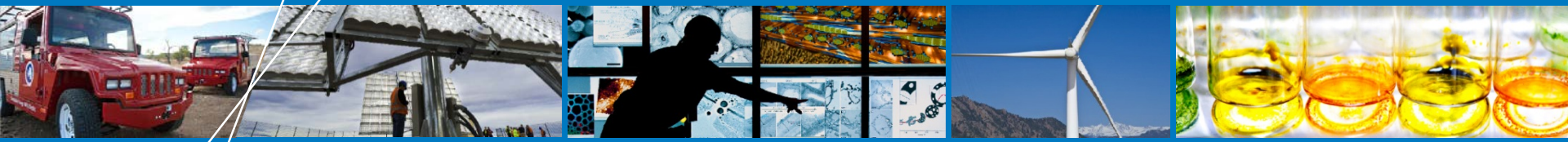
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

# Technology Validation: Fuel Cell Bus Evaluations



**Leslie Eudy**
**National Renewable Energy Laboratory**
**June 10, 2015**

Project ID# TV008

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

# Overview

## Timeline and Budget

- Project Start: FY03
- End: Project continuation and direction determined annually by DOE.
- Total DOE Funds Received to Date: $3.525 M (13 years)
- FY14 DOE funding: $300K
- FY15 planned DOE funding: $265

Additional funding: U.S. Department of Transportation (DOT) /Federal Transit Admin.

## 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 roadcall | 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

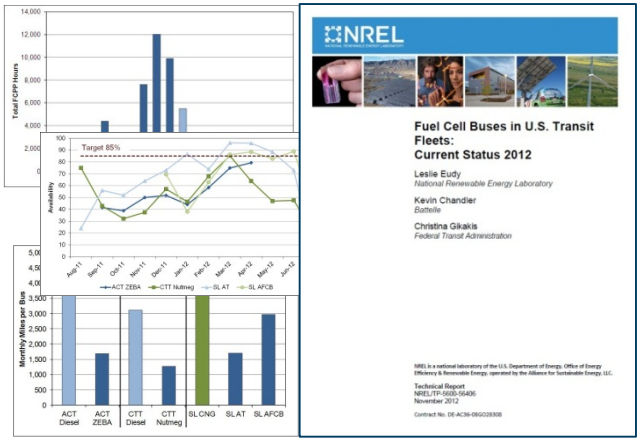
# Approach

## Data Collection/Analysis

- NREL third 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)

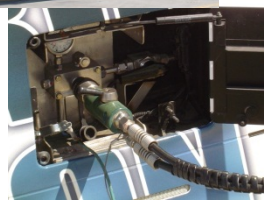
## Individual Site Reports

- 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 (milestone)

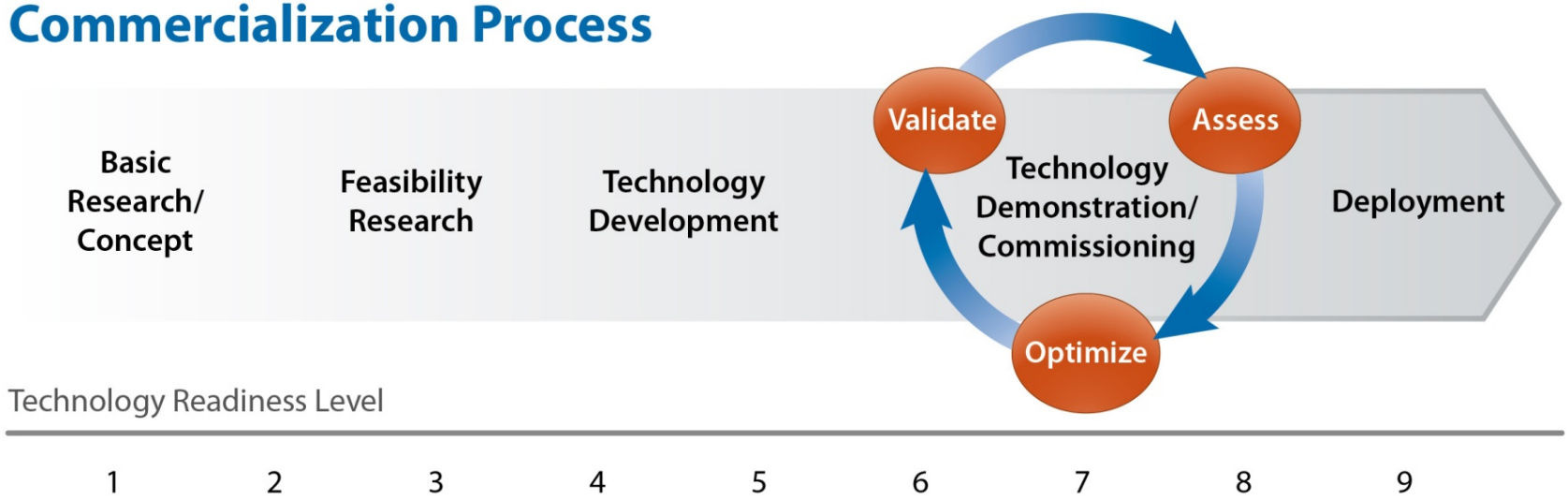
- Crosscutting analysis comparing results from all sites
- Assesses progress and needs for continued success
- Provides input on annual status for DOE/DOT Targets



# Accomplishments: Progress Toward Targets

# NREL Assesses Technology Readiness Levels

## Commercialization Process




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 | US Hybrid | 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-titanate batteries | 6 |
| EVAmerica | 35 | Ballard | Embedded Power | Battery dominant | Lithium-titanate batteries | 6 |

✓ Data included in Presentation

# Data Summary for 2015

## Specifications for FCEBs included in data summary

| FCEB Identifier | ACT ZEBA | SL AFCB |
|---|---|---|
| **Transit Agency** | AC Transit | SunLine |
| **Location** | Oakland, CA | Thousand Palms, CA |
| **Number of Buses** | 12 | 3 |
| **Bus OEM** | Van Hool | ElDorado National |
| **Bus length/height** | 40 ft / 136 in | 40 ft / 140 in |
| **Fuel Cell OEM** | US Hybrid | Ballard |
| **Model** | PureMotion 120 | FCvelocity–HD6 |
| **Power (kW)** | 120 | 150 |
| **Hybrid System** | Siemens ELFA, integrated by Van Hool | BAE Systems HybriDrive |
| **Design strategy** | FC dominant | FC dominant |
| **Energy Storage—OEM** | EnerDel | A123 |
| **Type** | Li-ion | Nanophosphate Li-ion |
| **Capacity** | 17.4 kWh | 11 kWh |
| **# cylinders** | 8 | 8 |
| **Capacity (kg) / Pressure (Bar)** | 40 / 350 | 50 / 350 |

ACT ZEBA

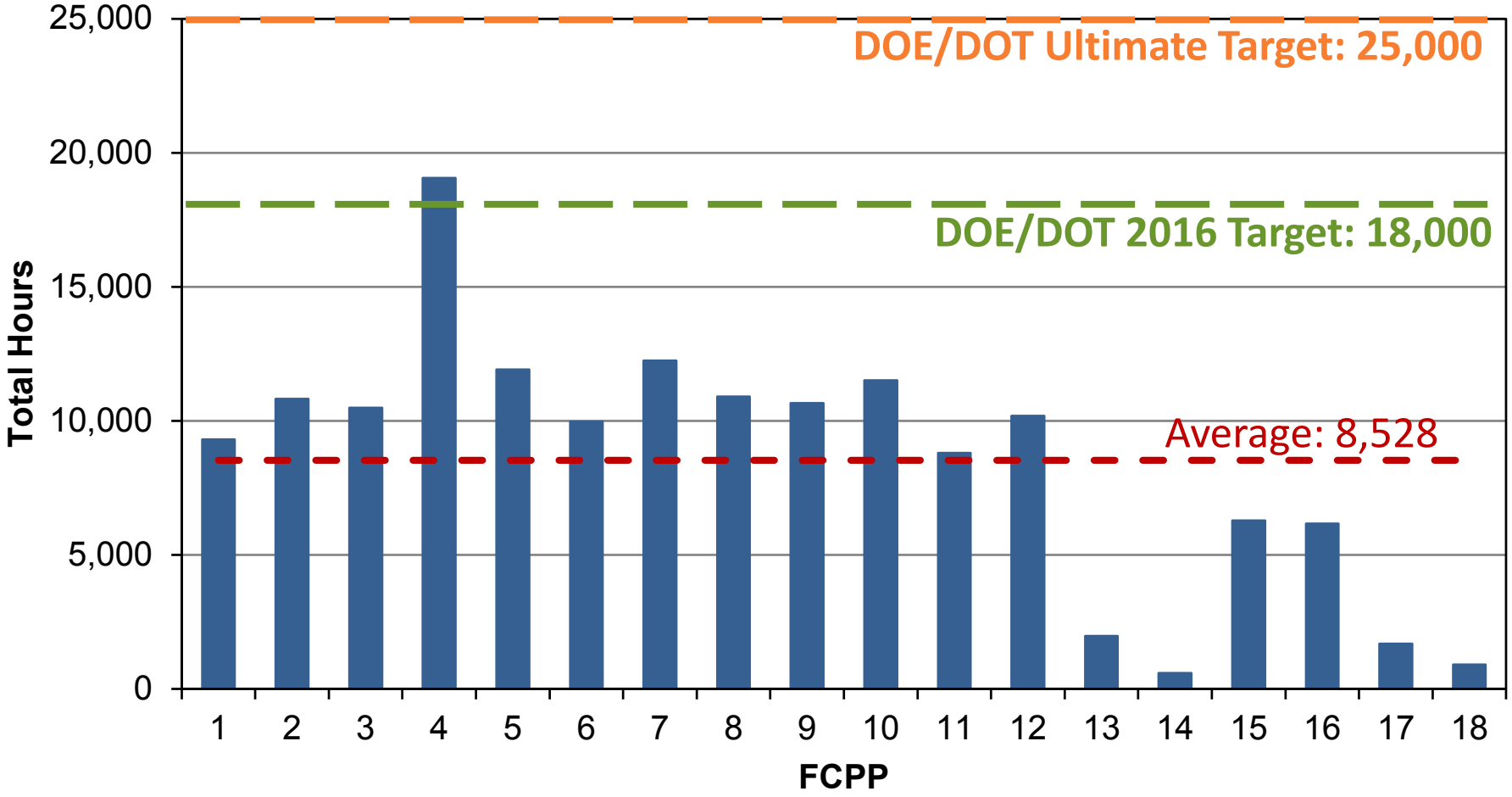
SL AFCB

OEM = original equipment manufacturer
ACT ZEBA = AC Transit Zero Emission Bay Area
SL AFCB = SunLine American Fuel Cell Bus
FC = fuel cell

# Accomplishments : Progress Toward Targets

## Top Fuel Cell Powerplant exceeds 19,000 Hours

Top FCPP > 19,000 hours, surpassing DOE/DOT target; 67% of FCPPs over 8,000 hours

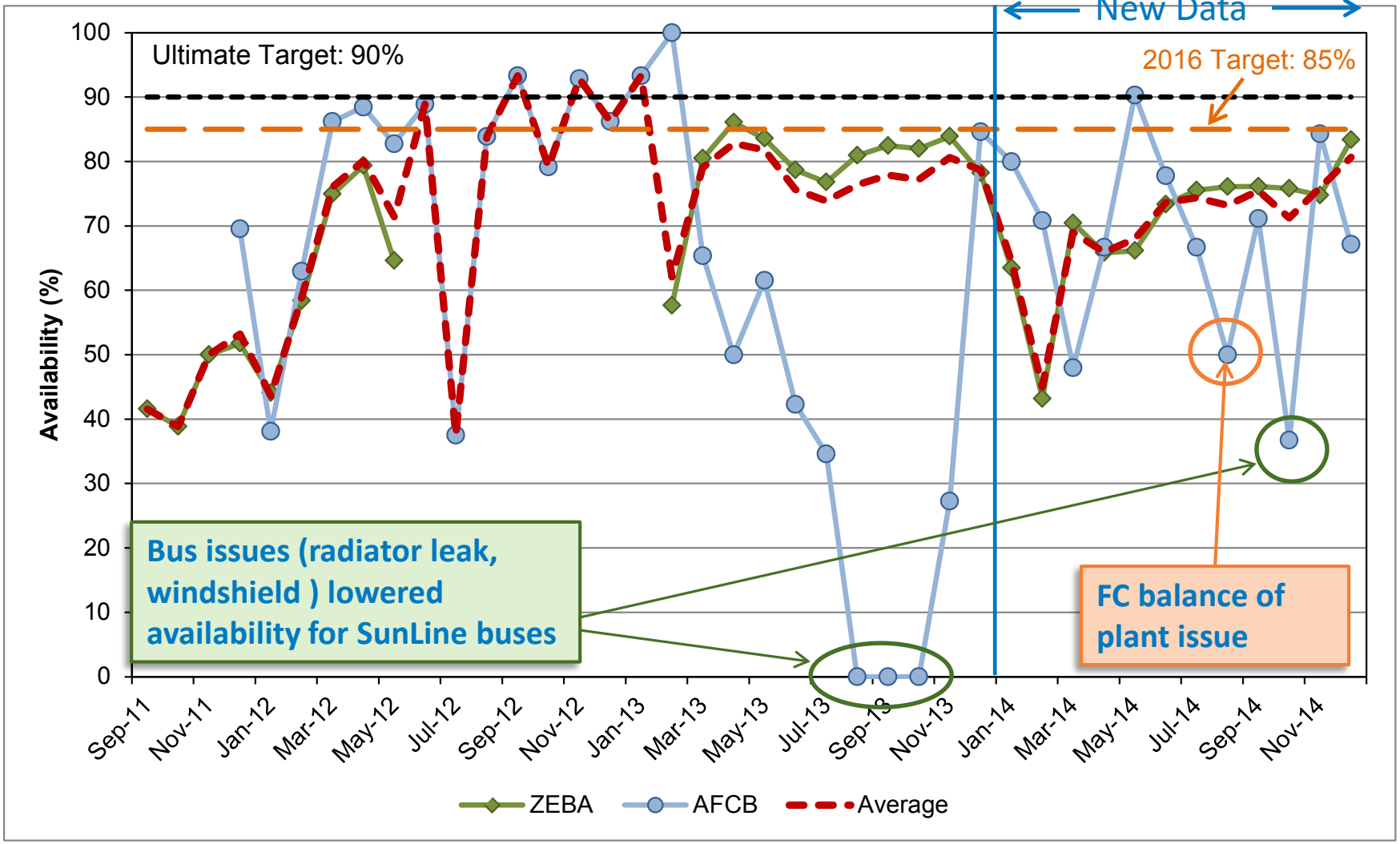



**Total hours accumulated on each FC powerplant (FCPP) as of 3/31/15**

# Accomplishments : Progress Toward Targets

# Average Bus Availability improves to 70%

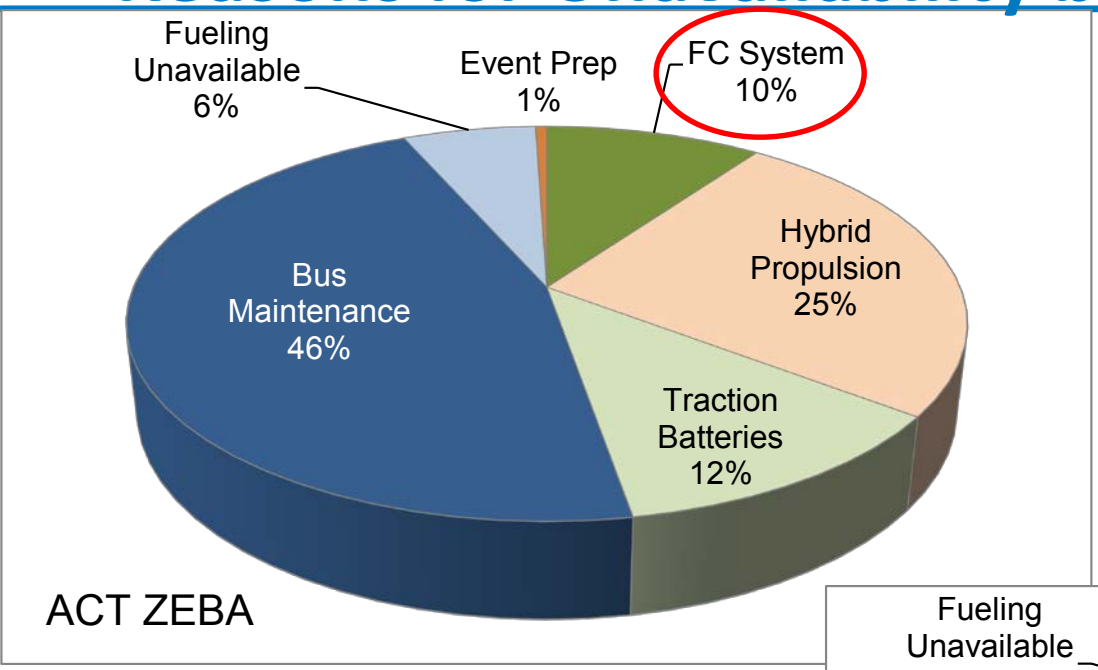
## Monthly bus availability




Availability = planned operation days compared to actual operation days

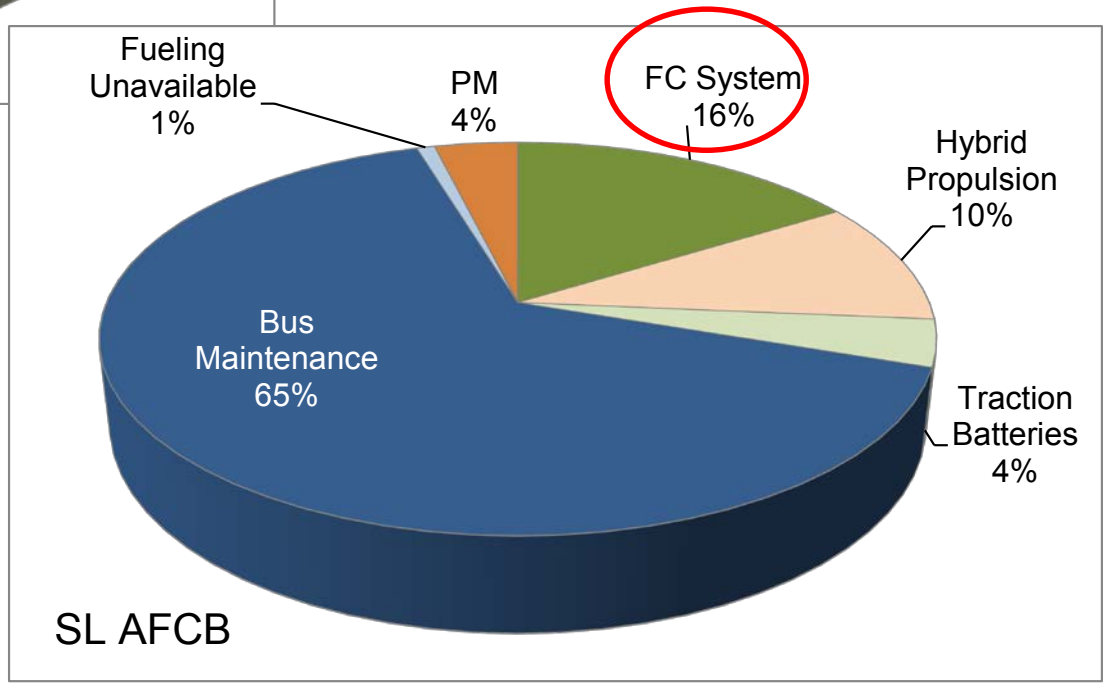
# Accomplishments : Progress Toward Targets

# Reasons for Unavailability by Site

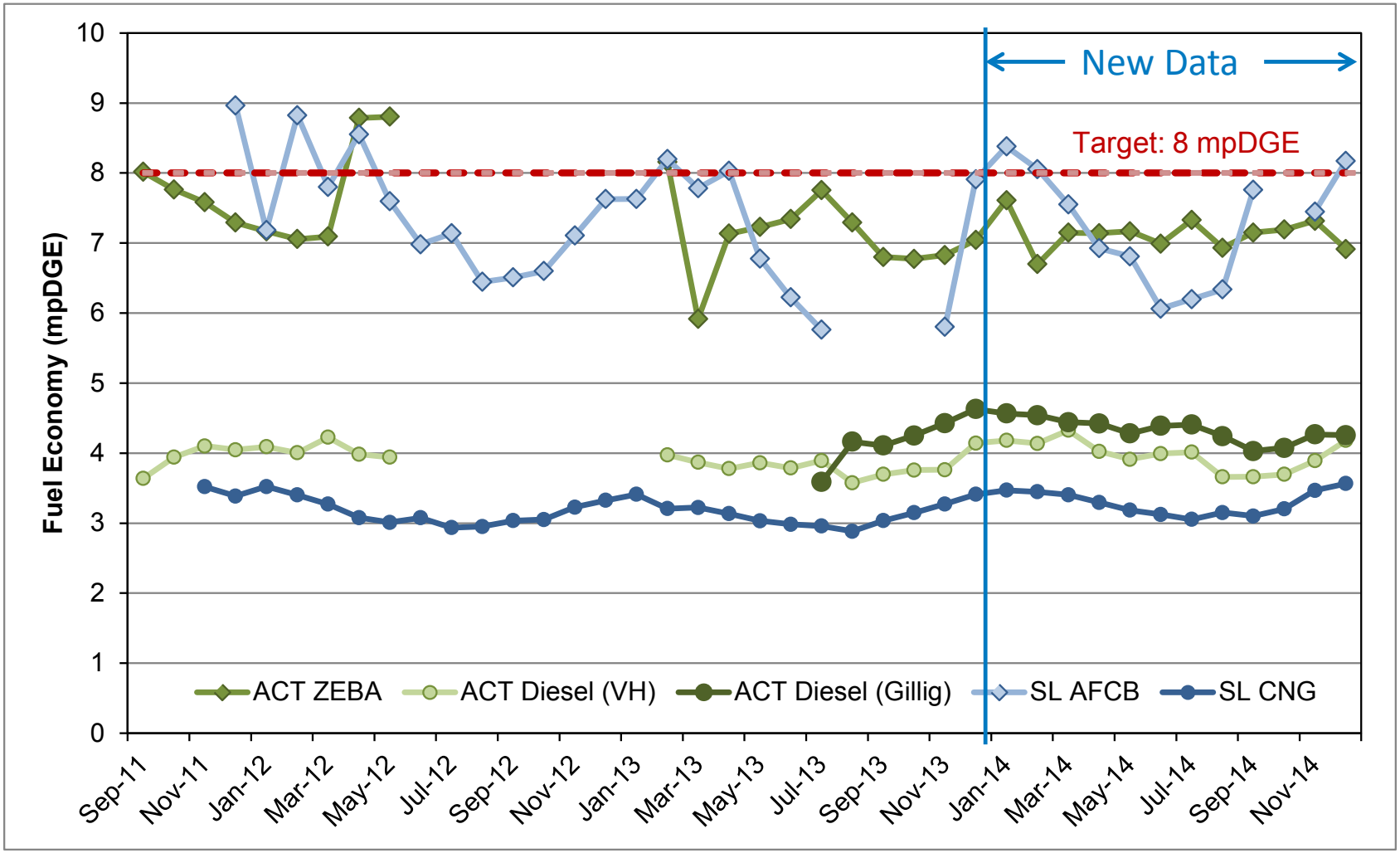



| ACT ZEBA | Number | % |
|---|---|---|
| FC System | 286 | 10 |
| Hybrid Propulsion | 733 | 25 |
| Traction Batteries | 344 | 12 |
| Bus Maintenance | 1,329 | 46 |
| Fueling Unavailable | 176 | 6 |
| Event Prep | 15 | 1 |
| Total days | 2,883 | 100 |

| SL AFCB | Number | % |
|---|---|---|
| Fuel Cell System | 59 | 16 |
| Hybrid Propulsion | 37 | 10 |
| Traction Batteries | 14 | 4 |
| Bus Maintenance | 237 | 65 |
| Fueling Unavailable | 3 | 1 |
| Preventative Maint. | 14 | 4 |
| Total days | 364 | 100 |



# Monthly Fuel Economy Compared to Baseline




Average

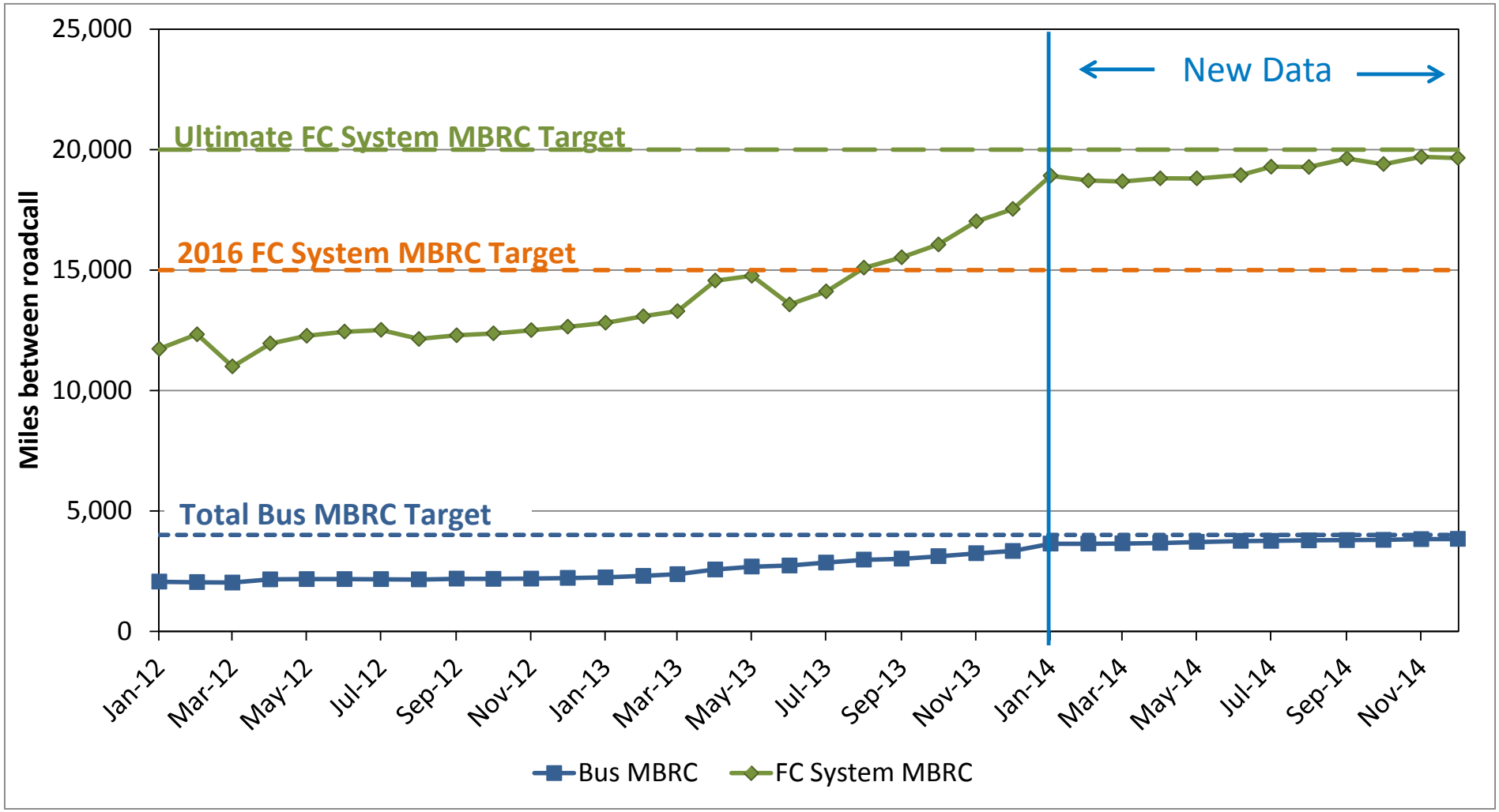
FCEB: 7.26

Diesel: 4.29

CNG: 3.43

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

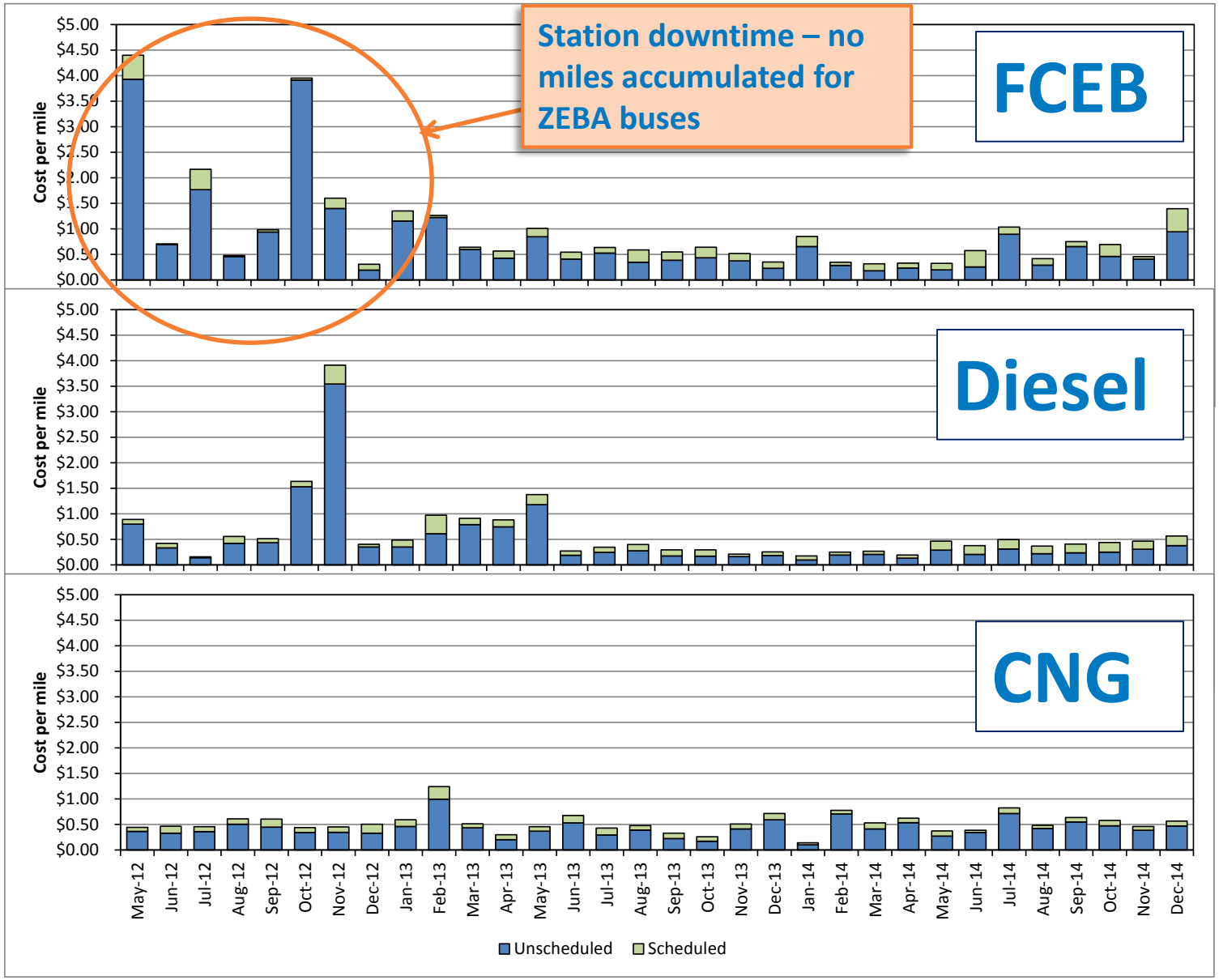
# Reliability: Miles Between Roadcall (MBRC)




**FC System MBRC surpasses 2016 target, approaching ultimate target**

# Accomplishments : Progress Toward Targets

## Scheduled and Unscheduled Maintenance Costs per Mile




Monthly high and low

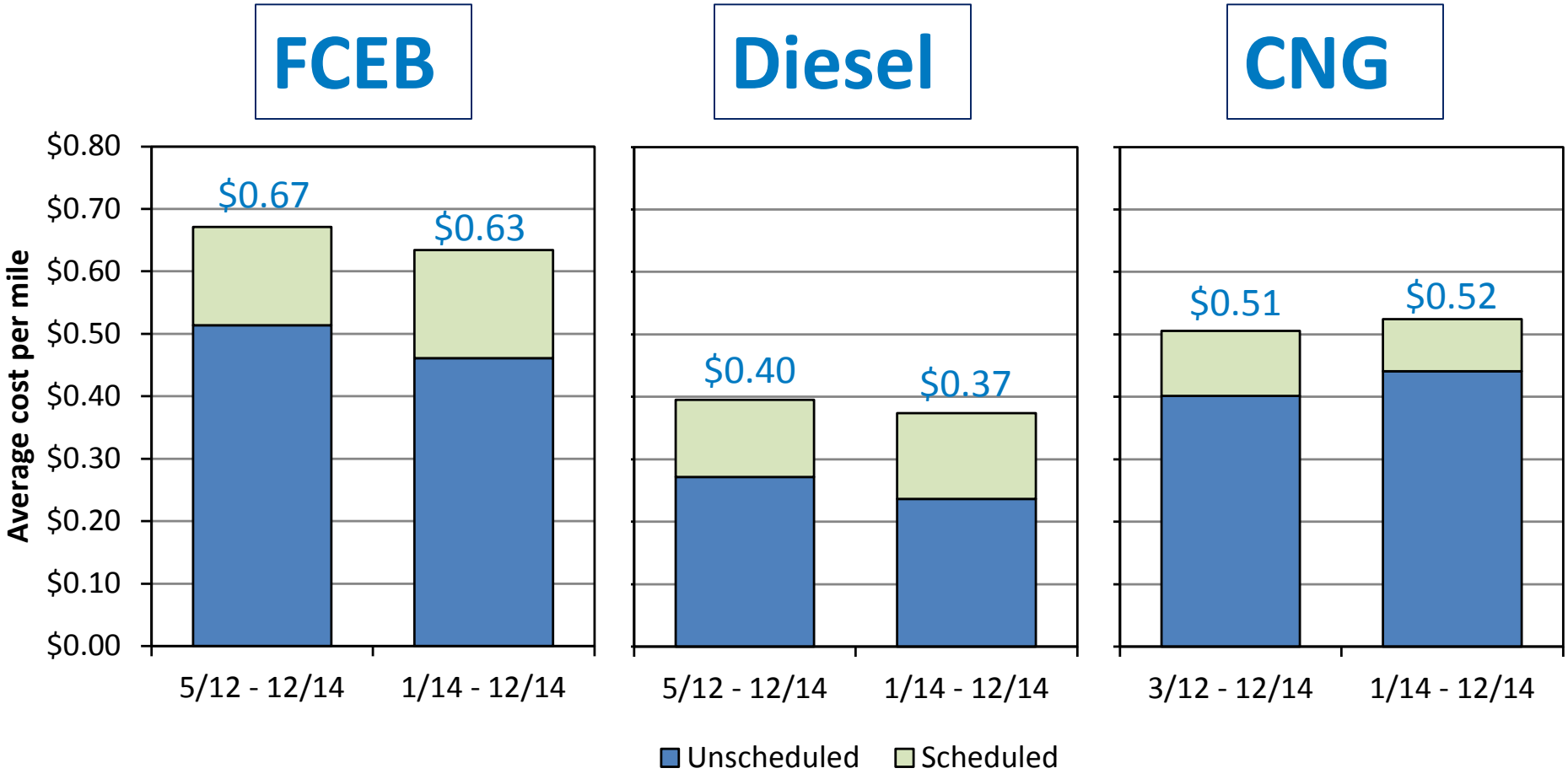
$4.40
$0.31

$3.91
$0.16

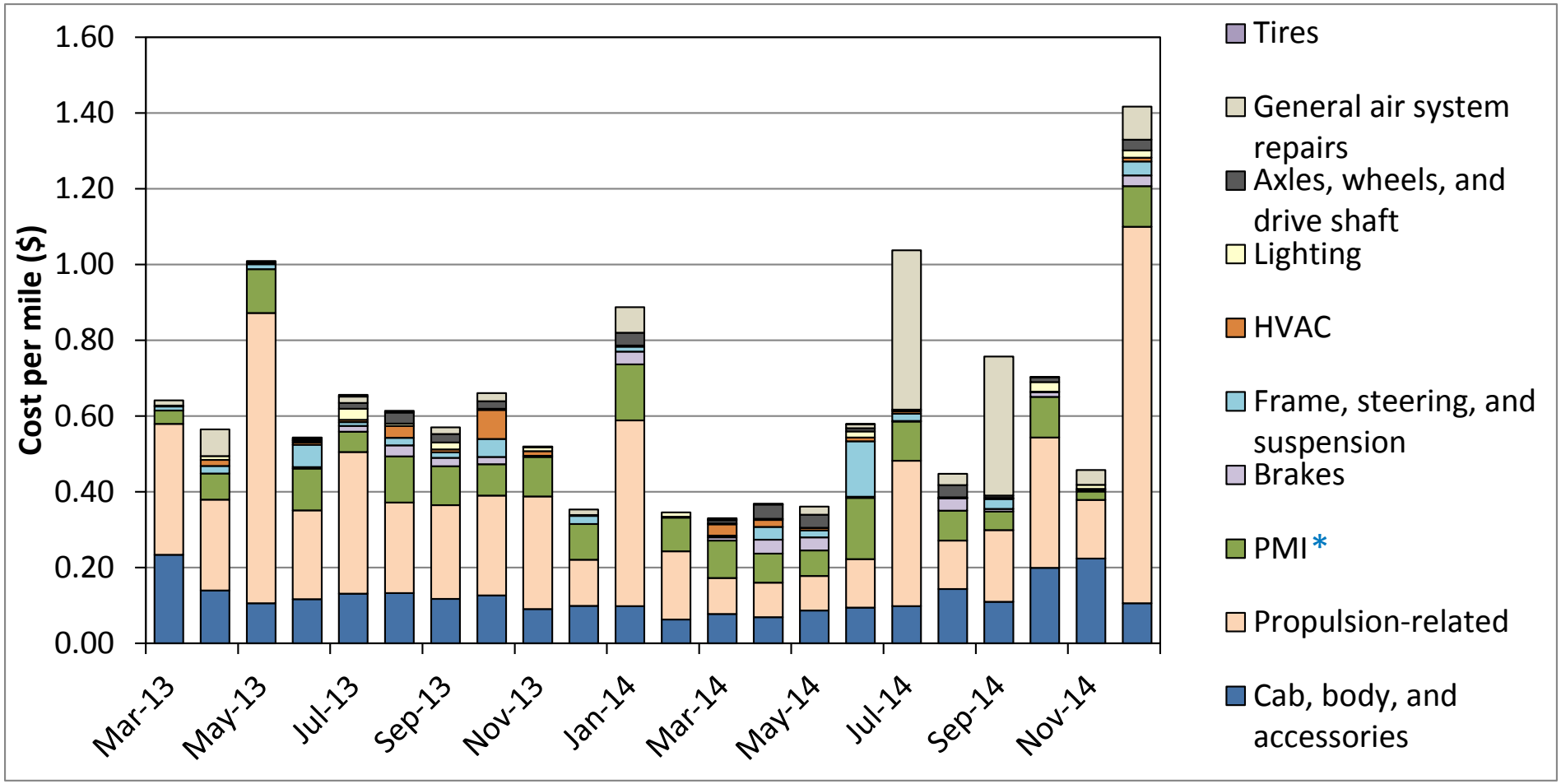
$1.24
$0.14

# Accomplishments : Progress Toward Targets

## Scheduled and Unscheduled Maintenance Costs per Mile



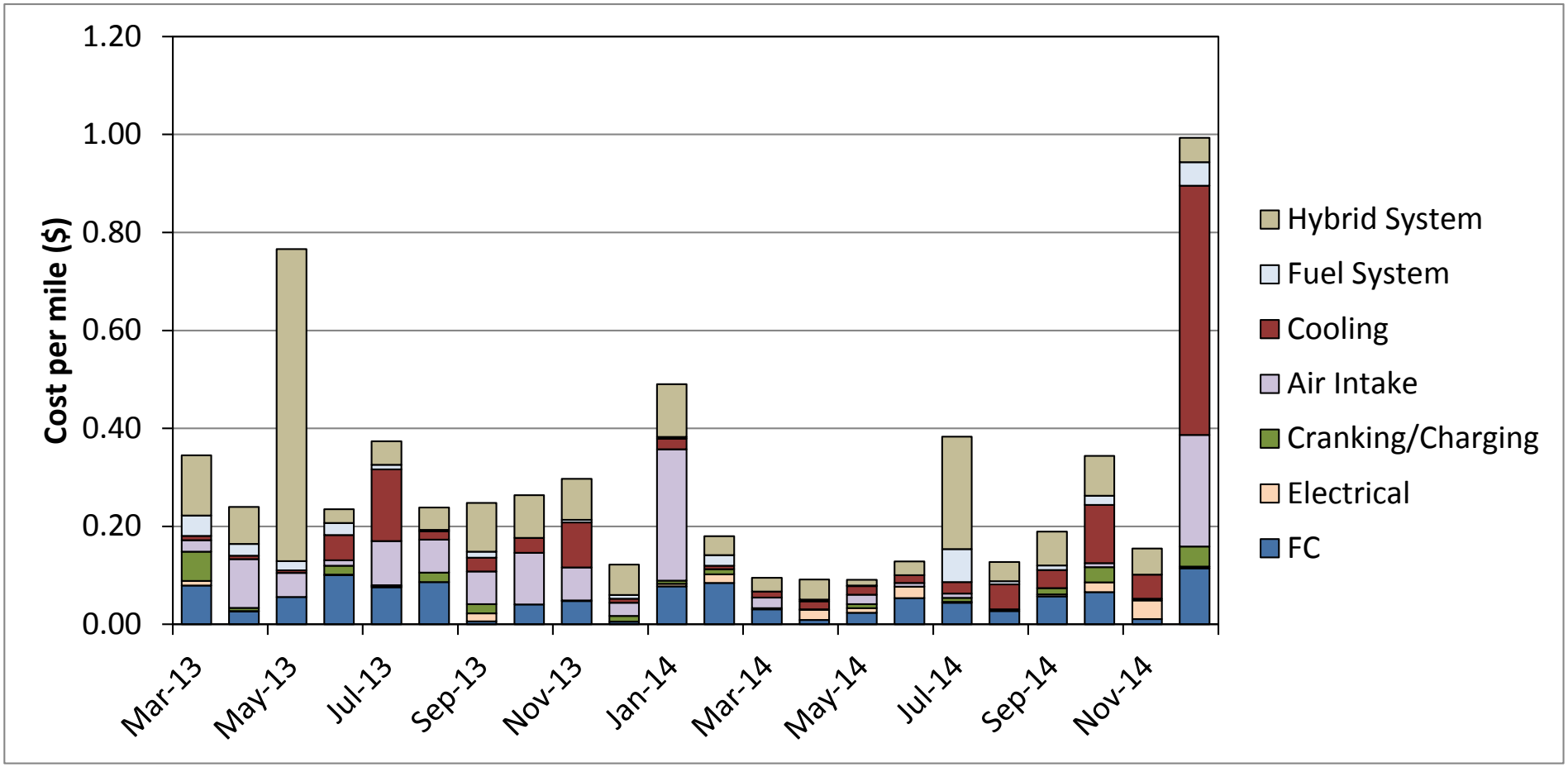
# Maintenance Cost per Mile by System




**Propulsion system costs make up 46.9% of total maintenance costs followed by Cab, body, and accessories at 19.6%**

*PMI – Preventative Maintenance Inspection

# Propulsion System Cost per Mile by Sub-System




**FC System costs are only 8.3% of total maintenance costs**
**Costs are high for some components:**
**Inverter replacement for 1 bus in May 2013**
**Coolant system issues with 2 buses in December 2014**

# Accomplishments and Progress:
# Responses to Previous Year Reviewers' Comments

- **Please highlight which systems had the least and greatest maintenance costs.**
  - Maintenance costs by system are included in the presentation. (Slide 14-15)
- **Would be useful to know if MBRC is prescribed by the manufacturer and if they are being overly conservative**
  - The MBRC targets were developed with industry input (primarily transit agencies) and are based on standard diesel technology. Actual MBRC varies by agency and depends on the diligence of maintenance practices at a depot. (i.e. maintaining scheduled PMs)
- **Would add information from other countries to gauge how close to commercialization this technology may be.**
  - We participate in International Fuel Cell Bus Workshops to share data with demonstrations outside the United States. Any detailed analysis/comparisons would require access to data (with similar metrics) from international projects which is currently not available and out of scope of this project.
- **NREL should continue to work with different configurations of FCEBs**
  - NREL is now collecting data on battery-dominant FCEBs, but does not have enough data to present results yet.
  - NREL is focused on manufacturer teams that intend to commercialize a product.

# Collaborations

- **Transit agencies provide data on buses, fleet experience, and training, and review reports**
  - California: AC Transit, Golden Gate Transit, Santa Clara VTA, SamTrans, SunLine, UC Irvine
  - Alabama: Birmingham-Jefferson County Transit Authority
  - Texas: Capital Metro, Austin
  - Massachusetts: Massachusetts Bay Transportation Authority
- **Manufacturers provide some data on buses and review reports**
  - Bus OEMs: Proterra, Van Hool, New Flyer, ElDorado National
  - FC OEMs: Ballard, Hydrogenics, Nuvera, US Hybrid
  - Hybrid system OEMs: BAE Systems, Van Hool, US Hybrid
- **Other organizations share information and analysis results**
  - National: California Air Resources Board, Northeast Advanced Vehicle Consortium, Center for Transportation and the Environment, CALSTART
  - International: Various organizations from Germany, Brazil, Canada, 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**
- **Develop robust supply chain for components and parts**
- **Increase learning curve for maintenance staff—training and tools**
- **Reduce cost, both capital and operating**

# Proposed Future Work

**Fuel Cell Electric Bus Evaluations for DOE and FTA**

| Demonstration | State | City | # Buses | 2014 3 | 2014 4 | 2015 1 | 2015 2 | 2015 3 | 2015 4 | 2016 1 | 2016 2 | 2016 3 | 2016 4 | 2017 1 | 2017 2 | 2017 3 | 2017 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ZEBA Demonstration * | CA | Oakland | 12 | AC Transit | | | | | | | | | | | | | |
| American Fuel Cell Bus (AFCB) * | CA | Thousand Palms | 1 | SunLine | | | | | | | | | | | | | |
| | NY | Ithaca | 1 | | | | | | TCAT | | | | | | | | |
| | OH | Canton, Cleveland | 2 | | | | | | | SARTA/GCRTA | | | | | | | |
| | CA | Irvine | 1 | | | | UCI | | | | | | | | | | |
| AFCB (TIGGER) | MI | Flint | 1 | | | | | Flint MTA | | | | | | | | | |
| | CA | Thousand Palms | 3 | SunLine | | | | | | | | | | | | | |
| Birmingham FCEB * | AL | Birmingham | 1 | BJCTA | | | | | | | | | | | | | |
| Massachusetts AFCB * | MA | Boston | 1 | | | | MBTA | | | | | | | | | | |
| Advanced Composite FCEB * | TX | Austin | 1 | | | Capital Metro | | | | | | | | | | | |
| | DC | Washington | | | | | | | | DCDOT | | | | | | | |
| Next-gen Compound Bus * | CA | San Francisco | 1 | | | | | | SFMTA | | | | | | | | |
| Battery Dominant AFCB * | CA | Thousand Palms | 1 | | | | | | | SunLine | | | | | | | |
| AFCB (LoNo) | CA | Thousand Palms | 5 | | | | | | | | | SunLine | | | | | |
| | OH | Canton | 5 | | | | | | | | | SARTA | | | | | |

Jun 2015

* National Fuel Cell Bus Program project

National Fuel Cell Bus Program

Color coded by Design Strategy:

- Fuel cell dominant hybrid electric
- Battery dominant hybrid electric
- Diesel hybrid with fuel cell primarily for accessories

# Proposed Future Work

- **Remainder of FY 2015**
  - Complete following data analyses/reports:
    - AC Transit, ZEBA Demo Report, Apr 2015
    - SunLine AFCB Report, May 2015
    - Birmingham FCEB Report, August 2015
    - 2015 Annual Status Report, Sep 2015
  - Begin data collection on FCEBs in Boston, Ithaca, University of California Irvine
- **FY 2016**
  - Kick off new FCEB evaluations as buses go into service
  - Complete Individual Site reports as scheduled
  - Complete annual crosscutting analysis across sites

# Technology Transfer Activities

**Project provides non-biased evaluation of technology developed by industry**

- **Project documents performance results and lessons learned to aid market in understanding needs for full commercialization**
  - Manufacturers
  - Transit agencies
  - Policy making organizations
  - Funding organizations
- **No technology (hardware/software) is developed through this project**

# 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 –19,000 | 18,000 | 25,000 |
| **Bus availability** | % | 70 | 85 | 90 |
| **Roadcall frequency[2] (Bus/fuel cell system)** | Miles between roadcall | 4,256 / 18,896 | 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 | 0.67 | 0.75 | 0.40 |
| **Fuel economy** | Miles per diesel gallon equivalent | 7.26 | 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: average for current designs