LABORATORY OF APPLIED THERMODYNAMICS

Ζήσης Σαμαράς
Καθηγητής

ARISTOTLE UNIVERSITY THESSALONIKI
SCHOOL OF ENGINEERING
DEPT. OF MECHANICAL ENGINEERING

Τεχνολογικές προοπτικές για καθαρά, χαμηλής κατανάλωσης οχήματα

Το μέλλον της αυτοκίνησης πέρα από το "Σκάνδαλο Dieselgate"

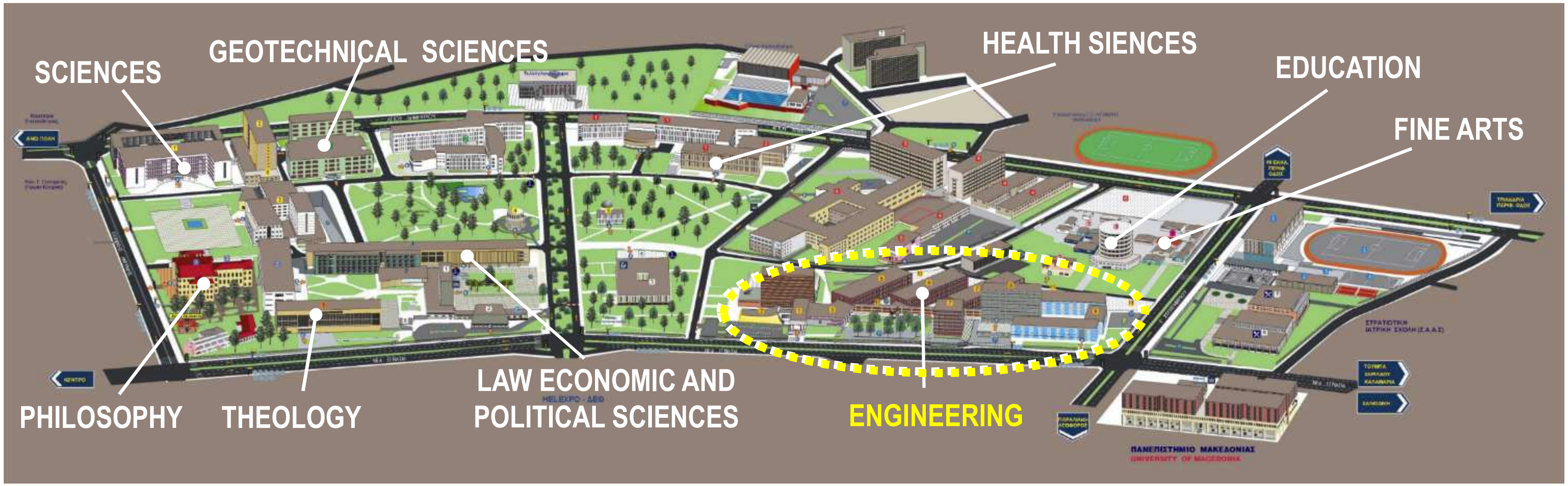
Τμήμα Επιστήμης και Τεχνολογίας Περιβάλλοντος,
Τεχνολογικό Πανεπιστήμιο Κύπρου, 2016-02-09

FACULTY OF ENGINEERING
ARISTOTLE UNIVERSITY OF THESSALONIKI

A University at the heart of the city

The largest University in Greece

70.000 students
2.100 faculty members
10 faculties
41 departments



Lab of Applied Thermodynamics: History and milestones

International recognition as top-class automotive research provider

Fuel efficiency, CO_2

Major automotive industry partnerships

Modeling and CAE

The dawn of European projects era

Shifting focus to emissions

Solar energy projects

Setting the foundations and lab infrastructure

1975
- LAT founded by Pr. Pattas

1989
- Athens buses retrofit project

2001
- New director: Pr Samaras

2008
- Major facilities overhaul > 1 ME invested

2014/15
- New expansion

Personnel

FACULTY

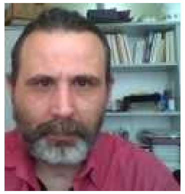
   

Pr. Z. Samaras | Pr. A. Tomboulides | Assoc.Pr. G.Koltsakis | Assoc.Pr. L.Ntziachristos

SECRETARIAT

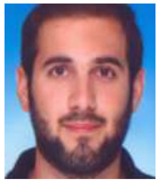
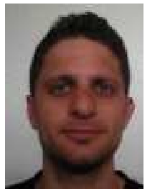
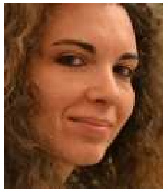
 

SENIOR RESEARCHERS

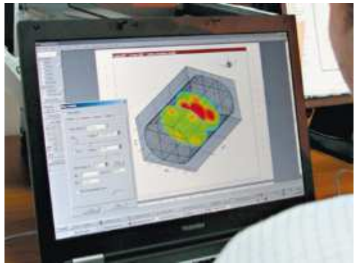
     

Dr P. Pistikopoulos | Dr I. Vouitsis | Dr S. Geivanidis | Dr D. Katsaounis | Dr A. Dimaratos | Dr D. Mertzis

Phd STUDENTS

Scientific & research areas

Exhaust gas emissions & after-treatment technology | Vehicle fuel efficiency | Renewable fuels

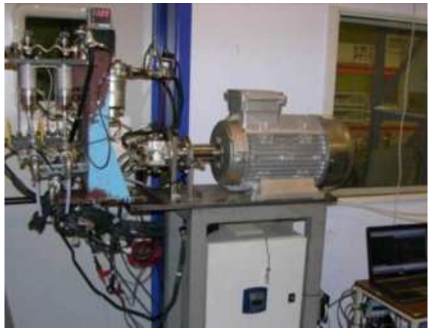
Extensive know-how in combustion engines and emissions **measurement** technology combined with advanced CAE and **modeling** techniques

…**keeping the big picture on vehicle environmental performance!**

Main Facilities

Chassis dyno for vehicle emissions testing

3 fully equipped engine benches for emissions testing



Fuel injector test rig

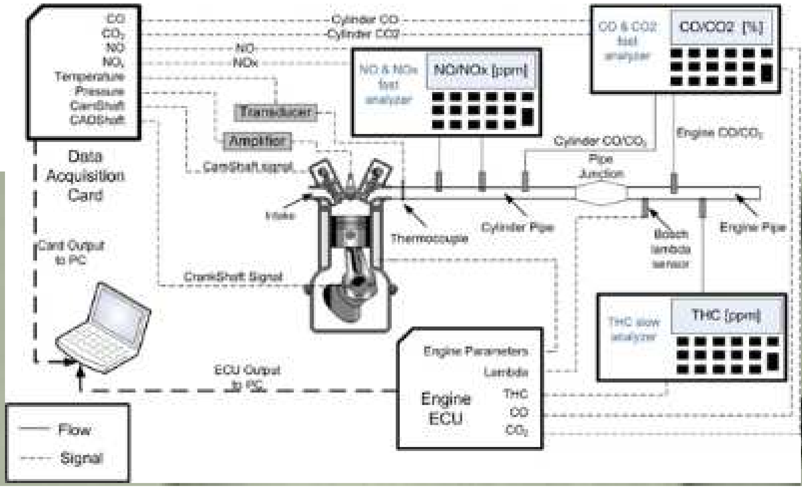
Mobile biomass gasification unit

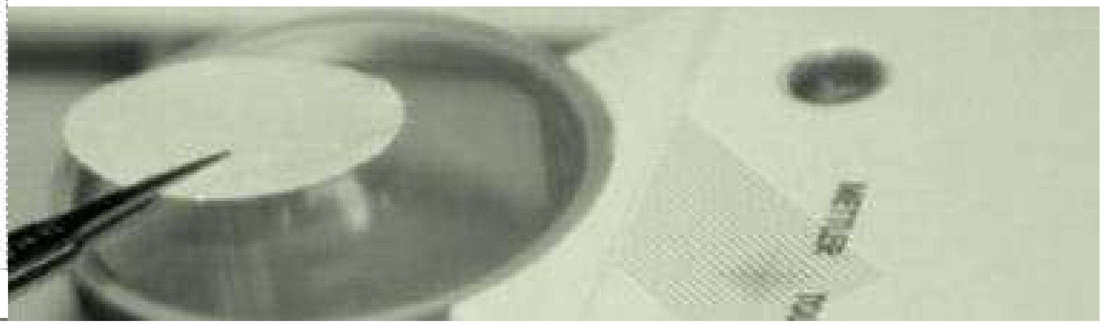
~400+ m^2 test facilities supporting non-stop measurements

~250 m^2 office area accommodating ~ 25 researchers

Equipment

State-of-the-art equipment for emissions measurement
obtained via regular investments from research funds [est. value > 5 Meuros]
carefully maintained by LAT skilled personnel





Sponsors and Clients

Long-term, trustful R&D partnerships with automotive industry
Technical consulting services supporting the European Commission

Alliances and Collaborations

VTT

TNO innovation for life

CRF CENTRO RICERCHE FIAT

University of Hertfordshire UH

TNO innovation for life

TRANSPORT & MOBILITY LEUVEN
Your link to integrated analyses !

RICARDO

TU Graz

IVECO

AVL

NILU

DLR

ARISTOTLE UNIVERSITY OF THESSALONIKI

DMI

berner & mattner
optimizing your development

FINNISH METEOROLOGICAL INS

TÜV NORD
Mobilität

POLITECNICO DI TORINO

POLITÉCNICA

IVL Swedish Environmental Research Institute

Telematics
Technologies
Transport
Traffic
Turin

Meteorologisk institutt
met.no

Universität Stuttgart

madrid

madrid calle 30

HelmholtzZentrum münchen
German Research Center for Environmental Health

UNIVERSIDAD POLITECNICA DE VALENCIA

KATHOLIEKE UNIVERSITEIT LEUVEN

SPQR

POLIS

DEKATI

ifp Innovation Energy Environment

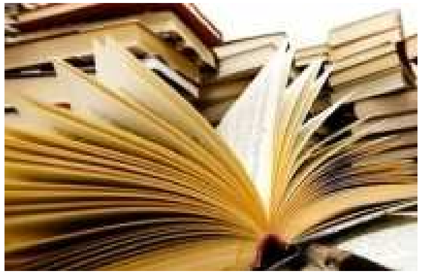
Fraunhofer

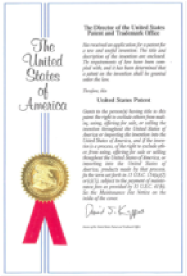
BMW

LMS ENGINEERING INNOVATION

MINI

Results






(19)

(11)

(12) EUROPEAN PATENT SPECIFICATI

(45) Date of publication and mention of the grant of the patent: 01.08.2012 Bulletin 2012/31

(51) Int Cl.: F01N 3/022 B01D 53/94

(21) Application number: 07804509.3

(86) International ap PCT/GR2007/0

(22) Date of filing: 20.09.2007

(87) International pu WO 2008/03512

(54) GAS TREATMENT DEVICE
GASBEHANDLUNGSVORRICHTUNG
DISPOSITIF DE TRAITEMENT DE GAZ

emisia
MISSION FOR ENVIRONMENT

30 PhDs completed
>150 journal papers
>3000 citations

Int'l patents

2 spin-off companies
offering innovative tools and solutions to the automotive industry
employing ~ 35 highly qualified engineers

Committed to highest standards of research quality,
inspiring the passion of engineering to our students,
turning creative ideas to products

We work on E A T, exhaustively!

Exothermia
modeling efficiency

Our background

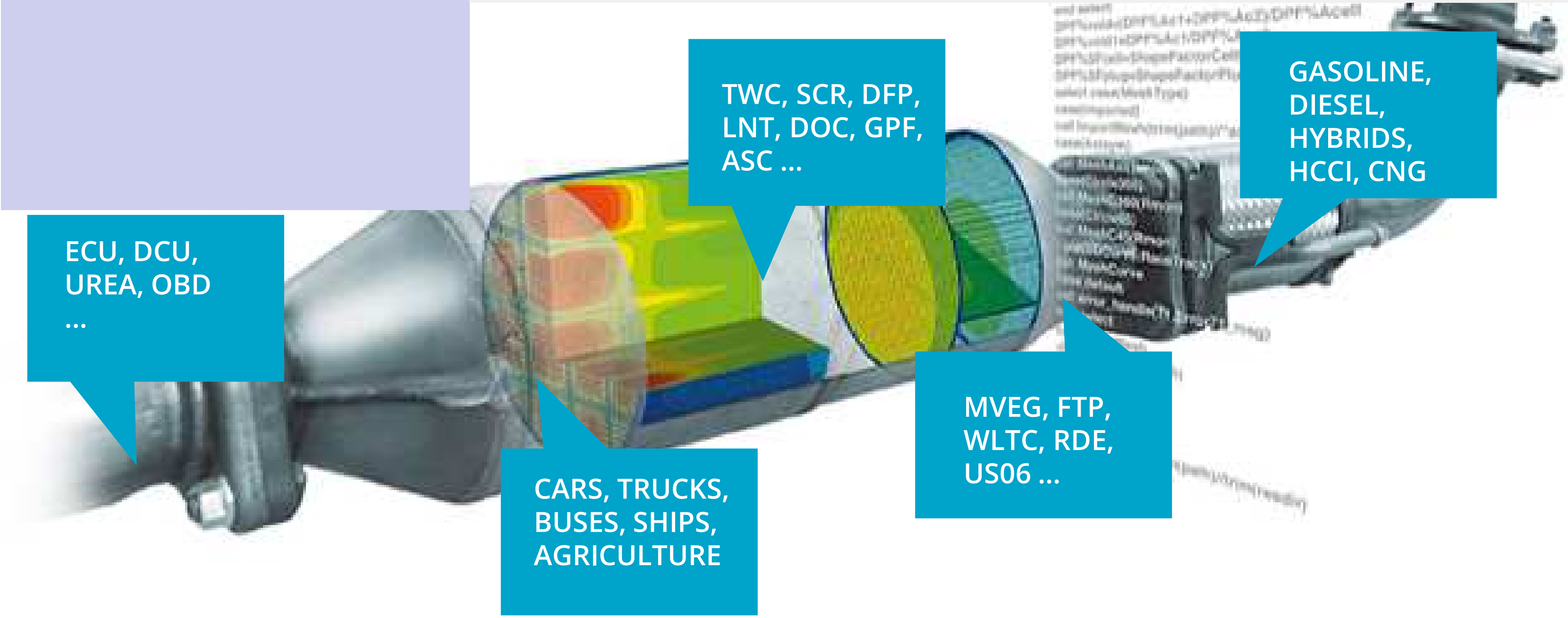
Exothermia was born in 2007 as a spin-off from Laboratory of Applied Thermodynamics (LAT), Aristotle University Thessaloniki in Greece.

Why simulation?

Complex problems call for expert solutions

Exhaust After-Treatment is a multi-parameter problem, exceeding the capacities of 'conventional' experimental methods.

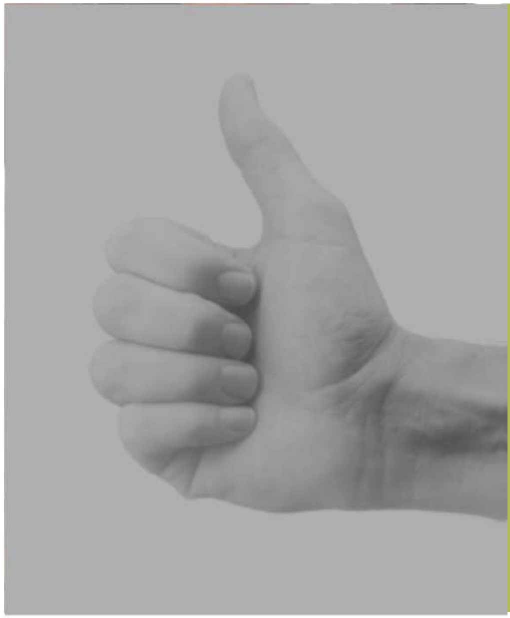
Acceptable costs are only possible by employing reliable simulation across the development process.



EATing is an art!

This is why!

Exothermia
modeling efficiency



We are committed to the highest quality of exhaust after-treatment CAE.

Our software and services are trusted by the leading OEMs, EAT suppliers and Universities around the globe.

TOYOTA · LAND-ROVER · Audi · PSA PEUGEOT CITROËN · automotive engineering iav · FIAT POWERTRAIN · DAIMLER

DOW · ALANTUM · CRF CENTRO RICERCHE FIAT · SOKEN NIPPON SOKEN, INC. · NGK · umicore · SÜD-CHEMIE · mtu

UNIVERSITY OF BIRMINGHAM · Queen's University Belfast · Loughborough University · WASEDA University · TU Graz · POLITECNICO DI MILANO

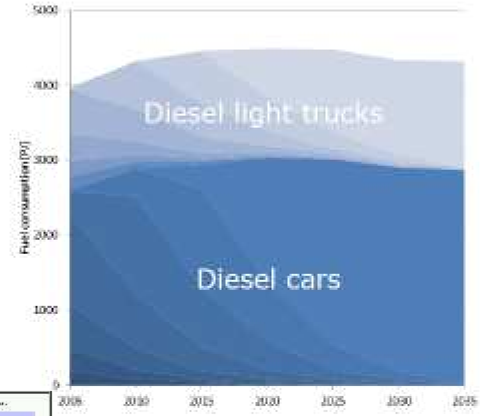
IBIDEN · CERAM · faurecia · Eberspächer · CORNING · HONDA

EMISIA and Tools

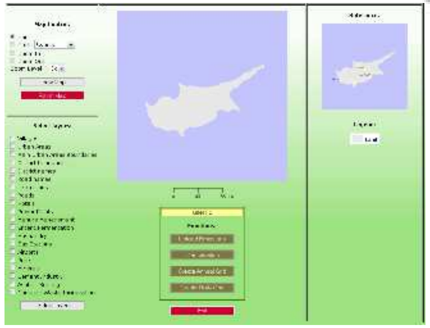
Brussels, December 4, 2013

Areas

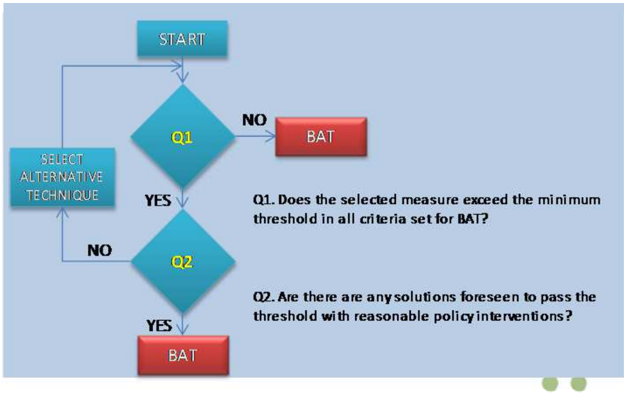
- Emission and energy inventories and projections



- Emission modelling
  - National
  - Regional
  - Street level



- Policy assessment
  - Regulations
  - Cost-benefit analysis



Suite of main tools

copert 4	• Estimates emissions from on-road vehicle fleets • Used by 22 out of 28 MS for official submission of road emission inventories • Developed for the European Environment Agency • Free for use
copert AUSTRALIA	• Estimates emissions from on-road vehicles in Australia • Developed in collaboration with Queensland Govt • Official method in National Pollutant Inventory (NPI) • Commercially available
Sibyl	• Includes historic and projected stock and activity data • Delivers alternative scenarios for energy and emissions • Includes advanced technologies and mobility patterns • Commercially available

Key customers

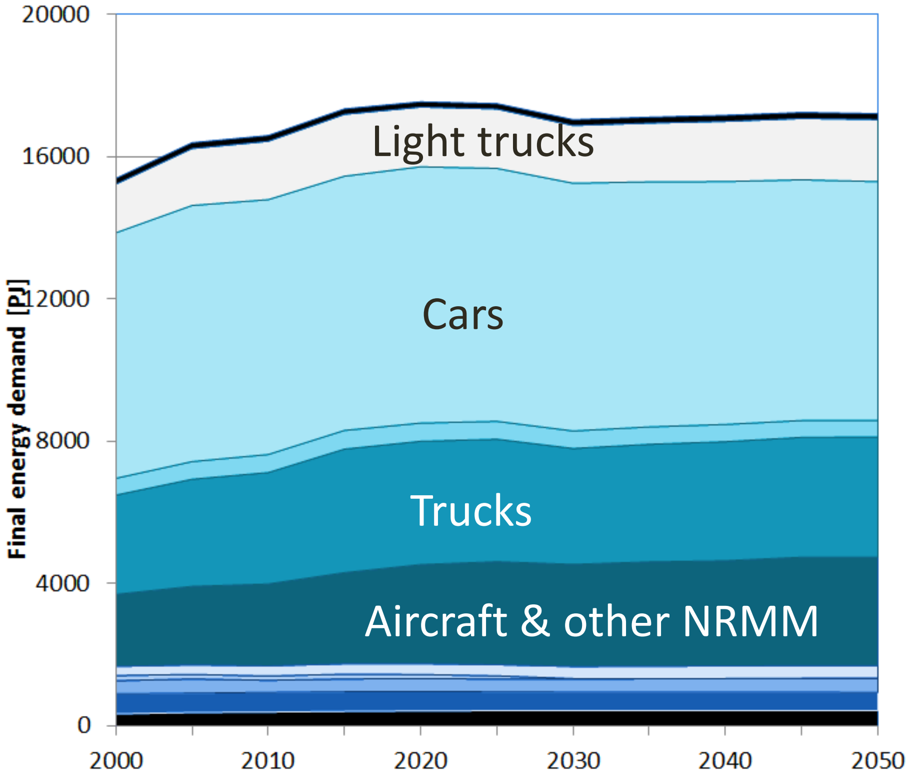
emisia

Outline

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

WHY WILL ROAD TRANSPORT EMISSIONS CONTINUE TO BE IMPORTANT?

Energy projection per mode



Baseline for EU27:

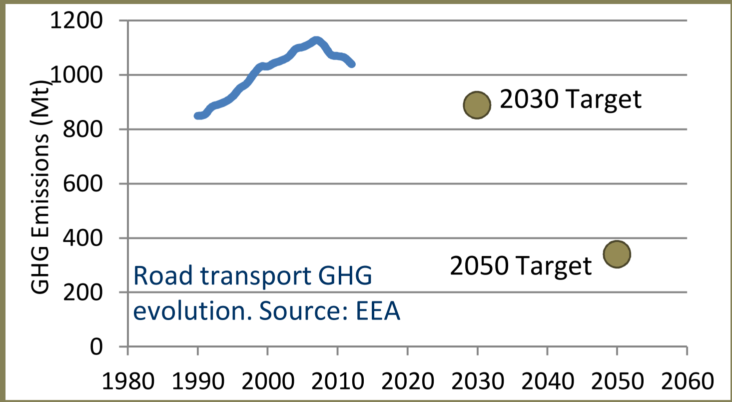
- Most important change:
  Gasoline:Diesel for cars drops from 2.0 in 2000 to 1.15 in 2030
- Non-road vehicles:
  Aircraft have biggest share in consumption – but here only LTO emissions are counted
- Mobile machines, ships, rail make up the rest

Source: Amann (ed.), 2012, Review of TSAP, IIASA

Greenhouse gases (GHGs)

- 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

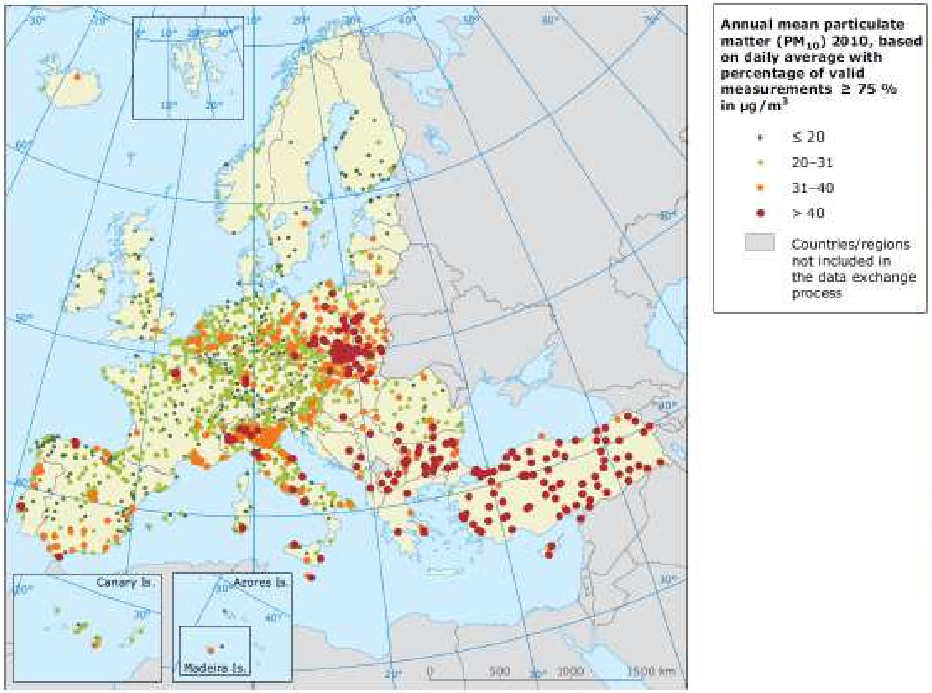
GHG emissions from transport have increased over 1990 base level



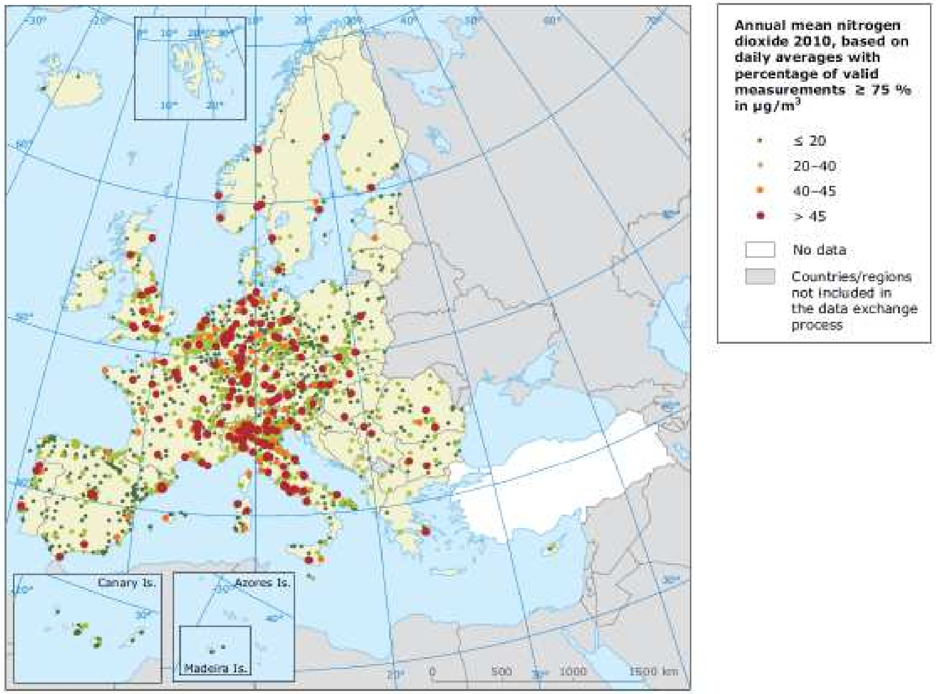
- Binding targets to reduce GHGs from road transport:
  - 95/147 gCO_2/km by PCs/Vans by 2020
  - 10 % of total energy consumption on renewables by 2020
  - Tyre pressure monitors, gear-shift indicators
  - Green procurement
  - …

Annual Mean Air Quality in the EU (PM and NO2)

PM_{10} Emission ● > 40 µg/m³



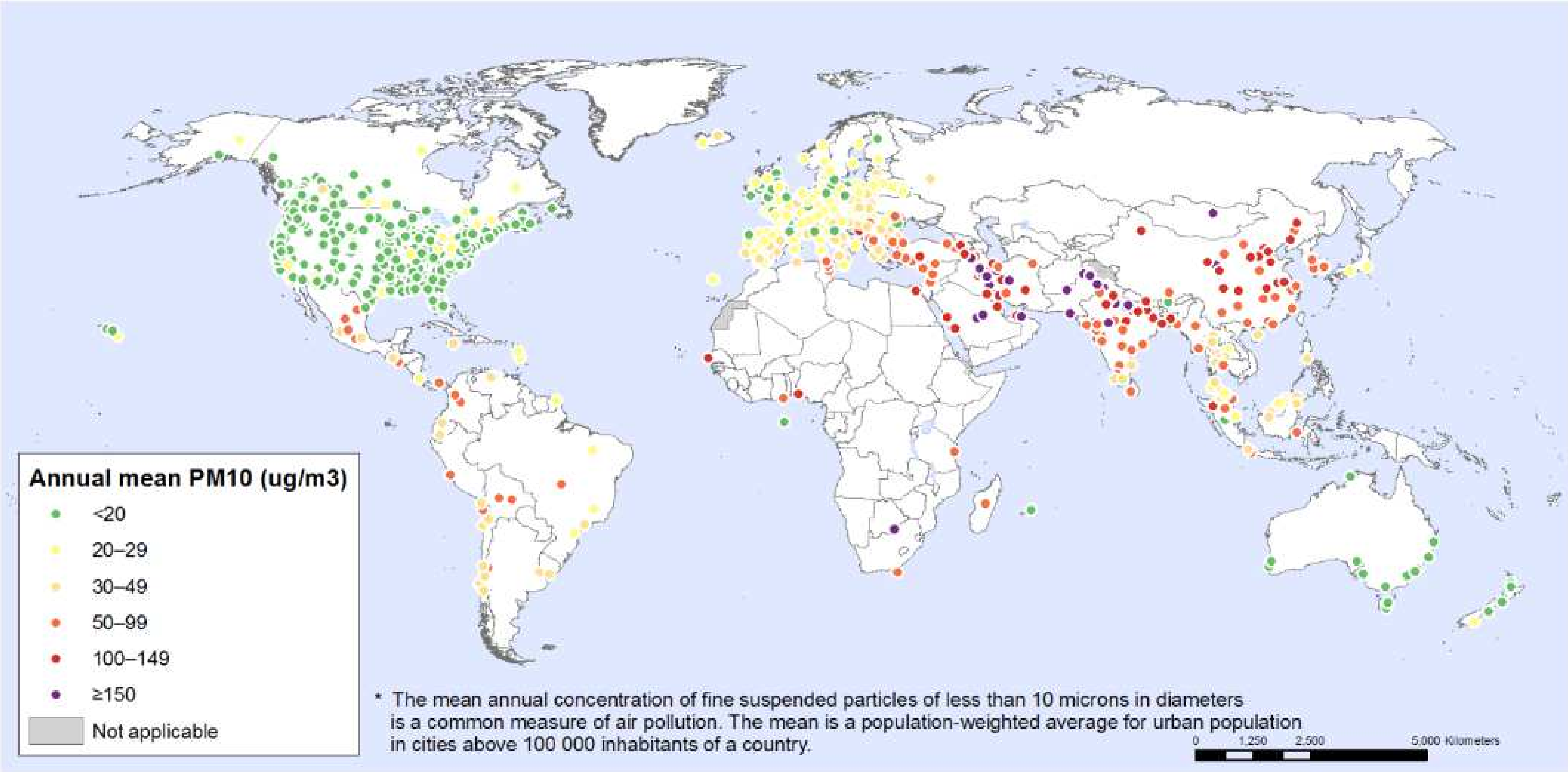
NO_2 Emission ● > 45 µg/m³



Source: European Environmental Agency (EEA) 2012

Some European areas show high Particulate Matter (PM) + NO_2 emission

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

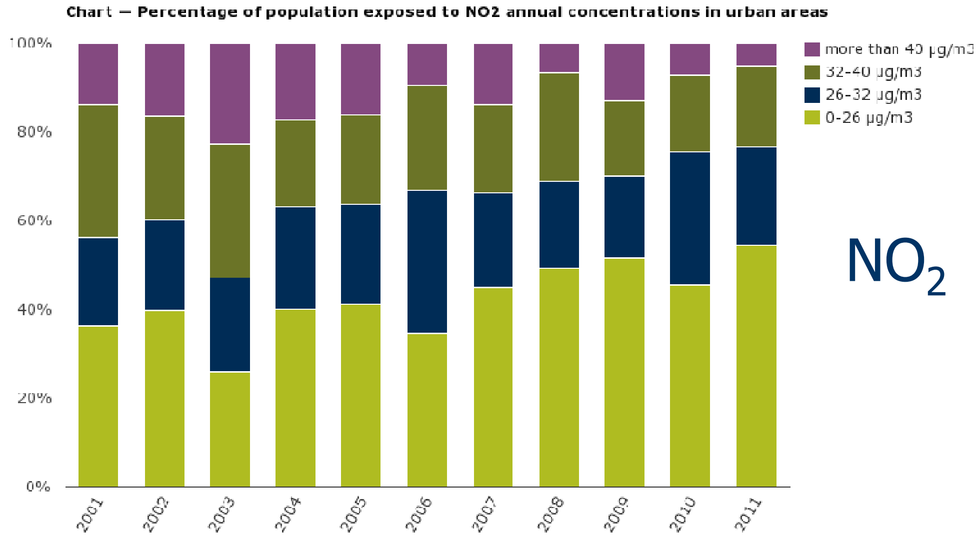


WHO Air Quality Guideline: Annual mean PM10 = 20 μg/m^3

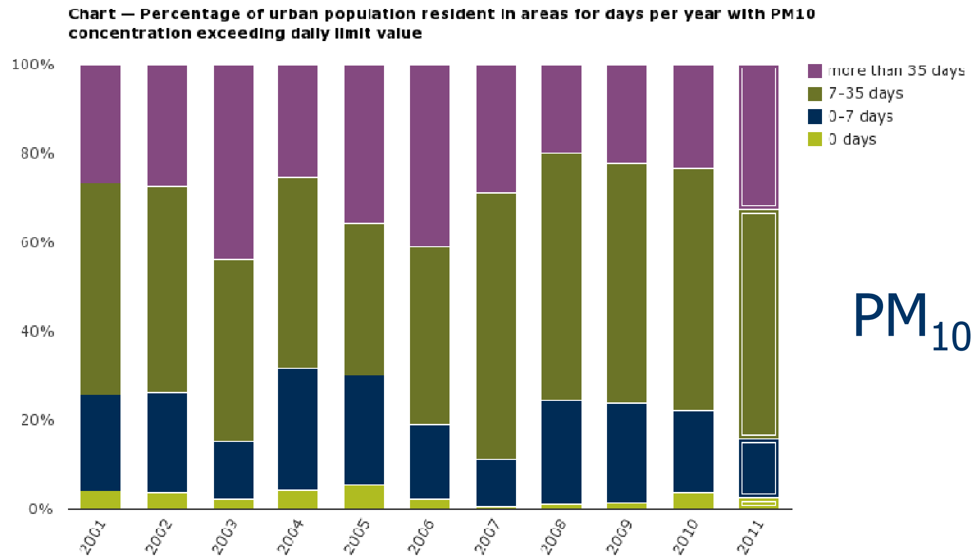
Source: WHO, 2012

Population exposed to high pollution

A significant fraction of the population continues to live in areas where acceptable AQ levels are not respected



NO_2

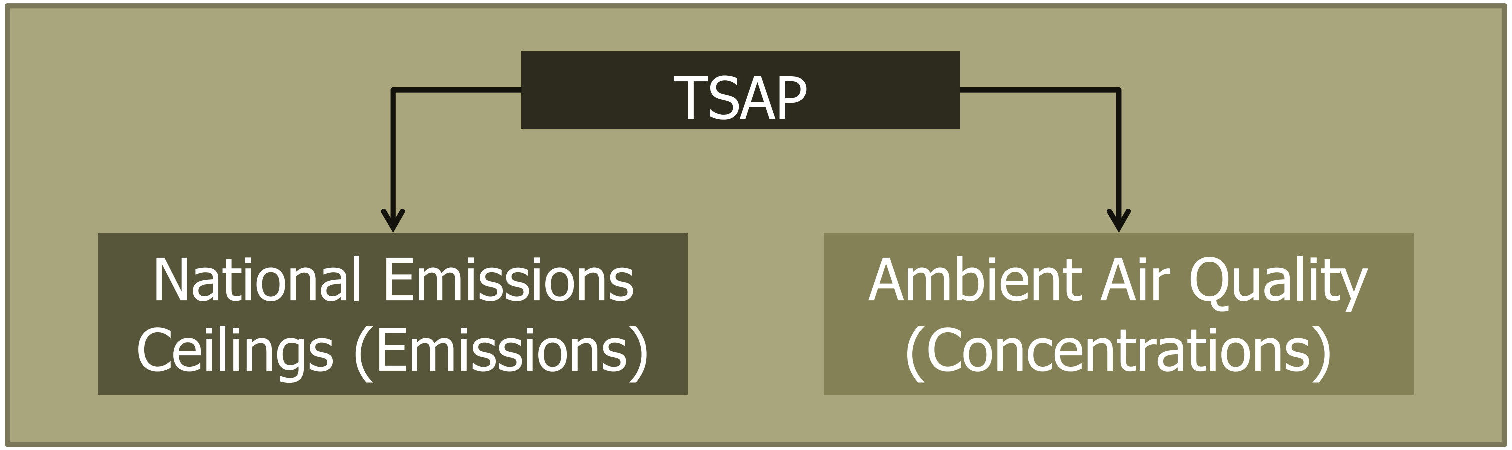


PM_{10}

Fraction of population above AQ limits

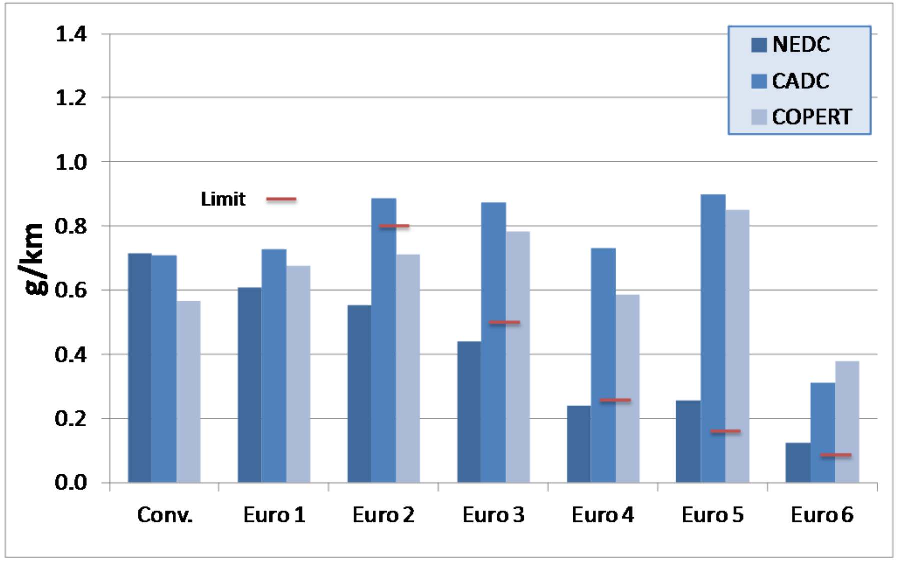
Source: European Environment Agency

Air pollutants



- The new Thematic Strategy on Air Pollution – TSAP - has the following expectations for road transport:
  - Implementation of efficiency improvements, decarbonisation, modal shifts, …
  - Implementation of real driving emissions control (Euro 6/VI PEMS and OBD impacts)
  - Additional measures (PTW emissions, NO_2 control, retrofits, …)

Emission levels - Diesel PC and HDV NO_x



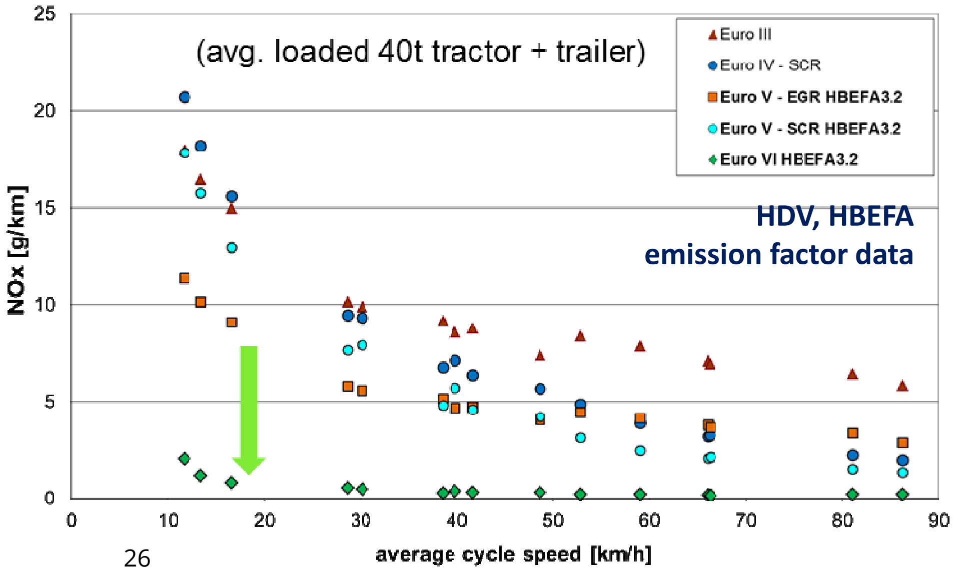
Significant exceedances of emission limits

Euro 3: 1.6×

Euro 4: 2.3×

Euro 5: 4.7×

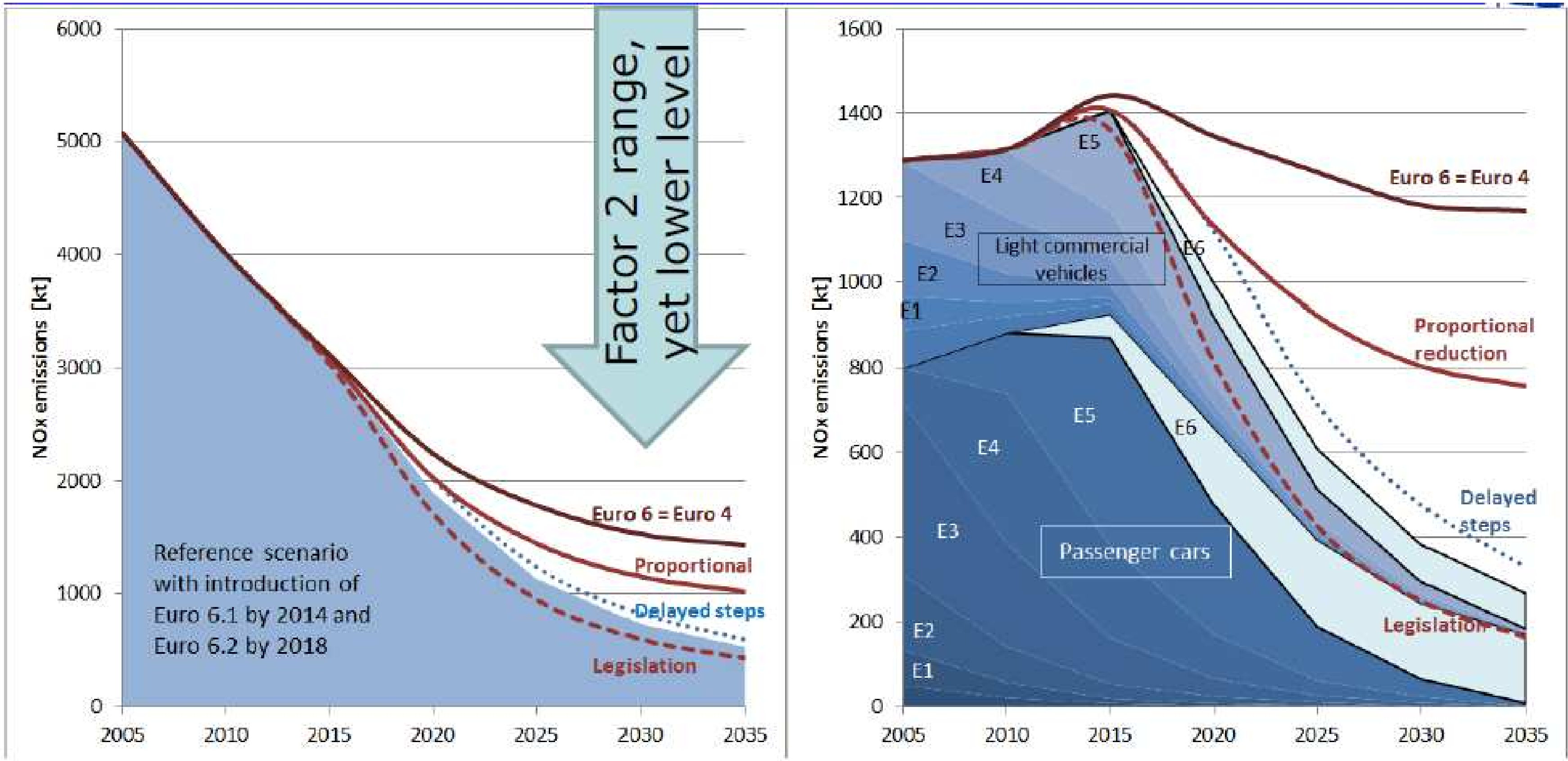
Euro 6b: 4.7× (estimate)



Good progress in HDV real world NOx due to improved test method (WHTC + PEMS in EU VI)

Source: ERMES consortium

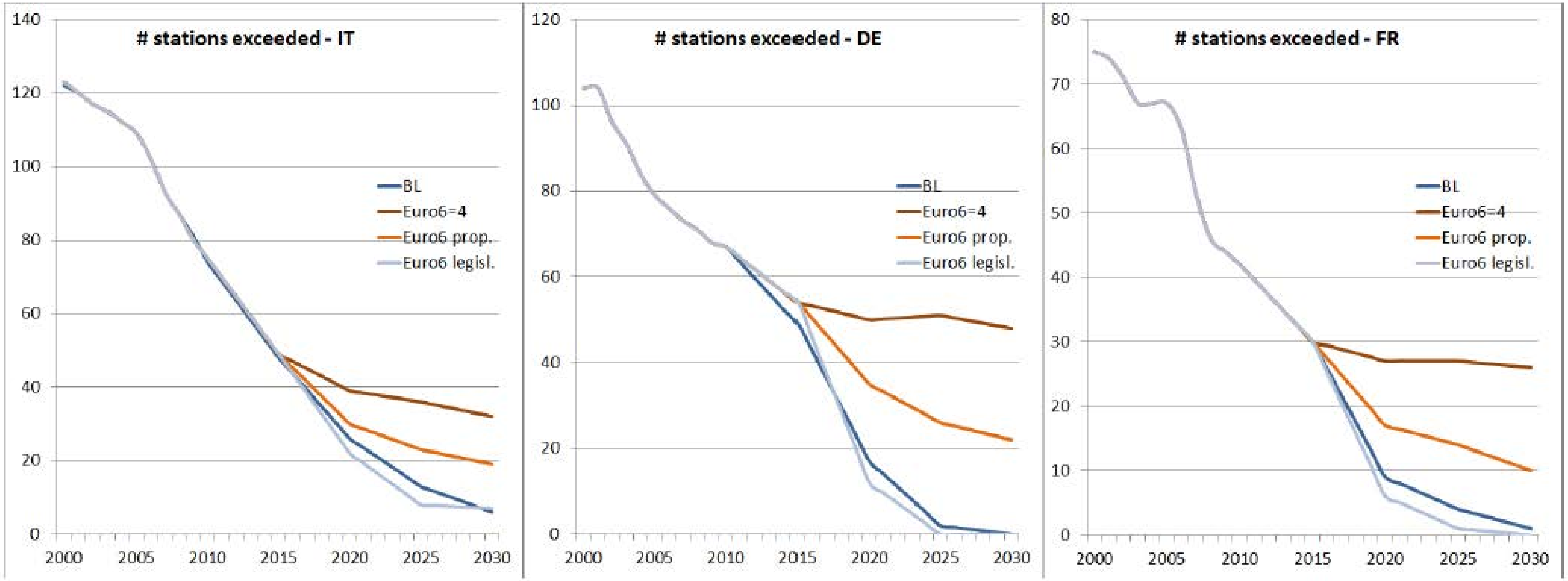
NO_x projections



"**Legislation**": Euro 6 = 80 mg/km from 2015. "**Delayed steps**": As Reference, but Euro 6.2 only from 2020 onwards. "**Proportional reduction**": Euro 6 = 380 mg/km from 2015.
"**Euro 6 = Euro 4**": Euro 6 = 730 mg/km from 2015

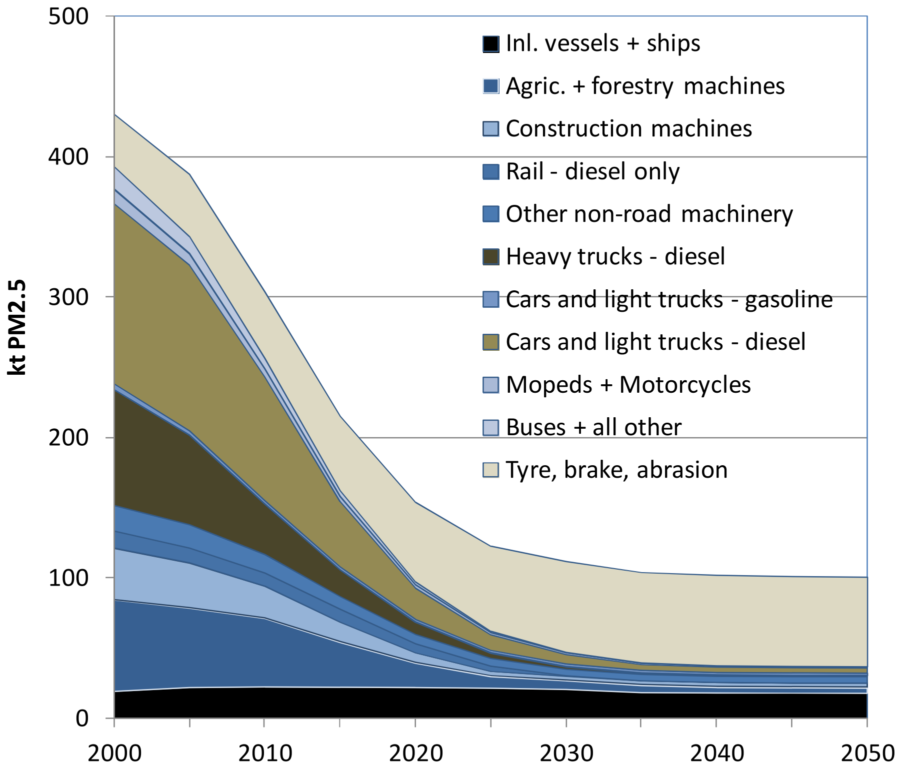
Source: Kleefeld and Ntziachristos (2012) TSAP Review

Impact of NOx evolution on exceedances



Euro 6 Diesel PC effectiveness will largely determine the evolution of air-quality in Europe

$PM_{2.5}$ projections



Baseline:

- Reductions until 2030 vs. 2005
  >90%: diesel HDV&LDV, locos, NRMM
  ~70% other mobile machines

- **Road abrasion**, tyre, clutch and brake wear increase with traffic volume, >80% of emissions from road vehicles in 2030

Source: Kleefeld and Ntziachristos (2012) TSAP Review

WHAT HAS EUROPEAN POLICY DONE SO FAR?

Regulations

Year	Regulation	Content
		Passenger Cars & Light Commercial Vehicles
2007	715/2007	Introduction of Euro 5 and Euro 6
	2007/46	New regulation on vehicle type approvals
2008	692/2008	Euro 5 & 6 implementation procedures and modalities
2009	79/2009	Extension of type approval for H_2 vehicles
	443/2009	CO_2 specific targets from passenger cars
	661/2009	Mandatory implementation of GSIs and TPMs on PCs
2010	406/2010	Certificate of conformity of H_2 vehicles
2011	510/2011	CO_2 specific targets from vans
	566/2011	IUPR and In-Service conformity testing for Euro 6
	725/2011	Certification of eco-innovations
2012	65/2012	Implementation of GSIs
	459/2012	PN number for GDIs and Euro 6 OBD limits
2013	195/2013	Introduction of eco-innovations as part of the type approvals
		Heavy Duty Vehicles
2009	595/2009	Delegated regulation on introduction of Euro VI
2011	582/2011	Implementing regulation on Euro VI limits and OBD
2012	64/2012	Derogations for existing models (OBD systems)
		Power two/three/four Wheelers
2013	168/2013	Introduction of Euro 4 and Euro 5

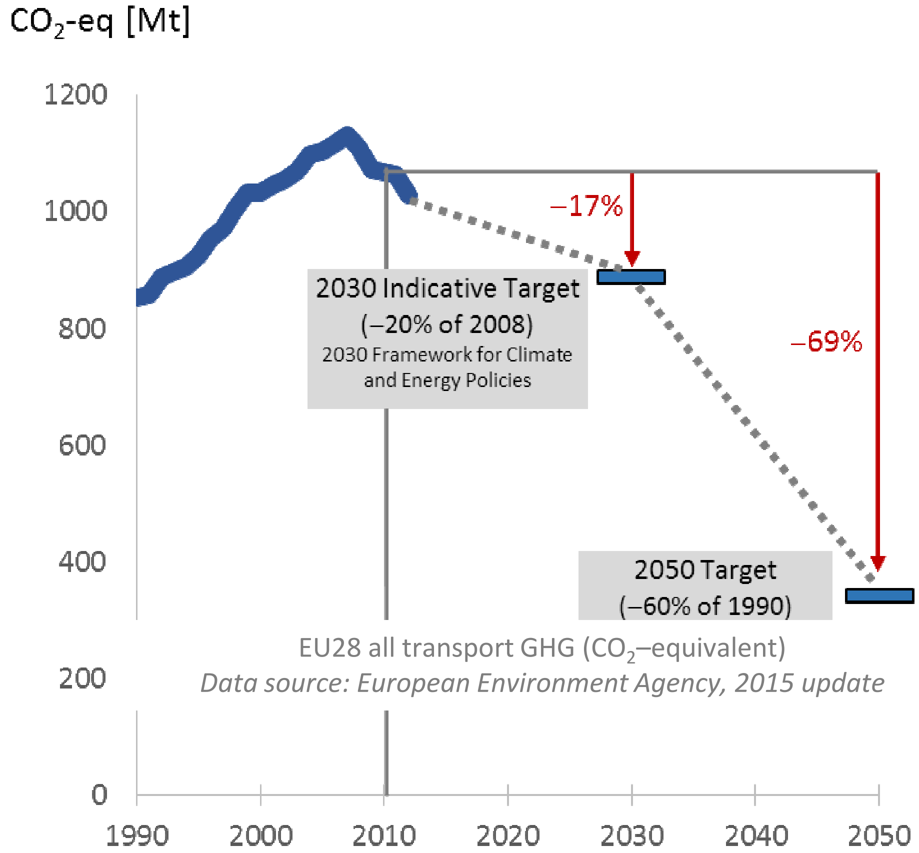
Regulations under preparation

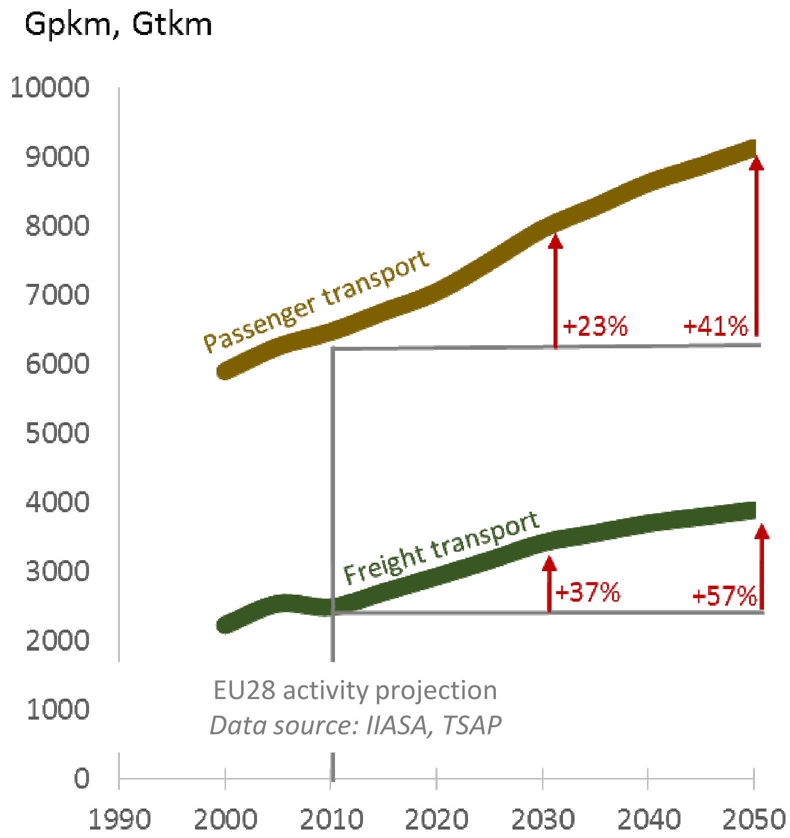
- CO_2 regulations
  - New cycle (WLTP) introduction and WLTP/NEDC correlation also
  - New CO_2 emissions targets for PCs and Vans
  - CO_2 labeling for HDVs
- Regulated air pollutants
  - Real driving emission control for PCs (RDE)
  - Euro 6 and VI OBD (incl. PM/PN monitoring)
  - GDI PN PMP
  - Euro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

CO_2 REGULATIONS

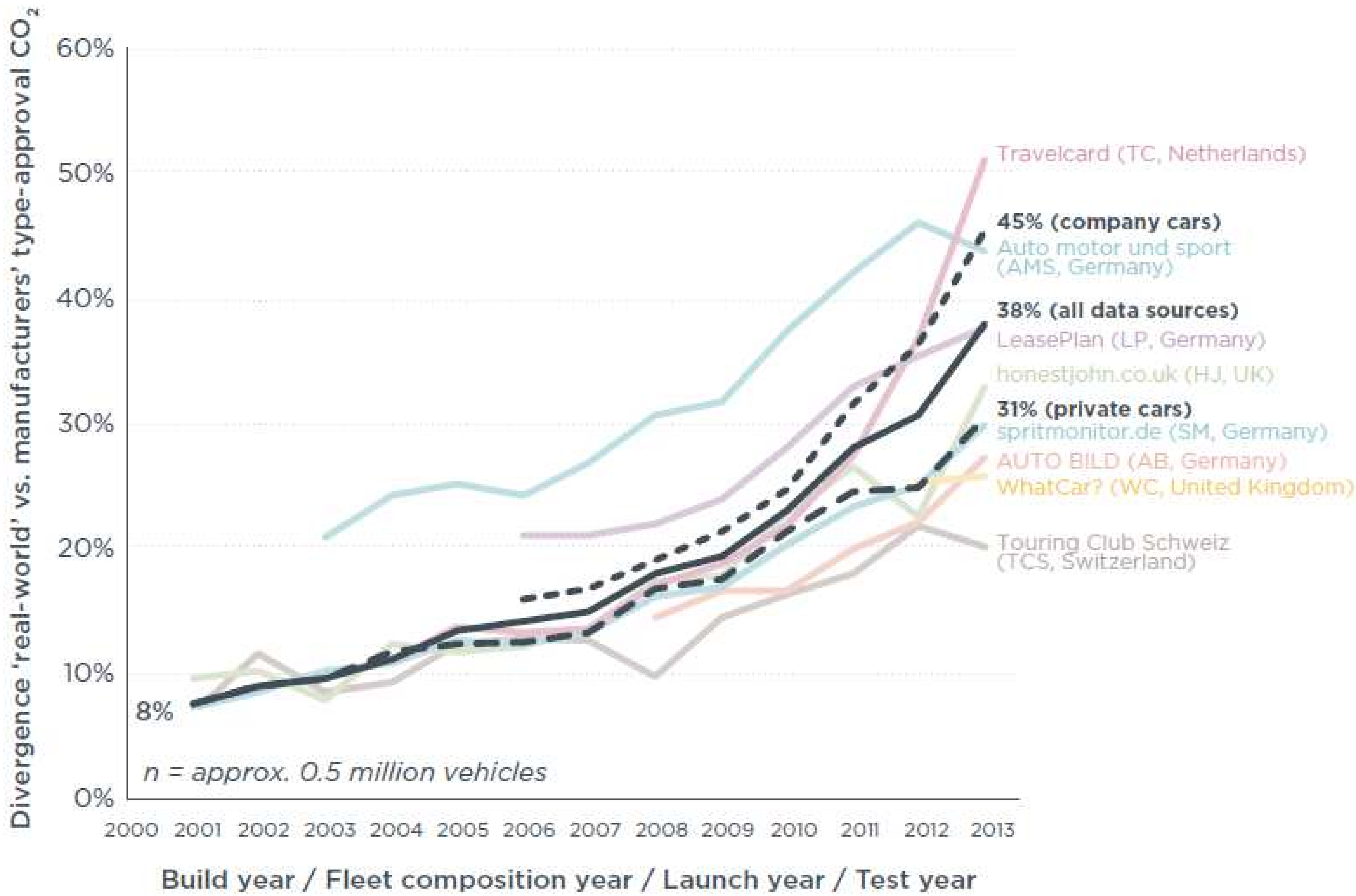
European objectives for Transport

Demanding CO_2 objectives despite projected strong activity growth





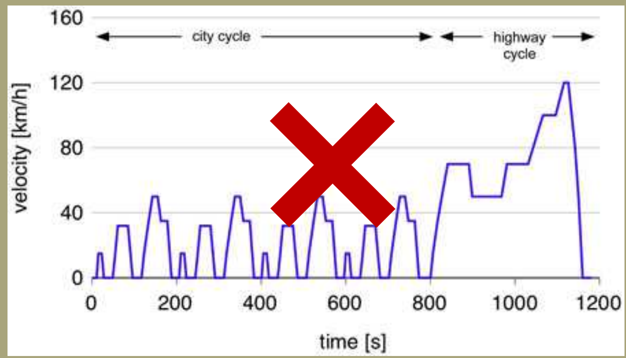
Divergence of real-world CO2 emissions from manufacturers' type-approval CO2 emissions

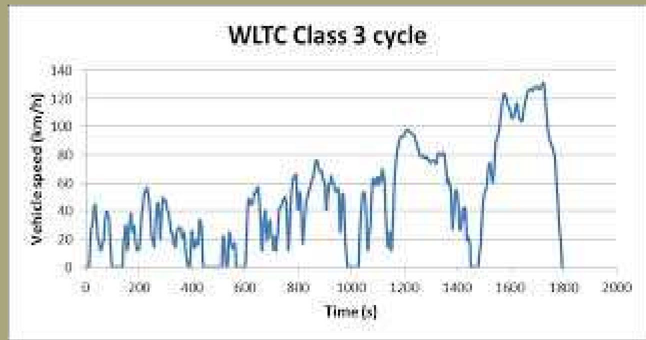


Source: ICCT. 2014

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

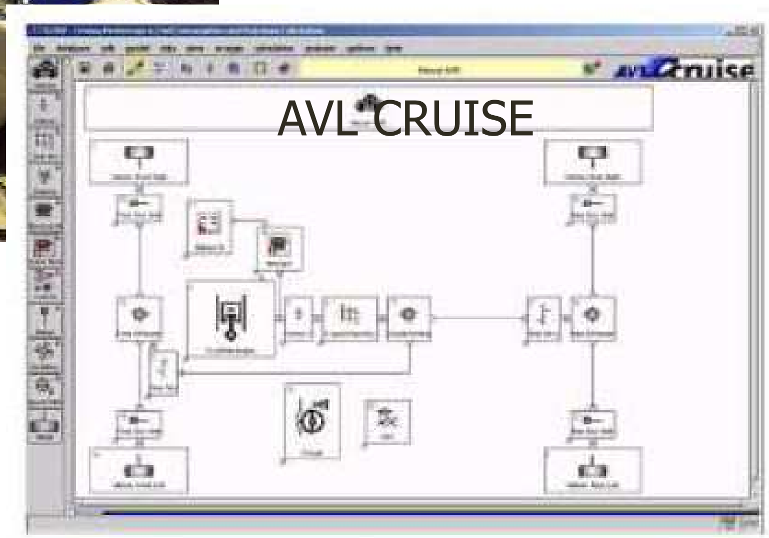


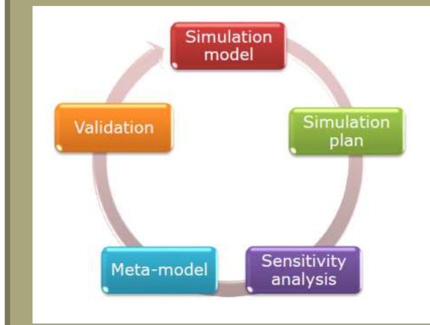


CO_2 WLTP-NEDC translation procedure

Chassis dyno tests
(~30 vehs)

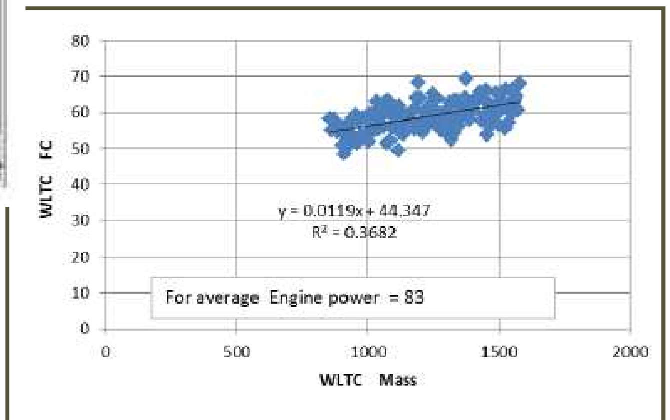
Vehicle level Technology
Simulations (~15000 sims)



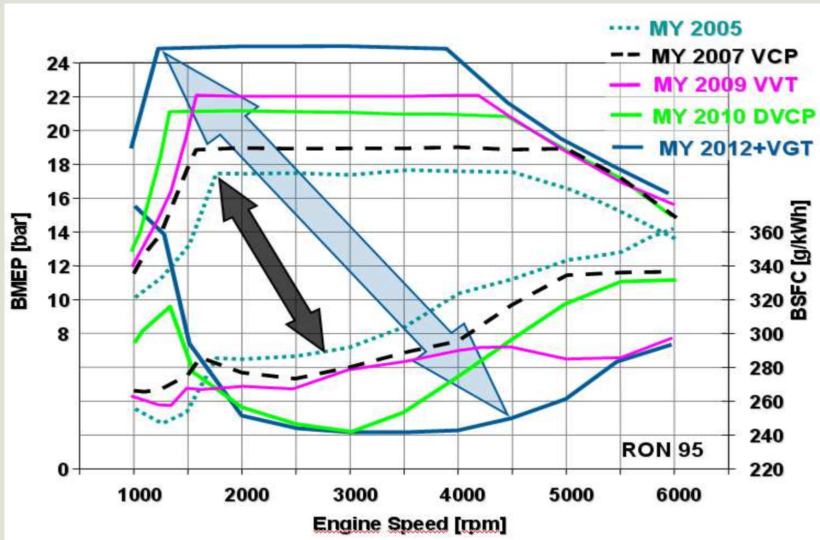
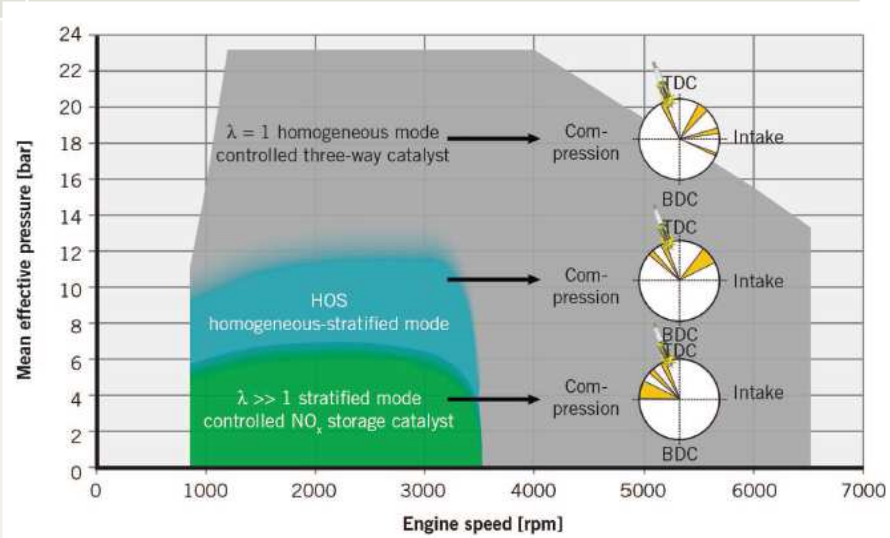


Overall approach

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



Technologies examined in WLTP-NEDC translation

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

Technologies examined in WLTP-NEDC translation

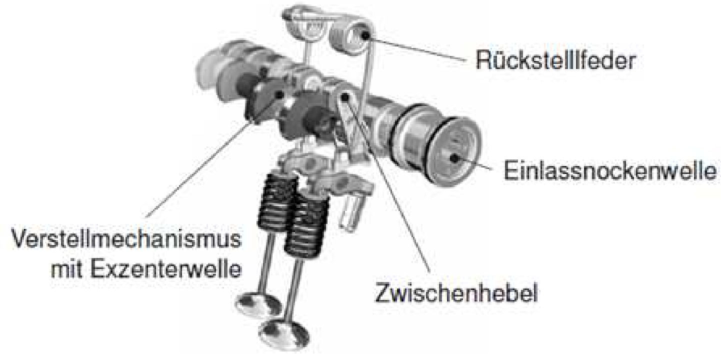
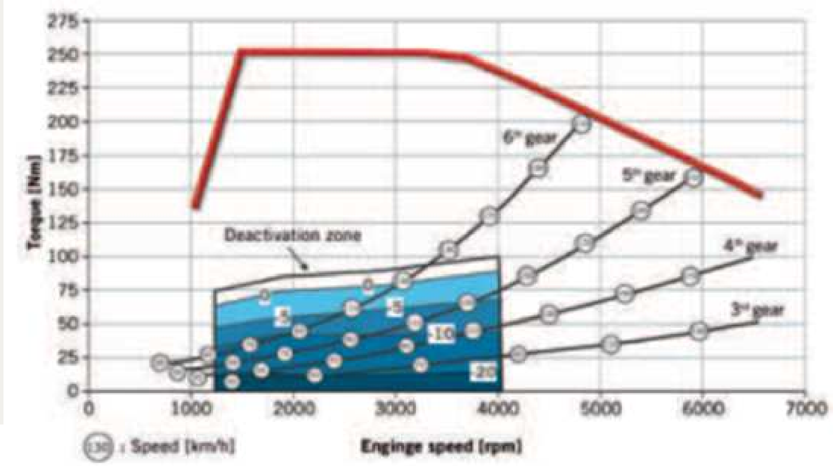
<table>
<tr><th>Technology</th><th></th></tr>
<tr><td>VVT
(e.g. Vanos, Valvetronic)</td><td>

Abb. 12-18: Vollvariable kontinuierliche Ventilsteuerung BMW Valvetronic [Bildquelle: BMW Group]</td></tr>
<tr><td>Cylinder deactivation</td><td>
</td></tr>
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Source: MTZ 03/2012 vol. 73

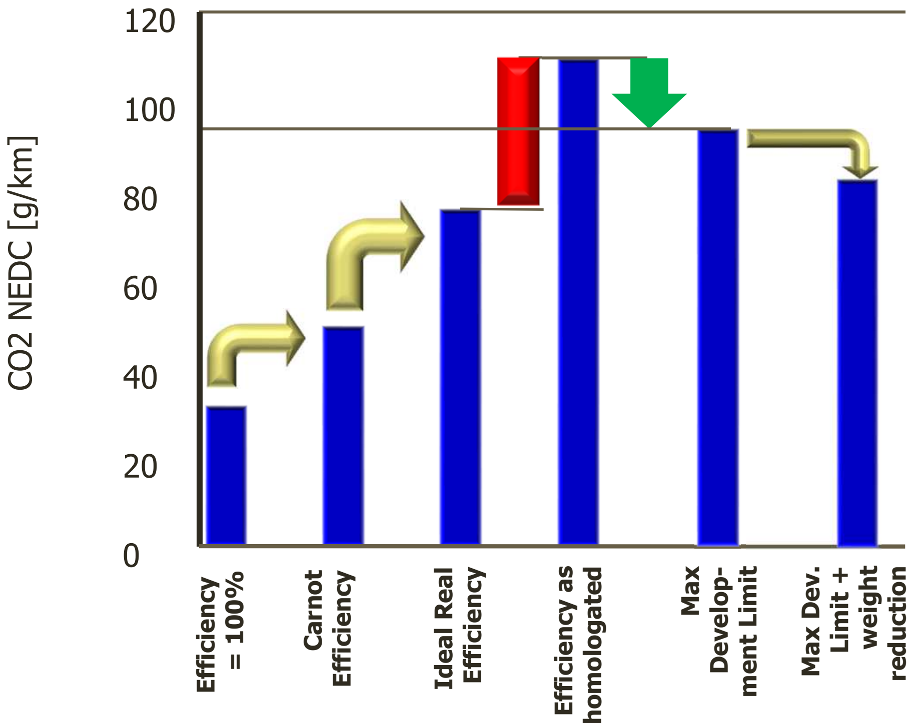
Technologies examined in WLTP-NEDC translation

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

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

From the Ideal to Reality

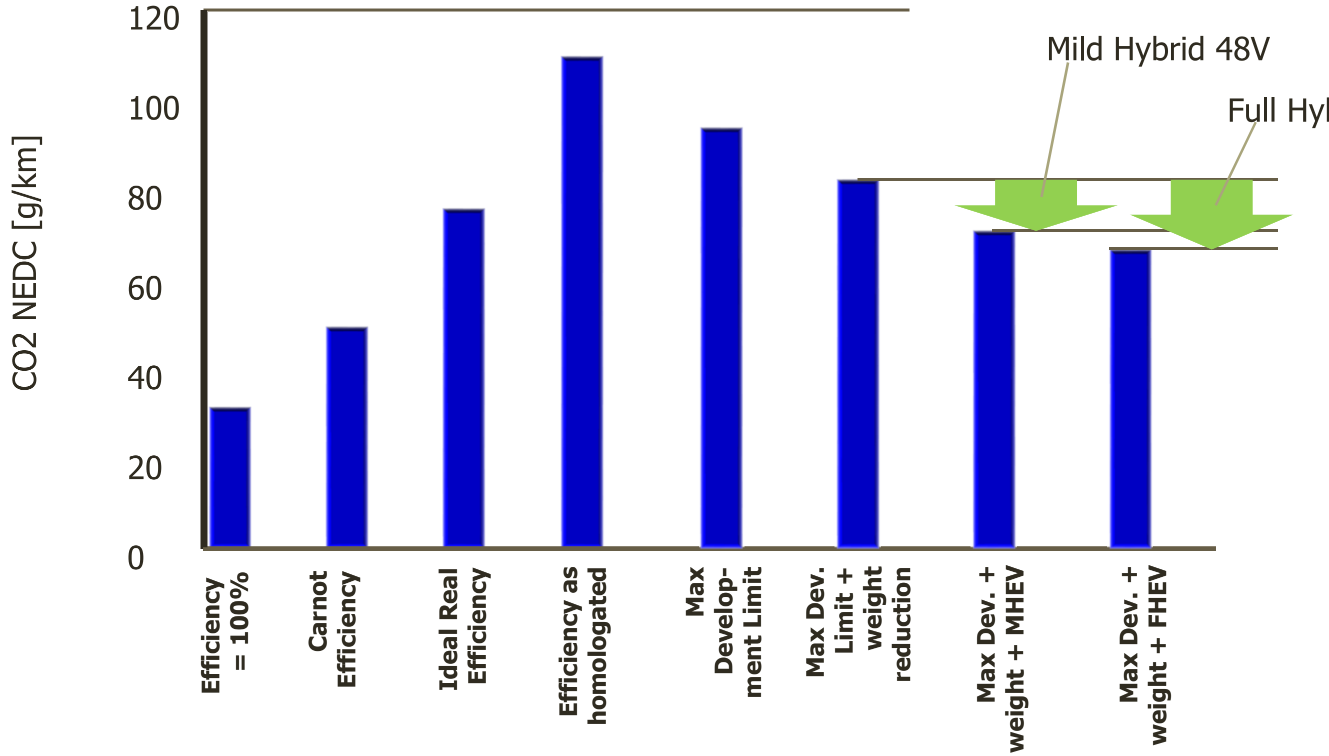


Further technology deployment to achieve 50% of the gap vs. the ideal real engine :

93-95 g/km can be reached without further vehicle actions like weight reduction / aero / rolling resistance

Realistic weight reduction can account for about 10% CO2 reduction

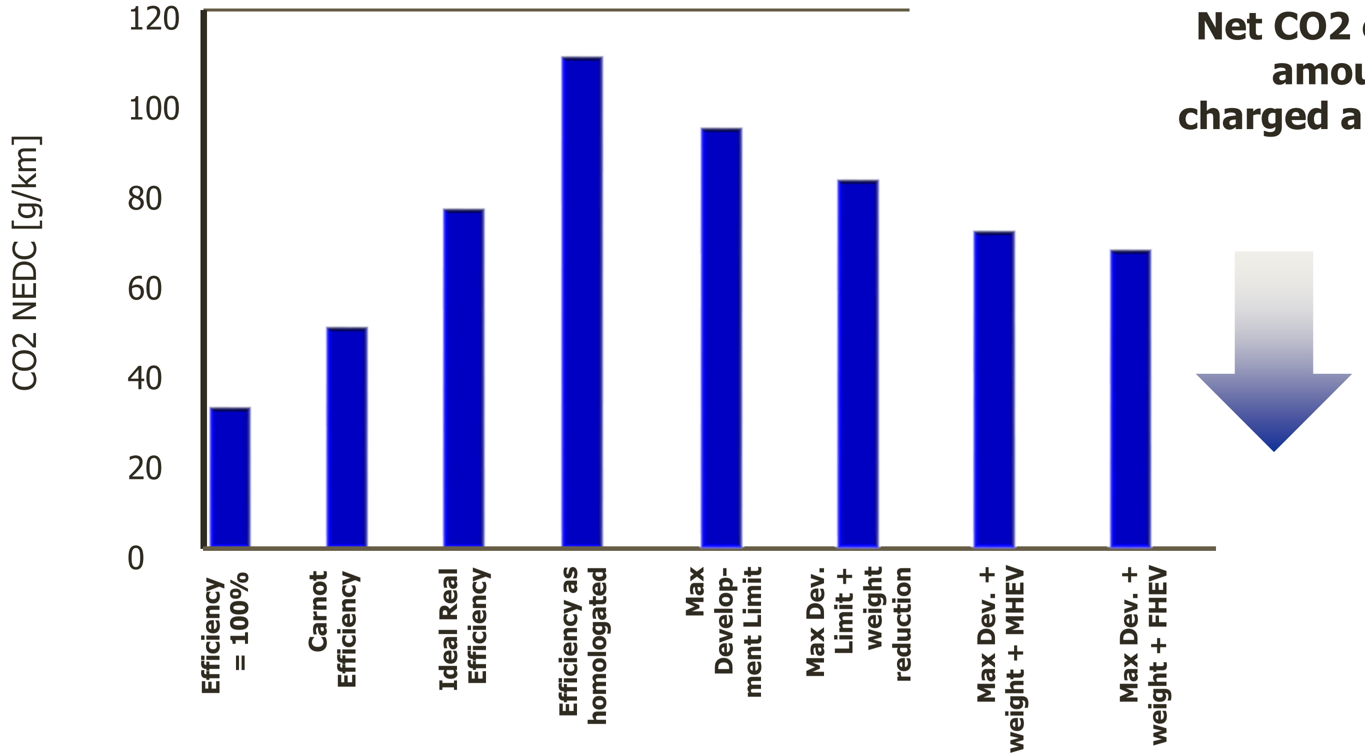
A Way Forward for the IC Engine



Introduce Hybrid Technology (48-400V)

- **Recuperation**
- **FE optimized operational strategy**
- **Electric driving**
- **Free shift schedule (NEDC)**

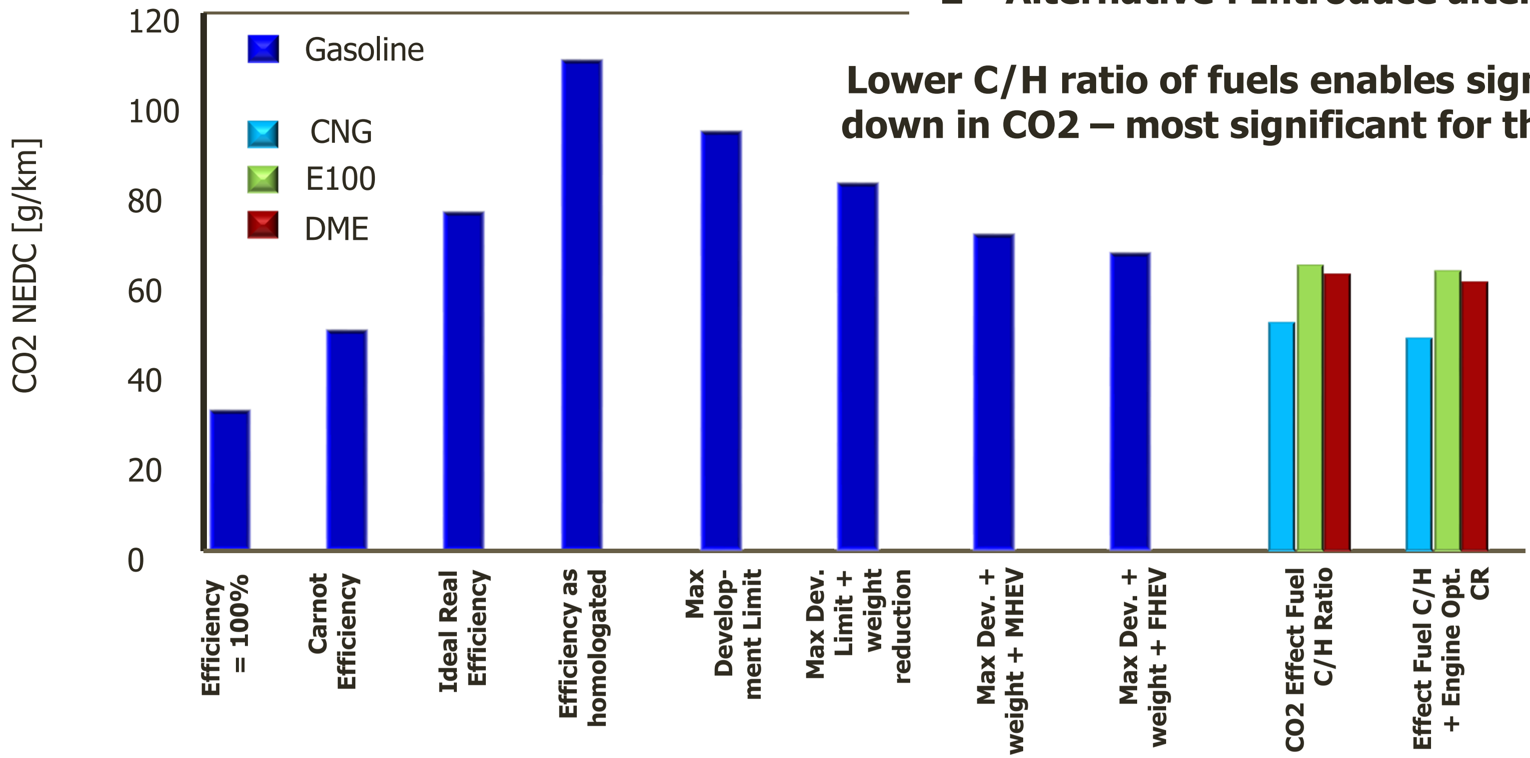
A Way Forward into a sustainable future



1st Alternative : Extend FHEV to PHEV

Net CO2 emission depends on amount of electric energy charged and power generation mix

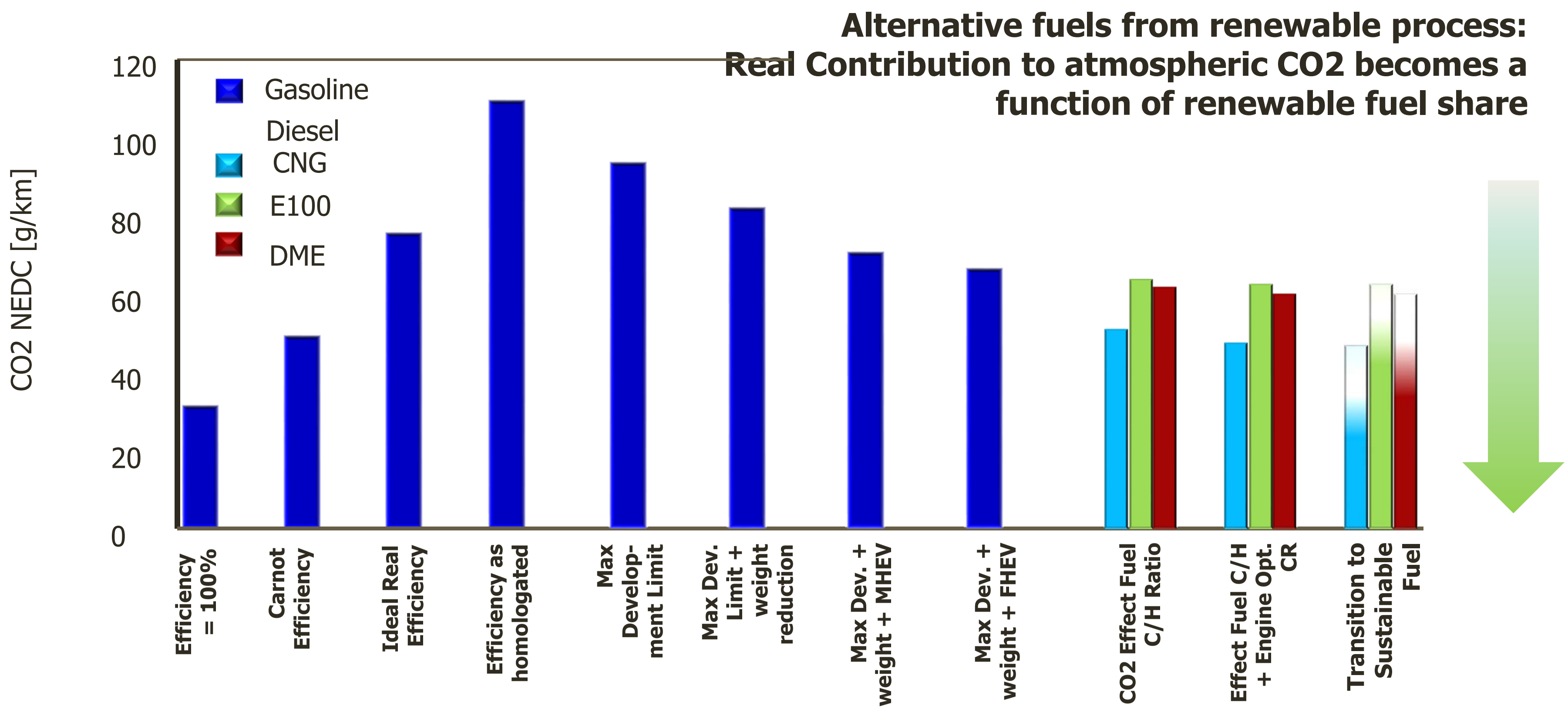
A Way Forward for the IC Engine



2nd Alternative : Introduce alternative fuels

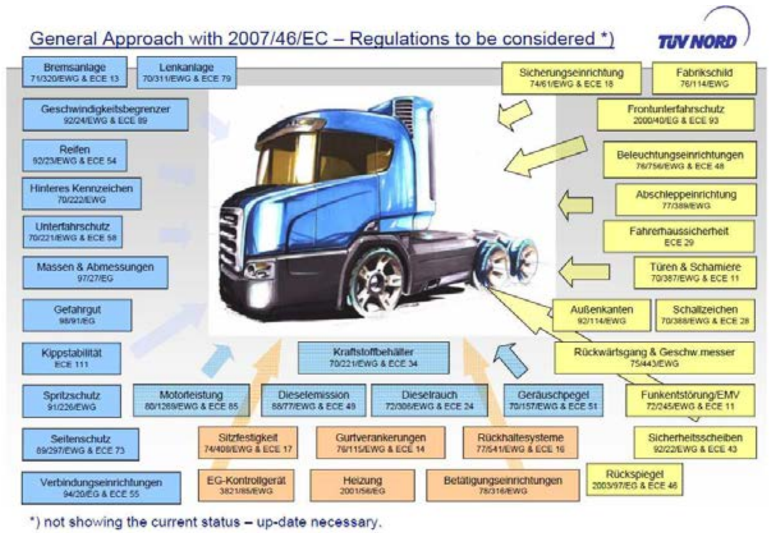
Lower C/H ratio of fuels enables significant step down in CO2 – most significant for the SI engine using CNG

A Way Forward for the IC Engine



CO_2 from HDVs

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



- 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

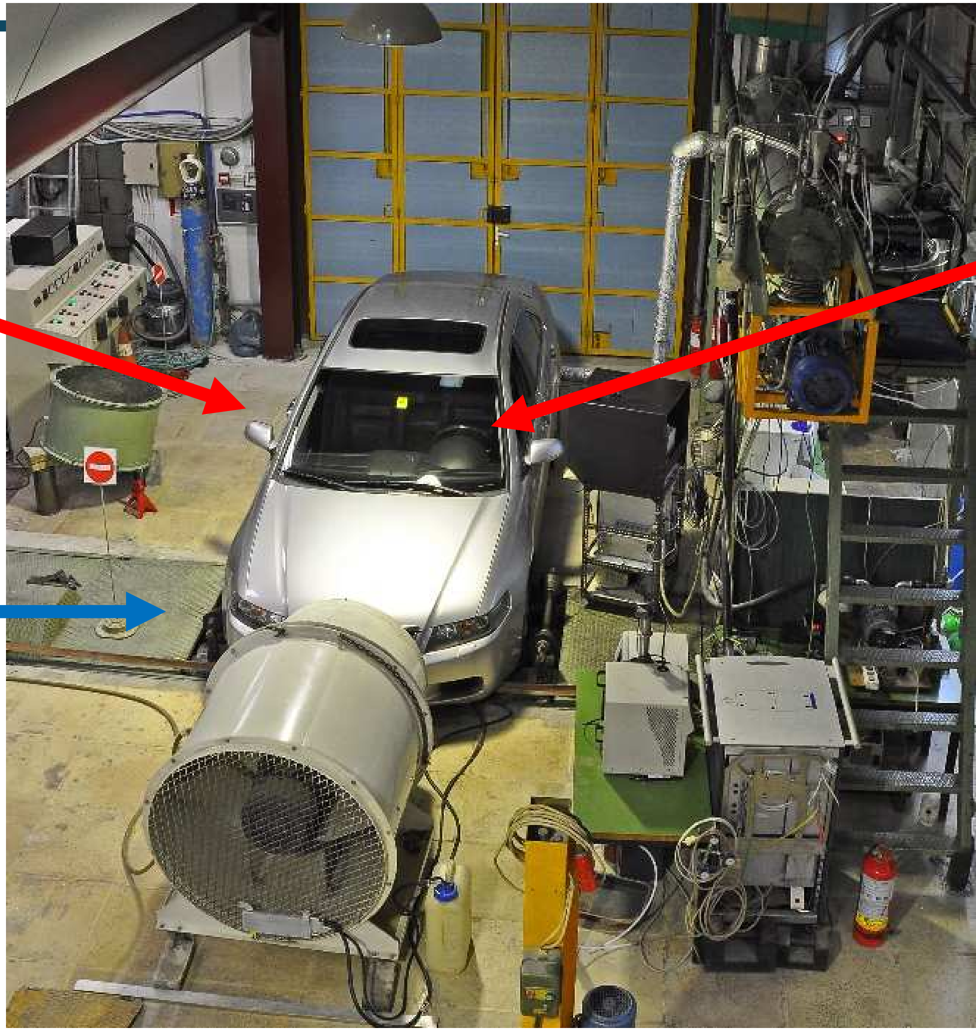
AIR POLLUTANTS REGULATIONS

DIESEL EMISSION CONTROL TECHNOLOGY

What is now the ‘new’ problem?

Non powered axle is stationary

Rollers used to simulate actual road load



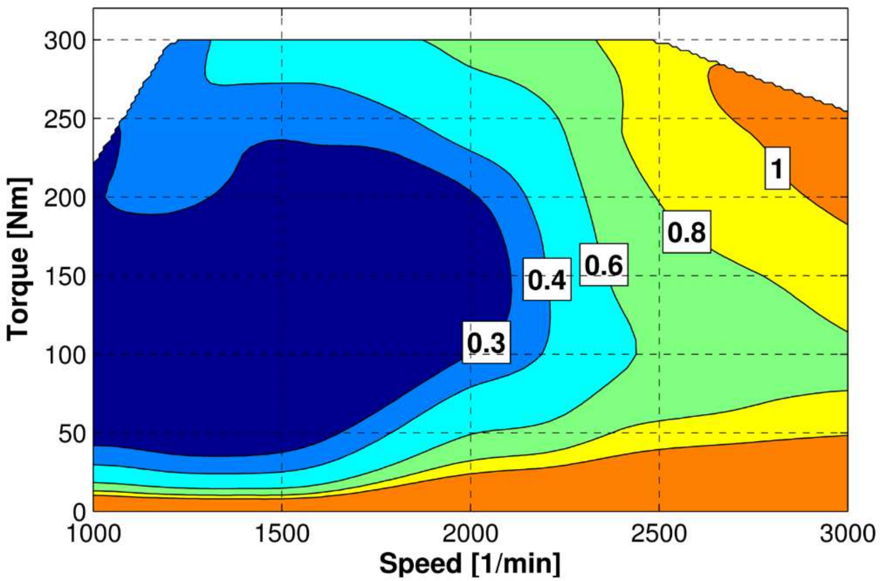
No steering

1. Temperature is set to up to 22-28^{o}C
2. Vehicle is pre-conditioned with given profiles and soaked to start with a cold-start

- The vehicle has many ‘hints’ to realise it is being tested

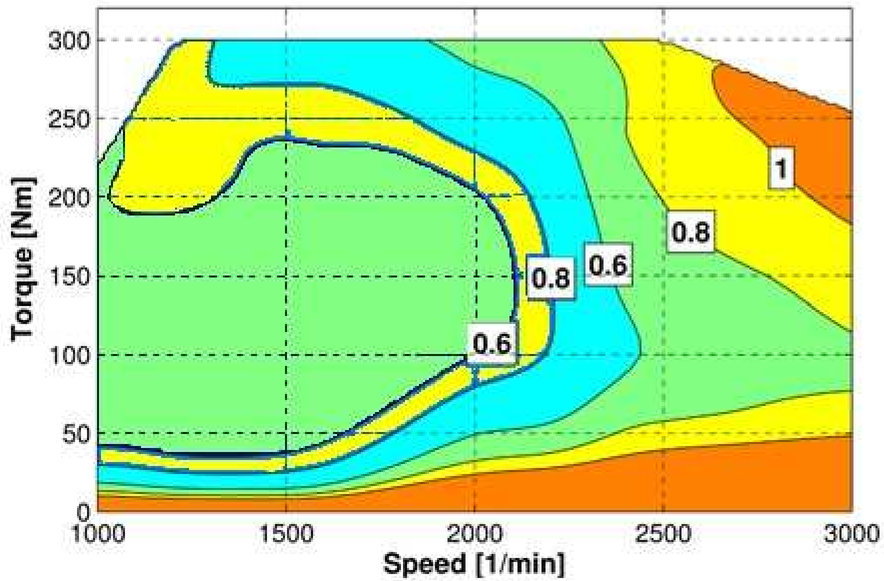
If the car recognizes it is being tested…

Regulated – In the lab



Typical NOx engine map [Regulated]
Source: Nuesch et al., Energies 2014, 7(5), 3148-3178

Defeat- On the road

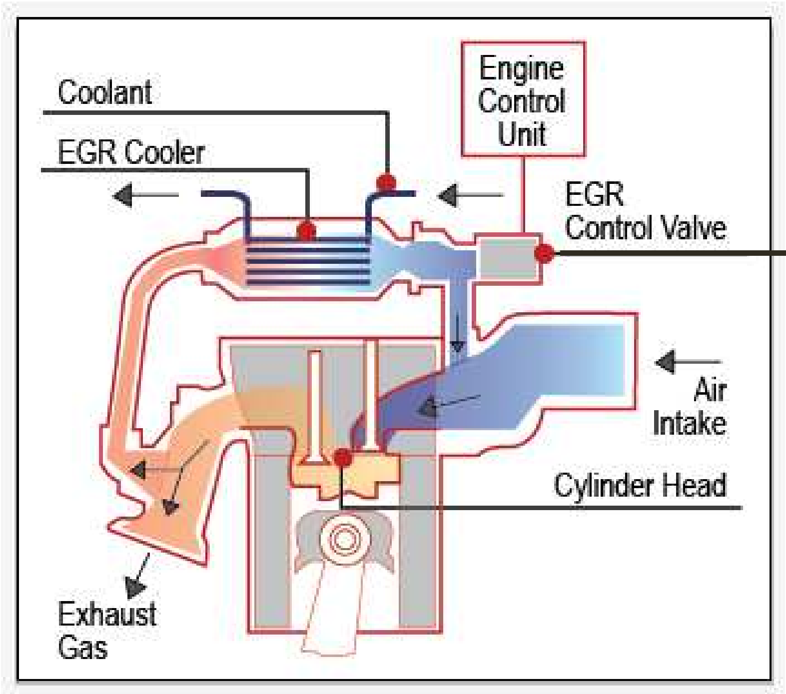


Assumed NOx engine map

Some history on diesel vehicle technologies

Emission Standard	Year Intro	Engine measures	Exhaust aftertreatment
Euro 1	1992	Combustion chamber and intake system improvements	None
Euro 2	1996	Direct Injection, fuel pressure improvement	Oxidation catalyst
Euro 3	2000	Exhaust Gas Recirculation, Common Rail Injection	Pre-catalyst and main catalyst First diesel particle filters
Euro 4	2005	Multiple injections, increase of injection pressure	Pre-catalyst and main catalyst, more extensive use of DPFs

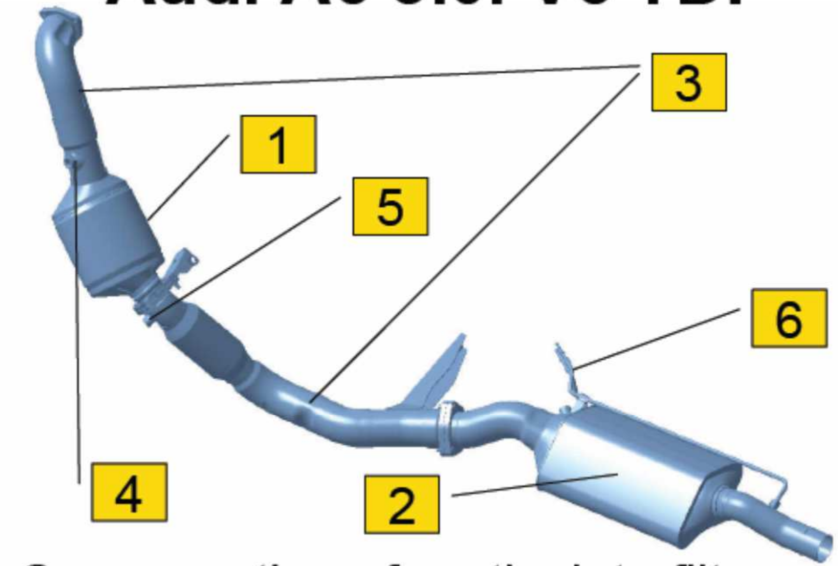
Exhaust gas recirculation used since Euro 4



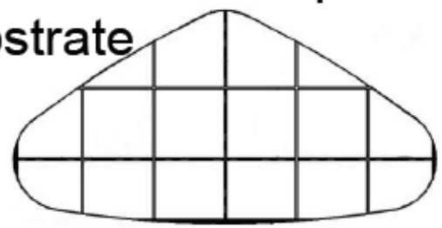
EGR decreases combustion temperature and hence reduces NOx

Typical Euro 5 diesel emission control

Audi A6 3.0l V6 TDI



Cross-section of particulate filter substrate



Optimized segmentation

Engine data

171 kW / 450 Nm

System components:

1.) Close-coupled DOC [1.6l]

2.) Particulate filter in underbody [4.0l]

3.) Air gap-insulated pipes between DOC and DPF

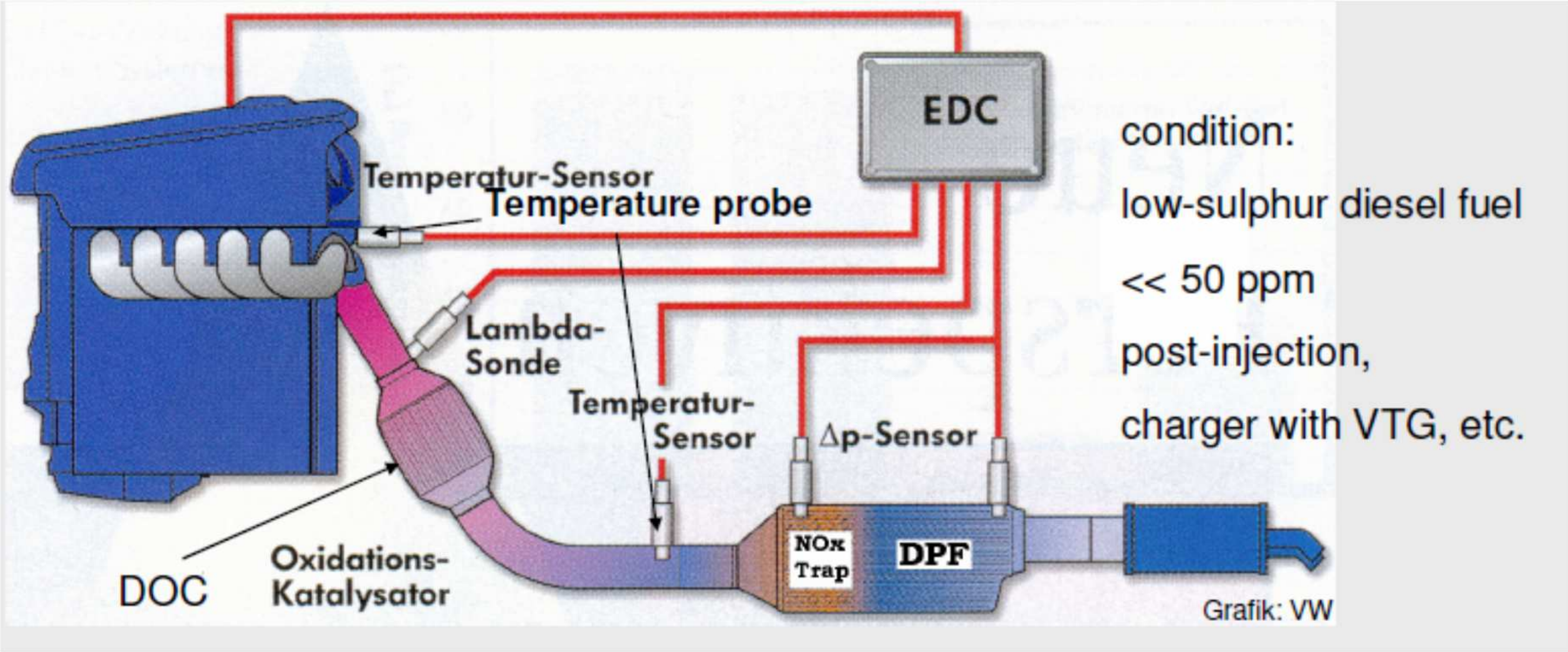
Sensors:

4.) λ probe upstream of oxidation cat.

5.) Temperature sensor downstream of oxidation cat. / upstream of DPF

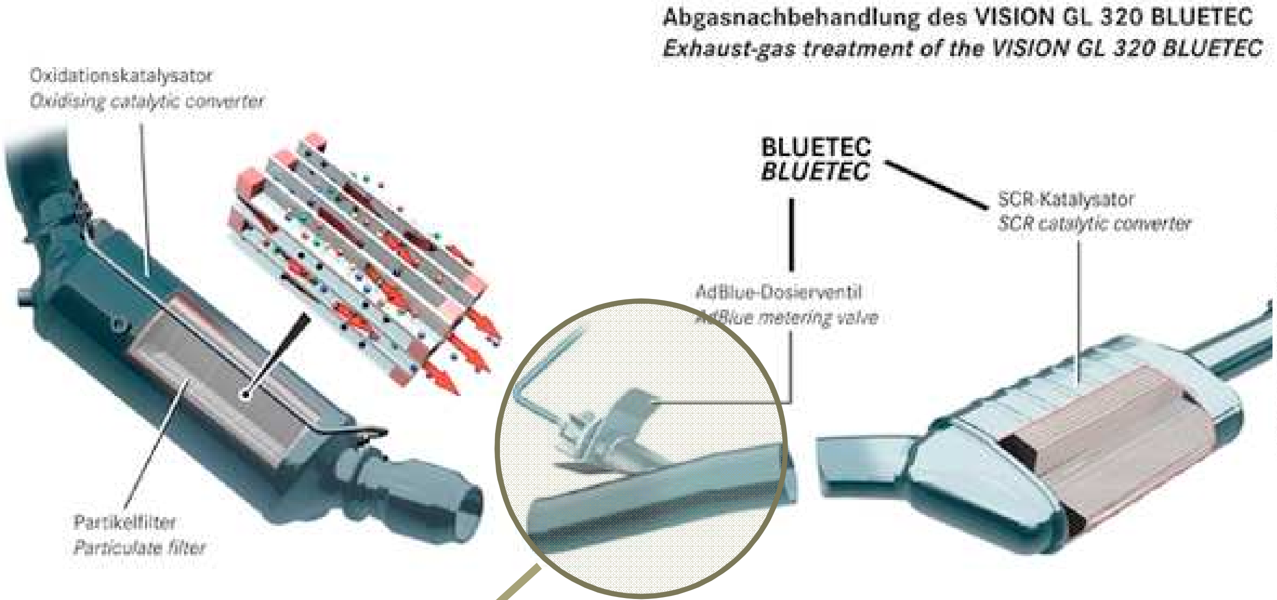
6.) Differential pressure lines

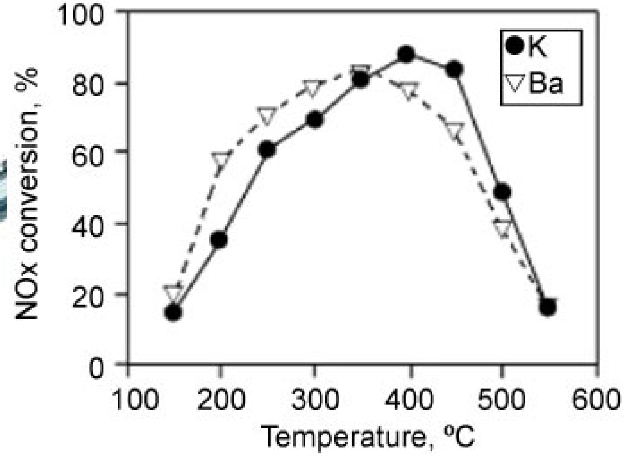
Typical Euro 6 diesel emission control



→ **Close-coupled DOC for fast reaction after cold-start (PM, HC)**
→ **Lean NOx Trap upstream of DPF to reduce NOx emissions (50-70%)**
→ **DPF: Diesel Particle Filter to reduce PM (>95%)**

Latest NO_x control for diesel vehicles



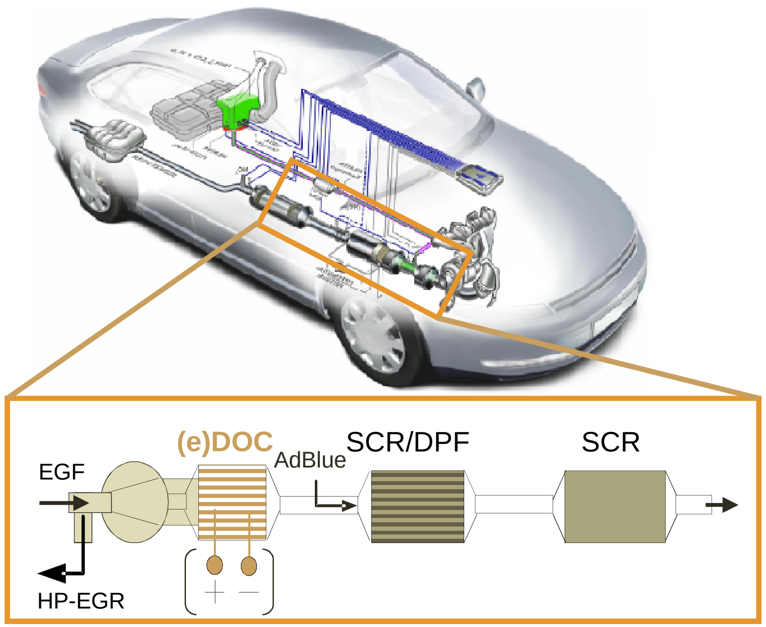


$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$

$$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$$

Sources: Mercedes-Benz, Johnson-Matthey

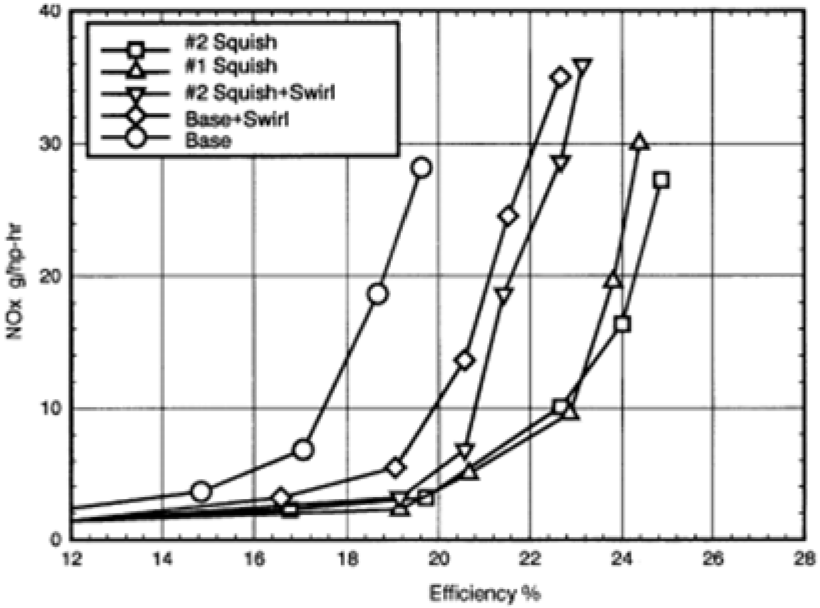
Possible Euro 6c diesel emission control



- Tandem SCR-system → SCR/DPF + SCR
- Optional: Electrically heated DOC (eDOC)

→ Tandem SCR-system enables high $DeNO_x$ efficiency under variety of boundary conditions
→ High catalyst activity during cold phase (close coupled SCR/DPF) and high load operation (under body SCR)
→ eDOC to improve heat-up of catalyst and exhaust system … if needed

Why these have not been effective?



Danaiah et al. (2012), doi: 10.5923/j.scit.20120201.09

There is a **fundamental trade-off** between fuel consumption and NOx emissions (all engines - not only diesel)

- Also because less frequent use of emission control
  - Increased the lifetime of the system
  - Decreased additive consumption

So, is diesel fundamentally dirty?

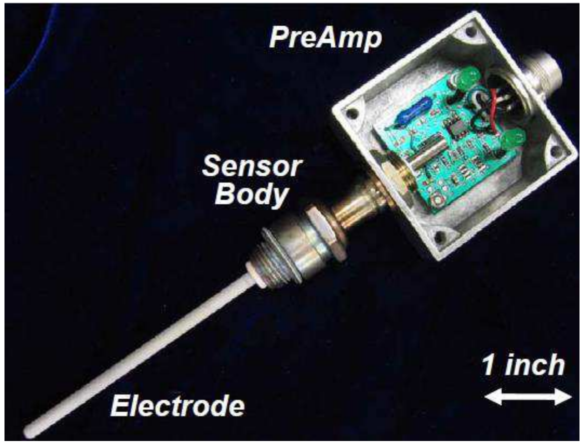
- Diesel NOx issues have taken advantage of loopholes in regulations
  - e.g. similar to CO_2 from ALL vehicle types
- Robust deNOx technology is currently available; can efficiently reduce NO_x within required limits
  - 10 years ago we had the same discussion for diesel PM that was satisfactorily addressed because of the PN limit
- New pieces of regulation are being prepared to achieve real-drive (RDE) NOx emissions control
- Diesel NOx+PM control is expensive hence one may expect diesel gradually be replaced by spark-ignition vehicles in the medium and small vehicle sectors

Why OBD?

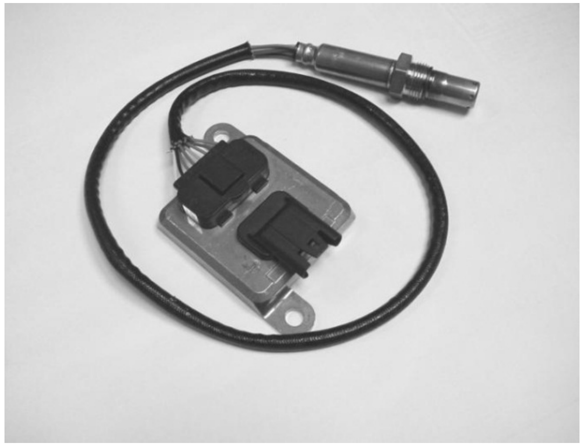
'OBD system' = system for emission control which has the capability of identifying the likely area of malfunction by means of fault codes stored in a computer memory

- 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

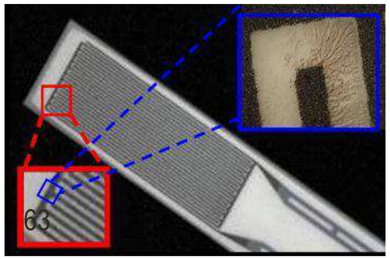
Urea Quality Sensor

Source: MECA

Soot sensing technologies

The need for particle sensors to comply with Light and Heavy duty OBD requirements is currently being approached by the sensor developers in different ways:

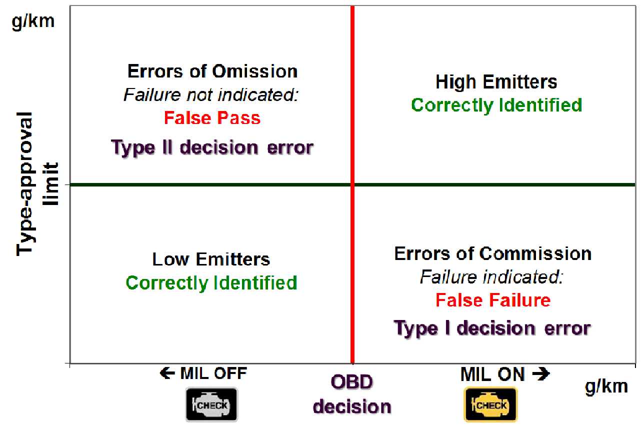
- Resistive: Bosch, Continental, Delphi, Electricfil, Stoneridge, *Sensata/Sensor-NITE*
- Particle charge: NTK-NGK, *Pegasor*, *Emisense/Watlow*
- Secondary filter: *Innexsys*
- Radio frequency: *General Electric Accusolve*

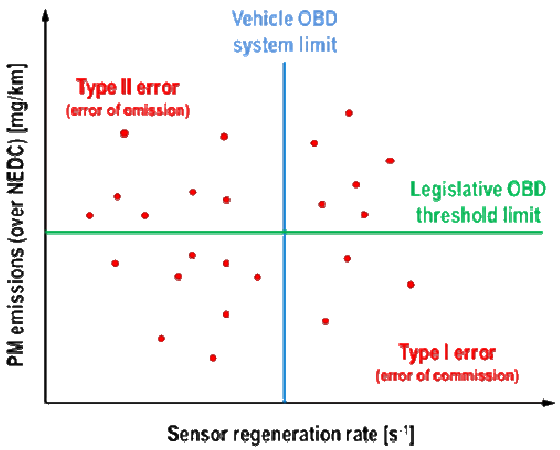



From measurement to diagnosis

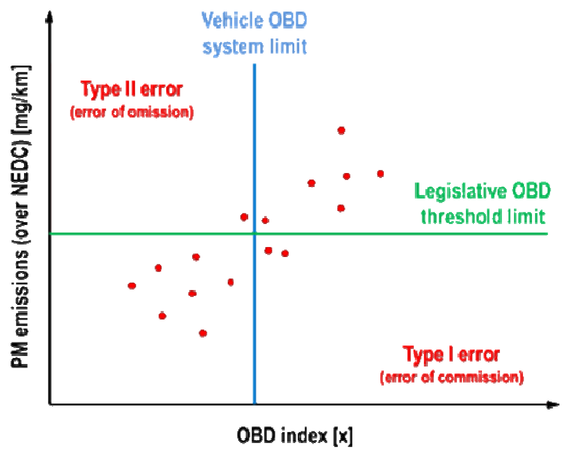
- Most sensors do not provide continuous signal or and an index with physical units
- Soot emissions highly depend on vehicle operation
- Need to correlate random operation emissions with type-approval cycle emissions

→ **Need of a robust OBD algorithm**



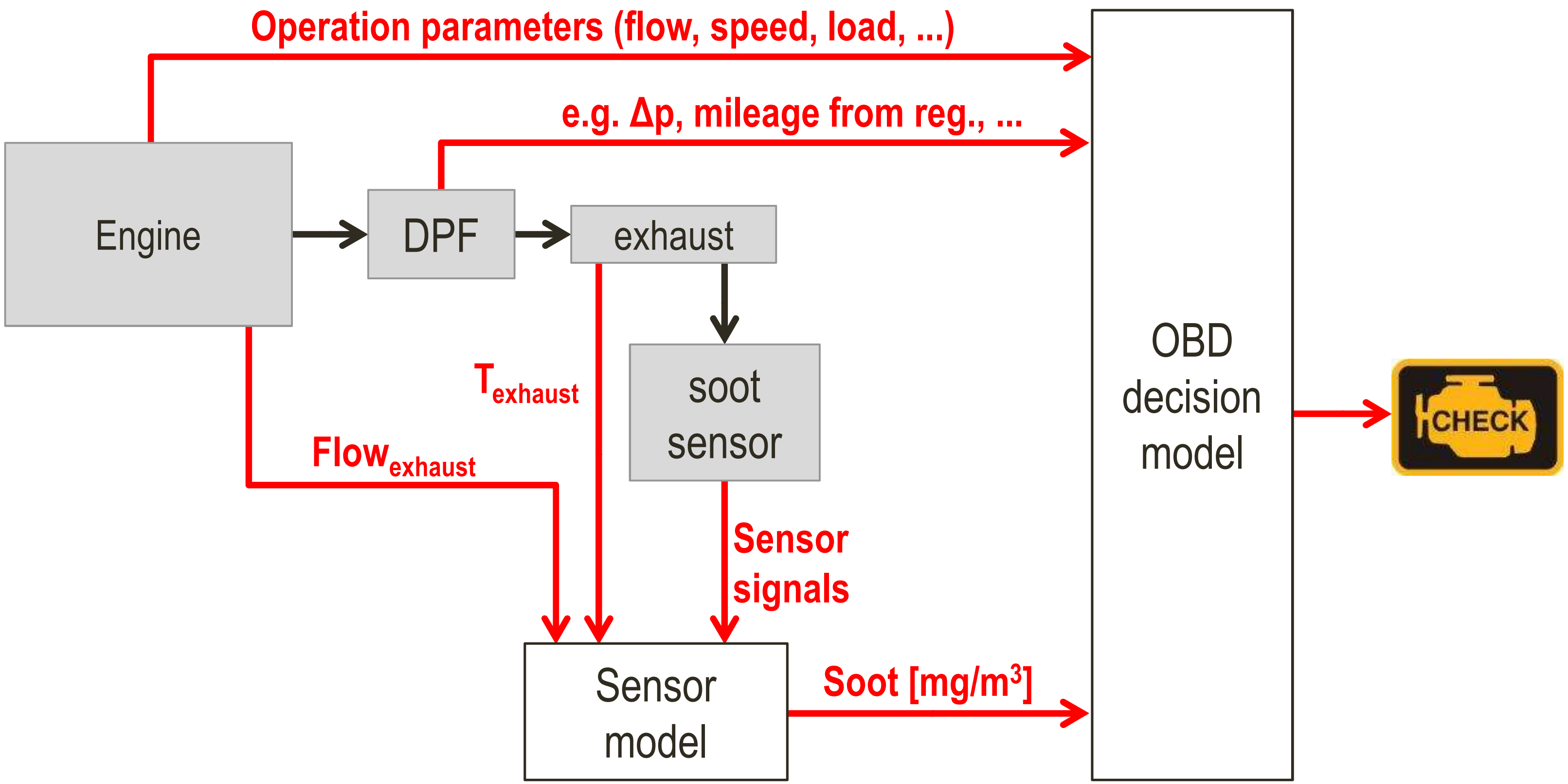


OBD algorithm



Models need to be developed to detect OTLs

Integrated OBD modeling



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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