INSTITUT FÜR ENERGIE- UND UMWELTFORSCHUNG HEIDELBERG

Electric traction for buses – yes, but which system?

The Trolley-hybrid as an efficient possibility to use renewable energy in public transport

Fabian Bergk

Contents

- Background of the project
- Comparison of different fuel concepts
  - Emissions
  - Costs
  - Fulfillment of operational demands
- First conclusions of the project

Background: Mobilitäts- und Kraftstoffstrategie

What is the MKS?

- Development of a „learning strategy“ including all modes
- Technology-open
- Focussing 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 (Batteries, Ultra-Caps, Fast-Chargers)

Trolley-hybrid as an efficient possibility to use renewable energy in public transport?
→ ongoing short study

Bildquelle: BMVI

Background: Drivers of Electrification

- 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

Goals of the „MKS“

2020 (Hamburg)/ 2026 (Bremen) all new busses without tailpipe emissions

Comparison of different fuel concepts

Object of comparison

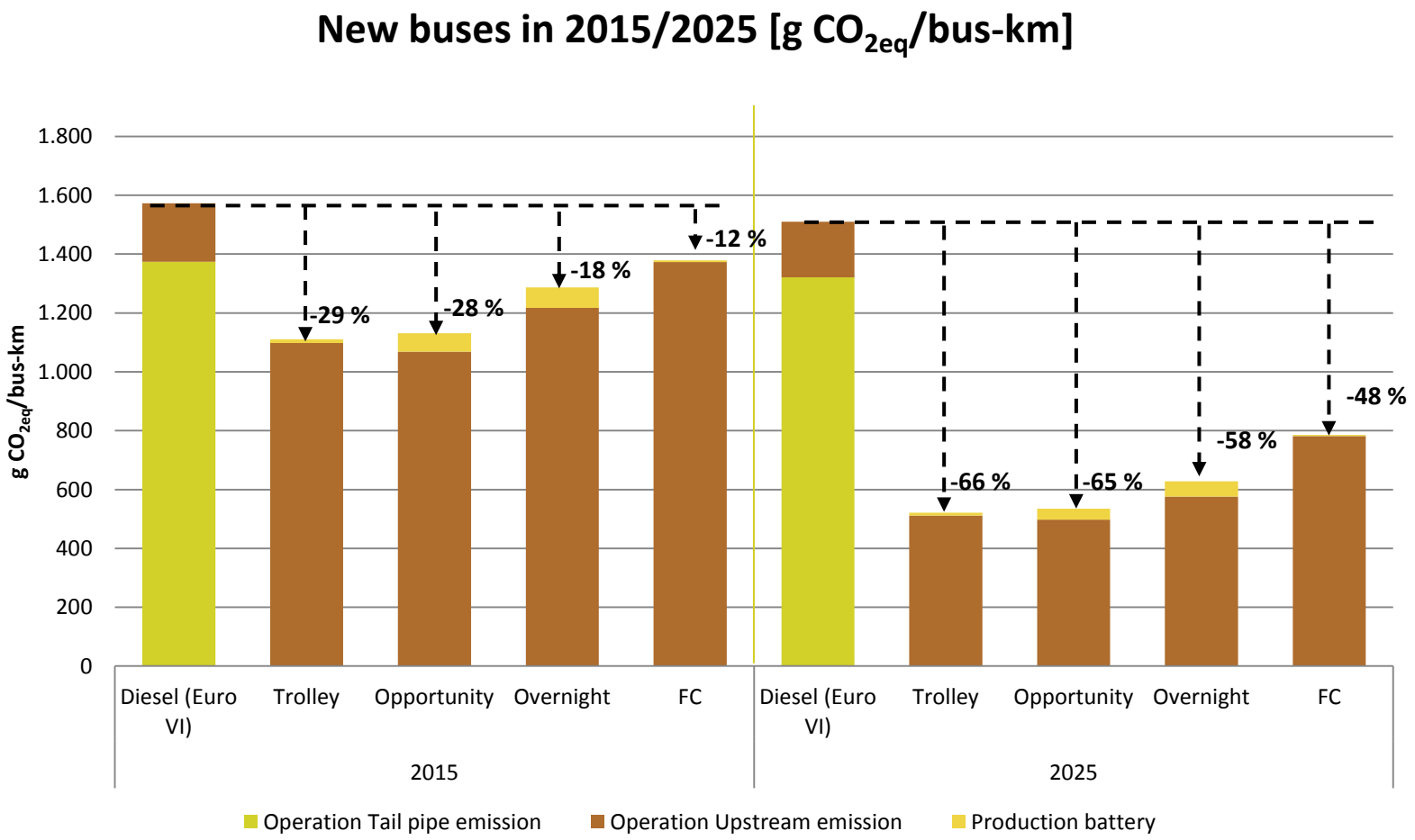
- Articulated Buses
- Concepts:
  - Diesel-Euro VI (Hybrid assumed from 2020)
  - Overnight-Charger
  - Opportunity-Charger
  - Trolley-Hybrid
  - Fuel-Cell-Hybrid

Comparison of different fuel concepts

Criteria:

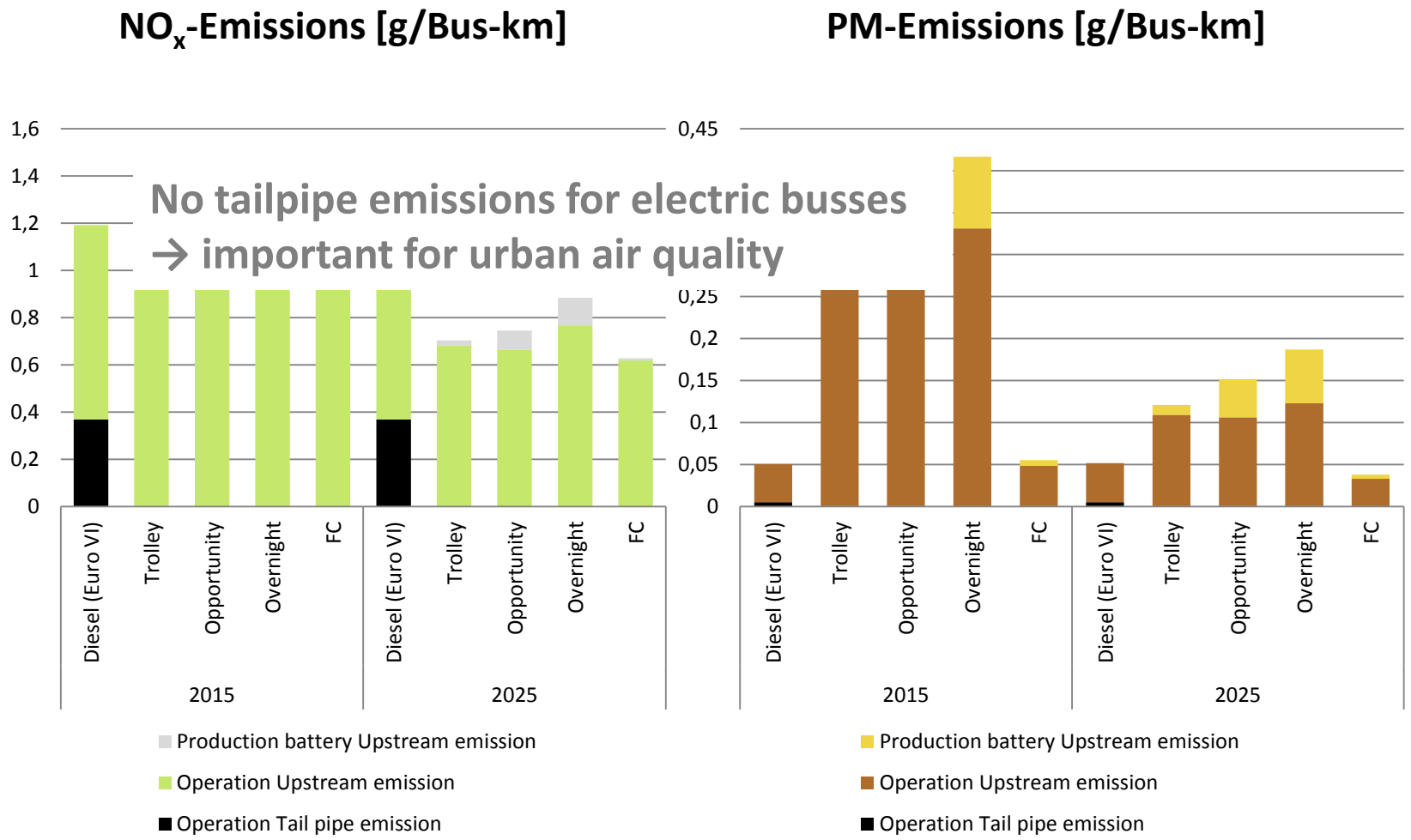
- Emissions (**GHG**, **air pollutants**, noise)
- **Costs**
  - Vehicles
  - Operation (Energy)
  - Infrastructure
- Operational Requirements (minimal constraints for the schedule, flexibility)
- …

Comparison of different fuel concepts – GHG-Emissions (well-to-wheel + battery)



Source: Prof. Pütz (energy consumption), TREMOD/ Leitstudie 2011 (emissions operation), elCar (upstream emissions battery)

Comparison of different fuel concepts – air pollutants



Source: Prof. Pütz (energy consumption), TREMOD/ Leitstudie 2011 (emissions operation), elCar (upstream emissions battery)

Comparison of different fuel concepts – technical specifications - *not final!*

Variante	Infrastructure	Vehicle		
	Energy supply	Energy storage	Energy converter	Power train
Dieselbus EURO VI (Hybrid assumed from 2020)	Gas station	Tank	ICE	Automatic transmission + Drive axle
Trolley-Hybrid	Catenary	Battery (70 kWh)	Electric engine + power electronics	Drive axle
Overnight eBus	Conventional charging (conductive)	Battery (400 kWh)	Electric engine + power electronics	Drive axle
Opportunity eBus	Fast charging (conductive, inductive)	Battery (180 kWh)	Electric engine + power electronics	Drive axle
Brennstoffzellen-Hybrid	Compressed hydrogen station	Compressed hydrogen tank + Battery (30 kWh)	Fuel cell stack + Electric engine + power electronics	Drive axle

Source: Prof. Dr. Ralph Pütz

Comparison of different fuel concepts – Vehicle Cost (2015) - *not final!*

Variant	Body	Impulsion			Total costs (only 1st battery)
	Including aircon, infotainment,…	Energy storage	Energy converter	Power train	
Dieselbus EURO VI	295.000 €	Tank 2.000 €	ICE 22.000 €	Automatic transmission 16.000 € drive axle 15.000 €	350.000 € (100%)
Trolley-Hybrid	340.000 € (incl. Pantograph)	Battery (70 kWh) 70.000 € from 2nd Battery: 21.000 €	Electric engine + power electronics 90.000 €	Drive axle 15.000 €	515.000 € (actual market price 780.000 €) 147% (223%)
Overnight eBus	295.000 €	Battery(400 kWh) 400.000 € from 2nd Battery: 120.000 €	Electric engine + power electronics 90.000 €	Drive axle 15.000 €	800.000 € (229%)
Opportunity eBus	295.000 €	Battery (180 kWh) 180.000 € From 2nd Battey: 54.000 €	Electric engine + power electronics 90.000 €	Drive axle 15.000 €	580.000 € (166%)
Fuel-Cell Hybrid	295.000 €	Compressed hydrogen tank 20.000 € + Battery (30 kWh) 30.000 € from 2nd Battery: 9.000 €	Fuel cell stack 1.000.000 € Electric engine + power electronics 90.000 €	Drive axle 15.000 €	1.450.000 € (414%)

Comparison of different fuel concepts – Vehicle Cost (2025) - *not final!*

Variant	Body Including aircon, infotainment,…	Impulsion			Total costs (only 1st battery)
		Energy storage	Energy converter	Power train	
Dieselbus EURO VI (Hybrid)	295.000 €	Tank 2.000 €	ICE 22.000 €	Hybridisiertes Automatikgetriebe 22.000 € drive axle 15.000 €	356.000 € (100%)
Trolley-Hybrid	340.000 € (inkl. Pantograph)	Battery (70 kWh) 21.000 € further Batteries: 21.000 €	Electric engine + power electronics 30.000 €	Drive axle 15.000 €	406.000 € 114%
Overnight eBus	295.000 €	Battery (400 kWh) 120.000 € further Batteries: 120.000 €	Electric engine + power electronics 30.000 €	Drive axle 15.000 €	460.000 € (129%)
Opportunity eBus	295.000 €	Battery (180 kWh) 54.000 € further Batteries: 54.000€	Electric engine + power electronics 30.000 €	Drive axle 15.000 €	394.000 € (113%)
Brennstoff-zellen-Hybrid	295.000 €	Compressed hydrogen tank 20.000 € + Battery (30 kWh) 9.000 € further Batteries: 9.000 €	Fuel cell stack 100.000 € Electric engine + power electronics 30.000 €	Drive axle 15.000 €	469.000 € (132%)

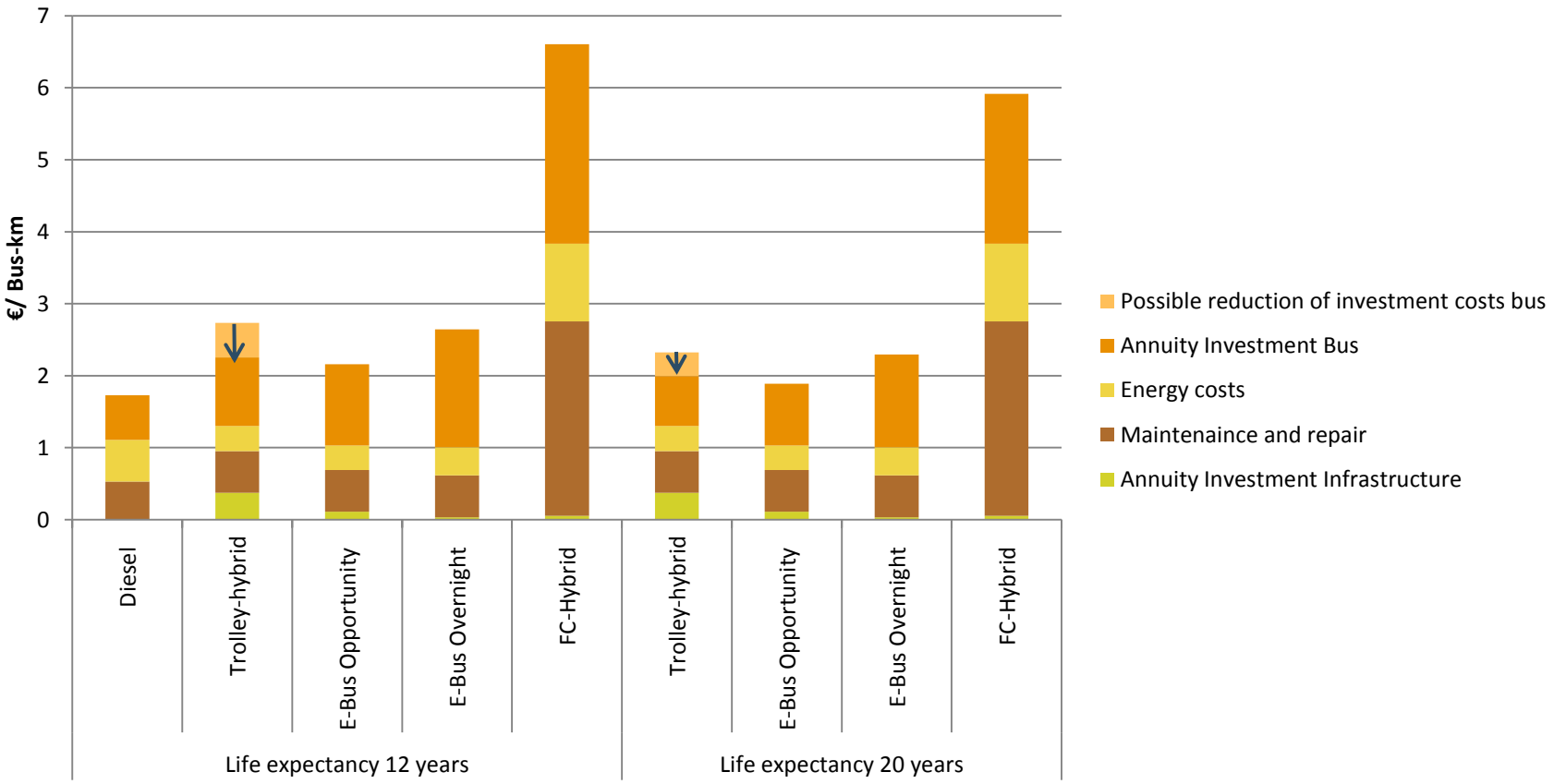
Source: Prof. Dr. Ralph Pütz

Comparison of different fuel concepts – Costs for articulated buses - *not final!*

Variante		Maintenance 2015	Maintenance 2025	Delta anuality Infrastructure	Energy price 2015	Energy price 2025
		€/a/Bus	€/a/Bus	€/a/Bus	€/ l, kWh	€/ l, kWh
1	EURO VI Diesel (ab 2025 hybridisiert)	31.500	31.500	0	1,15	1,65
2	Trolley-Hybrid	35.000	35.000	13.300	0,17	0,25
3	E-Bus Overnight	35.000	35.000	2.100	0,17	0,25
4	E-Bus Opportunity	35.000	35.000	6.700	0,17	0,25
5	FC-Hybrid	162.000	50.000	3.300	8,00	5,00

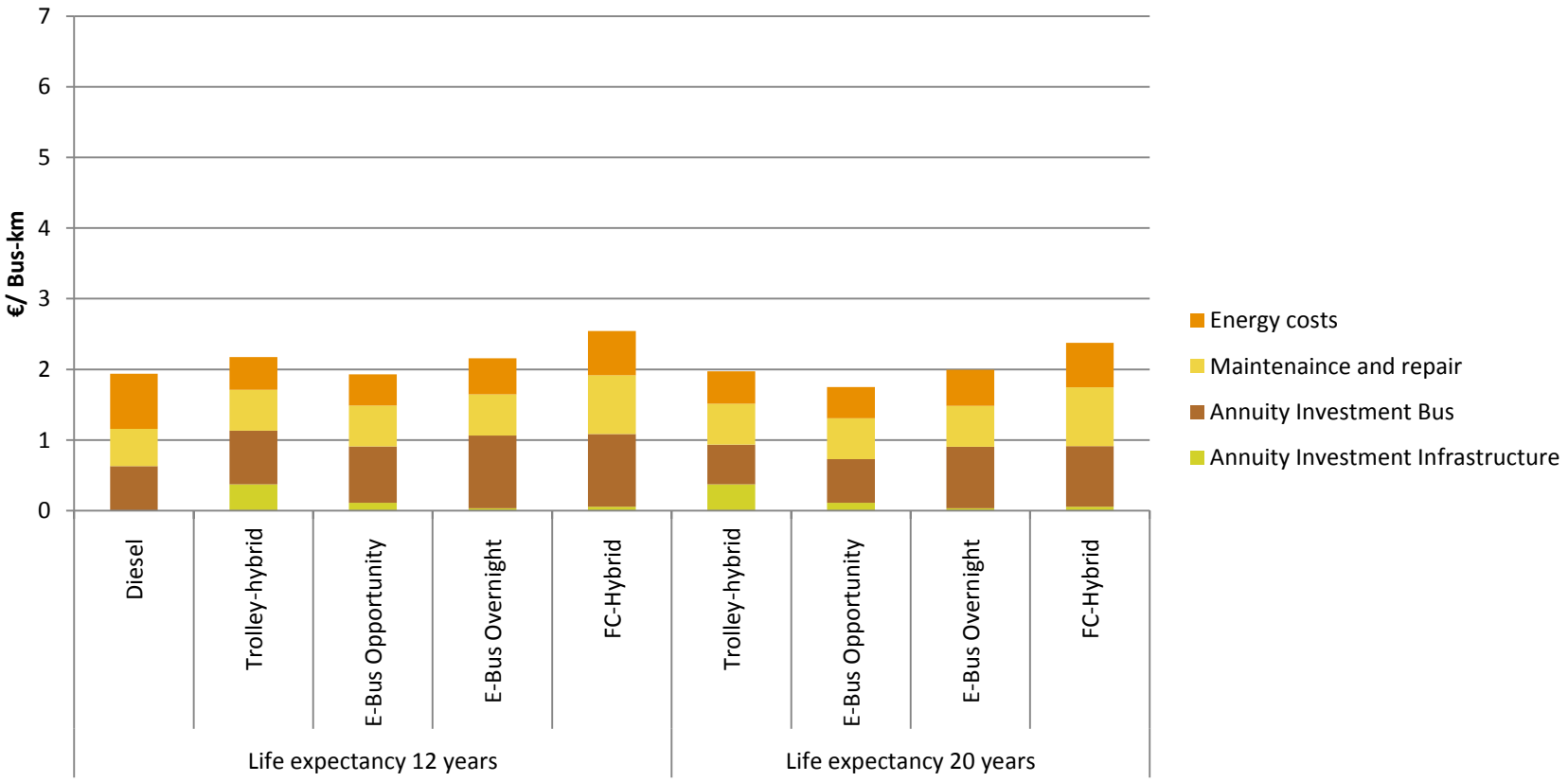
1-5		Fleet with 15 buses on a 15 km long line; Basis: SORT 2 (18 km/h), 22% rate of occupancy; 60.000 km/a
1-5		2nd battery (12 years in service) and 3rd battery (20 years in service)
5		2nd FC-stack (12 years in service) and 3 FC-stack (20 years in service)
1		Infrastructure for Diesel already installed, use of AdBlue is included
2-3		Depreciation Infrastructure (until residual value 0 €): 40 a
4-5		Depreciation Infrastructure (until residual value 0 €): 20 a
4		2 Fast charging stations per terminus
2		Conventional Trolley: 250.000€/km line w/o substation; 4 substations/15 km; 430.000€/substation Trolley-Hybrid: 50% of costs of infrastructure in comparison with conventional trolley

Total Costs of ownership per articulated bus (2015) - *not final!*



Source: Prof. Dr. Ralph Pütz

Total Costs of ownership per articulated bus (outlook 2025) - *not final!*



Source: Prof. Dr. Ralph Pütz

Comparison of different fuel concepts – operational requirements

Operational limitations of Opportunity-Chargers:

- High energy demand
  - high passenger demand/ high capacity vehicles
  - Demanding topography
- Little possibility to recharge/ Short turn over-time
  - Optimized operational plan
  - High average speed
  - Short frequency

Analysis of RWTH Aachen: Restrictions are relevant for about 25% of all lines in the City of Münster

First conclusions of the project

- Electric buses can reduce GHG-emissions through increased efficency an the usage of renewable energy
- All electric bus systems are subject to cost reductions in the next years. Therefore the economical gap between electric and conventional buses will significantly narrow in the next decade.
- 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
- All electric bus technologies have specific opportunities and risks, dependend on individual conditions (acceptance, operating strategy, etc.) – therefore it is necessary to evaluate the alternative technologies regarding the implementation to specific cases (line/ net)

What are the next steps in the project?

- Analysis of the acceptance and willingness-to-pay for electric buses
- Analysis of synergies to electromobility in other modes (e.g. charging infrastructure for electric cars)
- Shapening the field of application for the trolley-hybrid
  - What are suitable operational conditions?
  - Which combination of electric public transport are advantageous?
  - What benefit is possible for the electric net of the city?
- Developing possible implementation strategies for the trolley-hybrid

INSTITUT FÜR ENERGIE- UND UMWELTFORSCHUNG HEIDELBERG

Thank you for your attention!

Fabian Bergk

Wilckensstraße 3 69120 Heidelberg Telefon +49 (0)6 221. 47 67 - 0 Telefax +49 (0)6 221. 47 67 - 19 www.ifeu.de