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Bremen

NEMS: Electric Busses at Rotterdam

F.G. Rieck MSc, Professor Future Mobility, Rotterdam University of Applied Science
**E-REV Configuration**

Battery Power Module:
107 kWh allowing 80 km range or about 4 hour zero emission drive

Range Extender Module:
30 kW diesel electric for operational flexibility

e-Traction Module:
240 kW for silent, smooth and efficient direct drive

*E-REV= Extended Range Electric Vehicle*
Regenerative efficiency

Typical: 0.08 kWh per km per ton

22%-28% Recuperation

No rights can be claimed from this information
### Test results from practice

<table>
<thead>
<tr>
<th></th>
<th>Full Electric</th>
<th>50% mix Plug In</th>
<th>Full Hybrid Diesel-electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption (kWh/km)*</td>
<td>1.4</td>
<td>2.6</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>-65%</td>
<td>-35%</td>
<td>-5%</td>
</tr>
<tr>
<td>Driving Range (km)**</td>
<td>80</td>
<td>160 (570)</td>
<td>490</td>
</tr>
<tr>
<td>Energy-cost per km (€)**</td>
<td>0.21</td>
<td>0.35</td>
<td>0.49</td>
</tr>
</tbody>
</table>

Compared to diesel bus 0.4 litre/km (0.52 €/km)

* 10 kWh = 1 litre (Plug to Wheel excluding HVAC)
** Based on 100 kWh and 200 litre
*** At € 0.15 per kWh and € 1.30 per litre

No rights can be claimed from this information.
Energy consumption variation

Regressieanalyse energieverbruik e-Busz

\[ y = -0.0264x + 3.7246 \]

\[ R^2 = 0.83211 \]
### Total cost of operation

<table>
<thead>
<tr>
<th>Full-electric city bus (e-busz)</th>
<th>Base case</th>
<th>Conventional city bus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit</strong></td>
<td><strong>Total costs</strong></td>
<td><strong>Price difference</strong></td>
</tr>
<tr>
<td>Costs per functional unit</td>
<td>€ 785.275,63</td>
<td>€ 95,369,51-</td>
</tr>
<tr>
<td>Costs per km</td>
<td>€ 1,19</td>
<td>€ 0,14-</td>
</tr>
</tbody>
</table>

Based on functional unit: Transport of passengers inner city during 2x4 hours a day for a period of 10 years full electric.
Well to Wheel analysis

EV en ICE ketenrendementen in stadsverkeer voor verschillende centrales

P | R | O | P | R | O | P | R | O | P | R | O | P | R | O | P | R | O
---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---
0.74|0.69|0.65|0.71|0.66|0.61|0.72|0.67|0.63|0.65|0.49|0.50|0.41|0.31|0.17|0.15|0.12
0.13|0.13|0.06|0.15|0.14|0.06|0.14|0.14|0.18|0.19|0.09|0.25|0.25|0.12|0.72|0.71|0.70
0.14|0.29|0.20|0.14|0.14|0.32|0.14|0.19|0.25|0.43|0.25|0.34|0.57|0.11|0.14|0.18
Future Energy Scenario’s

Raw Energy Needs

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Relative Needed Raw Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE (2011)</td>
<td>0.8</td>
</tr>
<tr>
<td>ICE tarsand</td>
<td>1.4</td>
</tr>
<tr>
<td>EV dutch mix 2011</td>
<td>0.6</td>
</tr>
<tr>
<td>EV mix 2050</td>
<td>0.4</td>
</tr>
</tbody>
</table>

- **Fossil**
- **Electric**

Legend:
- Blue: useful
- Red: TTW-loss
- Green: WTT-loss
Test of concept

Many thanks to our consortium partners, pioneers, criticasters, students and operational staff of e-Traction, RET, Eneco and VDL

- After near 3 years operational experience
  - Practical but far to vulnerable E-REV
  - Full Electric > 80 km or 4 hours service
  - Consumption reduction 25% to 50% less
  - Engine noise int./ext. below 67dB/73dB
  - Potentially cost competitive as EV
- Work in progress
  - More easy to maintain
  - Operational reliability should improve
  - Low energy HVAC system needed
  - SORT123 to get comparable data

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Figure 10: SORT 2: Easy Urban

Acceleration $a_{\text{min}} = f(v)$
Deceleration $b = 0.8 \text{ m/s}^2$

$\alpha_{\text{min} 20} = 1.03 \text{ m/s}^2$
$\alpha_{\text{min} 40} = 0.62 \text{ m/s}^2$
$\alpha_{\text{min} 50} = 0.57 \text{ m/s}^2$

Average speed $v_m = 18 \text{ km/h}$

Distance (m)  | Time (s)
---|---
920 m | Calculated = 183.9 s

Rijsnelheid

Weerstandsvermogen

TotalDrivePower [W]  | Totaal weerstandsvermogen [W]
Lesson’s learned

- Regenerative braking in urban cycles saves about 25% energy (potential 40%), dive-ability should be tested off-line
- Direct drive of e-Traction/ZA makes 0.9 kWh/km feed to wheel energy use feasible, other tested systems need 10-15% more
- Average energy use of the E-REV depends on driving mode electric (=1), plug-in (2x electric), full hybrid (3x electric)
- Total energy cost varies between 0.2 en 0.5 €/km, to earn back batteries as much as possible full electric driving is mandatory
- HVAC of e-Busz works good but needs a low energy approach (reference to Artic Whisper, more personal comfort and e/g heat pump technology)
- Chauffeurs en passengers are enthusiastic about smoothness of drive and low noise level (<66 dB up to 80 km/h)
- Manuel plug-in charging is not practical, leads to mistakes and over-charging
- Need for on-line monitoring (e/g ViriCiti)

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Follow-up results

• Thanks to the practical experience the electric bus development went to a steep learning curve (ZEB)

• The concept has been successfully adopted by the industry
  – Ziehl Abegg started together with e-Traction deployment series production of The Wheel®
  – VDL introduced the Citea Electric at the UITP, several bus OEM’s are following this example
  – RET and e-Traction decided to continue the operational use of the significantly improved e-Busz in Rotterdam
Thank you for your attention