Overview

Timeline
• Project started in FY03
• End date: 10/2013*

Budget
• Pre-FY 2012 funding
  – DOE share: $2.277 M (9 yr)
• FY 2012: $300K
• Planned FY 2013: $300K
• Additional funding from DOT/Federal Transit Admin.

Tech. Val. Barriers
A. Lack of current fuel cell vehicle (bus) performance and durability data
C. Lack of current H₂ 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

*Project continuation and direction determined annually by DOE.
Relevance: Objectives

- 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

<table>
<thead>
<tr>
<th>Current Targets*</th>
<th>Units</th>
<th>2012 Status</th>
<th>2016 Target</th>
<th>Ultimate Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus lifetime</td>
<td>Years / miles</td>
<td>5/100,000</td>
<td>12/500,000</td>
<td>12/500,000</td>
</tr>
<tr>
<td>Powerplant lifetime</td>
<td>Hours</td>
<td>12,000</td>
<td>18,000</td>
<td>25,000</td>
</tr>
<tr>
<td>Bus availability</td>
<td>%</td>
<td>60</td>
<td>85</td>
<td>90</td>
</tr>
<tr>
<td>Roadcall frequency (Bus/fuel cell system)</td>
<td>Miles between road call</td>
<td>2,500/10,000</td>
<td>3,500/15,000</td>
<td>4,000/20,000</td>
</tr>
<tr>
<td>Operation time</td>
<td>Hours per day/ days per week</td>
<td>19/7</td>
<td>20/7</td>
<td>20/7</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>$/mile</td>
<td>1.20</td>
<td>0.75</td>
<td>0.40</td>
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<tr>
<td>Fuel economy</td>
<td>Miles per diesel gallon equivalent</td>
<td>7</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

Evaluation 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
U.S. FCEB Numbers Show Upward Trend

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

21 active FCEBs at the end of 2012; Estimated 28 by the end of 2013; Slight drop in 2014 as several prototype demonstrations end.
Accomplishments: Progress Toward Targets

NREL Assesses Technology Readiness Levels

Manufacturer teams for FCEBs currently operating in the United States

<table>
<thead>
<tr>
<th>Bus OEM</th>
<th>Length (ft)</th>
<th>Fuel Cell System</th>
<th>Hybrid System</th>
<th>Design Strategy</th>
<th>Energy Storage</th>
<th>TRL Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van Hool</td>
<td>40</td>
<td>ClearEdge Power</td>
<td>Siemens ELFA integrated by Van Hool</td>
<td>Fuel cell dominant</td>
<td>Lithium-based batteries</td>
<td>7</td>
</tr>
<tr>
<td>New Flyer</td>
<td>40</td>
<td>Ballard</td>
<td>Siemens ELFA integrated by Bluways</td>
<td>Fuel cell dominant</td>
<td>Lithium-based batteries</td>
<td>7</td>
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<tr>
<td>ElDorado</td>
<td>40</td>
<td>Ballard</td>
<td>BAE Systems</td>
<td>Fuel cell dominant</td>
<td>Lithium-based batteries</td>
<td>6</td>
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<tr>
<td>Proterra</td>
<td>35</td>
<td>Hydrogenics</td>
<td>Proterra integration</td>
<td>Battery dominant</td>
<td>Lithium-based batteries</td>
<td>6</td>
</tr>
<tr>
<td>Daimler (Orion)</td>
<td>40</td>
<td>Hydrogenics</td>
<td>BAE Systems</td>
<td>Diesel hybrid w/ FC</td>
<td>Lithium-based batteries</td>
<td>6 - 7</td>
</tr>
<tr>
<td>Ebus</td>
<td>22</td>
<td>Ballard</td>
<td>Ebus integration</td>
<td>Battery dominant</td>
<td>Nickel cadmium</td>
<td>6</td>
</tr>
</tbody>
</table>

Data included in Presentation

Commercialization Process

Technology Readiness Level

NATIONAL RENEWABLE ENERGY LABORATORY
Data summary includes three types of fuel cell dominant, FCEBs at three transit sites:

- **AC Transit, Oakland, CA**
  - 40-foot Van Hool buses with ClearEdge Power* FC (ZEBA)

- **CTTRANSIT, Hartford, CT**
  - 40-foot Van Hool buses with ClearEdge Power FC (Nutmeg)

- **SunLine, Thousand Palms, CA**
  - 40-foot New Flyer bus with Ballard FC and Bluways hybrid system (AT)
  - 40-foot ElDorado bus with Ballard FC and BAE Systems Hybrid drive (AFCB)

*Formerly UTC Power
Accomplishments: Progress Toward Targets
Top Fuel Cell Powerplant exceeds 12,000 Hours

Total hours accumulated on each FC powerplant (FCPP) as of 1/31/13

Fuel Cell Stack Hours of FCEBs

- ACT 4
- ACT 5
- ACT 6
- ACT 7
- ACT 8
- ACT 9
- ACT 10
- ACT 11
- ACT 12
- ACT 13
- ACT 14
- ACT 15
- ACT 16
- Nutmeg 1
- Nutmeg 2
- Nutmeg 3
- Nutmeg 4
- SL AT
- SL AFCB

Total Hours = 66,278

- 5,087 hours
- 9,949 hours
- 12,096 hours
- 7,667 hours
Accomplishments: Progress Toward Targets
More than 53,000 kg Hydrogen Dispensed
Accomplishments: Progress Toward Targets

Average Bus Availability at 57%; Highest at 85%

Monthly bus availability

Availability = planned operation days compared to actual operation days

Target: 90%
Accomplishments: Progress Toward Targets

Reasons for Unavailability

Unavailability primarily due to bus related issues—Air conditioning, doors, accidents, bus preventative maintenance

Availability = planned operation days compared to actual operation days
Accomplishments: Progress Toward Targets

Newest FCEB Bus Introduced Achieves 85% Availability

1st generation bus developed under FTA NFCBP: American Fuel Cell Bus

- BAE Systems hybrid drive, Ballard fuel cell, ElDorado National 40-foot bus
- Average availability: 85%
- Monthly miles: 3,445
- Fuel economy: 7.3 mpdge
- MBRC*: Bus 3,445; Propulsion system 6,316; FC System 12,632

*MBRC = miles between roadcall
Accomplishments: Progress Toward Targets

Average FCPP Availability Reaches 95%

Monthly FCPP availability

Target: 90%

Availability = planned operation days compared to actual operation days
Accomplishments: Progress Toward Targets

FC System MBRC* Increased to 17,558 miles (56% increase)

MBRC – 12 month rolling average

FC System MBRC 56% improvement from previous AMR

*MBRC = miles between roadcall
Accomplishments: Progress Toward Targets

Average Monthly Mileage Approaching 2,000

Monthly miles compared to conventional bus baseline

- Average monthly miles: 1,981
- Buses have operated as much as 20 hours in a day, 7 days per week
Accomplishments: Progress Toward Targets
FCEB Fuel Economy up to 2x over Baseline

New FC bus designs have twice the fuel economy as diesel buses
Accomplishments: Lessons Learned
ZEBA Fleet Successfully Back In Service after 9 months

- **Start-up of buses**
  - Re-wet procedure for fuel cell
  - Inspection of bus and components
  - Test drive

- **Driver training**
  - Refresher for drivers previously trained
  - Training for new drivers

- **Service start in Feb 2013**
  - Agency reports that the start-up process went extremely well
  - Buses were placed into service as soon as the start-up was completed and sufficient drivers were trained
  - Issues were minor – 24 V batteries all needed to be changed
  - No FC or traction battery issues so far
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
  - 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, DesignLine, EVAmerica
  - FC OEMs: Ballard, Hydrogenics, ClearEdge 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

<table>
<thead>
<tr>
<th>Demonstration</th>
<th>State</th>
<th># Buses</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
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<tbody>
<tr>
<td>Advanced Technology FCEB</td>
<td>CA</td>
<td>1</td>
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<tr>
<td>Nutmeg Hybrid FCEB *</td>
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<tr>
<td>MI</td>
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<tr>
<td>OH</td>
<td></td>
<td>1</td>
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<tr>
<td>ZEBA Demonstration</td>
<td>CA</td>
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<td>American Fuel Cell Bus (AFCB) *</td>
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<tr>
<td>AFCB (TIGGER)</td>
<td>CA</td>
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<tr>
<td>CT AFCB</td>
<td>CT</td>
<td>1</td>
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<td>Burbank FCEB</td>
<td>CA</td>
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<td>Hydrogen Hybrid FCEB *</td>
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<td>Compound Bus 2010 *</td>
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<td>Advanced Generation FCEB *</td>
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</tr>
</tbody>
</table>

* National Fuel Cell Bus Program project

**Color coded by Design Strategy:**
- Fuel cell dominant hybrid electric
- Battery dominant hybrid electric
- Diesel hybrid with fuel cell primarily for for accessories

**May 2013**
Future Work

• **Remainder of FY 2013**
  - Complete following data analyses/reports:
    - SunLine AFCB Report, Apr 2013
    - AC Transit, ZEBA Demo Report, Aug 2013
    - City of Burbank FCEB Report, Sept 2013
    - 2013 Annual Status Report, Sep 2013

• **FY 2014**
  - 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:

<table>
<thead>
<tr>
<th></th>
<th>Units</th>
<th>2013 Status</th>
<th>2016 Target</th>
<th>Ultimate Target</th>
</tr>
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<tbody>
<tr>
<td>Bus lifetime</td>
<td>Years / miles</td>
<td>5/100,000</td>
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<td>12/500,000</td>
</tr>
<tr>
<td>Powerplant lifetime</td>
<td>Hours</td>
<td>1,000 – 12,000</td>
<td>18,000</td>
<td>25,000</td>
</tr>
<tr>
<td>Bus availability</td>
<td>%</td>
<td>53 – 84</td>
<td>85</td>
<td>90</td>
</tr>
<tr>
<td>Roadcall frequency</td>
<td>Miles between</td>
<td>2,000 – 3,500 /</td>
<td>3,500/15,000</td>
<td>4,000/20,000</td>
</tr>
<tr>
<td></td>
<td>road call</td>
<td>7,000 – 20,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation time</td>
<td>Hours per day/</td>
<td>19/7</td>
<td>20/7</td>
<td>20/7</td>
</tr>
<tr>
<td></td>
<td>days per week</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>$/mile</td>
<td>0.39 – 1.30</td>
<td>0.75</td>
<td>0.40</td>
</tr>
<tr>
<td>Fuel economy</td>
<td>Miles per diesel</td>
<td>6 – 7.5</td>
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<td>8</td>
</tr>
<tr>
<td></td>
<td>gallon equivalent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>miles</td>
<td>220 – 325</td>
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</table>