LABORATORY OF APPLIED THERMODYNAMICS

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The current situation and future of vehicle emissions testing in Europe

TAIEX/ ECRAN Workshop on Climate Legislation in relation to Transport (cars and vans, labelling, renewables and fuel quality)
Wednesday, April 13th, Tirana, Albania

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EU legislation and emission standards
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EU legislation and emission standards

Laboratory emission testing

Real world emission testing

Other topics and discussion

Emission related legislation

Passenger cars

- Directive 91/441/EEC up to Regulations 715/2007, 692/2008 and amendments
  (initial "historical" Directive 70/220/EEC)

Heavy Duty Vehicles

- Directive 88/77/EEC up to Regulations 595/2009, 582/2011 and amendments

EU Emission Standards - Passenger Cars (PC)

EU Emission Standards for Passenger Cars (Category M_1*)

Stage	Date	CO	HC	HC+NOx	NOx	PM	PN
		g/km					*#/km*
Compression Ignition (Diesel)							
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)	-
Euro 2, IDI	1996.01	1.0	-	0.7	-	0.08	-
Euro 2, DI	1996.01[a]	1.0	-	0.9	-	0.10	-
Euro 3	2000.01	0.64	-	0.56	0.50	0.05	-
Euro 4	2005.01	0.50	-	0.30	0.25	0.025	-
Euro 5a	2009.09[b]	0.50	-	0.23	0.18	0.005[f]	-
Euro 5b	2011.09[c]	0.50	-	0.23	0.18	0.005[f]	6.0×10^{11}
Euro 6	2014.09	0.50	-	0.17	0.08	0.005[f]	6.0×10^{11}
Positive Ignition (Gasoline)							
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-	-
Euro 2	1996.01	2.2	-	0.5	-	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-	-
Euro 4	2005.01	1.0	0.10	-	0.08	-	-
Euro 5	2009.09[b]	1.0	0.10[d]	-	0.06	0.005[e,f]	-
Euro 6	2014.09	1.0	0.10[d]	-	0.06	0.005[e,f]	6.0×10^{11} e,g

* At the Euro 1..4 stages, passenger vehicles > 2,500 kg were type approved as Category N_1 vehicles
† Values in brackets are conformity of production (COP) limits
a. until 1999.09.30 (after that date DI engines must meet the IDI limits)
b. 2011.01 for all models
c. 2013.01 for all models
d. and NMHC = 0.068 g/km
e. applicable only to vehicles using DI engines
f. 0.0045 g/km using the PMP measurement procedure
g. 6.0×10^{12} 1/km within first three years from Euro 6 effective dates

Source: DieselNet

EU Emission Standards – Heavy Duty Vehicles (HDV)

EU Emission Standards for Heavy-Duty Diesel Engines: Steady-State Testing

Stage	Date	Test	CO	HC	NOx	PM	PN	Smoke
			g/kWh				*1/kWh*	*1/m*
Euro I	1992, ≤ 85 kW	ECE R-49	4.5	1.1	8.0	0.612		
	1992, > 85 kW		4.5	1.1	8.0	0.36		
Euro II	1996.10		4.0	1.1	7.0	0.25		
	1998.10		4.0	1.1	7.0	0.15		
Euro III	*1999.10 EEV only*	ESC & ELR	*1.5*	*0.25*	*2.0*	*0.02*		*0.15*
	2000.10		2.1	0.66	5.0	0.10[a]		0.8
Euro IV	2005.10		1.5	0.46	3.5	0.02		0.5
Euro V	2008.10		1.5	0.46	2.0	0.02		0.5
Euro VI	2013.01	WHSC	1.5	0.13	0.40	0.01	8.0×10^{11}	

a - PM = 0.13 g/kWh for engines < 0.75 dm^3 swept volume per cylinder and a rated power speed > 3000 min^{-1}

EU Emission Standards for Heavy-Duty Diesel and Gas Engines: Transient Testing

Stage	Date	Test	CO	NMHC	CH_4[a]	NOx	PM[b]	PN[e]
			g/kWh					*1/kWh*
Euro III	*1999.10 EEV only*	ETC	*3.0*	*0.40*	*0.65*	*2.0*	*0.02*	
	2000.10		5.45	0.78	1.6	5.0	0.16[c]	
Euro IV	2005.10		4.0	0.55	1.1	3.5	0.03	
Euro V	2008.10		4.0	0.55	1.1	2.0	0.03	
Euro VI	2013.01	WHTC	4.0	0.16[d]	0.5	0.46	0.01	6.0×10^{11}

a - for gas engines only (Euro III-V: NG only; Euro VI: NG + LPG)
b - not applicable for gas fueled engines at the Euro III-IV stages
c - PM = 0.21 g/kWh for engines < 0.75 dm^3 swept volume per cylinder and a rated power speed > 3000 min^{-1}
d - THC for diesel engines
e - for diesel engines; PN limit for positive ignition engines TBD

Source: DieselNet

Petrol passenger car technologies

Emission standard	Implementation year	Engine	Exhaust aftertreatment
Euro 1	1992	Fuel injection	3-way catalyst + “λ” sensor
Euro 2	1996	Electronic engine management	Larger catalyst
Euro 3	2000	OBD	Dual lambda (λ) sensor (+ pre-catalyst)
Euro 4	2005	Faster warm-up	Improvement of catalyst
Euro 5	2010	Optimization	Optimization

Diesel passenger car technologies

Emission standard	Implementation year	Engine	Exhaust aftertreatment
Euro 1	1992	Improvement of cylinder geometry	
Euro 2	1996	Direct injection, injection pressure increase	Oxidation catalyst
Euro 3	2000	Exhaust recirculation, Common Rail HP	Pre and main catalyst PSA: Diesel Particulate Filter (DPF)
Euro 4	2005	Multiple injections, pressure increase	Pre and main catalyst
Euro 5	2010	Injection optimization	Pre catalyst and DPF

Heavy Duty Vehicle technologies

Emission standard	Implementation year	Engine	Exhaust aftertreatment
Euro I	1992	Direct injection	-
Euro II	1996	Geometry improvements	
Euro III	2000	Increase of pressure	
Euro IV	2005	Exhaust Gas Recirculation	SCR (30% of the fleet)
Euro V	2010	Injection optimization	SCR (75% of the fleet) EGR (25% of the fleet)

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Source of visualization: DieselNet

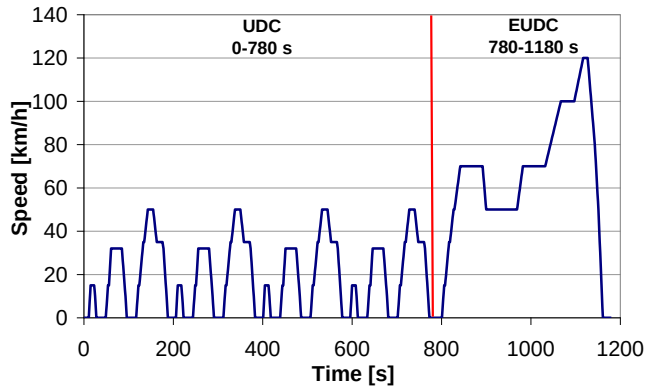
EU legislation and emission standards

Laboratory emission testing

Real world emission testing

Other topics and discussion

Legislated driving cycle: NEDC (New European Driving Cycle)



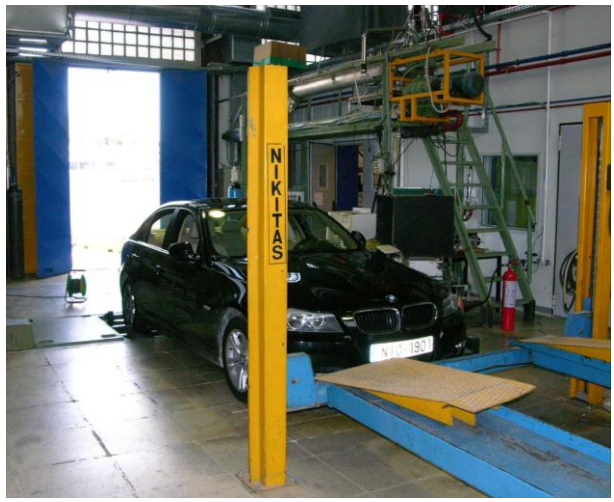
UDC (Urban Driving Cycle)

Simulation of driving in the city

EUDC (Extra Urban Driving)

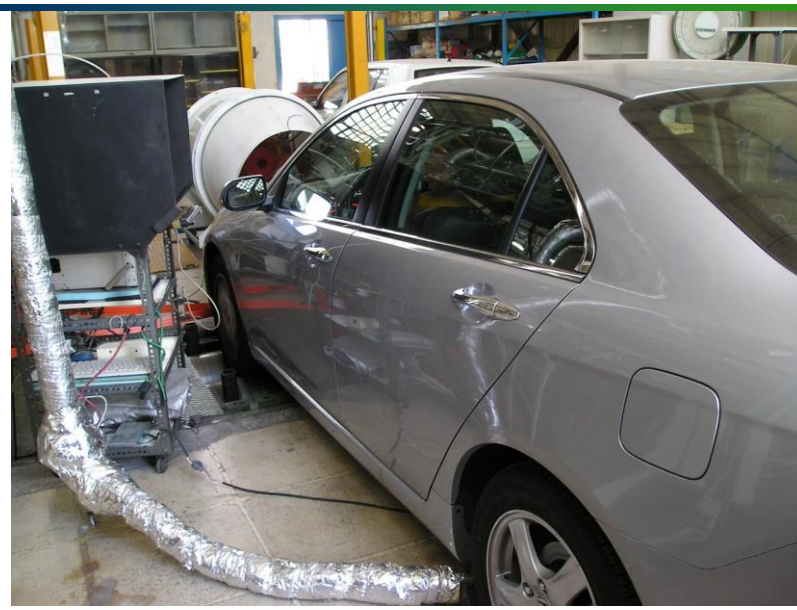
Simulation of driving out of the city (ring-road, motorway)

Vehicle dynamometer and CVS system

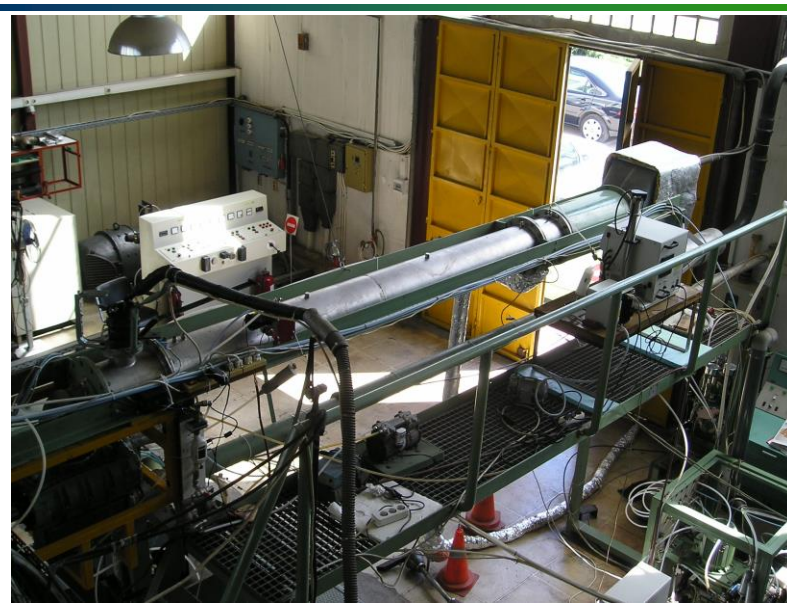


Vehicle dynamometer and CVS system

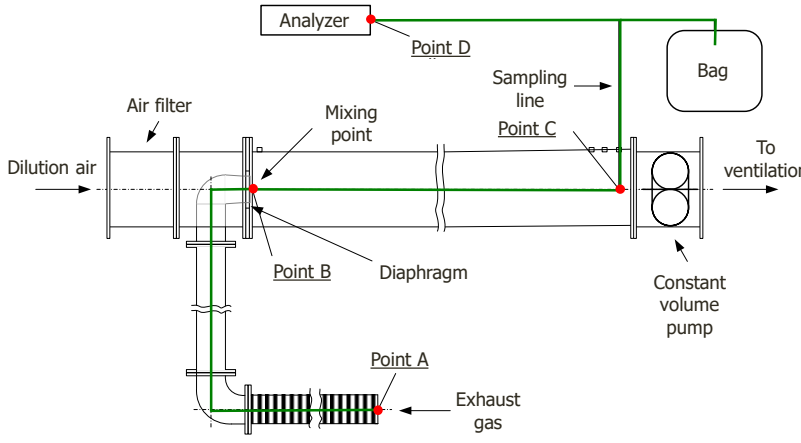
Vehicle dynamometer and CVS system



The CVS system



Constant Volume Sampling System (CVS)



Emission measurement on the engine
(e.g. for HDVs)

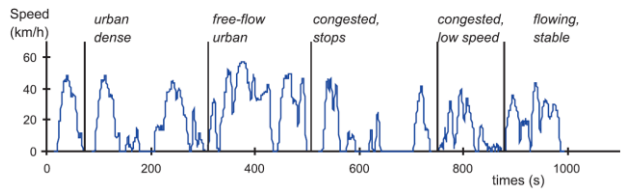
Exhaust gas analyzers

- CO NDIR (×2), CO_2 NDIR (×2), HC FID (×2), NO_x CLD, O_2 paramagnetic
- AMA i60 analyzer set (CO, CO_2, HC, NOx)
- NO_x and O_2 real-time sensors

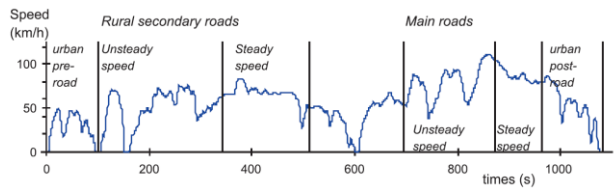
- Ultra fast response HC analyzer (Horiba) (T90<2 ms)
- Ultra fast response NO_x analyzer (Cambustion) (T90<4 ms)

Driving cycles simulating real world operation

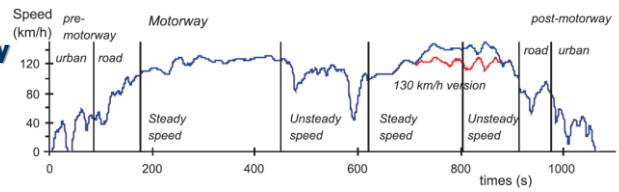
Artemis Urban



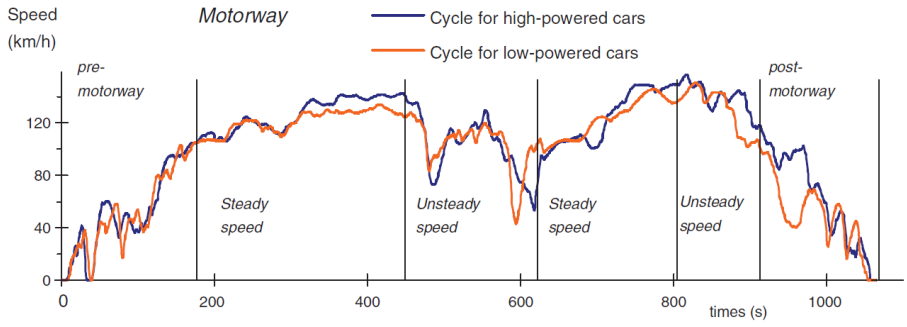
Artemis Road



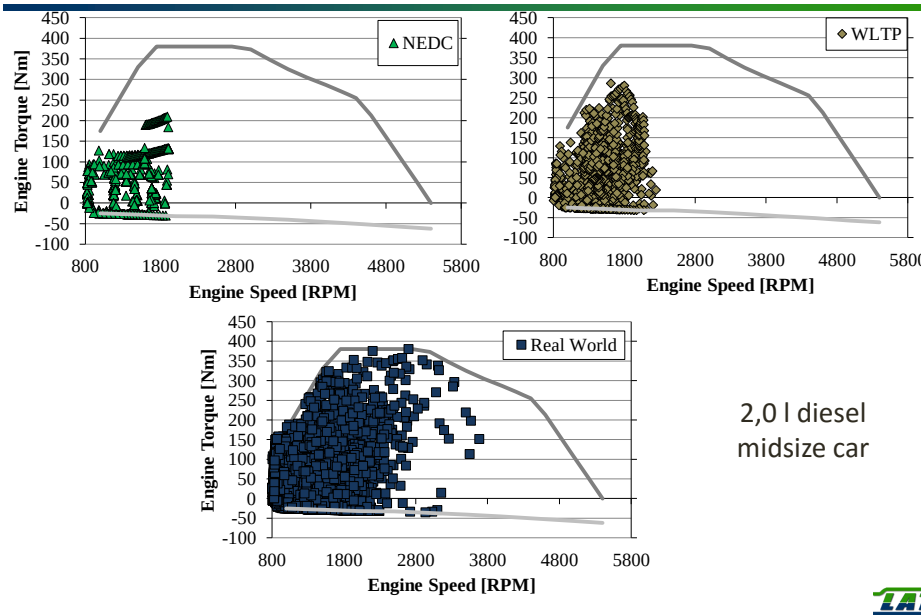
Artemis Motorway



Driving cycles for vehicles with different power to mass ratio



Engine map area covered by different driving cycles



2,0 l diesel
midsize car

EU legislation and emission standards

Laboratory emission testing

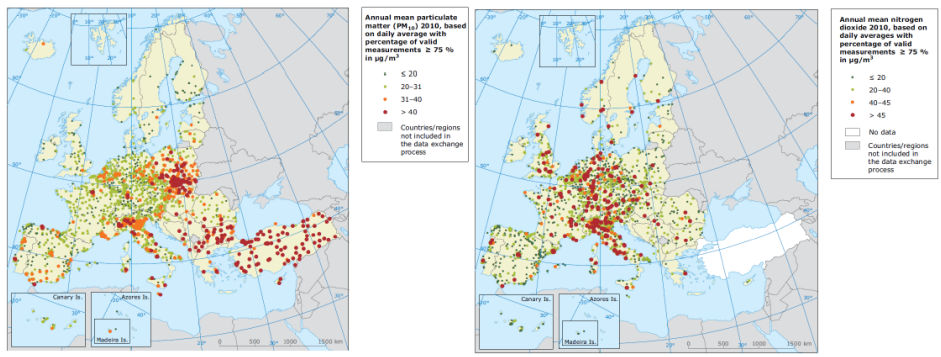
Real world emission testing

Other topics and discussion

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

PM_{10} Emission ● > 40 µg/m³

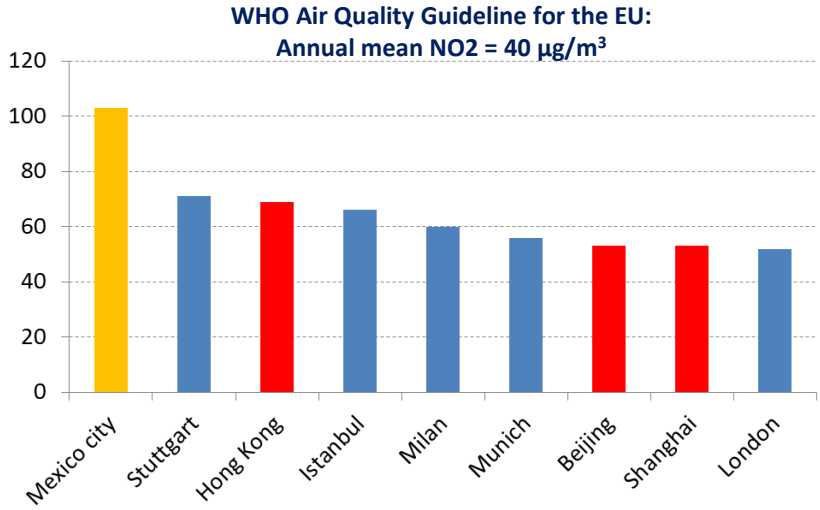
NO_2 Emission ● > 45 µg/m³



Source: European Environmental Agency (EEA) 2012

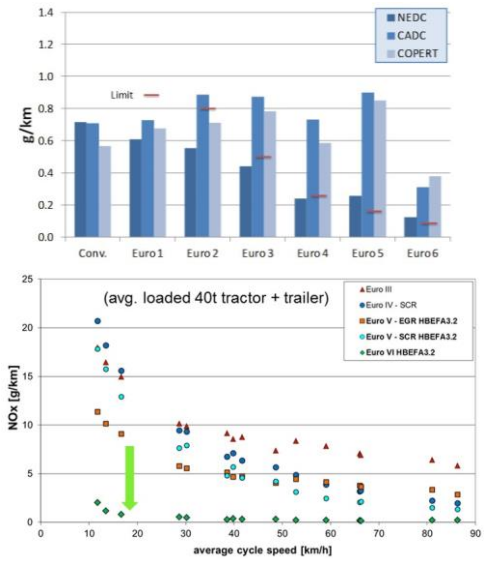
Some European areas show high Particulate Matter (PM) + NO_2 emission

NO_2 (µg/m³) concentrations in cities across the world
Average of 5 years annual averages (2008-2012)



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

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)

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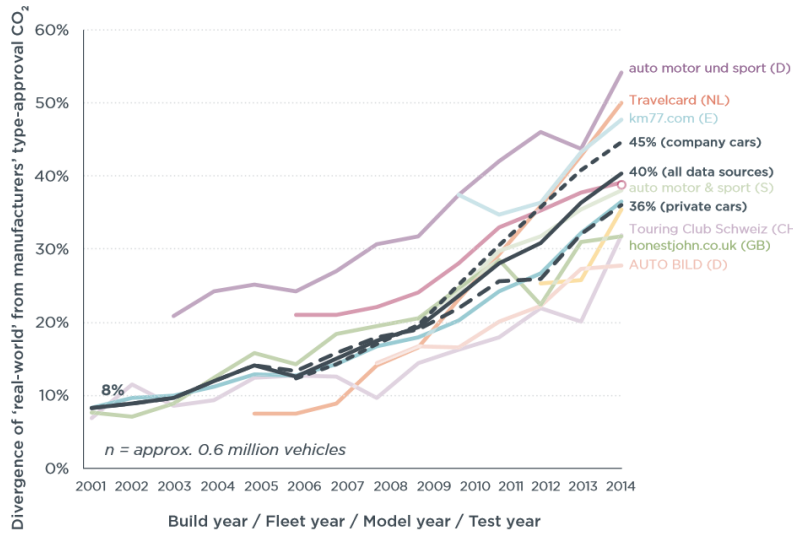
Source: ERMES consortium

Divergence of real-world CO_2 emissions from manufacturers' type-approval CO_2 emissions



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Source: ICCT. 2015

A growing gap

A growing gap between official laboratory and real-world on-road emissions. This negatively affects:

- Consumers - spend more on fuel
- Vehicle manufacturers - lose credibility
- Governments - vehicle tax revenue drops
- Society - not meeting air quality targets

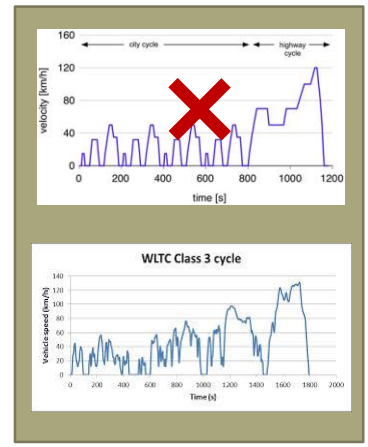
Common agreement : A revision of the vehicle test procedures is needed to make them better reflect real-world driving

A robust pollutant / CO_2 regulation requires

- A modern test procedure
- Independent retests
- On-road testing
- Transparency of test results

Hope in the implementation of WLTP

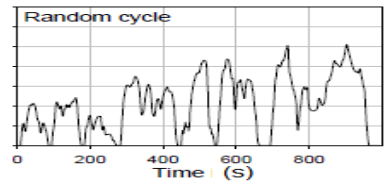
- WLTP adopted by UNECE-GTR in 2014 and will replace NEDC as a certification cycle
- Less relevant for emission standards
  - Limit values remain the same
  - RDE to complement/substitute chassis dyno in the long run
- Important to translate NEDC-based CO_2 targets of 2015 and 2020/21 to WLTP



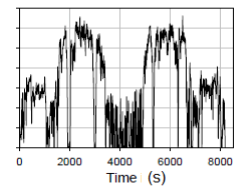
PEMS: From laboratory to the road

Two approaches followed:

1. Emissions testing with random driving cycles in the laboratory



2. On-road emissions testing with PEMS (Portable Emission Measurement System)



PEMS testing – Underlying principles

- PEMS equipment should:
  - measure and record concentrations of NOx, CO, CO_2, THC and PM/PN in the engine exhaust
  - record operation parameters, position from GPS and ambient conditions.
  - be reasonably small and light in order to facilitate installation and minimize modifications to car's mass and aerodynamic
  - work with low power consumption
  - be robust for frequent installations and removal,
- Definition of "boundary" conditions (i.e. conditions under which the emissions cannot exceed a given threshold)
- ***Development of a proper evaluation method to analyze the recorded emissions and vehicle activity***

Current status of LDV legislation on RDE

Timeline

- PEMS tests for vehicle family concept mandatory from 2015 – for reporting and monitoring
- Limits (defined by conformity factors, CF):
  - First step: CF of 2.1 applicable in 2017 for new types and 2019 for all types)
  - Second step: 1.5 applicable in 2020 for new types and 2021 for all types
- Evaluation method will be selected before 2017

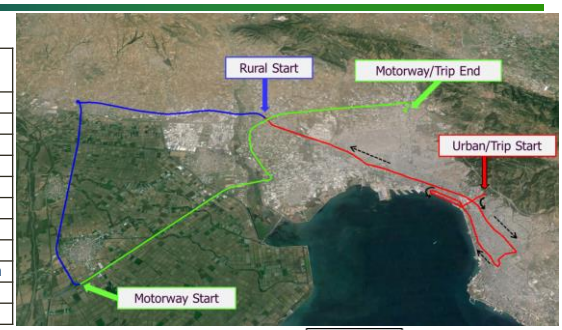
Boundary conditions for PEMS evaluation

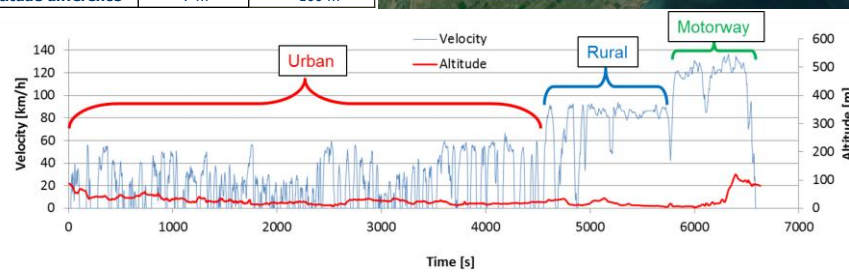
- **Normal conditions** of use will be controlled:
  - a) Evaluation method to convert test results into a corrected result by lower weighting of abnormal conditions
  - b) Introduce conditions describing thresholds for normal driving
- **Boundaries for route description** approx. values:
  - Mileage share urban/road/motorway: 30/40/30% [+/-5%]
  - Road gradients: 95 percentile below 3% gradient
- **Boundaries for trip description** approx. values:
  - Average speed: 15-30 km/h urban and > 100 km/h motorway
  - Maximum speed: generally below 145 (and below 160 km/h)
  - *Gear shift strategy: 95 percentile below 0.5 n_{norm}*
  - *Driving dynamics: 95 percentile of $v*a < 25\ m^2/s^3$ @ $a>0.1m/s^2$*

Boundary conditions for PEMS evaluation

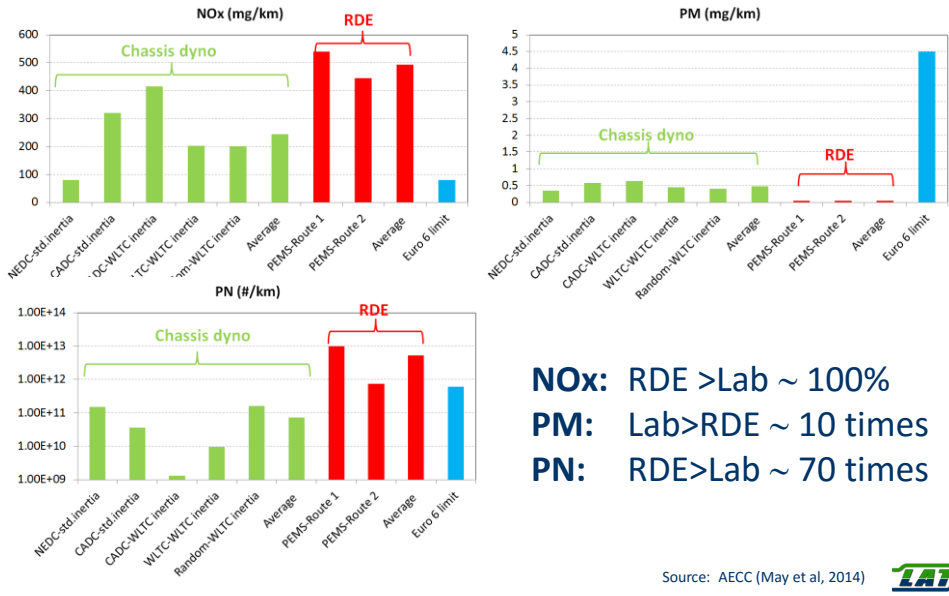
- RDE route in Thessaloniki region

		Thessaloniki RDE route	Legislation limits
Trip duration		110 min	90 – 120 min
Stop duration		22% of time	> 10% of time
Trip distance		77 km	> 46 km
Distance share	**Urban**	37%	29% – 44%
	Rural	29%	23% – 43%
	Motorway	34%	23% – 43%
Average speed	**Urban**	20.9 km/h	15 – 30 km/h
	Rural	82.7 km/h	60 – 90 km/h
	Motorway	117.6 km/h	100 – 145 km/h
Max altitude		115 m	< 700 m
Altitude difference		-7 m	± 100 m





How do actual cars behave in RDE?
Euro 6 diesel example



NOx: RDE >Lab ~ 100%
PM: Lab>RDE ~ 10 times
PN: RDE>Lab ~ 70 times

Source: AECC (May et al, 2014)

Summary on PEMS

- Testing with PEMS a key element of EU emissions regulations.
- Assessing methods to normalize data without jeopardizing the effectiveness in detecting RDE performance is the next challenge
- PEMS can effectively control vehicle gaseous emissions, accelerate the adoption of novel emission abatement technologies and will thereby contribute to air quality improvements throughout Europe
- PEMS PM emissions are very low (≪ 1 mg/km). Due to mass constraints PM measurement is not recommended
- Further work is required to ensure that robust measurements of PN are possible

EU legislation and emission standards

Laboratory emission testing

Real world emission testing

Other topics and discussion

On Board Diagnostics (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

Other areas under consideration:

- OBD for monitoring energy efficiency / CO_2 emission reduction:
  - engine technology deterioration/failure
  - regular maintenance: tyre pressure, MAC refrigerant level, etc.
- **OBD for continuously monitoring emissions** and adjust engine management accordingly in real time
- OBD for monitoring active and passive safety features like steering, brakes, airbags, seat belts,… exist since a long time, be standardised?

=> Regulatory issues to be investigated with a long term view, 2020+

What do the new regulations cover?

- More stringent emission limits for conventional pollutants
- Durability requirements for pollution control technologies
- CO_2 labelling
- Fuel evaporation control
- OBD Implementation

- Pending issues
  - In-use compliance
  - Off-cycle emissions
  - PN regulation
  - Roadworthiness testing

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
  - Non-road mobile machinery
  - Power two/three and four wheelers

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Thank you for your attention

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