Zero Emission Bus Deployment Best Practices

EV Roadmap 10
Portland, Oregon
June 20, 2017
About CTE

- Mission: To advance clean, sustainable, innovative transportation and energy technologies
- 501(3)(c) non-profit
- Membership-based organization
- Portfolio - $400+ million
  - Research, development, demonstration, and deployment
  - Alternative fuel and advanced vehicle technologies
- National presence
  - Atlanta, Berkeley, Los Angeles, St. Paul
- Project sponsorship
  - Federal Transit Administration
  - Departments of Energy, Defense, Interior, NASA, and EPA
Current Projects

Over $217 million active project portfolio
CTE Zero Emission Bus Projects

More than 140 ZEB’s with over 30 Transit Agencies!
CTE ZEB Services

• Grant Applications
• Fleet Transition Strategy and Planning (ZEB Roadmap)
• Market Surveys
• Requirements Analysis and Technology Assessment
• Technical Specifications and Procurement Evaluation
• Production Oversight, Buy America Audits, and Quality/Resident Inspections
• Deployment Project Management and Technical Assistance
• Benefits Analysis and Key Performance Indicator Reporting
Transit as a Proving Ground

- Bounded Duty Cycle
- Operating Hours
- Spare Ratio

- Professional Staff
- Centrally Fueled
- Cost to End User
Battery Electric Bus Deployments are Complicated

- Fuel costs can change hour to hour
- Bus performance can change drastically route to route
- Bus performance can change season to season
- Battery capacity changes over time
- Auxiliary loads have a much larger effect
- Drivers can make a huge difference on bus efficiency/range

*In most cases, deployment decisions cannot be made intuitively.*
Modeling Conditions: Batteries
# Route Modeling

<table>
<thead>
<tr>
<th>Route Description</th>
<th>OEM Brochure</th>
<th>CTE Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route A (summer, no passengers)</td>
<td>1.7 – 2.0</td>
<td>1.72</td>
</tr>
<tr>
<td>Route A (summer, avg. passengers)</td>
<td>1.7 – 2.0</td>
<td>2.11</td>
</tr>
<tr>
<td>Route A (summer, max passengers)</td>
<td>1.7 – 2.0</td>
<td>2.46</td>
</tr>
<tr>
<td>Route A (winter, no passengers)</td>
<td>1.7 – 2.0</td>
<td>1.91</td>
</tr>
<tr>
<td>Route A (winter, avg. passengers)</td>
<td>1.7 – 2.0</td>
<td>2.64</td>
</tr>
<tr>
<td>Route A (winter, max passengers)</td>
<td>1.7 – 2.0</td>
<td>3.10</td>
</tr>
<tr>
<td>Route B (fall, no passengers)</td>
<td>1.7 – 2.0</td>
<td>1.68</td>
</tr>
<tr>
<td>Route B (fall, avg. passengers)</td>
<td>1.7 – 2.0</td>
<td>2.06</td>
</tr>
<tr>
<td>Route B (fall, max passengers)</td>
<td>1.7 – 2.0</td>
<td>2.20</td>
</tr>
</tbody>
</table>

Worst Route, Worst Case: 6.17 kWh/mile
Evaluating Technology for Your Service

Technical Options
- Battery or Fuel Cell?
- Depot or On-route charging?
- Conductive or Inductive charging?
- Number/location of infrastructure?

Service Attributes
- Route scheduling
- Route density
- Terrain
- Climate
- Utility Rates

Find Best Fit Through Analysis & Modeling
Key Elements for ZEB Evaluation

• Determine which technology is right for your routes
  – Bus Modeling & Route Simulation
• Estimate Operating Costs
  – Rate Modeling & Fuel Cost Analysis
• Establish the Business Case
  – Life Cycle Cost Analysis
  – Risk Assessment
Bus Modeling and Route Simulation

Service Requirement

- Route Logistics
  - Length
  - Duration
  - Schedule
  - Frequency
- Duty Cycle
  - Speed
  - Accel./Decel
  - Grades
  - Passenger Load
  - Auxiliary Load
  - Deadhead
- Operating Environment
  - Traffic Congestion
  - Climate
ZEB Modeling Methodology

- Autonomie™ Simulation Software (developed by Argonne National Lab.)
- GUI utilizing MATLAB & Simulink software package
- Quick assembly of complex ZEB specifications:
  - Vehicle weight
  - Battery chemistry and energy capacity
  - Motor power output and energy requirements
  - Rolling resistance
Typical Route Model Results

- route data
- bus specifications
- operation plan

Model

- expected energy use
- average bus efficiency
- charging requirements

**Graphs:**
- Bus Speed
- Layover
- Battery SOC
- Charge Rate
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Rate Modeling & Fuel Cost Analysis

• Battery Electric Charging
  – Energy Consumption estimate from Route Modeling
  – Charger Specifications
  – Charging Profile
    • Charge Rate
    • Duration
    • Time of Day, Day of Week, Season
  – Utility Rate Schedules
• Hydrogen Fueling
  – Fuel Source and cost
  – O&M
Business Case Analysis

**Life Cycle Cost Analysis**

- Initial Capital Costs
  - Buses
  - Fueling and Power Infrastructure
  - Upgrades to Service Bays
- Construction Costs
  - Site Prep, Civil, Mechanical, Electrical, Installation, etc.
- Annual Fuel Cost from Rate Modeling
- Major Component Replacement
  - Batteries
  - Fuel Cells

**Risk Assessment**

- Power Outage/Grid Disruption
- Vendor Viability/Support
Key Performance indicators

Track & Analyze Performance - Take Corrective Action - Realize Benefits - Repeat