

### Electrified Buses in Brussels: Design Considerations and Charging Strategy

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## BACKGROUND





 Electrification of Diesel Buses: WHY?



- To improve Air Quality by reducing emissions
- To reduce the noise of buses in cities
- To get more energy efficient technology

#### Standard Bus:12m



#### Articulated Bus:18m



#### Use-Case Definition & Specifications

#### Modeling Method & Bus Architecture

#### Charging Scenarios & Battery Sizing

#### Summary



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#### **Electric Bus: Design Considerations**





- Road Characteristics
- Battery Chemistry
- Battery Aging
- Charging scenarios: Overnight or Opportunity
- Charging power
- Charging time
- Auxiliaries loads; incl. Air condition, etc.
- Bus schedule
- Bus autonomy and capacity

#### **Bus Lines and Use-case Definition**







Bus Line 17: Neighborhood bus → 12m standard Bus

Overnight Charging

12hr Autonomy

#### **Bus Lines and Use-case Definition**









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#### **E-Bus: Modeling Methodology**





#### **E-Bus: Architectures**

## (1) High Voltage Battery

High Voltage Battery → 600-750V







#### **EVSE**: Electric Vehicle Supply Equipment

### **E-Bus: Architectures**





#### (2) Low Voltage Battery+ DC/DC Converter



#### **Use-case Specifications**





	<b>Bus Line</b>	Length (m)	EMPTY (kg)	Full Load (kg)
<b>STIB/MVIB</b> nput	L 86	12.135	11.720	19000
	L 48	18.125	17.205	27065
	L 17	12.135	11.720	19000

#### **Different Battery Technologies for Electric Bus Lines**

	Battery Type	Capacity (Ah)	Wh/kg	W/kg	Weight (kg)
VUB	LTO	60	156	2700	1.45
Input	LFP	45	146	2500	0.99
	NMC	20	174	2300	0.428

All battery models are validated via real measurements (MOBI database) incl. battery aging  $\rightarrow$  @ different temperatures & current rates



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# Charging Scenarios & Battery Sizing → Bus Line 86



#### → Measurements of L86 → Diesel Bus

- Driving Cycle → back-forth
- Diesel Fuel Consumption  $\rightarrow$  8.02 Liter  $\rightarrow$  59l/100km
- Back-Forth trips  $\rightarrow$  Average distance 13.6km



# Charging Scenarios & Battery Sizing → Electrified Bus Line 86

CIVITAS

- Back-Forth Driving Cycle
- Wheel Power (kW) & Battery power (kW)
- Auxiliaries power  $\rightarrow$  3kW (Assumption)
- LFP battery (45 Ah)/700V



#### $\rightarrow$ LFP battery $\rightarrow$ 45Ah /700V

- Ebus Operation =12 hours
- Min. SoC ~ 10%
- Total Battery Energy= <u>175.25 kWh</u>
- Estimated Distance ~ <u>103 km</u>









High Voltage LFP Battery Pack: Energy (kWh)



#### **Overnight Charging: L86 Battery Sizing**

- ightarrow Selection of Battery Energy
- ightarrow 12hr Bus Operation
- $\rightarrow$  Charging power  $\rightarrow$  40kW <u>@ Depot</u>
- $\rightarrow$  Charging time  $\rightarrow$  4.25 hr (for LFP)





### Impact of Auxiliaries Energy Consumption $\rightarrow$ 12hr Bus Operation





Incl. 96% Efficiency for 48V DC/DC for Aux. loads

# Charging Scenarios & Battery Sizing → Electrified Bus Line 48



- Back-Forth Driving Cycle (50.5 kWh) & 17km → 2.97 kWh/km
- Wheel Power (kW) & Battery power (kW)
- Auxiliaries power  $\rightarrow$  3kW (assumption)
- LTO battery (60 Ah)/600V



### **Opportunity Charging: L48 Battery Sizing**

#### → L48- LTO (60Ah/600V)



- $\rightarrow$  Energy: 28 kWh  $\rightarrow$  Charging at both terminals
- $\rightarrow$  Charging power  $\rightarrow$  200kW  $\rightarrow$  7min



## → Electrified Bus Line 48



#### $\rightarrow$ Impact of Aux. Load consumption



# Charging Scenarios & Battery Sizing → Electrified Bus Line 17



- → Back-Forth Driving Cycle
- $\rightarrow$  Wheel Power (kW)
- → Battery Power (kW)
- $\rightarrow$  Auxiliaries power (average)  $\rightarrow$  3kW (assumption)
- → NMC (20Ah)/700V



#### **Overnight Charging: L17 Battery Sizing**



CIVITAS

- → Total energy = 265 kWh & travelling distance 211 km
- $\rightarrow$  12hr Bus Operation
- $\rightarrow$  Overnight Charging  $\rightarrow$  60kW
- $\rightarrow$  Charging time  $\rightarrow$  4.5hr
- $\rightarrow$  Travelling distance (Back-forth)= 13.93 km  $\rightarrow$  ~1.3 kWh/km





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<b>Bus Line</b>	Energy @12hr	<b>Charging Scenario</b>	Charging time
L 86	185 kWh (LFP)	OverNCharg: 40kW	4.25hr
L 48	28kWh (LTO)	OPPCharg.: 200 kW	7min
L 17	265 kWh	OverNCharg:60 kW	4.5 hr

- → NMC battery is not recommended for Opportunity charging due its limited charging rate
- → Auxiliaries loads have a significant impact on Bus energy consumption.

#### Well-to-Wheel (WTW): Evaluation



→ Energy Consumption → Ebus is based on <u>NMC 20Ah</u>

 $\rightarrow$  Average kg CO<sub>2eq</sub>/kWh for Ebus



#### **Energy Consumption**

	TTW	WTT
Diesel	2151.55	582.98
Elec (BE mix)	629.10	1207.87

Aver. kg $CO_{2eq}$ /kWh = 0.184 kg $CO_{2eq}$ /kWh		
Overnight Charging (E)	<u>Aver. kg CO<sub>2eq</sub></u>	
180 kWh	33.12/One-time Charging	

TTW= Tank-to-Wheel

WTT= Well-to-Tank



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