TOWARDS THE ELECTRIFICATION OF PUBLIC TRANSPORT VIA PUBLIC-PRIVATE PARTNERSHIP
THE EXAMPLE OF LUXEMBOURG

ANNUAL POLIS CONFERENCE 2017
6-7 December 2017, Brussels
Innovation in Transport for Sustainable Cities and Regions

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PRESENTATION OUTLINE

part 1	the past	Preparing for transition to electrified buses
part 2	the present	Launching the e-bus systems
part 3	the future	Researching cooperative electrified bus systems

1 THE PAST

THE PARTNERSHIP

THE GOVERNMENT
OF THE GRAND DUCHY OF LUXEMBOURG
Ministry of the Economy

LE GOUVERNEMENT
DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère du Développement durable
et des Infrastructures

Sales-Lentz
moving people

VOLVO

Objective: to gain experience how to decarbonise the network of buses and to enable the setup of eco-system for the testing and deployment of innovative sustainable technologies.

2013 Memorandum of Understanding (MoU)

The Ministry of Economy, the Minstry of Sustainable Development and Infrastructure (MDDI), bus operator Sales-Lentz and Volvo Bus Corporation sign a MoU on the establishment of Luxembourg as a test arena for sustainable public transport systems.

2016 The launch

- Volvo Bus Corporation creates in Luxembourg e-Bus Competence Center
- MDDI operates one opportunity charging station for the RGTR* bus line 226
- Sales-Lentz operates plug-in hybrid buses for the line 226
- Start of operations on the project line 226 begining of 2017

* PT authority (regional lines)

MOTIVATION AND ASSUMPTIONS

Public transport is essential in areas with high mobility demand

Negative effect of noise and air pollution on society is significant*

Electric buses are the best choice for public transport when considering

- noise,
- pollutants,
- GHG emissions
- energy efficiency

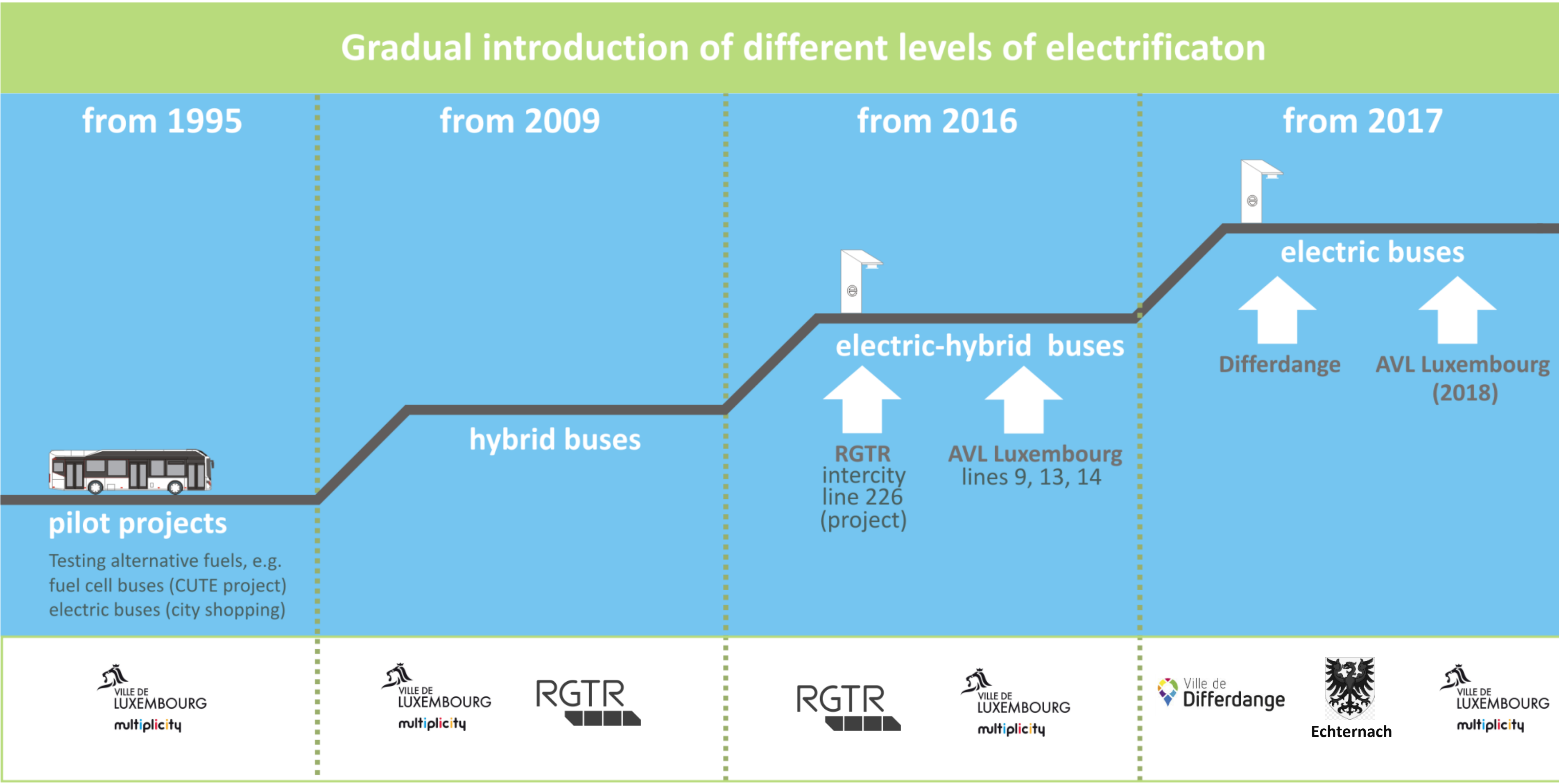
	energy**	NOx_{TTW}**	$PM10_{TTW}$**	noise
Electric opportunity	1.4 kWh/km	0	0	
Hydrogen	3.1 kWh/km	0	0	
Diesel	4.1 kWh/km	0.5-1.1	0.015	
CNG	5.1 kWh/km	1<	0.01 <	

Vendor lock-in for charging solutions should be avoided

* At least one million healthy life years are lost every year from traffic related noise in the western part of Europe.
Source: *Burden of disease from environmental noise. Quantification of healthy life years lost in Europe*, WHO (2011)

** Source: *CIVITAS Policy Note: Smart choices for cities, Alternative Fuel Buses* (2016)

ELECTRIFICATION TIMING



MDDI is planning to test different e-bus technologies for regional lines before large-scale rollout.

SYSTEM APPROACH – KEY TO SUCCESS

Luxembourg has the highest level of satisfaction with public transport in EU*

Satisfaction can be attributed to several improvements over the last years such as prioritisation (signals/bus lanes), new bus stops and real-time arrival information.

Public awareness of benefits of electrified buses improves the general image of buses. New livery and in-bus information are very important when launching „clean" buses.

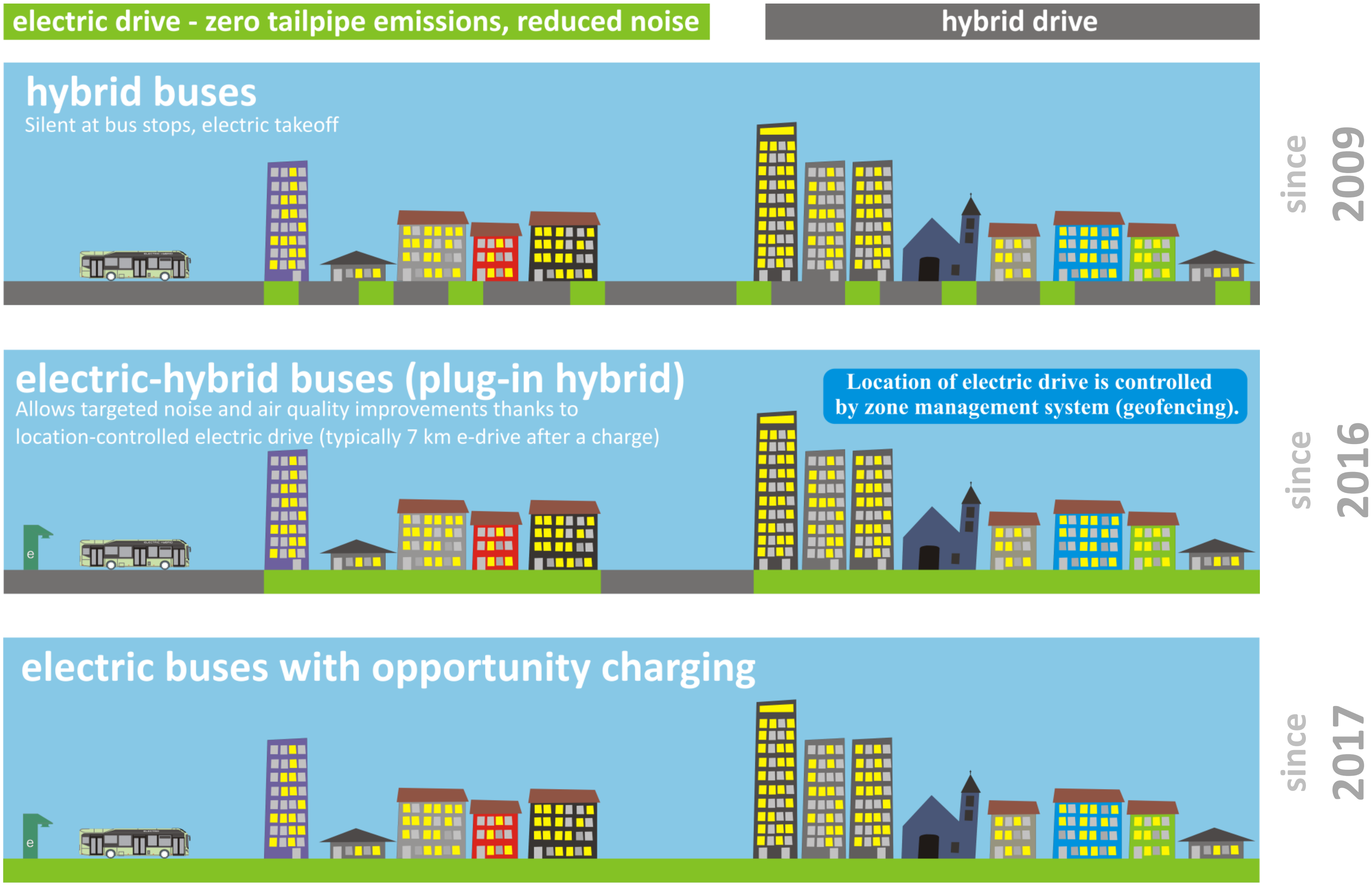
Information inside a bus

* Source: The Eurobarometer survey of 28,036 Europeans on their happiness with various aspects of public transport in 23 of the 28 Member States, 2014

2 THE PRESENT

THREE DEGREES OF ELECTRIFICATION IN LUXEMBOURG

Complementary approaches adapted to route characteristics, operational and environmental requirements



The near future: electric buses combining depot charging with opportunity charging

TOWARDS NOISE- AND EMISSIONS-FREE LIVABLE CITIES

2017

70 hybrid buses

17 electric-hybrid buses

6 electric buses

Several operators using electrified buses

Sales-Lentz moving people

VILLE DE LUXEMBOURG multiplicity

voyages emile weber

DEMYSCHANDELER

THREE MILESTONES IN 2017

RGTR intercity project line 226 operated with electric-hybrid buses

Luxembourg city AVL lines 9/13/14 operated with electric-hybrid buses

Differdange city lines with electric buses. 100% electrified PT city

In all cases the OppCharge* (opportunity charging) stations adopted by several different bus and charging station manufacturers are used to support competition and interoperability.

OPPCharge

* https://www.oppcharge.org/

ELECTRIC-HYBRID AND ELECTRIC LINES LAUNCHED IN 2017

Sustainable mobility testbeds

100% renewable energy

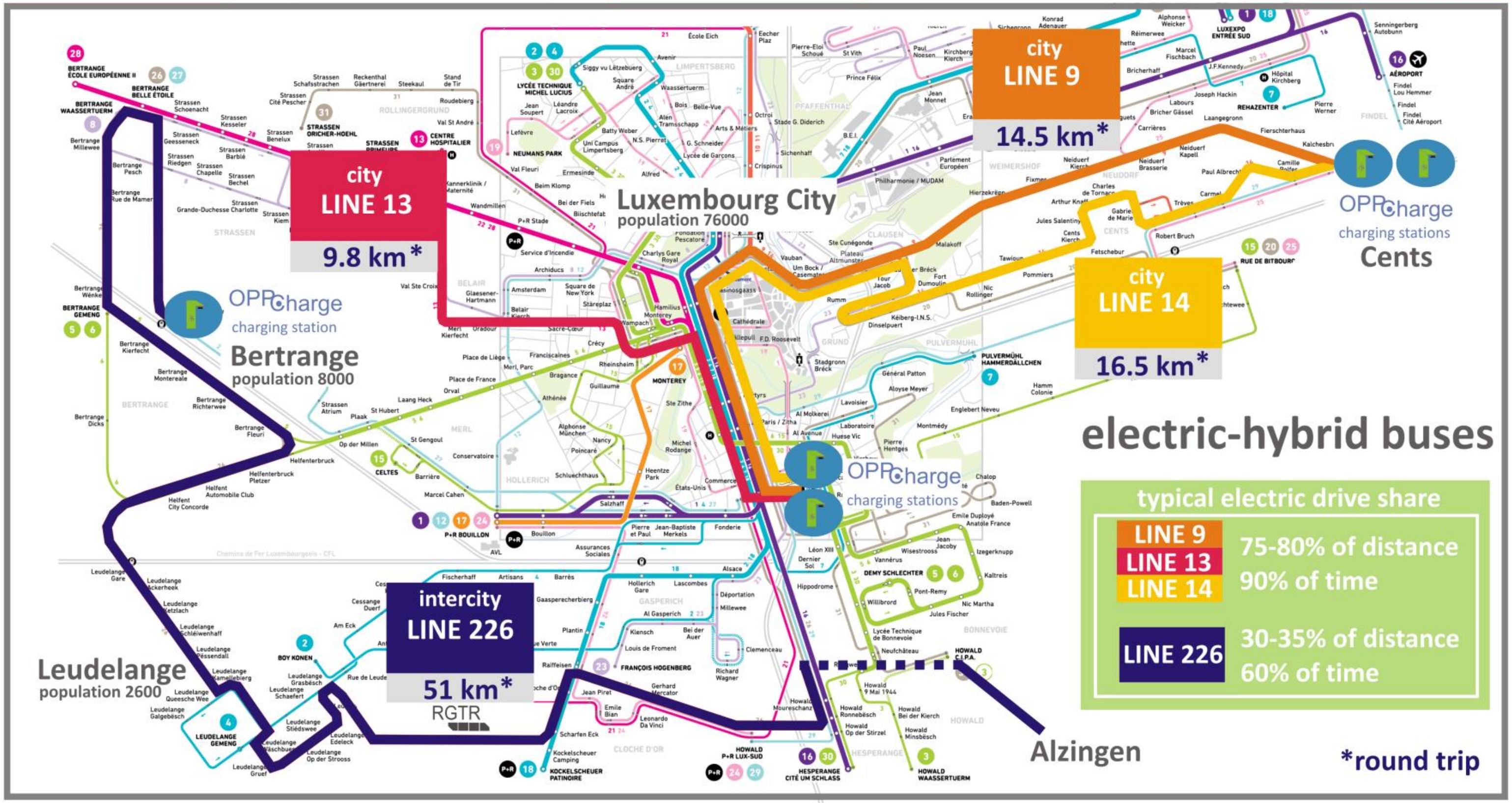
120km lines with opportunity charging stations

8 opportunity charging stations

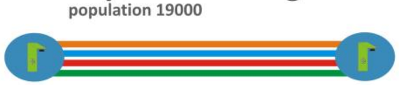
17 electric-hybrid buses

4 electric buses

Figure based on the city map designed by Jug Cerovic.



City of Differdange
population 19000



100% electric public transportation

LINES	1	2	3	4
28 km				

electric buses

Ville de Luxembourg multiplicity

RGTR

OPPCharge

ABB

Sales-Lentz moving people

VOLVO

heliox

Ville de Differdange

3 THE FUTURE

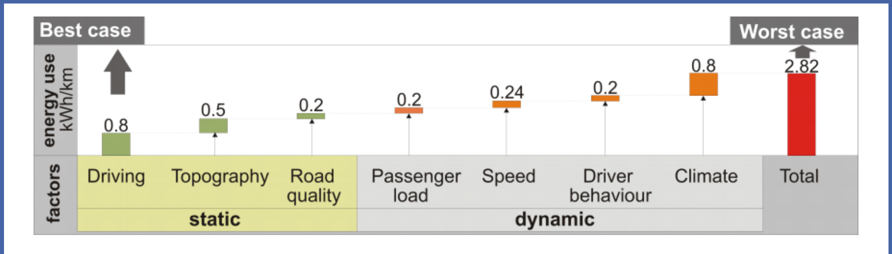
E-FUTURE CHALLENGES

1

With large-scale e-bus deployments the question of *when*, *where*, and for *how long* should battery charging occour becomes a new challenging research problem. The optimal strategy depends on the infrastructure, electricity pricing schemes, traffic conditions, e-bus fleet status etc.

2

There is a significant difference between the best and the worst case energy consumption of an electic bus.



The question is how to minimise the consumption via the emerging technologies, which allow to explore benefits of data and connectivity through the cooperative intelligent transportation systems (C-ITS) paradigm.

MAKING THE PT SYSTEMS BETTER VIA C-ITS

C-ITS can improve punctuality, comfort, reduce energy use and faciliate charging

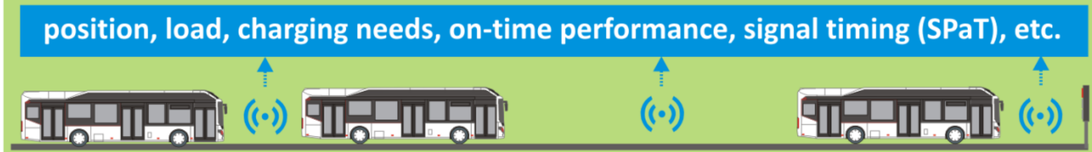
present

Non-cooperative approach with limited objectives, communications and data exchange

objective: punctuality
tools: transit signal priority (TSP), holding strategies

future

**Cooperative approach with extended set of objectives.
Relies on V2X connectivity, data exchange, and action coordination.
Advanced driver advisory systems enable execution of the actions.**



objectives: punctuality, increased comfort (less stop-and-go), energy use reduction
tools: cooperative transit signal priority, speed/dwell time advisory, platooning.

C-ITS is facing "chicken and egg" problem. Its deployment to public transport is however well justified from the point of view of societal interest. Moreover, its wide-scale implementation is easier to achieve than for private transport.

LOOKING TOGETHER INTO THE FUTURE

Luxembourg National Research Fund (FNR)

Luxembourg National Research Fund

Authorities, Operators, Industry

E-Bus Competence Center

University of Luxembourg

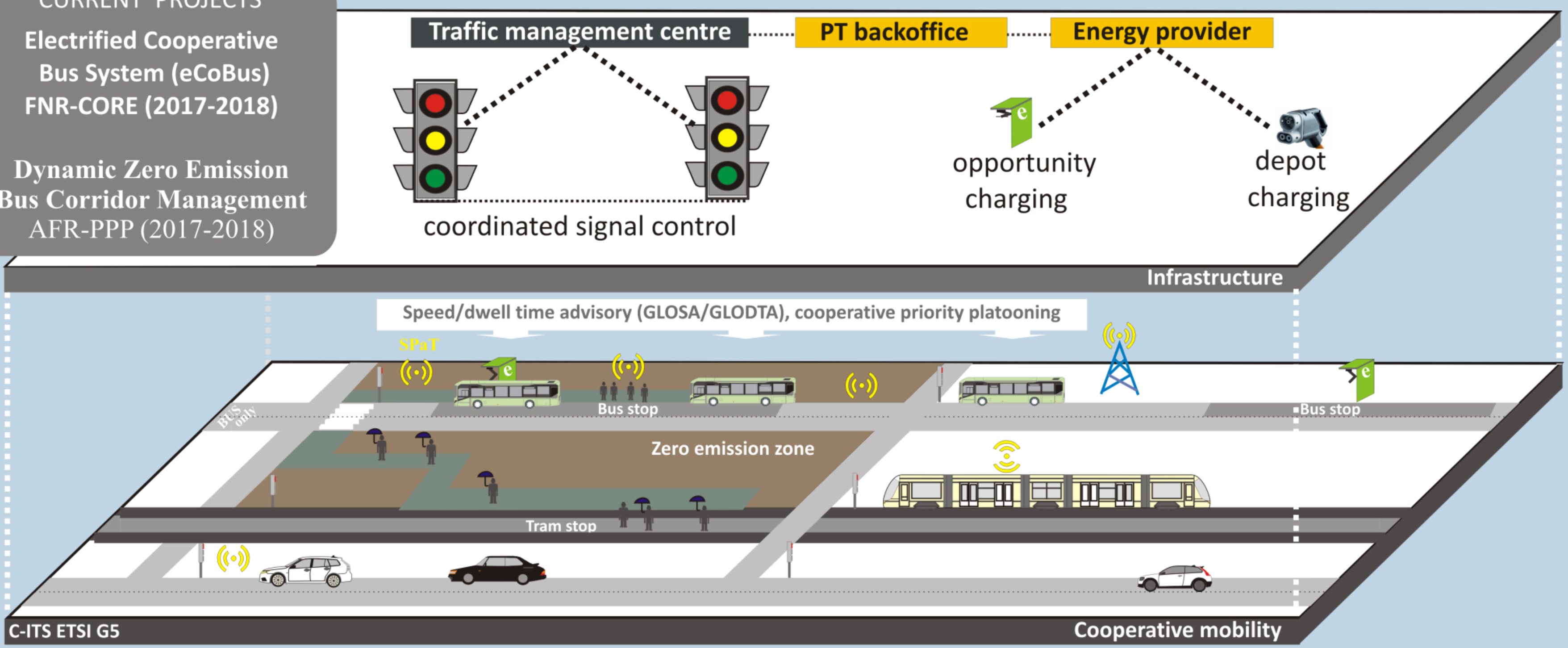
Luxembourg Institute of Science and Technology

→ **Research projects exploring benefits of cooperative intelligent transportation systems for e-mobility**

CURRENT PROJECTS

Electrified Cooperative Bus System (eCoBus) FNR-CORE (2017-2018)

Dynamic Zero Emission Bus Corridor Management
AFR-PPP (2017-2018)



Support from the national research funding (FNR) is essential.

SUMMARY

There is no single e-bus solution that fits all. The right level of electrification, battery size, and the way of charging depend on operational characteristics, energy source, environmental targets, etc.

An eco-system for testing and deploying innovative and sustainable technologies has been set-up in Luxembourg to look further into the future.

Using open charging interfaces such as OppCharge is essential as it supports competition and interoperability between equipment suppliers.

Thank you!

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RECOMMENDED READING

CIVITAS Policy Note: Smart choices for cities. Alternative Fuel Buses, 2016

ZeEUS eBus Report #2, UITP, 2017

Peak demand charges and electric transit buses,
U.S. Department of Transportation, Tech. Rep., 2014.

The role of cooperative ITS in supporting electric buses,
Proc. 12th ITS European Congress, 2017

How ITS can contribute to reducing CO2 emissions or road transport,
Proc. 12th ITS European Congress, 2017

C-ITS Platform Phase II report , European Comission, 2017

From stand-alone ITS to Connected ITS: what does it mean for cities and regions?
POLIS conference, 2016

OPPCharge

https://www.oppcharge.org/

ENVIRONMENT

Source: CIVITAS Policy Note: Smart choices for cities. Alternative Fuel Buses (2016)

Diesel		Euro V	Euro VI
GHG WTT	gCO_2e/km	1383	1317
NOx TTW (direct)	g/km	3.5	0.5-1.1
PM10[1] TTW (direct)	g/km	0.1	0.015

1Excl. PM from brakes, tires and road

Battery electric bus	Examples pathway		Euro -
GHG WTT	EU mix medium	CO2e/km	711
	Wind offshore	CO2e/km	0
	Electricity EU mix coal	CO2e/km	1474
	Electricity NG 7000 km	CO2e/km	731
NOx TTW (local)		g/km	0
PM10[1] TTW (local)		g/km	0

[1] Excl. PM from brakes, tyres and road. Due to regenerative braking EV's have less PM emission from the brakes than conventional vehicles.

(Bio-) CNG	Examples pathway		Euro VI
GHG WTT	EU mix	CO2e/km	1277
	Municipal waste	CO2e/km	273
	Liquid manure	CO2e/km	-1288
NOx TTW (local)		g/km	<1
PM10[1] TTW (local)		g/km	<0.01

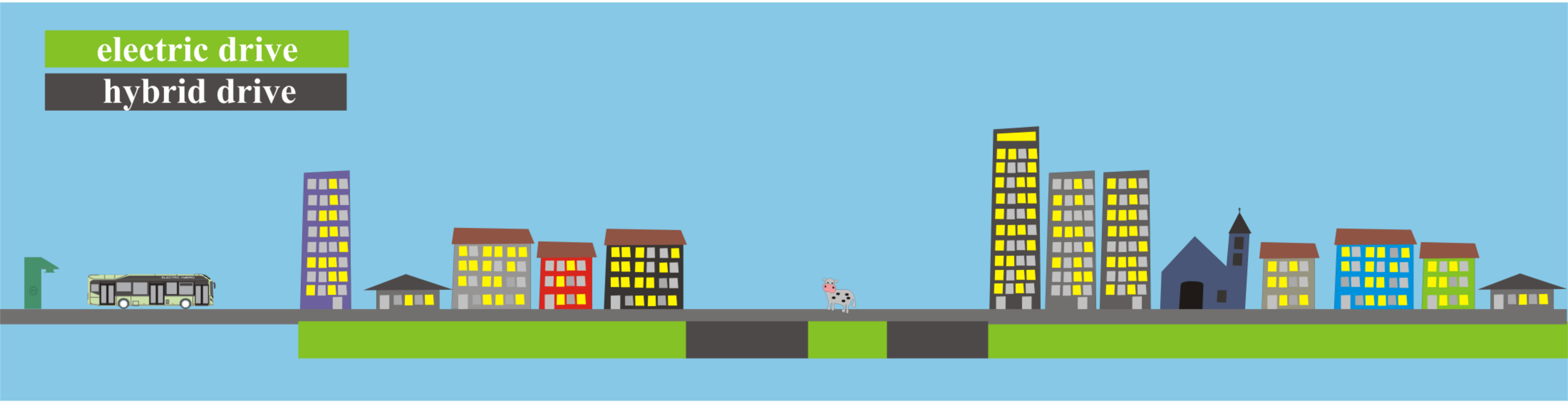
[1] Excl. PM from brakes, tyres and road.

Hydrogen, fuel cell electric	Examples pathway		Euro -
GHG WTT	EU mix (thermal)	CO2e/km	1290
	NG 7000km (electrolysis)	CO2e/km	2516
	Electricity EU mix (electrolysis)	CO2e/km	2849
	Electricity wind (electrolysis)		47
NOx TTW (local)		g/km	0
PM10[1] TTW (local)		g/km	0

[1] Excl. PM from brakes, tyres and road. Because fuel cell hybrids have regenerative braking, the PM emission from the brakes is lower than for conventional vehicles.

ELECTRIC-HYBRID BUS ZONE MANAGEMENT

Allows targeted noise and air quality improvements



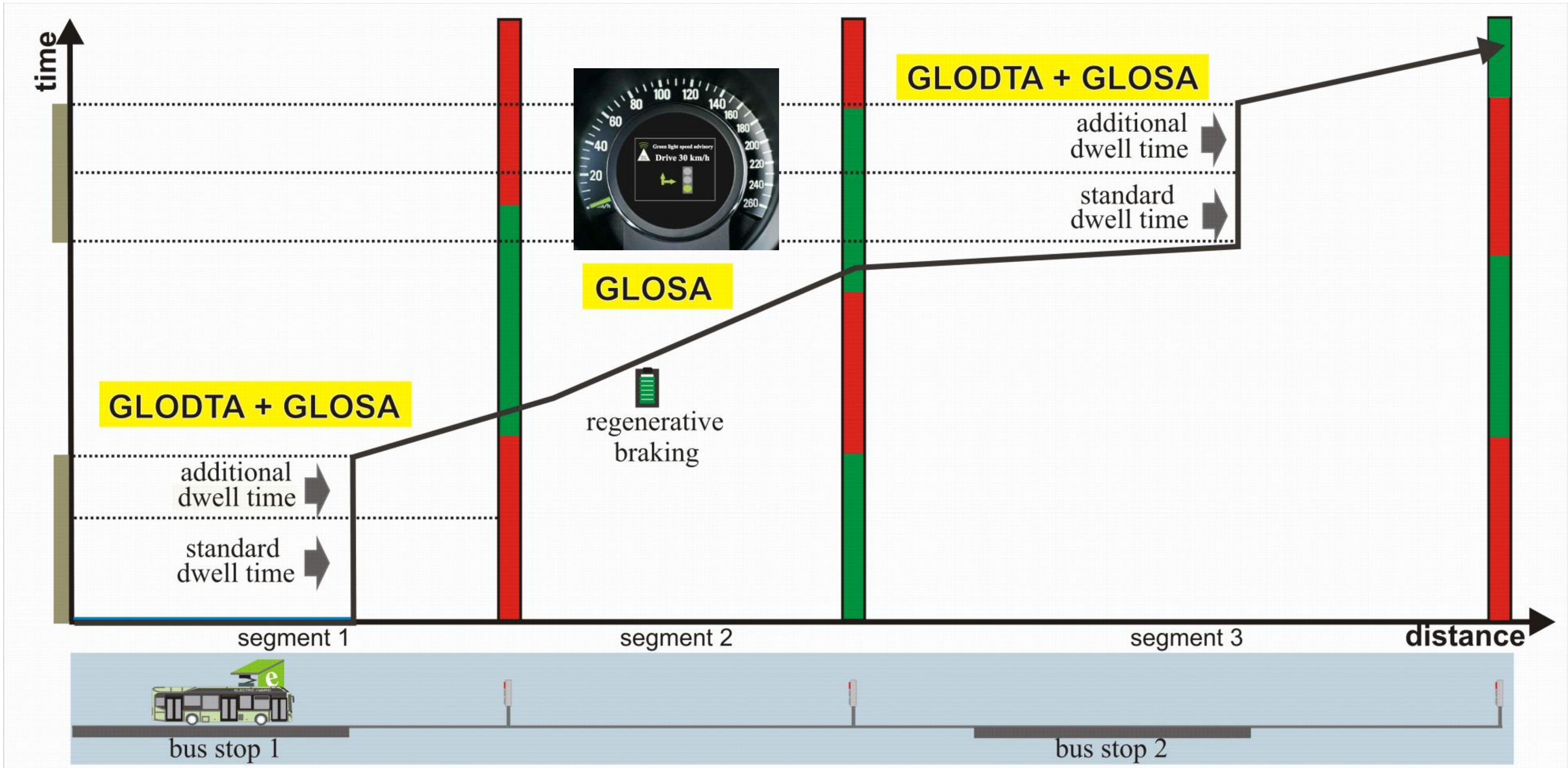
* **81%** electric time — **19%** diesel time

* **65%** electric distance — **35%** diesel distance

* example from real operations, 11 km route

GLOSA AND GLODTA EXAMPLE

STOP&GO IMPACTS EMISSIONS ENERGY AND COMFORT



Details in M.Seredynski, F.Viti, *Novel C-ITS support for Electric Buses with Opportunity Charging*, Proc. 20th International IEEE Conference on ITS, 2017