LABORATORY OF APPLIED THERMODYNAMICS

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Automotive Emissions Control: Technical Challenges and Opportunities

11th Concawe Symposium

Brussels, Radisson Blu, 2015-02-24

Acknowledgments

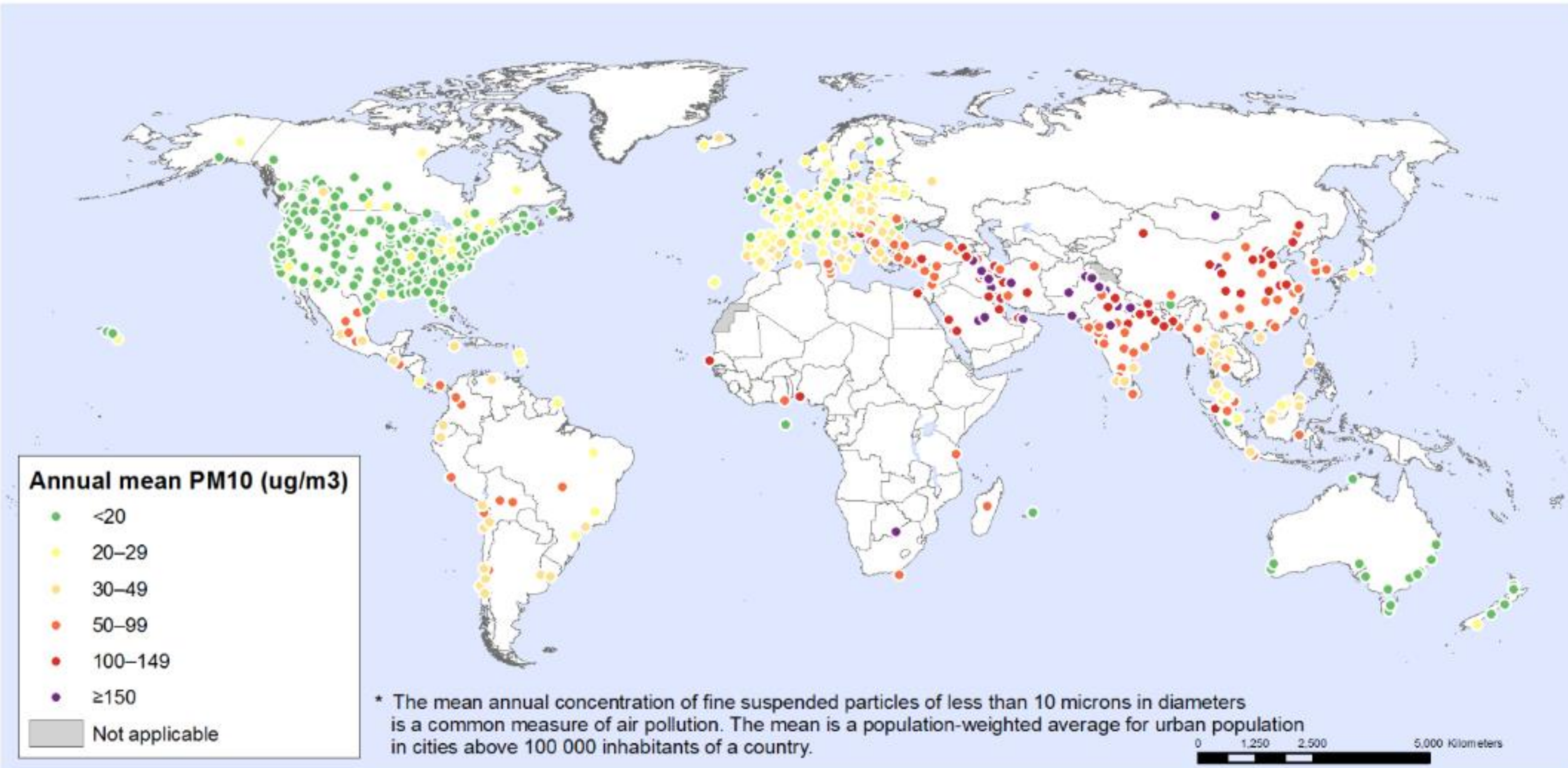
- Prof. Leonidas Ntziachristos, Dr. Savas Gkeivanidis (LAT)
- Dr. Giorgos Mellios, Mr. Thomas Papageorgiou (EMISIA)
- Dr. Georgios Fontaras, Dr. Barouch Giechaskiel (DG JRC)
- Dr Jens Borken-Kleefeld (IIASA)
- Dr Alexander Bergmann (AVL)
- Dr. Grigorios Koltsakis (Exothermia SA)

Outline

- The reasons that underpin the need for action to mitigate road transport emissions
- What have European regulations done so far and what is in the pipeline?
- What do these mean in terms of
  - Testing requirements
  - Impacts on vehicle technology

WHY ARE ROAD TRANSPORT EMISSIONS IMPORTANT (AND WILL CONTINUE TO BE)?

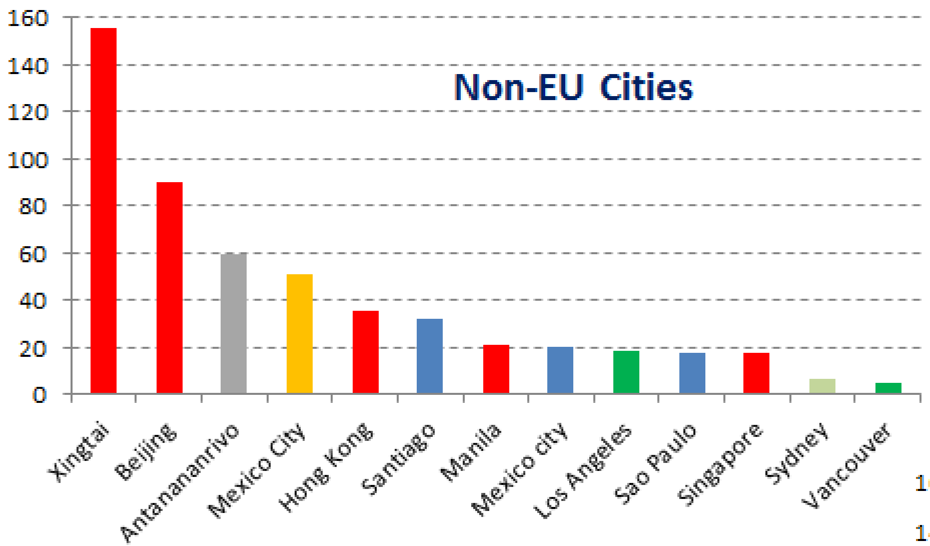
Exposure to PM_{10} in 1100 urban areas, 2003 – 2010



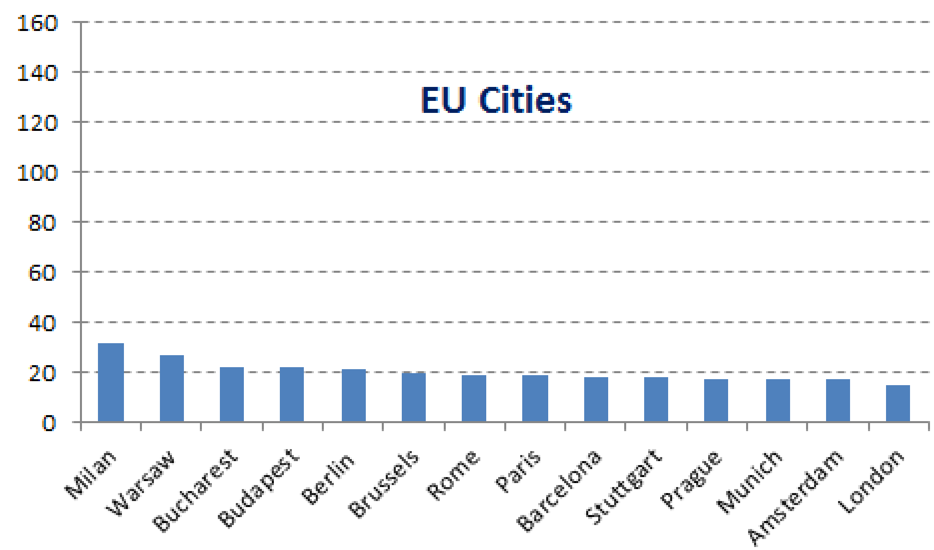
WHO Air Quality Guideline: Annual mean PM10 = 20 μg/m³

Source: WHO, 2012

$PM_{2.5}$ (µg/m^3) concentrations in cities across the world
Average of 5 years annual average (2008-2012)



N. America, C. & S America, Africa, East and S. East Asia

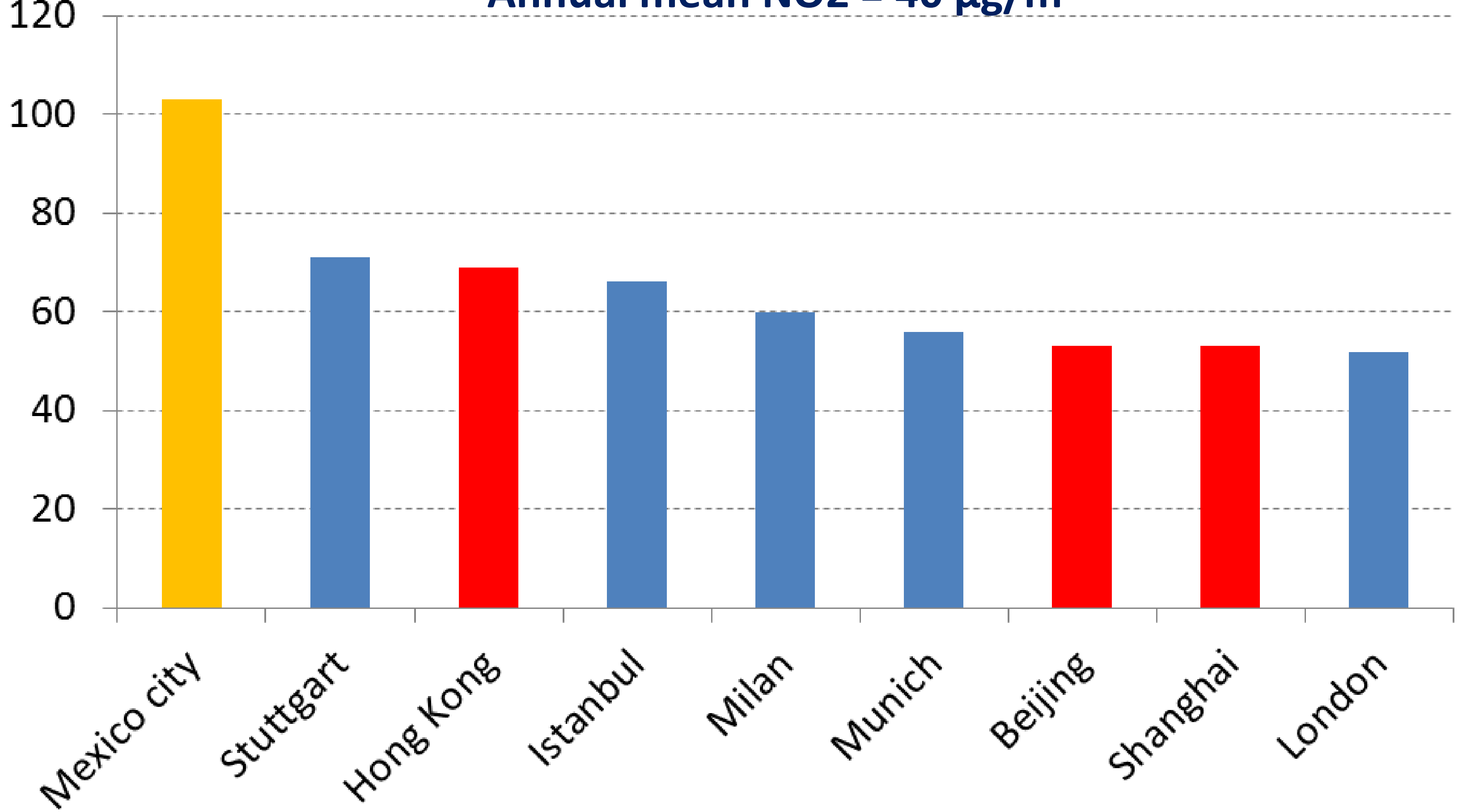


WHO Air Quality Guideline: Annual mean PM2.5 = 10 µg/m^3

Source: WHO, 2012

NO_2 (µg/m^3) concentrations in cities across the world
Average of 5 years annual averages (2008-2012)

WHO Air Quality Guideline for the EU:
Annual mean NO2 = 40 µg/m^3

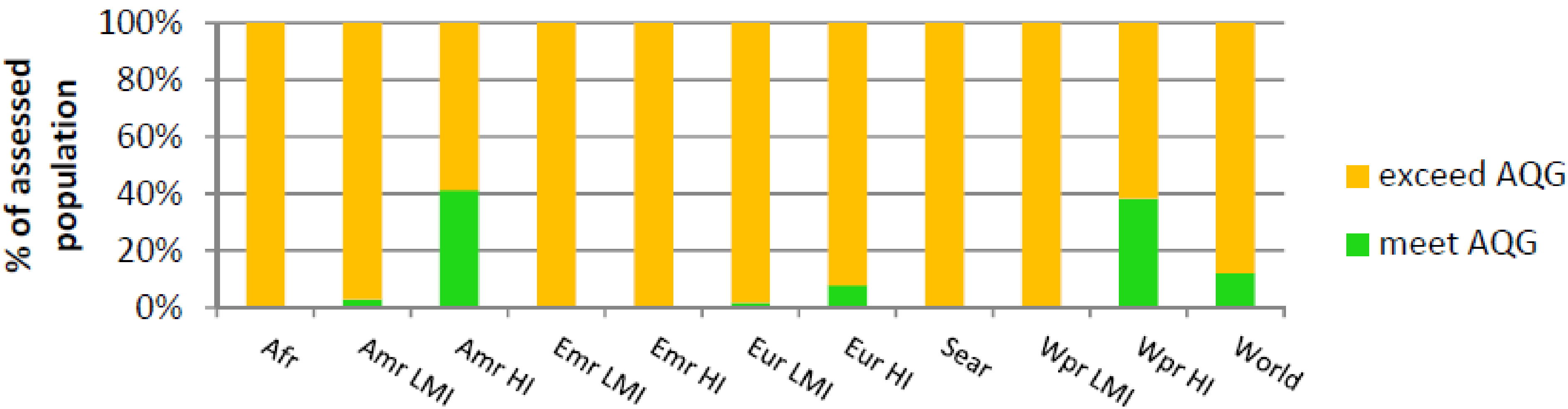


Source: Comparison of air quality for a number of world and European cities (london.gov.uk, 2014)

Population exposed to high pollution

Exceedances of WHO Air Quality Guidelines

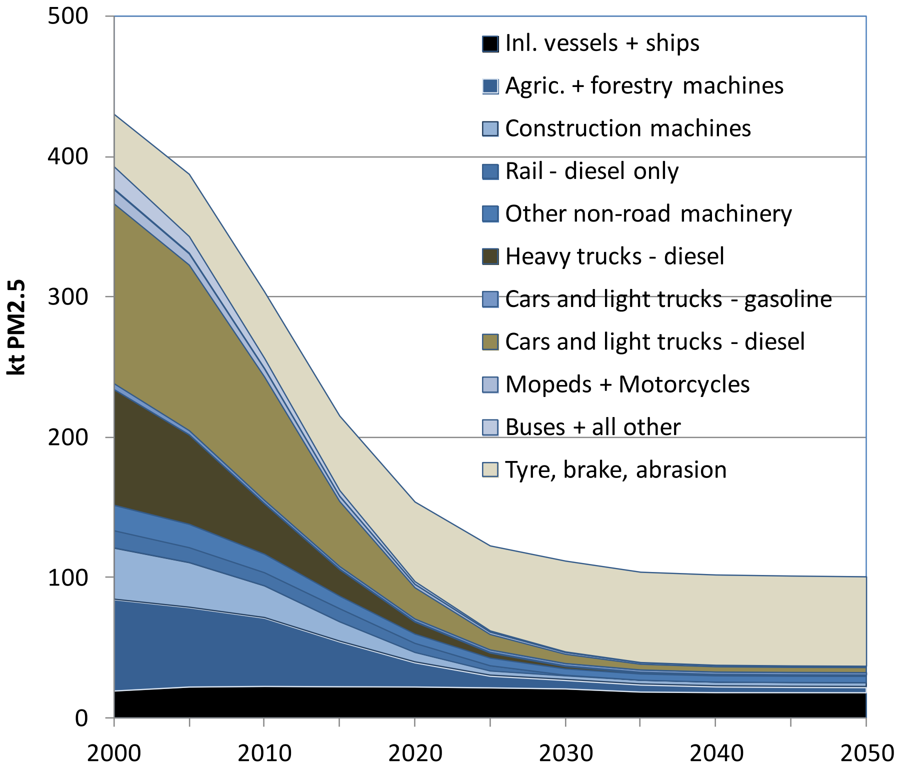
(Annual mean PM10: 20 μg/m^3; Annual mean PM2.5: 10 μg/m^3)

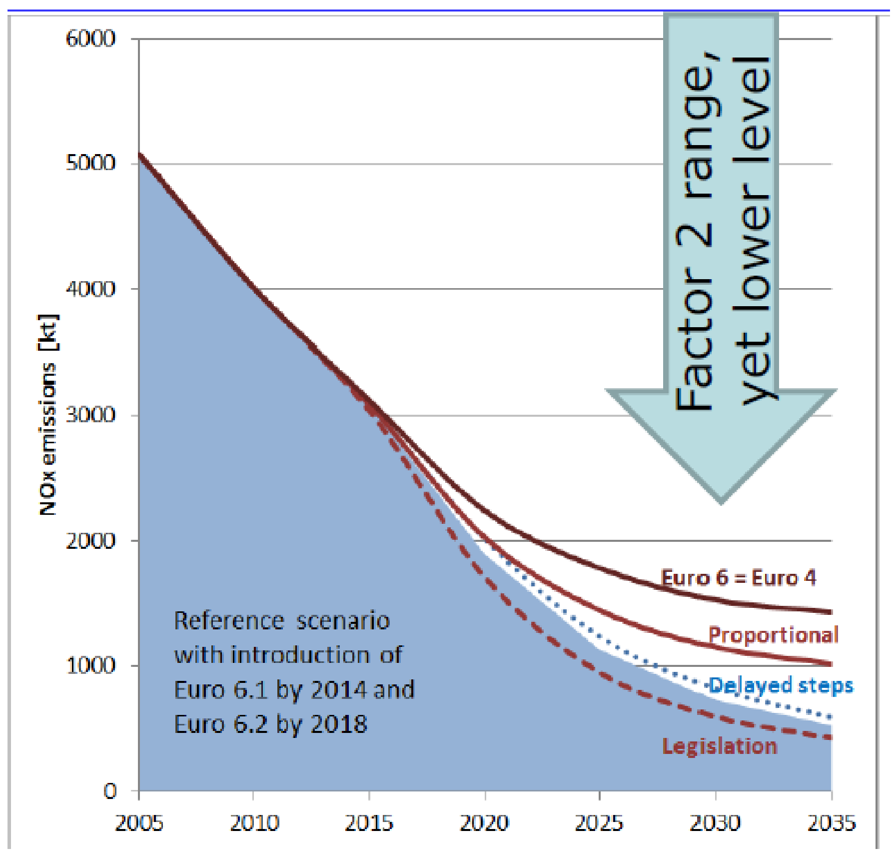


Afr: Africa; Amr: America; Emr: Eastern Mediterranean; Eur: Europe; Sear: South-East Asia; Wpr: Western Pacific; LMI: Low- and middle-income; HI: high-income

Source: WHO, 2012

EU Transport Emissions Projections





$PM_{2.5}$

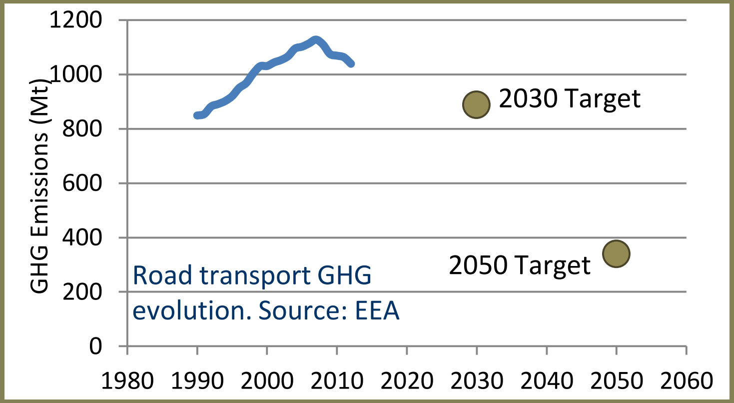
NO_x

Source: Kleefeld and Ntziachristos (2012) TSAP Review

Greenhouse gases (GHGs) emissions in the EU

- Transport accounts for 1/3 of total energy consumption and 1/4 of total GHGs
- Road transport alone contributes to 20% of total manmade EU GHG

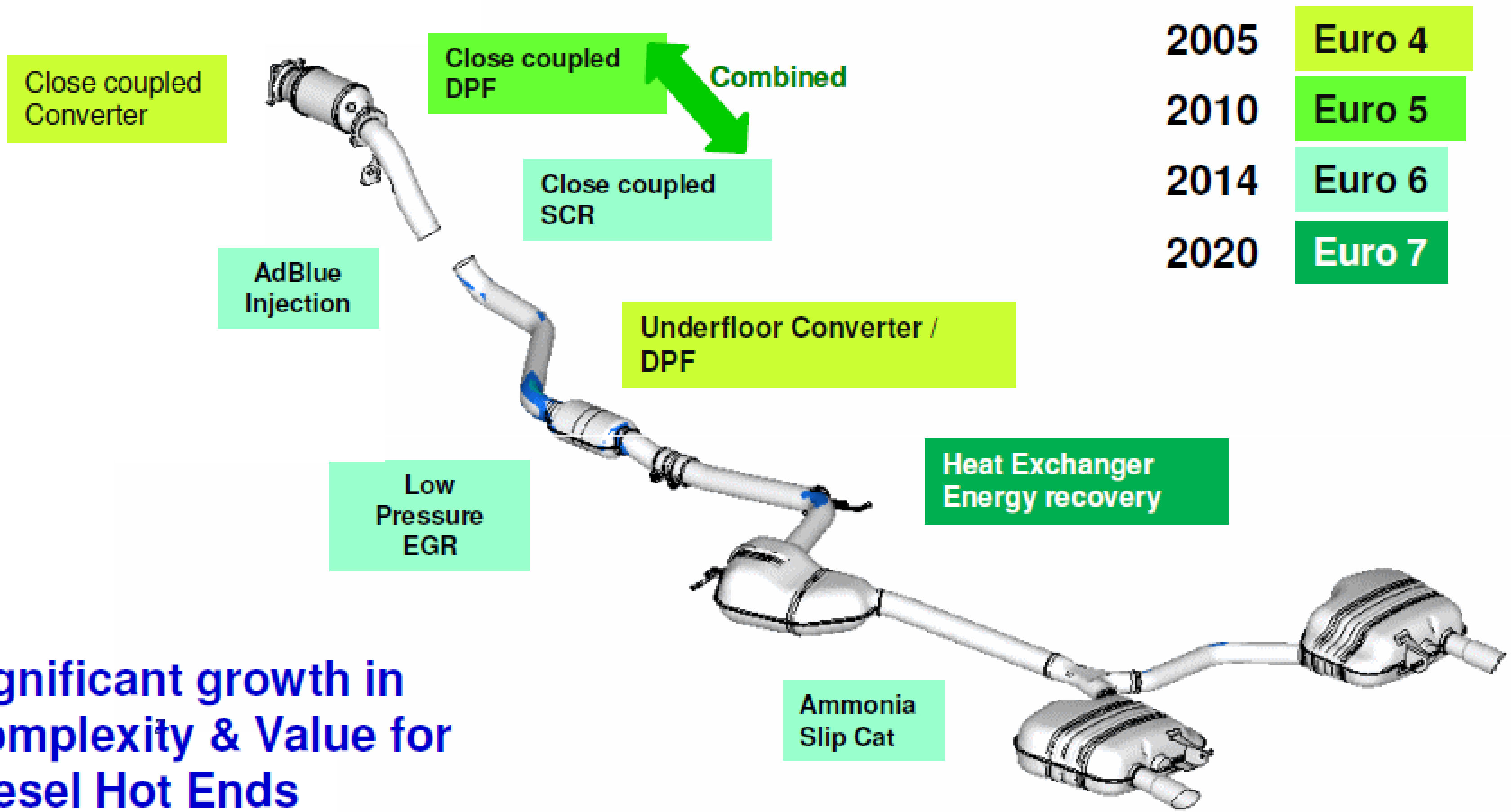
GHG emissions from transport have increased over 1990 base level



- Binding targets to reduce GHGs from road transport:
  - 95/147 gCO_2/km by PCs/Vans by 2020
  - 10 % of total energy consumption on renewables by 2020
  - Tyre pressure monitors, gear-shift indicators
  - Green procurement
  - …

WHAT HAS EUROPEAN POLICY DONE SO FAR?

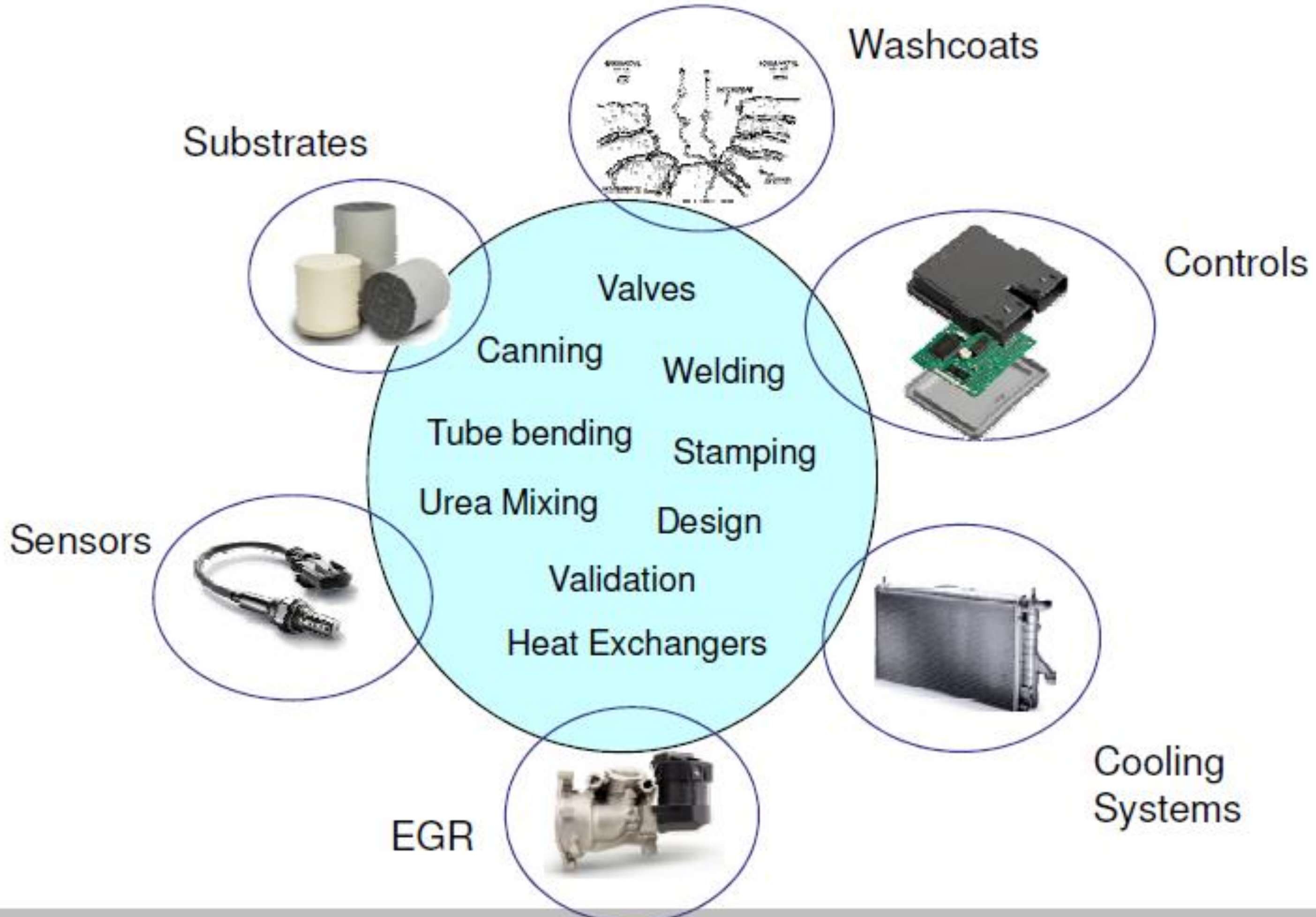
2005 to 2020 Exhaust Aftertreatment for Diesels



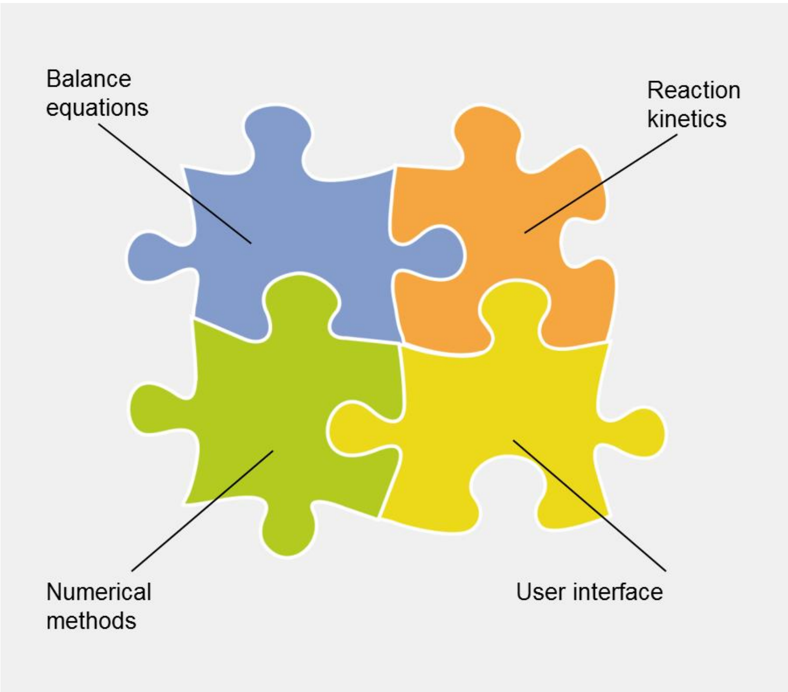
Significant growth in Complexity & Value for Diesel Hot Ends

Source: S. Zidat / E. Hansenne, Bosal Emission Control Systems, June 11, 2012

More in Involvement in Various Systems

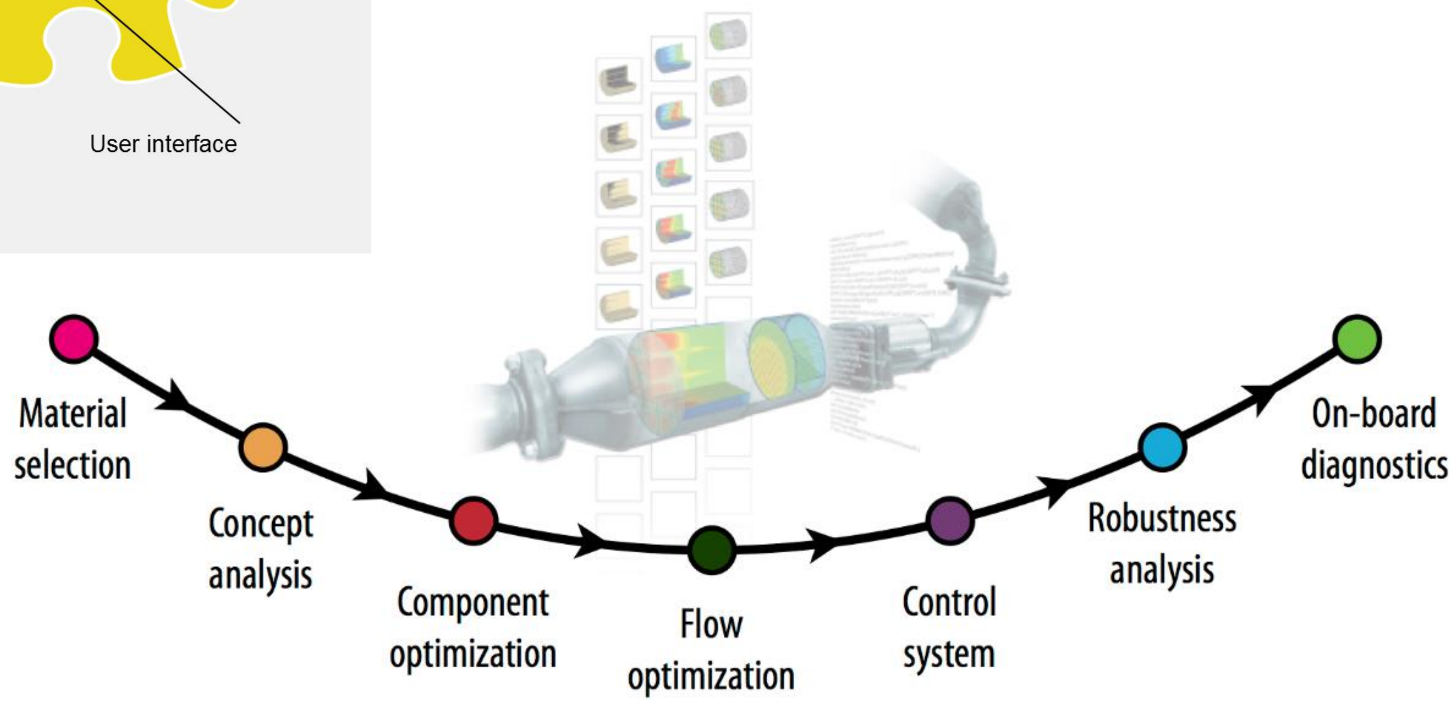


Model Based Development: a necessity in Exhaust Aftertreatment



Complicated

Several steps



Source: Exothermia SA

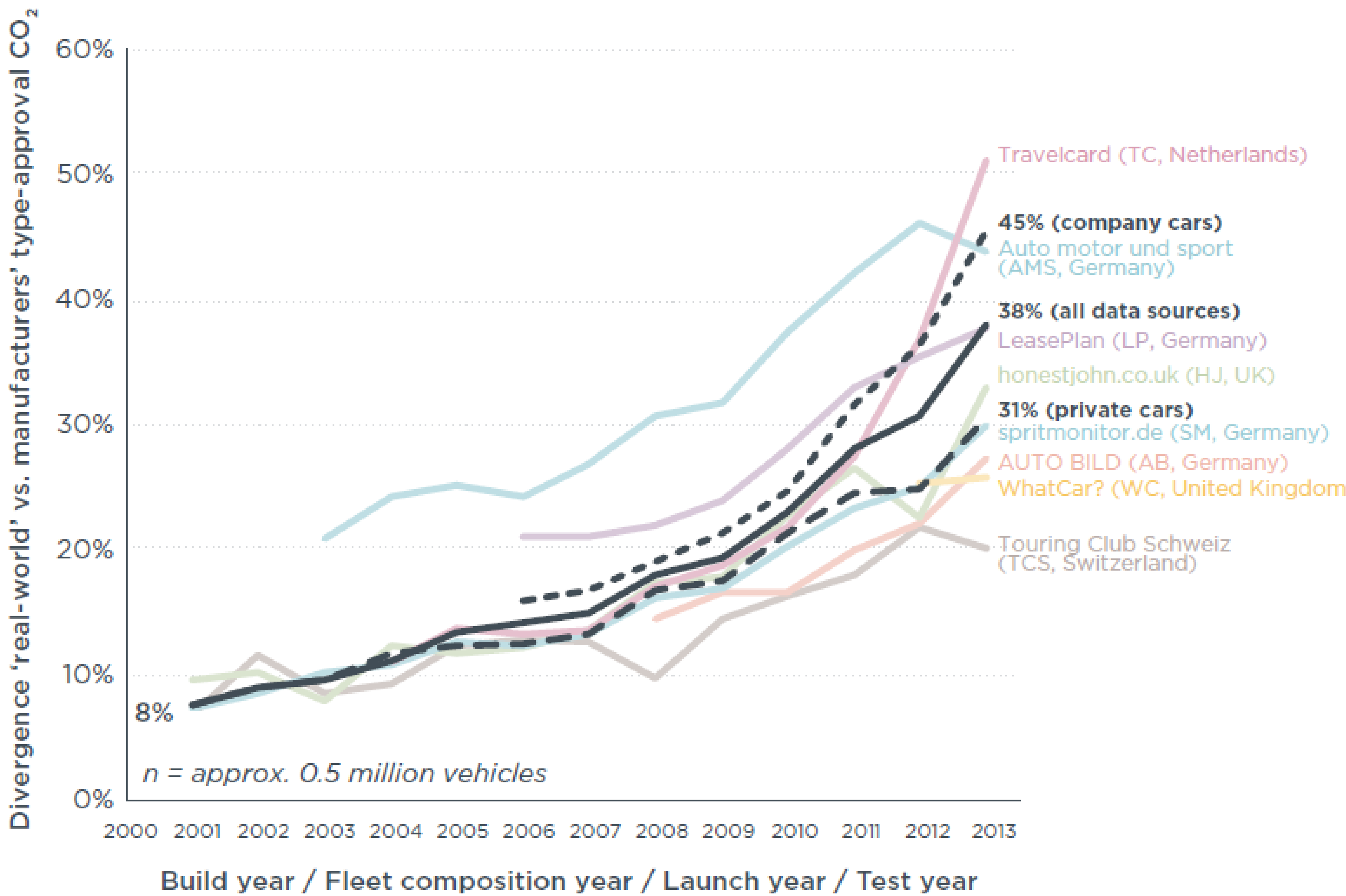
Aftertreatment technologies to 2020

- Gasoline technology for LDV
  - Low efficiency: Stoichiometric PFI with TWC
  - Moderate efficiency: Stoichiometric GDI with three way catalyst and GPF (or advanced engine PN suppression)
  - High efficiency: Lean-burn GDI + LNT + GPF
- Diesel technology for LDV
  - Small engines: EGR + DPF + LNT
  - Large engines: EGR + DPF + SCR

Regulations under preparation

- CO_2 regulations
  - CO_2 WLTP/NEDC correlation for PCs and Vans
  - CO_2 labeling for HDVs
- Regulated air pollutants
  - Real driving emission control for PCs (RDE)
  - Euro 6 and VI OBD (incl. PM/PN monitoring)
  - GDI PN PMP
  - Euro 6 PN PEMS
  - L-category vehicles (scooters, motorcycles, …)
- Other issues (durability, NO2, NH3, tyre and brake wear…)

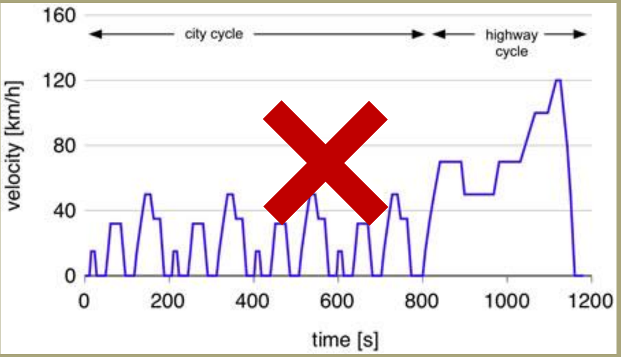
Divergence of real-world CO2 emissions from manufacturers' type-approval CO2 emissions

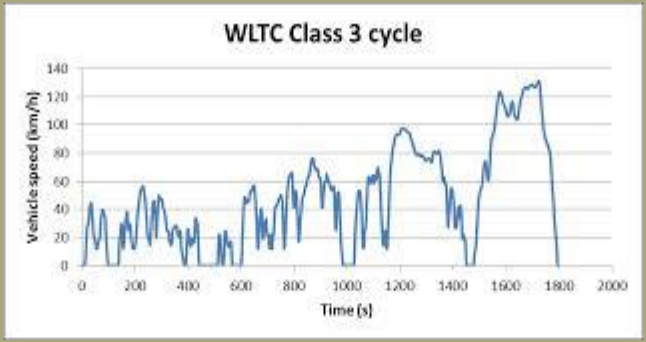


Source: ICCT. 2014

WLTP Implementation

- WLTP adopted by UNECE-GTR in 2014 and will replace NEDC as a certification cycle
- Less relevant for emission standards
  - Limit values remain the same
  - RDE to substitute chassis dyno in the long run
- Important to translate NEDC-based CO_2 targets of 2015 and 2020/21 to WLTP

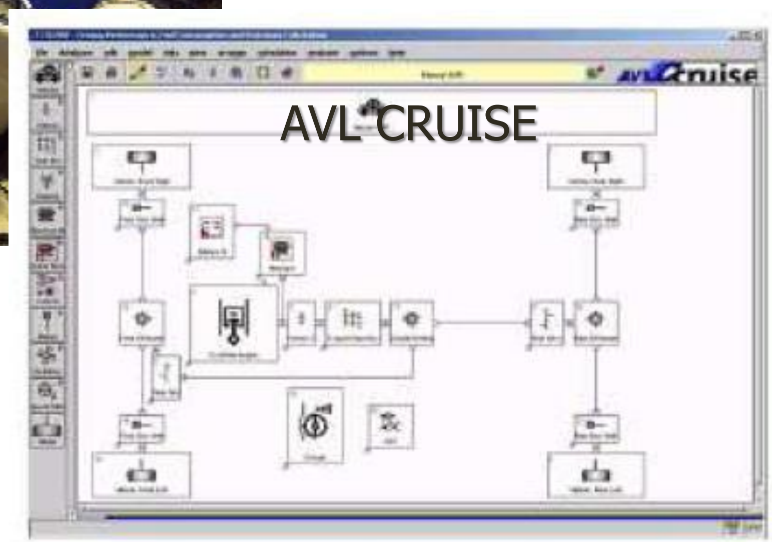


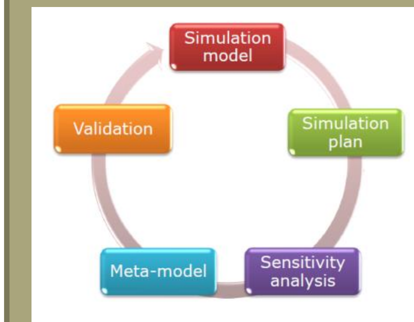


CO_2 WLTP-NEDC translation procedure

Chassis dyno tests
(~30 vehs)

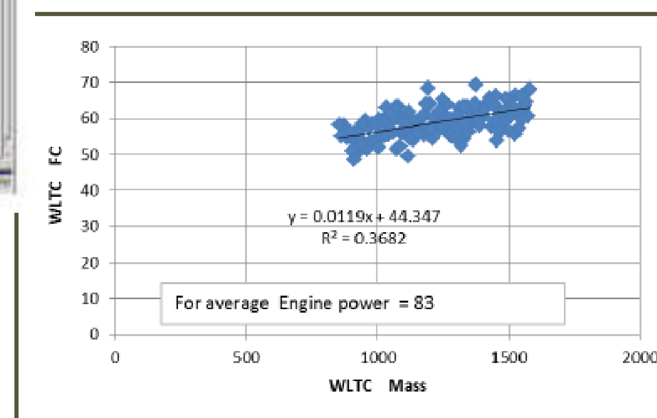
Vehicle level Technology
Simulations (~15000 sims)





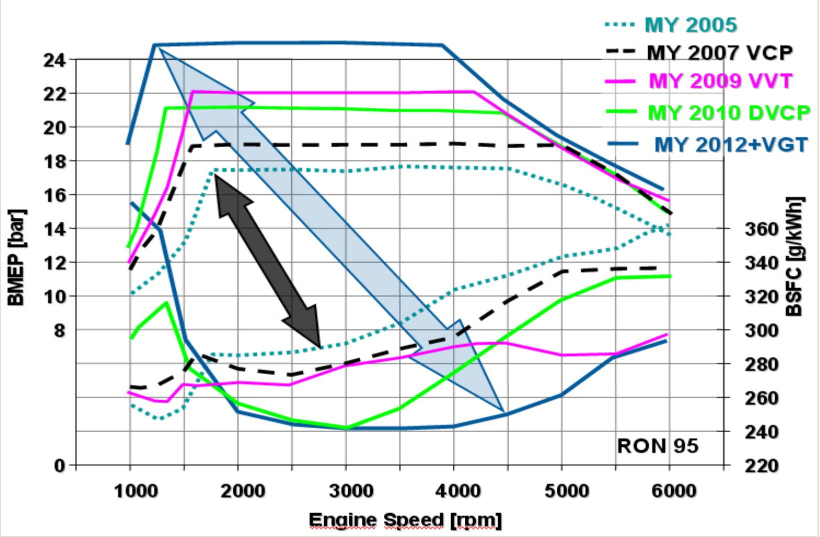
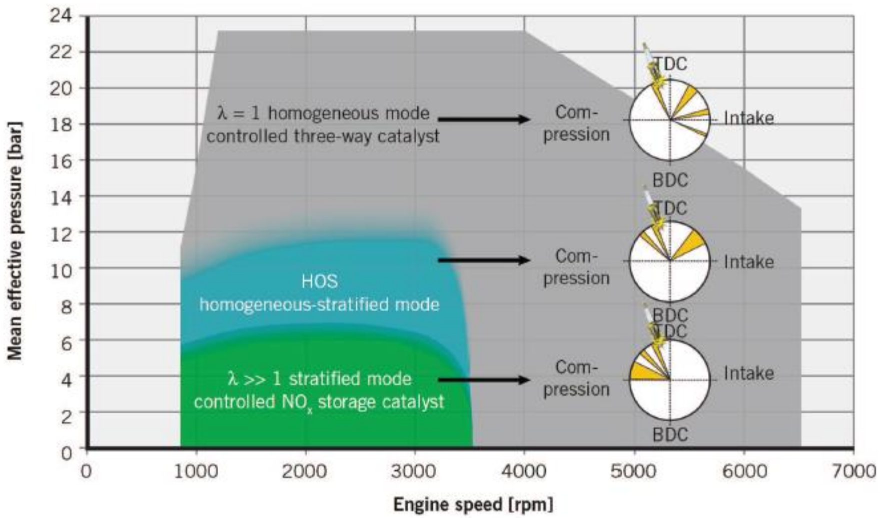
Overall approach

Segment-level simulations:
Meta-model (Physical or
statistical approach)



Technologies currently used for CO2 reduction

looked at in WLTP-NEDC translation

Technology	
Downspeeding, Downsizing Source: AVL	
Lean burn Source: MTZ 5/2013 Vol. 74	

Technologies currently used for CO2 reduction

looked at in WLTP-NEDC translation

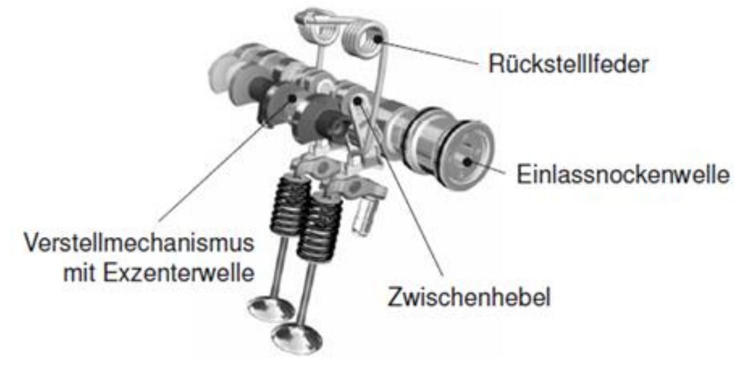
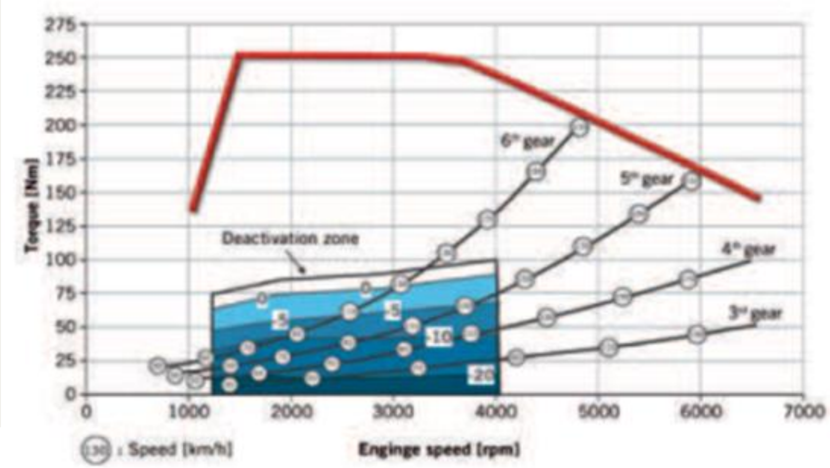
Technology	
VVT (e.g. Vanos, Valvetronic)	
Cylinder deactivation	

Abb. 12-18: Vollvariable kontinuierliche Ventilsteuerung BMW Valvetronic [Bildquelle: BMW Group]

Source: MTZ 03/2012 vol. 73

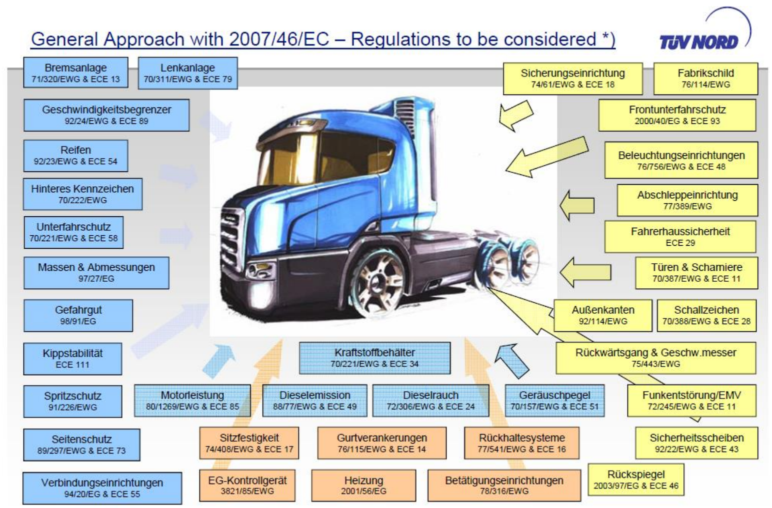
Technologies currently used for CO2 reduction

looked at in WLTP-NEDC translation

Technology
Start stop
Energy recuperation
Automatic/Manual transmission
2WD/4WD
EGR (gasoline and diesel)
Thermal management
DI/MPI
NSC and SCR
Road load (aero, RR, weight)
Auxiliaries
Mild/full hybrid

CO_2 from HDVs

- CO_2 emissions from HDV have not been addressed yet
  - Vehicle type approval complexity
  - Articulated vehicles carry different semi-trailers



*) not showing the current status – up-date necessary.

- Energy efficiency in trucks has always been in the forefront of vehicle / engine development
  - Fuel cost is the most significant criterion in choosing a truck
  - Energy efficiency improvements have already shifted CO_2 emissions downwards and have advanced relevant technologies

Monitoring CO_2 emissions from HDV

- Selected option: Vehicle Simulation
  - Simulation for whole vehicle supported by component testing
  - Joint Commission – ACEA effort
- VECTO Simulation tool (Version 1) launched by the JRC in 10/2012

VECTO
Vehicle Energy Consumption Calculation Tool

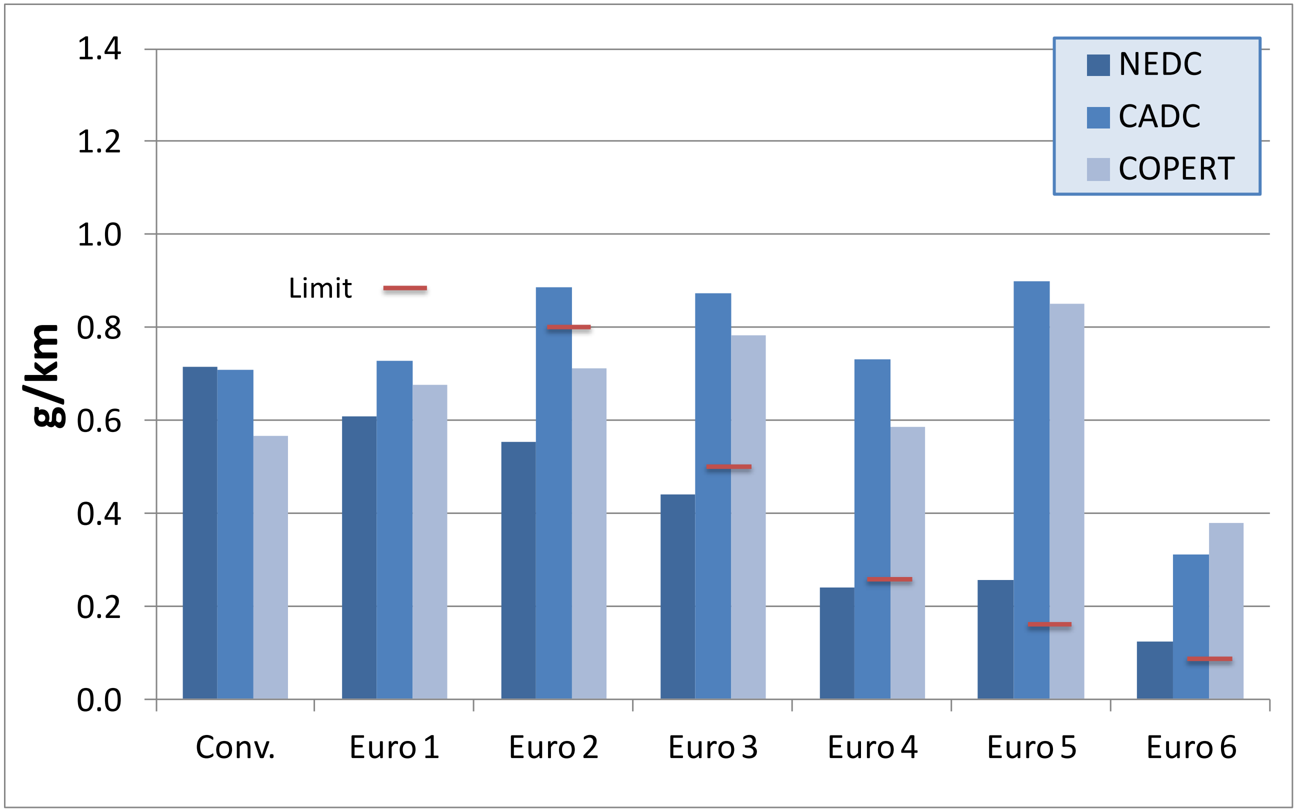
- 2012-2014: campaign towards final regulation
  - ACEA – JRC –Consultants experimental campaign (“Proof of Concept”)
  - Completion of simulation tool
  - Finalize regulation / harmonize with other activities (eg Heavy Duty Hybrid powertrains)

Source: Fontaras (2012) JRC Presentation

Alternative fuels

- Biofuels (biodiesel, bioethanol) sustainability questioned
  - Feedstock availability
  - Real CO_2 benefits obtained
  - Not positive air-quality impacts
- Renewable diesel (catalytic hydrogenation/de-oxidation of vegetable oils) - BTL
  - Well-controlled specifications
  - Paraffinic fuel
- Natural gas (CNG/LNG)
  - Target is a 20% reduction to CO_2 emissions
  - Adapted engine and vehicles to be studied in Horizon2020

Emission levels - Diesel PC NO_x



Significant exceedances of emission limits

Euro 3: 1.6×

Euro 4: 2.3×

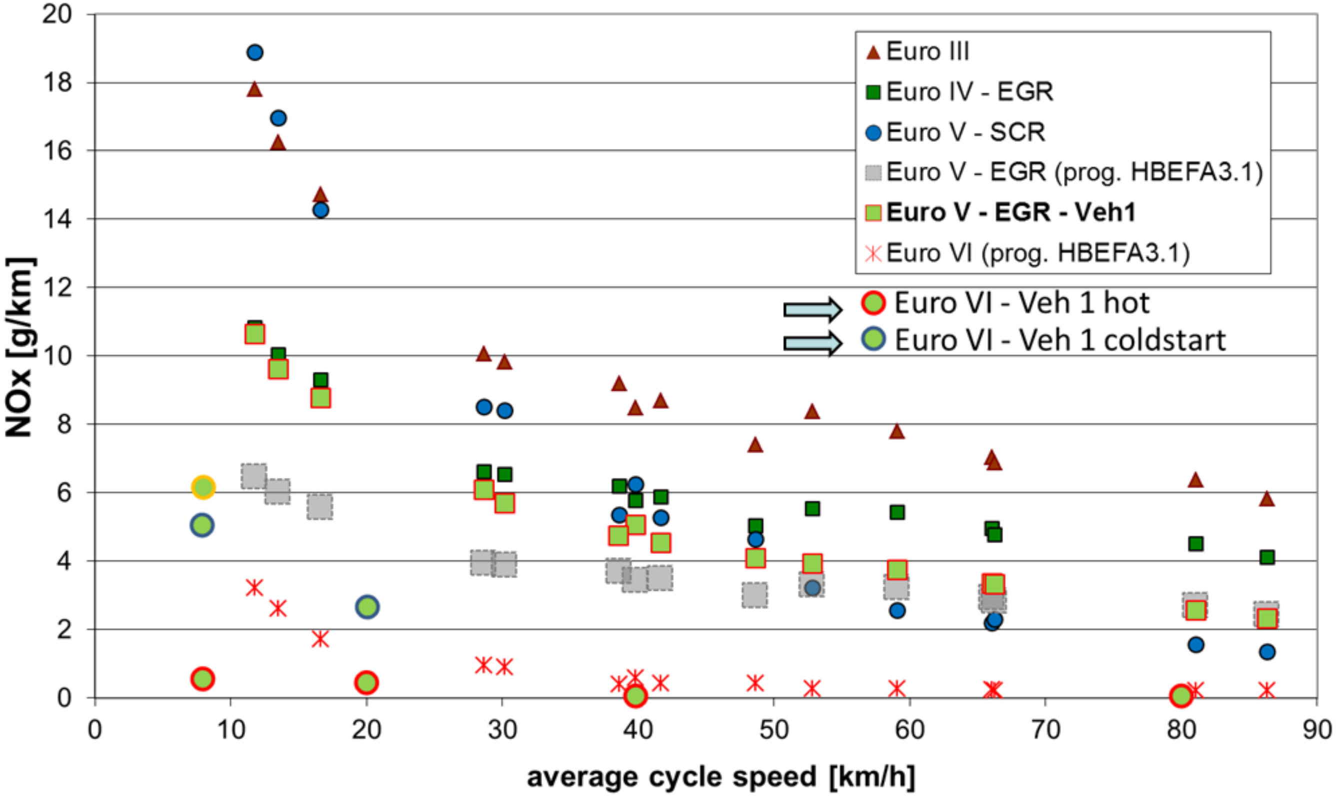
Euro 5: 4.7×

Euro 6b: 4.7× (estimate)

Source: ERMES consortium

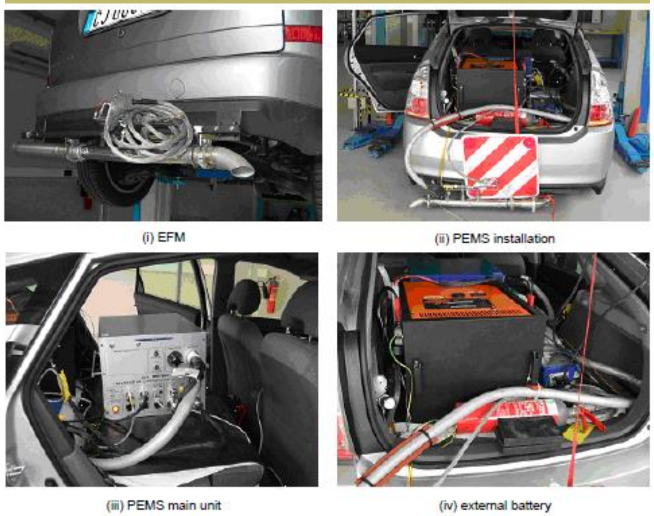
Euro VI HDV performance

Results for EURO VI (veh. 1 = Daimler, Actros)



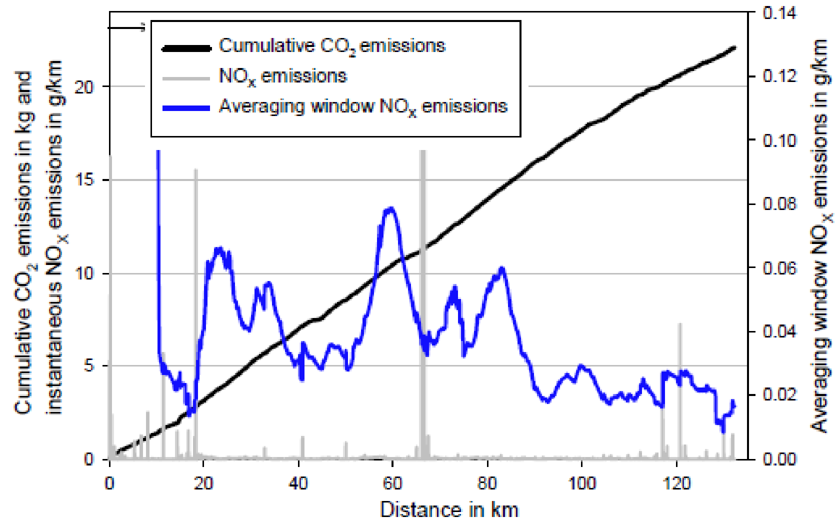
Real drive emissions control - procedure

1. Testing with PEMS

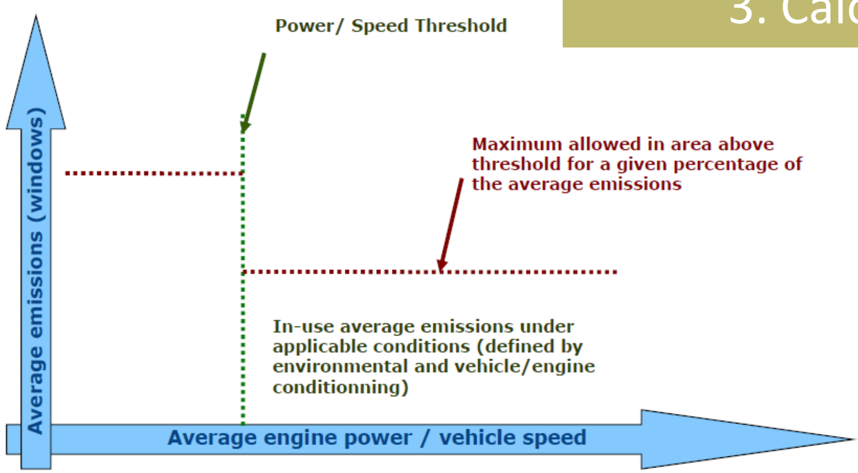


(i) EFM (ii) PEMS installation (iii) PEMS main unit (iv) external battery

2. Averaging window



3. Calculations

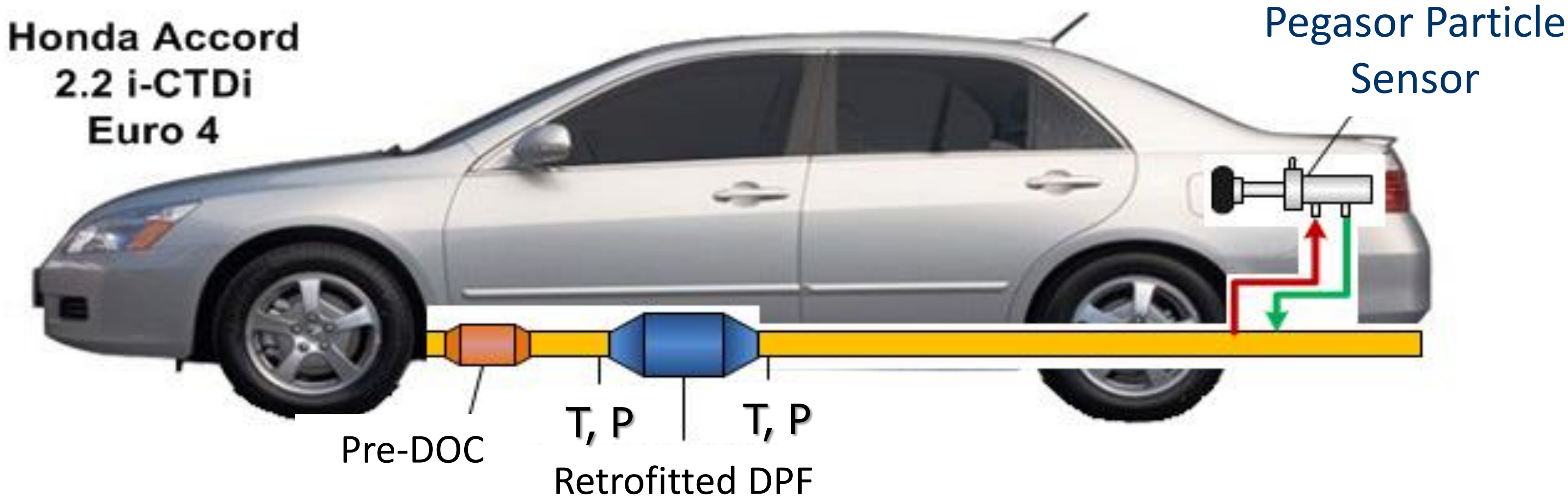


- A given number of points within testing boundary conditions should be within limits
- E.g. HDV IUC: 90% of valid windows lower than 1.5 x Emis. Stand.

EURO 6 PN PEMS

- Objective is to introduce PN in RDE
- Main issues to address:
  - Proportional or constant flow sampling
  - Real-time detector principle
  - Cold-start / regenerations
  - VPR
  - Calculations (PCRF, conversions, etc…)
- Proof of concept completed
  - Constant flow sampling
  - Diffusion charger as a particle "counter"
- Current status
  - On-road tests on LD vehicles

LAT's Approach to PN PEMS



Pegasor Particle Sensor
- Heated sensor (250°C)
- Heated sampling lines (200°C)

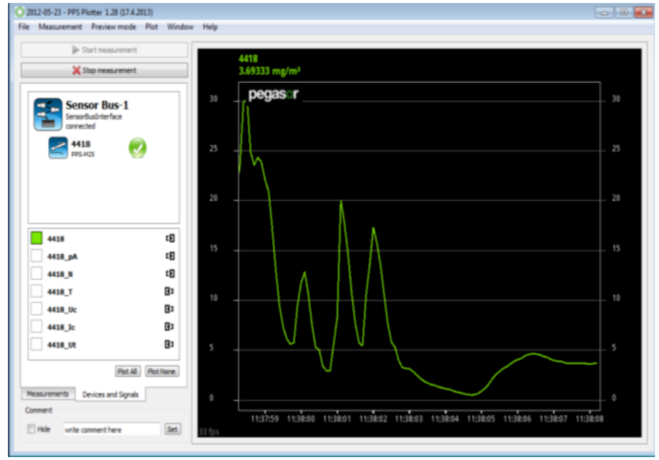
Sampling from tailpipe through an opening in the replacement wheel space

Underfloor protection

Data collected with PN PEMS

Engine data (OBD)

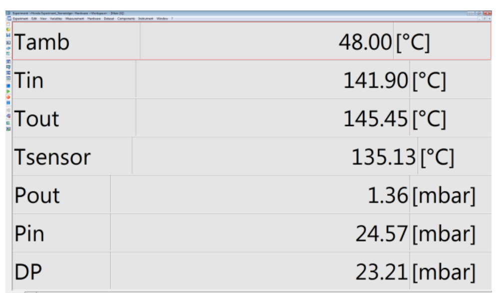
- Engine Coolant Temperature
- Intake Manifold Abs. Pressure
- Intake Air Temperature
- Intake Air Flowrate
- Engine RPM
- Calculated Load Value
- Vehicle Speed
- Fuel Rail Pressure
- Commanded EGR
- Ambient Temperature



Soot concentration (Pegasor Particle Sensor - PPS)

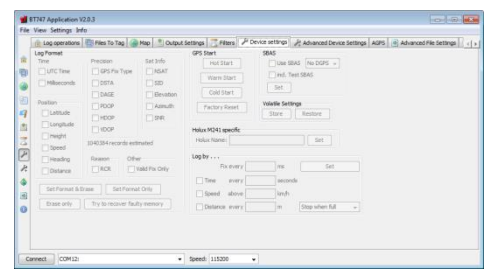
- Soot Conc. [mg/m^3]
- Number Conc. [#/cm^3]

More than 6000 km successfully collected



DPF operation parameters (T, P sensors)

- Inlet and outlet DPF Temperature
- Inlet and outlet DPF Pressure

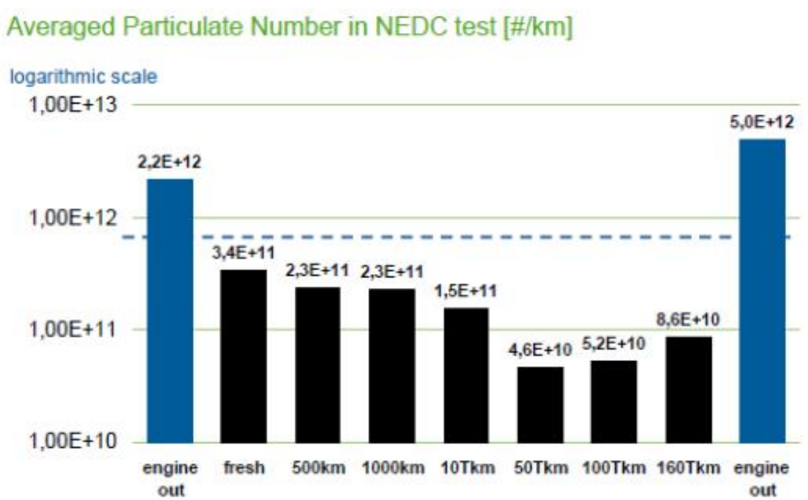


In-vehicle position logger (GPS)

- Vehicle position (lat., long., height)
- Vehicle speed [km/h]

Possible next steps in terms of GDI PN control

- Non zero number of sub-23 nm particles, even more so than diesel
  - Discussion to reduce cutpoint to 10 nm
  - New counter, new VPR
- GDI vehicles of today cannot meet PN_{2017} target
  - EtOH blends have been shown to reduce both PN and PM
  - Injection and combustion optimization can offer reductions
  - Can be met with already available GPFs



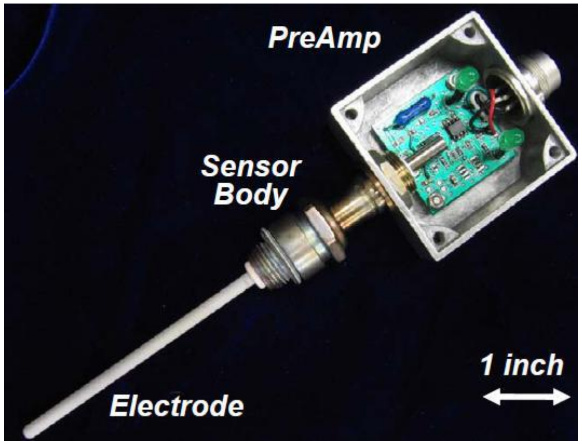
Source: Umicore (2012) CAPoC Conference

Why OBD?

<u>'OBD system'</u> = system for emission control which has the capability of identifying the likely area of malfunction by means of fault codes stored in a computer memory

- Identification of malfunction → early repair → less emissions
- Incentive to design more robust emission control systems
- Use at periodic inspections

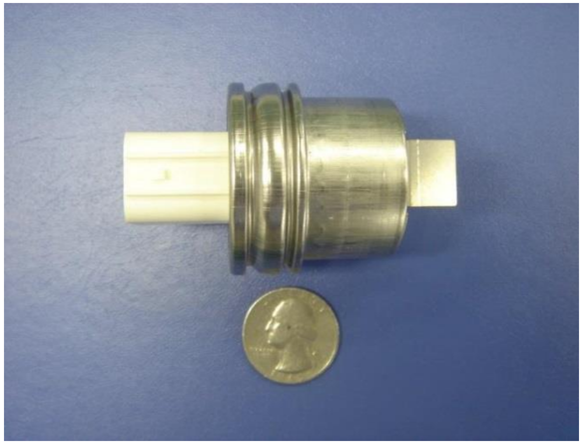
Diesel OBD sensor candidates



Soot Sensor


Combined O_2/NOx Sensor


Ammonia Sensor

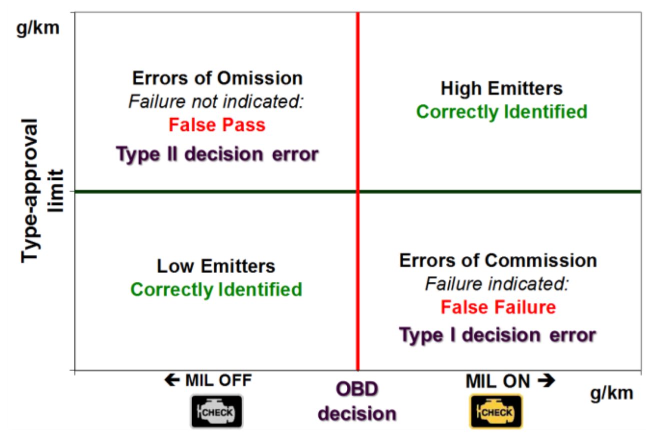

Urea Quality Sensor

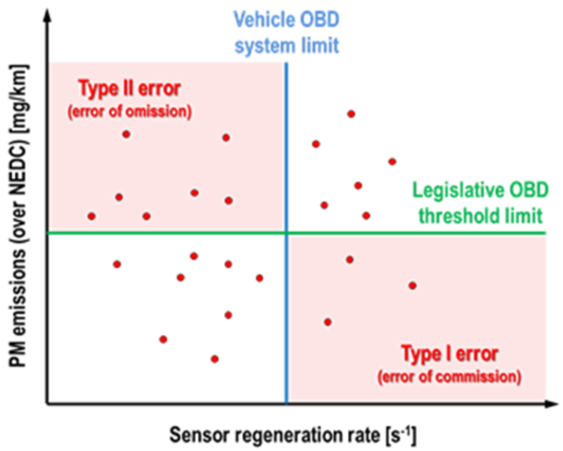
Source: MECA

From measurement to diagnosis

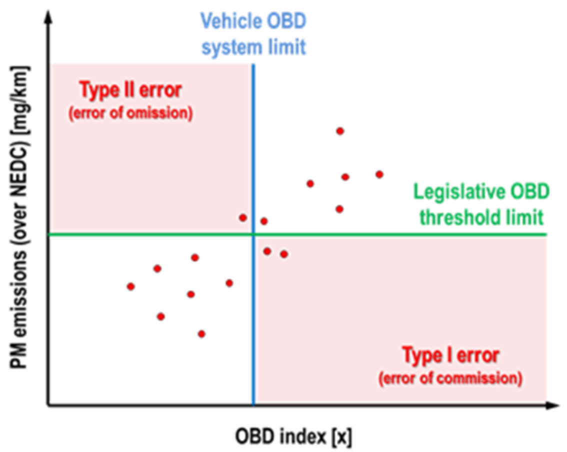
- Most sensors do not provide continuous signal or and an index with physical units
- Soot emissions highly depend on vehicle operation
- Need to correlate random operation emissions with type-approval cycle emissions

→ **Need of a robust OBD algorithm**





OBD algorithm



A “forgotten” category: two/three/four wheelers

Vehicle categorisation	L1e- A	L1e -B	L2e	L3e	L4e	L5e-A	L5e-B	L6e-A	L6e-B	L7e-Ae	L7e-Be	L7e-Ce
			 L2e-P	 L3e-A1	 L4e				 L6e-BP	 L7e-A1	 L7e-B1	 L7e-CU
Typical Photos of Models			 L2e-U	 L3e-A2					 L6e-BU	 L7e-A2	 L7e-B2	 L7e-CP
				 L3e-A3								
Key specifications	≤50cc, ≤45 km/h, <4 kW, C-O 25kmh	≤50cc, ≤45 km/h, <4 kW	≤50cc, ≤45 km/h, <4 kW, ≤270 kg (P: V 0.6m^3)			3W, <1000 kg, max 5 seats	3W, <1000 kg, max 2 seats, V 0.6m^3	<4kW, ≤425 kg, ≤45 km/h (D, G)	<6kW, <425 kg, ≤45 km/h (D, G)	<15kW, ≤450 kg	W/G<6, ≤450 kg	P: ≤450 kg, U: ≤600 kg, (D, G)

- Large diversity of individual vehicle types
  - Body-type
  - Engines (fuels, performance, operation)
  - Usage / operation

Outlook

- GHG control will continue to be in the forefront of EU policy and related technological advances
  - Gradual shift to natural gas vehicles
  - Variable degrees of hybridization
  - Technology and infrastructure based efficiency improvements

- ICEs will continue to be the powertrains of option for the foreseeable future. Main technology challenges:
  - Diesel (LD) NOx
  - OBD
  - NRMM
  - Power two/three and four wheelers

Thank you for your attention

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