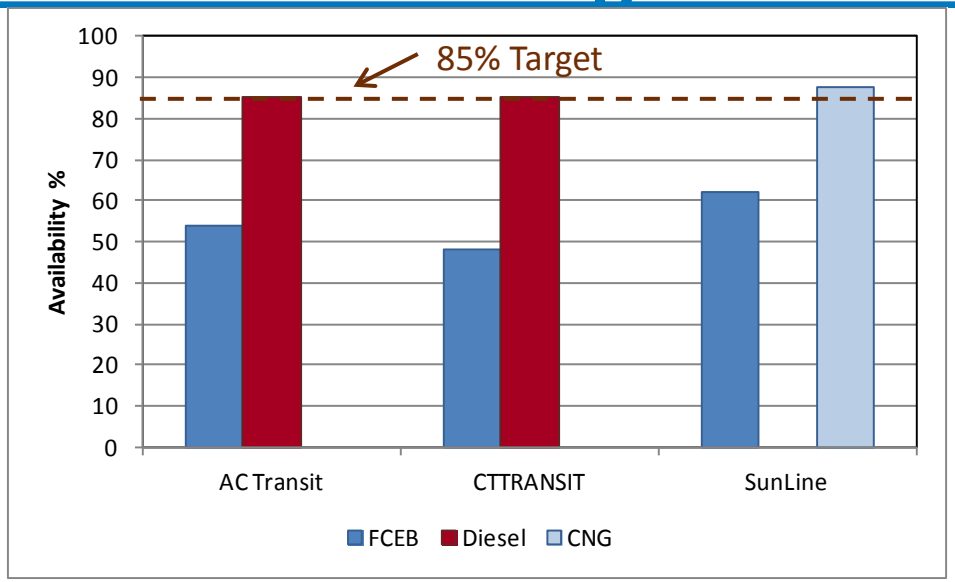


New FC bus designs have twice the fuel economy as diesel buses

- CTTRANSIT data include diesel hybrid buses in similar service as FCEBs:
  - FCEB – 7.78 mi/DGE
  - Diesel hybrid – 4.44 mpg
  - Standard diesel – 3.73 mpg

Accomplishments

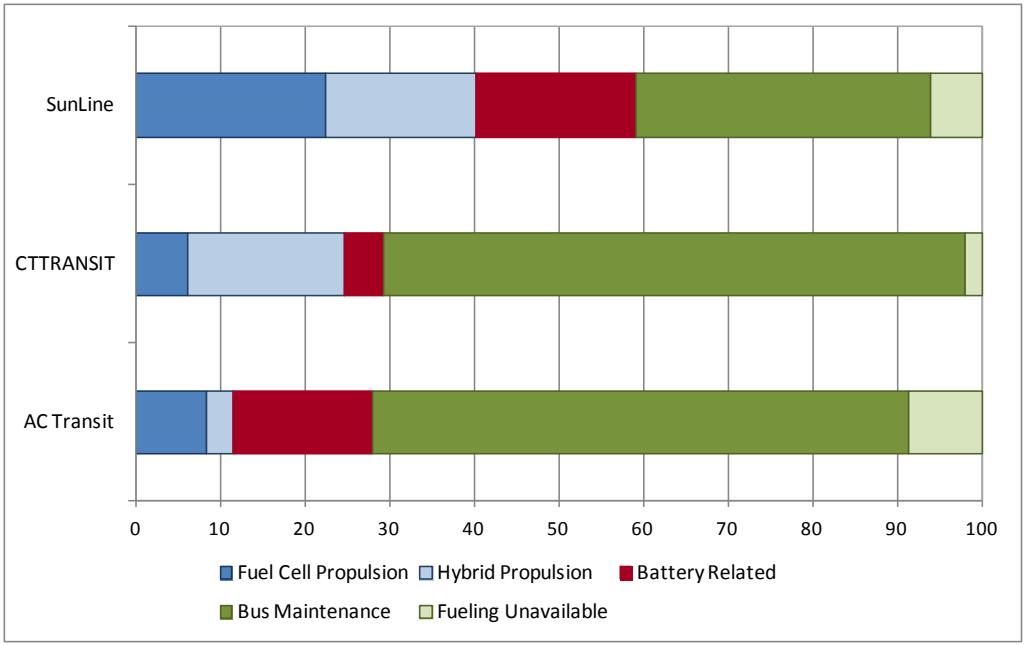
2nd Gen Average Availability at 53%



Average availability compared to conventional bus baseline

- Lower numbers expected during the 'break-in' period for new design

Newest data show increases in availability
Feb 2012 = 62% overall
9 of 17 buses over 70%



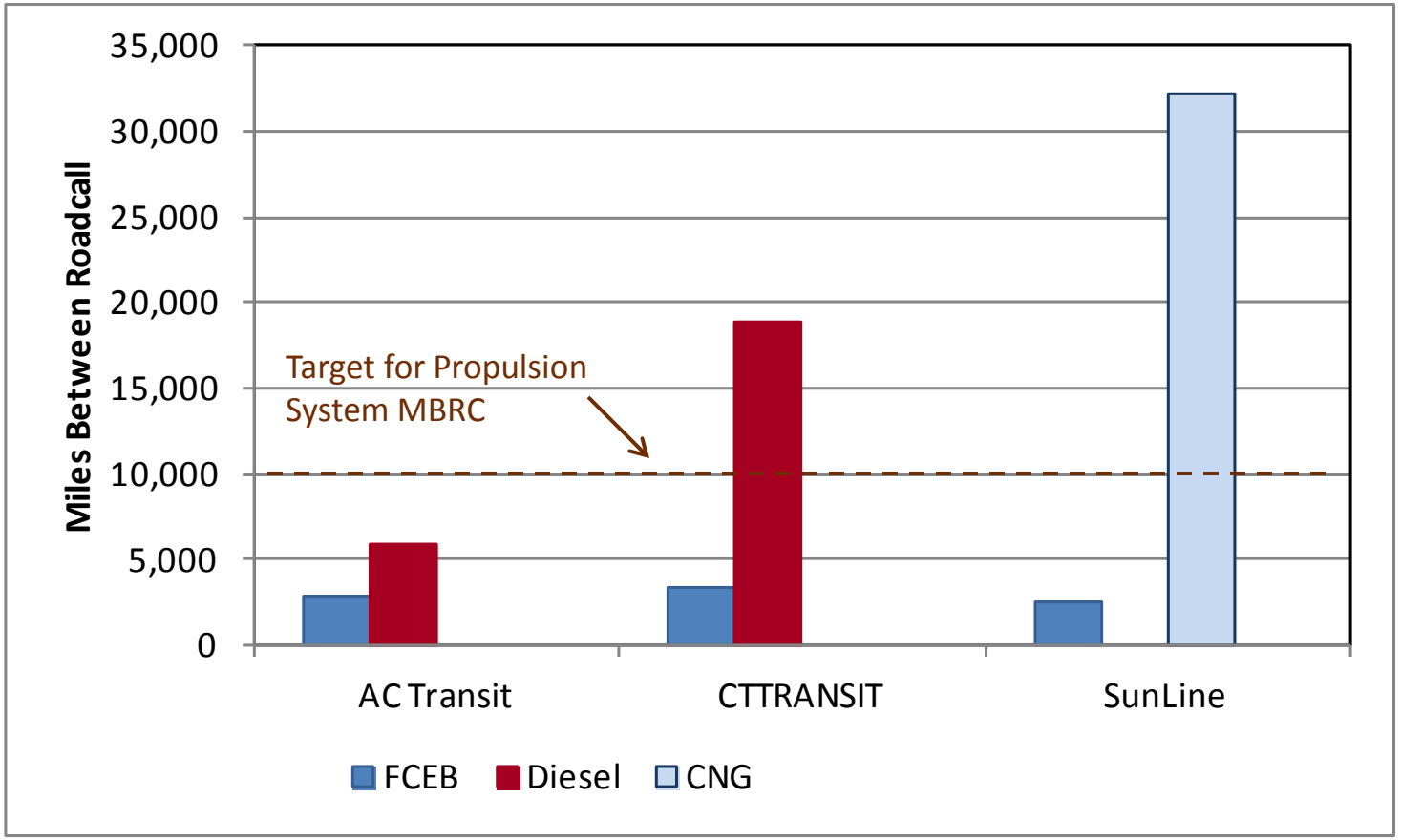
Reasons for unavailability – percent of total by category

- Not typically due to fuel cell issues
- Bus maintenance issues include accident repair, AC system problems, materials compatibility
- Hybrid issues primarily software related
- Not seeing as many battery issues as in previous designs

Availability = planned operation days compared to actual operation days

FC System MBRC* Increasing

Propulsion-system-only MBRC:



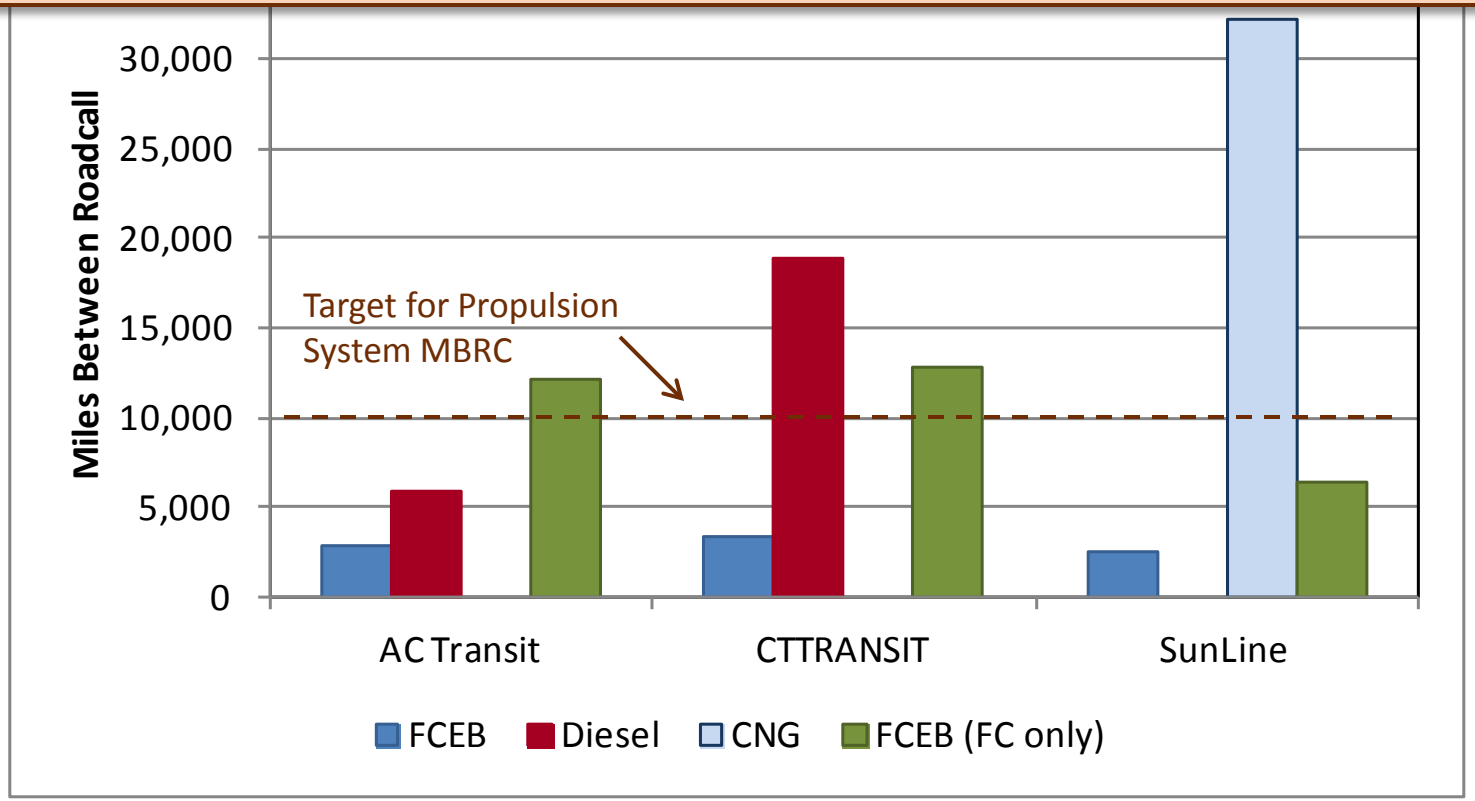
- Still lower than target, but improving
- Tends to vary widely by transit agency for any technology

*MBRC = miles between roadcall

FC System MBRC* Increasing – 38% improvement

Fuel cell-system-only MBRC:

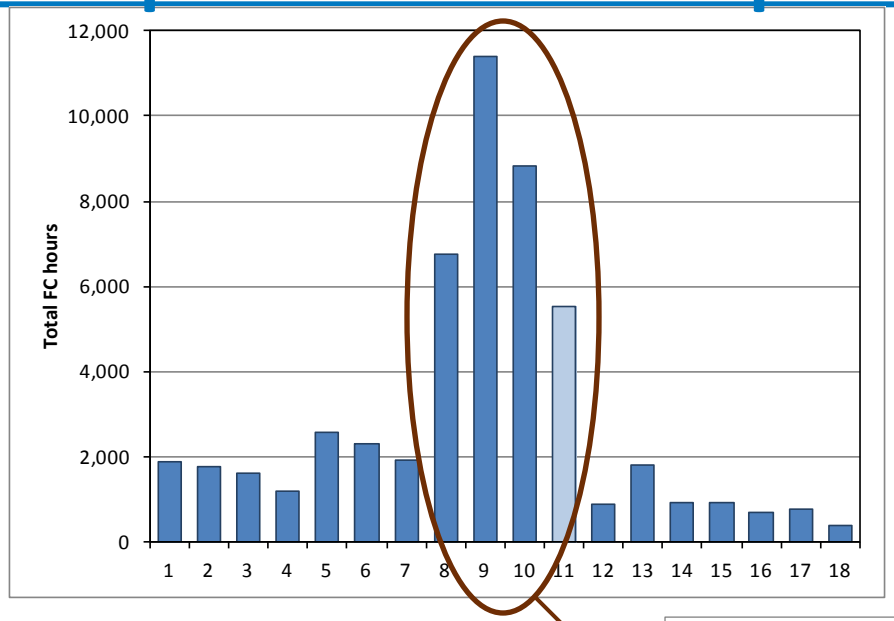
FC System MBRC 38% improvement from 1st gen FCEBs – 8,158 miles



- Shows that most roadcalls are not due to fuel cell system issues
- Newer design FCEBs still working through 'break-in' period

*MBRC = miles between roadcall

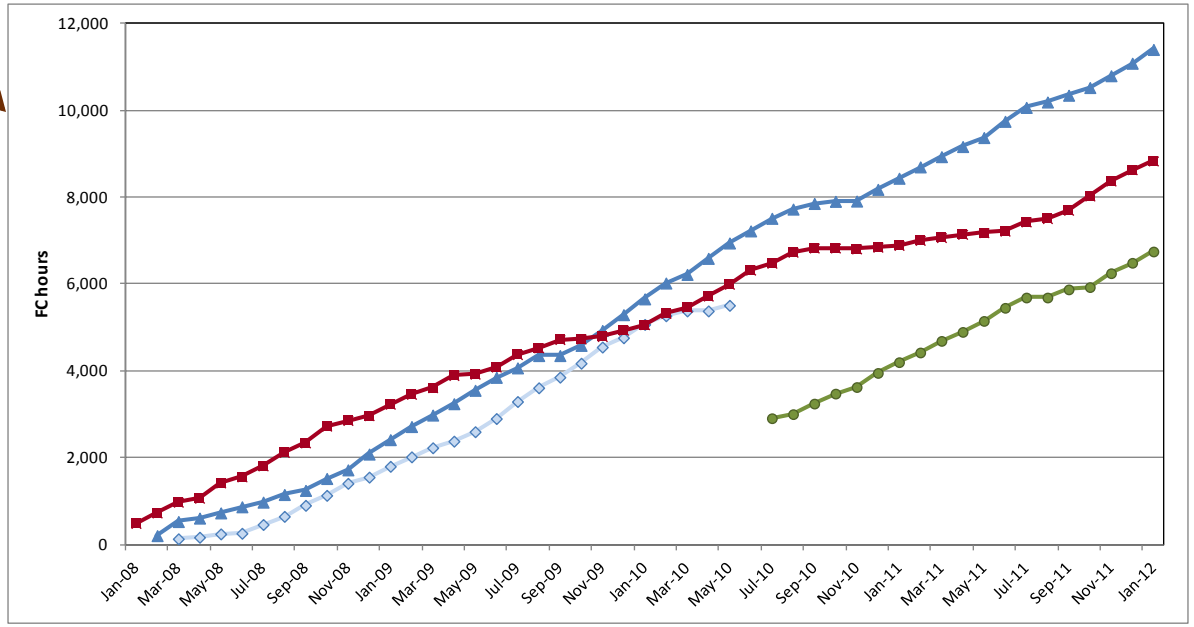
Top Fuel Cell Powerplant Exceeds 11,000 hours



- Total hours accumulated on each FC powerplant (FCPP) as of 1/31/12
- Transit application provides excellent opportunity to accumulate miles/hours faster

Bus fleet leaders

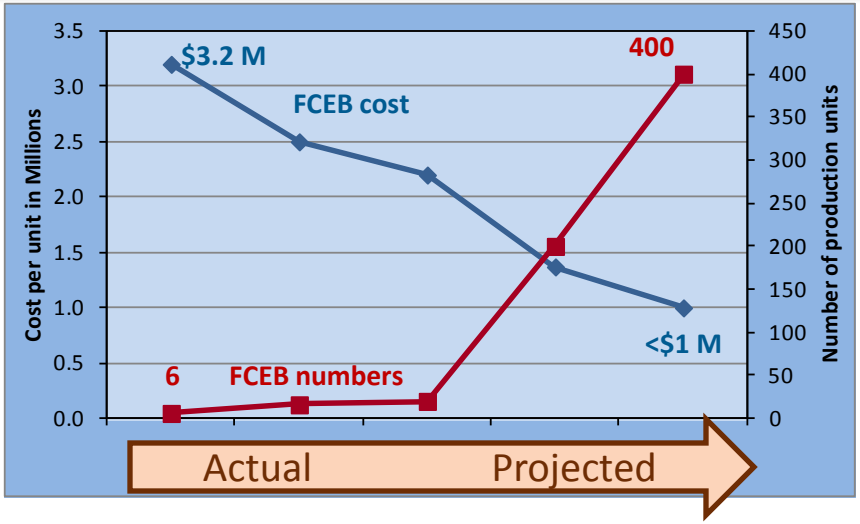
- 3 FCPPs over 6,000 h without repair or cell replacements
- Top FCPP now over 11,000 h



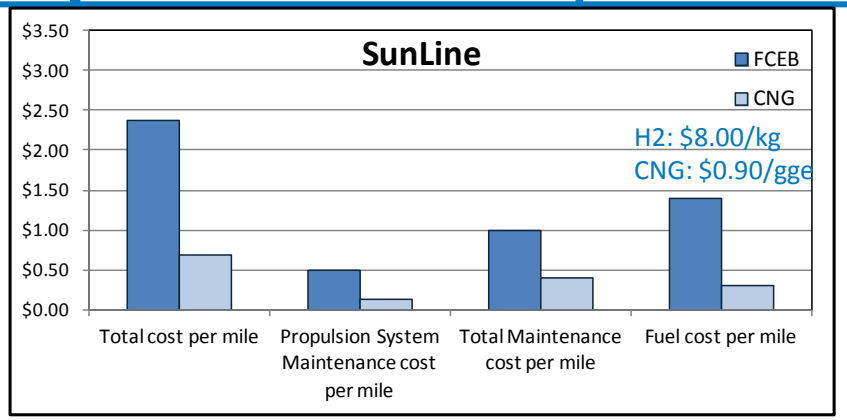
OEMs on a path to reduce capital cost to < $1M

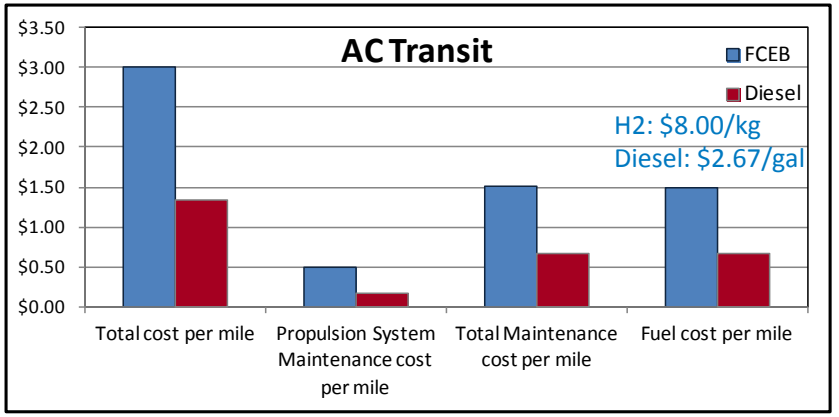
- **Fuel costs remain higher**
- **Operational costs still high**
- **Capital costs:**
  - Still higher, but coming down
  - Larger quantity orders should help

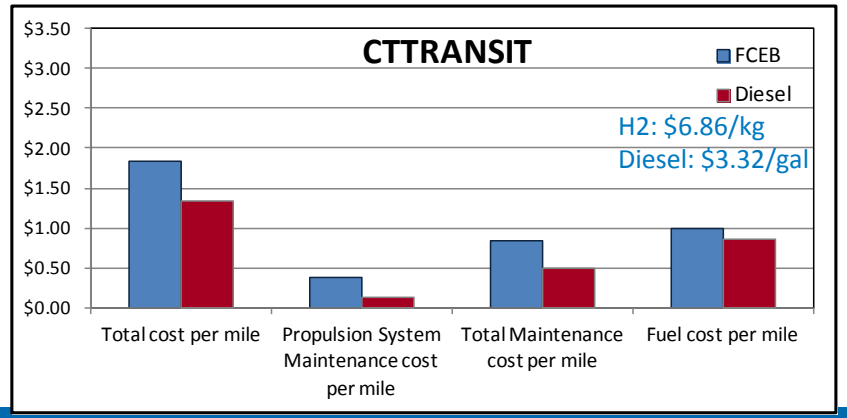
Projected cost reductions with increasing units



Source: FCHEA Fuel Cell Electric Bus White Paper, Mar 2011



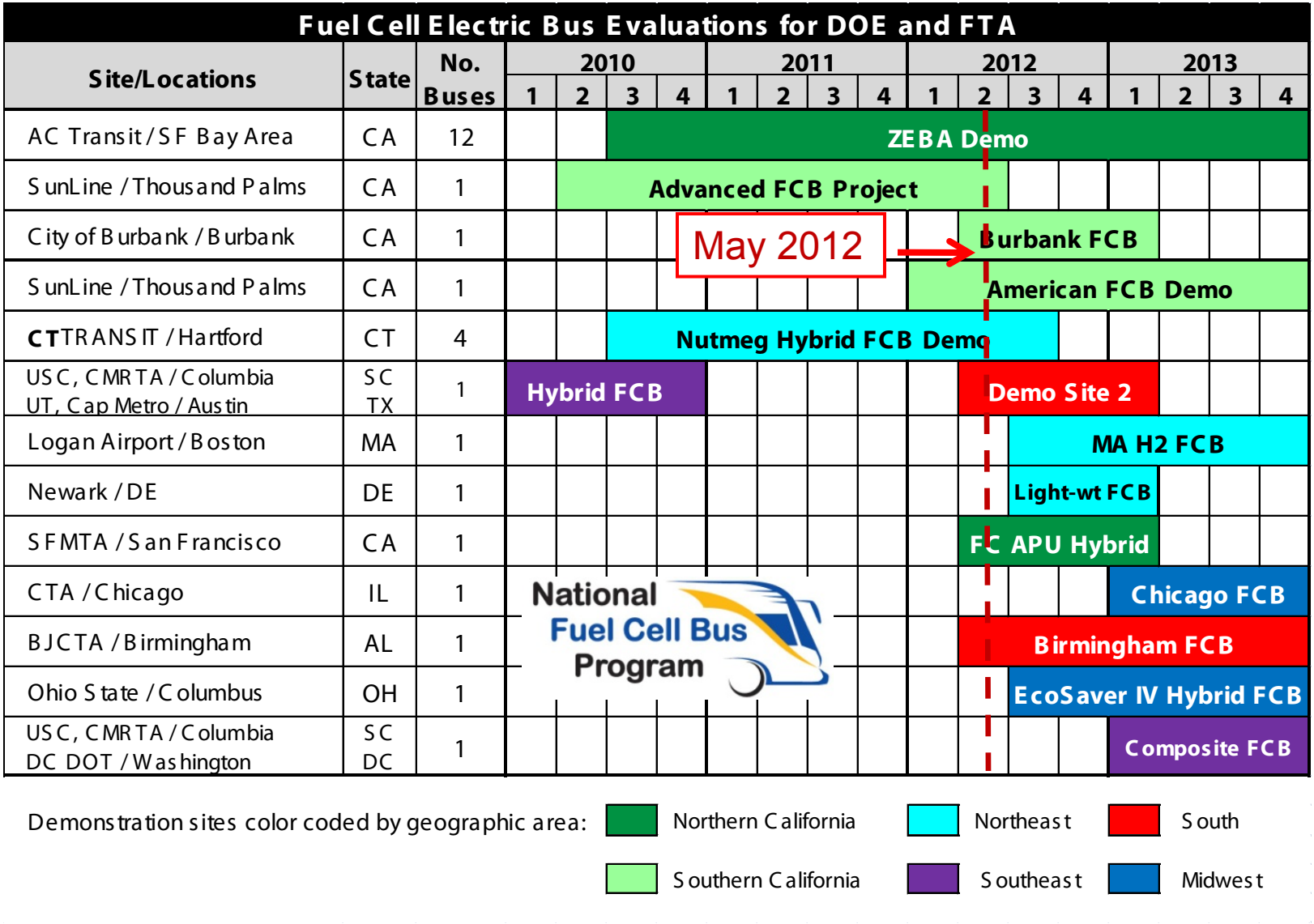




Collaborations

- **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
  - Alabama: Birmingham-Jefferson County
  - Ohio: Ohio State University
  - Illinois: Chicago Transit Authority
- **Manufacturers provide some data on buses and review reports**
  - Bus OEMs: Proterra, Van Hool, New Flyer, ElDorado National
  - FC OEMs: Ballard, Hydrogenics, UTC Power, Nuvera
  - Hybrid system OEMs: BAE Systems, Bluways, GE, Van Hool
- **Other organizations share information and data**
  - National: CARB, NAVC, CTE, CALSTART
  - International: Various organizations from Germany, Iceland, Brazil, Canada, China, Japan, England, Australia

Future Work


Fuel Cell Electric Bus Evaluations for DOE and FTA
Site/Locations
State
No. Buses
2010
2011
2012
2013
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
AC Transit / SF Bay Area
CA
12
ZEBA Demo
SunLine / Thousand Palms
CA
1
Advanced FCB Project
City of Burbank / Burbank
CA
1
Burbank FCB
SunLine / Thousand Palms
CA
1
American FCB Demo
CTTRANSIT / Hartford
CT
4
Nutmeg Hybrid FCB Demo
USC, CMRTA / Columbia
UT, Cap Metro / Austin
SC
TX
1
Hybrid FCB
Demo Site 2
Logan Airport / Boston
MA
1
MA H2 FCB
Newark / DE
DE
1
Light-wt FCB
SFMTA / San Francisco
CA
1
FC APU Hybrid
CTA / Chicago
IL
1
Chicago FCB
BJCTA / Birmingham
AL
1
Birmingham FCB
Ohio State / Columbus
OH
1
EcoSaver IV Hybrid FCB
USC, CMRTA / Columbia
DC DOT / Washington
SC
DC
1
Composite FCB
May 2012
National Fuel Cell Bus Program
Demonstration sites color coded by geographic area:
Northern California
Northeast
South
Southern California
Southeast
Midwest

Future Work

- **Remainder of FY 2012**
  - Continue data collection on 2nd generation FCEBs at AC Transit, SunLine, and City of Burbank
  - Continue data collection on FCEBs developed under the FTA program
  - Complete first crosscutting analysis of 2nd generation FCEBs at all sites
- **FY 2013**
  - Analyze data and report on FCEBs at Burbank, SunLine, and AC Transit
  - Explore new sites for potential data collection
  - Continue coordinating data collection activities with FTA
  - Complete annual crosscutting analysis across sites

Summary

Documented progress with 2nd generation FCEBs including:

- Mileage accumulation at 1,500 miles/month
- FCEB fuel economy consistently higher than diesel and CNG baseline
- FCEB designs approach 2x fuel economy; meeting target of 8 mpdge
- Average availability at 53%, most recent month up to 62%
- FCPP MBRC increasing – 38% improvement over 1st generation FCEBs
- Reliability data show road calls not typically due to FC system
- Top fuel cell powerplant surpasses 11,000 hours

	Units	2012 Status	Draft Target
Bus Lifetime	Years / miles	4.5 / 90,000	12 / 500,000
Powerplant Lifetime	Years / hours	4 / 11,000 +	6 / 25,000
Bus Use	Miles per month	1,500	3,000
Bus Availability	%	62	90
Fuel Economy	Miles per diesel gallon equivalent	8	8
Road call frequency	Miles between road call	2,239 / 2,928 / 11,279 (All, propulsion system, FCPP)	4,000 / 10,000 (All, Powerplant)