PUBLIC TRANSPORT GOVERNANCE, INTEGRATION, AND PARATRANSIT. CAPACITY BUILDING: LESSONS FROM AFRICA AND LATIN AMERICA

Strategies to accelerate electric mobility

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1. Introduction to Battery Electric Buses (BEB) and Zero Emission Buses (ZEB)
2. Market penetration and geographical imbalance
3. Performance and Cost
4. Barriers and Opportunities for ZEB
5. Flagship projects. ZeEUS and eBRT-2030
1. Introduction

• Urban mobility growth. Individual vs Mass transit

• Buses. High level of service. Accessibility

• Bus systems are still a major source of local emissions and GHG that worsen the air quality, and contribute to the global warming.

• Transition to **Battery Electric Buses (BEB) and Zero Emission Buses (ZEB)** to decarbonize current bus systems

• Wide spectrum of electric technologies on the market.

• Recommendations to BEB/ZEB tenders, deployment, maintenance.
2. BEB market

- Global stock of 10.4 million buses and coaches. Only 2% of the bus fleet was full electric in 2018.
- In 2022, nearly 66,000 electric buses were sold worldwide, representing about 4.5% of all bus sales.
- A total of 27 governments have pledged to achieve 100% ZEV bus and truck sales by 2040 and both the United States and European Union have also proposed stronger emissions standards for heavy-duty vehicles.
2. BEB market around the world

IEA (2022)
Conceptualization of battery electric vehicle

Is the electric service so simple?

“Charging facilities and operational schemes are the cornerstone of the electric bus systems”
3. BEB. Charging schemes

**Battery capacity of a single bus should be tailored for each charging scheme. Lack of flexibility**
### 3. EV Charging Infrastructure

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Gasoline/Diesel</th>
<th>Hydrogen</th>
<th>Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Conventional gasoline or diesel refueling</td>
<td>Hydrogen refueling (similar to natural gas refueling)</td>
<td>“Wired” charging using a plug</td>
</tr>
<tr>
<td>Time needed</td>
<td>5 min</td>
<td>5 min</td>
<td>4-8 hrs (slow) 20-30 min (fast)</td>
</tr>
<tr>
<td>Suitable for which powertrains</td>
<td>ICE, HEV, PHEV, REEV (hydrogen)</td>
<td>FCEV, REEV (hydrogen)</td>
<td>PHEV, BEV suitable for plug-in charging</td>
</tr>
<tr>
<td>Example car</td>
<td>All ICEs</td>
<td>Hyundai ix35 (FCEV)</td>
<td>Renault Zoe (BEV)</td>
</tr>
<tr>
<td>Current availability in Europe</td>
<td>Widely available: ~131,000 stations</td>
<td>Very limited: ~80 stations</td>
<td>Limited availability: &gt;20,000 (slow) &gt;1,000 (fast)</td>
</tr>
</tbody>
</table>

1. Time needed for full refueling or recharge. For fast-charging of battery, time to reach 80% of battery capacity is commonly used.
2. Since induction charging is still in pilot stage, common duration and power level are not yet established; power levels of 22 kW have been achieved.

### 3. BEB. Chemistries

<table>
<thead>
<tr>
<th>Battery type</th>
<th>Nominal voltage (V)</th>
<th>Energy density (Wh/kg)</th>
<th>Volumetric energy density (Wh/L)</th>
<th>Specific power (W/kg)</th>
<th>Life cycle</th>
<th>Self discharge (% per discharge)</th>
<th>Memory effect</th>
<th>Operating temperature (°C)</th>
<th>Production cost (S/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead acid (Pb-acid)</td>
<td>2.0</td>
<td>35</td>
<td>100</td>
<td>180</td>
<td>1000</td>
<td>&lt; 5</td>
<td>No</td>
<td>-15 to +50</td>
<td>60</td>
</tr>
<tr>
<td>Nickel-cadmium (Ni-Cd)</td>
<td>1.2</td>
<td>50-80</td>
<td>300</td>
<td>200</td>
<td>2000</td>
<td>10</td>
<td>Yes</td>
<td>-20 to +50</td>
<td>250-300</td>
</tr>
<tr>
<td>Nickel-metal hydride (Ni-MH)</td>
<td>1.2</td>
<td>70-95</td>
<td>180-220</td>
<td>200-300</td>
<td>&lt; 20</td>
<td>Rarely</td>
<td></td>
<td>-20 to +60</td>
<td>200-250</td>
</tr>
<tr>
<td>ZEBRA</td>
<td>2.6</td>
<td>90-120</td>
<td>160</td>
<td>155</td>
<td>&gt; 1200</td>
<td>&lt; 5</td>
<td>No</td>
<td>+245 to +350</td>
<td>230-345</td>
</tr>
<tr>
<td>Lithium-ion (Li-ion)</td>
<td>3.6</td>
<td>118-250</td>
<td>200-400</td>
<td>200-430</td>
<td>2000</td>
<td>&lt; 5</td>
<td>No</td>
<td>-20 to +60</td>
<td>150</td>
</tr>
<tr>
<td>Lithium-ion polymer (LiPo)</td>
<td>3.7</td>
<td>130-225</td>
<td>200-250</td>
<td>260-450</td>
<td>&gt; 1200</td>
<td>&lt; 5</td>
<td>No</td>
<td>-20 to +60</td>
<td>150</td>
</tr>
<tr>
<td>Lithium-iron phosphate (LiFePO₄)</td>
<td>3.2</td>
<td>120</td>
<td>220</td>
<td>2000-4500</td>
<td>&gt; 2000</td>
<td>&lt; 5</td>
<td>No</td>
<td>-45 to +70</td>
<td>350</td>
</tr>
<tr>
<td>Zinc-air (Zn-air)</td>
<td>1.65</td>
<td>460</td>
<td>1400</td>
<td>80-140</td>
<td>200</td>
<td>&lt; 5</td>
<td>No</td>
<td>-10 to +55</td>
<td>90-120</td>
</tr>
<tr>
<td>Lithium-sulfur (Li-S)</td>
<td>2.5</td>
<td>350-650</td>
<td>350</td>
<td>–</td>
<td>300</td>
<td>8-15</td>
<td>No</td>
<td>-60 to +60</td>
<td>100-150</td>
</tr>
<tr>
<td>Lithium-air (Li-air)</td>
<td>2.9</td>
<td>1300-2000</td>
<td>1520-2000</td>
<td>–</td>
<td>100</td>
<td>&lt; 5</td>
<td>No</td>
<td>-10 to +70</td>
<td>–</td>
</tr>
</tbody>
</table>

![Graph showing performance comparison between different battery chemistries](image-url)

Strategies to accelerate electric mobility
3. BEB. Impact of charging schemes on cost

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Capacity, C (kWh)</th>
<th>Consumption, fc (kWh/km)</th>
<th>Acq. Cost (kEuro/veh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus 12m</td>
<td>100-350</td>
<td>0.9-1.3</td>
<td>Night</td>
</tr>
<tr>
<td>Bus 18m</td>
<td>100-150</td>
<td>1.5-2.0</td>
<td>Opport.</td>
</tr>
<tr>
<td>Bus 18m</td>
<td>550</td>
<td>(prototype)</td>
<td>Night</td>
</tr>
</tbody>
</table>

Where:

\[ C > L \cdot f_c \]

- Opportunity charging /Terminal Charging
  - One charging station at terminal (1-0;0-1)
  - Two charging stations at terminals (1-1; 2-0)
  - Multiple charging stations at terminals (2-2)
  - On-route charging stations

The operational costs incurred by PTOs when deploying BEB are 10% higher than hybrid counterparts.

- Rolling stock needed is equal or bigger than ICE powertrains
- Purchasing cost is higher (maturity)

Note: e:electric  h:hybrid  d: diesel
Panama, 40% of the stock of selected public vehicles are to be EVs by 2030. Ghana’s recently released strategy contains a target that 4%, 16%, and 32% of new sales are to be EVs in 2025, 2030, and 2050, respectively. In addition, countries recently proposing tax-related policies include Angola, Brazil, Ecuador, Pakistan, Trinidad and Tobago, Tunisia, Uzbekistan, and Vietnam.
4. Barriers for Zero Emission V. in Africa and America

Current situation:
- Deficient air quality, low quality fuels, small penetration of Low emission powertrains.
- High ridership of transit services

Governance:
- Lack of Transit Agency or Public Body
- Multiple bus operators, atomized ecosystem
- Depot, Vehicle and battery ownership, ancient fleet

Technology:
- 4 eBus providers
- Energy consumption in warm countries (30% auxiliary consumption)

Economics:
- Service subsidies instead of Fuel subsidies (Ecuador)
- Price of electricity
- Incentives

Infrastructure:
- Electric grid is not prepared
- Redundant transit system
- Renewable energy
- Safety issues
4. Opportunities for Zero Emission Vehicles

- Big cities. Involvement of municipality, regional and national governments to deploy the required charging infrastructure (private / public)
- Conceptualization and development of electric models for midi/mini buses
- Renewable energy generation, hydrogen plants and fuel-cell vehicles

- Innovations driven by American and African countries:
  - Uberization (Quito, 2010): 8,810 licensed taxis (low Q)+4,759 executive taxis (high Q)
  - Shared taxis in routes (Santiago, 2004). Similar to current on-demand bus services
  - Buses of high level of service (Bogotá, Santiago). Right of way, ticketing out of vehicles, etc.
OPTIMOB: A technology-agnostic Decision Support Tool for assisting cities and bus agencies in the deployment of the most suitable electric bus fleet technology

Barcelona

5. Flagship projects (UITP): ZeEUS
Barcelona: Digital twin to perform Control strategies in route H12

BC) No control

0) Slack at holding points
1) Dynamic speed control
2) Traffic light priority

Round trip length: 22.56 km
Number of stops: 66
Number of vehicles: 21
Headway: 7 min

S0. Slacks
S1. Dynamic cruising speed
S2. S0+S1+ traffic light priority
Conclusions

• The majority of BEB routes with low-medium demand will rely on off-shift (overnight).
• e-Articulated buses with overnight charging schemes are still under development. Opportunity charging schemes in crowded and busy routes.
• Ultracapacitors offer a promising solution but they need on-street facilities.
• Lower emissions at the expenses of lowering flexibility and increasing operational cost.
• Bus Garages to service growing demand for heavy-duty electrification will need to be developed, and in many cases may require distribution and transmission grid upgrades (4-8 years....start now).
• Alternative solutions integrate local renewable capacity, combined with smart charging, which can help reduce both infrastructure costs.
• Innovation in mini/midi/standard buses for on-demand transport.