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Challenges of Battery Electric Busses – Assessment of Demonstration Activities in the IEA Technology Collaboration Program on Hybrid&Electric Vehicles

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Abstract

Urban public transport represents a promising sector regarding the implementation of electric buses due to its structured system layout and scheduled line management. In recent years, various types of electric buses, charging methods and strategies as well as energy storage systems have been tested practically in numerous projects worldwide. The aim here is to give a comprehensive overview of electric bus projects worldwide to identify the key issues for a broad successful implementation and to assess the current state of technology and economic aspects of battery-, plug-in hybrid- and trolley hybrid electric buses. The assessment shows that electric buses are up to three times more energy efficient than conventional diesel buses, however, their life cycle costs of 12 years are up to 25% higher. The most influential life cycle cost factors are the number of buses operating on a particular route, the investment costs of the bus, the energy consumption and the service lifetime of the bus.

1 Introduction

Battery Electric Bus Systems reached increasing attention in recent years. Several city councils and urban bus operators aim to electrify bus fleets partially/completely in near future (e.g. Hamburg, Dresden). Recent developments show that new charging strategies and advanced energy storage technologies enable full-day operation of electric buses, e.g. using the opportunity of fast charging concepts. Significant cost reductions are expected due to technology standardization and economies of scale. More than 20 bus producing companies in Europe already offer various types of electric buses. Main bus companies intend to start electric buses in series production. Electric bus systems have the potential to substitute diesel buses in the (near) future.

Figure1: Electric bus at charging station in Graz (Source: Graz Holding Linien)

The rapid development to prepare the broad rolling out of electric busses is underlined by the following press-releases of industry:

- *"Volvo and the European bus manufacturers Irizar, Solaris and VDL have agreed to ensure the interoperability of electric buses with charging Infrastructure provided by ABB, Heliox and Siemens. The objective is to ensure an open interface between electric buses and charging infrastructure and to facilitate the introduction of electric bus systems in European cities" (15.03.2016)*
- *"The public transport community is preparing for electric buses in Europe and standardization activities have started via the European body (CEN-CENELEC) and via the international organization for standardization (ISO/IEC). European standards are expected to come in place 2019 and international standards in 2020" (23.03.2016)*

For that reasons a new Task 33 "Battery Electric Busses" in the IEA Technology Collaborative Program on "Hybrid&Electric Vehicles" was initiated.

2 IEA Task 33 "Battery Electric Busses"

The objective of the Task 33 (2016 – 2018) is to analyze and assess the current state of technology & demonstration experiences of battery electric busses. This covers on one hand the bus technology e.g. battery or capacitor system, and on the other hand the charging infrastructure, e.g. fast charging stations at the bus stop and its optimal integration in an urban infrastructure, e.g. synergies with trams, metro or trolley bus systems. The task work is done based on an analysis of ongoing demonstration projects of battery electric busses worldwide. Based on this the future perspectives and challenges for battery electric busses are analyses and described. This includes the identification of major challanges e.g. technology, costs, public acceptance and the necessary R&D demand. Finally the key aspects for a successful broad introduction of battery electric buses and the necessary frame work conditions are concluded.

The work is done in a close cooperation of the relevant stakeholder from the three focus groups:

1. Provider of public transportation services,
2. System and technology provider
3. Research institutions

The results are continuously documented and disseminated via presentations, workshops, conference contributions and publications.

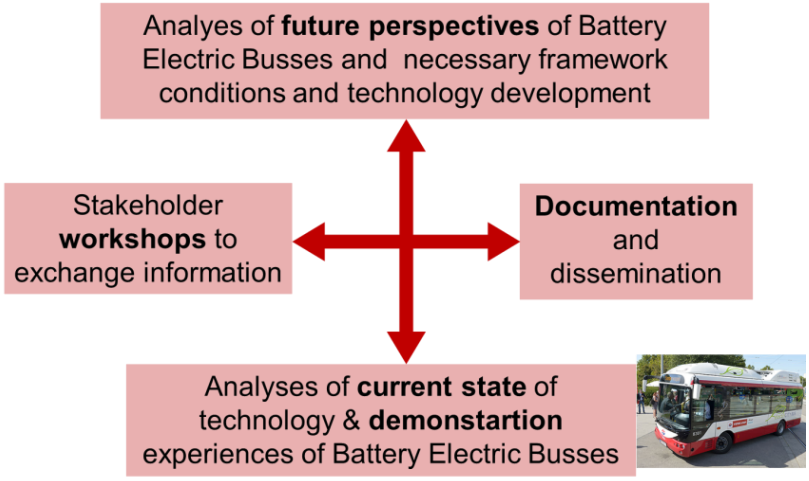

Figure 2: Objectives

The major activities are

- Identify &analyze state of technology and systems of battery electric buses
- Collect and document „International Success Stories“ in a common format
- Give overview of systems &technology providers with characteristic data
- Stakeholder involvement in 2 - 3 Workshops in combination with site visit
- Analyze combination of trolley and battery bus systems
- Integration and use of existing infrastructure of trams, trolleys and metro
- Identify success factors, e.g. size of bus, distances between bus stops
- Define loading strategies
- Analyze sustainability issues – economic, environmental &social aspects
- Identify R&D demand
- Conclude and summarize future perspectives
- Publish IEA HEV glossy Brochure of results
- Presentations and contribution at conferences

The most important activity of the working method is the organization of workshops in different member countries to involve the stakeholders in the value chain of battery electric busses, e.g. provider of public transportation services, system and technology provider, research institutions. The organization of workshops with participation from industry, research organizations, technology policy experts and governmental institutions provides an international basis for the exchange of information on the relevant activities. The focus of the expert workshops is to analyse, discuss and document the

1. State of technology for battery electric busses

2. Future perspectives of battery electric busses

The workshops are combined with a site visit to an ongoing demonstration of battery electric busses in daily life application.

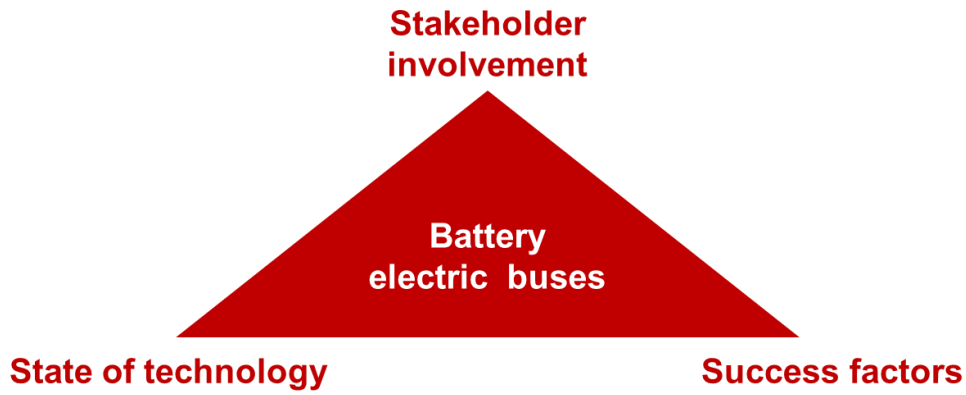

Figure 3: Working method

3 Assessment of demonstration projects

Numerous of innovative projects have been initiated in recent years, especially in central Europe, e.g. from pilot projects towards commercial use (e.g. Cologne, Maastricht, Graz). The evaluation and analysis of key aspects from 60 electric bus projects worldwide (e.g. charging strategies, electric energy storage systems) is ongoing. Urban public transport represents a promising sector regarding the implementation of electric buses due to its structured system layout and scheduled line management. In recent years, various types of electric buses, charging methods and strategies as well as energy storage systems have been tested practically in numerous projects worldwide. The aim here is to give a comprehensive overview of electric bus projects worldwide to identify the key issues for a broad successful implementation and to assess the current state of technology and economic aspects of battery-, plug-in hybrid- and trolley hybrid electric buses. The assessment is based on literature, expert interviews, case studies and life cycle cost analyses.

The analysis is based on the evaluation of 38 electric bus manufacturers and 58 electric bus projects worldwide. In these electric bus projects especially in central and northern Europe innovative charging strategies are used and highly developed electric energy storage systems have emerged in the last three years,. The assessment shows that electric buses are up to three times more energy efficient than conventional diesel buses; however, their life cycle costs of 12 years are up to 25% higher. The most influential life cycle cost factors are the number of buses operating on a particular route, the investment costs of the bus, the energy consumption and the service lifetime of the bus.

In the detailed analysis of five demonstration projects the following drivers for a successful implementation of electric bus systems in urban areas are identified: further technological development of electricity storage systems, standardization of charging infrastructure, an accurately planned electric bus system design to achieve an optimal trade-off between battery/passenger capacity and charging power/time and last but not least an adequate funding programs and broad stakeholder support. The final assessment indicate that battery electric bus systems using an „opportunity“ fast charging strategy are most promising to significantly substitute conventional diesel buses in next years.

This assessment is the initial activity in the IEA Technology Collaborative Program on “Hybrid&Electric Vehicles” (HEV) in Task 33 “Battery electric busses. In this analysis the electric bus systems are characterized by the types of electric buses (Figure 4), the charging technologies (Figure 5) and the

charging strategies (Figure 5). The main focus of the assessment is on battery electric buses, Plug-In Hybrid Buses with ICE and (Hybrid) Trolley buses.

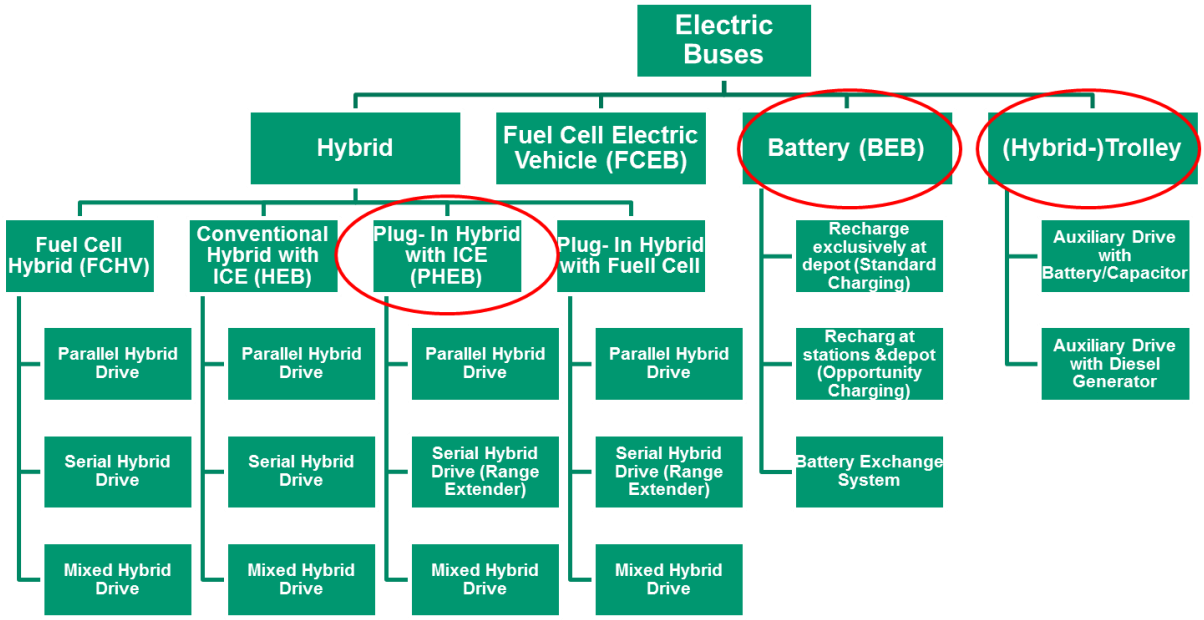

Figure 4: Types of electric buses

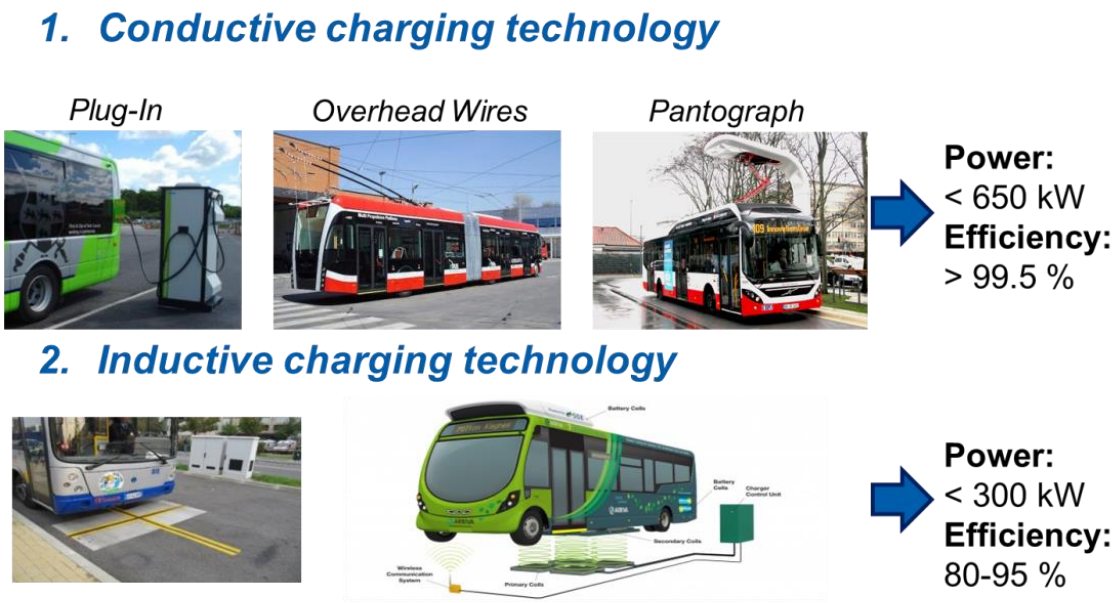

Figure 5: Charging technologies

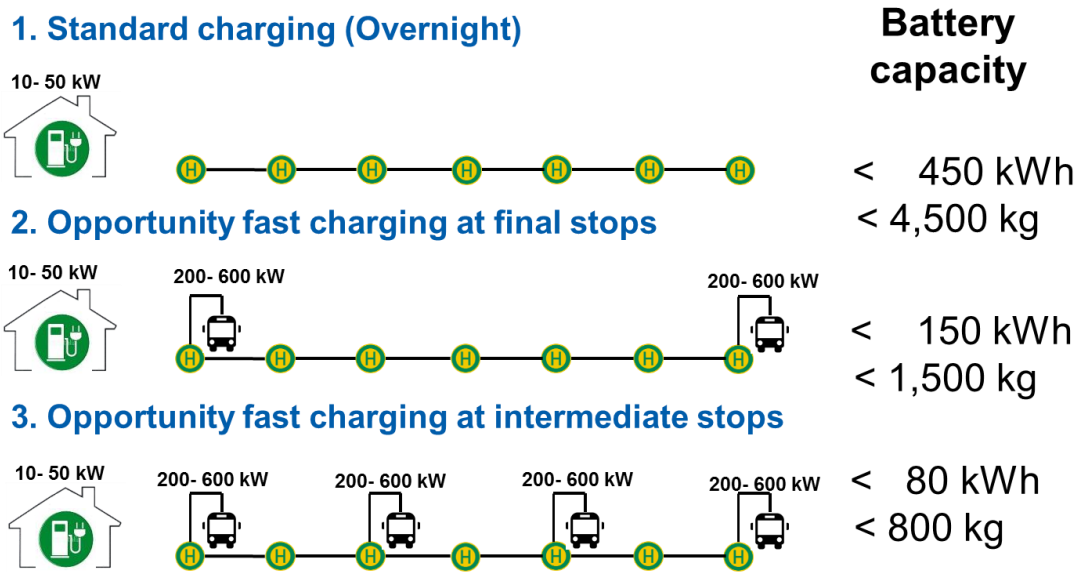

Figure 5: Charging strategies

In total there are 58 demonstration projects of electric buses analyzed (Figure 6) [1], of which the battery electric buses are most dominant, and of which are most located in European countries. In Figure 7 the bus types & lengths and their charging strategies in these demonstration projects are shown. Most of them are a combination of battery electric buses and opportunity fast charging. In Figure 8 the types of the demonstrated energy storage systems are shown, which are dominated by battery electric buses using LFP battery systems, which are also mainly used for trolley buses and plug in hybrid buses. By focusing on 12 m battery electric bus (Figure 9) the energy consumption is in average about 1.5 kWh/km. The Lithium Iron battery costs (Figure 10) are in the range of 300 – 400 €/kWh.

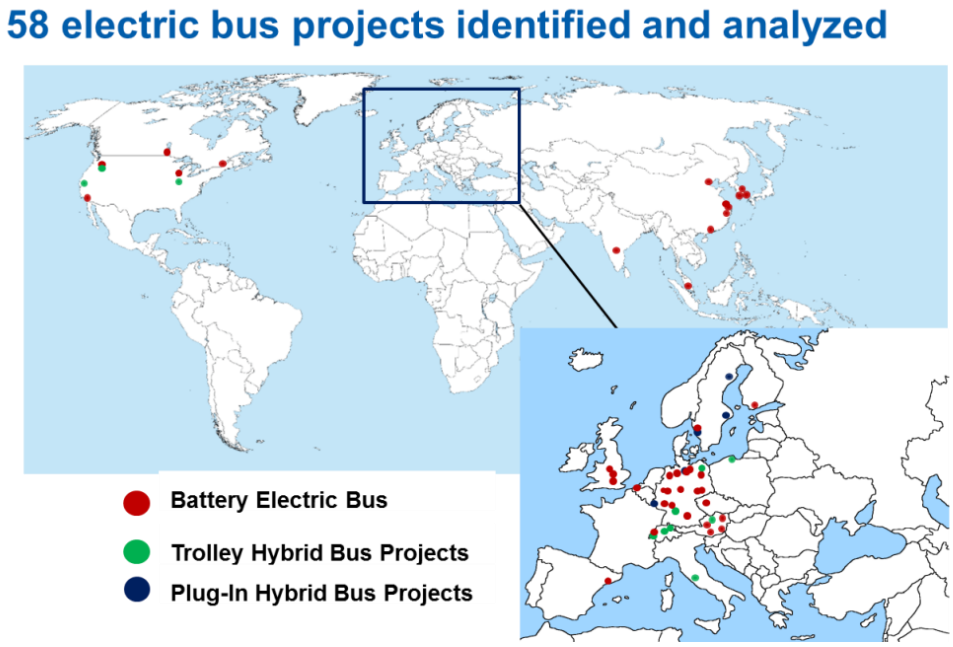

Figure 6: Analysed demonstration projects of electric buses [1]

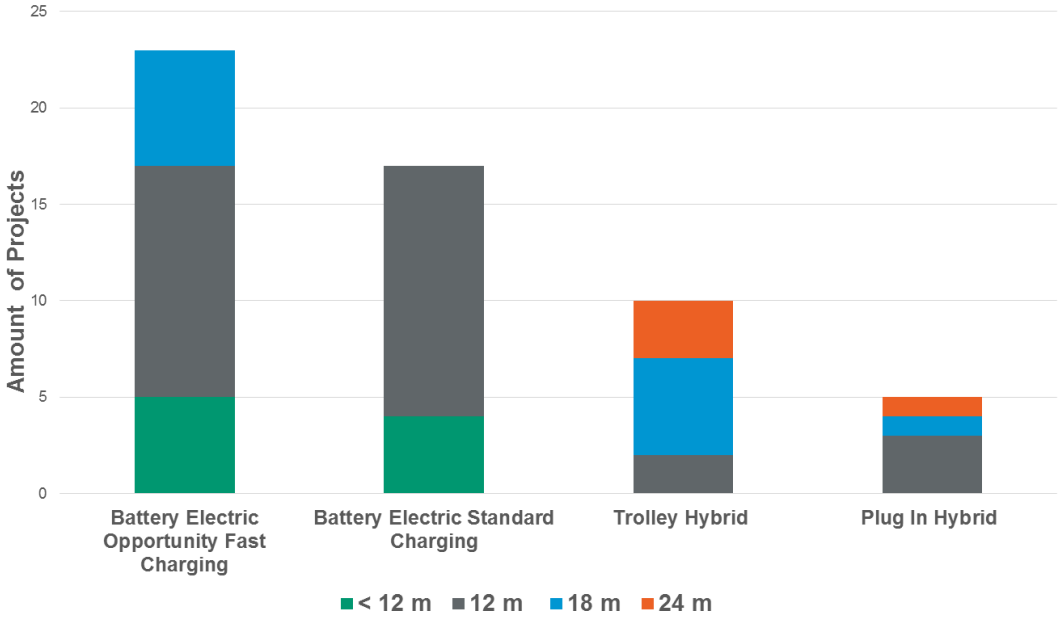

Figure 7: Bus types & lengths and their charging strategies [1]

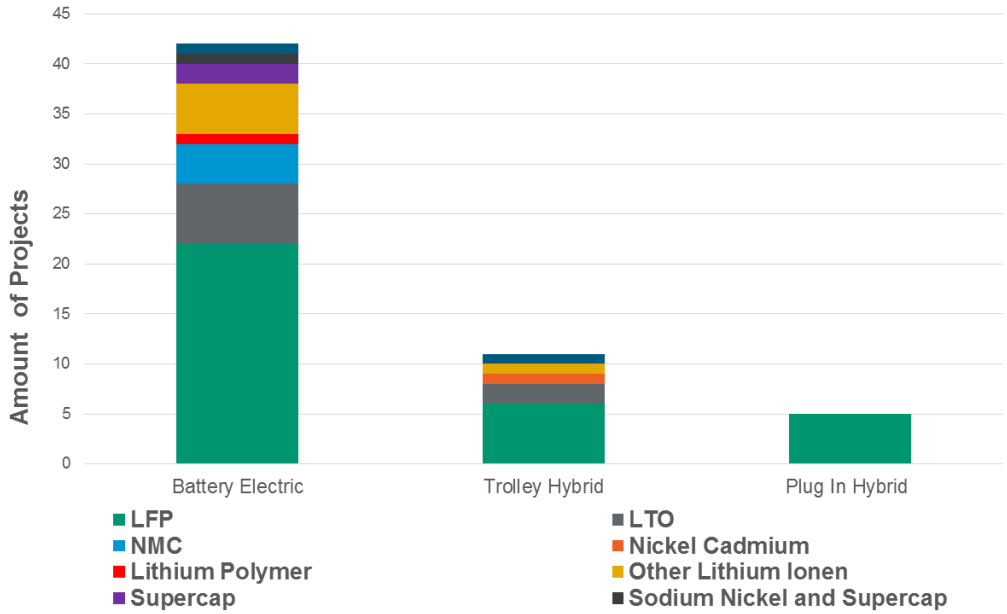

Figure 8: Type of energy storage systems [1]

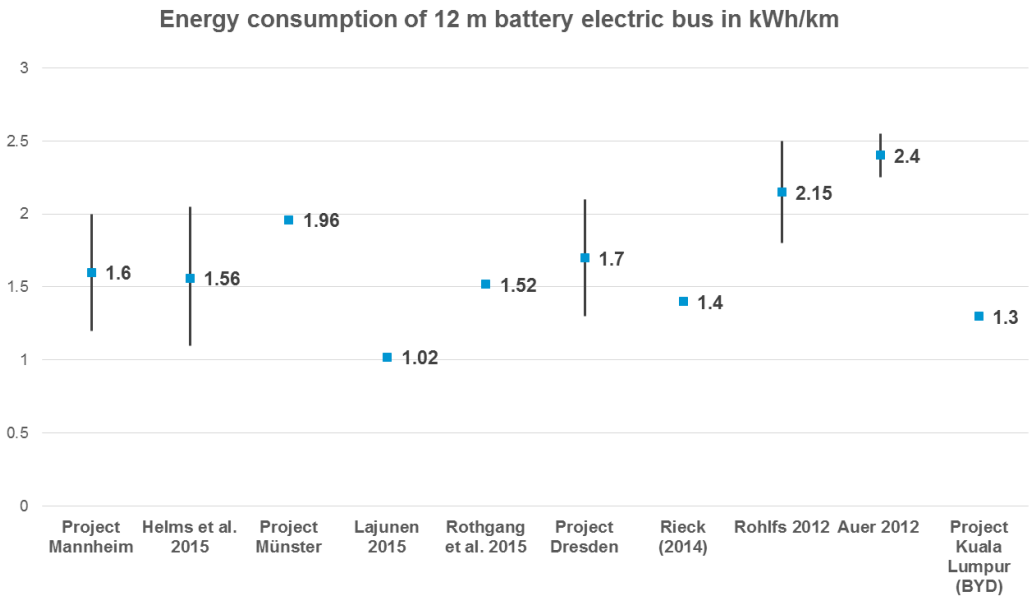

Figure 9: Energy consumption of 12 m battery electric bus in kWh/km [1]

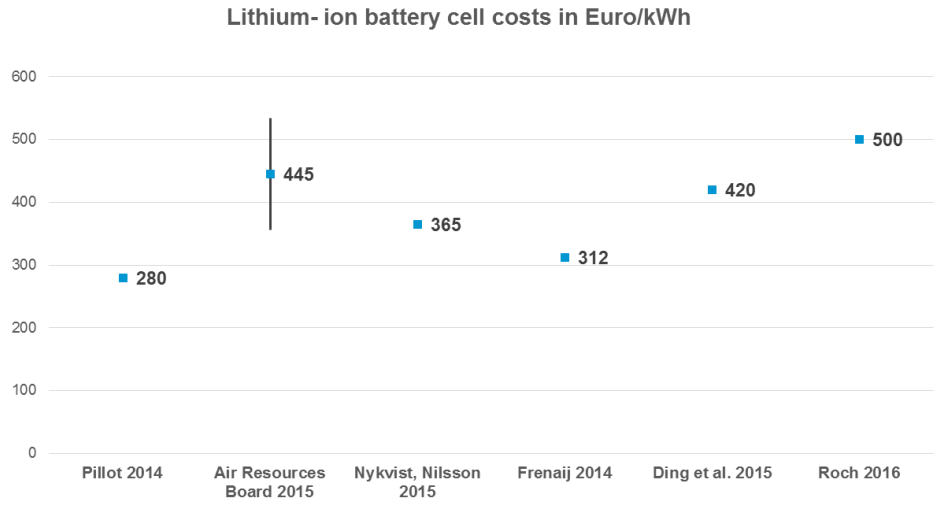

Figure 10: Battery costs €/kWh [1]

Based on practical data derived from the bus demonstration projects a comparison of the life cycle costs of battery bus to diesel bus (Figure 11) is done by using the main data and assumption shown in Table 1. The life time of the battery is assumed to be 6 years and then it is replaced. As the battery costs will further decrease the capital costs for the new battery starting in year 7 are lower and that is resulting in lower costs for the battery electric bus after year 6. In total the cost per kilometer of the battery electric bus incl. the charging infrastructure are about 25% higher than the costs of the conventional diesel bus. In Figure 12 the main influencing parameters on life cycle costs of battery bus and their influence on the costs per kilometer are shown. The following 10 most influential factors are identified

1. Number of buses operating on route 0.44 €/km
2. Acquisition costs of the bus 0.27 €/km

3. Energy consumption 0.21 €/km
4. Operating Life of the bus 0.20 €/km
5. Battery Costs 0.15 €/km
6. Maintenance costs bus/charger 0.15 €/km
7. Lifetime of battery 0.11 €/km
8. Costs for fast/depot chargers 0.09 €/km
9. Electricity cost increases/decreases per year 0.04 €/km
10. Battery cost decreases/year 0.03 €/km

Table 1: Main data and assumption for the life cycle cost analysis [1]

Parameter	E-bus	Diesel EURO VI bus
Acquisition costs in Euro	270,000 – 330,000	210,000 – 280,000
Fuel/electricity costs	150 €/MWh	1 €/l
Operating life km	600,000 – 900,000	600,000 – 900,000
Fuel/electricity consumption	1.1 – 2.1 kWh/100km	35 – 45 l/100km
Battery capacity	LFP 95 kWh	-
Acquisition costs battery	800 – 1,250 €/kWh	-
Battery lifetime (years)	5 - 7	-
Acquisition costs charging station at depot	5,000 – 25,000 €/bus	-
Acquisition costs fast charging station	100,000 – 220,000 €/station	-

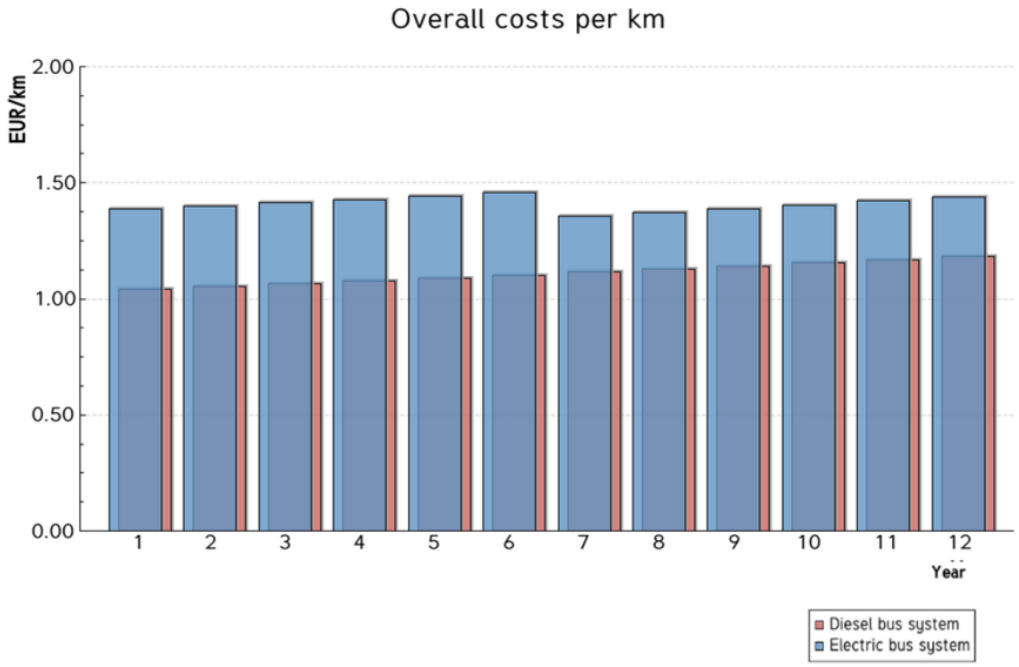

Figure 11: Comparison of life cycle costs of battery bus to diesel bus [1]

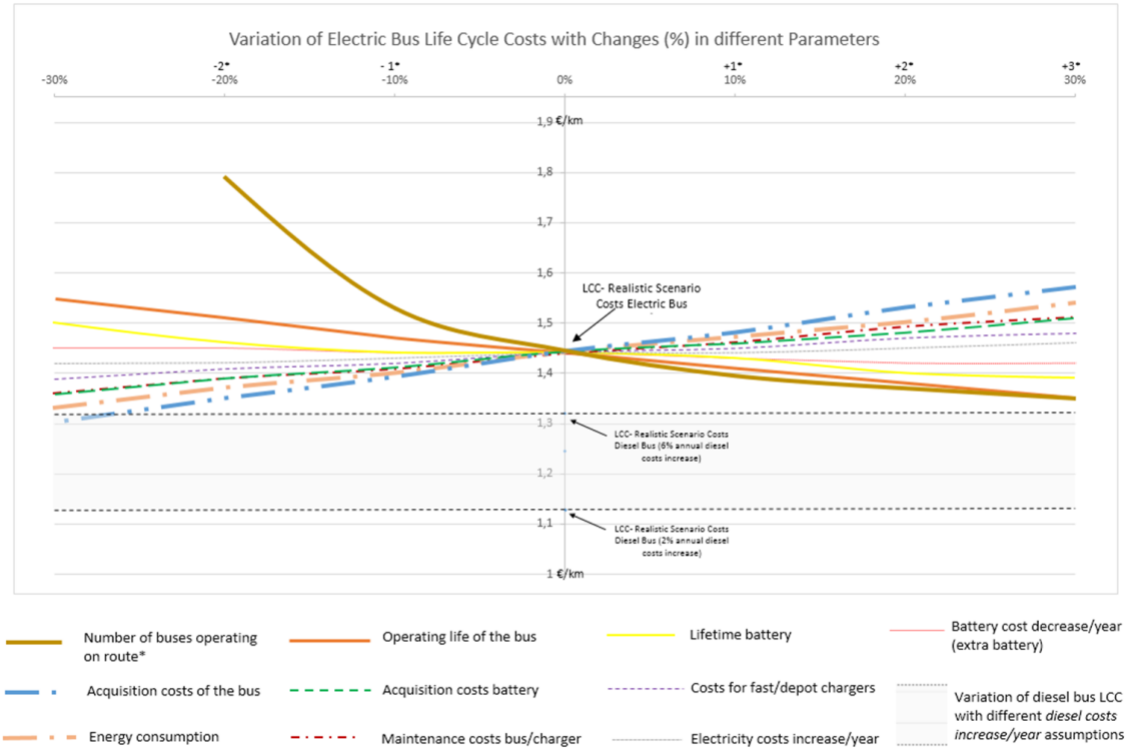

Figure 12: Main influencing parameters on life cycle costs of battery bus [1]

4 Conclusions

The main conclusions of the assessment are

- Battery electric buses have the technical potential to substitute diesel buses in the future in urban areas
- Average system availability of battery electric buses is demonstrated > 80%
- Battery electric buses are in average up to three times more energy efficient than diesel buses on TtW - Basis
- Currently, battery electric bus systems are at least about 25 % more expensive over the entire life cycle compared to diesel buses
- Most influential cost factors in electric bus systems:
    - Acquisition costs of the bus
    - Energy consumption
    - Operating Life
    - Acquisition costs of battery pack
    - Maintenance costs for bus and fast chargers

The Commercial market launch of battery electric buses will be supported by

- Rapid development of electric energy storage systems (LFP, LTO batteries and Supercaps)
- Expected further cost reductions of battery cells
- Economies of scale and standardization processes

The Plug- In Hybrid buses are considered as transition technology in cities towards 100% emission free buses and might be interesting at the regional level for longer distances with constant speed.

The Trolley Hybrid buses have a great potential in cities in which required infrastructure for trolley buses already exists and battery trolley buses will open new challenges to extend the operation area without further investment in infrastructure.

References

[1] Landerl. P., Jungmeier G. (2016): *Status and Future Perspectives of Electric Busses in Urban Public Transport – An Assessment of Current Demonstration projects, State of Technology and Economic Aspects*, Graz, Austria

[2] http://www.ieahev.org/tasks/task-33-battery-electric-busses/

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Highlights of professional experiences:

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- Operating Agent of IEA HEV Task 33 "Battery Electric Buses"
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