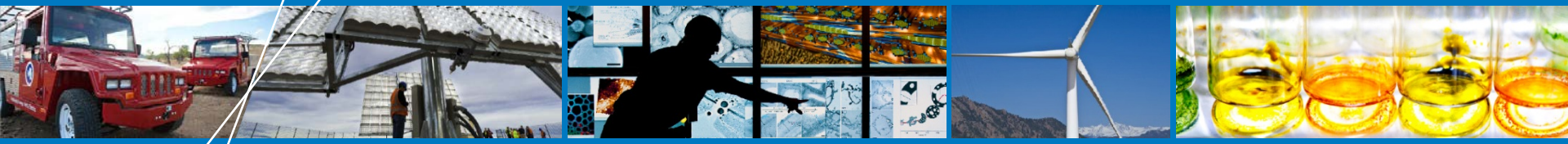
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Technology Validation: Fuel Cell Bus Evaluations



Leslie Eudy
National Renewable Energy Laboratory
June 19, 2014

Project ID#
TV008

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

Overview

Timeline

- **Project start date: FY03**
- **Project end date: 10/2014***

*Project continuation and direction determined annually by DOE.

Budget

FY13 DOE funding: $300K
Planned FY14 DOE funding: $300K
Total DOE project value (pre-FY2013): $2.577 M (11 yr)

Additional funding: DOT/Federal Transit Admin. and CARB

Barriers

- **A. Lack of current fuel cell vehicle (bus) performance and durability data**
- **C. Lack of current H_2 fueling infrastructure performance and availability data**

Partners

- **Transit Fleets: Operational data, fleet experience**
- **Manufacturers: Vehicle specs, data, and review**
- **Fuel providers: Fueling data and review**

Relevance

- Validate fuel cell electric bus (FCEB) performance and cost compared to DOE/DOT targets and conventional technologies
- Document progress and "lessons learned" on implementing fuel cell systems in transit operations to address barriers to market acceptance

Current Targets*	Units	2016 Target	Ultimate Target
Bus lifetime	Years / miles	12/500,000	12/500,000
Powerplant lifetime	Hours	18,000	25,000
Bus availability	%	85	90
Roadcall frequency (Bus/fuel cell system)	Miles between road call	3,500/15,000	4,000/20,000
Operation time	Hours per day/ days per week	20/7	20/7
Maintenance cost	$/mile	0.75	0.40
Fuel economy	Miles per diesel gallon equivalent	8	8

* Fuel Cell Technologies Program Record # 12012, Sep 2012, www.hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf

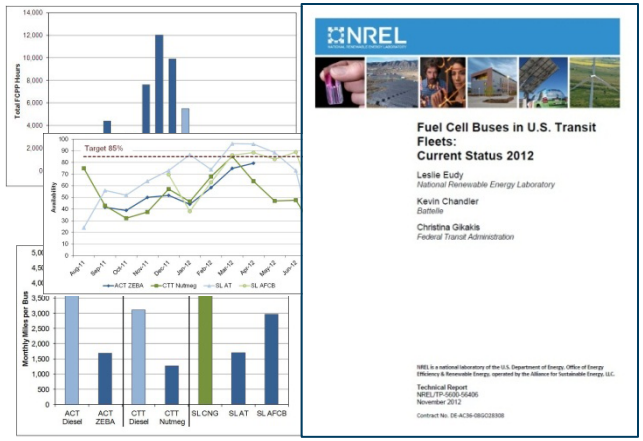
Approach

Data Collection/Analysis

- NREL 3rd Party analysis uses standard protocol for collecting existing data from transit partners
- Includes comparisons to conventional technology buses in similar service (diesel, CNG, diesel hybrid)

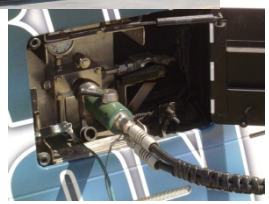
Individual Site Reports

- Documents performance results and experience for each transit agency
- Builds database of results
- Reports published and posted on NREL web site



Annual FCEB status report

- Crosscutting analysis comparing results from all sites
- Assesses progress and needs for continued success
- Provides input on annual status for DOE/DOT Targets



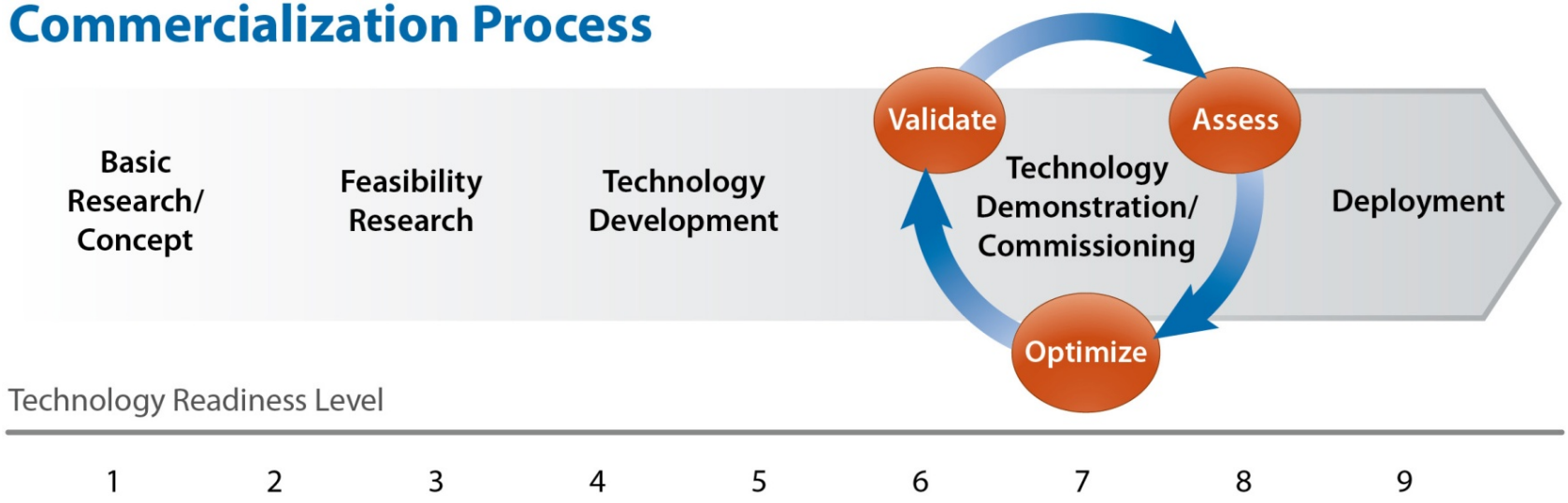
Accomplishments: Progress Toward Targets
NREL Assesses Technology Readiness Levels

Manufacturer teams for FCEBs currently operating in the United States

Bus OEM	Length (ft)	Fuel Cell System	Hybrid System	Design Strategy	Energy Storage	TRL Level
Van Hool	40	ClearEdge Power	Siemens ELFA integrated by Van Hool	Fuel cell dominant	Lithium-based batteries	7 ✓
New Flyer	40	Ballard	Siemens ELFA integrated by Bluways	Fuel cell dominant	Lithium-based batteries	7 ✓
ElDorado	40	Ballard	BAE Systems	Fuel cell dominant	Lithium-based batteries	7 ✓
Proterra	35	Hydrogenics	Proterra integration	Battery dominant	Lithium-based batteries	6

✓ Data included in Presentation

Commercialization Process



Data Summary for 2014

Specifications for FCEBs included in data summary

New fleet

FCEB Identifier	ACT ZEBA	BCT AT	SL AT	SL AFCB
Transit Agency	AC Transit	BC Transit	SunLine	SunLine
Number of Buses	12	20	1	1
Bus OEM	Van Hool	New Flyer	New Flyer	ElDorado National
Bus length/height	40 ft / 136 in	40 ft / 137 in	40 ft / 137 in	40 ft / 140 in
Fuel Cell OEM	ClearEdge Power	Ballard	Ballard	Ballard
Model	PureMotion 120	FCvelocity, HD6	FCvelocity, HD6	FCvelocity, HD6
Power (kW)	120	150	150	150
Hybrid System	Siemens ELFA, integrated by Van Hool	Siemens ELFA, integrated by Bluways	Siemens ELFA, integrated by Bluways	BAE Systems HybriDrive
Design strategy	FC dominant	FC dominant	FC dominant	FC dominant
Energy Storage - OEM	EnerDel	Valence	Valence	A123
Type	Li-ion	Li-ion	Li-ion	Nanophosphate Li-ion
Capacity	17.4 kWh	47 kWh	47 kWh	11 kWh
# cylinders	8	8	6	8
Capacity (kg) / Pressure (Bar)	40 / 350	56 / 350	43 / 350	50 / 350

ACT ZEBA

BCT

SL AT

SL AFCB

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Energy Storage - OEM	EnerDel	Valence	Valence	A123
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Hybrid system optimization and integration is the primary difference between designs

ACT ZEBA

BCT

SL AT

SL AFCB

Hybrid System Comparison

ACT ZEBA

BCT

SL AT

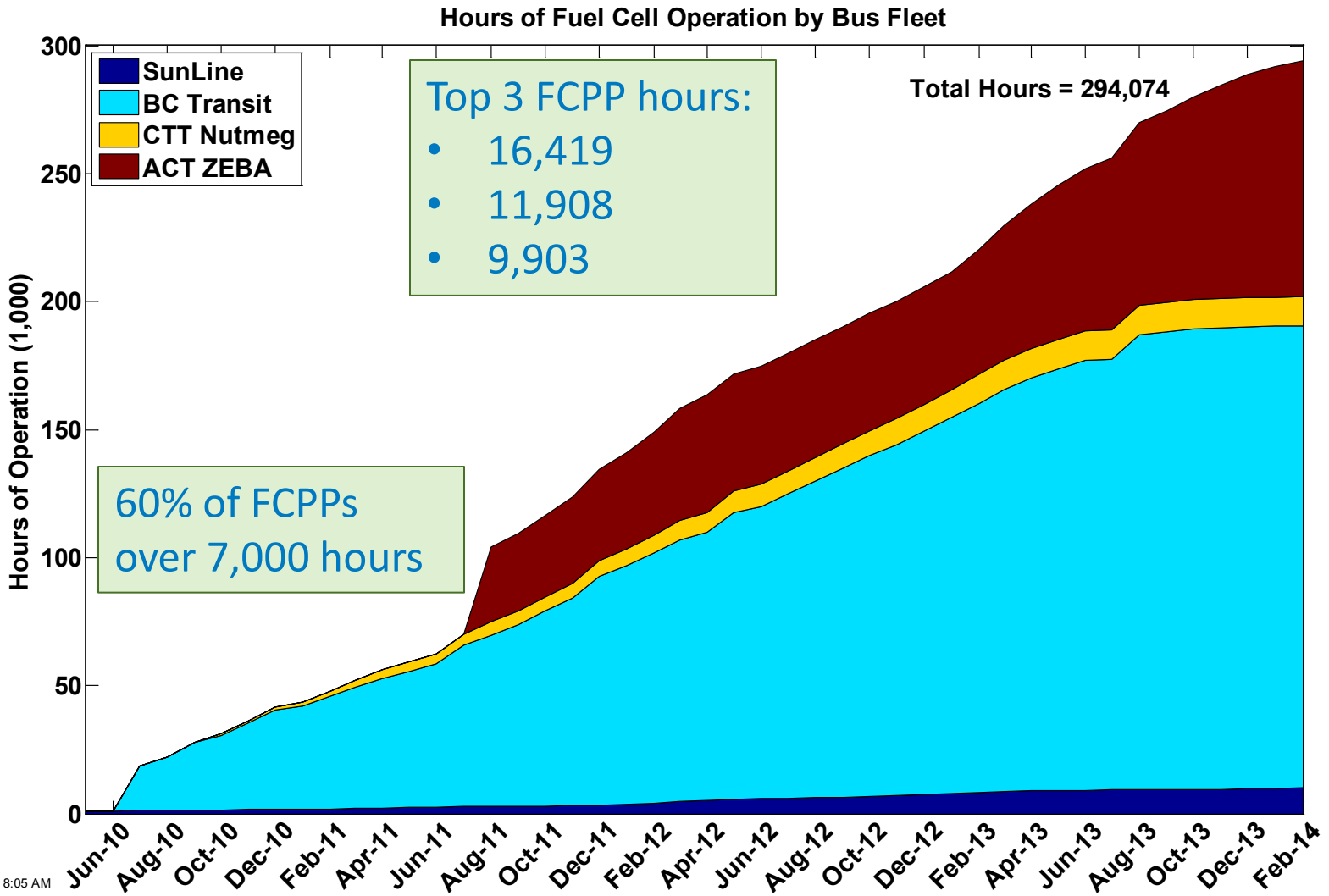
SL AFCB

Hybrid System	Comparison of Design and Integration Challenges
Siemens ELFA, integrated by Van Hool	ZEBA – 2010 deployment, first time integration by bus OEM using proven components, needed significant optimizations early in demo, multiple software changes to system and battery controls, experienced early issues with diagnosing intermittent faults
Siemens ELFA, integrated by Bluways (originally ISE)	BCT – 2010 deployment, optimized for reliability as opposed to fuel efficiency, original integrator went bankrupt forcing other partners to step up support, non-moveable deadline for deployment (2010 Olympics) resulted in less time to fully optimize and test, made several modifications after deployment – primary changes were increased hydrogen storage to improve range and added heating for winter
Siemens ELFA, integrated by Bluways (originally ISE)	AT – 2009 deployment, pilot bus to BCT fleet, early tests of pilot bus in BC showed improvements were needed to meet BCT requirements, bus was later updated to almost match BCT specs – primary difference is hydrogen storage, bus was sold to SunLine and put into service in California
BAE Systems HybriDrive	AFCB – late 2012 deployment, design based on a proven diesel hybrid propulsion design (more than 3,000 are operating around the world), modified to FC system power , integrator worked closely with OEM, plan to move toward full integration by bus OEM for future builds, at least 6 more buses being produced for several agencies

Accomplishments : Progress Toward Targets

Top Fuel Cell Powerplant exceeds 16,000 Hours

Total hours accumulated on each FC powerplant (FCPP) as of 2/28/14



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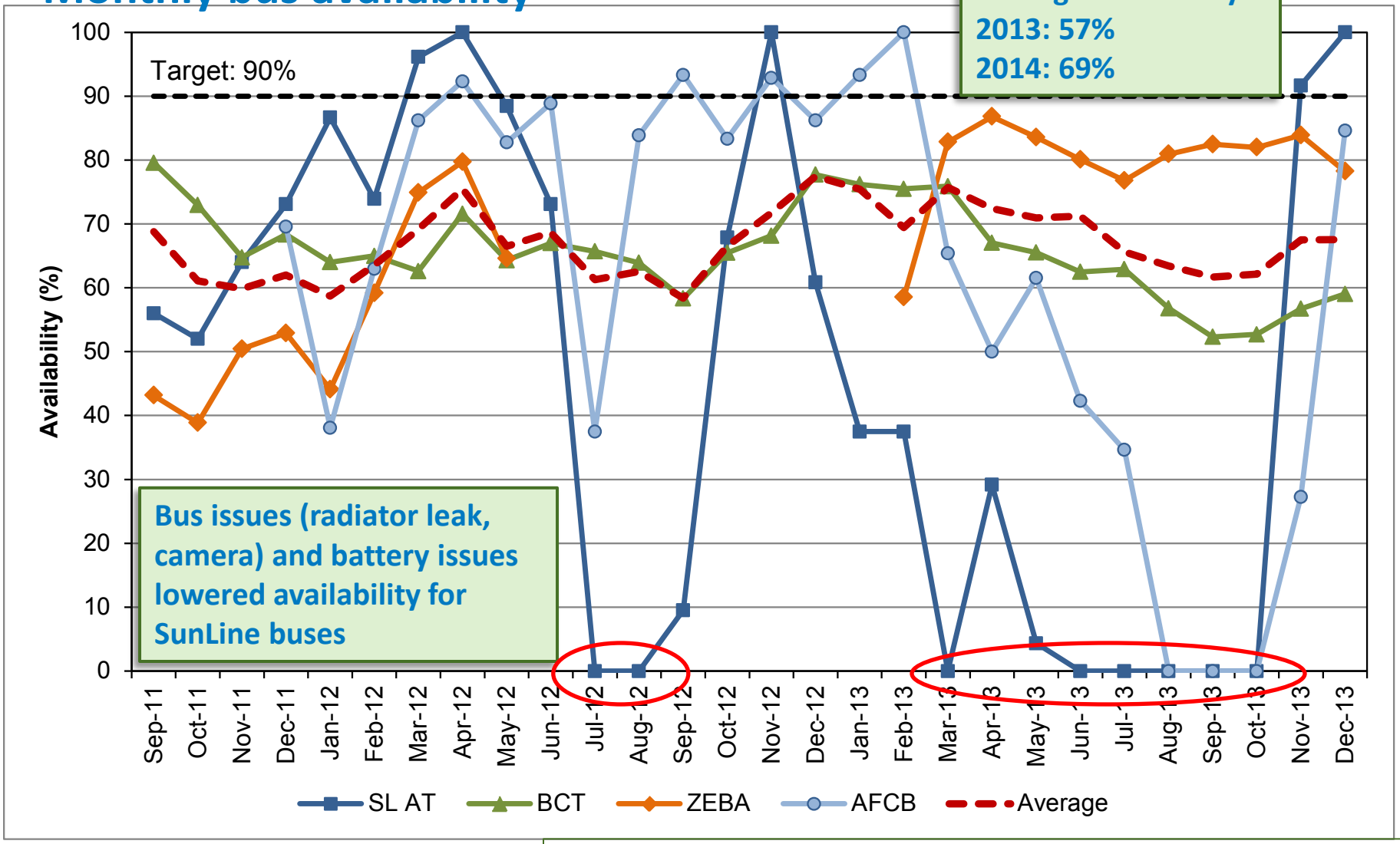
Accomplishments : Progress Toward Targets

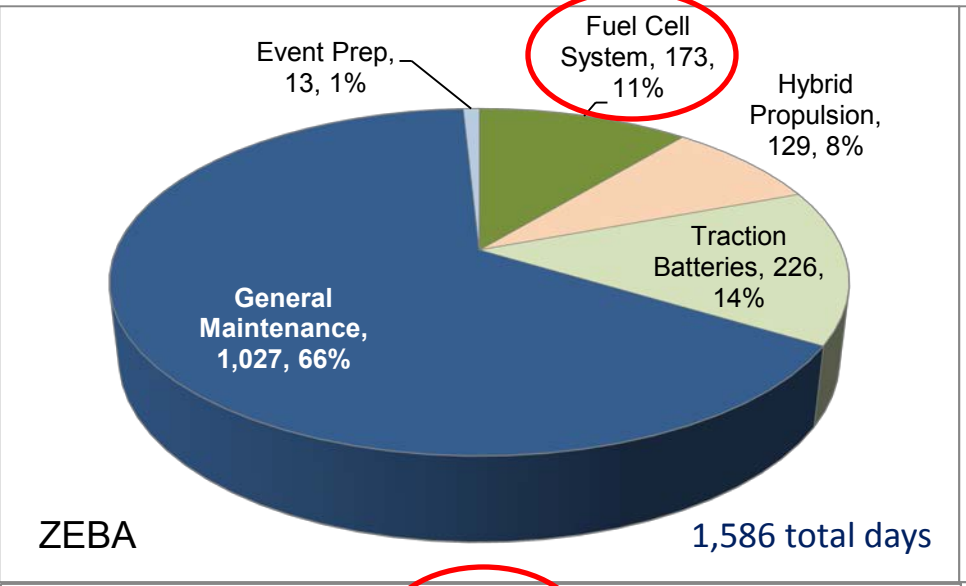
Average Bus Availability improves by 20%

Monthly bus availability



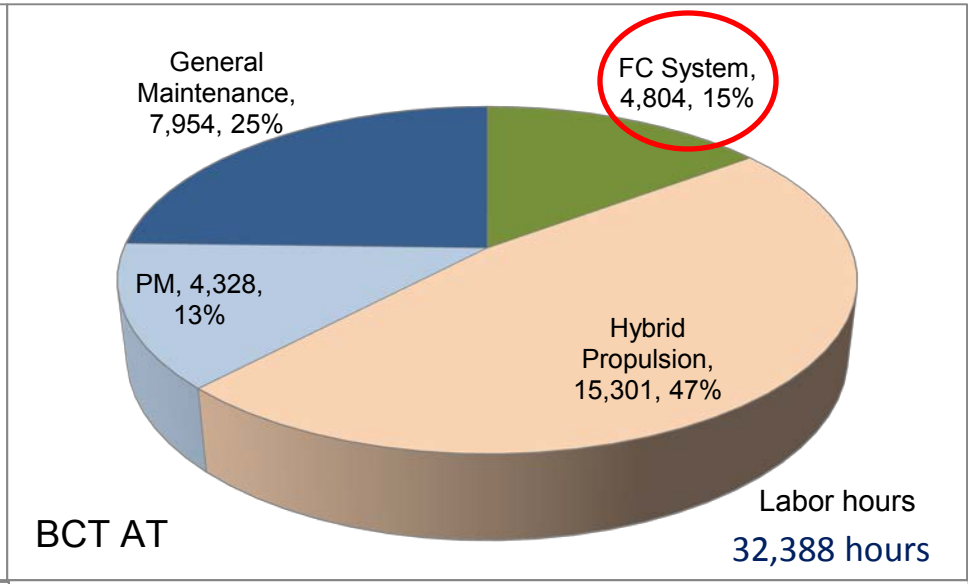
Availability = planned operation days compared to actual operation days

Reasons for Unavailability by Site



ZEBA

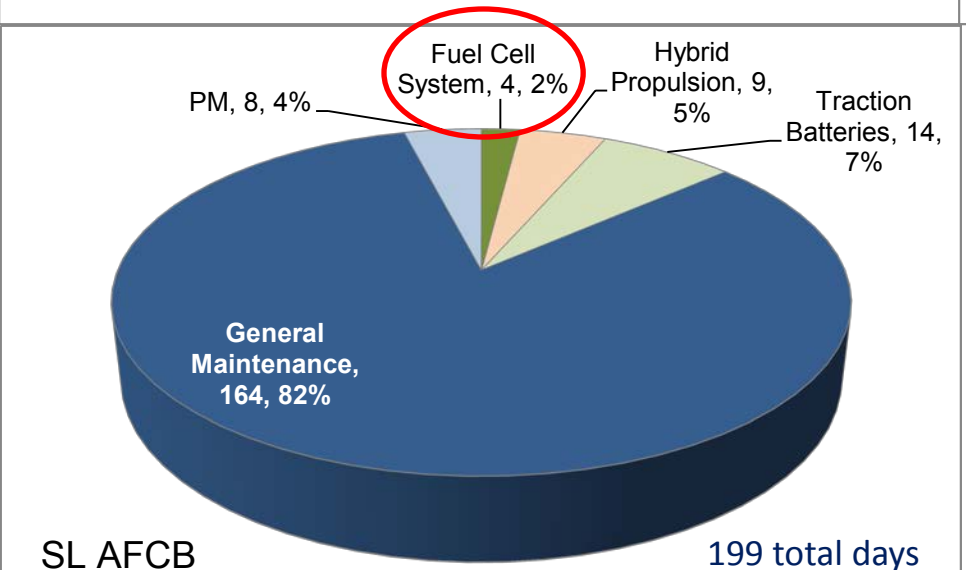
1,586 total days



BCT AT

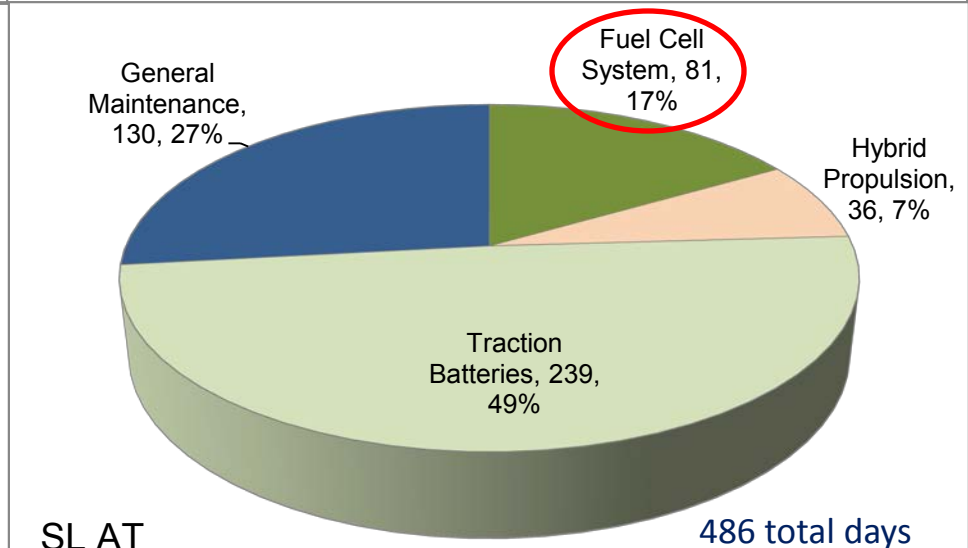
Labor hours

32,388 hours



SL AFCB

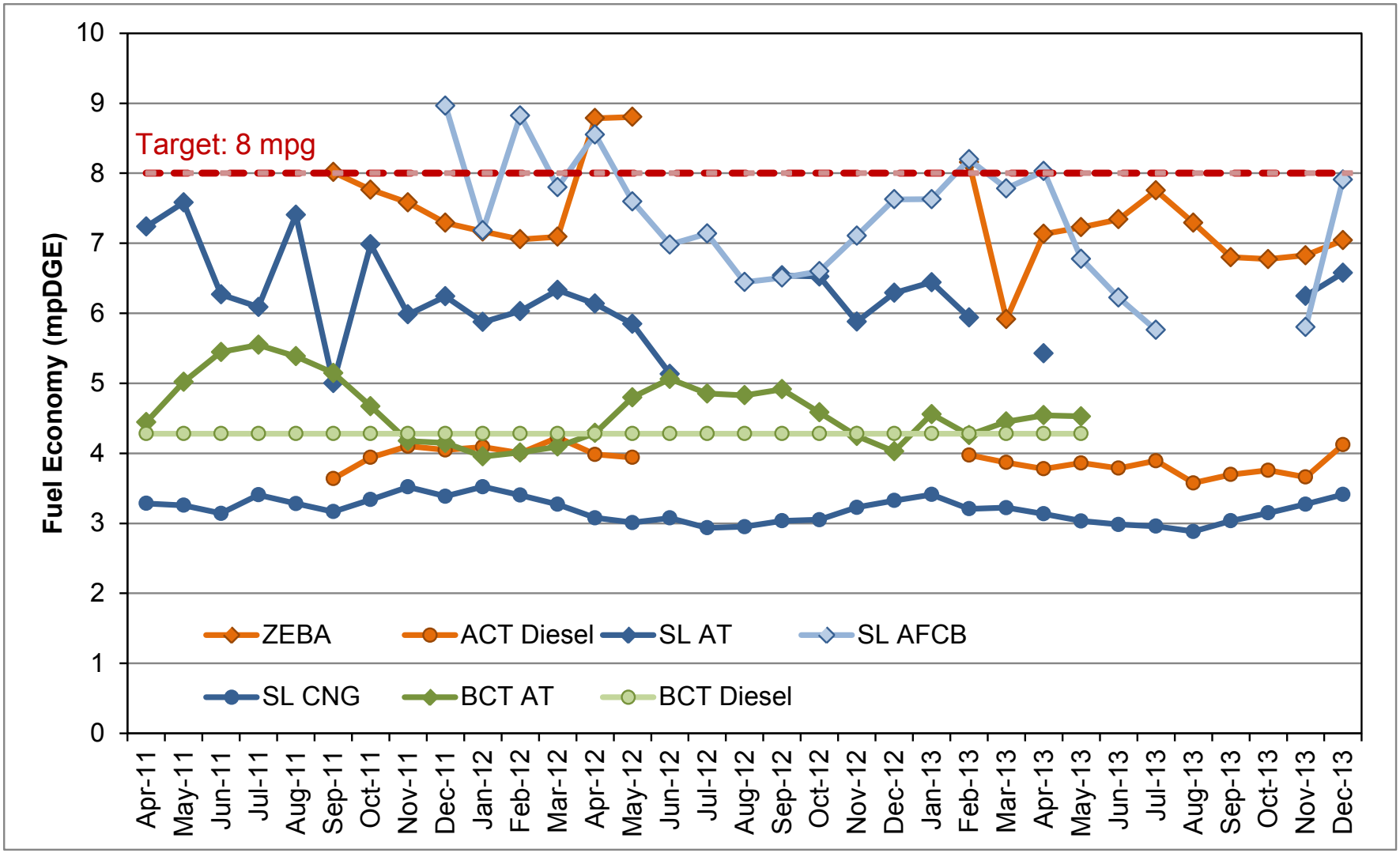
199 total days



SL AT

486 total days

Monthly Fuel Economy compared to Baseline



Highly variable depending on duty cycle: average speed, terrain, auxiliary loads

Comparison to Previous Generation FCEBs

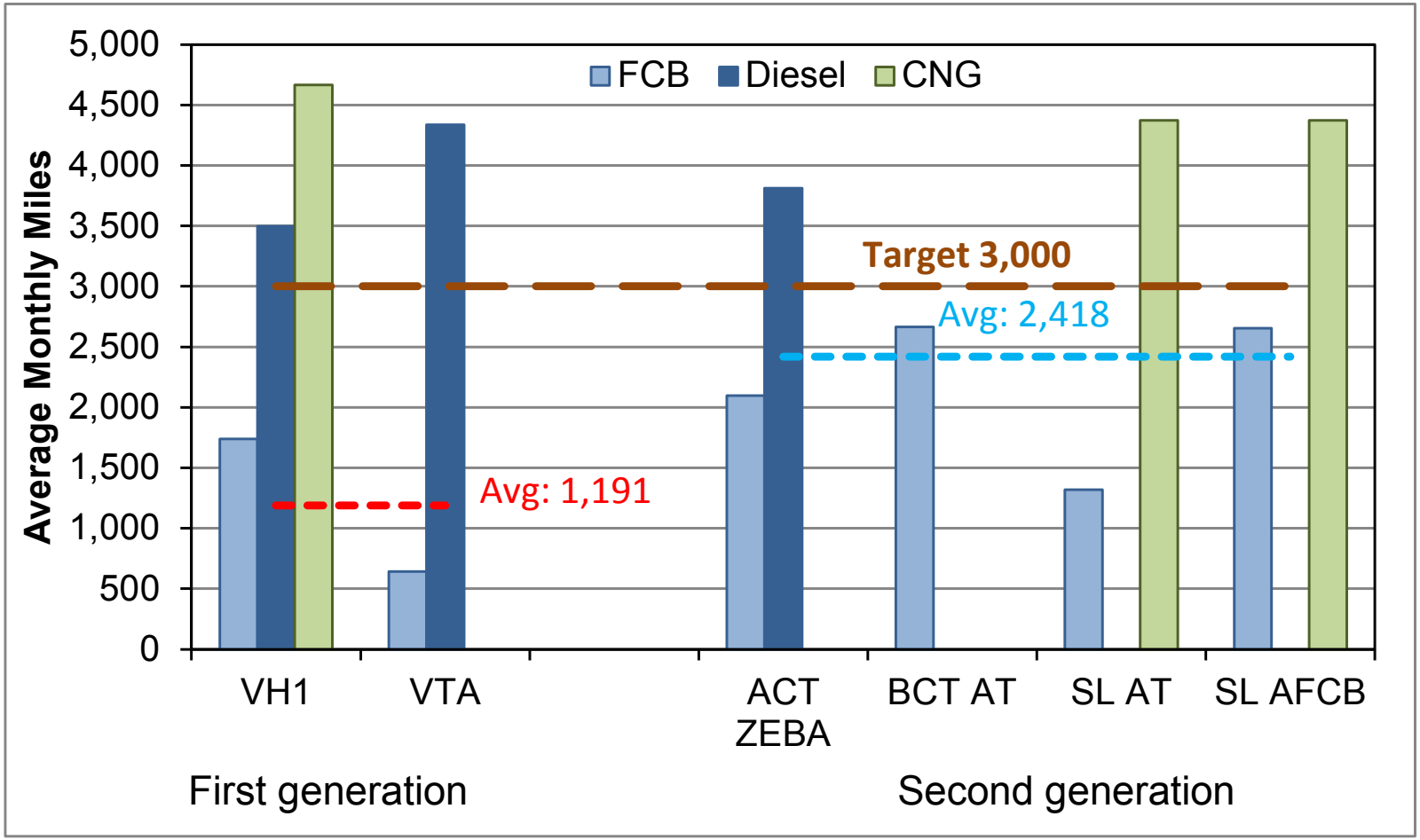
Specifications for 1st Generation FCEBs

FCEB Identifier	VH1 (Van Hool 1st Gen)	VTA
Transit Agency	AC Transit, CTTRANSIT, SunLine	Santa Clara Valley Transportation Authority (VTA)
Number of Buses	5	3
Bus OEM	Van Hool	Gillig
Bus length/height	40 ft / 139 in	40 ft / 144 in
Fuel Cell OEM	UTC Power	Ballard
Model	PureMotion 120	P5-2
Power (kW)	120	300
Hybrid System	Siemens ELFA, integrated by ISE Corp	Not a hybrid system
Design strategy	FC dominant	N/A
Energy Storage - OEM	MES-DEA	N/A
Type	sodium/Nickel Chloride	N/A
Capacity	53 kWh	N/A
# cylinders	8	11
Capacity (kg) / Pressure (Bar)	50 / 350	55 / 350

VH1

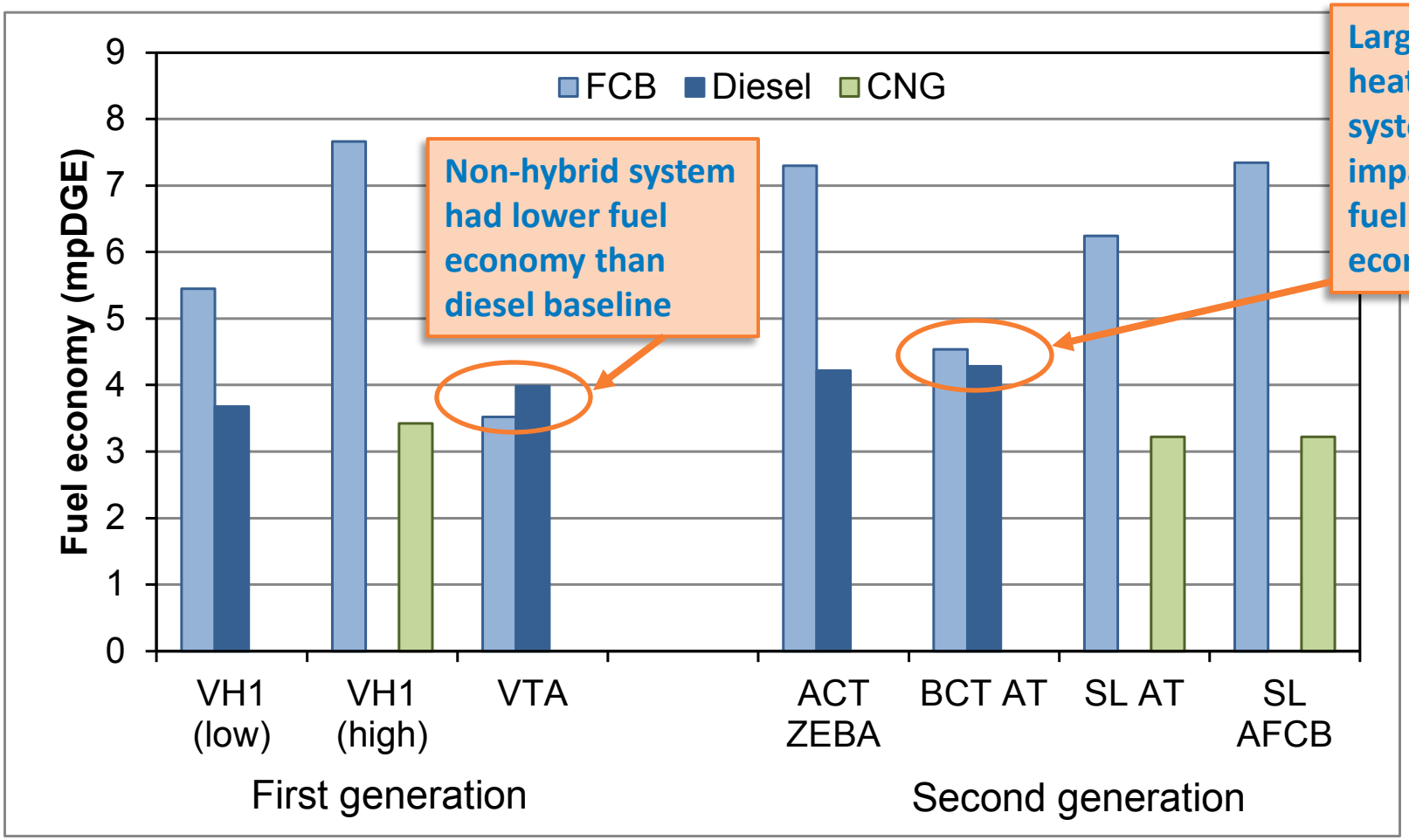
VTA

Monthly Miles 2 Times higher than 1st Gen



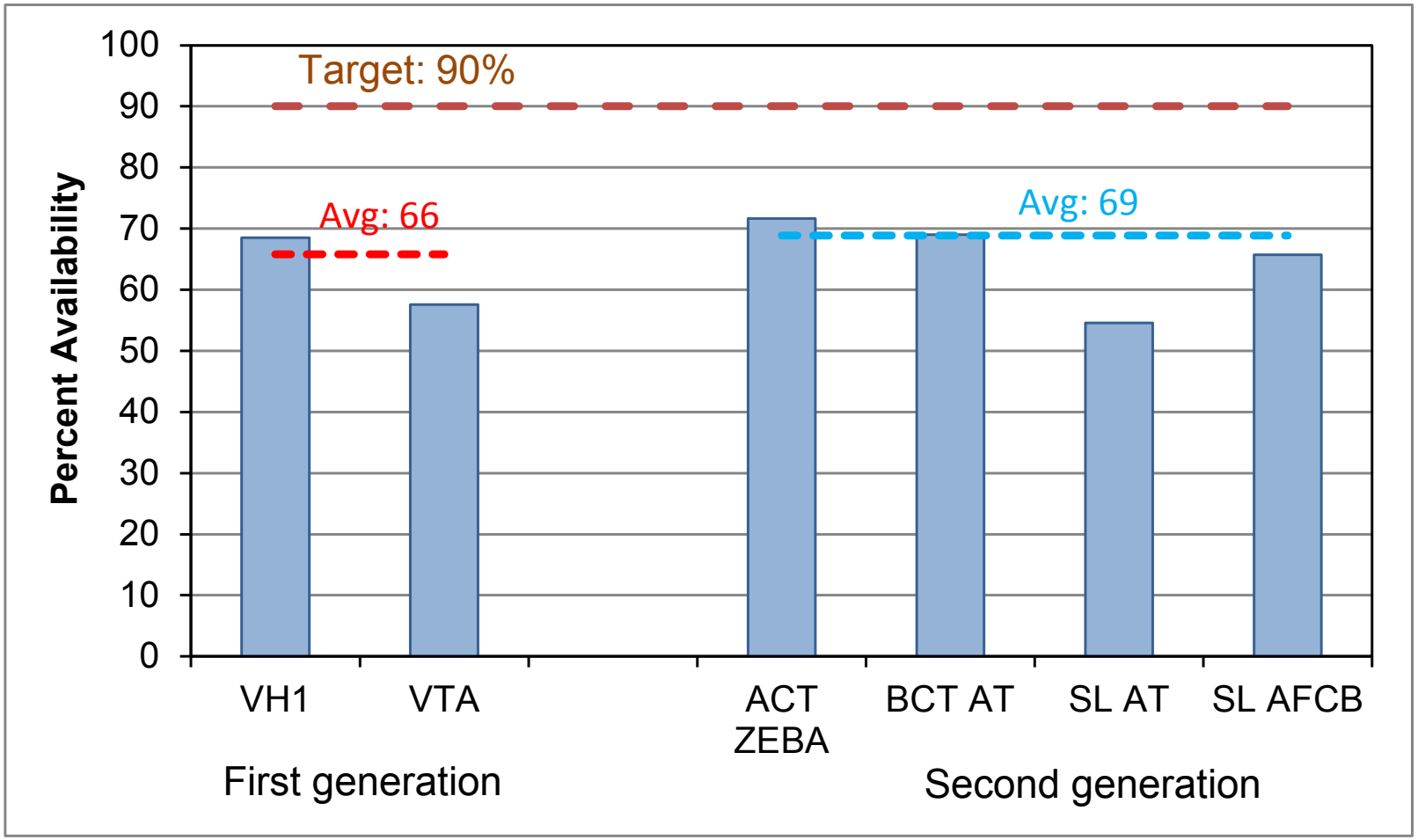
Transit agencies are increasing service; approaching target, but still lower than conventional buses

Fuel Economy up to 2 Times Better than Baseline



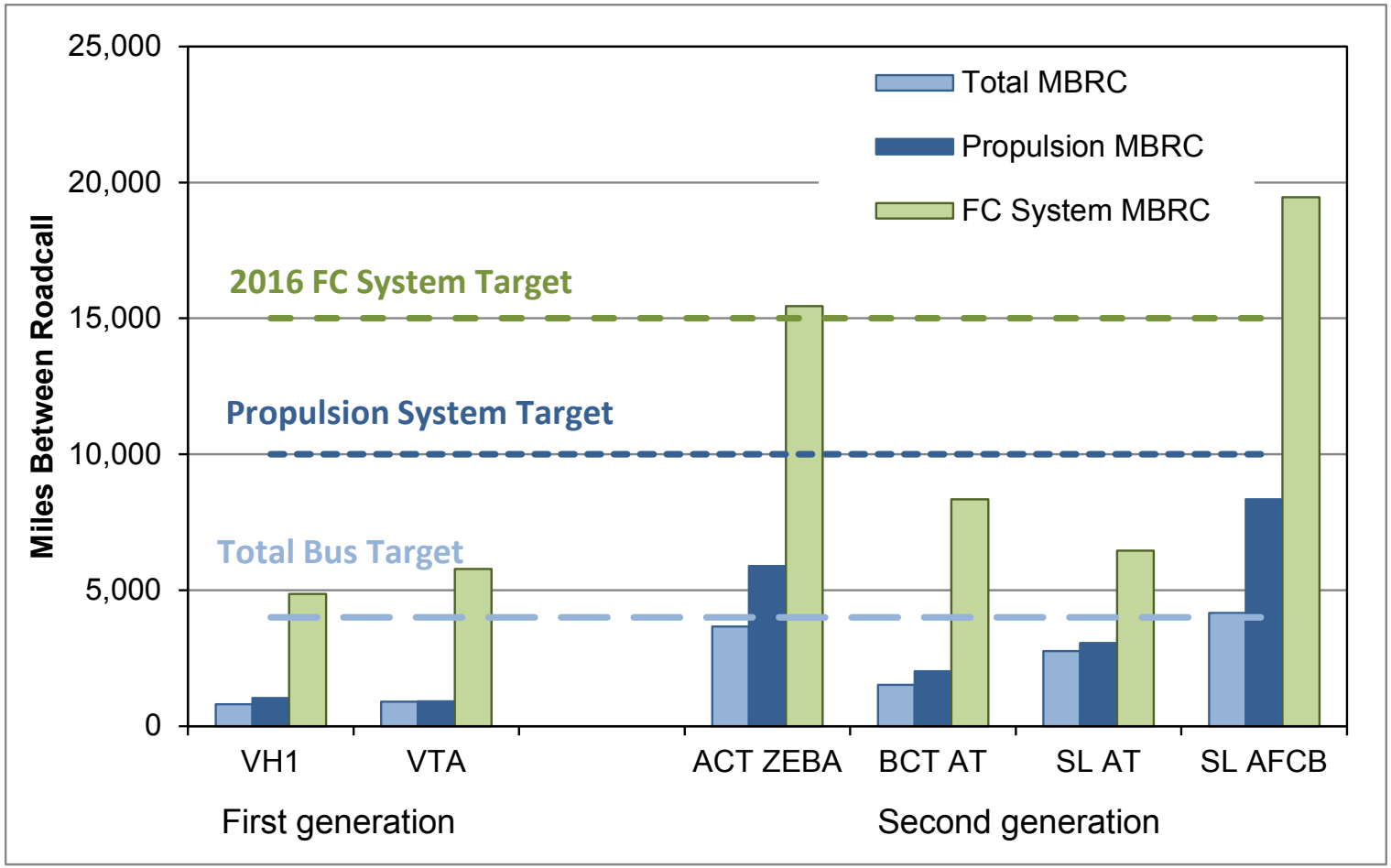
Lowest fuel economy was for 1st gen system that was not a hybrid (VTA)
Highly variable depending on duty cycle, but generally higher than baseline buses

Availability Increased to 69%



Recent issues with FCEBs at SunLine lowered availability for 2nd gen
SL AFCB - Difficulty of diagnosing source of leak resulted in extended downtime
Availability was 84% prior to issue.

Reliability: Bus MBRC 48% higher than 1st Gen



	Total MBRC	Propulsion MBRC	FC System MBRC
1st Gen average	1,263	1,555	7,710
2nd Gen average	1,863	2,523	9,554
Percent improvement	48%	62%	24%

*MBRC = miles between roadcall

Responses to Previous Year Reviewers' Comments

- **Consider looking at past data to show progress. Compare data from previous generation buses.**
  - Comparisons to first generation FCEBs included in this presentation (Slides 14-17)
- **Provide more detail in the differences in generations of buses to better inform the direction in the performance of the products.**
  - Selected specifications of the early and current generation buses are included in the presentation. (Slide 6)
- **If possible, NREL should identify the cause of the large increase in fuel economy and availability of the AFCB over the AT buses at SunLine.**
  - Descriptions of the difference in these systems are included in the presentation (slides 6-8)

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
  - Alabama: Birmingham-Jefferson County
  - Texas: Capital Metro, Austin
  - 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, ClearEdge Power, Nuvera
  - Hybrid system OEMs: BAE Systems, GE, Van Hool, US Hybrid
- **Other organizations share information and data**
  - National: CARB, NAVC, CTE, CALSTART
  - International: Various organizations from Germany, Iceland, Brazil, Canada, China, Japan, England, Norway, Italy, Sweden

Remaining Challenges and Barriers

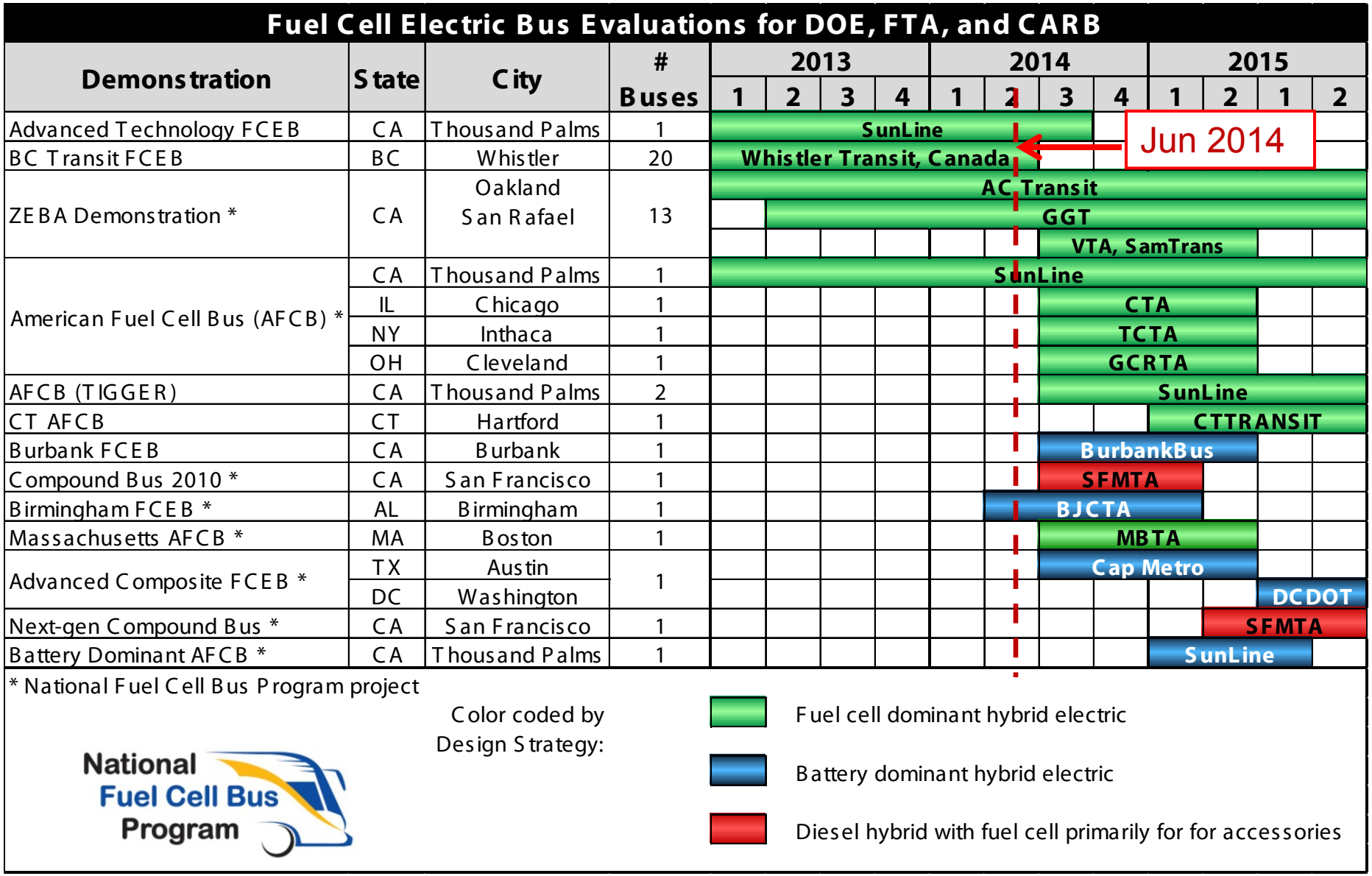
For technology validation and data collection project:

- **Establish good relationships with additional transit agencies to allow data collection for new FCEB designs**
- **Continue data collection to track progress as buses age, and to understand operational costs after buses are out of warranty**

For industry to meet technical targets and commercialize FCEBs:

- **Increase durability and reliability of the fuel cell, battery system, and other components**
- **Improve integration/optimization of systems and components**
- **Transition build process with OEM taking the primary role for bus production**
- **Transition all maintenance to transit staff (no onsite OEM support)**
- **Reduce cost, both capital and operating**

Proposed Future Work



Proposed Future Work

- **Remainder of FY 2014**
  - Complete following data analyses/reports:
    - AC Transit, ZEBA Demo Report, Apr 2014
    - SunLine AFCB Report, Jun 2014
    - BC Transit Final Report, Aug 2014 (demo ended Mar 2014)
    - 2013 Annual Status Report, Sep 2014
  - Begin data collection on FCEBs in Birmingham and Austin
- **FY 2015**
  - Kick off new FCEB evaluations as buses go into service
  - Complete Individual Site reports as scheduled
  - Complete annual crosscutting analysis across sites

Summary

Documented progress toward targets:

	Units	Current Status	2016 Target	Ultimate Target
Bus lifetime	Years / miles	5/100,000	12/500,000	12/500,000
Powerplant lifetime[1]	Hours	1,000 – 16,000	18,000	25,000
Bus availability	%	55 – 72	85	90
Roadcall frequency[2] (Bus/fuel cell system)	Miles between road call	1,500 – 4,000 / 6,000 – 19,000	3,500/15,000	4,000/20,000
Operation time	Hours per day/ days per week	19/7	20/7	20/7
Maintenance cost	$/mile	0.39 – 1.60	0.75	0.40
Fuel economy	Miles per diesel gallon equivalent	4.5 – 7.3	8	8
Range	miles	220 – 310	300	300

[1] Fuel cell hours accumulated to date from newest FCPP to oldest FCPP. Does not indicate end of life.

[2] MBRC: range from lowest to highest for current designs