Propulsion technology trends across major bus operators in Europe, North America and South-East Asia

Judith Cohen
Railway and Transport Strategy Centre, Centre for Transport Studies

Mark Trompet
Head of Bus Benchmarking
Railway and Transport Strategy Centre, Centre for Transport Studies
Aims of this research

• Share thinking on the **future direction of bus propulsion** and the trend towards zero local emissions

• Understand (cost) implications for future **fleet decisions**

• Understand practical considerations that need to be addressed early on in **planning for electrification**

• Take the opportunities and mitigate the risks of the rapidly-developing market in **zero local emissions vehicles**
The International Bus Benchmarking Group

- Presentation shows high level, anonymised results from a study executed for and with the thirteen member cities of the IBBG
1. Environmental Visions and Measurement
Bus operations have both positive and negative environmental impacts

Indirect environmental impact

- 😊 Reduce car use
- 😊 Reduce congestion
- 😊 Enable urban density

Direct environmental impact

- 😞 Fuel use
- 😞 Air pollution
- 😞 Use of road space
Different operators/cities prioritise different environmental issues

Energy efficiency: 6 operators

Climate change, CO2, and Greenhouse Gases (GHG): 5 operators

Renewable/alternative energy: 3 operators

Air quality and health: 5 operators

Sustainability: 3 operators

Go ‘green’: 1 operator

No environmental vision reported: 3 operators
CO$_2$ is the most commonly measured facet of environmental performance

- Eight of thirteen IBBG organisations have targets for CO$_2$
  - But ten report it, illustrating that it is politically useful to do so
- 50% of thirteen IBBG organisations measure CO$_2$ equivalent.
- Only three IBBG organisations have calculated avoided carbon
- Seven members have targets for NOx and PM$_{10}$
  - PM$_{2.5}$ is more dangerous than PM$_{10}$ but targeted by only five members
Considerations for different emissions

Local Pollutants (NOx, PM)
- Local health/smog impacts
- Affect the specific area in which they are emitted
- Therefore emissions at the tailpipe are most important
- Diesel produces most

Greenhouse Gases (CO₂, CH₄, N₂O)
- Effects are global
- Cause the same climate change impact wherever they are emitted
- Therefore reporting should take into account emissions at the tailpipe and elsewhere
- CNG produces slightly more greenhouse gases
Many organisations prioritise EITHER local pollutants OR greenhouse gases. This seems to depend on local air quality.

Air quality is a major issue. Focus is on reducing NOx/PM even at the expense of greater fuel consumption.

Organisational focus is on GHG and climate change. Engine technology regulations reduce NOx/PM anyway.

Implications for vehicle choices:

- CNG
- Euro V/VI vehicles
- Electrification even if the electricity is not ‘clean’ (e.g. from coal)

More likely to avoid CNG

Electrification supports aims if renewables used to generate grid electricity.
2. Propulsion Choices
In 2013, conventional diesel buses dominate but B5 biodiesel is widely used.
There are two main strategic trends in propulsion: towards zero local emissions; and away from diesel.

**Trend 1: Away from pure diesel, to hybrids and CNG**
- Last 5 years: 6
- Next 5 years: 5
- 10+ years: 1

**Trend 2: Towards zero local emissions**
- Last 5 years: 2
- Next 5 years: 7
- 10+ years: 1

- Hybrid
- CNG
- Electric
- Other zero-emission
- Chargeable Hybrid
Biodiesel can reduce CO$_2$ emissions with minimal additional cost

Biodiesel can reduce whole life CO2 emissions by 15-25% if it is based on waste products (e.g. animal tallow) and not plants grown specially.

The main drawback of biodiesel is the need for more filter changes. This can slightly increase maintenance costs, by +2-5%.

One operator also reported higher NOx emissions.

Higher blends (>B20) are more problematic: they can increase maintenance costs, invalidate vehicle warranty, and have a higher risk of freezing in cold weather.

One operator helped to create a local supply chain.
Hybrid use has doubled in 5 years, but whole life costs remain uncertain

- 10% of IBBG vehicles are hybrids
  - In 2009, only one member had a significant fleet of hybrids
  - Since 2009, 6 organisations have moved towards hybrids
  - By 2019, 5 more organisations expect to be buying hybrids

Average estimated fuel savings: 24%
Average for standard 9/12m buses: 12%
Average for articulated and double deck buses: 43%

Average purchase price is 35% more than standard diesel, but has reduced from 55% more in 2009

Savings are better for larger buses because hybridisation enables downsizing the engine.
CNG reduces local pollutants; outcomes for whole life costs vary

- 5% of IBBG vehicles are CNG
  - Between 2009-2014, 5 organisations have moved towards CNG

<table>
<thead>
<tr>
<th>Whole life cost</th>
<th>Bus 1</th>
<th>Bus 2</th>
<th>Bus 3</th>
<th>Bus 4</th>
<th>Bus 5</th>
<th>Bus 6</th>
<th>Bus 7</th>
<th>Bus 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions</td>
<td>-90% (v. Euro 3)</td>
<td>= (v. Euro 4+)</td>
<td>-NOX +CO₂e</td>
<td>ND</td>
<td>=</td>
<td>+CO₂e</td>
<td>-PM =CO₂</td>
<td>ND</td>
</tr>
</tbody>
</table>

- The difference in business cases is probably down to local CNG infrastructure, cost and availability factors
  - Double decker CNGs not readily available

- CNG requires outdoor facilities or a LOT of ventilation due to flammable gas refuelling
Zero local emissions are the future, but hydrogen fuel cells are not currently realistic

“There is only one way, and that is towards zero emissions. How long will it take? I don’t know.”
– Van Hool (pers. comm.)

Up to 2020, the majority of buses in operation will still be diesel.

By 2030, the majority of buses on the road will be zero local emissions

Hydrogen buses cost between 200% and 600% of diesels

Hydrogen fuel cells have similar weight issues to batteries

Hydrogen fuel cells are an alternative to a battery – the drivetrain is electric

Fuel cells overcome logistical issues of battery electric buses – charging, battery life etc.

If hydrogen fuel cell buses were cheaper, would they be preferable to battery electric?
# Electric Battery Buses vs. Conventional Diesel

## Key Points

- **No local emissions, lower lifetime environmental impact**

## Comparisons

<table>
<thead>
<tr>
<th></th>
<th>Bus 1</th>
<th>Bus 2</th>
<th>Bus 3</th>
<th>Bus 4</th>
<th>Bus 5</th>
<th>Bus 6</th>
<th>Bus 7</th>
<th>Bus 8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Whole life cost</strong></td>
<td>-26%</td>
<td>=</td>
<td>=</td>
<td></td>
<td></td>
<td>+</td>
<td>+58%</td>
<td>+100%</td>
</tr>
<tr>
<td><strong>Purchase cost</strong></td>
<td>+33%</td>
<td>+50%</td>
<td>+100%</td>
<td>+150%</td>
<td>+200%</td>
<td></td>
<td></td>
<td>+100%</td>
</tr>
<tr>
<td><strong>Fuel consumption</strong></td>
<td>-70%</td>
<td>-70%</td>
<td></td>
<td>-90%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CO2 emissions</strong></td>
<td></td>
<td></td>
<td>-70%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-81%</td>
</tr>
</tbody>
</table>

### Key:
- ++ significant increase, + minor increase, - minor decrease, -- significant decrease
- ?: uncertain, (blank): information unavailable, =: no change

## Additional Notes

- Specific equipment include charging facilities (possibly a major expense) and tools for servicing high-voltage equipment
- Performance is good except for problems driving up steep hills
**Trolleybuses** have lower fuel costs and last a long time, but the infrastructure required is expensive.

- **Lower whole life environmental impact**
- **40-50% lower energy use and cost than diesel**
- **60-90% lower emissions, depending on electricity**
- ** Longer vehicle life**

Trolleybuses with significant off-wire capacity (battery-trolley hybrids) may be an important emerging technology in cities with trolley wires. This solution solves problems of range and charging equipment by using existing infrastructure.
3. Practicalities of Autonomous Electric Buses
Consider operations and implementation as well as cost when choosing electrification strategy.

Cost
- Purchase
- Infrastructure
- Maintenance
- Battery replacement

Operational considerations
- Range
- Scheduling impacts
  - Recovery time
  - Peakiness of supply
- Deployment flexibility
- Fleet spare ratios

Implementation issues
- Supporting infrastructure
- Stakeholder opinions
Depot charging is simpler, but on-road charging enables lighter buses and greater range

**Depot base station**

- ✔ Simpler
- ✔ Lower cost equipment

- ✗ Lower range (100-250km)
- ✗ Bigger, heavier batteries
- ✗ Makes whole bus heavy – reduces passenger capacity

**Charge time**

- 3-8hr slow charge, 1-3hr med charge

**On-road**

- ✔ Quick
- ✔ Not going back to the depot
- ✔ Greater autonomy >500km

- ✗ High charging station cost
- ✗ Higher dwell or recovery times, depending on charge location
- ✗ Charging devices occupy public space (and are unattractive)

**Charge time**

- 5-21 min/hour of service (12m bus)
On-road charging technologies

**Pantograph**
- Pantograph raises from roof of bus or charger lowers down to collector on bus roof
- Low precision needed
- Charging stations are expensive

**Ground induction**
- Precision docking needed, which can add time to stops
- Parked cars or ice can block it
- Some models overheat if no ‘time off’ between buses

*Image: BBC*

*Image: Busbar system demo in Sweden*
A call to action on interoperability for on-route charging

• Non-standardised, non-interoperable on-route charging equipment is a major risk

• Charging equipment is currently proprietary and matched to a bus type…

• …if operators buy one type of bus and on-route charging kit, they cannot charge another manufacturer’s bus on that route without duplicating the equipment.

• There is currently a window of opportunity for standardisation and interoperability while the technology is developing
4. Conclusions
Conclusions – Environmental Visions

• Organisations’ environmental priorities differ
  – Generally, either ‘NOx/PM’ or ‘greenhouse’ gases are given greater priority

• Measuring and communicating environmental performance is **politically important**

• **Avoided carbon** is significant and a selling point for bus / transit
  – Benefits due to denser land use can be huge, 2-4 times the modal shift impacts, but are often not accounted for
Conclusions – From diesel dominance to electric future

- **Five years ago**, 91% of IBBG buses were conventional diesels and 2% were hybrid.

- **Now**, 10% are hybrid and 1% are zero local emissions.

- **In 5 years**, 7 more organisations expect to be buying or testing electric battery buses.

- **In 10 years**, most IBBG members expect to be buying zero local emission vehicles.

- **In 15 years**, a manufacturer expects >50% of vehicles on the road to be zero local emission.
## Summary of Propulsion Findings

<table>
<thead>
<tr>
<th>Propulsion Trend</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biodiesel</strong></td>
<td>Same purchase price</td>
<td>2-5% higher maintenance costs</td>
<td>Use if sustainable biodiesel available at reasonable price</td>
</tr>
<tr>
<td></td>
<td>Carbon savings if reused biodiesel used</td>
<td>Plant based biodiesel may not be low carbon</td>
<td></td>
</tr>
<tr>
<td><strong>Diesel hybrid</strong></td>
<td>40% lower fuel costs for artics /double deckers</td>
<td>Fuel savings less than expected for 9/12m vehicles</td>
<td>Check whole life cost</td>
</tr>
<tr>
<td></td>
<td>Prices coming down</td>
<td></td>
<td>Use for large vehicles</td>
</tr>
<tr>
<td><strong>CNG</strong></td>
<td>Lower local pollutants</td>
<td>High cost if no local infrastructure</td>
<td>Use if cheaper locally</td>
</tr>
<tr>
<td></td>
<td>Cheaper in some places</td>
<td>Slightly higher GHGs</td>
<td>Consider if smog a problem</td>
</tr>
<tr>
<td></td>
<td>Subsidies for vehicles</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Electric battery</strong></td>
<td>Zero local emissions</td>
<td>Operational constraints</td>
<td>Keep options open</td>
</tr>
<tr>
<td></td>
<td>Good for public image</td>
<td>Infrastructure costs</td>
<td>Develop operating strategy</td>
</tr>
<tr>
<td><strong>Hydrogen fuel cell</strong></td>
<td>Zero local emissions</td>
<td>Expensive</td>
<td>Participate in funded development projects</td>
</tr>
<tr>
<td></td>
<td>Runs all day</td>
<td>No commercial market</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions – Aside from cost, electric buses present significant new logistical and operational challenges

- Battery types, life, charging, and conditioning are complex – a knowledgeable battery expert can be invaluable

- Battery technology continues to develop, and further innovations are expected

- Different technologies may be required for different routes or types of routes

- There is a need and an opportunity for interoperability for electric vehicle on-road charging
Thank You