Fuel Cell Electric Buses – Transitioning to Zero Emissions

Renewable Power to Clean Fuels Symposium
NW Natural Gas – Portland
May 20, 2019
About CTE

• **Mission**: To advance clean, sustainable, innovative transportation and energy technologies

• **501(3)(c) non-profit** engineering and planning firm

• **Portfolio - >$500 million**
  – Research, demonstration, deployment
  – **86 Active Projects** Totaling over **$300 million**

• Focused on **Zero-Emission** Technologies

• **National Presence**
  Atlanta, Berkeley, Los Angeles, St. Paul
47 CTE Members

Leadership Circle Members

[Logos of various companies and organizations]

Members

[Logos of various companies and organizations]
Managing The Transition to ZEBs

Prototype Development & Demonstration
Support technology providers by finding funding for and managing technology research, development, and demonstration programs

Smart Deployment
Support early adopters by providing the best technical solutions for initial deployments

Fleet Transition
Help fleet operators plan for full electrification

Our program growth closely follows the industry as it evolves

2000

2010

2018
Project Activity

Active Projects by Program Area

<table>
<thead>
<tr>
<th>Active Projects*</th>
<th>Vehicles</th>
<th>Emissions Reduced (tons CO2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>56</td>
<td>457</td>
<td>355,936</td>
</tr>
<tr>
<td>24</td>
<td>103</td>
<td>**</td>
</tr>
<tr>
<td>6</td>
<td>3,666</td>
<td>4,347,614</td>
</tr>
</tbody>
</table>

Our Projects Fight Climate Change!
Zero-Emission Projects

ZEB Transition Planning Projects
ZEB Smart Deployment Projects
Class 8 Fuel Cell Truck

• **Specifications**
  – 85 kW Fuel Cell
  – 100 kWh Battery
  – 420 kW (560 HP) Motor
  – 30 kg Hydrogen Storage
  – Plug-in Capable

• **Performance**
  – 80,000 lbs GVWR
  – 150-Mile Range
  – 65 mph Top Speed
  – Power: Maintains 30 MPH on 6% Grade
  – Torque: Enough to Start on 20% Grade
  – Port of Los Angeles – June 2018

https://www.todaystruck.com/focus-kenworth-zero-emissions-cargo-transport/
UPS Class 6 Fuel Cell Step-Van

15 2007 Trucks Retrofitted with Fuel Cells
  – 33 kW Fuel Cell
  – 49 kWh Battery
  – 9.8 kg Hydrogen Storage
  – 125-Mile Range

4 New UPS Truck
Fuel Cell Top Loader

Electric Top Loader with Wireless Charging and 90 kW Fuel Cell Range Extender

Approximate Size and Weight of ETL

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Weight/Measurement*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight without Load</td>
<td>181,000 lbs.</td>
</tr>
<tr>
<td>Front Axle Loading with Load</td>
<td>230,000 lbs.</td>
</tr>
<tr>
<td>Overall Length</td>
<td>35 feet</td>
</tr>
<tr>
<td>Overall Width Over Drive Tires</td>
<td>16 feet</td>
</tr>
</tbody>
</table>

*Based on Hyster-Yale Diesel H1150HD-CH, 6-high Top Loader
H$_2$ Station Development

• Largest Fuel Retailer in the World

• Developing Light- and Heavy-Duty Fueling Stations

• One 1,000 kg/day Truck Fueling Station with 100% Renewable Hydrogen (Port of Long Beach)

• Two 1,000 kg/day Truck Fueling Stations Port of LA and Ontario Airport
ZEB Awards & Sales
U.S. Fuel Cell Electric Buses

Fuel Cell Transit Buses in the United States

- **Illinois**: 2
  - Planned: 2 Buses
    - Champaign-Urbana
- **Michigan**: 2
  - Current: 2 Buses
    - Flint
- **Massachusetts**: 1
  - Current: 1 Bus
    - Boston
- **Ohio**: 12
  - Current: 6 Buses
    - Canton, Columbus
  - Planned: 6 Buses
    - Canton

**California**: 54

- Current: 25 Buses
  - San Francisco Bay Area (13), Thousand Palms (10), Santa Ana (1), Irvine (1).
- Planned: 29 Buses
  - Oakland (11), Santa Ana (10), Thousand Palms (8).

Source: DOE and NREL
Worldwide Acceptance

FUEL CELL BUSES WORLDWIDE

Over 10 million miles of proven service worldwide; 3 million miles at AC Transit and over 1 million at SunLine Transit.
CARB Innovative Clean Transit Regulation

- **Full transition** to zero-emission buses by **2040**
- **2023**, 25% of the total number of new bus purchases in each calendar year must be zero-emission buses
- **2026**, 50% of the total number of new bus purchases in each calendar year must be zero-emission buses
- **2029**, 100% new bus purchases must be zero-emission buses
- Purchased new buses **delivered within two years** from the initial date of a Notice to Proceed
- **Rollout Plans** by large transit agencies (100 or more buses) by **July 1, 2020**
CTE Fuel Cell Electric Bus Projects

- AC Transit Expanded Service (13 Buses)
- OCTA Demonstration (1 ElDorado Bus)
- CUMTD Articulated Buses (2 Buses)
- AC Transit ZEB Study/ZEB Corridor (BEB/FCEB)
- San Diego ZEB Study (BEB/FCEB)
- LA Metro ZEB Study
- Spokane Transit and Shasta Regional Transportation ZEB Studies
FCEBCC and Next Steps

• Fuel Cell Electric Bus Commercialization Consortium (FCEBCC)
  o $45 million
  o 20 Buses
  o Two Stations
  o Facility Upgrades

• Next Step
  100-Bus Initiative
ZEB OEMs

- NEW FLYER OF AMERICA
- GreenPower Bus
- Proterra
- BYD
- VanHool
- NovaBus
- Gillig
- Eldorado National - California
- Motor Coach Industries
- Complete Coach Works
Operational Efficiency

THE KISS PRINCIPLE

KEEP IT SIMPLE, STUPID
FCEB Advantages

300–350 miles

Proven range

Significant reduction in vehicle weight (carry more passengers)

Rapid refueling speeds (6 to 10 minutes)

1:1 replacement of conventional vehicles
Durability: >32,000 Hours/2.8 Million Miles

<table>
<thead>
<tr>
<th>Bus</th>
<th>FUEL CELL HOURS</th>
<th>Vehicle Miles Life to Date</th>
</tr>
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<tbody>
<tr>
<td>FC4</td>
<td>25,520</td>
<td>241,032</td>
</tr>
<tr>
<td>FC5</td>
<td>25,170</td>
<td>238,295</td>
</tr>
<tr>
<td>FC6</td>
<td>25,661</td>
<td>208,174</td>
</tr>
<tr>
<td>FC7</td>
<td>32,134</td>
<td>223,414</td>
</tr>
<tr>
<td>FC8</td>
<td>24,354</td>
<td>173,971</td>
</tr>
<tr>
<td>FC9</td>
<td>25,178</td>
<td>217,514</td>
</tr>
<tr>
<td>FC10</td>
<td>27,767</td>
<td>251,463</td>
</tr>
<tr>
<td>FC11</td>
<td>28,322</td>
<td>248,532</td>
</tr>
<tr>
<td>FC12</td>
<td>4,122</td>
<td>235,333</td>
</tr>
<tr>
<td>FC13</td>
<td>17,494</td>
<td>170,300</td>
</tr>
<tr>
<td>FC14</td>
<td>28,911</td>
<td>242,462</td>
</tr>
<tr>
<td>FC15</td>
<td>23,901</td>
<td>200,389</td>
</tr>
<tr>
<td>FC16</td>
<td>28,543</td>
<td>225,175</td>
</tr>
<tr>
<td>TOTALS</td>
<td>317,077</td>
<td>2,875,874</td>
</tr>
<tr>
<td>Average</td>
<td>26,388</td>
<td>221,221</td>
</tr>
</tbody>
</table>

NOTE: FC7 and FC12 fuel cells were manufactured by UTC in 2003, 14 years ago with an expected EOL of 5,000 hours. The other 11 fuel cells were manufactured by UTC in 2008 and 2009.

* LDV Station converted to Messer commercial station as of September 2018. AC Transit stopped recording fuel dispensed as of May 2018.

1) Fuel Cell on FC7 retired on 5/14/18 with 32,134 hours.
2) Fuel Cell on FC12 retired 11/21/18 with 25,969 hrs.
## New Flyer XHE40 Performance

### AC Transit 54 Line Service

<table>
<thead>
<tr>
<th>Date</th>
<th>Run</th>
<th>Time Out</th>
<th>Time In</th>
<th>Odometer</th>
<th>Run Time</th>
<th>Miles Run</th>
<th>Total Fuel (kg)*</th>
<th>Miles per kg</th>
<th>Miles per DGE (1.13)</th>
<th>Projected Range Based on 36 kg of Useable H2</th>
<th>Approximate Battery-Only Range</th>
<th>Total Projected Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/10/19</td>
<td>54-0002</td>
<td>7:04 AM</td>
<td>10:42 PM</td>
<td>1697.4</td>
<td></td>
<td>15:46 hrs</td>
<td>198.9</td>
<td>23.8</td>
<td>8.36</td>
<td>300.9</td>
<td>20</td>
<td>320.9</td>
</tr>
<tr>
<td>4/11/19</td>
<td>54-0002</td>
<td>7:04 AM</td>
<td>10:42 PM</td>
<td>1896.3</td>
<td></td>
<td>15:46 hrs</td>
<td>202</td>
<td>22.4</td>
<td>9.02</td>
<td>324.6</td>
<td>20</td>
<td>344.6</td>
</tr>
<tr>
<td>4/12/19</td>
<td>54-2002</td>
<td>7:04 AM</td>
<td>10:42 PM</td>
<td>2098.3</td>
<td></td>
<td>15:46 hrs</td>
<td>202</td>
<td>22.4</td>
<td>9.02</td>
<td>324.6</td>
<td>20</td>
<td>344.6</td>
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<tr>
<td>4/13/19</td>
<td>54-2002</td>
<td>7:04 AM</td>
<td>10:42 PM</td>
<td>2298.5</td>
<td></td>
<td>15:46 hrs</td>
<td>200.2</td>
<td>20.9</td>
<td>9.58</td>
<td>344.8</td>
<td>20</td>
<td>364.8</td>
</tr>
</tbody>
</table>

Footnotes

* Three different drivers. Variation in fuel consumption based on how different drivers drive and ambient temperature.

### AC Transit

- Load = 17 Average; 34 Max
- 300 to 344 miles on H2
- 20 miles on battery

### OCTA

- Seated Load (40)
- 330 miles on H₂
- 20 miles on battery
100-Bus Initiative

NEED
Transit agencies will need both Battery-Electric and Fuel Cell Electric Buses (FCEBs) to meet the California Air Resources Board goal of 100% zero emission buses by 2040.

OBJECTIVE
Drive down the capital cost of North American FCEBs to the point where they are commercially viable for transit properties seeking zero-emission solutions — $850,000/bus.

ACTION
Four or more transit agencies in northern and southern California, purchasing up to 25 FCEBs each, and installing hydrogen fueling stations and facility upgrades where needed.

Driving Price Down

Source: New Flyer Industries
H₂ Infrastructure Challenges

**PARSE**

**P**rice and delivery of H₂ on parity with conventional fuels. Also equipment maintenance cost reduction.

**A**rea of fueling footprint to refuel 50, 100, or 200 buses.

**R**enewables for hydrogen production; **Resiliency** - Natural Disasters; Also **Redundancy** to ensure near 100% service reliability.

**S**peed of refueling in the normal 8- to 10-hour night window; Also **Scalability** for future expansion.

**E**ntry-Level Startup and Equity (CapEX) needed to build at an affordable price, utilizing baseline components for future scale up.
The Challenge for 100% ZEB Deployment

Infrastructure and Scalability

Fleet Size

Effort and Cost

FCEB

BEB
Fueling Station Evolution

40’ x 60’ (50-Bus Capacity)

Parallel Fueling

12- to 15-Bus Capacity; Expand to 30 Buses

Underground LH2 Tanks and Pumps
International ZEB Conference in San Francisco
September 26 & 27, 2019

WWW.ZEBConference.com

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