Battery-Electric AGVs

Clean Air in Ports

Antwerp, October 8th 2013
AGV Container-Terminal

- Automated Guided Vehicles (AGV) are heavy duty vehicles for the automated transportation of containers within ports.
- AGVs are guided by a navigation and a fleet management system.
- High availability with up to 7,000 operating hours per year and vehicle, 24/7 operation.

- Transport of containers with up to 40t (single lift) and 60t (twinlift 2x20’) between quay cranes and container stacks.
- Average travel distance is approx. 800 m per move.
AGV Milestones

- 1988: diesel-hydraulic AGV (first prototype)
- 1991: diesel-hydraulic AGV (series-production)
- 2006: diesel-electric AGV (series-production)
- 2009: first battery-electric AGV test-vehicle
  - batteries in container on AGV
  - successful feasibility study

Government-funded research project “Battery-AGV” to achieve implementation readiness.
Government-funded research project Battery-AGV

„Development of Battery Driven Container Transport Vehicles and Field Test at the Container Terminal Altenwerder in Hamburg“

- Development of two Battery-AGV prototype vehicles
- Development of a fully automated battery changing and charging station
- Long term field test of the Battery-AGVs under real operating conditions

- 01.06.2010 until 30.09.2011

- Funded by:
Public-funded research project B-AGV

- Battery concept

Battery-AGV

9 x 80V Batteries

exchangeable battery (720V, 400Ah or 460Ah)
Battery exchange & charging is fully automatic

Decoupling of driving and charging.

**No reduction of vehicle performance,**
**only short downtime for battery change.**

Station is integrated in existing software system.
Public-funded research project B-AGV

- Reconfiguration of powertrain

### diesel-electric
- diesel engine
- fuel tank
- generator
- DC-circuit
- AC/DC converter
- DC/AC converter
- electric motor
- wheel

### battery-electric
- electricity
- battery
- switch
- DC-circuit
- DC/AC converter
- electric motor
- wheel

Simple system, small number of components inside vehicle
Public-funded research project B-AGV

- Efficiencies of diesel-electric and battery-electric powertrains

E-AGV (diesel-electric)

Efficiencies:
- Diesel motor 35% (average)
- Generator 92%
- Rectifier 97%
- Converter 97%
- Electric motor 93%
- Axle 92%

\[ \eta_{E-AGV} = 26\% \]

Battery-AGV

Efficiencies:
- Battery 75% incl. charger
- Converter 97%
- Electric motor 93%
- Axle 92%
- Add. dead weight 90%

\[ \eta_{B-AGV} = 56\% \]

- Additional energy savings of battery powered AGV during idling times!
Advantages:

- No local emissions: Future increase of emission regulations can always be fulfilled.
- Reduced maintenance through omission of the diesel engine.
- Lower generation of noise.
- No start up time of the diesel engine => productivity increase.
- Independent from energy source (fossil fuels, nuclear power, water power, wind power, solar power, …).
- Independent of crude oil and diesel price trends and availability.
- Reduced global emissions.
Diesel-Electric AGV:

- Diesel fuel inclusive fabrication and transportation, 3.13 kg CO\(_2\)/Liter*
- AGV-drive 7.4 l / Oph
- 23.2 kg CO\(_2\) per operating hour

Battery-AGV:

- German energy mix 0.56 kg CO\(_2\)/kWh*
- Batterysystem \(\eta_{\text{tot}}=75\% \rightarrow 0.77 \text{ kg CO}_2/\text{kWh}
- AGV-drive 15 kWh / Oph
- 11.7 kg CO\(_2\) per operating hour

Operation of the battery AGV generates about 50% CO\(_2\) of the E-AGV

\(\rightarrow 50\% \text{ CO}_2\)-savings with the „German Energy Mix“!

\(\rightarrow \) additional reduction of CO\(_2\) with the use of „green“ energy

*Quelle: Infozentrum UmweltWirtschaft, Bayrisches Landesamt für Umwelt
Public-funded research project B-AGV
Results from Field Test

- Successful integration of two battery AGVs into existing fleet.
- Both Battery-AGVs with > 7,500 operating hours each.
- Operating time with one battery > 16 h (peak operation).
- Energy consumption per operational hour 15 kWh (battery output).
- Until today > 1000 automatic battery changes.
- Battery charging time ca. 7 h.
- Keep up operation during winter time, temperatures below 0°C.
- **System is very reliable during 24/7 operation.**
- Zero local exhaust emissions, reduced noise emissions.
Transportation System’s Total Cost of Ownership

TCO for a fleet size of 60 AGVs, includes
- Investment [+15%],
- Fuel/energy [-51%],
- Maintenance [-41%]

Energy Cost Comparison AGVs
Diesel-electric versus Battery-electric

<table>
<thead>
<tr>
<th>Type of AGV</th>
<th>E-AGV (diesel-electric with all-speed engine)</th>
<th>B-AGV (lead-acid, agv, &amp; fuel on detr. gear, at-electric convert)</th>
<th>Difference (saving)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption per operating hr</td>
<td>7.4 kWh</td>
<td>20.0 kWh out of electr. grid</td>
<td>-12.6 kWh</td>
</tr>
<tr>
<td>Energy cost per unit (low &amp; conservative value)</td>
<td>0.80 €/hr</td>
<td>0.14 €/kWh</td>
<td>-0.66 €/hr</td>
</tr>
<tr>
<td>Energy cost per oper. hr (low &amp; conservative value)</td>
<td>5.92 €/hr</td>
<td>2.91 €/hr</td>
<td>-3.01 €/hr</td>
</tr>
<tr>
<td>Energy cost per year (6,000 oper. hrs / year)</td>
<td>35,520 € / year</td>
<td>17,460 € / year</td>
<td>-18,060 € / year</td>
</tr>
<tr>
<td>Energy cost per year for fleet of 60 AGVs</td>
<td>2,130 Mio € / year</td>
<td>1,041 Mio € / year</td>
<td>-1,089 Mio € / year</td>
</tr>
</tbody>
</table>

Re-invest for lead-acid batteries
- 21%
- 15%
- 10%
- 51%
Commercial Launch: Long Beach Container Terminal
– Situation after 2018/2019

72 Battery-AGVs
Commercial Launch: Maasvlakte II, Rotterdam

APMT: 37 Battery-Lift-AGVs

RWG: 59 Battery-Lift-AGVs
Due to 24/7 operation the fleet of 96 AGVs can be compared to a fleet of more than 3,000 passenger cars (~ same operational parameters (diesel consumption etc.)).

This means that:

- Establishing a fleet of 96 Battery-AGVs is equal to a fleet of 3000 electric passenger cars (Netherlands 05.2012: 1750 electric cars).
- Global CO2-Emission are reduced by than ~7000tons/year with 96 B-AGVs compared to 96 Diesel AGVs.
What`s next?

Government-funded research project BESIC
(BESIC: Battery-Electric Heavy-Duty Vehicles in Intelligent Container-Terminals)

- Increased B-AGV fleet
- Battery Charging and Energy Management
- Test of Lithium-Ion Batteries


- Partners: HHLA VATTENFALL efzn TEREX
Batteries will be charged when required for operation.
- a surplus of ("green") energy is available.

Advantages:
- Energy peak shaving.
- Increased use of "green" energy.
- Reduced energy costs.
- Batteries as part of a smart grid.
## Selection of Battery-Type – Current Status

<table>
<thead>
<tr>
<th></th>
<th>Lithium</th>
<th>Lead-Acid</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maturity of Battery</strong></td>
<td>has to „customized“</td>
<td>proven, fork lift battery</td>
</tr>
<tr>
<td><strong>Maturity of Charger</strong></td>
<td>not available?</td>
<td>proven</td>
</tr>
<tr>
<td><strong>Load Cycles</strong></td>
<td>~4x more cycles promised</td>
<td>~1200 cycles</td>
</tr>
<tr>
<td><strong>Complexity</strong></td>
<td>(multiple) BMS required</td>
<td>„plug &amp; play“</td>
</tr>
<tr>
<td><strong>Spec. Energy (Wh/kg)</strong></td>
<td>~3,5x higher</td>
<td></td>
</tr>
<tr>
<td><strong>Spec. Power (W/kg)</strong></td>
<td>~2x higher</td>
<td></td>
</tr>
<tr>
<td><strong>Recharge Time</strong></td>
<td>*~5x faster</td>
<td>*</td>
</tr>
<tr>
<td><strong>Durability (shocks etc.)</strong></td>
<td>has to be tested</td>
<td>successful field tests</td>
</tr>
<tr>
<td><strong>Costs - Invest</strong></td>
<td>&gt;10x lead-acid (battery sys)</td>
<td></td>
</tr>
<tr>
<td><strong>Costs - Operation</strong></td>
<td>? better efficiency promised</td>
<td>lower cost than diesel</td>
</tr>
<tr>
<td><strong>Costs - Maintenance</strong></td>
<td>? maintenance free?</td>
<td>refill of water etc.</td>
</tr>
<tr>
<td><strong>Recycling</strong></td>
<td>? to be developed</td>
<td>99% recycling rate</td>
</tr>
</tbody>
</table>

* Recharge: Lithium-Batteries can be recharged much faster, but recharge time might be limited by equipment (e.g. cables – high currents!). Furthermore the whole charging concept has to be compared (e.g. battery exchange vs. loading battery in vehicle).
## Vision – Full Electric Terminals

<table>
<thead>
<tr>
<th>Straddle Carrier Layout</th>
<th>RTG + Terminal Truck Layout</th>
<th>RMG/ASC + low Straddle Carrier (Sprinter/Shuttle/Runner) Layout</th>
<th>RTG + AGV Layout</th>
<th>RMG/ASC + AGV Layout</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Straddle Carrier Layout" /></td>
<td><img src="image2" alt="RTG + Terminal Truck Layout" /></td>
<td><img src="image3" alt="RMG/ASC + low Straddle Carrier (Sprinter/Shuttle/Runner) Layout" /></td>
<td><img src="image4" alt="RTG + AGV Layout" /></td>
<td><img src="image5" alt="RMG/ASC + AGV Layout" /></td>
</tr>
</tbody>
</table>

### Quay Gantry (QC)

<table>
<thead>
<tr>
<th>electrified</th>
<th>electrified</th>
<th>electrified</th>
<th>electrified</th>
<th>electrified</th>
</tr>
</thead>
</table>

### Transport System

<table>
<thead>
<tr>
<th>diesel electric</th>
<th>diesel mechanic</th>
<th>diesel electric</th>
<th>diesel electric battery electric</th>
<th>diesel electric battery electric</th>
</tr>
</thead>
</table>

### Storage System

<table>
<thead>
<tr>
<th>diesel electric</th>
<th>diesel electric</th>
<th>electrified</th>
<th>diesel electric</th>
<th>diesel electric electrified</th>
</tr>
</thead>
</table>

### Landside (Rail/Truck)

<table>
<thead>
<tr>
<th>partly electrified</th>
<th>partly electrified</th>
<th>partly electrified</th>
<th>partly electrified</th>
<th>partly electrified</th>
</tr>
</thead>
</table>
Back-up
Lift-AGV for Decoupling Stack and Transportation in Container-Handling

- AGVs are equipped with a lift platform.
- AGV will deposit containers on racks, does not have to wait for crane.
- Racks will be installed at stack.

To decouple the interconnected handling systems.

To reduce the number of vehicles (costs) or to improve the performance of the transportation system.

To improve the stacking system performance.