Institute for Power Electronics and Electrical Drives
Electrochemical Energy Conversion and Storage Systems
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Electrification of bus routes with ebuses & fast charging stations – in case of no overhead wires –

26.10.2012

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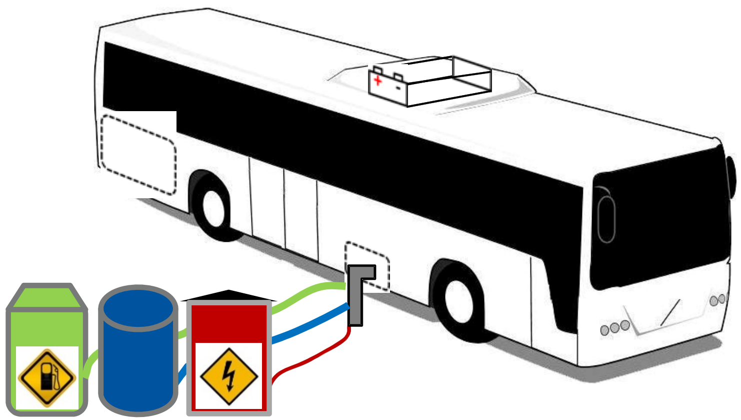

Electrification von Public Busses: It will happen! How quickly? Maybe faster than you expect!

- **A new market is emerging : Public busses will be electrified before cars will!**
  - Return on investment (ROI) regarding battery system is faster with e-busses than with e-cars because they are used more. Cars stand most of the time.
  - Not only money counts: Some customers (municipalities) apply environmental and image considerations in addition to funding aspects; they want moving electric hardware soon – while funding programms for hybrids and hydrogen are running out
  - New business models with local power supply companies may help in the municipal transition process and – most importantly – with the funding
  - Cost-Trends: Costs of electric busses will trend down since the most expensive compound – **the battery – is expected to improve in price and performance considerably.** Diesel bus costs begin to trend up (emission standard, fuel costs); TCO/500.000km will become very important in decision making

How much energy can be stored in one kg of battery cell?

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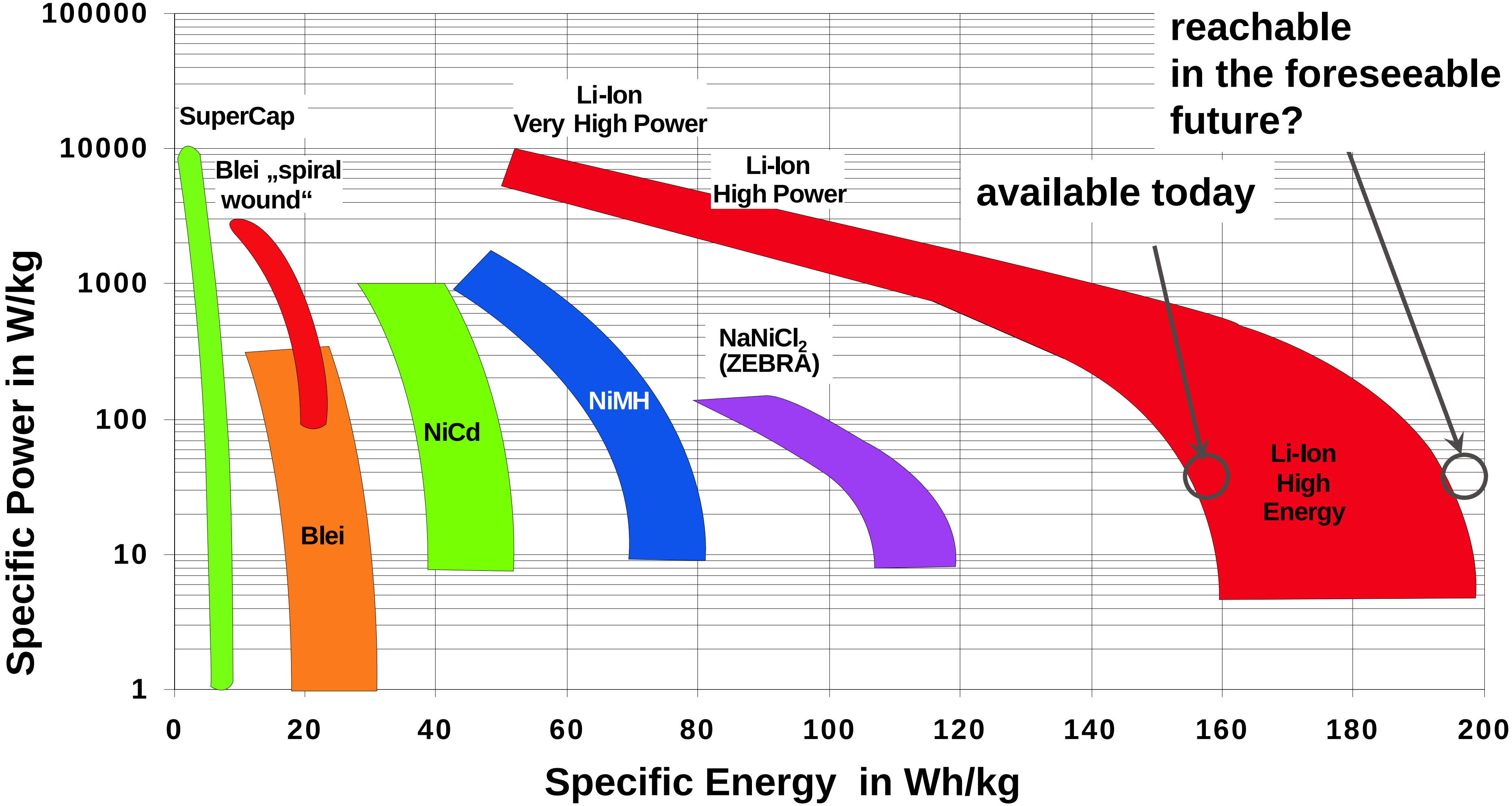
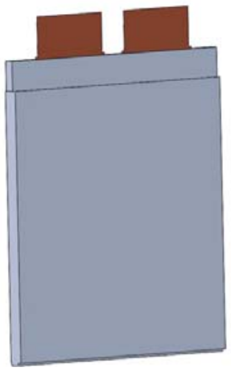


Today: ~ 160 Wh/kg **Foreseeable future: ~ 200 Wh/kg**

Optimization potential going from the battery cell to the battery pack:

Energy density is being reduced by **20 to 40 %**

going from the cell to the pack:



+ Electrical Safety Systems
+ Thermal Safety
  Thermal Management
+ Electronics for Monitoring
  und BMS
+ Reliable mechanical
  installation (inkl. Crash)

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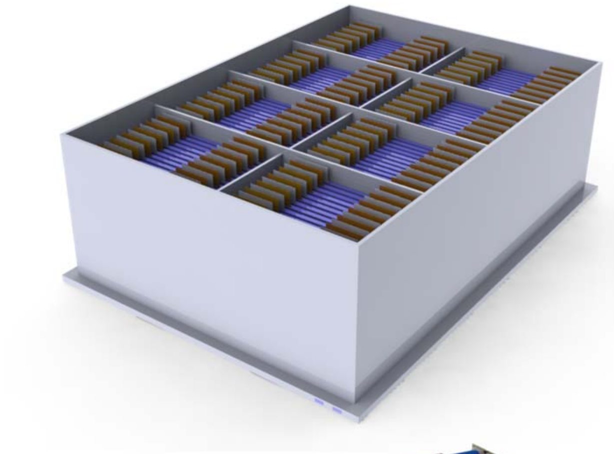
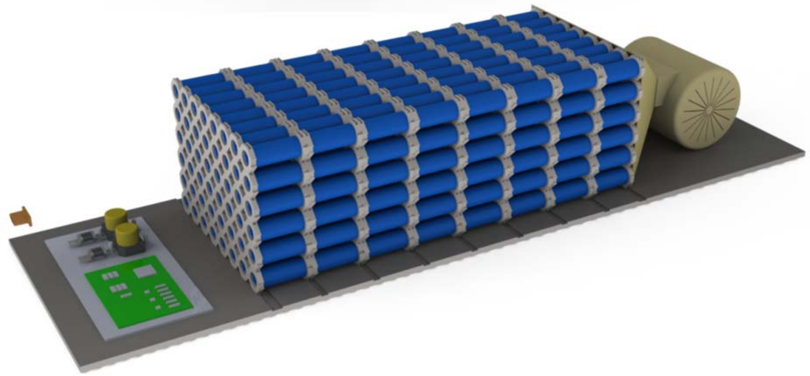
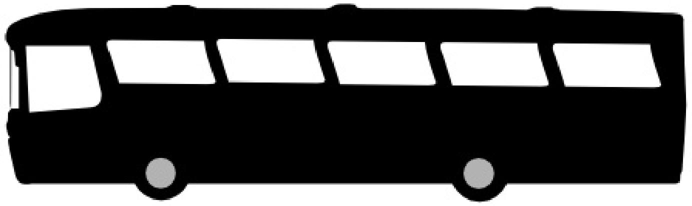




E-Busses use their battery system more than e-cars – chance and risk at the same time:



	Public Buses	**Passenger Car**
Range:	Depending on operation concept 10 - 50 km	>80 km
Operation hours per year	5,000 / year	400 / year
Average speed	18 km/h	30 km/h
15 years ➔	**16.875 full cycles**	**2.250 full cycles**

Who offers E-Busses?

- The new market is being approached by **relatively small and nimble companies** that are free of amortization needs regarding engineering efforts in „old“ concepts
- Established manufacturers tend to focus on their „old“ concepts that have not payed yet for their devellopment: Euro-IV-Norm, hybrids, hydrogen-fuel cell concepts
- Direct imports of cheap e-busses from **China**: Very risky!
- **Bus manufacturers in the european periphery:** Poland, Czechoslovakia, Turkey

Good entry chance for new players, if…

- **… they put the best of both worlds together:**
  - Integration in existing bus chassis and power electronics of European manufactures
  - Less expensive batteries from Asia
    - Requires performance checks, life time analysis and prognosis (independant quality assurance)
    - Ideally: Selection of suppliers guaranteeing a specific life time of their products
- **… they generate momentum and demonstrate new electric busses and charging concepts quickly – and successfully**
- …they **ideally use of public funding programs** to reduce risks
- …they make good use out of their closeness to markets and existing customer base for commercialization – which the Chinese can not match!

➔ This has already started!

Operational Requirements for E-Busses

- Long hours each day: up to 20 hours, up to 300 km/day
- Short charging duration („few minutes“, charging time should be approx. 10% or less of „driving time“)
- Dealing with the heat issue = potential noise problem: During charging about 10% of energy is lost as heat
- Very high reliability even at bad weather conditions
- Fast & easy exchangeability of components in case of failures
- Easy on bus drivers
- Heating in winter, cooling in summer (- on battery power?)
- Benchmarking costs near those of diesel buses

Infrastructure Requirements

- Assumption: A typical 12 m-Bus:
  - Ø-speed: 18 km/h
  - Energy consumption: 2.5 kWh/km (1,8 - 2,5kWh/km)

45 kWh consumption per hour

- Charging somewhere at the bus line
  - Accumulated non-driving time (Stops/hour): 20 min/h

20 min/h available time translates to 135 kW/h charging power

Source: Zonda New Energy BRT City E-Bus China;
http://www.zonda.com/en/NewsView.asp?ID=494

Example of a 12m-bus-battery system for <u>fast charging</u>

- Distance between 2 charges: 14 km
- Average speed: 18 km/h => 47 min. bus driving time for 14 km
- Energy requirement/charge: 25 – 35 kWh (1,8 - 2,5kWh/km for 12m-Bus)
- Depth of discharge: about 50% => 50 - 70kWh
- Charging duration: 5 min. (9,8% of sum of driving + charging time for 14km-cycle)
- Power of charge: 35 kWh/charge within 5min. => 420kW
- For a 70kWh-Battery this means approx. 6C charging rate => OK
- Lifetime: Up to ~7 years, depending on various factors (depth of (dis-)charge, temperature, etc.)
- A 70kWh LiIon-High Power-Battery system incl. cooling system:
  - approx. 1,5t weight (less weight in later years)
  - approx. 200.000€ invest costs “near future” (approx. 80.000€ in later years?)

Options of charging e-busses:

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- Battery exchange (battery on e-bus or on special trailer)
- Fast charging (opportunity charging)
- Slow charging (~2-4x / 24 hours)
- “One time charging”: Charging over night (1 charge / 24 hours)
- Induction

Comparison of Battery Use with Different Charging Strategies

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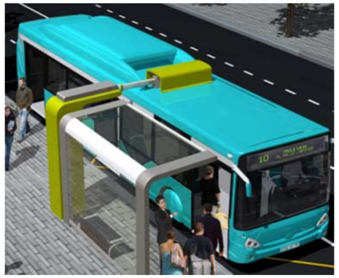


	Battery exchange	**Charging at every bus stop**	**Charging at final destination**	**One charge per day**
Number of cycles / day	3 – 8	150 – 250	5 – 20	1
Size of battery	50 – 200 kWh	5 – 10 kWh	50 – 100 kWh	200 – 400 kWh
Rate of charge	~ 1 C	~ 50 C	~ 5 - 10 C	~ 0,2 C
Rate of discharge	< 1 C	~ 10 C	~ 1 C	< 0,2 C
System Costs	High?	High?	Moderate?	Moderate?

Driving the bus all day with the same battery and only one charge

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http://www.hybrid-autos.info

- Charging only at night (in bus depot, power grid friendly)
- Minimum of ~10 hours of operation required per day (suitable only for a fraction of the entire municipal public bus fleet)
- Very large & heavy battery needed; „weight-conflict“ regarding number of passengers

Battery weight for „one-charge-per-day“ (12m bus)

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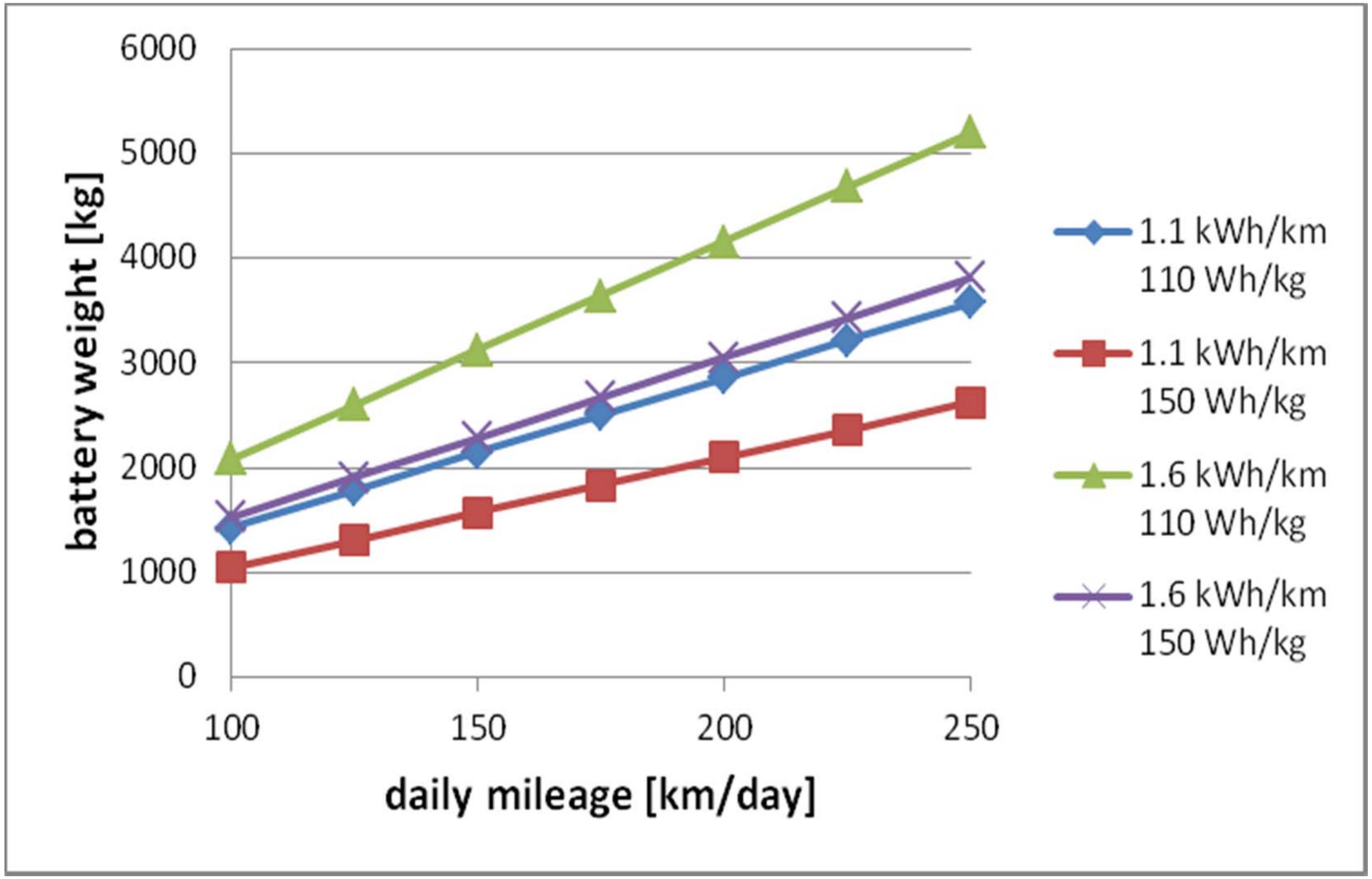
70% DOD Battery operation



Battery exchange

- Batteries either on bus roof or in luggage compartment
- Battery exchange by trailer exchange is being discussed, (and now being developed), however this may be a number of challenges in handling daily public bus operations

Source: Youtube

Quelle Wallner Energietechnik

Fast battery exchange of buses

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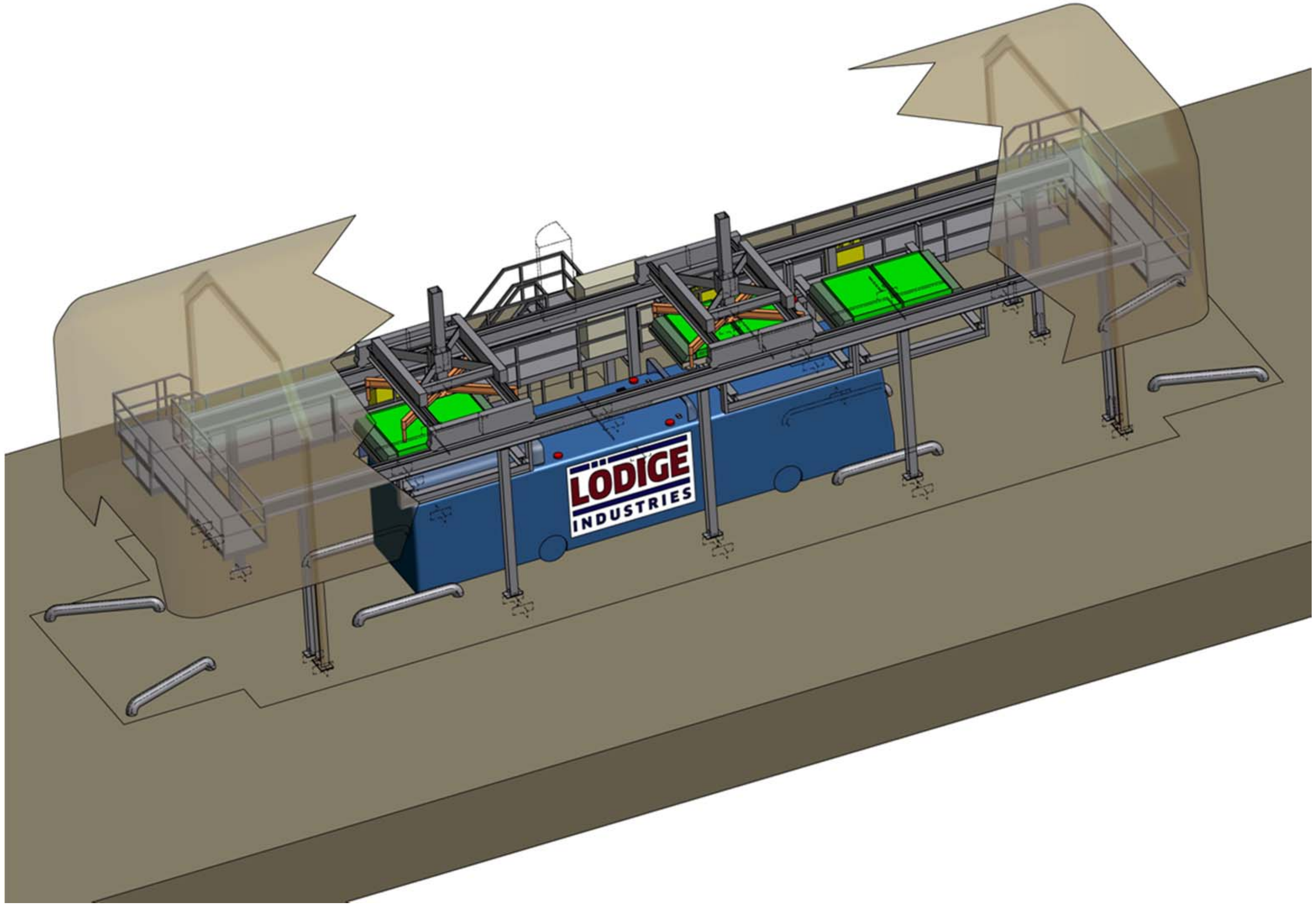

Fast battery exchange of buses – an example

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- 12m E-Bus
- 2 battery packs (assumption: 1 in the bus, 1 in the station)
- Distance between 2 batteriy exchanges: 10km, => 18 km/h average speed, 33 minutes/10 km
- Energy requirement between 2 battery changes : 18 - 25kWh (1,8 - 2,5kWh/km for a 12m-Bus)
- Depth of discharge approx. 60% => 30 - 42kWh per battery
- Time availabele for charging: up to ~30min.
- Power of charge: 25kWh within 30min. => 50kW
- For a 42 kWh-battery this means approx. 1,2C current rate, no problem for high energy-LiIon-battery cells
- Peak power requirement of bus (accelaration at higher speed) can be up to ~200kW (5C current rate), therefore high power-LiIon-cells recommended
- 42 kWh LiIon-HighPower-battery =>
  - **appr. 850 – 1000 kg system-weight per 1 battery**
  - **approx. 150.000€ invest / 2 batteries in “near future”**
  - **~100.000€ in later years (?)**

What kind of battery cells?

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… for an e-bus with true fast charging (example: 10 fast charges per day) ?

- High power cells
- Cycle lifetime 20.000 – 30.000 cycles (@ 30 – 50% DOD)
- Average rate of discharge < 1C, max. rate of charge ~ 10C

… for an e-bus with only one charge per day ?

- High energy cells
- Cycle lifetime 3.000 – 5.000 cycles (@ 70 – 90% DOD)
- Average rate of discharge < 0,1C, max. rate of charge ~ 1C
  (very little requirements regarding cooling of battery pack)

Plug-based system with *manual* plugging in Chinese bus-depot

Source: http://www.youtube.com/

Induction, at specific stations

Induction charged battery electric mini buses in Turin, Italy

Source:
http://citytransport.info/Electbus.htm

Induction: „PrimoveCity“ system by Bombardier

- Tested with 1 bus on 1.2 km public road in Lommel, Belgium, in summer 2011 (http://primovecity.bombardier.com)

Fast charging by trolley wire at a bus stop:

- China Shanghai City
- Charging of Supercaps
- 1~2 km/charge
- ~1 Minute/charge

Opbrid S.L.: Fast charging of hybrid buses

- Serial diesel-electric hybrid buses, electric only mode possible
- 150 or 200 kWh battery pack (about 2 t of weight on roof!)
- DC charger, output power 100-240 kW
- About 1 hour charging time for „0% → 100%“ charge
- Problem: Where do the 10 – 24 kW waste heat during charging go, especially in the summer?
  - Into the air by ventilation (noise at the bus stop!!) or active cooling (costs battery power)?
  - Into the battery, heating it eventually up, compromising battery life time?

Charging the bus battery using trolley wires or panthograph for sections of the route

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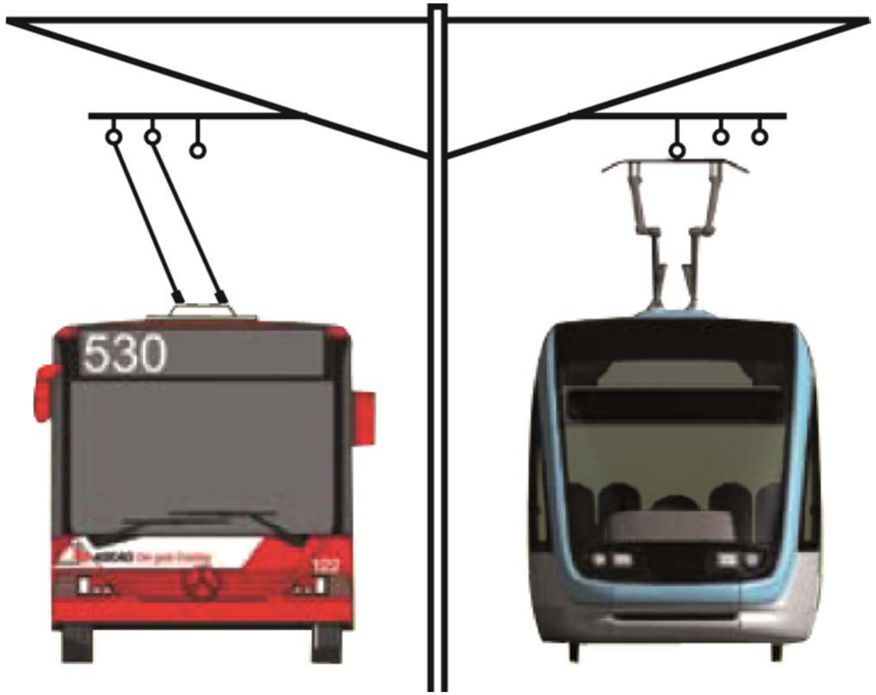
- Charging at bus stop (requires high performance batteries, high charging power may cause a problem for infrastructure)
- Double use of infrastructure by partial joint use of an overhead trolley line by both tram and trolley bus

http://www.treehugger.com



Source: Prof. Müller-Hellmann

Automatized fast charging (up to 500kW, approx. 5-7min.)

- Electric connection + communication plugged by a robot from a pit in the street (underneath the bus)

Demonstration of the first high capacity battery-bus route with true fast charging and study of grid interaction in the City of Muenster (Germany)

Based on previous project:

At ISEA of RWTH Aachen University:
Werner Rohlfs, Philipp Sinhuber, Matthias Rogge

26.10.2012

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Highlights:

- **1 city bus route operated only by electric busses**
- **5 fully electric 12m-buses:**
  - 1 funded by the previous R&D-project of the German government
  - 4 part-funded by this FP7-project
- **3 fast charging stations: 2** end of bus route + 1 bus depot
- Fast charging with **up to 500 kW for 5-6 Minutes**, up to 50 kWh/charge
  - Length of bus route (12 km) can be easily traveled twice with one charge in case of problems at one of the two charging stations
  - Range is dependent on specific energy consumption of the bus (kWh/km)
- **Stationary battery storage container** at one charging station to study grid interaction
- Integration of the **municipal planning process** to one effort
- **Integration of other electric mobility achievements** in the project (separately funded), examples: plug-in-hybrid buses, hybrid-buses, Park&Ride-charging facilities

Automatized fast charging for e-buses

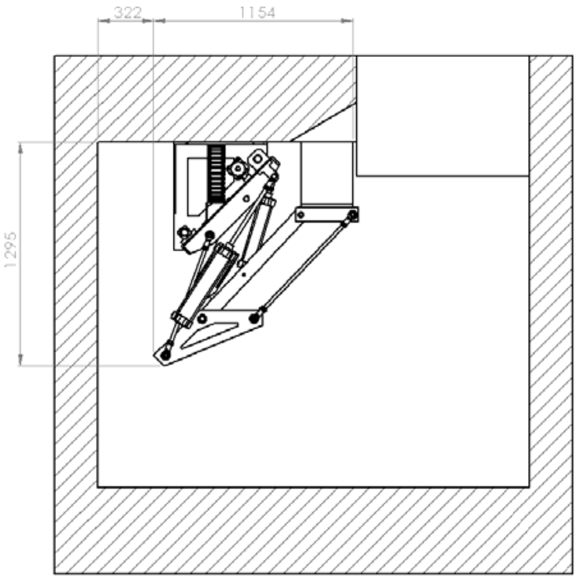
Automatized „Pop-Up Pits“
(in foto the original manual version currently used at airports to supply airplains)

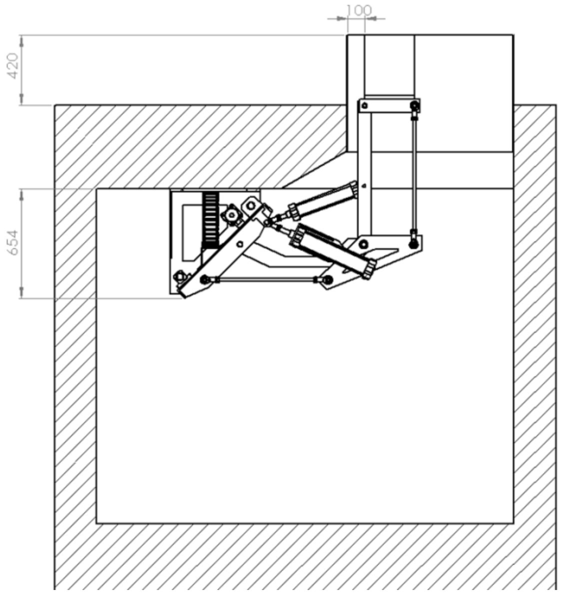
Submersible: No vandalism, space-saving, little optical „nuisance“

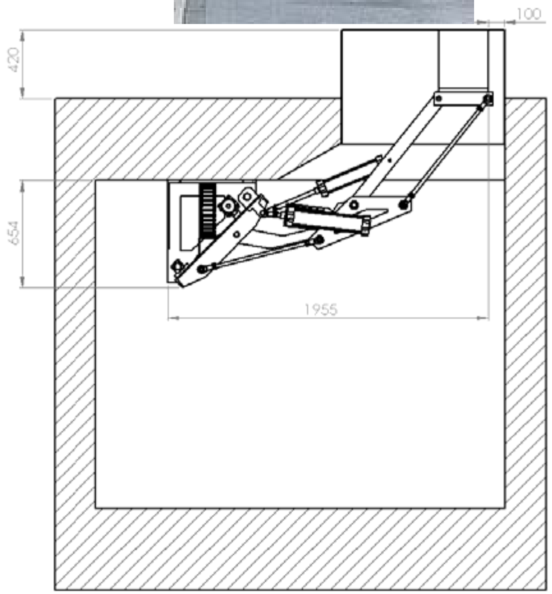
Low-cost due to mostly commercially available components

Connecting robot underneath the e-bus

- Pit in the road at the bus stop houses the robot
- Bus positioning with approx. 25 cm of tolerance
- Both street pit and bus connector space covered with lids (sliding to the side)
- Coupling of power and communication contacts







Elements of a bus stop (at end of bus route)

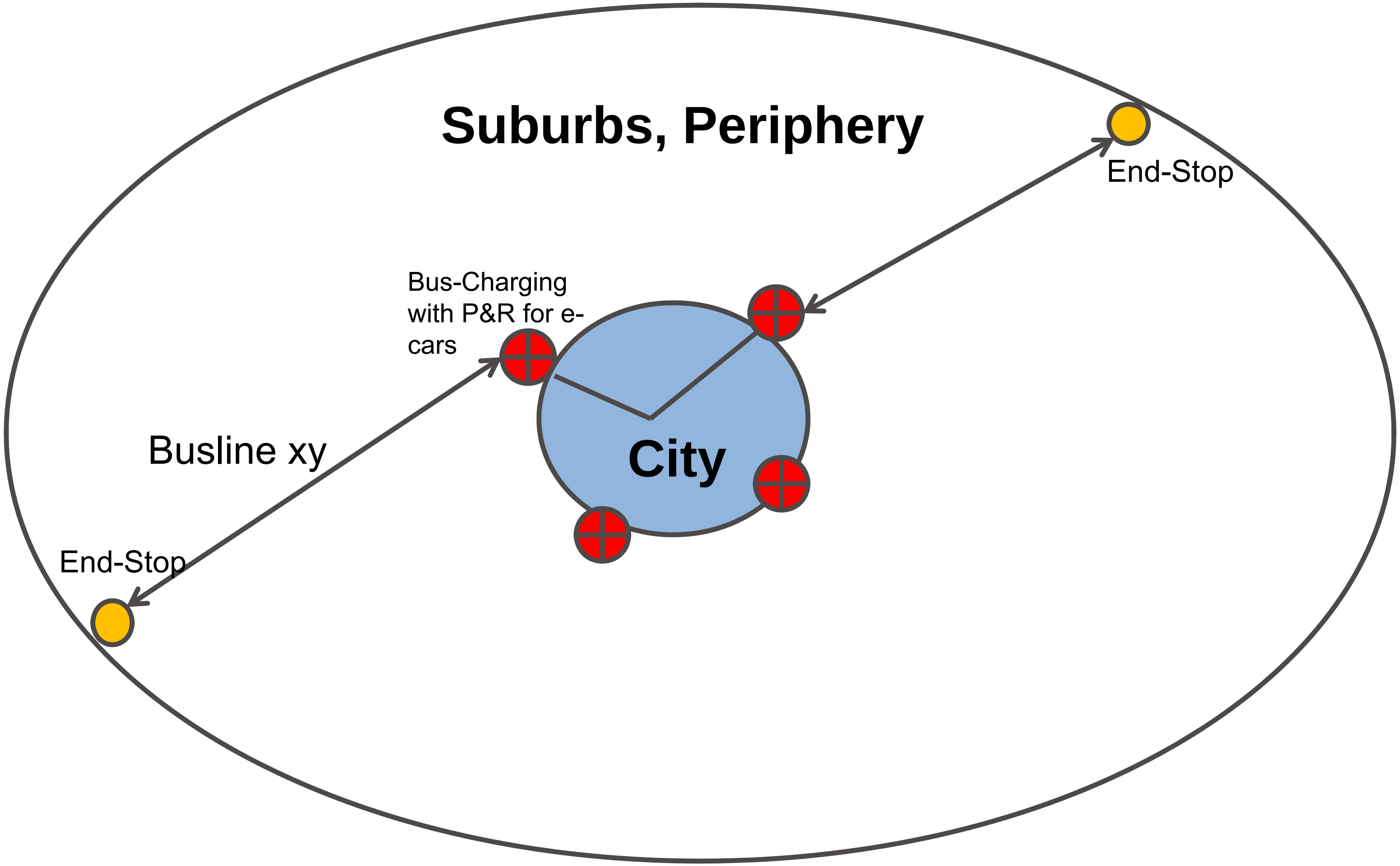
- **Visible**:
  - Power electronics for charging station
  - Only where applicable: Stationary battery container
  - Optinal: Infrastructure for charging of electric cars at P&R facilities
- **Not visible:** Covered pit with robot in the street

Example of
stationary battery container

Source: aegps.com

Source http://www.bus-bild.de/:

Few fast charging stations, many electrified buses



To be competely electrified: Bus service on route 14 in the City of Muenster, Germany

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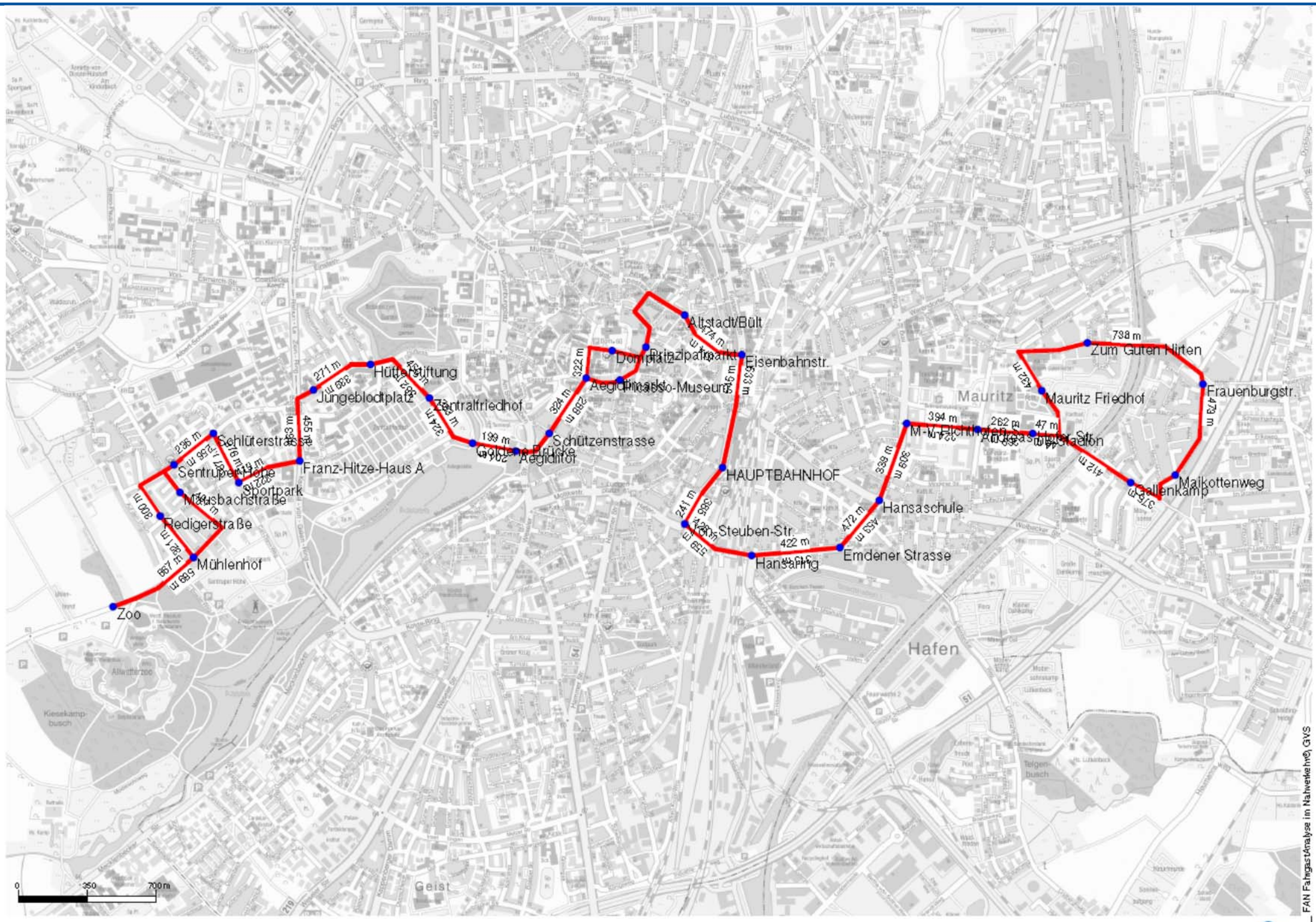

Linienverlauf der Stadtbuslinie 14 mit Metrierung

STADTWERKE

„Brother and sister“ will get closer:

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Local Public Transport ⟷ **Local Power Company**

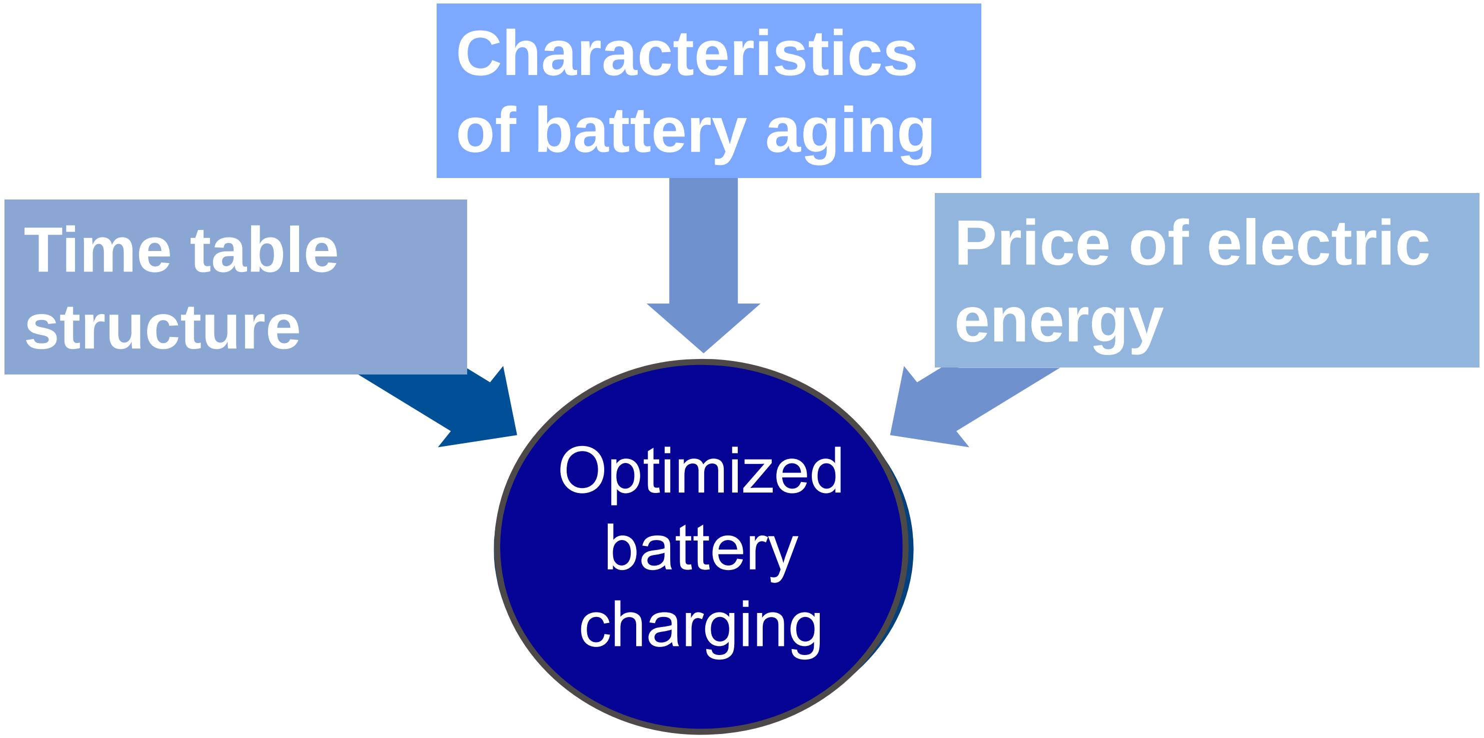
- Local Public Transport
  - Bus Routes
  - Passengers
- Local Power Company
  - Power Grid
  - Customers

New municipal city planning & devellopment

- **A new layer-model: Several maps need to be integrated into one:**
  - The power grid map
  - The bus and trolley route system map
  - The map with clusters of big local power consumers and local producers (solar, wind)

- **The „intersections“ are potential candidats for future…**
  - fast charging stations for e-busses
  - decentral stationary battery storage installations (for grid stabilization purposes)
  - power consumers and/or producers

Intelligent charging strategies reduce mobility costs



Thanks for your attention!