Economic Aspects of Battery Electric Buses

DLR | Institute of Vehicle Concepts

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When will large bus transit fleets be all electric? China clearly sets the pace

- **China**: in part already today!
  - 20 % E-bus share in 2017 - but 70 % in sales (2016)!
  - 99 % of the world BEB fleet is located in China
  - Shenzhen has already transferred its whole 16000 bus fleet to BEB

- **Germany**: 2030 (and following years)
  - Transition from demonstration to commercialisation phase
  - 100 % E-buses by 2030 announced by the biggest cities:
    - Berlin, Hamburg, München, Köln, Frankfurt

- **USA**: 2030-2040
  - Los Angeles: 2030
  - San Francisco: 2035
  - New York: all-electric latest until 2040

→ It will be a mix of battery electric buses (BEB), fuel cell electric buses (FCEB) and trolley electric buses (TEB).
TCO of battery electric buses (BEB)
Analysis of recent e-bus TCO studies

• TE [2018]: Electric buses arrive on time – Marketplace, economic, technology, environmental and policy perspectives for fully electric buses in the EU (Transport& Environment)

• BNEF [2018]: Electric Buses in Cities - Driving Towards Cleaner Air and Lower CO₂ (Bloomberg New Energy Finance)

• Tong [2017]: Life cycle ownership cost and environmental externality of alternative fuel options for transit buses (Carnegie Institution for Science)

• Element Energy [2017]: Fuel cell buses in Europe: Latest developments and commercialization pathway (Element Energy)

• McKinsey [2016]: What’s sparking electric vehicle adoption in the truck industry (McKinsey)

• Roland Berger [2018]: Fuel Cells and Hydrogen for Green Energy in European Cities and Regions (Multi-stakeholder study for FCHJU)
The most recent 2018 BEB TCO studies of Bloomberg New Energy Finance (BNEF), Transport & Environment (TE) and Tong (next slide, 2017) suggest (near) cost parity of BEB and DB — but at different absolute cost levels!

- TCO of overnight charging BEB is lower than TCO of opportunity charging BEB according to BNEF and TE - but higher acc. to Tong (next slide)

- **TE** estimates much higher infrastructure CAPEX than BNEF and Tong
• **Tong [2017]**: If CAPEX are subsidized to a large degree, BEB outperform DB in terms of TCO (e.g. the German federal government funds 80% of CAPEX markup to DB)

• **Element Energy (Ballard) [2017]** stress potential need of additional BEB because of range limitations (and thus, the mark-up of FCEB against BEB and DB decreases)

• Some studies also include external (environmental) costs which shifts the picture towards BEB -> the external cost effect however is not that big on total TCO (ca. 5-10%)
• **Roland Berger [2018]** claims TCO markups today:
  - 80% (FCEB vs. DB)
  - 42% (FCEB vs. BEB)
  - 26% (BEB vs. DB)

  FCEB TCO markups are projected to decrease down to
  - 16% (FCEB vs. DB)
  - 9% (FCEB vs. BEB)
  - 7% (BEB vs. DB)

  → Robust drop of CAPEX and fuel costs required

• **McKinsey [2016]**: TCO parity of BEB/DB will be attained between 2023-2025 (earliest in Europe, then in China, followed by the US)

  This (FCHJU funded) study estimates much higher BEB costs than the other studies

  • 175 cities and industry stakeholders involved
BEB CAPEX

• **Economies of scale** will likely reduce BEB costs in the future
  • Batteries
  • Series bus production

• **High** up-front **battery cost** is still major cost driver (2-2.5 times higher BEB price than DB)
  • Battery prices will decrease in the long term provided there are no significant battery production capacity constraints and critical raw materials are available sufficiently

• Unsubsidized CAPEX cost parity with diesel buses between 2023 and 2030 studies say

• **Prices of buses within China** are generally much **lower than in US and EU**: DB: 94 k$, BEB: 250 k$ (Asian Development Bank [2018]) -> but same cost markup factor between BEB and DB
## Trends of BEB OPEX

<table>
<thead>
<tr>
<th>Energy</th>
<th>Maintenance</th>
<th>Component replacement</th>
<th>Driver</th>
</tr>
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</table>
| • Drivetrain efficiency uptake  
• Advanced HVAC systems like heat pumps | • Electric drivetrains require less maintenance than diesel drivetrains  
Issues:  
• Availability enhancement  
• Decrease of downtimes | • Battery lifetimes will improve through  
• LTO-based battery chemistries  
• cell balancing  
• improved thermal management  
• Longtime goal: no battery exchange during bus lifetime of 12-15 years | • Driver costs form substantial part of TCO – but are usually not included in the studies  
• Today: additional driver demand (service interruptions)  
• If bus operation can be automated (SAE Level 5), driver costs (0.8-1.5 €/km in Germany) can be omitted (at least partly), reducing TCO substantially |
| • Diesel price increase (taxes, also on CO2... ?); regional price and tax levels differ |  |  |  |
| • *Diesel* is non-critical in countries with poor infrastructure - whereas *electricity supply* often is |  |  |  |

*Issues:*

*• Availability enhancement  
• Decrease of downtimes*
Infrastructure

• Charging infrastructure is in absolute terms a big investment position, but becomes less important on a cost per km base

• With large fleets, bigger investments into new substations or even grid upgrades might become necessary

• Back-up solutions in case of blackouts? (hydrogen might be better suitable for multi-day energy storage)
BEB TCO - study comparison

- There is a wide TCO span across and within studies depending on the frame conditions
- Also the single cost blocks and assumptions (infrastructure costs, energy and lifetime in particular) differ widely across studies
- BEB have nearly reached cost parity with DB claim three out of four studies
  - But: additional BEB may be needed due to limited operational flexibility (range)
  - Also: additional risk costs due to availability issues?
- Tong [2017] calculate higher costs both for DB and FCEB
- High BEB TCO in Roland Berger [2018] (financed by FCHJU) attributable to additional knowledge of the FCEB community?
  → More in-depth study-comparison is required to harmonize the study-inherent different frame conditions of the studies (mileage, energy costs,...)
Subsidies / Public Funding

- Subsidies can close the (current) TCO gap – it is a mix of funding sources
- National and supranational funding (usually CAPEX) is often a prerequisite for economic viability
- Current German national funding scheme (80% of BEB CAPEX markup against DB) caused a run on (limited) funds
- Joint procurement will lower BEB prices through scale effects
- China shifts from CAPEX to OPEX subsidies and the cut of diesel fuel subsidies
Generalized economic aspects

• The analyzed BEB TCO studies come to quite different results
• In practice, the case individual BEB TCO will depend on a variety of frame conditions:
  • Line network structure (line lengths, daily mileage, elevation profile)
  • Type and number of required recharging infrastructure
  • Climatic conditions
  • Energy costs (diesel, electricity, sectoral coupling incentives)
  • Labor costs (reserves in case of service interruptions)
  • Bus CAPEX and level of subsidy (or taxation/penalty respectively)
  • Bus lifetime and annual mileage
  • Interest level (what if the central banks increase interests)
  • Risk allowances

→ every case is different – and linked to country, operational and site specific conditions
# Technology development

## The future bus

- How will future e-bus technologies shape the next generation BEB?

<table>
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<tr>
<th>Technology</th>
<th>Features</th>
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<tr>
<td><strong>Battery</strong></td>
<td>- cost decrease&lt;br&gt;- increased cycle stability and energy density</td>
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<tr>
<td><strong>Drivetrain</strong></td>
<td>- gearless PMSM free up space for passengers</td>
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<tr>
<td><strong>Lightweight construction</strong></td>
<td>- lightweight structures can open up mass reserves for larger capacity batteries</td>
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<tr>
<td><strong>Automation</strong></td>
<td>- no drivers cabin required freeing up space for passengers&lt;br&gt;- smaller, flexible units&lt;br&gt;- mobility-as-a-service</td>
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<td><strong>Modular design</strong></td>
<td>- Modular passenger/freight capsules</td>
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proEME - Decision Support Model for Busses

- TCO web tool and mock-up for trucks has been developed as an outcome of the ICVUE project
- Now, DLR develops within the ProEME project a DSM (decision support model) for trucks and a tool is planned also for busses
- We will be happy to cooperate with interested parties
  contact: oezcan.deniz@dlr.de
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Thank you for your attention

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