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Trolleymotion at Berlin metropolitan 2016

electric bus fleets

the way to reach the Targets

Environment

UITP Position paper of June 2015

BUS SYSTEMS IN EUROPE : TOWARDS A HIGHER QUALITY OF URBAN LIFE AND A REDUCTION OF POLLUTANTS AND CO_2 EMISSIONS

In view of the announced mid-term review of the **Transport White Paper**, **UITP** stresses that the European Union needs a comprehensive approach towards a more sustainable mobility in Europe. In order to reach the **EU's GHG emission reduction objectives**, technological efforts need to be combined with a strong shift towards collective modes of transport. Concerning the announced **EU policy** initiatives towards **cleaner air** and a further **reduction of CO_2** emissions of heavy duty vehicles (HDVs), the European bus sector welcomes these initiatives and underlines the contribution which buses and public transport in general already make towards these aims.

Target - E-mobility in the bus sector

- How cities can **change their diesel fleets** of busses with **clean e-bus** systems?

- Which type of **bus lines** and **schedules** are to operate? Which **infrastructure** for e-bus possibilities are already existing and which ones are to develop complete new?

- How the **infrastructure** of the **depots** are prepared for e-bus systems?

- How …..

For all these questions we recommend to do an analyse of the existing situation and a study of new solution possibilities with the possibility of the cities by a consulting support first.

Outlook

- Technology wise the **e-bus solutions** have except the Trolley bus solution **only field test experience** in more or less little quantities of vehicles running in Europe.
- The cities will need new **solutions** of **electrical energy distribution** for e-bus fleets.
- An **existing infrastructure** for **Trolleybuses** can be easy used to extend the range of lines with a **Trolley Hybrid system**.
- For all other **e-Bus system** solutions the electrical energy has to be provided on the **battery charging station** (depot, end bus stop, intermediate charging stations etc.)
- To fulfil the political targets to **reduce CO_2**, it is necessary to make in the next years a decision which system will be the **best solution** for the cities and operator.

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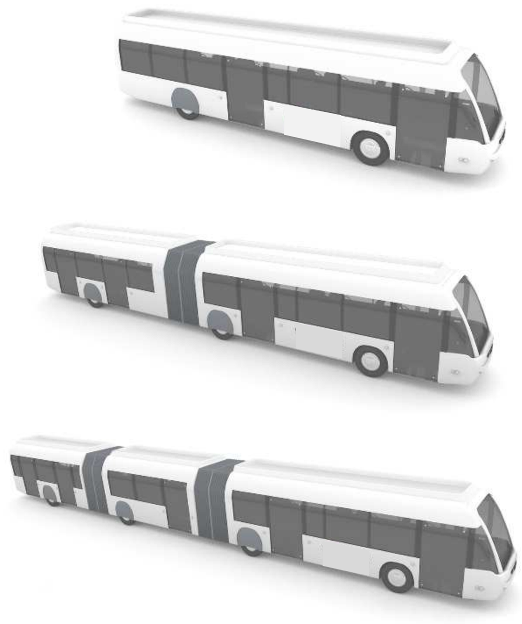
Technical system - e-Bus-solutions on the market



- 12m
- 18.75m
- 25m

- In-Motion-Charging
- Opportunity Inductive Charging
- Opportunity Flash Charging
- Opportunity Fast Charging
- Overnight-Charging
- Range Extender

Different solutions

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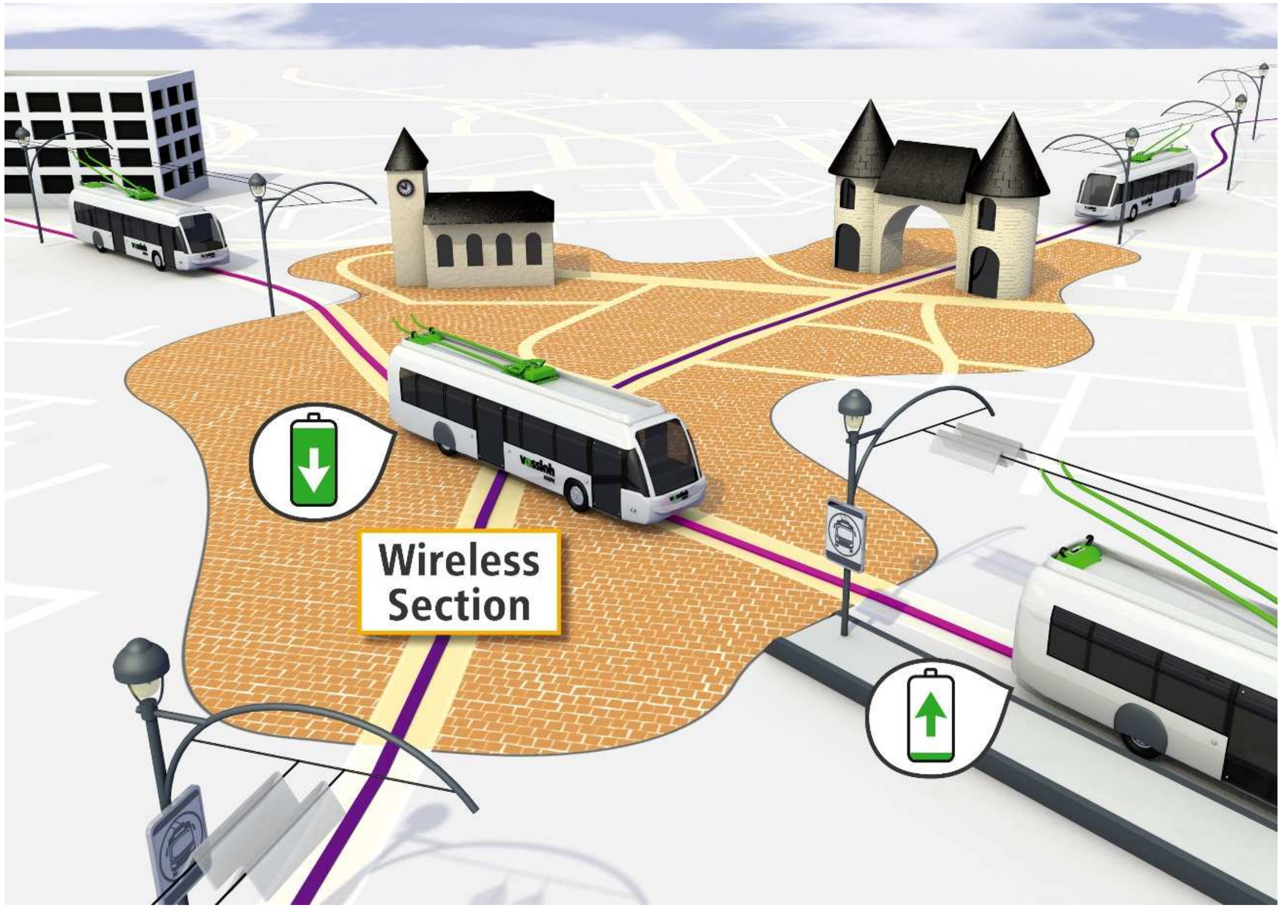
Technical system - e-Bus references

References from all kind of e-buses

Technical system - e-Bus with „In-Motion-Charging“ (IMC)



Wireless Section(s)

- Up to 50% of line
- Up to 50% of time
- ca 4km per section (max 15km)

Charging Sections

Charging time

- ➢ Slow roads
- ➢ End stations

Energy consumption

- ➢ Steep roads

Inexpensive installation

- ➢ Straight roads

Optimized charging time by In-Motion-Charging

Technical Solutions → Energy Pack

- discharging power: 120kW (220kW boosting)
- charging power: 100kW (190kW boosting)
- energy capacity: 30kWh
- capacity hub: 90%
- weight: 980kg
- type battery: lithium-ion (LTO)
- energy recuperation: yes
- retrofit solution: yes

➢ HESS Energy Pack → high power energy storage with battery charger from Vossloh Kiepe
➢ Retrofit solution for existing Trolleybusses with Diesel-Generator

Energy Pack as retrofit solution

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Technical Solutions

… a light design for bus bodies is required, to transport batteries, traction technology and finally a lot of passengers too!!!

... for example **CO-BOLT** ® aluminium space frame technology.

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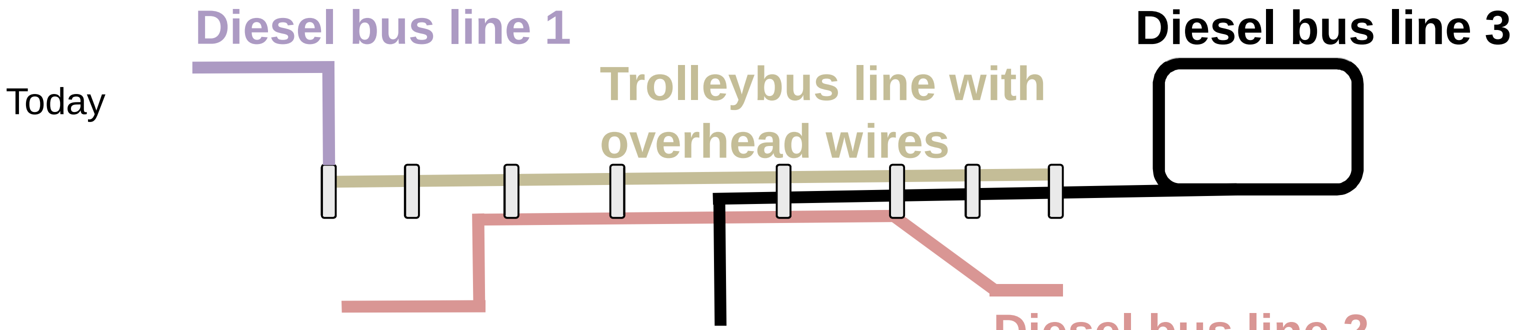
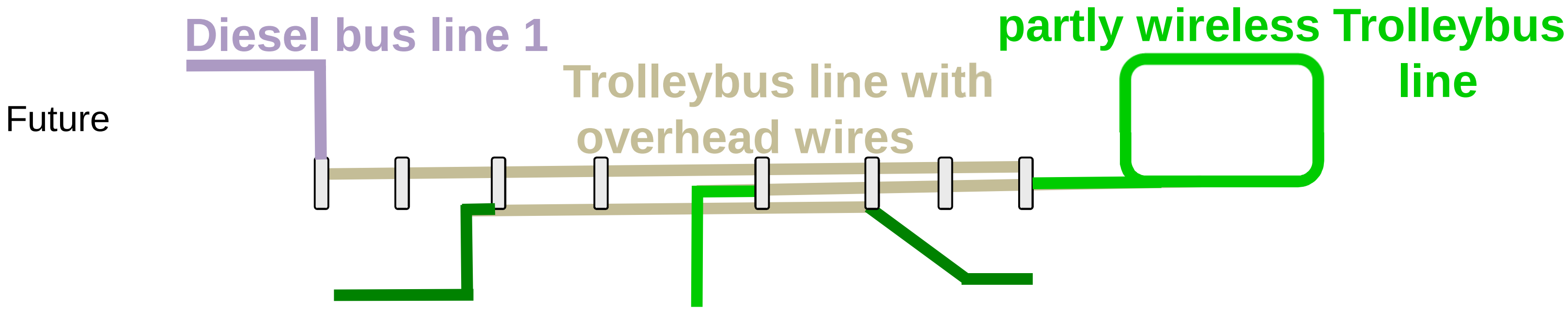
Transforming Diesel bus lines into partly wireless Trolley bus lines

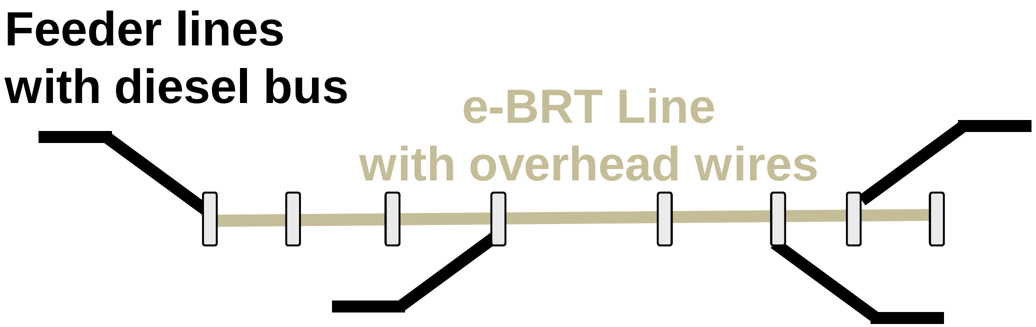


parallel lines: take benefit of existing overhead wires



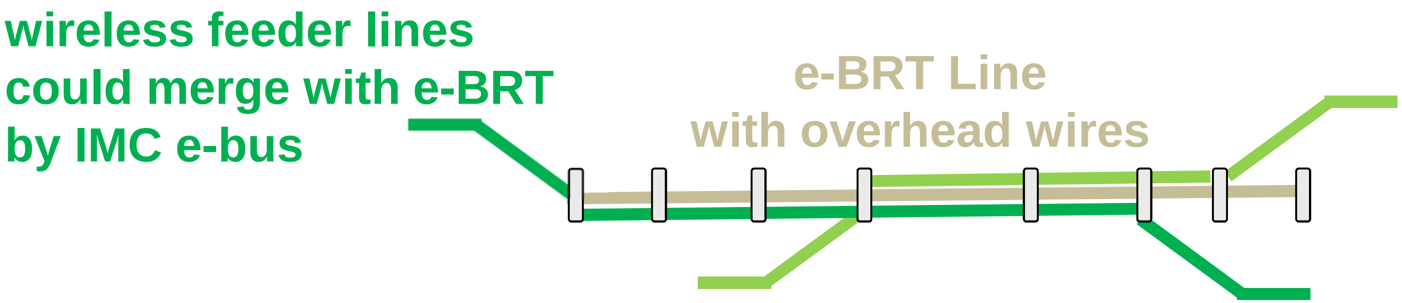
Wires become charging infrastructure

New electric Bus Rapid Transit (e-BRT) system with IMC bus feeders



passengers change bus from feeder bus to e-BRT bus

IMC feeder buses arrive at e-BRT destinations → less bus exchanges needed



Optimized passengers transportation

Advantages of a Trolley bus system compared with a tram

- No installation of rails into the street (thus not years of traffic disturbance)
- Significant less infrastructure investments (factor 10)
- More silent (in and outside the vehicle)
- Less vibrations (especially important on bridges and near historical sites)
- Much faster to build up a new system
- Flexible as a conventional bus (with Battery or Diesel back-up unit)
- 50 % less expensive vehicle (with half of life time → keeps the city modern)
- Not rail bound → flexible → reliable operation
- With same visual impact of catenary vs over head wire

Less expensive than a tram

Valid conclusions of a trial project

A trial project of the following set up:

- 3 battery buses
- 12 m bus length
- in moderate climate
- on a line with short distance
- on flat road
- low velocity and
- low pace with
- long pause times.

Allows conclusions for that set up – **for that set up only.**

Different

- Number of buses → different infrastructure
- Bus length → different energy consumption & charging time
- Climate → different energy consumption & charging time
- Line → different energy consumption & charging time?
- Gradient of road → different energy consumption
- Velocity of vehicle → different energy consumption per hour
- Pace → different charging concept?
- Pause times → different charging concept?

- Different set up → different conclusions

…. might require a complete different concept

Understand basic Physics (refreshment from school)

Verify the plausibility of suggestions

I) Power [W] x time [h] = **Energy [Wh]** {Watt hour}

50 W x 2 h = 100 Wh

II) **Electrical Power [W]** = Current [A] {Ampere} x Tension [V] {Voltage}

420 000 W = 700 A x 600 V

III) k {kilo} = 1 000 / M {Mega] = 1 000 000

420 000 W = 420 kW = 0,42 MW

Tanking electrical energy = Current [A] x Tension [V] x Time

Current [A] {Ampere} – limited by heat / cable diameter (installation in vehicle)

Tension [V] {Voltage} – limited by insulation levels

The only free parameter for tanking electrical energy is the TIME

Understand basic Physics (refreshment from school)

Tanking electrical energy

Power [kW] x time [h] = tanked Energy [kWh]

300 kW x 5 min / 60 min/h = 25 kWh (opportunity charging)

400 kW x 15 sec / 3600 sec/h = 1,6 kWh (flash charging)

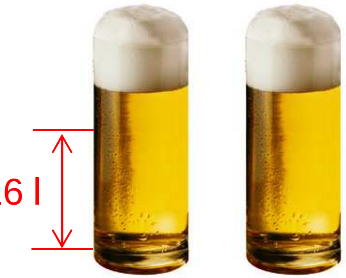
1,6 kWh - How much is this in km? GUESS

1,1 km (12m bus – 1,5 kWh/km)

0,64 km (18m bus – 2,5 kWh/km)

1,6 kWh - How much is that in diesel fuel? GUESS

0,16 l (10 kWh/l)



Kölsch

Tanking electrical energy is a bottleneck

Two major challenges for e-buses
Energy Storing & Energy Tanking

High energy density of Diesel: 11.800 Wh/kg or 10 kWh/liter implies two major differences:

	(1) Energy Storage	(2) Energy Tanking
Diesel 40% efficiency**	11 800 Wh/kg 4 720 Wh/kg	78 000 kW* 31 200 kW
Electric LTO “Tesla”	Electric Energy Storage (Battery Chemistry) **** 80 Wh/kg power cells / 65 Wh/kg pack 245 Wh/kg energy cells / 130 Wh/kg pack	Electric Energy Tanking (Physics / Infra structure) 300 kW continuous power
Factors	**73** (4720 / 65) **36** (4720/130)	**> 100** (31 200 / 300)

* 130*** l / min tanking speed x 60 min / h x 10 kWh/l = 78 000 kW energy tanking (e.g. heating);
*** Source http://www.hectronic.com/tanken/zapfsaeule-hecpump/
** assumed average efficiency of a combustion engine for generating electricity for traction and air conditioning
**** Source: Presentation Prof Sauer 29.02.2016 ElekBu 2016 - 7. VDV-Akademie Konferenz Elektrobusse

Tanking electrical energy = challenge

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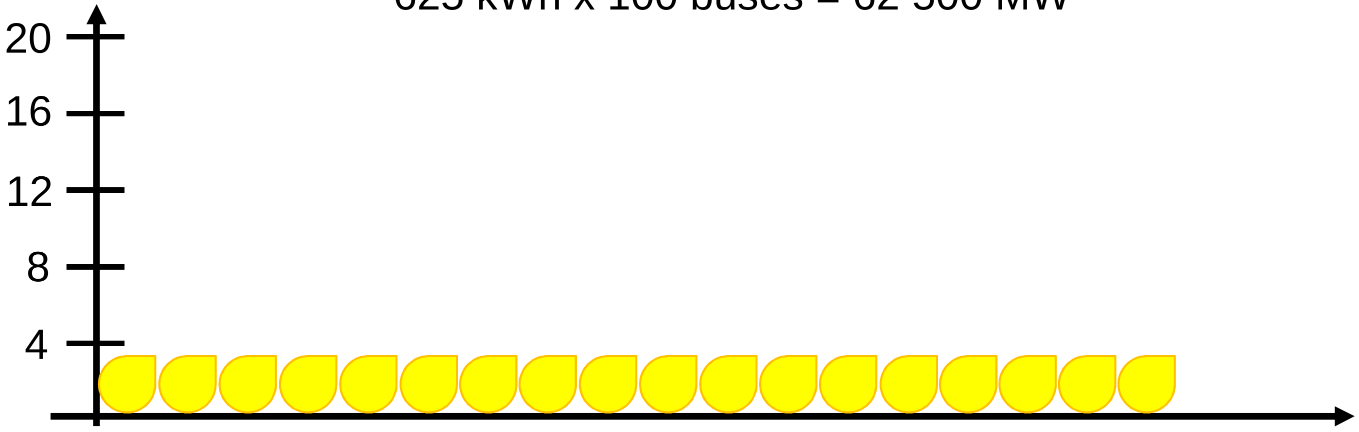
Energy Consumption

Average energy consumption over 18 hours



Example of daily operation:
250 km x 2,5 kWh/km = 625 kWh
625 kWh x 100 buses = 62 500 MW

Energy

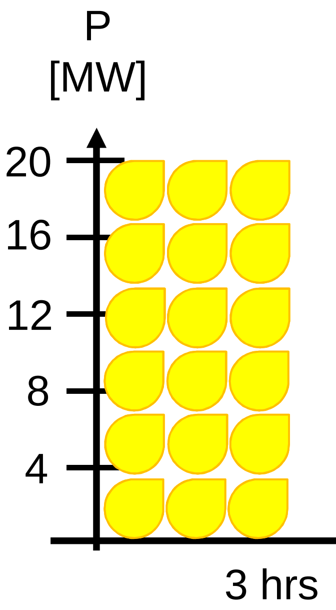
1h

100 buses

The consumption is distributed over the day

Charging Cost

Overnight charging in 3 hours



Example of daily operation:
250 km x 2,5 kWh/km = 625 kWh
625 kWh x 100 buses = 62,5 MW

62 500 MW / 3h = 21 MW

For comparison: German medium gas power stations
Dortmund (KDO) has 26 MW
Bochum (KBO) has 21.MW

Time [h]

Energy

1h

100 buses

Short charging time → higher power required for fleet charging

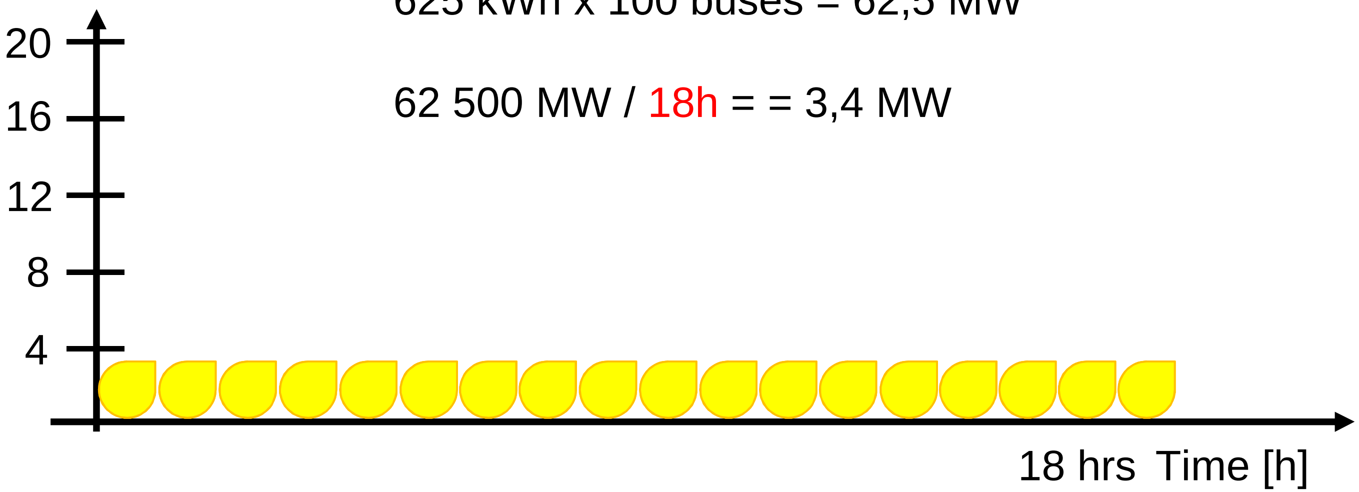
Charging Cost

In Motion Charging

Example of daily operation:
250 km x 2,5 kWh/km = 625 kWh
625 kWh x 100 buses = 62,5 MW

62 500 MW / 18h = = 3,4 MW

P
[MW]



Energy

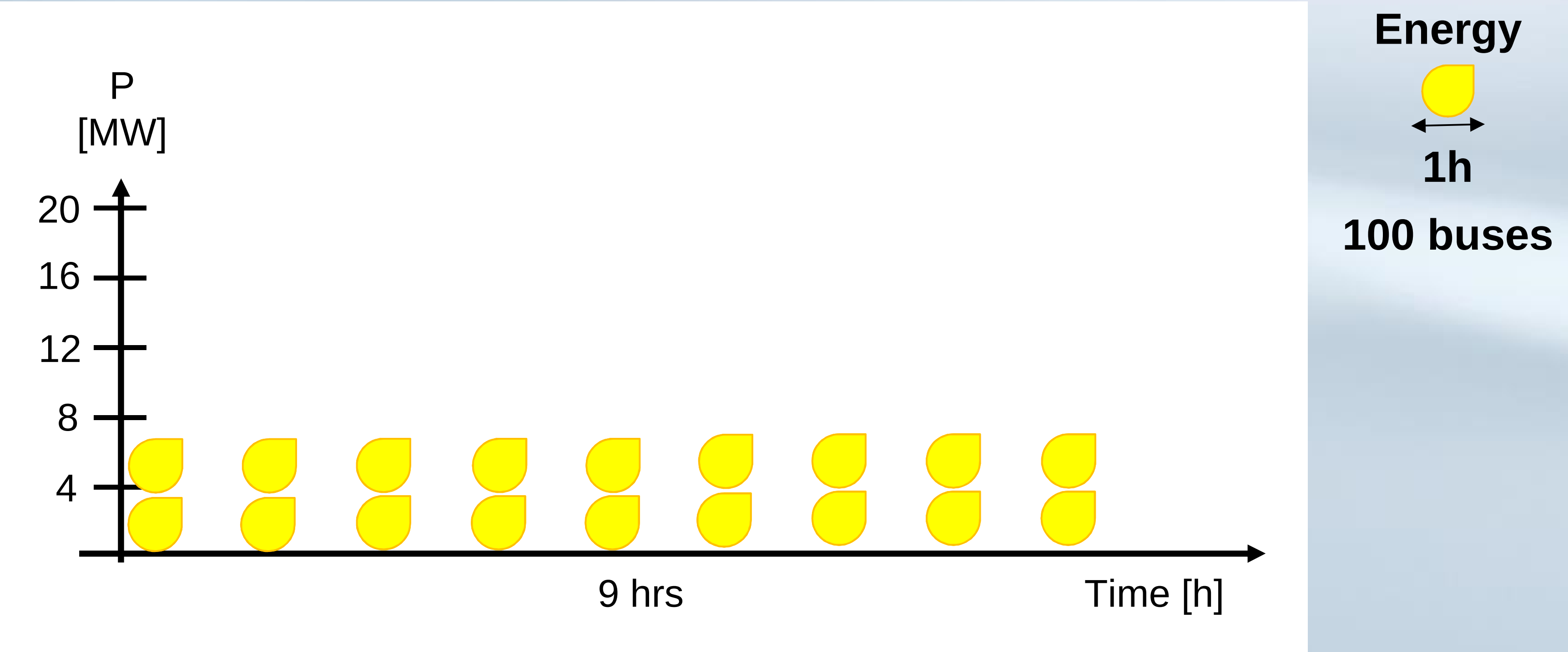
1h

100 buses

Energy tanking18h instead of 3h → moderate power

Charging Cost

Opportunity charging



Infrastructure active ca 50% of operating time

Standing charging: idle time due to opportunity charging

For 1 hour driving → idle time of standing bus

Assumed charging power: 250 kW
Energy consumptions: 12m: 1,5 kWh/km; 18m: 2,5 kWh/km; 24m: 3,5 kWh/km

Velocity of bus		12m standard bus			18m articulated bus			24m double art. bus		
10	km/h	3,6	min	6%	6	min	9%	8,4	min	12%
15	km/h	5,4	min	8%	9	min	13%	12,6	min	17%
20	km/h	7,2	min	11%	12	min	17%	16,8	min	22%
30	km/h	10,8	min	15%	18	min	23%	25,2	min	30%

Higher velocity
→ more energy consumption per hour
Longer vehicle → longer charging time / idle time
→ higher costs due to x% additional buses (& driver?)

Therefore opportunity battery bus mainly suitable for:
→ Low average velocity lines
→ Short vehicles

Tanking of electrical energy

Concept of e-bus tanking meanwhile Standing vs In Motion Charging

Charging meanwhile Standing means charging

- 100% of the energy (traction, air conditioning, heating?)
- During limited time
- With limited power

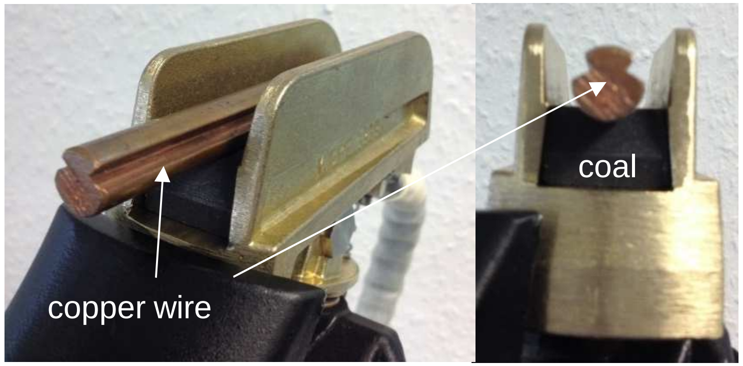
In Motion Charging (IMC)

- 50% of the energy* (for 50% wireless)
- During 9h - 18h of operation time
- With powerful** air cooled power supply

** In Motion Charging with 600 V or 750 V (+20% peak 900 V) x 700 A
= **420 kW** continuous / 504 kW peak or 525 kW continuous / **630 kW** peak

* The rest goes straight from copper overhead wire
via the coal to the motors – bypassing the battery

btw: Energy transfer from cooper wire via coal to vehicle also for trams, locomotives up to high speed trains (up to 12 MW)



IMC is the most powerful charging concept for battery buses → bottleneck gets resolved

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Which e-bus concept would be suitable for your city?

Which **vehicles size** do you need?

Recommendation of concepts:

Solo

→ Battery bus *

Standing Charging

or IMC Bus **

Charging In Motion

Articulated

→ Battery bus with Range Extender or IMC bus

Double articulated

→ Diesel-electrical Hybrid, Trolleybus or IMC bus

* For lines with suitable requirements like range, available charging time and space for charging station

** For lines with high energy consumption: speed, acceleration, slopes, heating & air-condition, big fleet

System of overhead wires – Norway / Bergen

Straight overhead wire lines are almost not perceived

System of overhead wires – Fribourg / Switzerland

Straight overhead wire lines are almost not perceived

System of overhead wires – Arnheim / Netherlands

Straight overhead wire lines are almost not perceived

System of overhead wires – Lausanne / Switzerland

Street café at the water front (Lac Leman)
„Café Zero Emission“ instead of „Café noxious fumes“

international e-bus conference 2016
trolleymotion

Straight overhead wire lines are almost not perceived

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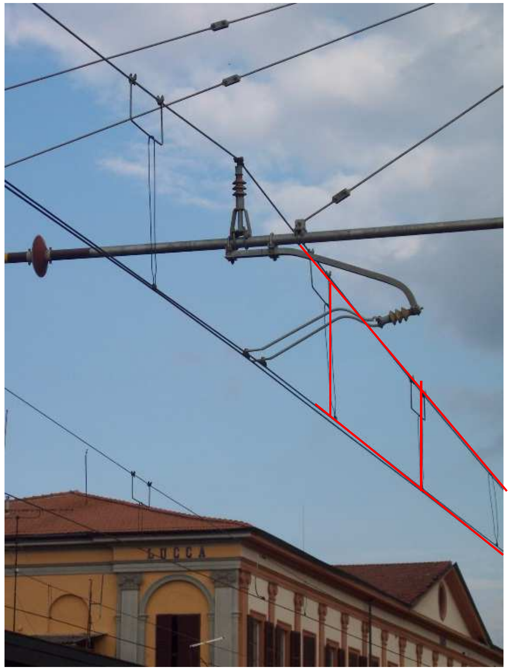
Different visual impact of overhead wire system?

Tram / Light rail vehicle	Trolley bus
	

→ The visual impact is the same
In Germany exist already 68 overhead wire systems (65+3)

international e-bus
conference 2016
trolleymotion

Over head wires are well known & accepted

System of overhead wires – Parma / Italy

Almost invisible infrastructure

Modern e-bus propulsion systems

System of overhead wire – Pescara / Italy

Beautiful infrastructure Italian style

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Trolley bus: an reliable e-bus even for extremes




Trolley buses run in 300 cities around the globe

- Short/long (9,7m Midi-Lyon until 25m Double articulated)
- High/low elevation (Quitos plateau on 2850 m. or coastal roads)
- Salty/sandy (at sea or in the desert of Riad)
- Hot/cold (Saudi Arabia until Belarus Minsk / Latvia Riga)
- Steep/flat (San Francisco > 20% gradient)
- Most powerful (2 x 160 kW → 320 kW for 18m Bus)
- Backup to Duo (Diesel-Generator-Set from 50kW till 175kW Genoa, Rimini, Fribourg)
- Energy storage Supercap and/or Batteries (different chemistries, cooling concepts etc)
- Networks New mounted networks with unexperienced operator (Ryjadh)

Trolley buses run reliable

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Quality of Life Ranking: TOP 15 Cities in the World

2015	2014	2012	2010	City	Country	Index 2010	
1	1	1	1	Vienna	Austria	108.6	
2	2	2	2	Zürich	Switzerland	108.0	Trolley bus
3	3	3	4	Auckland	New Zealand	107.4	
4	4	4	7	Munich	Germany	107.0	
5	5	5	4	Vancouver	Canada	107.4	Trolley bus
6	6	6	6	Düsseldorf	Germany	107.2	
7	7	7	7	Frankfurt	Germany	107.0	
8	8	8	3	Geneva	Switzerland	107.9	Trolley bus
9	9	9	11	Copenhagen	Denmark	106.2	
10	10	10	10	Sydney	Australia	106.3	
11	11	12	13	Amsterdam	Netherlands	105.7	
12	12	13	12	Wellington	New Zealand	105.9	Trolley bus
13	10	10	9	Bern	Switzerland	106.5	Trolley bus
14		16	17	Berlin	Germany	105.0	
15	15	15	16	Toronto	Canada	105.3	

5 (15) Trolleybus system

33%

https://en.wikipedia.org/wiki/Mercer_Quality_of_Living_Survey

Trolley bus = ? = Quality of Life

Why the wires?

- Reliable e-bus concept with very high availability → Low vehicle reserve needed
- Highest energy efficiency
- "Unlimited" energy available "just in time"
  → convenient for heating & air conditioning, infotainment
- High passenger capacity possible up to 220 pers/bus (with few personnel)
- Fast with powerful climbing characteristics
- Range of Zero Emission operation is "unlimited"
- IMC battery charging is easy on battery and therefore on battery live time
- Universal interface for battery charging (not tying up to an unique provider with monopole)
- Bus driver doesn't have to wait for battery recharging (TCO)
- Low peak power requirement for substations (= battery charging)
- Most economical zero emission bus operation for medium to high transportation capacity

Wires are needed for intensive e-mobility

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Quality of Life Ranking: TOP 15 Cities in the World

2015	2014	2012	2010	City	Country	Index 2010	Overhead wire system
1	1	1	1	Vienna	Austria	108.6	Tram
2	2	2	2	Zürich	Switzerland	108.0	Trolley & Tram
3	3	3	4	Auckland	New Zealand	107.4	Metro (Pantograph)
4	4	4	7	Munich	Germany	107.0	Tram
5	5	5	4	Vancouver	Canada	107.4	Trolley
6	6	6	6	Düsseldorf	Germany	107.2	Tram
7	7	7	7	Frankfurt	Germany	107.0	Tram
8	8	8	3	Geneva	Switzerland	107.9	Trolley & Tram
9	9	9	11	Copenhagen	Denmark	106.2	S-Bahn
10	10	10	10	Sydney	Australia	106.3	Light Rail
11	11	12	13	Amsterdam	Netherlands	105.7	Tram
12	12	13	12	Wellington	New Zealand	105.9	Trolley
13	10	10	9	Bern	Switzerland	106.5	Trolley
14		16	17	Berlin	Germany	105.0	Tram
15	15	15	16	Toronto	Canada	105.3	Tram

5 (15) Trolleybus system

33%

100%

of these cities have **overhead wires**

https://en.wikipedia.org/wiki/Mercer_Quality_of_Living_Survey

Over head wires = ? = Quality of Life

What is the target of your city?

- Target of city: Measurable improvements of air quality?
  Reduce noise?
  Switch to renewable energy?

- One solution: Replace heavy duty diesel bus traffic with
  fleet of articulated or double articulated electrical buses

- Focus on public urban person traffic powered by electrical buses

- Do the right thing: Become emission free with IMC
- And do it right: Go for high quality

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if you have any questions – please contact any of these companies:

www.hess-ag.ch

www.kuma.ch

www.vossloh-kiepe.com

Thank you for your attention

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Concepts pro and contra of different charging systems (1/2)

Over Night Charging

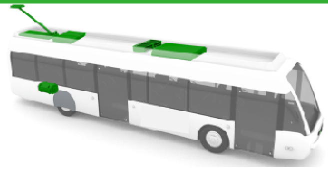
pro

+ operation similar to a Diesel bus
+ long life of battery
+ emission free

contra

- reduced passengers capacity
  → additional buses & bus drivers
- limited range <250km
- charging buses in parallel during few hours → requires high power infrastructure for big fleets
  → high costs especially for buses over 12m

Opportunity Charging



pro

+ unlimited range
+ more passengers (little battery)
+ emission free

contra

- idle time for bus and driver
  → additional buses
- idle time increases with bus length & HVAC
- reduced life time of battery
- charging stations to be fit into the city
- less flexibility to compensation delays

Concepts pro and contra of different charging systems (2/2)

range extender

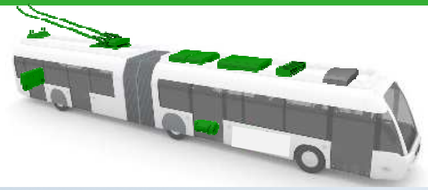
pro

+ 12m – 24m busses (more passengers)
+ unlimited range
+ higher average speed
+ bus ride without recharging all the time
+ less investment of infrastructure for charging

contra

- not zero-emission or fuel cell technology
- reduced life time of battery

In Motion Charging (IMC)



pro

+ 12m – 24m busses (more passengers)
+ unlimited zero-emission range
+ higher average speed
+ perfect for gradients
+ full heating & air condition
+ suitable even for big fleets
+ most power full energy supply
+ high efficient energy tanking
+ sensitive battery charging

contra

- Infrastructure visible (but not previewed)