Introduction to Bus Electro-Mobility Development in Germany

Hinrich Helms, Fabian Bergk and Nicolas Legner
Beijing, November 20th 2015
The ifeu

- In **1971**, professors and students founded the AGU: Working Group on Environmental Protection at the University of Heidelberg.

- The need for independent environmental research led to the foundation of ifeu as a non-profit organisation in **1978**.

- In **1992**, ifeu was incorporated been a GmbH (limited liability company) with non-profit status as of **1999**.
• At present, ifeu has a staff of about 60 scientists who work as an interdisciplinary team with a broad variety of expertise on current environmental topics.

• The institute is committed to the goal of a sustainable society.
Financing

• Financing solely through *project-related funds* to allow a politically and economically *independent ecological research*.

  – Approximately *two-third* of the research projects and assessments are commissioned by federal and state ministries, local authorities, the Environmental Protection Agency and other public bodies.

  – *A third* of the orders come from the private sector.
Clients (selection)

European Union
- European Environment Agency
- European Commission

World Bank, UNEP, FAO, etc.
- UNIDO
- IEA
- UNFCCC
- THE WORLD BANK

Non-governmental Organisations
- Greenpeace
- NABU
- VCD
- Bund

Departments of Federal, State and Local Governments
- Federal Ministry Department (Environment, Economy, Transport)
- State Departments

Transport and Logistic Service Providers
- DB
- Deutsche Post
## Clients (selection)

<table>
<thead>
<tr>
<th>Industrial Associations</th>
<th>Companies</th>
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</thead>
<tbody>
<tr>
<td>PlasticsEurope</td>
<td>Coca-Cola</td>
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<td>edana</td>
<td>DANONE</td>
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<tr>
<td>Auto Club Europa</td>
<td>PET CYCLE</td>
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<tr>
<td>DGfH</td>
<td>SIG</td>
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<td>Verband Metallverpackungen</td>
<td>BMW</td>
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<td>BMW</td>
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<td>MVV Energie</td>
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<td>BAYER</td>
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<td>Red Bull</td>
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<td>P&amp;G</td>
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<td>Tetra Pak</td>
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</tbody>
</table>

## Organisations of Development cooperation

- inWent
- CDG Carl Duisberg Gesellschaft e.V.
- Intenationale Weiterbildung und Entwicklung gGmbH
- GOPA Worldwide Consultants
- giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
- Kimberly-Clark
- Tetra Pak

## Schools, Public Services, ASEW, Consumer Advice Centre

- MVV Energie
- BAYER
- Red Bull
- P&G
- Tetra Pak

## Foundations

- DGB Grüne Pumpe
- BMW
- Danone
- Shell
- BMW

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## Departments

<table>
<thead>
<tr>
<th>Department</th>
<th>Head of Department</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nutrition and Biomass</strong></td>
<td>Guido Reinhardt, PhD, biologist, chemist, mathematician</td>
</tr>
<tr>
<td><strong>Industry and Products</strong></td>
<td>Jürgen Giegrich MSc, physicist</td>
</tr>
<tr>
<td><strong>Transport</strong></td>
<td>Udo Lambrecht MSc, physicist</td>
</tr>
<tr>
<td><strong>Energy</strong></td>
<td>Lothar Eisenmann MSc, physicist</td>
</tr>
</tbody>
</table>
Areas of Work

- Waste Management and Resource Conservation
- Environmental Education
- Energy (and Renewable Energies)
- Industry and Products
- Nutrition and Biomass
- Sustainability
- Life Cycle Assessment (LCA)
- Risk Assessment
- Environmental Impact Analysis (EIA)
- Strategic Environmental Assessment (SEA)
- Traffic and Transport
- ... and many others
Agenda.

1. National strategy on electric mobility
2. Overview on Electric/Hybrid Bus Programme
3. Evaluation Results of Electric Buses in Germany
4. Comparison of different drive train options
Timeline of Electric Mobility Policy in Germany

- National Strategy Conference Electric Mobility (2008)
- Economic Stimulus Package II (2009)
- National Electromobility Development Plan (2009)
- Joint Agency for Electric Mobility – GGEMO (2010)
- National Electric Mobility Platform (2010)
- Government Program Electromobility (2011)
- Electric Mobility Act (2014)
Model Regions Electromobility 2009 - 2011

- Part of the Economic Stimulus Package II
- Funding of electric mobility projects in 8 regions by the Federal Ministry of Transport and Digital Infrastructure (BMVI)
- Coordination and management by NOW GmbH (National Organisation Hydrogen and Fuel Cell Technology)
National Electromobility Development Plan

- Electromobility as part of a national strategy to become ...
  - a lead market for electromobility
  - a leading supplier of electromobility

- National Development Plan Electromobility (2009)
  - Goal of 1 Million vehicles until 2020
  - Goal of 6 Million vehicles until 2030

(For comparison: Currently 44 Million passenger cars registered in Germany)
National Platform for Electric Mobility

- Founded May 2010 and reports to the Federal Government
- Brings together stakeholders from industry, science, politics, trade unions and associations for a strategic dialogue
- Observes and analyses the development in the field of electro mobility
- Seven Working Groups with about 20 representatives develop measures and recommendations for electro mobility:
  - Drive train technology
  - Battery technology
  - Charging infrastructure and grid integration
  - Standardisation and certification
  - Materials and recycling
  - Education and training
  - Framework conditions
National Platform for Electric Mobility

- Supported by the Joint Agency for Electric Mobility (Gemeinsamen Geschäftsstelle Elektromobilität (GGEMO))
- Collaboration of four ministries:
  - Federal Ministry for Economic Affairs and Energy
  - Federal Ministry of Transport and Digital Infrastructure
  - Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
  - Federal Ministry of Education and Research
National Platform: The approach

- Systemic from the users’ point of view
- Open technology, covering battery electric vehicles (BEV) but also plug-in hybrids (PHEV) and range extenders (REEV)
- Market oriented

![Diagram showing the three phases of the national platform: pre-market phase, market ramp-up phase, and mass-market phase. Each phase focuses on different aspects such as R&D, training, market building, and sustainable business models.]
Discussed measures

- Introducing a special depreciation of 50% in the first year for commercial users because fleets and company cars are seen as a gateway to electric mobility
- Strengthening investment partnerships between the public and private sectors to develop publicly accessible charging infrastructure
- Implementing the EU directive on alternative fuels including the expansion of the charging infrastructure
- Implementing public and private initiatives to integrate electric vehicles in fleets
- Continuing research and development with Federal Government support
- Promoting the establishment of a long-term cell manufacturing facility in Germany
Showcase Program 2012-2015

- Living Lab BW E-Mobil (Baden-Württemberg)
- International Showcase of Electromobility (Berlin / Brandenburg)
- Our horse powers becomes electric (Lower Saxony)
- Electromobility connects (Bavaria / Saxony)
German E-Mobility Law (EmoG)

Effective from June 2015

Enables municipality for privilege electric vehicles

- Definition of privileged vehicles
- Implements Labelling on licence plate
- Enables privileges for parking
- Enables use of bus lanes
- Enables access to restricted areas
New registrations of alternative drive trains

- New registrations rising, but still limited

Total: 3 Mio per year
Agenda.

1. National strategy on electric mobility
2. Overview on Electric/Hybrid Bus Programme
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4. Comparison of different drive train options
Drivers for Electrification of Buses

• Reduction of (fossil) energy consumption
• Reduction of GHG-Emissions
• Integration of renewable energy
• Integration of new technologies (Batteries, Ultra-Caps, Fast-Chargers)
• Rising oil prices
• Emissions of air pollutants
• Noise
Overview of electric bus program

- Funding by
  - Federal Ministry for Economic Affairs and Energy
  - Federal Ministry of Transport and Digital Infrastructure
  - Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
- Subsidies for market penetration of hybrid (diesel-electric) buses
- Pilot projects for electric buses
Funding for Hybrid Bus

- Since 2012 as part of the National Climate Protection Initiative (NKI) of the Ministry for the Environment (BMUB)
- 60 Hybrid buses funded in 6 transport companies over the last two years
- Extended until 2017
  - Up 35% of additional costs for Plug-In Hybrids
  - For conventional hybrid limited for vehicle costs at 100,000 € for solo and 200,000 € for articulated buses
Pilot projects with alternative buses in Germany

- 29 projects
- 34 companies
- 171 diesel hybrid buses
- 86 solo buses
- 85 articulated buses
- 25 electric buses
- 12 Fuel cell buses

Supporting ministries:
- BMVI
- BMUB
- BMWi

Source: [AG Innovative Antriebe Bus 2015]
A closer look at selected bus projects...

- 29 projects
- 34 companies
- 171 diesel hybrid buses
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Supporting ministries:
- BMVI
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- BMWi

Source: [AG Innovative Antriebe Bus 2015]
Berlin: E-Bus Berlin

- Four vehicles on Line 204
- Urbino 12 Electric from Solaris
  - 90 kWh Li-Ion-Battery
  - Battery weight 1.1 Tonne
  - 70 passenger capacity
  - 160 kW electric engine

Source: http://e-bus.berlin/
Berlin: E-Bus Berlin

- Inductive fast charging with 200 kW (4-7 Minutes)
- Charging system Primove of Bombardier
- Concept opportunity charging at terminal stops

Source: [http://e-bus.berlin/](http://e-bus.berlin/)
A closer look at selected bus projects...

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Source: [AG Innovative Antriebe Bus 2015]
Hannover: Emission free local traffic Hannover

- Test of 3 Electric buses (Solo)
- 140-160 kWh Battery pack
- Circular Line 100/200 (only 1 terminal stop)
- 16 km total length, 10 Minute daytime frequency
- Recharging from tram catenary lines (6 Min. for 25 kWh)

Source: http://www.erneuerbar-mobil.de/
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Source: [AG Innovative Antriebe Bus 2015]
Hamburg: HELD

HELD: Hamburg Electric Bus Demonstration

- 3 PlugIn Hybrids and 3 Electric Buses until 2017
- Line 109 over 10 km in inner city
- Opportunity charging at terminal stops
- Fast charging with up to 300 kW
- Pantograph connection

Source: http://www.erneuerbar-mobil.de/
Hamburg: Blankenese

- Rampini Solo-Bus with Siemens Engine (12 m)
- 180 kWh LFP-Battery (100 km Range)
- 5.2 km route on Line 48 in HH-Blankenese (18 Minutes = as for Diesel)
- Steep road up to 16% grad
- Conductive nighttime charging depot and short recharging periods at terminal stop (20 Minutes)

Source: http://griin.de/mobilitaetskonzepete/erster-elektro-bus-in-hamburg-blankenese
A closer look at selected bus projects...

29 projects
34 companies
171 diesel hybrid buses
86 solo buses
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Supporting ministries:
- BMVI
- BMUB
- BMWi

Source: [AG Innovative Antriebe Bus 2015]
Braunschweig: emil (Showcase project)

- Test of 4 Solaris Electric Buses since 2014 on Line M19
  - 1 x 12 m Solo Bus (60 kWh Primove Battery)
  - 4 x 18 m Articulated Bus (90 kWh Primove Battery)
- Primove Inductive Charging System (> 90 % Efficiency)
- Fast charging with 200 kW

source: http://www.verkehr-bs.de/unternehmen/forschungsprojekt-emil/elektrobus.html
Agenda.

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Composition of the Working Group:

- 25 Transport Companies
- Industry representatives (10 manufacturer and supplier of innovative city buses)
- Association of German Transport Companies (VDV)
- Representatives of Transport Associations
- 8 Organisations from science and consulting
Evaluation data and categories

Evaluation based on
a. Continuous web based data collection
b. Single emission measurements

Evaluation categories
• Road capability
• Energy efficiency
• Emission/GHG Reduction
• Cost effectiveness
• Acceptance

Source: own representation based on [AG innovative Antriebe Bus 2015]
Total mileage evaluated so far ...
Total mileage evaluated so far …

- Daily operation data of more than 10 Million km have been collected since 2013
- Good data base for hybrid and diesel buses
- Fewer data for electric buses included so far, because...
  - ... only 4 electric buses have been evaluated so far
  - ... electric buses have a lower monthly performance (daily range of electric buses limits the monthly mileage)
- But more electric buses are currently being operated ... ... more data to be expected
Monthly performance of hybrid buses ranges from 2200 km to 7900 km depending on the company.

Average: 4,400 km

Number of hybrid buses: 123

Timeframe: Jan 2013 – Sep 2014

Source: own representation based on [AG innovative Antriebe Bus 2015]
... and monthly performance of battery buses

Number of electric buses: 4
Time frame: Jan 2013 – Sep 2014

Source: own representation based on [AG innovative Antriebe Bus 2015]
Hybrid buses: availability and defects

Hybrid buses total: 533,637 h

- Operation: 82.0%
- Hybrid defect: 5.7%
- Other defect: 9.0%
- Maintenance: 3.3%

Number of hybrid buses: 111
Space of time: Jan 2013 – Sep 2014

Source: own representation based on [AG innovative Antriebe Bus 2015]
Electric buses: availability and defects

Electric buses total: 8,492 h

- Operation: 66.7%
- Other defect: 18.3%
- Maintenance: 12.5%
- EV Defect: 1.3%
- Charging station defect: 1.3%

Number of electric buses: 4
Space of time: Jan 2013 – Sep 2014

Source: own representation based on [AG innovative Antriebe Bus 2015]
Availability Overview

Hybrid buses:

- Availability of 82 %
- Hybrid specific defects caused failures of 6 % of operating hours (other defects 9 %)
- The percentage of maintenance is comparable to conventional buses

Electric buses:

- Availability of 67 %
- The small quantity (only 4 buses) stresses one-time incidents
- Two of the four buses have an availability of about 80 %
- Development of availability shows an increasing learning curve during the survey
Fuel savings of hybrid buses compared to diesel

Parallel buses have higher savings compared to serial buses

Number of buses: 123
Timeframe: Jan 2013 – Sep 2014

Source: own representation based on [AG innovative Antriebe Bus 2015]
Correlation of fuel consumption to temperature

Hybrid buses has heating and cooling!

Source: own representation based on [AG innovative Antriebe Bus 2015]
Correlation of fuel consumption to temperature

Diesel bus only with heating, but no air conditioning!

Source: own representation based on [AG innovative Antriebe Bus 2015]

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Electric bus consumption for heating

Heating consumption can be as propulsion consumption

Source: own representation based on AG innovative Antriebe Bus 2015
Emission behaviour of hybrid solo buses compared to conventional diesel bus – Euro V EEV

Solo buses of all cities and lines
Reference: Solaris + MAN, EEV

- CO2
  - EFBEL, Hybrid (Serial): -38%
  - EFBEL, Hybrid (Parallel): -18%
  - EFBEL, Diesel (Euro VI): -51%
  - EFBEL, Diesel (light-weight): -60%

- NOx
  - EFBEL, Hybrid (Serial): -56%
  - EFBEL, Hybrid (Parallel): -51%
  - EFBEL, Diesel (Euro VI): -10%
  - EFBEL, Diesel (light-weight): -29%

- NO2
  - EFBEL, Hybrid (Serial): -96%
  - EFBEL, Hybrid (Parallel): -58%
  - EFBEL, Diesel (Euro VI): -51%
  - EFBEL, Diesel (light-weight): -29%

Source: own representation based on [AG innovative Antriebe Bus 2015 0]

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Running time of the diesel engine

**Space of time:** 01.01.2013 – 01.12.2013

**Vehicles:** 5 articulated serial-hybrid SSB

**Total time**
- Diesel engine running: 54%
- Diesel engine off: 46%

**Driving time (65%)**
- Diesel engine running: 40%
- Diesel engine off: 60%

**Downtime (35%)**
- Diesel engine running: 81%
- Diesel engine off: 19%

In Stuttgart regenerative breaking 80 kWh/100km (36% of total energy)
Running time of the diesel engine

**Space of time:** 01.03.2014 – 31.10.2014

**Vehicles:** 7 Solo parallel-hybrid VHH

- **Total time:**
  - Diesel engine running: 83%
  - Diesel engine off: 17%

- **Driving time (55%):**
  - Diesel engine running: 94%
  - Diesel engine off: 6%

- **Downtime (45%):**
  - Diesel engine running: 70%
  - Diesel engine off: 30%*

* estimated

**Source:** own representation based on [AG innovative Antriebe Bus 2015]
Share of electric driving (hybrid buses)

Decrease with speed

<table>
<thead>
<tr>
<th>km/h</th>
<th>Articulated Hybrid (Serial)</th>
<th>Solo Hybrid (Serial)</th>
<th>Solo Hybrid (Parallel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>90</td>
<td>80</td>
<td>70</td>
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<tr>
<td>5</td>
<td>85</td>
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<tr>
<td>65</td>
<td>25</td>
<td>10</td>
<td>0</td>
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</tbody>
</table>

% of operation time

Source: own representation based on [AG innovative Antriebe Bus 2015]

All cities and lines, EFBEL incl. downtime
Cost situation: Conventional Diesel Bus

Total costs today dominated by fuel consumption, invest and maintenance

- 35% fuel consumption
- 27% maintenance
- 29% debt service
- 4% others
- 5% supply

Source: own representation based on [AG innovative Antriebe Bus 2015]
Total costs of hybrid and reference bus

Hybrid Buses decrease energy costs, but still increase invest and maintenance => Future perspective?
Agenda.

1. National strategy on electric mobility
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Mobility and Fuels Strategy (MFS)

What is the MFS?
- Initiated by the German Ministry of Transport (BMVI) in 2011
- Development of a „learning strategy“ including all modes
- Technology-open
- Focusing on mid and long-term solutions
- Participation of stakeholders from politics, economy, science
- Publication of scientific studies on different topics

Goals:
- Reduction of (fossil) energy consumption
- Reduction of GHG-Emissions
- Integration of renewable energy
- Integration of new technologies and mobility concepts
Comparative Study on Bus Power trains

- Bus power trains in public transport compared
  - Overview on use worldwide and in Germany
  - Energy and environmental assessment compared to diesel
  - Cost situation in Germany compared to diesel

- Comparison of the situation today and the future perspective
Comparison of different fuel concepts

Object of comparison
- Articulated Buses

Concepts:
- Diesel-Euro VI (Hybrid assumed from 2020)
- Overnight-Charger
- Opportunity-Charger
- Trolley-Hybrid
- Fuel-Cell-Hybrid

Criteria:
- Emissions (GHG, criteria)
- Costs
  - Vehicles
  - Operation (Energy)
  - Infrastructure
- Operational Requirements (minimal constraints for the schedule, flexibility)
## Comparison of different fuel concepts – technical specifications

<table>
<thead>
<tr>
<th>Variante</th>
<th>Infrastructure</th>
<th>Vehicle</th>
<th>Energy converter</th>
<th>Power train</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy supply</td>
<td>Energy storage</td>
<td></td>
<td></td>
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<tr>
<td>Dieselbus EURO VI</td>
<td>Gas station</td>
<td>Tank</td>
<td>ICE</td>
<td>Automatic transmission + Drive axle</td>
</tr>
<tr>
<td>(Hybrid assumed from 2020)</td>
<td></td>
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</tr>
<tr>
<td>Trolley-Hybrid</td>
<td>Catenary</td>
<td>Battery (70 kWh)</td>
<td>Electric engine + power electronics</td>
<td>Drive axle</td>
</tr>
<tr>
<td>Overnight eBus</td>
<td>Conventional charging (conductive)</td>
<td>Battery (400 kWh)</td>
<td>Electric engine + power electronics</td>
<td>Drive axle</td>
</tr>
<tr>
<td>Opportunity eBus</td>
<td>Fast charging (conductive, inductive)</td>
<td>Battery (180 kWh)</td>
<td>Electric engine + power electronics</td>
<td>Drive axle</td>
</tr>
<tr>
<td>Brennstoffzellen-Hybrid</td>
<td>Compressed hydrogen station</td>
<td>Compressed hydrogen tank + Battery (30 kWh)</td>
<td>Fuel cell stack + Electric engine + power electronics</td>
<td>Drive axle</td>
</tr>
</tbody>
</table>
Comparison of different fuel concepts – GHG-Emissions (well-to-wheel + battery)

New buses in 2015/2025 [g CO$_{2eq}$/bus-km]

German electricity split

- Trolley: 2015 -29%, 2025 -66%
- Opportunity: 2015 -28%, 2025 -65%
- Overnight: 2015 -18%, 2025 -58%
- FC: 2015 -12%, 2025 -48%
- Diesel (Euro VI): 2015 -18%, 2025 -12%

Source: Prof. Pütz (energy consumption), TREMOD/ Leitstudie 2011 (emissions operation), elCar (upstream emissions battery)
Comparison of different fuel concepts – air pollutants

**NO\textsubscript{x} -Emissions [g/Bus-km]**

- No tailpipe emissions for electric busses → important for urban air quality

**PM-Emissions [g/Bus-km]**

Source: Prof. Pütz (energy consumption), TREMOD/ Leitstudie 2011 (emissions operation), elCar (upstream emissions battery)
Total Costs of ownership per articulated bus (2015) – preliminary results!

Source: Prof. Dr. Ralph Pütz

- Possible reduction of investment costs bus
- Annuity Investment Bus
- Energy costs
- Maintenance and repair
- Annuity Investment Infrastructure
Total Costs of ownership per articulated bus (outlook 2025) – **preliminary results!**

Energy costs
Maintenaince and repair
Annuity Investment Bus
Annuity Investment Infrastructure
First conclusions of the project

- Electric buses can reduce GHG-emissions through increased efficiency and the use of renewable energy
- All electric bus systems are subject to cost reductions in the next years. The economic gap between conventional buses will significantly narrow in the next decade
- All electric bus technologies have specific opportunities and risks, depending on individual conditions (acceptance, operating strategy, etc.)...

... therefore it is necessary to evaluate all alternative technologies regarding the implementation to specific cases (line/net)
First conclusions of the project

● The Hybrid-Trolleybus is one feasible technology of electric buses

● The economical differences between the electric bus technologies depend
  – on the cost development and life expectancy of batteries and fuel cell stacks
  – the costs and utilisation of charging infrastructure
First conclusions of the project

- The Hybrid-Trolleybus is one feasible technology of electric buses ...

... and maybe the Trolley bus has a comeback in Germany!

Source: based on [Spousta et al., 2013], [Müller, 1995], http://www.trolleymotion.eu/ (accessed 13.10.15)
Thank you for your attention!

Hinrich Helms, Fabian Bergk and Nicolas Legner