Electric bus research supporting strategy to large scale deployment

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Comprehensive steps into electrifying the bus system

"Vehicles" (ECV -eBus)

- Components
- Vehicular technology
- Single vehicles

"System" (ECV)

- Systemic view
- Charging technology
- Operation concepts
- A few vehicles

Pre-commercial pilot (ePELI)

- Market dialogue: building the business ecosystem
- Pre-commercial pilot with operators
- Innovation platform
- Small fleet & charging infrastructure

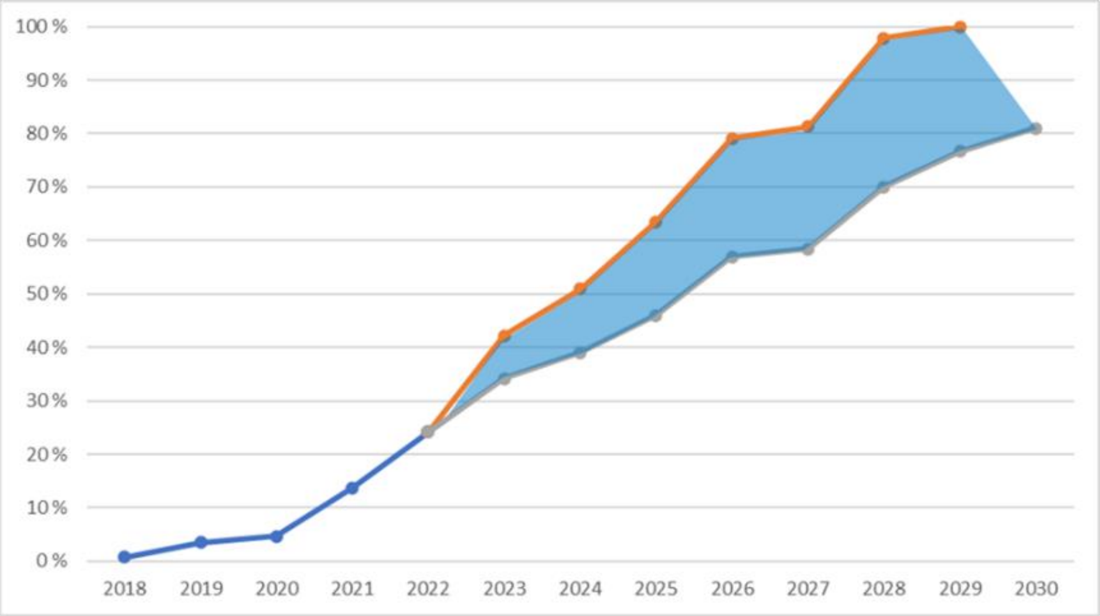
Commercial electric bus operation

- Normal commercial procurement
- Value chains and service providers established
- Several bus operators active
- Charging infrastructure available

HSL timeline: 2012 — 2014 — 2016 – 2019 — 2019 →

Helsinki region city bus fleet scenario

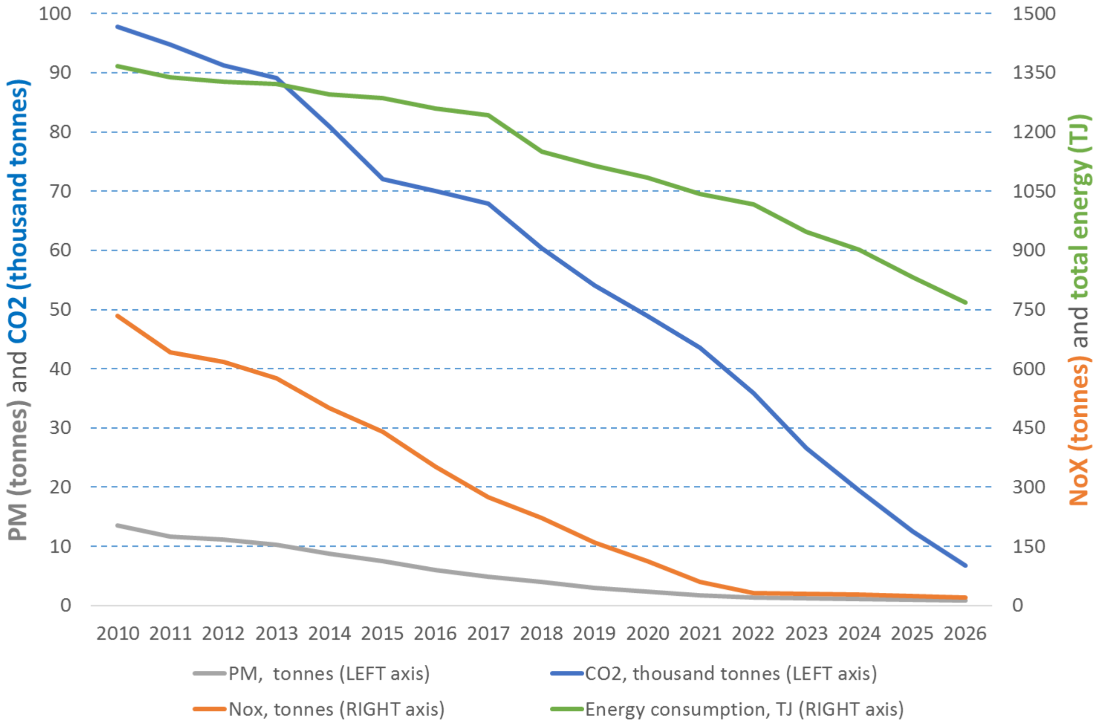
- Total number of buses ~1300
- Currently 14 opportunity charging points (300–450 kW)
- Commercial tendering of electric buses started in 2019
- Significant growth in the e-bus fleet and charging infrastructure in the upcoming years



Blue: electric fleet today
Grey: requirement by the CVD
Orange: best case scenario

HSL scenario emissions and energy use

- Goals for emissions reductions by 2025 (reference 2010):
  - NOx -92%
  - PM -95%
  - CO_2 -90%
- Fossil free 2030
- Zero-emission 2035



Bus fleet in the Helsinki region

- Mostly using 12-13 m twin-axle or 15 m tri-axle buses
- Articulated buses since 2021
- Gas buses in decline (high maintenance costs, safety)
- No plug-in hybrid buses in use

Bus type	Charging	Manufacturer	Amount	Start date	Monitored
Two-axle, 12 m	Pantograph + plug	Linkker	2	23.1.2017	
Two-axle, 12 m	Pantograph + plug	VDL	7	12.8.2019	
Two-axle, 12 m	Plug	Yutong	30	12.8.2019	
Three axle, 15 m	Plug	Yutong	15	4.1.2021	
Low floor, 12 m Three-axle, 15 m	Plug	Yutong	28	16.8.2021	
Two-axle, 12 m Three door, 13 / 15 m	Plug	BYD	32	16.8.2021	
Articulated, 18 m	Pantograph + plug	BYD	44	16.8.2021	
Three door, 13 / 15 m	Plug	BYD	70	15.8.2022	
Articulated, 18 m	Pantograph + plug	Volvo	19	August 2022	
Low-floor, 12 m	Plug	Volvo	42	August 2022	
		Total	**285**		

2017: 10 Linkker (55 kWh battery)

2019 -> VDL Citea (216 kWh battery)

2019 -> Yutong depot-charged (300 kWh)

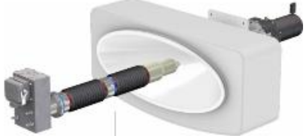
Opportunity vs depot charging system

- HSL is using roof-mounted ACD (pantograph)
  - Lighter infrastructure (charging mast & dome)
  - Easier to install to the city architecture
  - A pantograph failure will not render a charger out of service
- Initially chargers at both ends of the line, and vehicles were charged always at both ends
- Current trend is to concentrate opportunity charging in terminals / nodal points mostly for trunk routes (articulated buses)
- Many recent contracts have been won with large-battery depot charging

Technical feasibility of fast charging

- Current capability up to 600 kW (1000 kW)
- Several alternatives for contacting interface
- Standardised communication protocol CCS
- Pantograph solutions identified as **most feasible** for e-buses
- Contacting also from the side or underneath
- Conductive or inductive
- Stable grid connection essential (battery buffer)

Pictures: Volvo, OppChargei



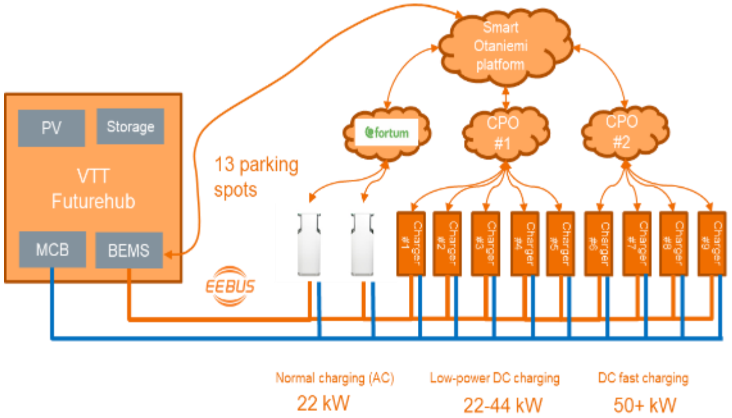
Pictures: PVI, Stäubli

Picture: Bombardier

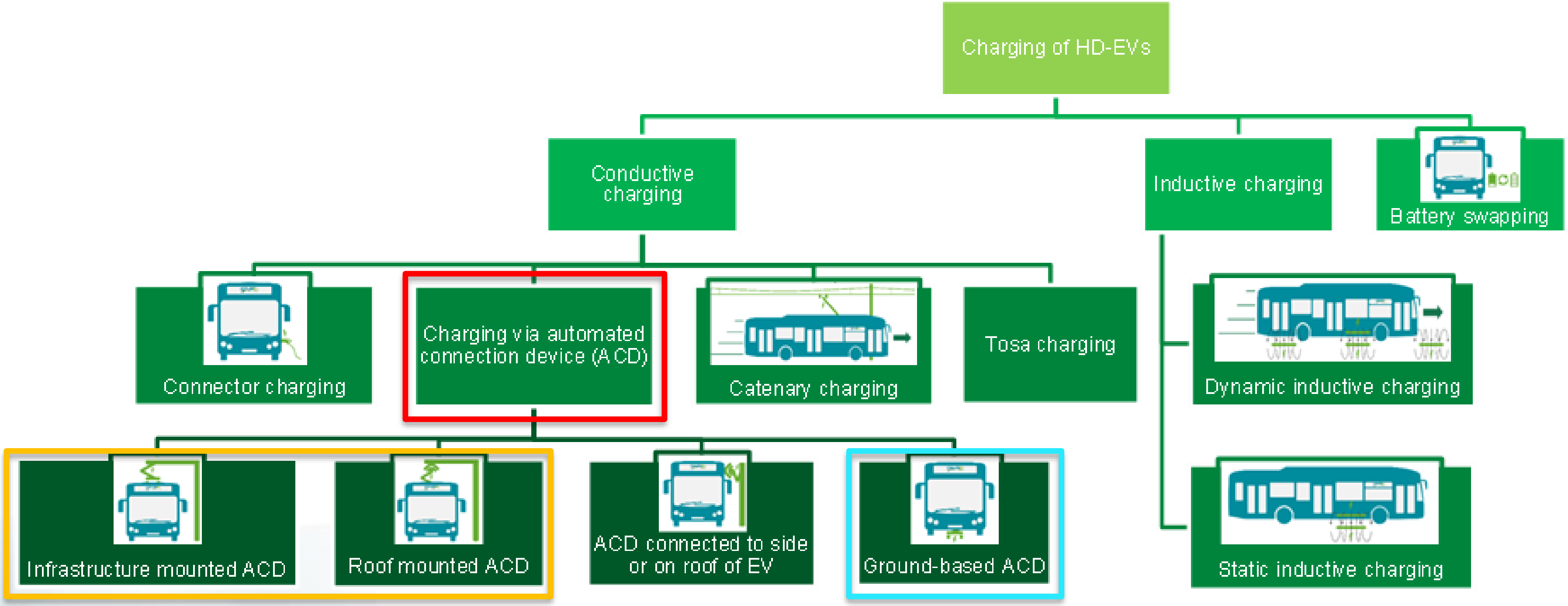
Pictures: Alstom

EV charging research & services @VTT

- **Interoperability**
  - Laboratory and field facilities + equipment
- **Testbeds** – Smart Otaniemi platforms
  - At new VTT building (Futurehub, Otaniemi, Espoo)
    - Fast & expandable DC charging, storage battery option and several AC charging locations
  - At Otaniemi area (ZEMhub initiative)
    - Several planned, also high power (HPC)
- **Megawatt-level charging** – HPC
  - FEMMA project - for moving machinery
- **Wireless charging**
  - REFLECTIVE project - for autonomous vehicles
- **Standardisation**
  - ASSURED project – charging of heavy vehicles
- **Cybersecurity**
  - VTT has capabilities, will be applied to charging



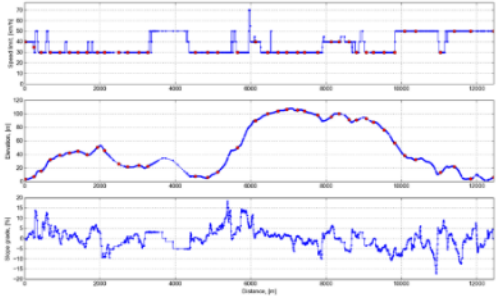
HVDC charging technologies for HD-EVs

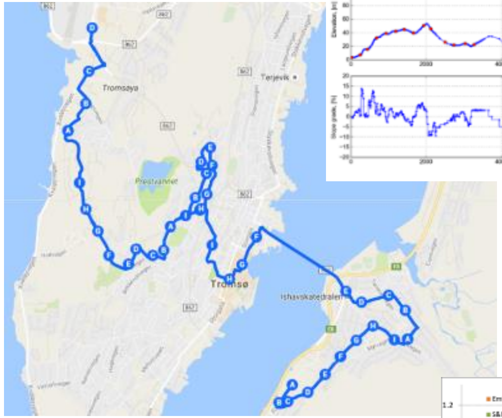


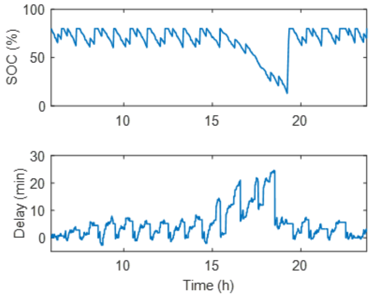
VTT

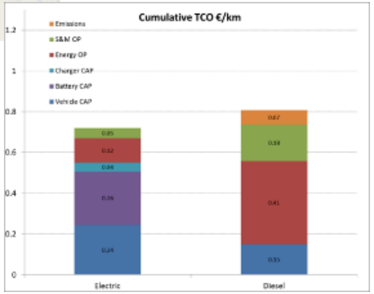
System solutions from specific and detailed analysis – Smart eFleet

- Construction of bus lines / network from digital map data or open sources (e.g. OSM, google maps, GTFS)
- Many types of electric vehicles can be modelled
  - Finding out most potential lines/cases to electrify
  - Dimensioning the vehicles and machines, batteries
  - Location and dimensioning the charging nodes
  - Analysing the sensitivity of operations and margins
- Finding the optimal solution for the case
- Analysis of fleets, statistical analysis, optimisation



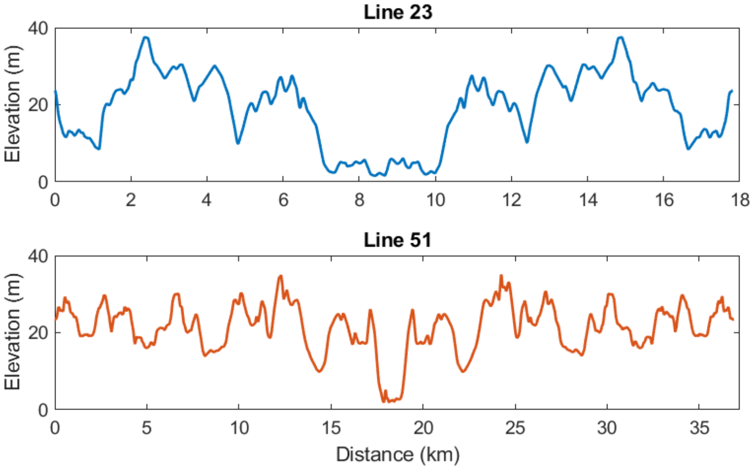


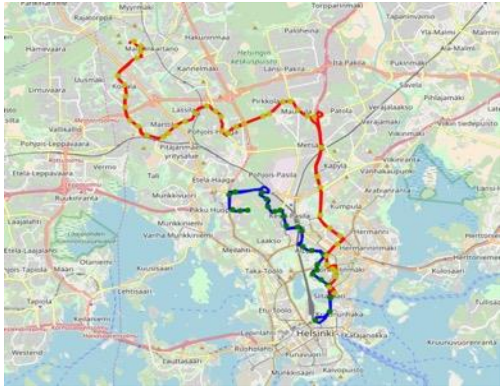




Extensive simulations with short and long bus lines

	Roundtrip length	Commercial speed	Stop density	CEG
Line 23	17.2 km	11.7 - 27.3 (km/h)	2.7 (1/km)	10.2 (m/km)
Line 51	36 km	16.6 - 27.7 (km/h)	2.4 (1/km)	7.2 (m/km)





Summary of results on line 23 and 51

	Line 23				Line 51			
Battery type	**LTO**		**NMC**		**LTO**		**NMC**	
Number of chargers	2	1	2	1	2	1	2	1
Average consumption (kWh/km)	0.97	0.99	0.95	0.94	0.88	0.87	0.84	0.84
Average delta SOC (%)	12.0	23.0	6.9	11.6	22.6	36.0	10.9	18.3
Disturbance risk (%)	0	0	0	0.3	0	29.2	0	1.3
Charging queue formation (per bus per day)	0.03	0.003	0.10	0.065	0.64	0.67	1.32	1.28
Average queueing time (s)	14	5	31	47	109	178	177	266

Summary

- Electric buses are market-ready for large-scale deployment at a competetive cost
- Optimal electrification requires systemic approach and good collaboration with all stakeholders
- Cities and transport authorities have a key role in defining strategies and putting them to action
- Remaining open issues and challenges
  - Electric buses with auxiliary diesel heaters are not zero emission!
  - Depot charging vs opportunity charging vs hybrid mix on full roll-out
  - Zero-emission range extenders and thermal management an option
  - Automated user-centric scalable and cost-efficient charging solutions

Thank you for your attention!