Electrifying bus systems

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This is already happening – HSL fleet strategy

91,1 milj. km / 1350 linja-autoa käytön mukainen jakauma

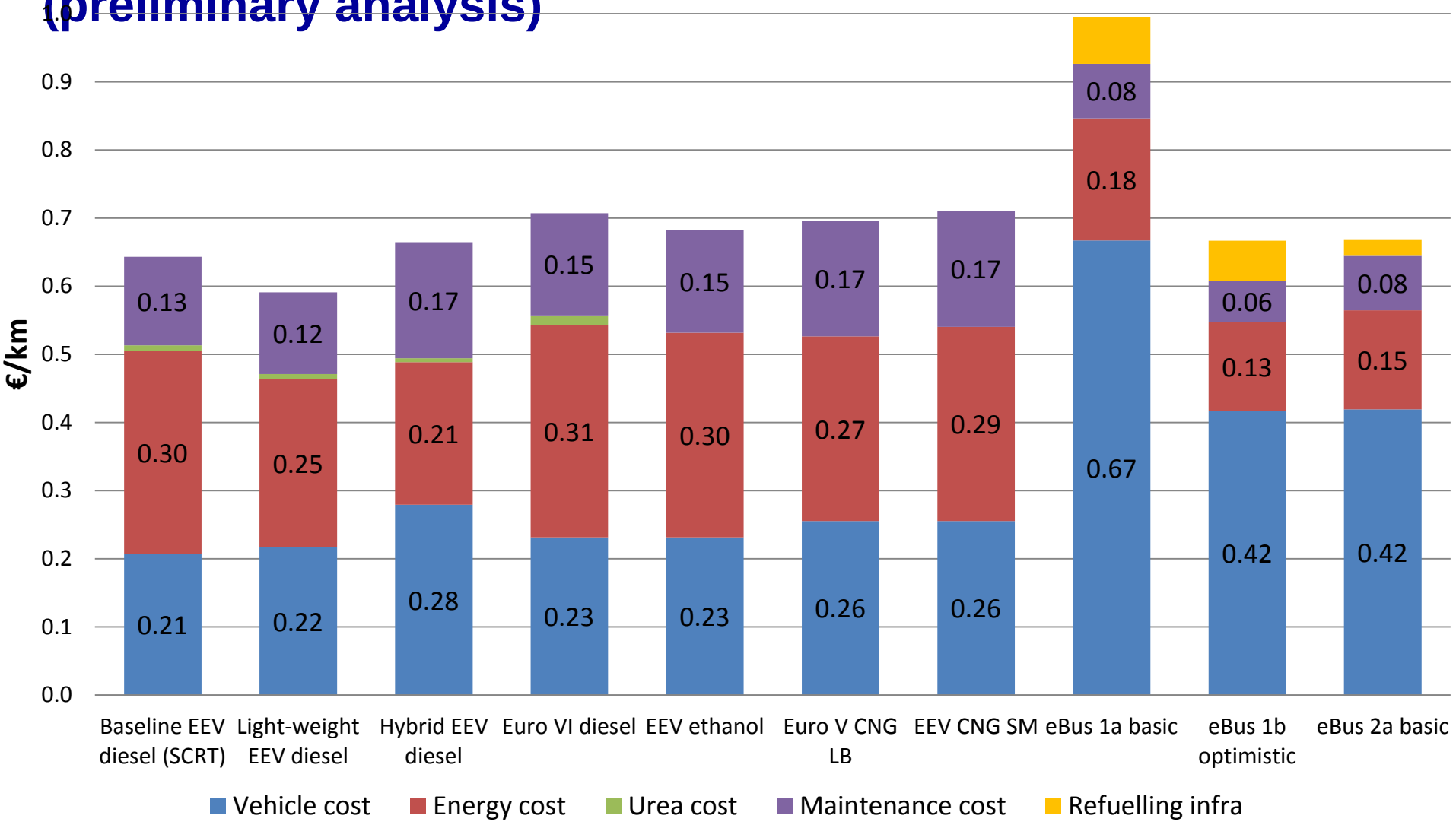
8.10.2013

Bussin euroluokitus	2010	2011	2012	2013	2014	2015	2016	2017	2018
euro 1	1 %								
euro 2	31 %	18 %	14 %	7 %	5 %	2 %			
euro 3	29 %	26 %	26 %	23 %	20 %	14 %	4 %		
euro 4	7 %	7 %	7 %	7 %	7 %	7 %	7 %		
euro 5	4 %	4 %	4 %	4 %	4 %	4 %	4 %	3 %	
EEV	28 %	45 %	47 %	54 %	55 %	55 %	55 %	55 %	48 %
EEV light			1 %	5 %	6 %	9 %	12 %	18 %	18 %
hybridi			0,2 %	0,2 %	1,0 %	2,5 %	5,0 %	8,0 %	10,0 %
hybridi 50% plug									
euro 6					2 %	5 %	10 %	12 %	14 %
euro x									2 %
Sähköbussit						1 %	3 %	4 %	8 %
YHT	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %
100% bio-pa.		1 %	4 %	7 %	15 %	30 %	45 %	60 %	75 %
	2010	2011	2012	2013	2014	2015	2016	2017	2018
Nox	879,42 ton.	-14,89 %	-18,41 %	-24,61 %	-34,91 %	-44,95 %	-54,76 %	-61,42 %	78,32 %
PM	14,6 ton.	-19,29 %	-23,71 %	-29,61 %	-42,47 %	-55,75 %	-68,98 %	-75,33 %	-81,72 %
CO2	112795 ton	-4,97 %	-7,13 %	-9,14 %	-14,99 %	-23,64 %	-33,25 %	-40,45 %	-51,28 %

Why are electric buses attractive?

- Lower energy costs
- City buses are the ideal case for e-mobility:
  - Route length
  - Schedule
  - Operating range
  - Operating time
- High utilisation rate
- Quiet
- Passenger comfort
- No local emissions
- Multimodality potential (rail, tram, machinery)
- What about the total cost of ownership?

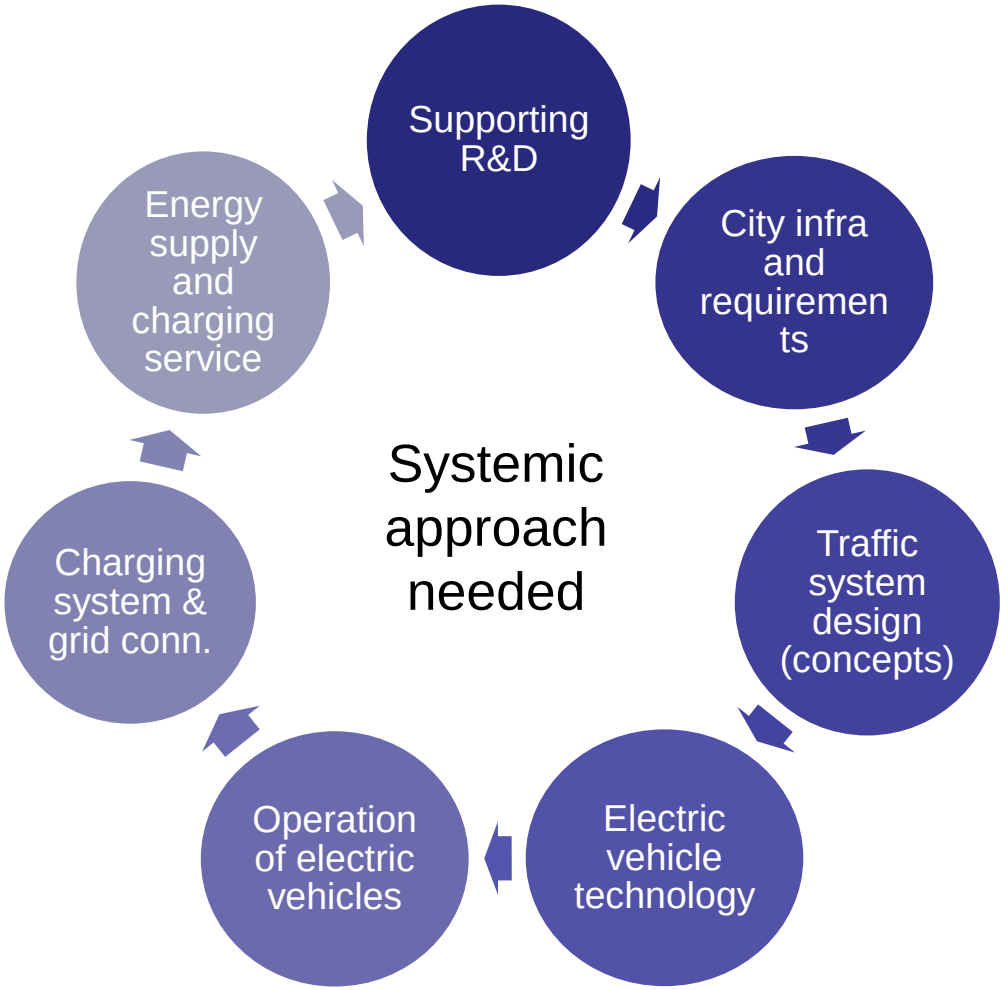
Approximated total ownership costs of electric buses (preliminary analysis)



- eBus1 is with a large battery (depot charging), eBus2 with a small battery (opportunity charging)
- Variant "eBus1 optimistic" assumes improvement in battery cost&lifetime (same potential exists for eBus2 variant)

Prerequisites for utilising the potential

- Conventional fuel to be replaced with electricity (energy management)
- Electric vehicle incl. battery to be optimised
- System concepts and charging infrastructure
- This requires
  - Up-to-date with technology
  - Identifying new businesses and service concepts
  - Rethinking multimodal electric transport system
  - Understanding techno-economics



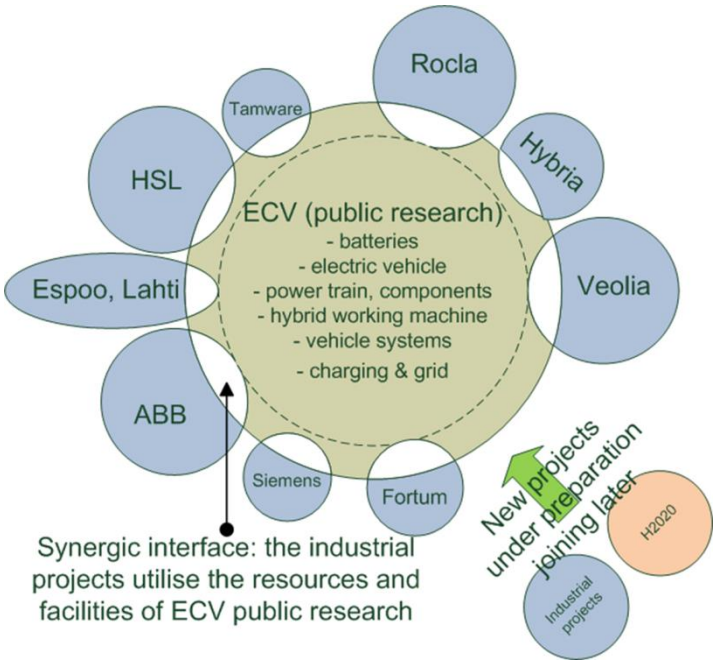
Facilitating the WIN-WIN on eBuses

Vision & goal (at initial state)	Decision making & verification	Solution	Owner
Managed risks and increased productivity	Risk analysis with sensitivity, component lifetime, batteries	Interplay and roles of key stakeholders	All
Straightforward charging and energy management	Charging technology, ownership models, charging as a service	Emerging businesses	Services
Optimised powertrain and vehicle	R&D platforms, demonstrators, vehicle-in-the-loop, simulation	Right eBus for vehicle tender	Vehicle manuf.
Reduced TCO	eBus technology options rationale and piloting	Winning offers for operation tender	PTO, city
Life quality, fleet efficiency and reduced emissions	Urban planning, traffic system, operation concepts, infrastructure	Sustainable public transport strategy	PTA, city

Requirement – strong reference projects

Electric Commercial Vehicles - ECV

- Industrial R&D network in Tekes EVE programme
- 2nd phase duration 2 years (2014 – 2015)
- Total volume ~18 M€
- Five research partners, 30 participating companies
- International (FP7, H2020) link (ZeEUS.eu)
- ECV covers the whole innovation chain of electric commercial vehicles
  - Components (batteries, motors, inverters etc.)
  - Subsystems (power train, energy management etc.)
  - Modelling (xEV's, energy storages, power trains)
  - Laboratory testing (xEV's, and components)
  - Electric prototype bus development platform (VTT)
  - Living lab field tests (buses, demonstrations, AGV)
- Business development through joint R & D



ECV-eBus & eBusSystem – the Espoo spearhead

Public sector
Private sector
Bus operator
Research

The transport system

How do electric buses fit into the public transport system?

- Ministry of Transport
- Helsinki Region Transport
- City of Espoo
- Veolia, Aalto University

Green Public E-Mobility

The vehicle

How do electric buses perform?

- Veolia, VTT
- Bus manufacturers (BYD, Caetano, Ebusco, VDL)
- Component manufacturers (Visedo, Tamware, Vacon)
- Transport Safety Agency

The energy supply

How can electric buses be charged and how is the grid affected?

- Smart grid, grid services and smart bus depot
- Utilities (Fortum), Siemens, charger manufacturers
- Rail traffic synergy, cities
- VTT, TUT, LUT

ECV-eBus project

- The aim is to find out usability of electric buses in commercial transport
- Field study and laboratory research
  - Electric bus test line 11 Tapiola-Friisilänaukio
  - Vehicle laboratory
    - Full-size electric bus prototype as a development platform
  - Battery laboratory
    - climatic chambers for components
  - Simulation tools
- Challenging weather conditions
- Part of Tekes EVE programme
  - A major section of ECV
  - The scope of eBus ~4.6 M€

eBusSystem – Electric city Bus Systems

- Project coordination by VTT
- Partners: HSL, Espoo, Fortum, Lahti
  - The project is open to additional cities to join
- Project collaborates tightly with Veolia's eBus project
- Goals for the project:
  - Find standard solutions for different type of bus lines
  - Develop methods for cost/benefit analysis
  - Develop knowledge and services that is needed for introducing electric buses in wide scale
  - Communicates the demand of charging systems for industry

eBusSystem – Electric city Bus Systems

- Piloting of opportunity charging system
  - Planned schedule is to start the pilot during 2015
  - Piloting on line 11 together with eBus project
  - Automatic fast charging system – supplier not chosen yet
- Building up business models for charging services
  - Discussions with energy companies
  - Workshop together with several public authorities – focus on purchasing, ownership and maintenance of charging infrastructure
- Following technical development in industry
  - Continuous communication with several companies

Objectives of field study and laboratory research

- Field study
  - Impacts of challenging weather conditions

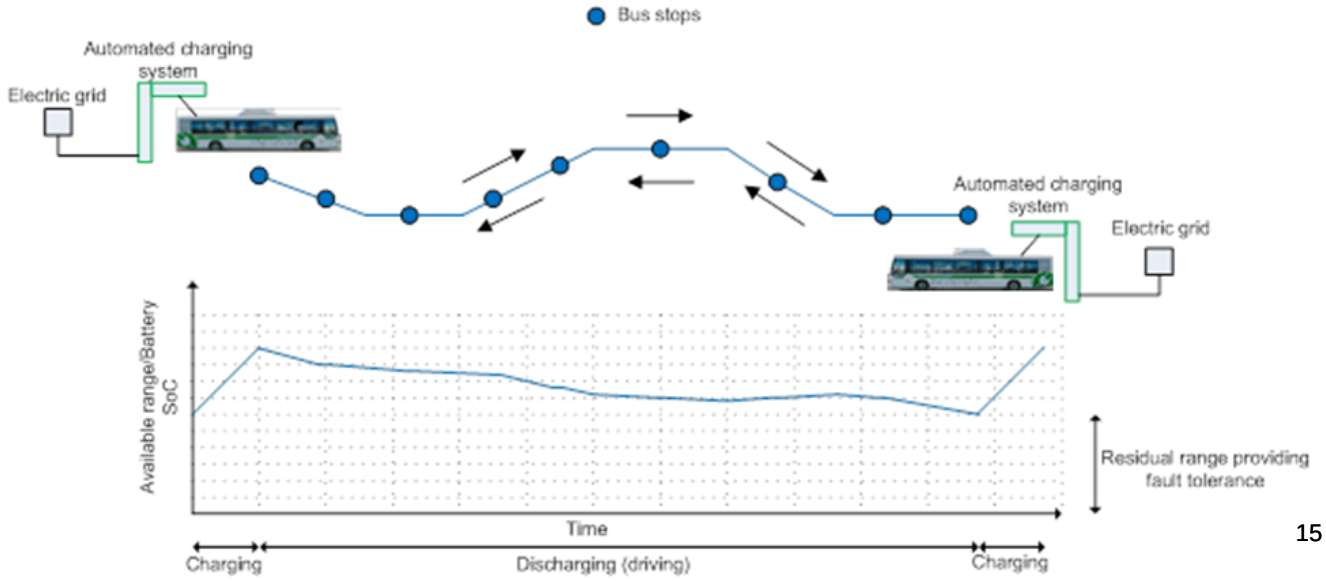
  (energy consumption, battery life cycle, electric bus technology)

- Laboratory research
  - Energy efficiency of different driving cycles
  - Flow of energy and energy losses
  - Comparison of different technologies
  - Battery life cycle

Requirement – keeping up to date with technology and concepts

Technology and concepts

- Things to address
  - Charging technology development and standardisation
  - Electric vehicle, powertrain and traction battery developments
  - Vehicle performance analysis both in laboratory and fleets
  - Lifetime and life cycle cost of key components
  - Concepts of operation, dimensioning of charging infrastructure and traction battery



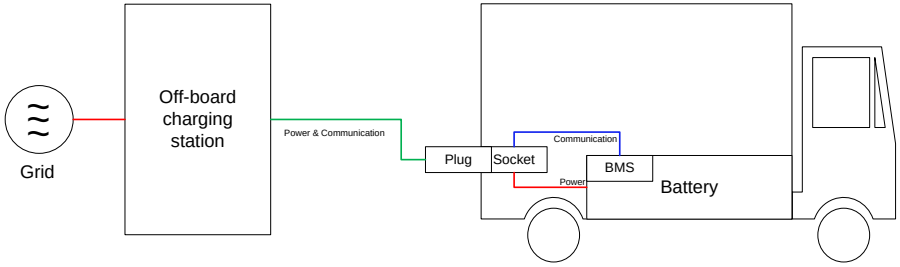
Charging concepts

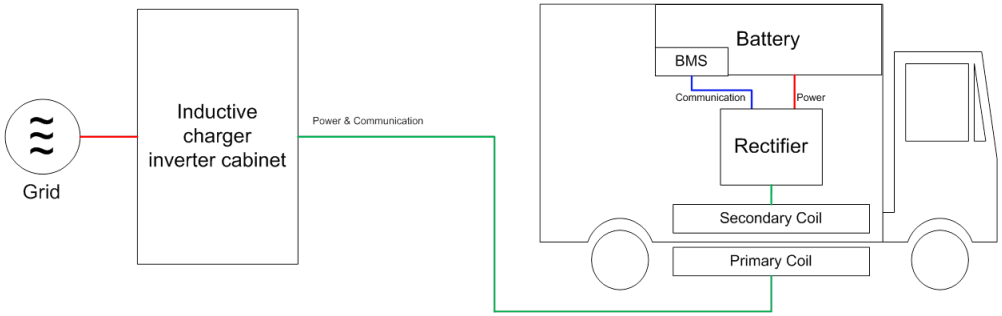
Charging concept	Infrastructure costs	Vehicle costs	Operation costs	Concept feasibility
1. Overnight charging in the depot	Low, Chargers only in the depot	High, Large battery capasity	High, low battery lifetime, high energy consumption	Possible in demonstrational phase
2. Overnight charging + fast charging during the day	Moderate, Chargers both in the depot and terminals	Moderate, slightly smaller battery capasity	Moderate, slightly longer battery lifetime, additional costs if extra buses and drivers needed	Possible in demonstrational phase, parking space in bus terminals limits in wider scale use
3. Opportunity charging (automatic high-power charging)	High, expensive charging systems in terminals	Moderate, small battery, expensive technology depending on system	Low, no changes into normal bus operations	Feasible only as a large system where there are enough vehicels to take advantage of the investment

Potential charging methods

Charging with cable & socket

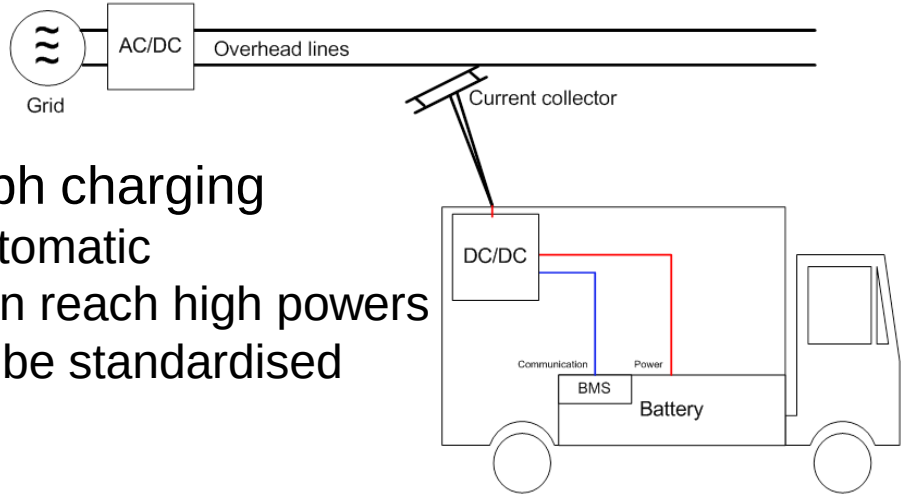
- Manual operation
- Partly standardised, low power





Inductive charging

- Contactless
- Automatic
- Can reach high powers
- Not standardised



Pantograph charging

- Automatic
- Can reach high powers
- To be standardised

Potential charging methods

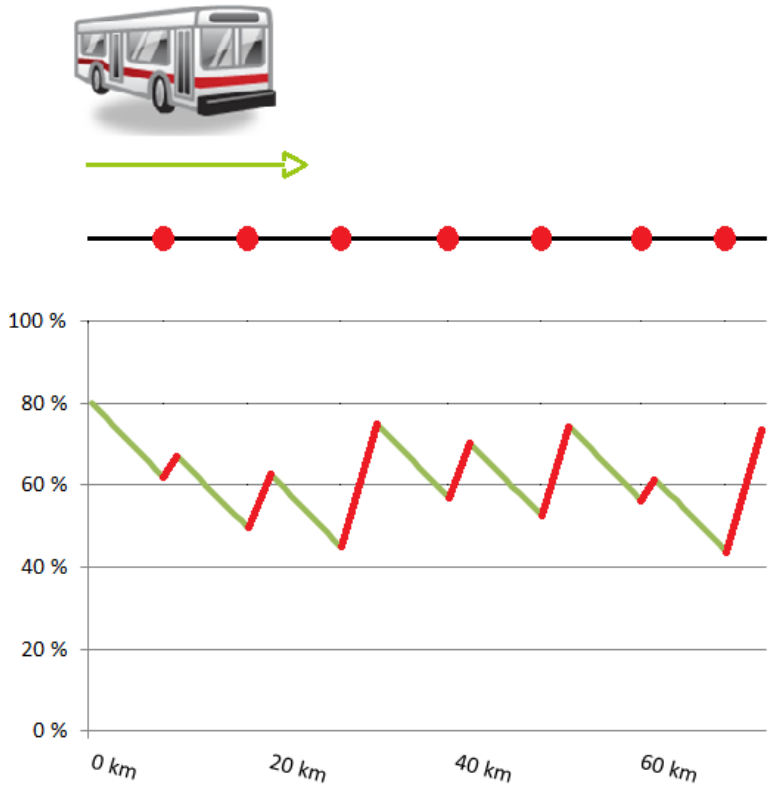
Siemens

ABB

Conductix

Fast opportunity charging during the day

- Charging in bus terminals, end stops or along the line
- Battery is mostly used in the middle area of state of charge
  - → Extended battery lifetime
  - → Extra capacity always available in case that one charging would fail

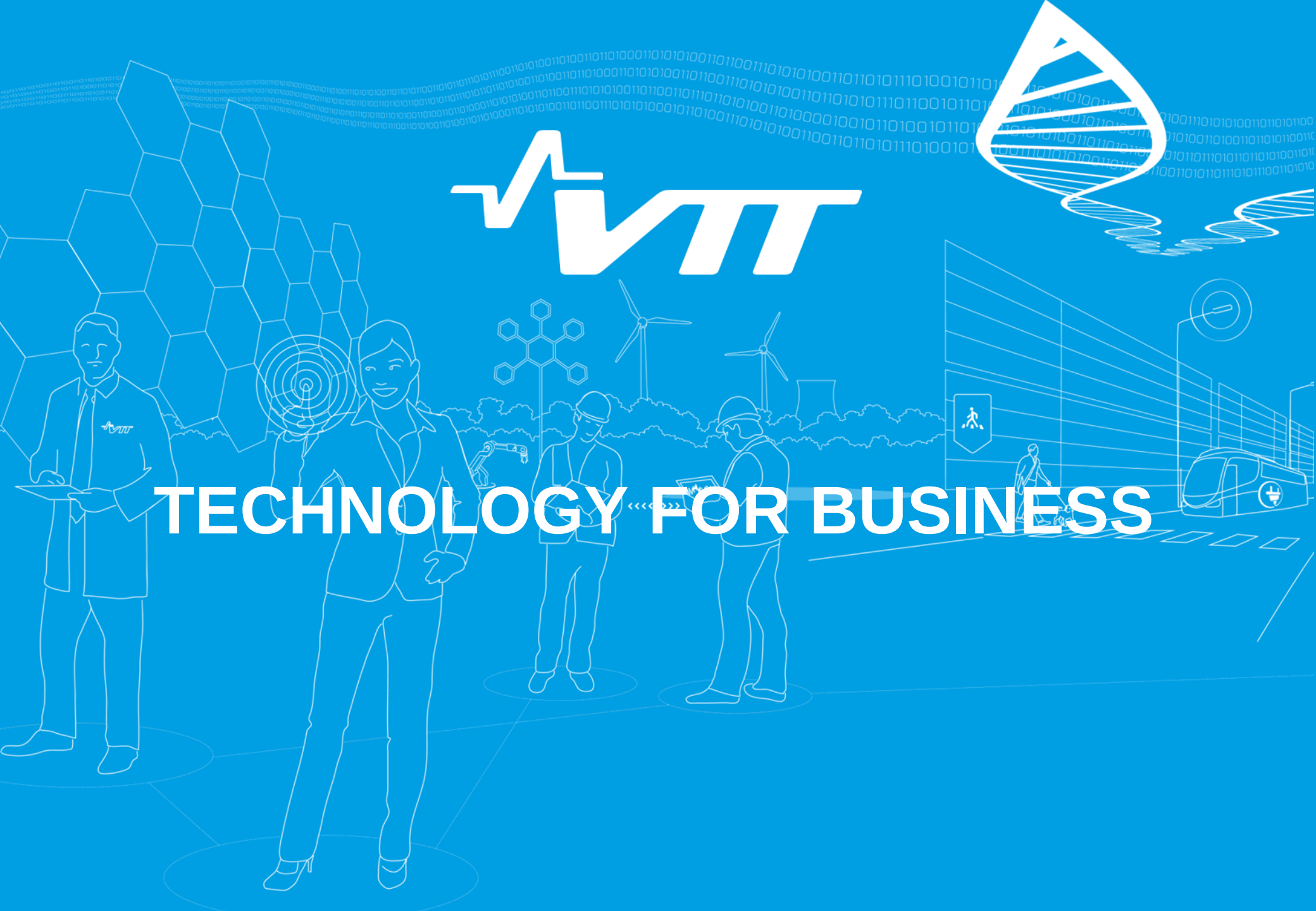


eBusSystem – early findings

- In electric buses wider scale introduction is worth to invest charging infrastructure to minimise battery capacity
- Opportunity charging power has to be moderate to large (100 – 500 kW) in order to the necessary energy can be charged with no loss to productivity
- Extra buses and drivers increase electric bus operating costs unreasonably
- Electric city bus systems and business models may vary between different cities

Summary and conclusions

- Electric bus systems are fast emerging
  - Both vehicle technology and charging equipment available
- Electric city buses are heavy duty sweet spot, other use cases and applications will follow
- Designing an efficient ebus system requires systemic approach
  - Optimised vehicle and battery
  - Operation concept analysis
  - Charging infrastructure and energy management
- New business and service models are emerging
- Co-operation of key players required: city, PTA, PTO, energy company, service providers (e.g. charging service)
- Our value proposition: reduced system-level TCO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