Electric transport logistic vehicle technology and its application

Results of the IA-HEV Task 27 “Electrification of transport logistic vehicles”

1st Workshop held in Stuttgart, March 19th, 2015

suggested citation format:

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IA-HEV Task Force 27
Electrification of transport logistic vehicles

eLogV

1st Workshop: “Electric transport logistic vehicle technology and its application”
10:00 – 16:00 CET, March 19th, 2015
at the German Aerospace Center (DLR), Pfaffenwaldring 38-40, 70569 Stuttgart, Germany

Welcome and statements
10:00 - 10:10 Welcome
10:10 - 10:20 Statement of Task Partner, Bob Moran, Office for Low Emission Vehicles, United Kingdom
10:20 - 10:30 Statement of Task Partner, Eric Beers, Hytruck, The Netherlands

Session 1: R&D for electrified transport logistics vehicles
10:30 - 11:00 Latest developments of battery systems, Felix von Borck, Akasol, Germany
11:00 - 11:30 Latest developments of fuel cell systems, Sebastian Wider, Ballard representative, Germany
11:30 - 11:45 Coffee break

Session 2: Possible fields of application for electrified transport logistics vehicles
11:45 - 12:15 Real world data from electric UPS vehicles and their implications for transport logistic vehicles, Dr. Sebastian Stütz, Fraunhofer IML, Germany
12:15 - 12:45 Electric heavy duty vehicle for urban environment - Case study Mannheim, Prof. Bernecker, Heilbronn University, Germany
12:45 - 13:30 Lunch break

Session 3: Workshop
13:30 - 13:45 Introduction
13:45 - 15:15 Hurdles of implementation
15:15 - 15:30 Coffee break
15:30 - 15:45 Summary of the day

Excursion
15:45 - 17:45 Stuttgart Airport (efleet project)

End of Workshop
AUTOMATISIERTER PRODUKTION VON BATTERIESYSTEMEN FÜR ELEKTROBUSSE IN DEUTSCHLAND

EIN ERFAHRUNGSBERICHT
AGENDA

1 Robuste Produktgestaltung
2 Wirtschaftliches Design
3 Produktionsgerechtes Design
4 Wirtschaftliche Automatisierung
5 Beispiel von Batteriesystemen für Elektrobusse
6 Zusammenfassung Produktion
7 Offene Fragen auf dem Weg zum Markt der Zukunft
8 Schlussbemerkung
ROBUSTE PRODUKTGESTALTUNG
ANFORDERUNGEN

Kosten:
- Anzahl der Teile
- Materialien
- Prozesse

Package:
- Wh/kg
- Wh/l
- 3% Luft

Sicherheit:
- Zelle
- Moduldesign

Leistung:
- thermisch
- elektrisch
- mechanisch
ROBUSTE PRODUKTGESTALTUNG
BEISPIEL BATTERIEMODUL

1 Kühlmittelauslass
2 Minuspol
3 BMS CAN Verbindung
4 Pluspol
5 Kühlmitteleinlass
6 Robustes Gehäuse
Batteriemodule werden zusätzlich zum UN Transporttest folgenden Untersuchungen unterzogen:

- Anwendungsspezifische Vibrationsprofile
- Anwendungsspezifische Crash-Tests
WIRTSCHAFTLICHES DESIGN
ZIELE

- Reduktion der Anzahl der notwendigen Bauteile und Komponenten
- Funktionsintegration entwickeln
- Verwendung kostengünstiger Materialien
- Nutzung wirtschaftlicher Füge- und Montagetechnologien
- Verwendung von Gleichteilen
PRODUKTIONSGERECHTES DESIGN
ANFORDERUNGEN

• Automatisierbare Prozesse verwenden

• Bauteile für die Automatisierung gestalten

• Zusammenlegung von Verarbeitungsschritten zur Reduzierung des Handlingaufwandes

• Geringer Flächenbedarf durch kompakte Anordnung der Stationen

• Automatisch mess- und überwachbare Qualitätsprüfungen
WIRTSCHAFTLICHE AUTOMATISIERUNG
LASTENHEFT MODULMONTAGE

- Entwicklung und Herstellung einer automatisierten Montagezelle für Batteriemodule
- Produktionskapazität der Anlage orientiert sich an dem aktuellen Bestellvolumen, nicht an den Prognosen der Marktentwicklung
WIRTSCHAFTLICHE AUTOMATISIERUNG
LASTENHEFT MODULMONTAGE

- Kapazität von 20MWh pro Jahr (Einschichtbetrieb) oder 1.000 Batteriesysteme für E-PKW bzw. 200 Batteriesysteme für Elektrobusse

- Grundfläche: 30qm Roboterzelle

- Material Ein- und Ausbringung, Systemmontage, Verkehrsflächen, Produktionstests. Summe: 300qm

- Skalierbarkeit in Einheiten von 20MWh
WIRTSCHAFTLICHE AUTOMATISIERUNG
BEISPIEL MODULMONTAGE

Konzept 2013:

• Montageschritte
• Prinzip und Layout
• Grundfläche
WIRTSCHAFTLICHE AUTOMATISIERUNG
BEISPIEL MODULMONTAGE

3D Konstruktion 2013:

• Entwicklung der Stationen
• Detailkonstruktion
• Ablaufentwicklung
• Sicherheit
• Qualität
• Überwachung
WIRTSCHAFTLICHE AUTOMATISIERUNG
BEISPIEL MODULMONTAGE

Inbetriebnahme 2014:
WIRTSCHAFTLICHE AUTOMATISIERUNG
BEISPIEL MODULMONTAGE

Inbetriebnahme 2014:
WIRTSCHAFTLICHE AUTOMATISIERUNG
BEISPIEL MODULMONTAGE

Inbetriebnahme 2014:
WIRTSCHAFTLICHE AUTOMATISIERUNG
BEISPIEL MODULMONTAGE

Inbetriebnahme 2014:
Dieses Projekt (HA-Projekt-Nr.: 416/14-06) wird im Rahmen der Hessen ModellProjekte gefördert aus Mitteln des Landes Hessen und der Europäischen Union (Europäischer Fonds für Regionale Entwicklung - EFRE).
ZUSAMMENFASSUNG
AUTOMATISIERTE BATTERIEPRODUKTION

- Das Thema automatisierte Produktion von Hochvolt-Batteriesystemen ist interdisziplinär und sehr komplex

- Der Einfluss der Produktionsqualität der Zellen und der Module ist heute und in Zukunft entscheidend für die Robustheit der Batterie

- Der nächste Schritt ist die Validierung der Zuverlässigkeit über Lebensdauer auf Systemebene beim Einsatz von innovativen Produktionsprozessen mit neuen Verfahren
BEISPIEL BATTERIESYSTEME
BASISEINHEIT 30KWH

1. Zelle
2. AKAMODULE
3. Hochfester Batterietrog
4. Thermische Isolation
5. Kühlmittelverbinder
6. Kühlmittelanschluss
7. Elektrische Verbinder
8. Hauptschützbox
9. HV-Stecker mit Interlock
10. BMS Master
11. Safety Control Unit
ANMERKUNGEN
EINFLÜSSE AUF DIE KOSTEN DES ELEKTROBUSSES

• Batteriepreise variieren um den Faktor 1,2

• Die Betriebstemperatur der Batterie beeinflusst die Lebensdauer um den Faktor 3

• Die Auswahl der Zellchemie und des Zelldesigns beeinflussen die Lebensdauer um den Faktor 4

• Lebensdauergarantien der Batteriehersteller variieren um den Faktor 4

• Nachladehäufigkeiten während des Betriebs (Tagesfahrleistung) beeinflussen die Batteriegröße um den Faktor 5
ANMERKUNGEN
WAS IST DER OPTIMALE ELEKTROBUS?

• Der der den Einkäufer zufriedenstellt?

• Der den die Werkstattleitung wählen würde?

• Der der dem Bürgermeister die Wiederwahl sichert?

• Der mit der höchsten Verfügbarkeit!

• Der der die Machbarkeit eines breiten Umstieges nachweist!

• Der der aufzeigt auf welches Detail beim Umstieg von Diesel auf Batterie zu achten ist!
ANMERKUNGEN
WAS DARF DER OPTIMALE ELEKTROBUS KOSTEN?

• Weniger als der Diesel?

• Wieviel mehr als für einen Diesel wäre die Gesellschaft bereit für einen Elektrobus zu zahlen?

• Wie hoch ist der Anteil der Vollkosten des Busses auf den Ticketpreis?

• Wer entscheidet sich für den Bau einer Straßenbahn um Kosten zu sparen?
ANMERKUNGEN
OFFENE FRAGEN

• Was passiert wenn Elektrobusse zur Pflicht werden und schnelle Entscheidungen auf der Basis geringer Erfahrung mit hohem Risiko getroffen werden müssen?

• Braucht der Elektrobus eine eigene Kategorie bei der Projektierung und Kostenbetrachtung zwischen Produkt (Dieselbus) und Projekt (Straßenbahn)?

• Was muss nachgewiesen sein, bevor die Entscheidung zum breiten Wechsel vom Diesel- zum Elektrobus gefällt werden kann?
SCHLUSSBEMERKUNG

- Sicherheit von Zellchemie: Heute entscheidet nicht die Reaktivität des Kraftstoffes über die Sicherheitsbewertung des Kraftfahrzeugs

- Beim Streben nach 200Wh/kg und 200€/kWh sollten wir nicht vergessen, uns auf die optimale Anwendung der heute verfügbaren Technologien zu konzentrieren

- Potentiale zur Reduzierung der Vollkosten liegen in der intelligenten Reduzierung der installierten Kapazität und damit der Nutzung der zyklischen Lebensdauer innerhalb der kalendarischen Lebensdauer

- Der Markthochlauf für hochwertige Batterieprodukte wird in den Nischen erfolgen in denen Langlebigkeit, Sicherheit, Robustheit und Leistungsdichte zwingend erforderlich sind
VIELN DANK
FÜR IHRE AUFMERKSAMKEIT!
Latest developments of Fuel Cell Technologies
Material Handling and Heavy Duty Applications

March 19th, 2015
Why Ballard?
The Technology Leader with Unmatched Experience

- **Power Products**: to meet the power needs of customers through the delivery of high value, clean energy products that reduce customer costs and risks: Fuel cell stacks; motive modules; stationary systems

- **Technology Solutions**: to help customers solve difficult technical and business challenges in their proton exchange membrane (PEM) fuel cell programs
  - customized, bundled technology solutions & specialized engineering services
  - access to the Company’s deep IP portfolio and know-how

**Ballard Power Systems:**
- 355 employees
- Public listed company with HQ in Vancouver, Canada
- Product engineering in Canada, USA & Denmark
- Over **30 years** of experience with largest PEM IP portfolio
- Shipped more than **200MW** of PEM fuel cell products worldwide
- **Millions** of kilometers driven by Ballard powered fuel cell buses
- Technology used by major automotive OEMs
## Ballard Fuel Cell Product Portfolio

### Complete Range of Power Products

<table>
<thead>
<tr>
<th>Fuel Cell Stacks</th>
<th>Fuel Cell Modules</th>
<th>Complete Fuel Cell Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FCgen®-1020ACS</strong></td>
<td><strong>FCvelocity®-9SSL</strong></td>
<td><strong>ElectraGen-H2</strong></td>
</tr>
<tr>
<td>- 500W-2kW</td>
<td>- 4-20kW</td>
<td>- 2.5kW &amp; 5kW</td>
</tr>
<tr>
<td>- Up to 8k hrs</td>
<td>- Up to 12k hrs</td>
<td>- Direct hydrogen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Methanol fuelled</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Indoor (rack-mountable) &amp; outdoor use</td>
</tr>
<tr>
<td><strong>FCgen®-1300</strong></td>
<td><strong>FCvelocity®-1100</strong></td>
<td><strong>ElectraGen-ME</strong></td>
</tr>
<tr>
<td>- 2-8kW</td>
<td>- 100kW</td>
<td>- 2.5kW &amp; 5kW</td>
</tr>
<tr>
<td>- Up to 30k hrs</td>
<td>- &gt; 10k hrs</td>
<td>- Methanol fuelled</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Outdoor use</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Multi-MW power</td>
</tr>
</tbody>
</table>

Ballard’s product portfolio includes industry-leading PEM fuel cell stacks, fuel cell modules and complete fuel cell system solutions
Material Handling Overview
Why Fuel Cells for Material Handling?

- **Increased lift truck uptime**
  - Eliminate need to change batteries
  - Quick refuelling vs. long battery charging
  - Extended runtime
  - Consistent power

- **More productive warehouse floor space**
  - Eliminate need for battery room

- **Environmental benefits**
  - Zero emissions
  - Reduced GHG emissions
  - Eliminate need to handle, store, and dispose of lead & acid

- **Centralized H$_2$ Infrastructure**
  - Enables low-cost H$_2$ fuelling solution

- **Target Customer**
  - Food, retail, mfg, distribution
  - Large fleets (> 30 trucks)
  - Multi-shift operation (>1 shift/day)
Value Proposition

Fleet Operator Challenges & Industry Trends

- **Lack of productivity**
  - Traditional forklifts lose speed & power as battery runs down
  - Up to 20 minutes to swap a battery
- **Wasted floor space in facilities**
  - Battery storage rooms necessary
  - Particularly concerning for greenfield projects
- **Maintenance & battery replacement creates expensive operations**
  - Typical battery life ~5 years
- **Increased focus on employee health & safety**
  - Desire for more environmentally friendly, safer work environment

Ballard Products

- **FCvelocity®-9SSL**
  - Fuel Cell Stack
- **FCgen®-1020ACS**
  - Fuel Cell Stack

Value Add

- **Increased productivity**
  - Up to 15%
  - Enable forklifts to operate at consistent full speed
  - Refuel typically takes < 2 minutes
- **Battery rooms eliminated, allowing more room for products**
- **Drop-in replacement in current major forklift brands**
- **Reduced operational expenses**
  - Economic lifetime up to 1.5-2.0x longer than lead acid batteries
- **Environmental benefits**
  - Zero emissions along with recycling
  - Up to 80% reduction in greenhouse gases

March 5, 2015 • 7
Total Cost of Ownership Model

Assumptions

Forklift Fleet: 230 trucks
  Class 3 – 180 trucks
  Class 2 – 40 trucks
  Class 1 – 10 trucks

Operation:
  New greenfield distribution center
  2.5 shifts per day

Lead-Acid Batteries:
  3 batteries per forklift
  1 battery charger per forklift
  20 minutes per battery change-out
  Battery replacement interval: 3-4 yrs

Fuel Cell Solution:
  1 fuel cell system per forklift
  3 minute H₂ re-fuelling time
  Fuel cell stack lifetime: 10,000 hours
  Product lifetime: 7-10 years

Hydrogen Cost: $8 per kg

Electricity Cost: $0.10 per kWh

Labor cost: $25 per hour

Incentive: 30% “grant in lieu of credit”

Value proposition for new greenfield facility ...

- Increase productivity by 15%
- IRR > 50%
- Payback < 1yr
- Savings > $3M
- Reduce carbon footprint by 80%

Total Cost of Ownership for Greenfield Warehouse Deployment
Flooded Lead-Acid Battery - Fuel Cell Solution
Cumulative Non-Discounted Savings ($ USD)

Model - Non-Discounted Savings - fuel cells vs batteries

US govt incentives drive payback < 1yr
  - Fuel Cells: $1,000/kW up to 30%
  - H₂ Infrastructure: up to $200,000

Battery replacement interval at 3-4 yrs

Without US govt incentives, payback > 3 yrs
### Addressable Market

#### Global Industrial Forklift Sales

<table>
<thead>
<tr>
<th>Region</th>
<th>Units/yr</th>
<th>$USm/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>191,000</td>
<td>$8,060</td>
</tr>
<tr>
<td>Europe</td>
<td>411,000</td>
<td>$11,150</td>
</tr>
<tr>
<td>Asia</td>
<td>266,000</td>
<td>$10,280</td>
</tr>
<tr>
<td>Rest of World</td>
<td>83,000</td>
<td>$2,460</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>951,000</td>
<td>$31,950</td>
</tr>
</tbody>
</table>

#### North American Installed Base

<table>
<thead>
<tr>
<th>Installed Base - Total</th>
<th>Forklifts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1,700,000</td>
</tr>
<tr>
<td>Electric</td>
<td>850,000</td>
</tr>
<tr>
<td>Address. by Plug</td>
<td>380,000</td>
</tr>
</tbody>
</table>

#### N/A Market Stack Opportunity*

<table>
<thead>
<tr>
<th>Stack Opportunity*</th>
<th>Stacks/yr</th>
<th>$USm/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Addressable Market</td>
<td>191,000</td>
<td>$760</td>
</tr>
<tr>
<td>Serviceable Addressable Market</td>
<td>24,000</td>
<td>$96</td>
</tr>
</tbody>
</table>

*Target = new sales  
Note: Market figures taken from 2007

Stack ASP = $4,000

---

#### Target Region: N/A
- High throughput productivity
- Available LH2 infrastructure
- US Govt subsidies

#### Target Application
- **Primary** = Greenfield Facilities: New electric forklift truck sales
- **Secondary** = Brownfield Facilities: Conversion of existing trucks and battery infrastructure

#### Target Customer
- High throughput DC’s
- Refrigerated warehouses
- Manufacturing facilities

#### Operating Characteristics
- > 2 shifts per day
- > 30 forklift trucks
- Availability of low-cost H2

#### Value Proposition
- Productivity savings
- Reduced GHG emissions

---

*Total North American SAM: 24,000 units/yr  
Stacks: ~$100m per year  
Systems: ~$500m per year*
Ballard’s FCvelocity®-9SSL

- **Ballard’s FCvelocity®-9SSL Fuel Cell Stack**
  - Technology from auto development programs
  - 4th generation fuel cell product for forklifts

- **Key Attributes**
  - Scalable architecture: 4-20kW
  - Operating Life: 10,000 hours operation
  - Fuel: H₂

- **Cost Reduction**
  - Hardware cost reduction of 76%
  - New MEA technology - 50% red’n in catalyst
  - Reduced stack assembly and test time
  - Higher yields from semi-continuous mfg
  - Reduction in MEA-related scrap materials
  - Material volume pricing
  - Plate prod’n - increase capacity & reduce scrap

- **Manufacturing Capacity**
  - 3,500 units per year ☑ expandable
Ballard’s FCvelocity®-1020ACS

- Ballard’s FCvelocity®-1020ACS Fuel Cell Stack
  - Technology from telecom backup power programs
  - 4th generation of air-cooled fuel cell stack

- Key Attributes
  - Scalable architecture: 500W to 3kW
  - Operating Life: 5,000 hours operation
  - Simple Integration: Open-cathode stack eliminates humidifier, coolant pump, radiator
  - Fuel: H₂

- Cost Reduction
  - Implementation of lower cost hardware
  - Reduced stack assembly and test time
  - Higher yields from semi-continuous mfg process
  - New MEA technology - lower cost, simplify prod’n
  - Reduction in MEA-related scrap materials
  - Material volume pricing

- Manufacturing Capacity
  - 6,000 units per year expandable
Balance of Plant

- **Recommended BOP**
  - **Air Supply Subsystem**
    - Fan, intake filter, ducting ..
    - Compressor .................
    - Humidifier ...................
  - **Fuel Supply Subsystem**
    - Fuel storage ...............
    - Pressure regulator ..........
    - Supply valve ...............  
    - Purge valve ................
    - Anode recirculation blower
  - **Coolant Subsystem**
    - Coolant pump ..............
    - Radiator ...................
  - **Battery or Ultra-Capacitors**
    - DC energy storage ...........
  - **Power Electronics**
    - Regulated DC power .......
  - **Controls**
    - Start/Stop, hybridization ..

Ballard’s 1020 air-cooled fuel cell stack enables a simple, low-cost product solution for *light* applications.
System Integration

Today's Fuel Cells for proven, reliable power.

What is GenDrive®

- What are GenDrive fuel cells?
  - Complete fuel cell engine in a box
  - Superior alternative to industrial lead-acid batteries in motive power equipment
- What do GenDrive fuel cells do?
  - Replace lead-acid batteries permanently
  - Run on hydrogen gas and can be refueled in as little as 60 seconds by operator at convenient self-service dispensers
  - Produce clean power at constant voltage
  - Run 1.5-2 times as long as a battery on pallet trucks
  - Produce no emissions except water and heat
- Features and improvements
  - Enhanced products
  - Common architecture
  - Expansion of product lines - Over 50 configurations

Plug Power GenDrive™ is a *seamless* battery replacement solution for industrial forklift truck applications
Ballard fuel cells enable Plug Power systems to address the full range of material handling equipment.
Customer Value

- 8 sites deployed with Plug GenDrive®
- Houston warehouse fleet of 72 pallet trucks and 26 reach trucks powered by fuel cells. Reduces operating costs by $100k/yr.

- 3 sites deployed with Plug GenDrive®
- Calgary distribution centre with ~ 100 units. Reduces operating cost by $269k/year and reduces CO₂ emissions by 530 tons/year.
  - Avoided battery infrastructure
  - Zero-emission, quiet

- 85 Plug GenDrive® units deployed at South Carolina manufacturing plant.
  - Improves forklift productivity.
  - Saves 1.8M kWh/year of electricity.
  - Avoids 1,200 tons of CO₂ emissions/year.
Heavy Duty
Why FC Buses?

Why Fuel Cell Buses?

FC buses are the most flexible zero emissions option – unlike other electric solutions, they can be operated like diesel buses

- **High daily ranges**
  - ... of 300 km on average without refuelling – Extension possible

- **Performance**
  - ... comparable to diesel buses, e.g. acceleration or gradeability

- **Full route flexibility**
  - ... not bound to any required infrastructure on the route

- **Fast refuelling**
  - ... down to 7 minutes possible – Also several refuelling cycles per day possible

- **High passenger comfort**
  - ... due to reduced noise levels and smooth driving experience

- **Technology maturity**
  - ... with more than ten years and 7 M km of operational experience
Ballard Field Experience

Global deployments; multiple OEM customers focused on performance, availability & durability

Phase 5: (2002 -2009)
Large scale pre-commercial European deployment focused on validating performance (CUTE; HyFLEET:CUTE)

Phase 4: (1999)
Automotive technology injection; Single motor concept

Phase 3: (1996 -1999)
Initial Fleet Demonstrations (Chicago & Vancouver)

Phase 2: (1992 -1993)
First Article Prototype

Phase 1: (1991)
Technology Concept
Ballard Field Experience

75 HD modules deployed in revenue service since 2008
Ballard Technology Leadership

4,000 hrs
Demonstrated in service (TFL)

>10,000 hrs
3 Million km’s
Demonstrated in service (BC Transit)

17,266 hrs
Enhanced MEA; Demonstrated in Service (TFL)

Accelerated Testing in Process
Offered with a 15,000 hr warranty

Leveraging Automotive technology & volumes

Improved component robustness & reduced warranty accrual costs

High volume manufacturing equipment & processes; common components to other markets

50% Cost Reduction ($/kW)
• Next generation fuel cell bus module:
  o 100kW units delivered in mid-2014 for early customer trials
  o Commercial release planned for 2015
  o Substantial cost reduction
    ▪ Latest generation fuel cell stacks – automated manufacturing and assembly processes
    ▪ Reduced parts count – simplified humidification and resulting balance of plant
  o Scalable design
  o Improved durability
  o Fully integrated power module
    ▪ Air compressor and coolant pump included
    ▪ Integrated HRB motor controller (internally mounted)
    ▪ Reduced preventive maintenance activities
  o Module lifetime 10+ years
  o Offered with a 15,000-hour warranty
Systems Integration Support

• **World Class Engineering support**
  o 30 years of experience with fuel cell buses
  o Integration kits, hardware and software interfaces
  o On-site commissioning support

• **Strong Customer Base**

![Brands Logos]

ElDorado National  Wrightbus  BAE Systems  tuttoTrasporti  SOLARIS  VDL  NEW FLYER  Mercedes-Benz  VanHool
Global Service & Support

Preventative and Corrective Maintenance Training Provided at each Deployment Site

- ESPACE Lier, Belgium
  - European Service Centre
  - Co-located with Van Hool
  - Service Technicians
  - Full Parts Inventory

- Burnaby, Canada
  - Global and North America Service Center
  - Telephone support
  - Service Technicians
  - Full Parts Inventory
  - Flying Doctors
  - Engineering

- Aberdeen, UK
  - UK Service Center
  - Telephone support
  - Service Technician

Preventative and Corrective Maintenance Training Provided at each Deployment Site
Thank You
BATTERY POWERED VEHICLES IN URBAN DISTRIBUTION

Real world data from electric delivery vehicles and their implications for transport logistic vehicles

Sebastian Stütz, Fraunhofer IML
Stuttgart, 19 March 2015
AGENDA

- ELMO – A research project centred around BEVs in urban distribution
- Practical hurdles against electrified urban logistics
- Practical experiences of BEVs in urban distribution
  - Reliability and performance
  - User acceptance
  - Economic aspects
- Wrap up: Obstacles to the deployment of BEVs in transport logistics
- Outlook: Directions for future work
“ELMO” A research project centred around battery powered electric vehicles in urban distribution

<table>
<thead>
<tr>
<th>Capabilities of electric vehicles in urban distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project period</td>
</tr>
<tr>
<td>Time frame of data capture</td>
</tr>
<tr>
<td>Total number of records</td>
</tr>
<tr>
<td>Total mileage</td>
</tr>
<tr>
<td>Total electricity consumed</td>
</tr>
<tr>
<td>Total driving time</td>
</tr>
<tr>
<td>Number of customers served</td>
</tr>
</tbody>
</table>
“ELMO” A research project centred around battery powered electric vehicles in urban distribution

Smith Newton 7.5t

P80-E 7.5t

Business:
Laundry service with own fleet

Business:
Package delivery service

Photographs and logos courtesy of CWS boco, UPS, Smith Electric Vehicles and EFA-S
© Fraunhofer IML – Slide 4
“ELMO”  A research project centred around battery powered electric vehicles in urban distribution

<table>
<thead>
<tr>
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<th>Smith Newton 7.5t</th>
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<tr>
<td>Manufacturer</td>
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<td>Morgan Olson / EFA-S</td>
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<tr>
<td>Product type</td>
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<td>Conversion</td>
</tr>
<tr>
<td>Weight in kg</td>
<td>4,260</td>
<td>3,500</td>
</tr>
<tr>
<td>Max. payload in kg</td>
<td>3,230</td>
<td>3,450</td>
</tr>
<tr>
<td>Power in kW (HP)</td>
<td>80 (109)</td>
<td>90 (122)</td>
</tr>
<tr>
<td>Torque in Nm</td>
<td>600</td>
<td>300</td>
</tr>
<tr>
<td>Battery capacity</td>
<td>80 kWh</td>
<td>62 kWh</td>
</tr>
<tr>
<td>Driving range in km</td>
<td>50-160</td>
<td>80-100</td>
</tr>
<tr>
<td>Top speed in km/h</td>
<td>80</td>
<td>80</td>
</tr>
</tbody>
</table>

Photographs and logos courtesy of Smith Electric Vehicles US Corp and EFA-S
Practical hurdles against electrified urban logistics

- Scarce market supply of N2 class models
- Low OEM commitment
- Vehicle supply characterised by uncertainty
- Procurement decisions require precise and reliable range information (non-existent!)
- Physical transfer of vehicles is costly
- Authorities lack experiences with BEVs, prolonging the process of technical examination and registration
Practical experiences of BEVs in urban distribution
Reliability in terms of utilisation

- Fleet average:
  - Days in operation: 74%
  - Unplanned outage days: 26%

- Most reliable vehicle:
  - Days in operation: 93%
  - Unplanned outage days: 7%

- Least reliable vehicle:
  - Days in operation: 66%
  - Unplanned outage days: 34%
Practical experiences of BEVs in urban distribution
Reliability in terms of utilisation over time

![Graph showing reliability over time](image_url)
Practical experiences of BEVs in urban distribution

Reliability in terms of operational issues

Reasons for vehicle outage overall

- About half all disuse is due to technical difficulties with the electric drive train
- At least every 6th day of downtime is due to distrust among local dispatch
- Charging problems are a non-issue
Practical experiences of BEVs in urban distribution
Reliability in terms of operational issues

Reasons for individual vehicle outage

- Vehicle suffers from unplanned maintenance measures of electric drive train
- Major share of other maintenance measures due to natural wear and tear of mechanical components not related to the drive train itself (door locks, wipers, etc.)

Maintenance, other: 22%
Mainenance electric drive: 48%
Not required, no reason given: 30%
Practical experiences of BEVs in urban distribution
Reliability in terms of operational issues

Reasons for individual vehicle outage

- Frequent outages before or during shift quickly generated distrust among dispatchers
- Dispatch degraded the vehicle from regular operation to reserve, hence 1 in 3 days “not required”

- Maintenance, other
- Maintenance electric drive
- Reliability issues
- Not required, no reason given
Practical experiences of BEVs in urban distribution

Interim conclusion: reliability of BEVs in urban logistics

- General reliability highly volatile, yet single vehicles reach well over 90%
- Technical difficulties with the drive train itself cause about half the outages
- Technical problems with charging have not been recorded
- Lack of technical support for BEVs leads to longer downtimes compared to ICE vehicles
- Lack of experience along with technical issues generate “organisational range anxiety”: overcautions route planning and dispatching
Practical experiences of BEVs in urban distribution
Driving performance

Promised range

49 km (avg) 60 km (target) 118 km (max)

Actual ranges

203 km (theor. max)
Practical experiences of BEVs in urban distribution
Cumulative driving performance

- Maximum vehicle ranges are never exploited, large safety buffers remain.
- Low battery utilisation would have allowed higher vehicle utilisation of at least 50% during winter and over 100% during summer.
- Target range of 60 km could have been technically reached anytime and was impeded by overcautious dispatching.
Practical experiences of BEVs in urban distribution
Driving performance

Promised range

Actual ranges

0 km 80 km 100 km 130 km

74 km (avg) 75 km (target) 117 km (max)

© Fraunhofer IML -- Slide 15
Vehicle ranges are mostly exploited close to the maximum.

Winter (Dec to Feb) presents a challenge to the fleet:

- Vehicles meet their technical limits
- Dispatch decommissions low performing vehicles in favour of most reliable ones ➔ fleet utilisation drops by at least 25%
Practical experiences of BEVs in urban distribution
Interim conclusion: achievement of requirements

- CWS boco
  - Range requirements could be met technically by vehicles deployed
  - Poor reliability triggered overcautious planning which kept the vehicles from reaching the range requirements
  - Notable potential to increase transportation performance remained unused

- UPS
  - Range requirements could be met during most of the year
  - Vehicles utilised a high share of their battery capacity, yet, performance could have been increased by at least 10%
  - Ambient conditions during winter kept parts of the fleet from reaching the targeted ranges; some vehicles partly decommissioned
Practical experiences of BEVs in urban distribution
User acceptance: Drivers

Positive feedback
- No need to “start” the electric drive and, hence, allows to move off earlier after a stop
- Silence inside driver’s cabin allows calling dispatch during transit
- Electric drive allows bypassing the waiting queue at the company filling station saving about 15 minutes of idle time

Neutral feedback
- Silent drive technology does not require a higher level of attention; drivers reported that they have to anticipate the behaviour of all people on and by the road anyway.

Negative feedback rare
Practical experiences of BEVs in urban distribution
User acceptance: Management

- Generally open to explore the specific strengths and weaknesses of drive technology beyond standard Diesel
- Dissatisfied with vendor’s technical support and response to reliability issues
- Decommissioned all vehicles after field test
Practical experiences of BEVs in urban distribution
User acceptance: Management

- Generally open to explore the specific strengths and weaknesses of drive technology beyond standard Diesel
- Awareness of technical limitations ➔ “route cherry picking” for electric vehicles
- Operation managers excited about new technology and optimistic about increased use of electric vehicles in own fleet
- Wish for near future: significant increase in range from about 80kms up to 120kms could lead to electrification of more than half of current fleet
Economic aspects
Operational costs

- **Infrastructure costs**
  - Costs for charging infrastructure itself are negligibly low
  - Operating more than only few vehicles requires upgrade of main connection to electric grid which can easily cost a five-digit sum in Euros

- **Maintenance costs**
  - Infrastructure hardly needs maintenance
  - Reliability issues lead to an additional burden of maintenance costs for vehicles
  - Aside from these issues, project partners expect savings of at least 50% because of longer maintenance intervals
Conservative calculations lead to estimated cost savings of about >70% per km when holding electricity vs. Diesel fuel consumption.

Main drivers for electric energy consumption (descending order):
- Actual route length
- Stop density/frequency
- Ambient conditions

Optimally utilised vehicles under the observed conditions could thus create total savings of at least 2,500-3,000 EUR per year.
Wrap up

Obstacles to the deployment of BEVs in transport logistics

Corporate users

- "Organisational range anxiety" causes overcautious decision making
  - Operational level: Dispatch and route planning keep vehicles from reaching full and optimal utilisation
  - Tactical level: Uncertainty about technical and economic potential pushes vehicles out of fleet planning and procurement

- Makeshift (i.e. ICE conversion) solutions
  - Possible technological lock-in for maintenance and support
  - Converting end-of-life ICEs can affect acceptance among driver staff
Obstacles to the deployment of BEVs in transport logistics

Automotive industry
- Scarce supply of suitable models at competitive prices: “chicken-egg-problem”
- Low willingness to produce and support electric models
- Like for ICE engines, standard driving cycles are used to provide information about energy consumption and maximum ranges
- Bottlenecks in service infrastructure

Authorities
- Administrative bodies often lack qualification
  - Process of vehicle licensing extended
  - Police, fire brigades, and emergency services lack experiences
Wrap up

Obstacles to the deployment of BEVs in transport logistics

A side note on attempts to extend public charging infrastructure:

Corporate fleet operators…

- … have their own charging points at loading bays or inside their terminals
- … usually charge their vehicles at night when off duty
- … consider charging en route as impractical and time-consuming
- … therefore are rarely interested in an extensive network of public charging points
### Outlook

#### Directions for future work

### Automotive industry
- Offer models meeting fleet operators’ needs at competitive prices

### Authorities
- Regulatory framework to facilitate new, BEV-exclusive business models

### Corporate users
- Improve decision making and overcome “organisational range anxiety”

### Scholars
- Help industry to manage range restrictions: Improve battery technology and vehicle design and adopt planning algorithms to the needs of BEVs

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**Key to success of e-mobility: economic efficiency!**
Thanks for a lot listening!

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ELECTRICALLY DRIVEN HEAVY COMMERCIAL VEHICLES IN URBAN AREAS

Results of a Case Study

Electric transport logistic vehicle technology and its application

Stuttgart March 19th, 2015
Agenda

- Mission & research questions
- Electrically driven heavy commercial vehicles
- Application fields & evaluation criteria
- Real life cases
- Results & conclusion
- Discussion
Mission & research questions

- **Usability** of electrically driven heavy commercial vehicles
  - **vehicle-related** technological feasibility and reliability
  - **trip-related** suitability for electric driving
- Post-utilization of **former military properties** for logistical purposes
- Highlighting **opportunities** ...
  - ... for **cities and regions**
  - ... for **companies** (carriers, freight forwarders, shippers)
- **Public acceptance** of electrically operated logistics vehicles
- **Generalization** of results
Mannheim and the Rhine-Neckar region

- One of Germany’s most important logistic hub areas
- More than 8’500 producing companies with more than 170’000 employees
- Shortage of land, especially for logistical purposes
- About 4’000 FTL each day
- About 50’000 km with conventionally driven heavy commercial vehicles each day
- Environmental problems (noise, particulate matter, greenhouse gas emissions)
- Restricted quality of life
Advantages of electrically driven heavy commercial vehicles

Local advantages

- Less ...
  - ... noise
  - ... particulate matter
  - ... air pollutants (e.g. nitrogen oxide)

Global advantages

- Less ...
  - ... greenhouse gas emissions
# Sample vehicle “E-Force”

## Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor</td>
<td>hybrid synchron, water cooled</td>
</tr>
<tr>
<td>Continuous power</td>
<td>2 x 93 kW</td>
</tr>
<tr>
<td>Max. power</td>
<td>2 x 150 kW</td>
</tr>
<tr>
<td>Top speed</td>
<td>87 km/h (limited)</td>
</tr>
<tr>
<td>Max. payload</td>
<td>10 t</td>
</tr>
</tbody>
</table>

## Battery

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>LiFeP04 2 x 120 kWh 400 V</td>
</tr>
<tr>
<td>Weight</td>
<td>2 x 1'300 kg</td>
</tr>
<tr>
<td>Time to charge</td>
<td>6 hours @ 44 kW</td>
</tr>
<tr>
<td>Battery exchange</td>
<td>5 min.</td>
</tr>
</tbody>
</table>

## Consumption

<table>
<thead>
<tr>
<th>Type</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
<td>60-90 kWh / 100 km</td>
</tr>
<tr>
<td>Highway</td>
<td>80 - 100 kWh / 100 km</td>
</tr>
</tbody>
</table>

## Operating range

<table>
<thead>
<tr>
<th>Type</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
<td>300-350 km</td>
</tr>
<tr>
<td>Highway</td>
<td>200-250 km</td>
</tr>
</tbody>
</table>

*Source: E-Force AG: Fact Sheet „E-Force“ (2015); all Pictures: © E-Force*
Noise reduction

Source: Pallas et al: Noise emission assessment of a hybrid electric mid-size truck, Laboratory of Environmental Acoustics LAE, Lyon 2013
Reduction of greenhouse gases (CO2)

![Graph showing CO2 emissions for different types of vehicles.]

- Diesel (Euro VI): 730 g CO2/km
- Electrically driven (electricity mix DE): 463 g CO2/km (42% reduction)
- Electrically driven (electricity mix CH): 48 g CO2/km (94% reduction)

Operating range of electrically driven vehicles

- **75 kilometers**
  - round trip without re-charging
  - additional trips without re-charging

- **150 kilometers**
  - round trip without re-charging

- **300 kilometers**
  - round trip with re-charging at destination
Application fields

- **A:** Local distribution with electric vehicles (LTL)
  - ![Diagram of local distribution with electric vehicles (LTL)]

- **B:** Long-haul semitrailer transport (FTL), operated by electric tractors within the city
  - ![Diagram of long-haul transport with electric tractors]

- **C:** Electric heavy commercial vehicles or tractors operating in pre-haul and post-haul of intermodal (combined) transport solutions
  - ![Diagram of electric heavy commercial vehicles or tractors]

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Baden-Württemberg

STADTMANNHEIM

IHK Rhein-Neckar

Hochschule Heilbronn

Fraunhofer IAO
## Evaluation criteria

<table>
<thead>
<tr>
<th></th>
<th>unlimited</th>
<th>with restrictions</th>
<th>prospective</th>
<th>unrealistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric vehicle</td>
<td>available</td>
<td>available with modifications</td>
<td>ongoing development process</td>
<td>not planned</td>
</tr>
<tr>
<td>Single trip</td>
<td>without re-charging</td>
<td>with re-charging</td>
<td>enhanced battery technology needed</td>
<td>unsuited</td>
</tr>
<tr>
<td>Day trip</td>
<td>without re-charging</td>
<td>with re-charging</td>
<td>enhanced battery technology needed</td>
<td>unsuited</td>
</tr>
<tr>
<td>Flexibility</td>
<td>additional trips possible</td>
<td>restricted to current day-trip</td>
<td>current day trip needs to be modified</td>
<td>unsuited</td>
</tr>
<tr>
<td>Breaks</td>
<td>sufficient</td>
<td>minor extensions needed</td>
<td>redesign of breaks and driving time needed</td>
<td>not sufficient</td>
</tr>
</tbody>
</table>
Real Life cases

- Evaluation of **real life cases** on current truck operations in the Rhine-Neckar region

- **Land transport**
  - **Round trips** with semi-trailers (FTL) between regional manufacturing and storage areas
  - **B2B urban distribution** (parts, packages and general cargo) with heavy commercial vehicles
  - **B2C customer deliveries** (general cargo and building materials) with heavy commercial vehicles

- **Road feeder services in air cargo**
  - **Collection and distribution of air cargo items** with medium-sized (N2) or heavy (N3) commercial vehicles
  - **Round trip for air cargo items** between Mannheim and Frankfurt Airport with heavy commercial vehicles
Real Life Case A: Groupage operations

Facts

- Collection and distribution of general cargo (chemicals, building materials) for various shippers and consignees
- Consumer deliveries with building materials
- Usage of medium commercial vehicles (N2) < 12 tonnes
- Substitution by heavy commercial vehicles (N3) < 18 t planned
- Day-trips up to 300 km (143-190 km in average) with daily route planning and scheduling
- Trucks operating from 7 a.m. to 4 p.m. (single-shift operation)
- Up to three breaks (about 20 minutes) between the runs for loading and unloading

Findings

- (Nearly) all trips < 300 km could be operated with the electrically driven vehicle „E-Force”
- Resting time (4 p.m. to 7 a.m.) is sufficient for re-charging
- The company is very interested in checking out an electrically driven truck
Real Life Case B: Road Feeder Services (RFS) in Air Cargo

**Facts**

- Collection of air cargo items from various consignors during daytime (three trips per shift)
- Round trips between freight forwarder and Frankfurt airport at night (two trips per shift)
- Usage of heavy commercial vehicles (N3)
- Scheduled break of one hour after finishing the daytime operations
- Additional break of one hour within day and night trip (unloading and loading time)

**Findings**

- All trips can be operated with the electrically driven vehicle „E-Force“
- A heavy commercial vehicle with a maximum mass exceeding 18 tonnes – as it is used at present – is not available yet (maybe forthcoming in 2015)
- Breaks of about an hour are not sufficient for re-charging the batteries completely; thus a battery-exchange system is needed
Results

- All real life cases are in step with actual practice as they represent **real truck operations** by freight forwarders in the Rhine-Neckar region.
- The **application fields** that were selected, i.e.
  - collection and distribution
  - pre-haul and post-haul in combined transport
  - FTL and LTL operations are **representative** for numerous similar truck operations
- According to the results of the real life cases the **number of trips that could be electrically operated** with vehicles which are **already available** is much higher than estimated.
Conclusion

- According to the real life cases **up to 75 % of all truck operations** with heavy commercial vehicles in the Rhine-Neckar area could be operated electrically, but ...

- Operating electric trucks in the selected cases is still **not profitable**
  - The purchase price for „E-Force“ is about EUR 335’000 (as of February 2015), compared to EUR 95’000 for a comparable diesel truck
  - Operating costs are 55 % less, compared to a diesel truck
  - Maintenance costs are 35 % less, compared to a diesel truck

- Additional **public support**, e.g. tax exemptions or subsidies, is considered to be useful for market penetration

- In **Switzerland**, electrically driven vehicles are exempted from road charging (0.37 CHF per km)

- **Economies of scale** through high-volume production and decreasing battery costs are going to increase efficiency
  - Battery prices are expected to decline by 38 % until 2020

- **New properties** for freight forwarders and carriers operating electrically driven vehicles are complementary measures

- **Additional real life cases** should be evaluated to get more information on the existing possibilities of electric driving
Initial responses
Thank you for listening …

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...research and solutions for a sustainable world
“Barriers”
Possible barriers have been discussed and identified from the participants:

- **Driving range**
- **Infrastructure**
  - Long distance transportation
  - Last mile delivery in metropolitan areas
- **No business case for OEMs**
  - OEMs do not accept orders of size <50
  - No EVs offered by OEMs/retailers
  - Cannot capture economies of scale
- **Lack of information/specs**
  - Before purchasing the EV
  - About the 2nd hand market
  - During the cruise (when to recharge, where to find station, etc.)
- **Technology cost and availability**
- **Lack of public awareness/interest**
- **Missing recharging standards (many standards)**
“Barriers”

- Missing H2 infrastructure
- Limited public procurement
- Less flexibility in multi-purpose logistics tasks/fleet
  - Difficulty in relocating the fleet to a different city
- External costs of ICEs are not priced
  - Noise/CO2 impacts
- Limited warranty/lack of trained personnel for maintenance & repair
- Technology reliability
- Subsidies to ICEs (ease of access, cheap price for rental and leasing)
- Public charging blocked by ICE vehicles
“Drivers”
Possible drivers have been discussed and identified from the individual perspectives of the participants which are clustered and explained in more detail in the following:

• **General perspective:**
  – The rising awareness on climate change and, therefore, increasing demand for all electric vehicles
  – Addressing all-electric vehicle usage in city transportation policy (low emission vehicle in terms of noise or CO₂ and pollutants)
  – Making progress in standardization issues (e.g. charging infrastructure)
  – Benchmarking: Information transparency regarding technical, economical and acceptability issues of vehicle operation (e.g. driving experiences, vehicle performance, etc.)
  – Charging infrastructure availability
Technology perspective:
- Further developments in battery technology (e.g. enhancing specific power/energy density) to improve operating performance (e.g. driving range)
- Autonomous driving
- Second-life concepts for battery usage

Fleet operator perspective:
- Purpose design of the vehicle especially matched to requirements of the transport task and of the requirements of the drivers
- Using the positive "green" image of all electric vehicles as unique selling point (USP)
“Drivers”

- New business model by offering grid power of the all-electric vehicle fleet
- Driving restrictions within high polluted areas
- Clear and stable boundary conditions – low risk for the investment in all-electric vehicles
- Availability of all-electric vehicles
- Reduced payback periods through multi-shift operations
- Economic efficiency
- Time savings due to no waiting line at charging points in contrast to fueling stations
“Drivers”

• **Energy provider perspective:**
  – New business model by making charging points available

• **Vehicle industry perspective:**
  – Credit points for low emission vehicles required to be allowed to sell vehicles on the market (in analogy to the passenger car regulation in the USA, California)
  – Clear and stable boundary conditions – low risk for the investment in R&D as well as production capacity for all-electric vehicles
“Strategies”
“Strategies”

- **Marketing and communication for more Awareness:**
  - EV centre for all questions and education
  - More awareness for the end customers by advertising and TV commercials
  - Strengthen awareness for overall change of mind towards CO2 goals
  - More real life tests and demo projects and a good communication around it
  - Bring it in the discussion for the city future
  - By involving end customer in supporting CO2 – neutral logistics (involve the whole chain)
• **Subsidies:**
  – Easy and clear/ transparent subsidies
  – Incentives for EV trucks on EU base

• **Facts and figures:**
  – Good analyze of the business case
  – Clear picture of the ecology targets during the lifecycle
“Strategies”

- **Targets:**
  - Clear targets: 2025 => …. EV trucks: 2035=> ……EV trucks
  - Bring together customer demands for larger quantities and lower vehicle costs.
  - Standard EU “zero Emission” arias/cities like Madrid, London, Stockholm, Amsterdam etc (it will be for the OEM’s easier when all cities will have the same requirements and time schedules)
  - Manufacturer (OEM): longer battery warranty and full mobility solution service (repair and maintenance contract for longer period > 8 year)
“Expectations”
First, the participants identified the problems (blue cards) that should be overcome.

• Incentives and regulations at EU level: The problem is that there are several different strategies in the EU.
  – The task could act as a catalyzer to bundle the European strategies for the incentives and regulations.
• City specific issues: The problem is that there is no common strategy among the cities. Furthermore, electrification of logistics does not have a high priority for many cities, but only passenger cars.

– Participants identified that cooperation with city networks and metropolis regions is crucial for task 27 in order to increase awareness and to bundle the strategies. Moreover, cities may benefit from bundling their requirements and procurements. Furthermore, the task may prepare a publicly available TCO-tool in order to show the hotspots. Another suggestion was to think on private-public-partnerships for electrified logistic vehicles, which was discussed among participants without a consensus.
“Expectations”

- Variety of applications for LDV/HDV: One of the problems is the variety of different applications for the electrified vehicles, which are not standardized.
  - The Task may accelerate the cooperation of different industrial companies, in order to bundle the requirements and standards, so that higher production volumes are possible, which will reduce the costs.

- Focus on R&D: R&D is the key for the electrification of logistics vehicles
  - The task can also accelerate the cooperation of research organizations.
“Expectations”

- There is a need to transfer the information from desktop to the “real life”
  - The task may use platforms, workshops, PR activities etc. in order to increase the awareness and knowledge transfer