Selected Problems of the Measurements of Particulate Matter from Vehicles Performed under Actual Operating Conditions

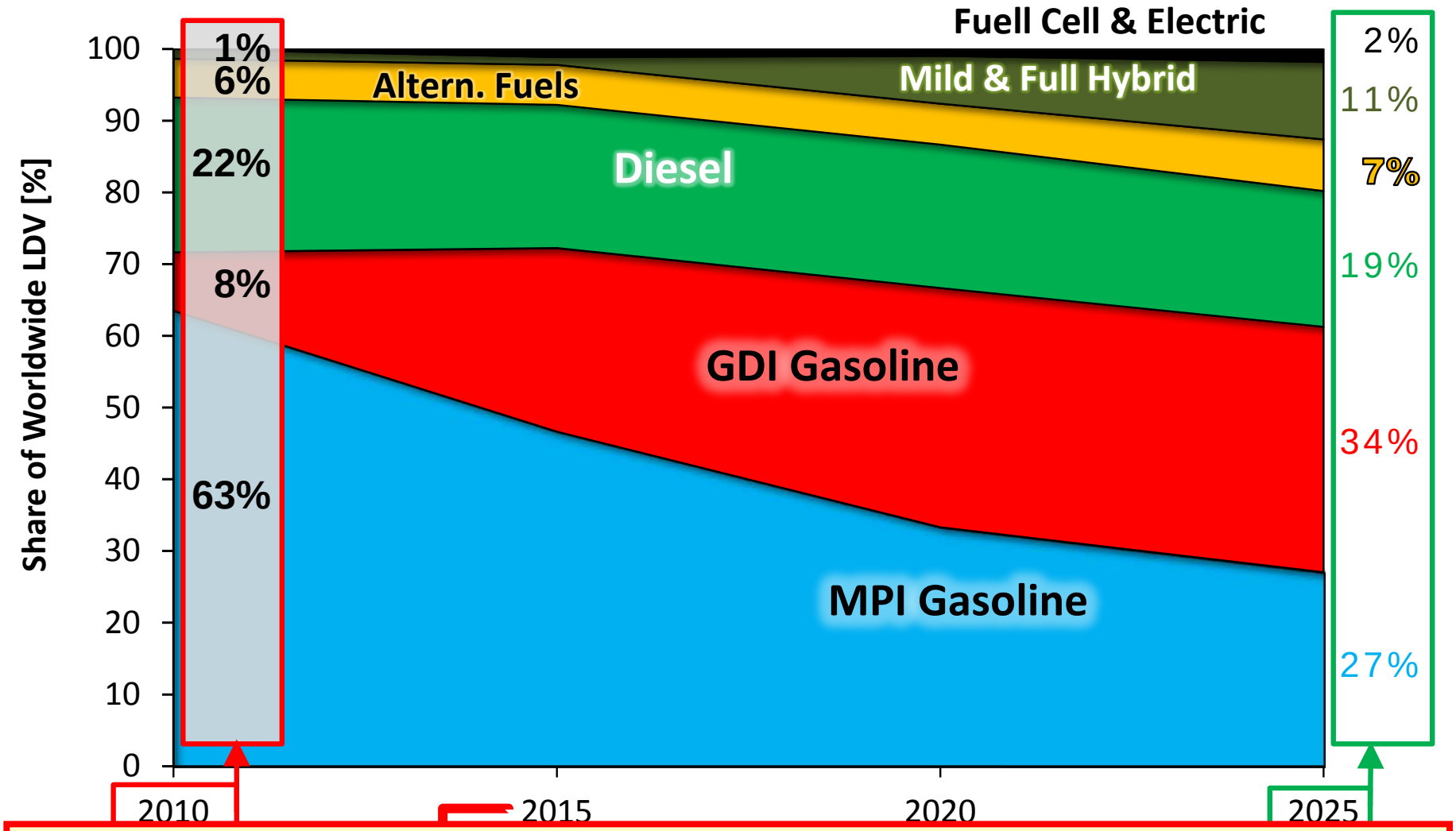
Jerzy MERKISZ
Jacek PIELECHA
Paweł FUĆ

Institute of Combustion Engines and Transport
Poznan University of Technology, Poland

Outline of the presentation

1. Introduction
2. Specificity of Polish vehicle fleet vs. EU
3. Reasons for our investigations
4. Selected measurements of LDV
5. Selected measurements of city buses
6. Conclusions

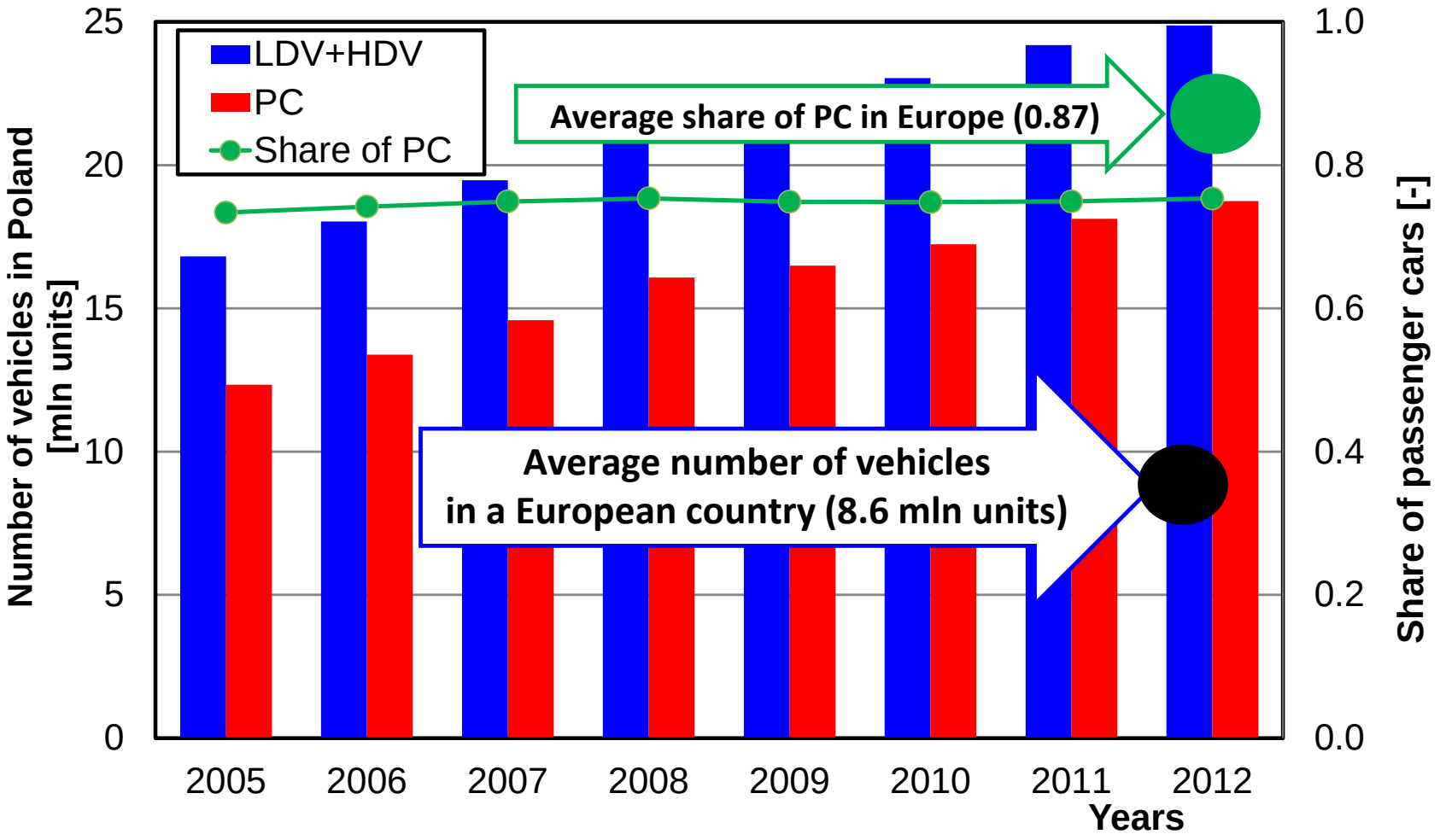
The internal combustion engine will remain dominant



Combustion Engines in Powertrains:

2025 → 98%, 'pure' IC – 80%; 2040 → 95%

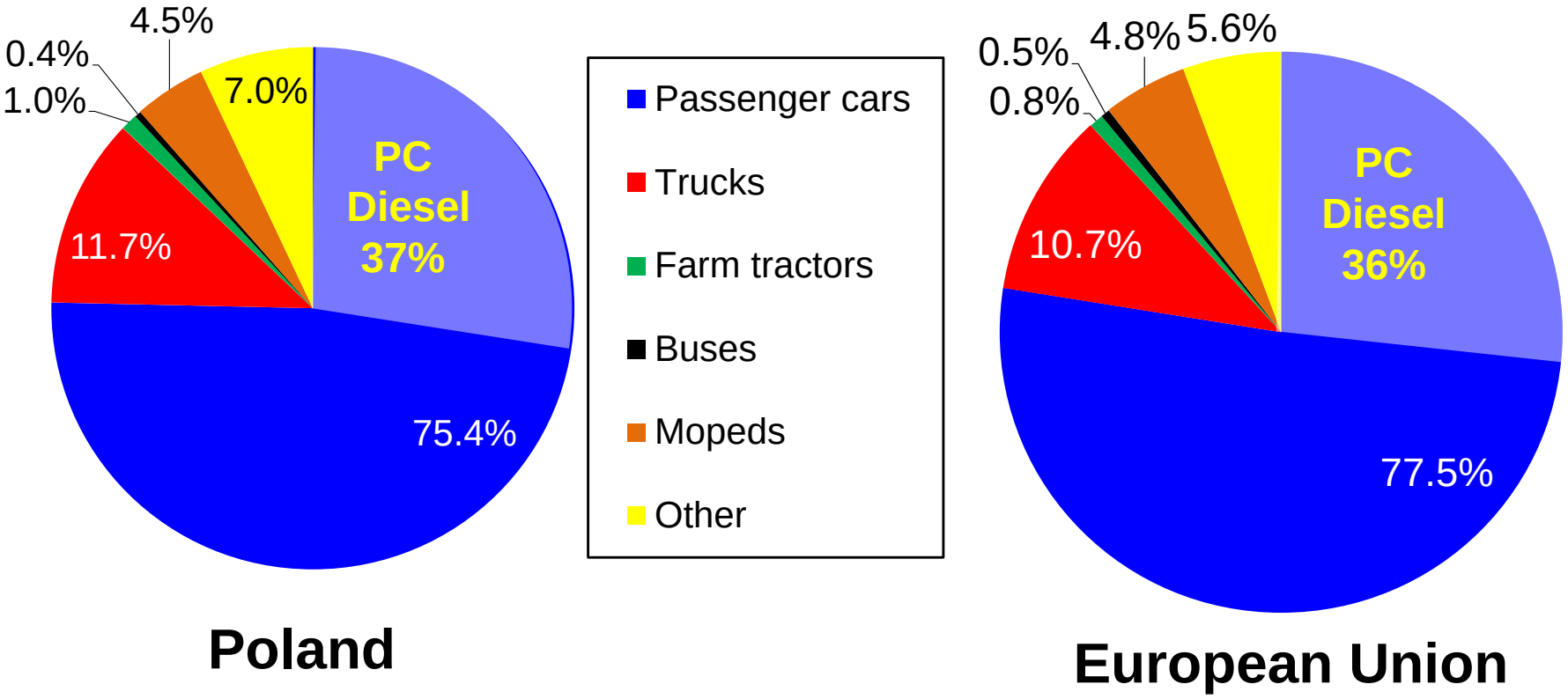
Polish vs. European automotive market analysis



Number of vehicles: Poland – 18 mln; average EU – 8.6 mln

Average share of PC: Poland – 0.75; EU – 0.87

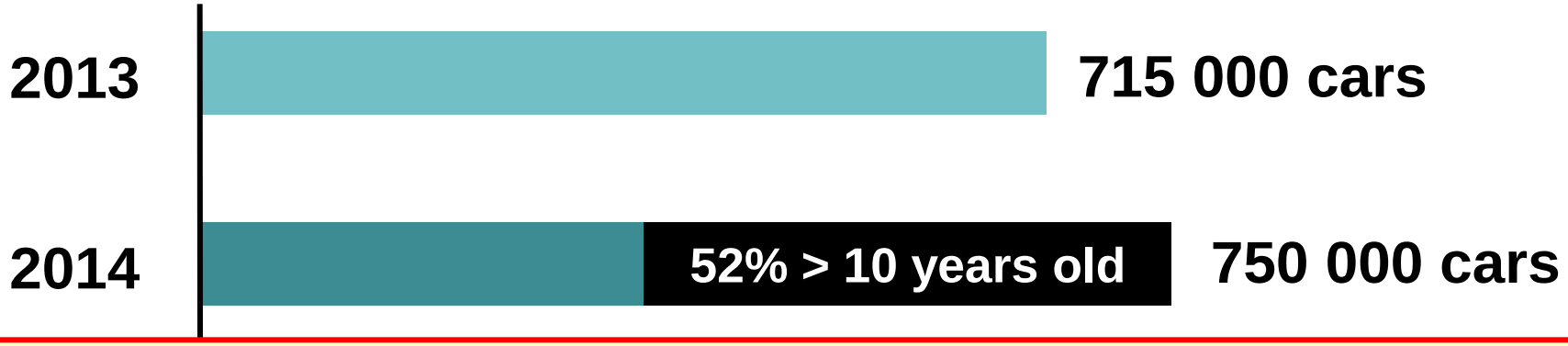
Vehicle categories in Poland and Europe



Poland **European Union**

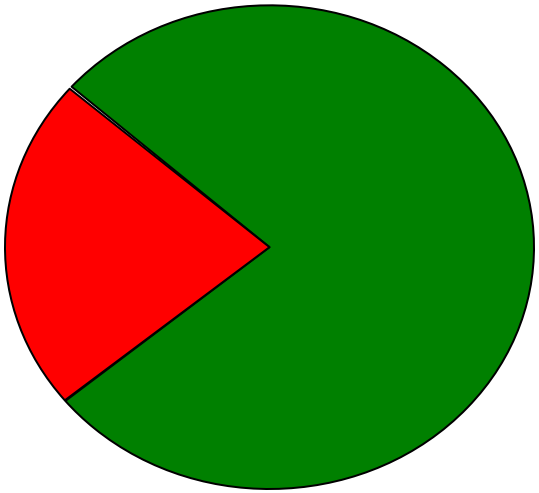
Poland and UE: ~ 500 passenger vehicles per 1000 citizens
Poland: Diesel vs. Gasoline 3 : 5 (Diesel share 37%)
Europe: Diesel vs. Gasoline 5 : 14 (Diesel share 36%)

Import of used vehicles to Poland



The average value of these used vehicle = € 4 000

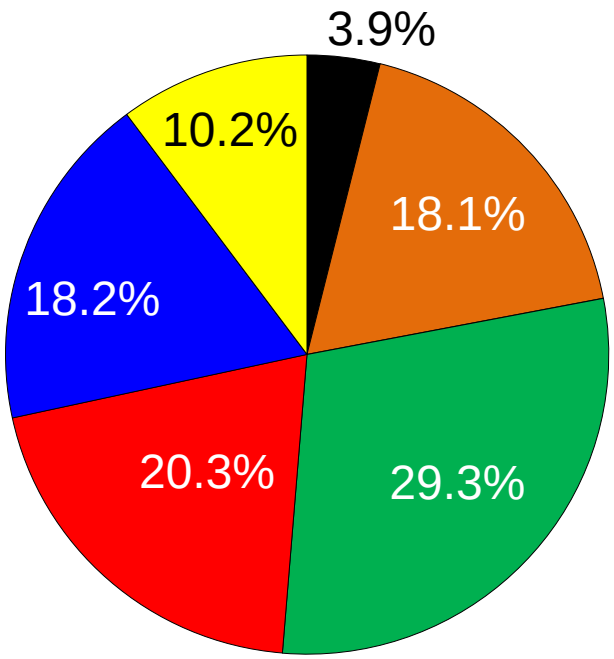
Origin of used vehicles:

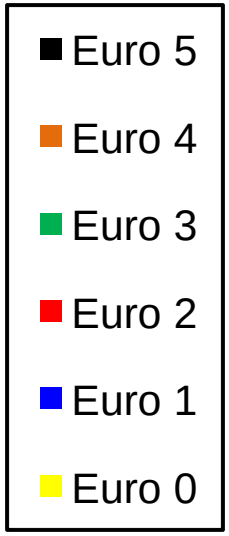


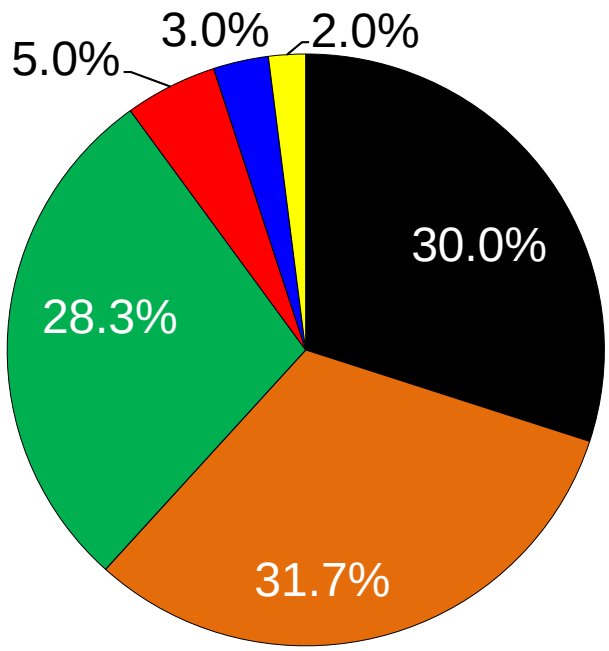
Poland (21%)

Germany (38%)
Belgium (12%)
The Netherlands (11%)
Italy (8%)
USA (6%)

Vehicle emission technology (Poland vs. Europe)







Poland (average vehicle age 14.7) **Europe (average vehicle age 8.6)**

4%	**vehicles up to 5 years old (E5)**	**30%**
18%	**from 6 to 10 years old (E4)**	**32%**
29%	**from 10 to 15 years old (E3)**	**28%**
49%	**from 16 to 30 years old (E0-2)**	**10%**

Emission tests according to standards vs. RDE

Aplications

RDE PEMS

Type of testing

No possibility of testing past certain mileage

LDV GVW < 3.5 tons

Limits

Passenger cars LDV

Chassis-dyno

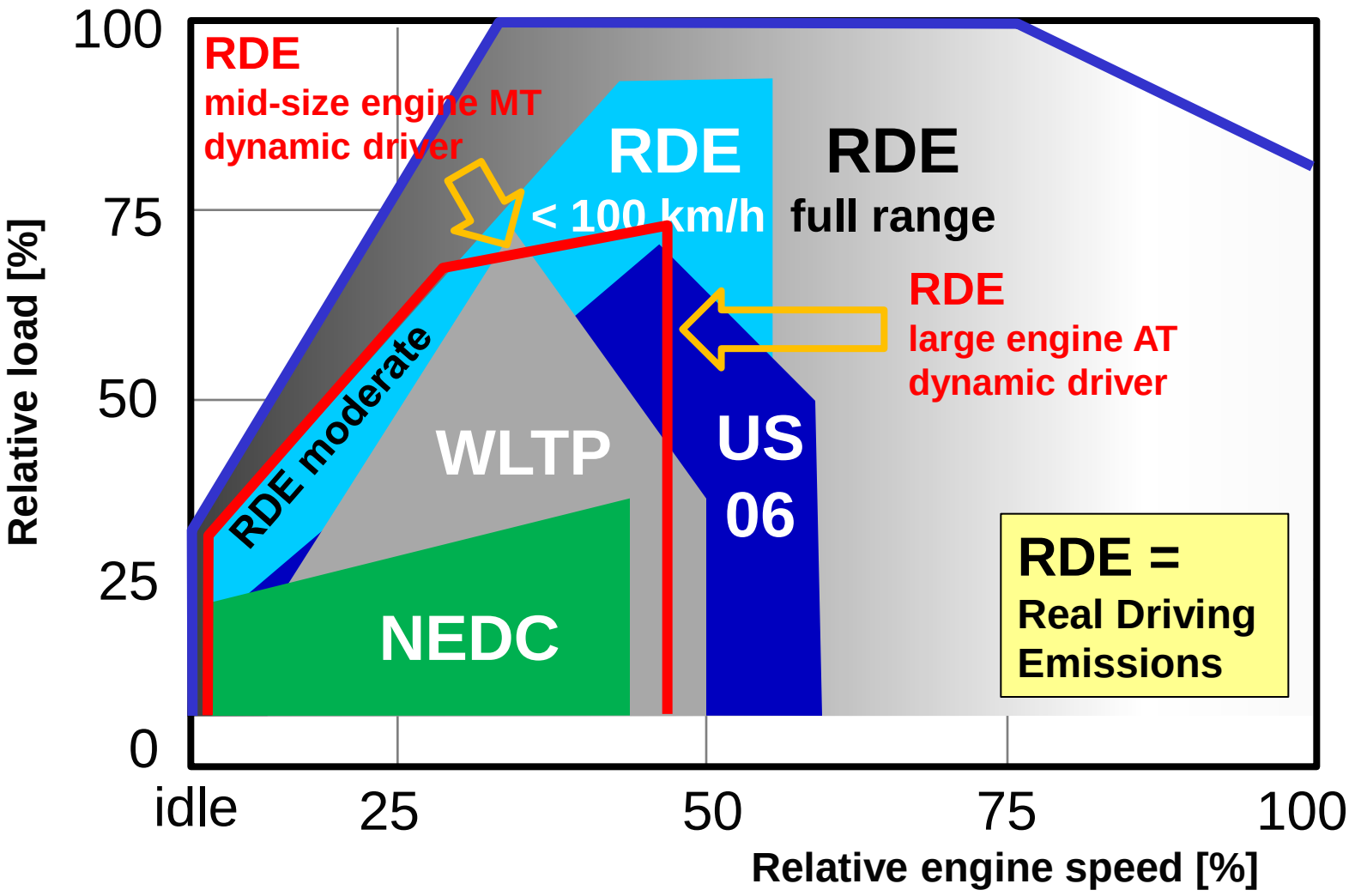
mass / distance [g/km]

Trucks, busses (HDV) Non-road applications

Engine-dyno

mass / work [g/kWh]

Engine parameters in various emission tests



Based on:
M.O.V.E. (AVL)

Stress on RDE! (PEMS)

$FC_{real} > FC_{stand}$

Test potential under real operating conditions

Modeling of transport environmental performance

Exhaust emissions modeling

- CORINAIR
- PART 5
- MOBILE 6
- RAINS

Simulation software

- ERMES
- COPERT 4
- VISIM
- VISUM

$$m\ [g] = E_{stand}\ [g/km] \times N\ [-] \times S\ [km]$$

m – emission mass [g]

E_{stand} – according emission standard [g/km]

All emission models have been calculated based on emission standards from Euro 1/I to Euro 6/VI

Definition of exhaust emission indexes

Emission obtained in the test – E_{stand}

Emission obtained in real conditions – E_{real} (PEMS)

$$E_{real} = k \times E_{stand}$$

k – exhaust emission indexes

Exhaust emission indexes k – LDV

Emission indexes $k = \frac{E_{real}}{E_{stand}}$

Real emission [g/km] = $\frac{\text{Mass pollution (PEMS)}}{\text{Distance (OBD, GPS)}}$

$k\ [-] = \frac{m_{real}\ [g] / S\ [km]}{E_{stand\ LDV}\ [g/km]}$

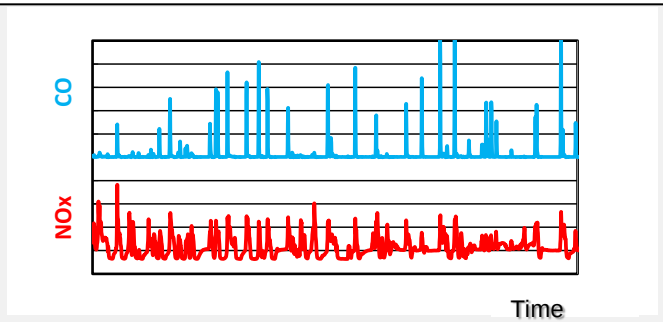
$k < 1$ 

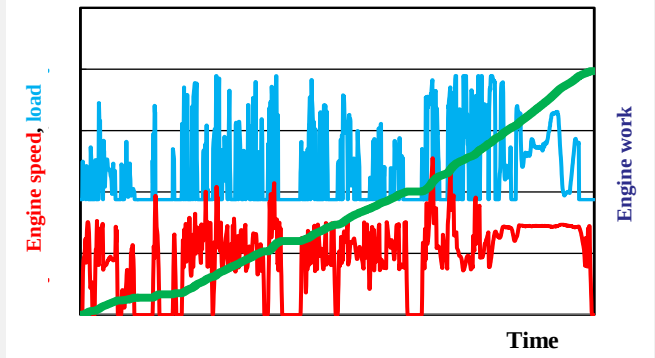
$k = 1$ 

$k > 1$ 

Exhaust emission indexes k – HDV and other…

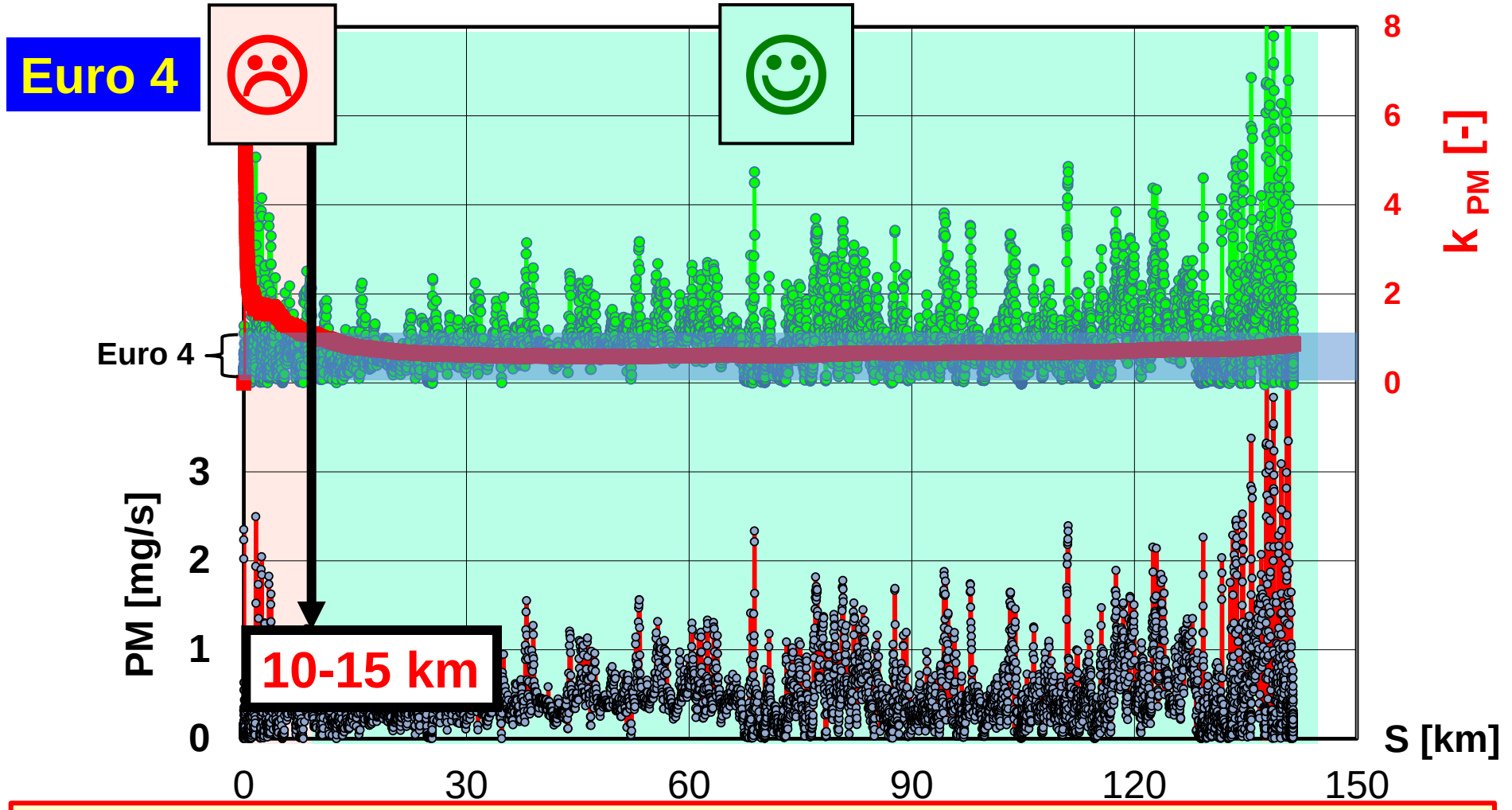
$$\text{Real emission [g/kWh]} = \frac{\text{Mass polution (PEMS)}}{\text{Engine energy (OBD, CAN)}}$$





$$k\,[-] = \frac{\overline{E}_{real,\,avg}\ [g/h] \,/\, \Sigma\, N_e\ [kW]}{E_{stand\ HDV}\ [g/kWh]}$$

LDV – PM emission index

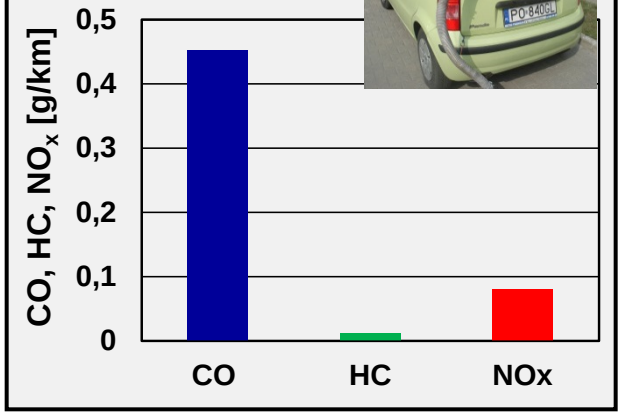


Emission index values depend on the cold start and warm-up parameters and on vehicle mileage

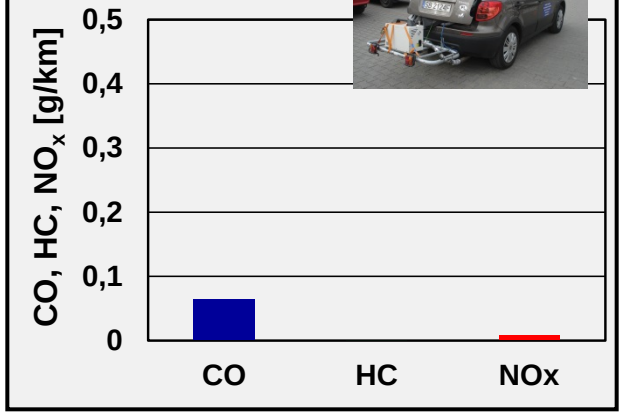
RDE in Poznan University of Technology

LDV – exhaust emission indexes; Gasoline engines

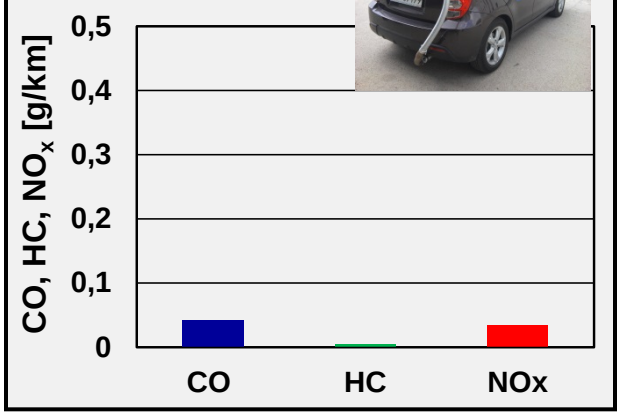
Euro 3

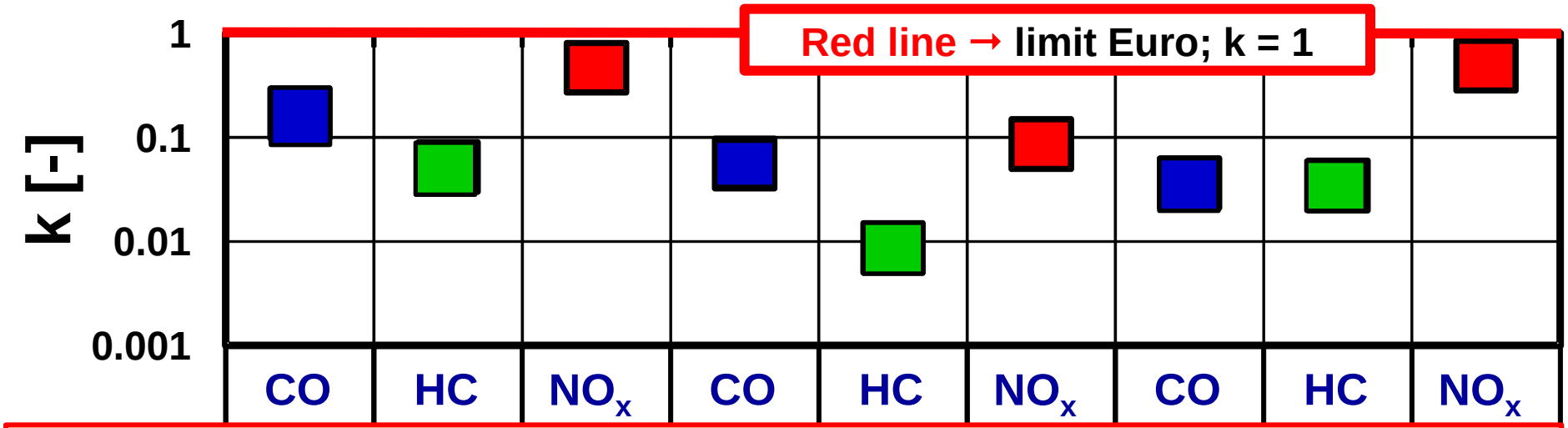


Euro 4



Euro 5





Real exhaust emissions < emission standard limits

LDV – exhaust emission indexes; Diesel engines

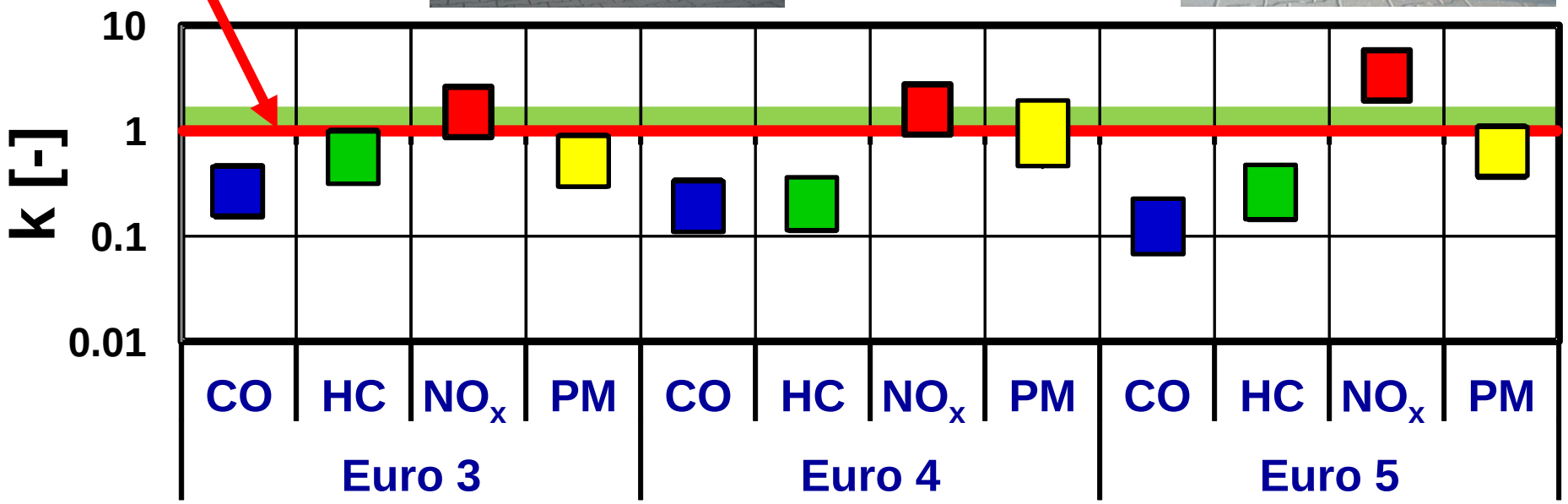
NO_x emission is 2 ÷ 5 times higher vs. standard; problems with PM (k = 2)

possible limit value

+50%

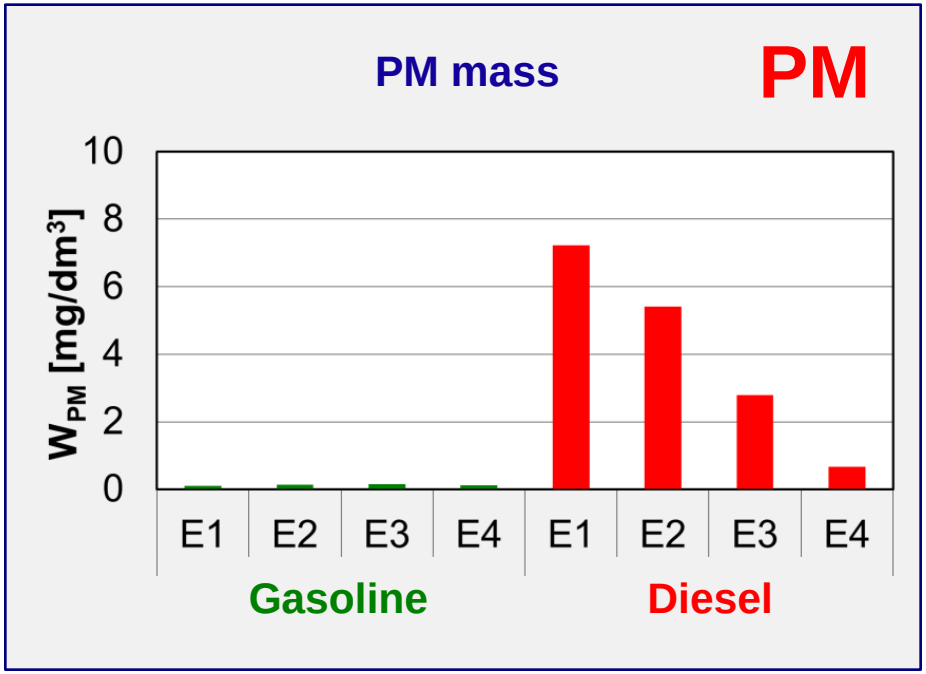
1.5

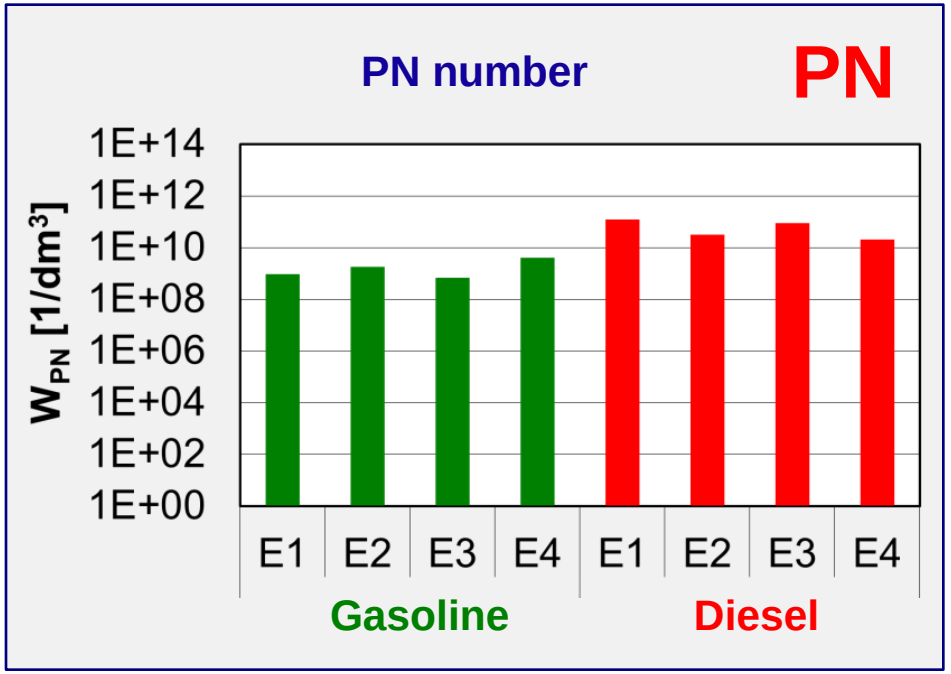
1



Particle emission testing: cold start

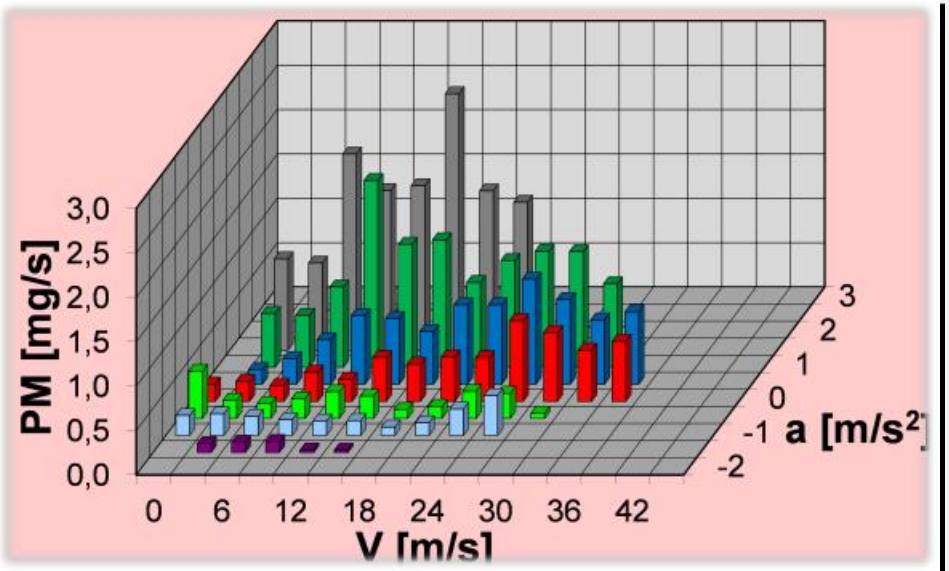
Engine emission technology vs PM mass and PN number





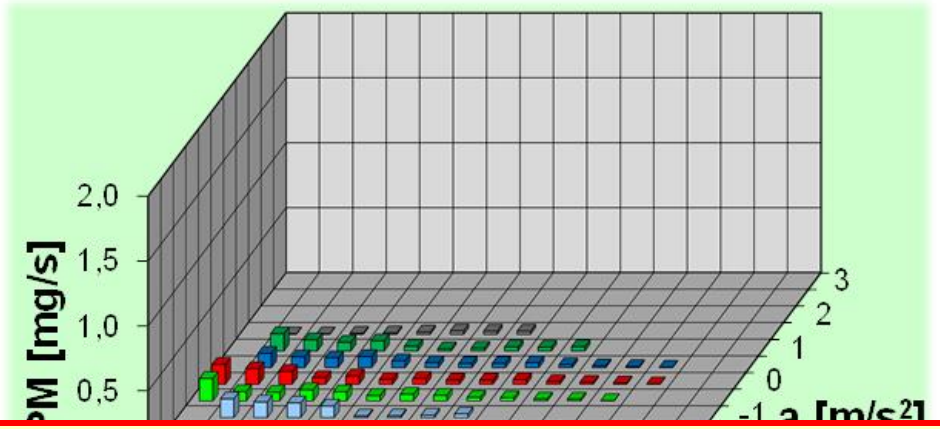
PM from gasoline engine = 1% PM of diesel engine
PN from gasoline engine = 80% PN of diesel engine

Particle emisson testing: PM – mass



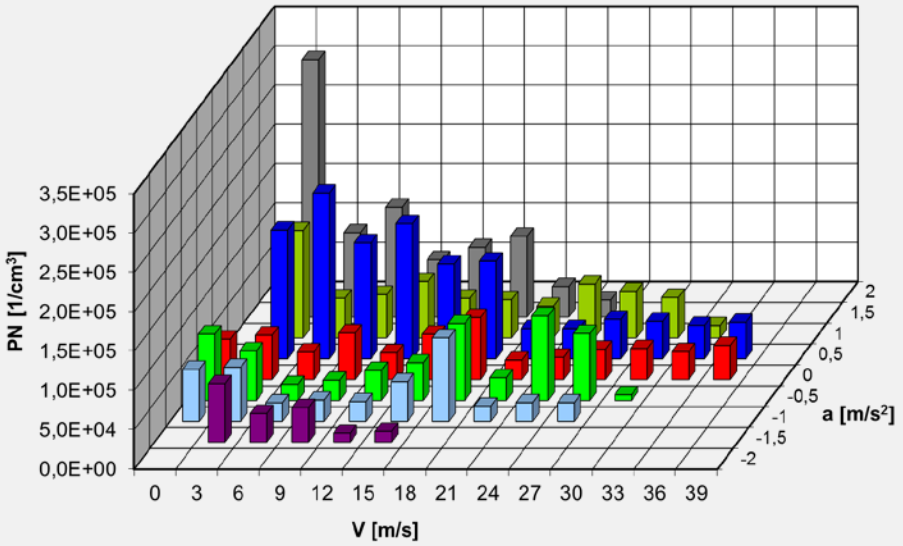
w/o DPF

with DPF



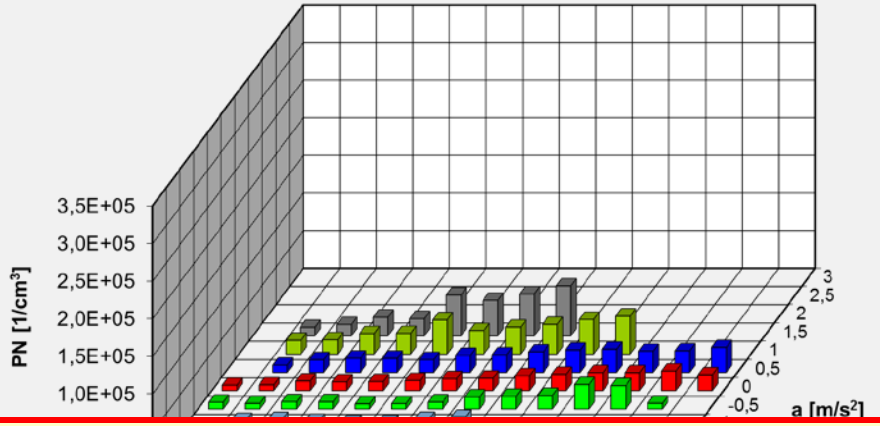
PM: emission 30 times lower when DPF applied

Particle emission testing: PN – number



Vehicle without DPF filter

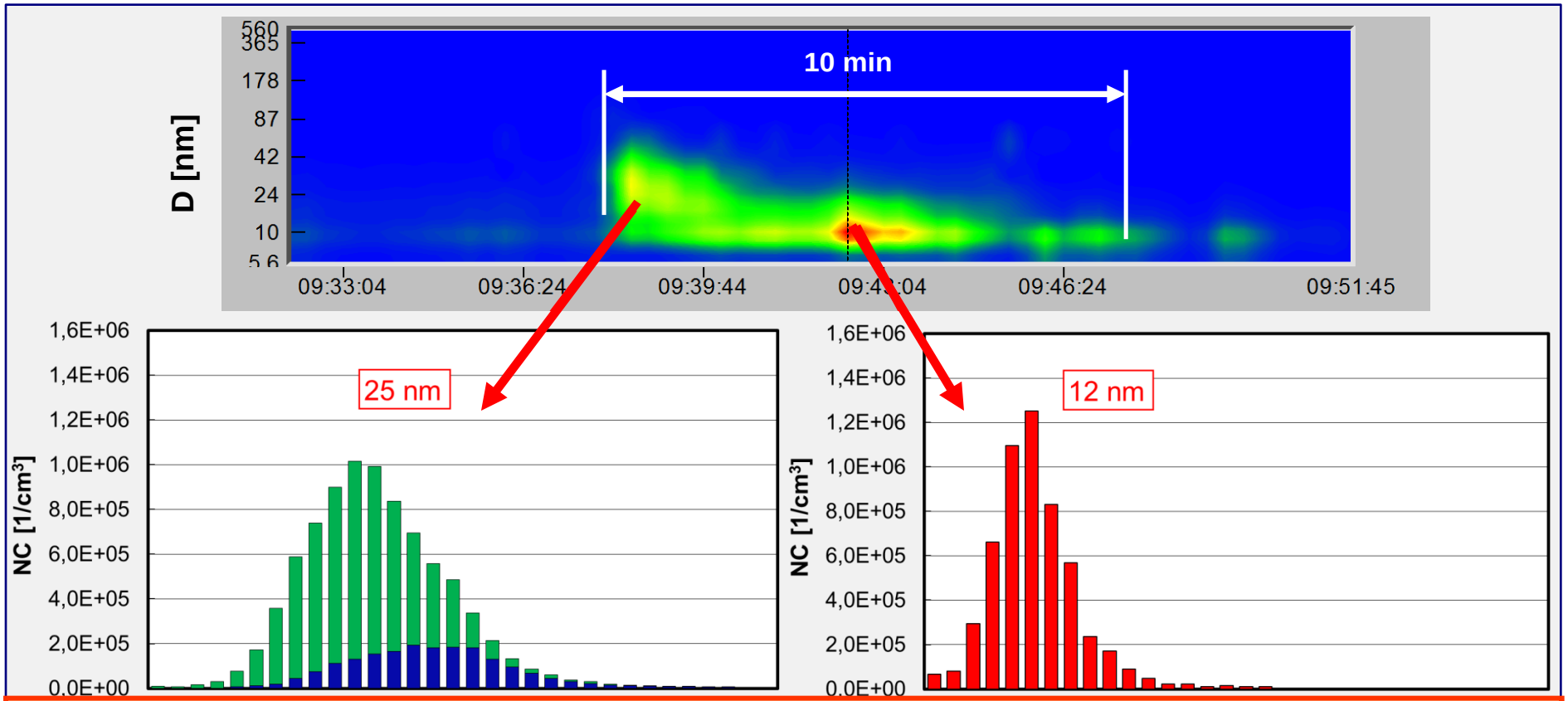
Vehicle with DPF filter



PN: emission 20 times lower when DPF applied

Particle emission testing – DPF regeneration

DPF regeneration vs PM diameter



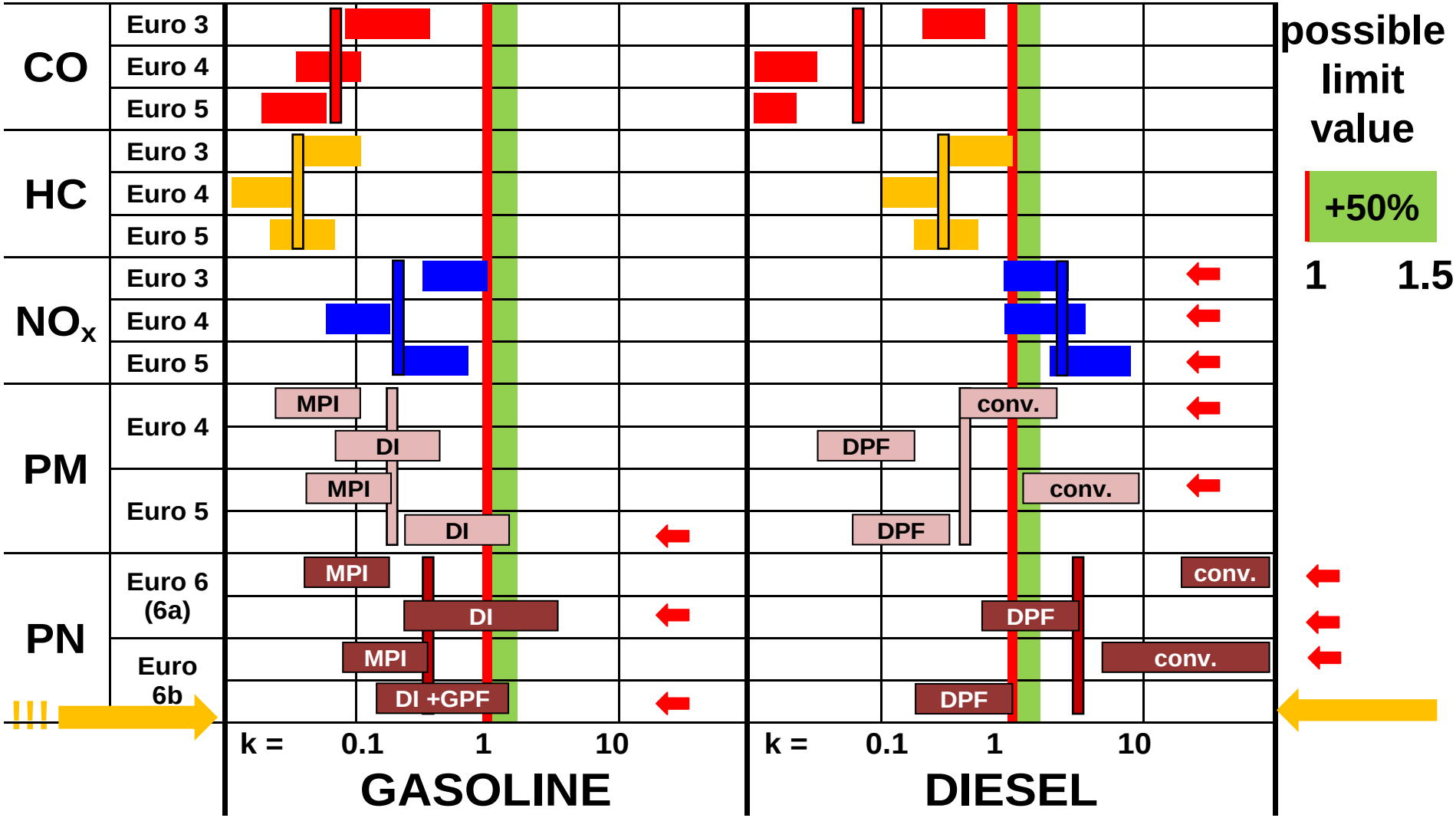
During DPF regeneration process:

- **PN grows 1000 times !!!**
- **average particle diameter 3 times smaller**

Summary: k – exhaust emission indexes

LDV: Gasoline engines (DI): problems with PN ⬅

Diesel engines: problems with NO_x, PM and PN ⬅



Conclusions: LDV emissions – urban driving

CO: 

(2×↑) : DIESEL FUEL

HC: 

(2×↑) : DIESEL FUEL

NO_x: 

: DIESEL FUEL (4×↑)

PM (+DPF): 

: DIESEL FUEL (2×↑)

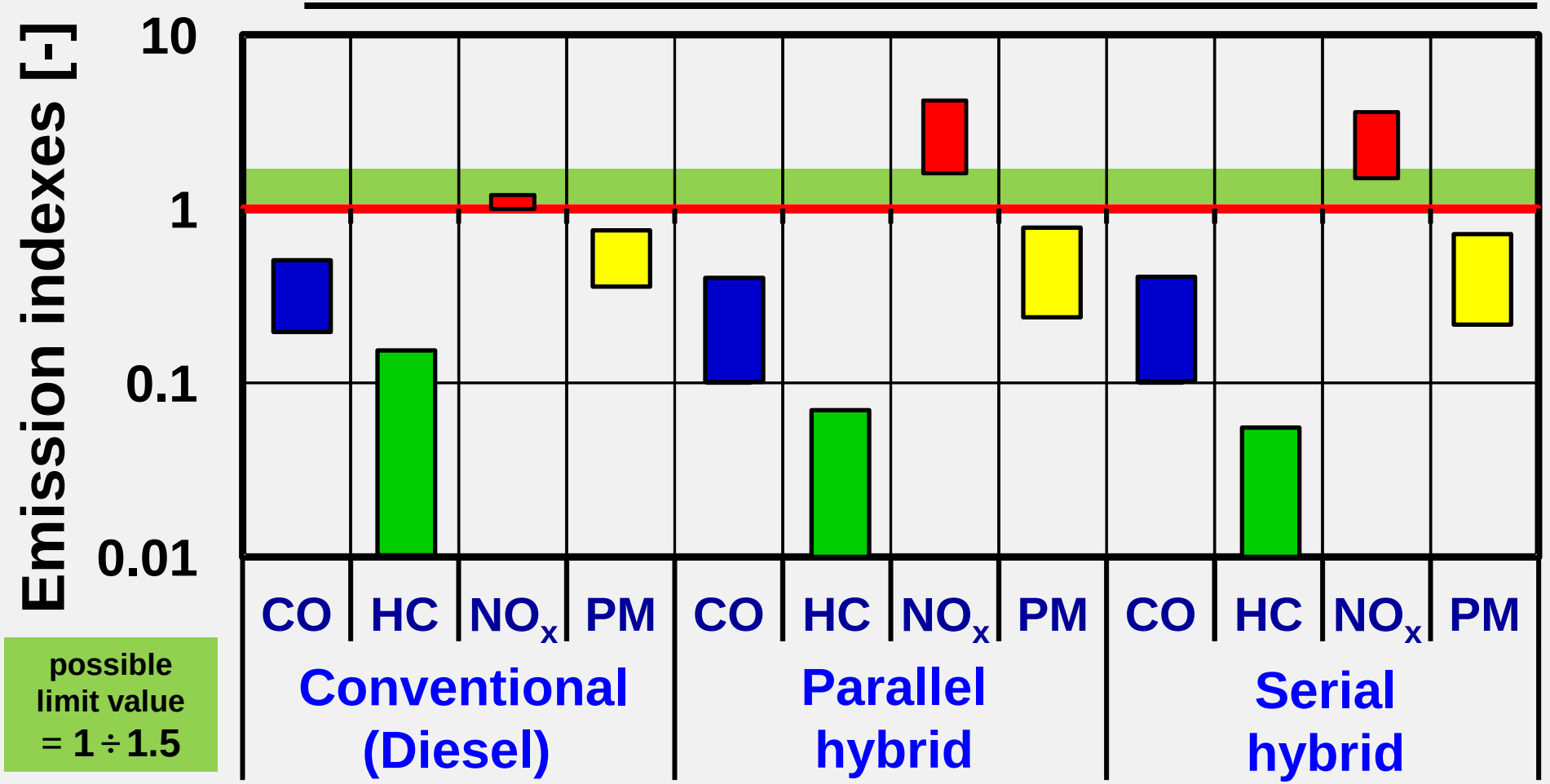
PN (+xPF): 

(2×↑) : DIESEL FUEL

Characteristics of city buses

	Diesel conventional	Parallel hybrid	Serial hybrid
			
[redacted]	DAF PR265	Cummins ISB 6.7 250 B + Allison Ep50	Cummins ISB 6.7 285H + Vossloh Kiepe
[redacted]	9.2 L	6.7 L	6.7 L
[redacted]	1450 N·m 1100–1710 rpm	1008 N·m 1200 rpm	1008 N·m 1200 rpm
[redacted]	Euro V–EEV SCR/DPF	Euro V–EEV SCR/DPF	Euro V–EEV SCR/DPF

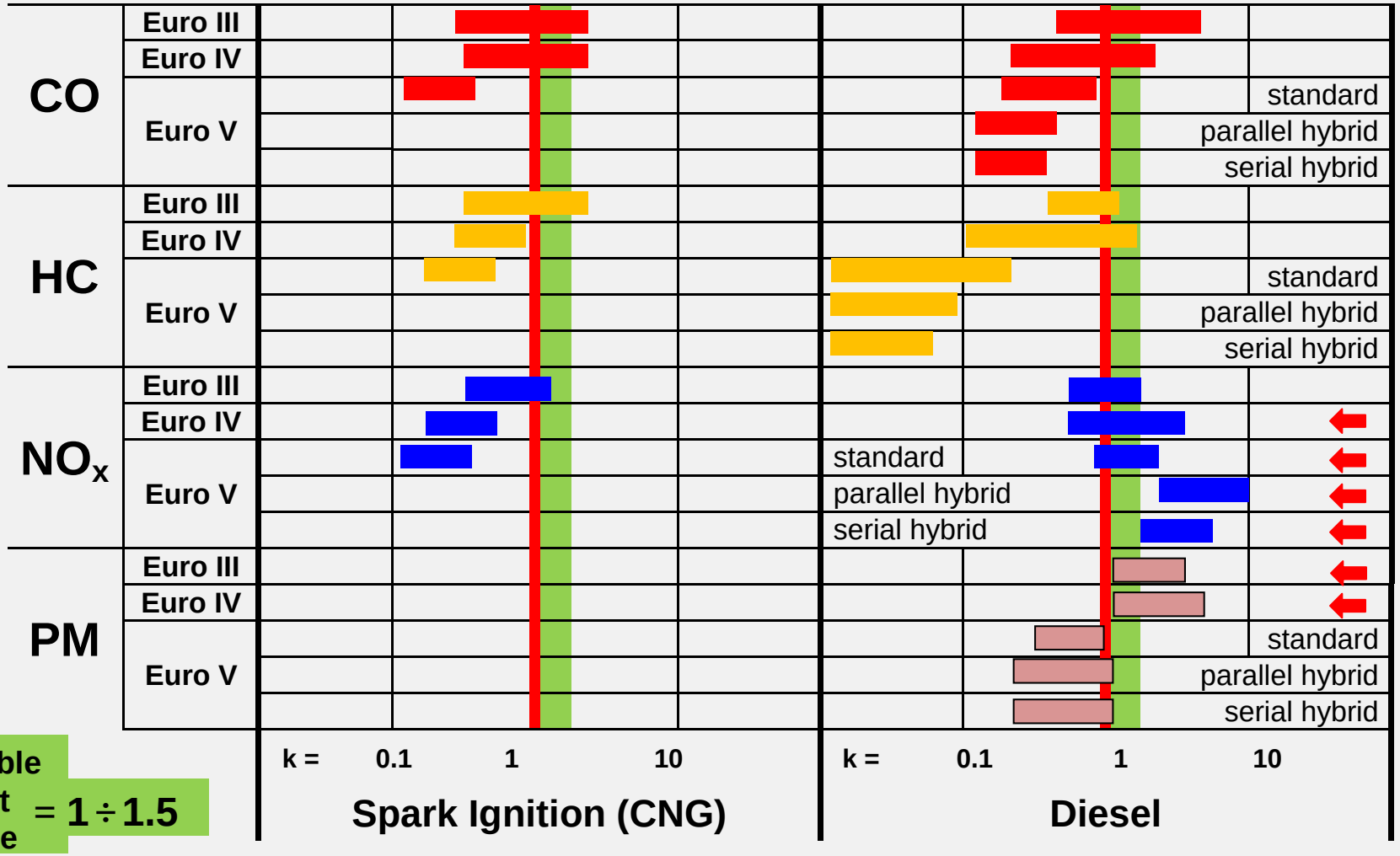
Exhaust emission indexes of city buses



For all powertrains CO, HC and PM: k < 1

for hybrid powertrains NO_x: k = 2 ÷ 5

Summary: exhaust emission indexes of all city buses



HDV: Spark ignition (CNG) engines: no problems

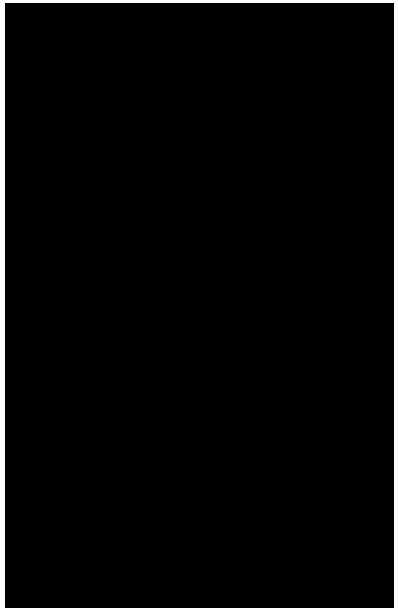
Diesel engines: problems with NO_x and PM ⬅

Retrofitting in older technology city buses

Before

Bus (before retrofitting):
Diesel Engine w/o DPF
Euro III

After



Retrofitting
Catalyst:
- Pt/Al_2O_3
- experimental

DPF:
- SiC + cat (passive reg.)

Bus (after retrofitting):
Diesel Engine
Euro III + Catalyst + DPF

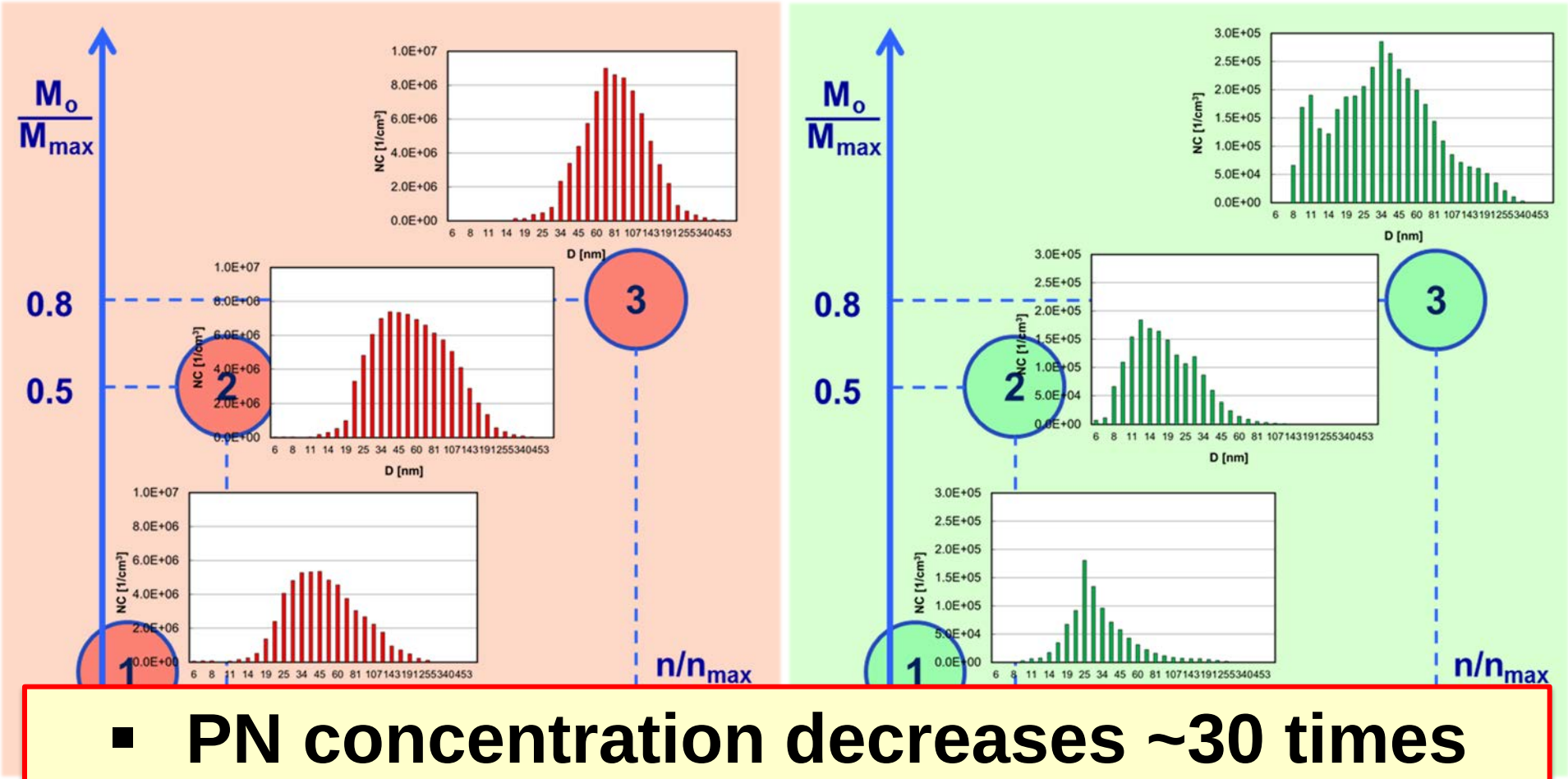
Aftertreatment of authors' design (retrofitting) is very good for older technology city buses

Particle size distribution – retrofitting

Before

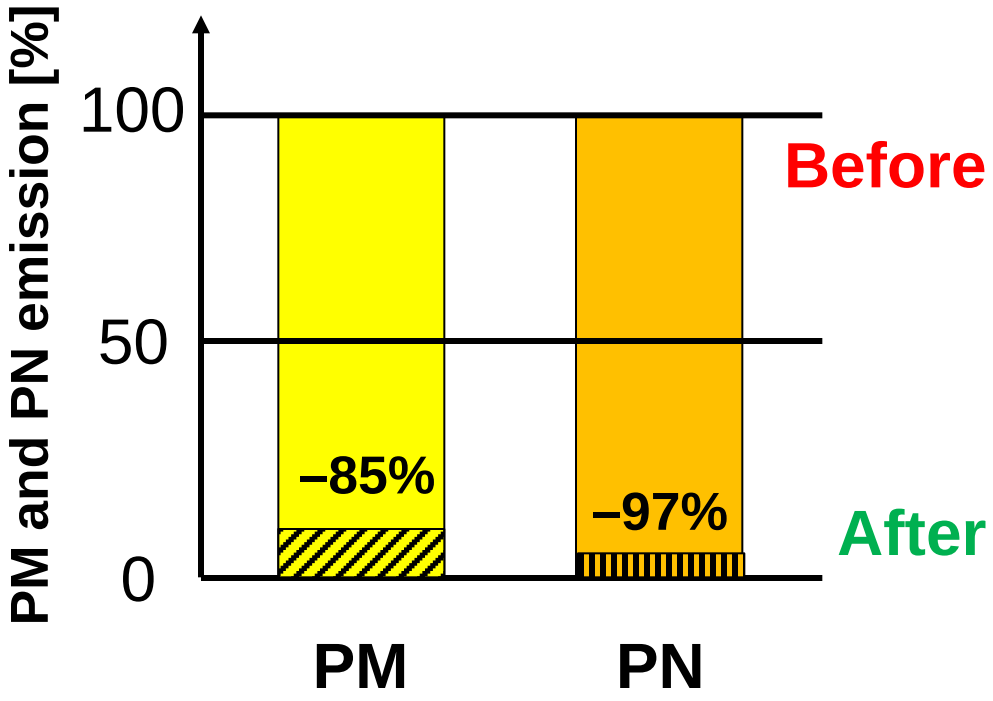
After

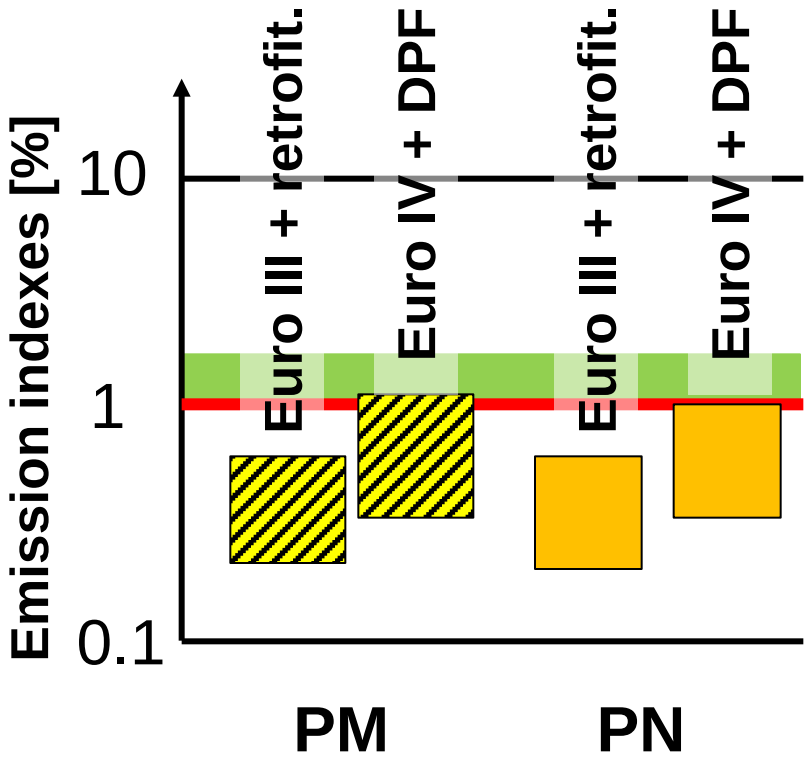
Note: in the figures other scales!



- PN concentration decreases ~30 times
- average particle diameter 2 times smaller

Retrofitting in used city buses





Euro III buses retrofitted with authors' aftertreatment system can be 'cleaner' than Euro IV buses

Conclusions

Conclusions from the studies in real traffic conditions:

- **our data of emission indexes allow to adjust the emissions calculated based on emission standards to real emissions**
- **our limit proposal: k emission index up to 1.5**
- **the following emission limits are exceeded:**
  Gasoline (direct injection): PN
  Diesel: NO_x, PM




Conclusions

Gaseous

PM/PN

PUT +

Gaseous

PM/PN

PUT ++

Gaseous/PM/PN

PUT +++

2008 2010 2012 2014 2016

PUT = Poznan University of Technology

Research and development works performed at Poznan University of Technology in real traffic conditions are in line with and ahead of global trends in exhaust emission testing

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Thank you so much for your kind attention

jerzy.merkisz@put.poznan.pl; **www.cel.put.poznan**