UM Fleet Electrification: PCCN Subgroup study: Blue Buses

-- Electrification of transit buses (status, data, trends)
-- Financial models and incentives (Federal, State and local).
-- Preliminary results for electrifying our buses
Sept 27, 2019
Electric Buses in Cities
Driving Towards Cleaner Air and Lower CO₂
March 29, 2018

Capital and Infrastructure Costs for BEBs

Analysis depicting the estimated lifetime costs of electric buses with associated health benefits (right) and without (left).

Figure 8: Different e-buses financing approaches

- **Pay upfront for all**
  - Still the most popular option today.
  - Most often covered by grants from national governments or from the EU.
  - Occasionally covered through operating budgets or with debt.

- **Lower upfront costs**
  - Pay for the bus, lease the battery.

- **Joining forces / joint purchasing**
  - Joint purchases by two or more bus operators to increase buying power and lower upfront costs. Example: San Francisco Municipal Railway and King County make a joint order.

- **Lease (operating lease or capital lease)**
  - Operational or capital lease with different time frames and ending conditions. Offers flexibility to the fleet operator in case of technological shift. Can be cheaper than debt financing. Example: Still relatively new, first used by a bus operator in Warsaw and the New York MTA. Provides options to its customers as well. 
  - Probably not an option for municipal public transport fleet operations as it is a short-term solution, but private coach operators could find it useful.
  - Examples: None yet.

- **Rent all**
  - Allows operators to avoid large initial capital investments.

Source: Bloomberg New Energy Finance

Table 3: Types of charging infrastructure used with e-buses

<table>
<thead>
<tr>
<th>Traditional plug-in charging</th>
<th>Pantograph charging</th>
<th>Inductive charging (wireless)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Traditional plug-in charging icon" /></td>
<td><img src="image" alt="Pantograph charging icon" /></td>
<td><img src="image" alt="Inductive charging icon" /></td>
</tr>
</tbody>
</table>

Figure 9: Different types of electric bus charging configuration for selected European e-bus projects

Source: Bloomberg New Energy Finance. Note: this is not an exhaustive list of e-bus projects. Data is from the ZeBUS (Zero Emission Urban Bus System) project, an EU-funded project focusing on the challenges of the electrification of bus systems with an objective to collect statistically valid data from the deployment of e-bus systems and then analyzing the data to deliver a "lessons learned" guidelines. Terminal refers to the last stop on buses' route, where layover happens.
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Electrification Study for BluEBus:

Outline
• Bus Schedule
• Battery Capacity and Charging Rate Selection
• Vehicle and Charging Model
• Charging Infrastructure
• Cost Analysis
• CO₂ Emission Reduction Analysis

Summary and Ongoing Effort
1. Financial on a scenario:
   - Depending on diesel fuel cost, payback time is predicted to be 8-12 years
   - VW funds, if awarded, will allow $177k/year savings immediately and an additional new bus to be added to service to reduce the risk
2. Emission:
   - Depending on electricity content, emission reduction is predicted to be 353 tonsCO₂/year

Northwood route (4 buses)

Operation and schedule affect the economics and GHG reductions.
Routes: Preliminary analysis of Northwood Route (ongoing effort)

<table>
<thead>
<tr>
<th>Route</th>
<th>Distance (mile)</th>
<th>Duration (min)</th>
<th>Operating Time (hr)</th>
<th>#Bus</th>
<th>Headway (min)</th>
<th>Max cycle charge time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwood</td>
<td>7.78</td>
<td>36</td>
<td>20.5</td>
<td>4</td>
<td>10</td>
<td>4</td>
</tr>
</tbody>
</table>

Route approximately 20 hrs/day x 17 mi= 340 mi/day
Simulations indicate 2.3 kWh/mi (winter efficiency ~18MPGe)
UMTRI Data: Hybrid = 5.2 MPG in mild spring temps
Ken Keeler Data: Diesel bus 4.16 MPG
Bus cost $420k→$750k (charger + construction cost $75k to $600k)

- 36 min to finish a trip
- A bus approaches the stop every 10 min
- 4 buses are running on the Northwood Route for now
- Therefore, Max. 4 min for opportunity charge

Charging Infrastructure:

- Support
  - Research and NSF Center effort
  - Future AAATA route

Aligned with construction plans at Bonisteel Blvd

Power Conversion Equipment and a Charging Mast (480V Substations)

Potential locations for equipment:
1. Adjacent to Cooley Building
2. In front of PML or Duderstadt
Battery Capacity and Charging Rate Selection

1. Long-ranged bus (660 kWh) and depot charging DCFC (125 kW)
   - 5 buses are needed
   - 5 DCFC charging station
   - Large depth of discharge (DOD)
   - Small C rate

<table>
<thead>
<tr>
<th>Item</th>
<th>Price per each</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric (660kWh)</td>
<td>849,000</td>
<td>5</td>
<td>4,245,000</td>
</tr>
<tr>
<td>Ext. Warranty</td>
<td>112,500</td>
<td>5</td>
<td>562,500</td>
</tr>
<tr>
<td>Depot Charger (125kW)</td>
<td>65,000</td>
<td>5</td>
<td>325,000</td>
</tr>
<tr>
<td>Charger Installation</td>
<td>45,000</td>
<td>5</td>
<td>225,000</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>5,375,000</td>
</tr>
</tbody>
</table>

For five buses, average running time per day:
\[ 20.5\text{hr} \times 60 \left(\frac{\text{min}}{\text{hr}}\right) \times \frac{4}{3} = 984 \text{ min} \]

1. Short-ranged bus (200 kWh) and on route charging xFC (440 kW)
   - 4 buses for a sustainable operation
   - Only 1 xFC is needed
   - Smaller depth of discharge (DOD)
   - Large C rate

<table>
<thead>
<tr>
<th>Item</th>
<th>Price per each</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Fast Charged</td>
<td>749,000</td>
<td>4</td>
<td>2,996,000</td>
</tr>
<tr>
<td>Ext. Warranty</td>
<td>112,500</td>
<td>4</td>
<td>450,000</td>
</tr>
<tr>
<td>EnRoute Charger (500kW)</td>
<td>275,000</td>
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<td>275,000</td>
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<tr>
<td>Charger Installation</td>
<td>250,000</td>
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<td>250,000</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>3,971,000</td>
</tr>
</tbody>
</table>

Cost Analysis with Different Diesel Prices (no incentives)

- Avg price of 2017 fiscal year = 1.8 /gal >> 12 years to payback
- Avg price of 2019 in Michigan is about = 3 /gal >> 8 years to payback
CO₂ Emission Analysis with Different Electricity Source

Electricity generation sources for eBlue Bus

- 472,693 MWh nonrenewable energy was purchased by Umich in 2017, DTE fuel mix (https://newlook.dteenergy.com/wps/wcm/connect/dte-web-home/community-and-news/common/environment/fuel-mix)
- DTE 472,693 MWh nonrenewable and 200,000 MWh renewable Power-Purchase Agreement beginning at 2021 (https://record.umich.edu/articles/u-m-cut-emissions-through-renewable-energy-purchase-dte-energy)
- Solely from Natural Gas power plant (considering the 15 MW new turbine in UM central power plant (https://news.umich.edu/u-m-central-power-plant-expansion-expected-to-reduce-emissions)


Fuel and Maintenance Cost

1. Fuel Saving:
   \[ \text{Diesel Cost} - \text{Electricity Cost} = 62296 \left( \frac{\text{gal}}{\text{year}} \right) \times 1.8 \left( \frac{\text{dollars}}{\text{gal}} \right) - 795073.3 \left( \frac{\text{MWh}}{\text{year}} \right) \times 0.0733 \left( \frac{\text{dollars}}{\text{gal}} \right) = 53853.9 \left( \frac{\text{dollars}}{\text{year}} \right) \]

2. Maintenance Saving:
   \[ 65098.8 \left( \frac{\text{mile}}{\text{each bus \times year}} \right) \times (1.22 - 0.76) \left( \frac{\text{mile}}{\text{dollar}} \right) \times 4 (\text{# bus}) = 119781.8 \left( \frac{\text{dollar}}{\text{year}} \right) \]

Fuel and Main. Saving for four buses per year:
\[ 53853.9 + 119781.8 = 177k \text{ USD} \]

Saving $177k/year
Saving 353 tonsCO₂/year
from 4 buses serving one route