All-Electric Airport Shuttle Buses

The WAVE of the Future

May 21, 2015
30, 35, 40 and 60 foot electric buses are commercially available

- At least 7 OEM vendors offer new electric buses
- Existing bus fleet can be remanufactured to new condition with electric power train
- All-electric buses are suitable for essentially all airport shuttle services

Most commonly expressed reservations
- Electric buses do not have suitable range for 24/7 airport operations
- Electric buses are too expensive
Electric Bus Performance | Clean & Comfortable

Electric buses are comfortable for passengers and drivers

- Quite and smooth operation
- Comfortable ride
- Clean and odor-free
- No soot stains on bus or buildings
- Inductive charging is totally autonomous: no cables or wires, no external driver responsibilities
Electric buses have no emissions

- Zero carbon dioxide ($\text{CO}_2$), nitrogen oxide ($\text{NO}_x$), sulfur dioxide ($\text{SO}_2$), and particulate matter (PM) emissions
- Excellent contribution to sustainability goals
- Electric buses are one of the few opportunities airports have for eliminating a substantial component of their emissions inventory
Electric Bus Performance | Low Maintenance

Electric buses have low maintenance costs

- No internal combustion engine: no high temperature stress, oil changes, oil leaks, or oil filter disposal
- Fewer moving parts: less vibration, less to break
- No cooling system: no antifreeze leaks, hose ruptures, or radiator failures
- No transmission: no overhauls, fluid changes, or fluid leaks
- Regenerative breaking: less wear and tear, fewer overhauls
# All-Electric v. CNG Vehicles | A Comparison

<table>
<thead>
<tr>
<th>Factors</th>
<th>Compressed Natural Gas &quot;CNG&quot;</th>
<th>Battery-Powered Electric</th>
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</thead>
<tbody>
<tr>
<td>Tailpipe Emissions</td>
<td>Better than diesel</td>
<td>None</td>
</tr>
<tr>
<td>Total Emissions</td>
<td>Somewhat lower than diesel*</td>
<td>Much lower than CNG</td>
</tr>
<tr>
<td>Range</td>
<td>Can handle long routes</td>
<td>Not optimal for long routes</td>
</tr>
<tr>
<td>Fueling Costs</td>
<td>1/3 less than diesel</td>
<td>1/2 less than CNG</td>
</tr>
<tr>
<td>Noise</td>
<td>Internal combustion engine</td>
<td>Quiet</td>
</tr>
<tr>
<td>Ride</td>
<td>Transmission</td>
<td>No transmission</td>
</tr>
<tr>
<td>Maintenance</td>
<td>1/5 more than diesel</td>
<td>1/3 less than diesel</td>
</tr>
</tbody>
</table>

*But no life-cycle climate change benefits.*
Electric Bus Performance | Operating Costs

Operating costs are lower than other options

- Overall maintenance about one third less than diesel buses
- Fuel costs are at least 65% lower
  - Electricity $0.28/mile (based on $0.08/kWh)
  - Diesel $0.88/mile (based on $3.78/gal)
  - CNG $0.90/mile (based on $2.49/gal)
- Battery replacement required in year 6-7
  - 12 year battery warranty now offered.
- Inductive charging extends battery life by ensuring operation within the 20-90% charge range
Electric Buses | Initial Capital Costs

Initial cost of electric buses are higher than conventional buses

- Electric buses are more expensive than diesel or CNG buses; somewhat higher than hybrid diesel-electric buses
- Electric bus prices are coming down as the market expands
- Repowered, remanufactured bus with a new bus warranty and VIN is comparable to a new diesel bus

Grants and federal funding are available for all-electric airport shuttle buses

- FAA's Zero Electric Vehicle (ZEV) program
- FAA's VALE program
Bus Range | Limited Duty Cycles

Current all-electric buses have limited range

Electric Bus Range for Five Manufacturers
Range Extension | Suitable for Airports

WAVE Extended bus range

Electric Bus Range with WAVE Technology
WAVE’s WPT | The Technology

Output Power to Vehicle

Magnetic Field

Receiver Electronics

Transmitter Electronics

Current

Input Power from Grid
An Elegant Solution | Minimal Infrastructure

WPT Charge Pad

WPT Enclosure Box
Electric Buses | Total Cost of Ownership

Electric bus lifecycle costs are lower than conventional buses

• Environmental benefits are in addition to the illustrated TOC

Total Cost of Ownership for Alternative Bus Technologies
$10+M in awarded contracts

Variable route lengths

Multiple vehicle platforms

High profile locations
Utah Transit Authority | Commercial Deployment

- 50 kW charging system
- Feeder shuttle for light rail “TRAX” system
- Full Service launch October 29, 2014

Bus charging over snow (Dec 13, 2013)

Charging system primary pad

Rемanufactured all-electric ZEPS bus from CCW
Monterey Salinas Transit | Waterfront Route

- All-electric trolley replaces diesel trolley
- 4.5 mile route - 50 kW charging system
- Operational Q2 2015
McAllen Metro | A Green Route in Texas

- Route will provide all electric service to the airport, hospital and shopping center
- 50 kW charging system for two Complete Coach Works “ZEPS” buses
- Awarded the grant after a competitive bidding process
Antelope Valley | A New BYD Partnership

- Home of BYD’s manufacturing plant
- Long duty cycles
- 50 kW charging system
- Commitment to fully electrification
  - Initial order of 2 buses & 2 chargers
- Operational Q3 2015
County Connection | A New Gillig Partnership

- WAVE will partner with Gillig, BAE Systems, and XALT Batteries to provide County Connection with four all-electric 30 foot trolley buses for service in Walnut Creek.

- County Connection Board approved WAVE as their wireless charging provider in March 2015, after an extensive review of commercially available en route charging solutions.
WAVE is working on inductively charged GSE

- Expand electric GSE applications; eliminate emissions
- Smaller batteries; quick charging
- Simplify workflow; interchangeable infrastructure used by all vehicles
- Practical for new terminal or concourse
WAVE Services

• Full service, turnkey solution, including electric vehicle(s) and WAVE charging system
• Service level agreements
• System maintenance

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