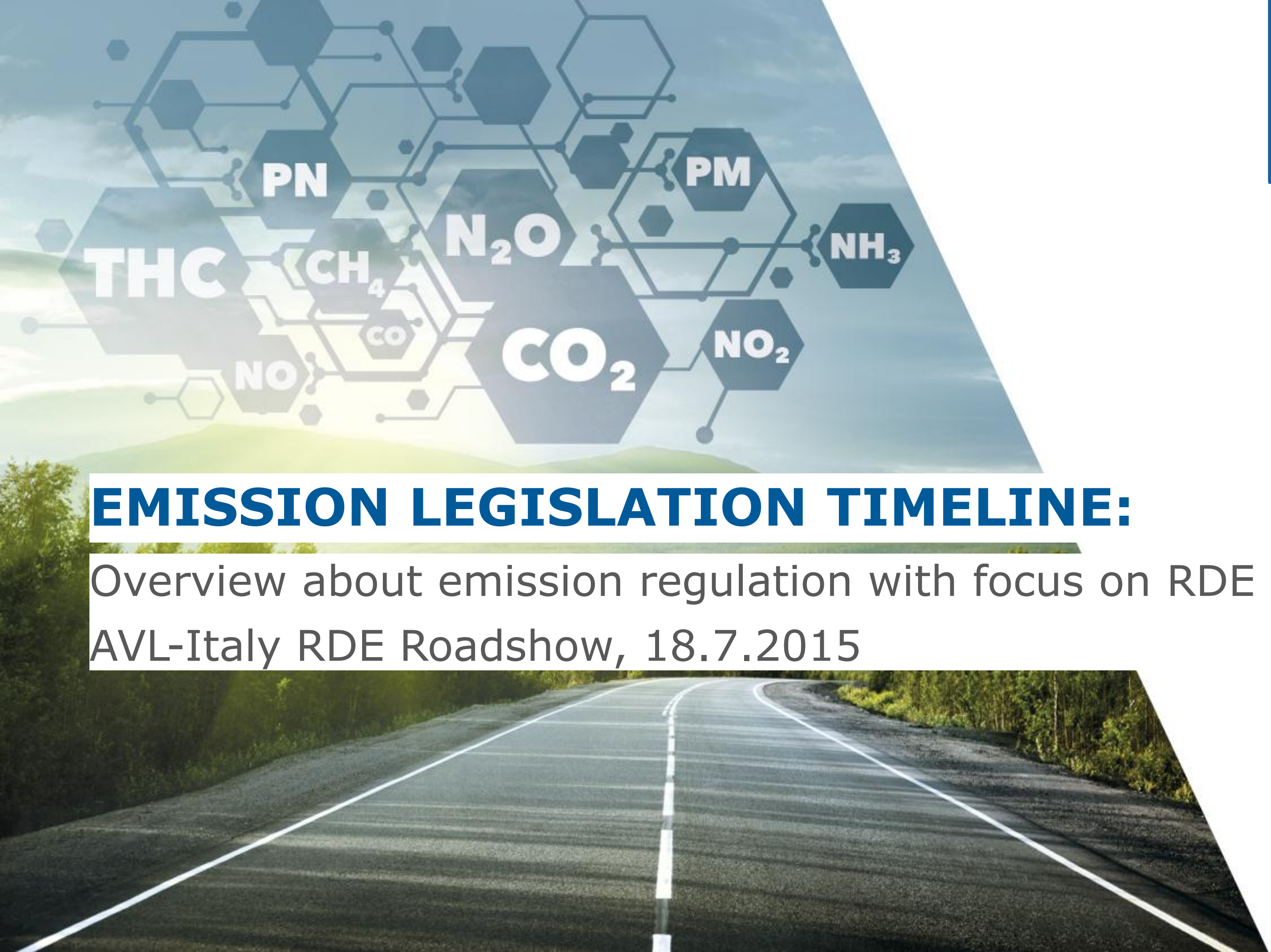

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EMISSION LEGISLATION TIMELINE:

Overview about emission regulation with focus on RDE

AVL-Italy RDE Roadshow, 18.7.2015

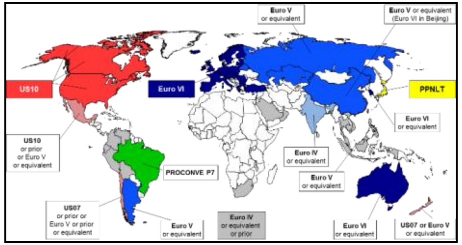
Engeljehringer Kurt

AVL List GmbH

Public

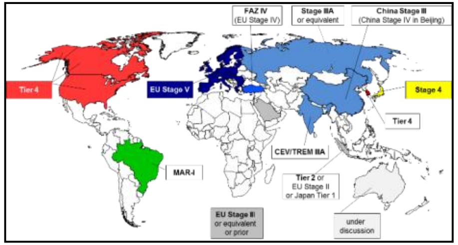
CONTENT: EMISSION LEGISLATION

Heavy Duty Vehicle Engines



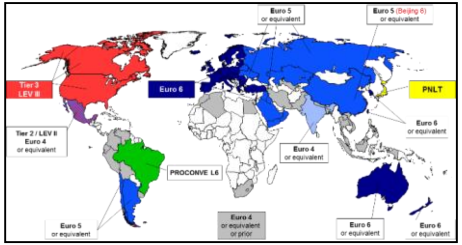
- Overview
- Low NOx CARB Option
- Emission testing for Hybrid Powertrains
- CO2 and fuel consumption testing for HD-Vehicles

Non-Road Engines



- Overview
- In-Service compliance by PEMS in discussion
- PN in Europe in discussion (to force closed PDF)

Light Duty Vehicle



- Overview
- What drives the EU emission legislation
- CO2 Reduction
- GTR-15 (WLTC)
- Real Driving Emissions (RDE)

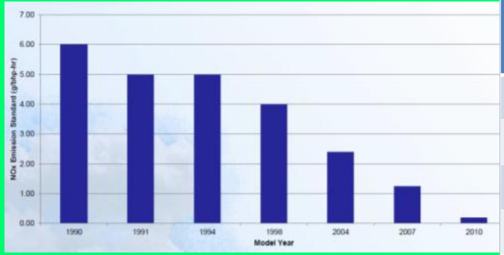
EMISSION TIMELINE – HEAVY DUTY

Heavy Duty Vehicle Engines

Country	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025

US-EPA – US10

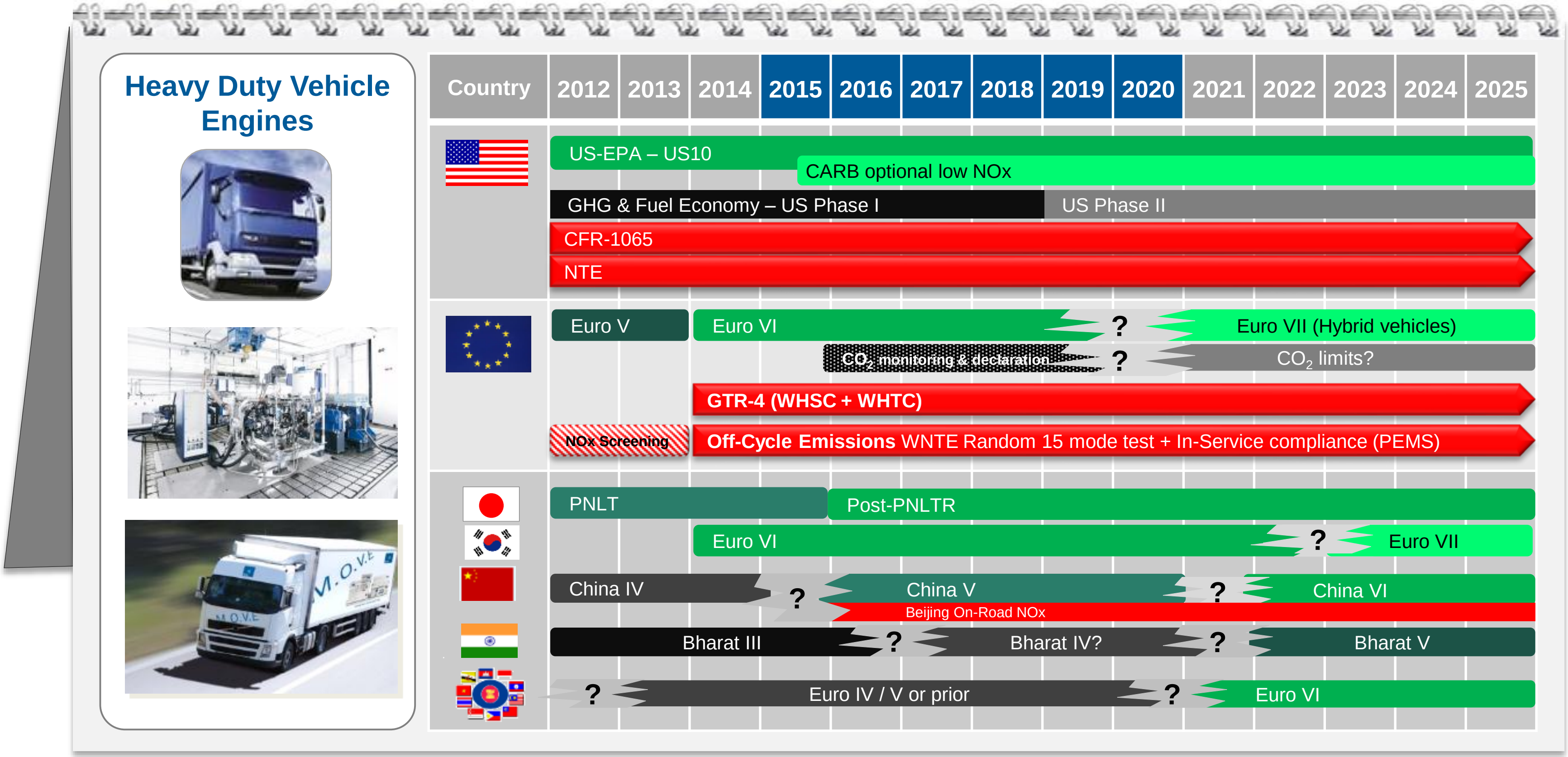
CARB optional low NOx



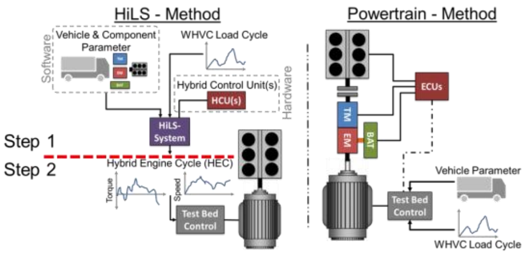
NOx Level (g/bhp-hr)	% Below Current Standard
0.2 (Current)	
0.1	- 50%
0.05	- 75%
0.02	- 90%

- CARB propose an “optional” lower NOx Limit for California. The 2010 NOx emission standard 0.20 g/bhp-hr, should be reduced by a factor of 10.
- How to measure is part of a program at SWR “Evaluating Technologies and Methods to Lower Nitrogen Oxide Emissions from Heavy-Duty Vehicles”.

EMISSION TIMELINE – HEAVY DUTY

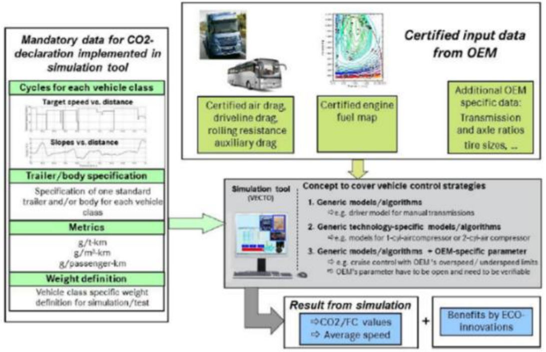


HEAVY-DUTY HYBRID, CO2 AND FC TESTING



Test Prozedur für Hybrid NFZ

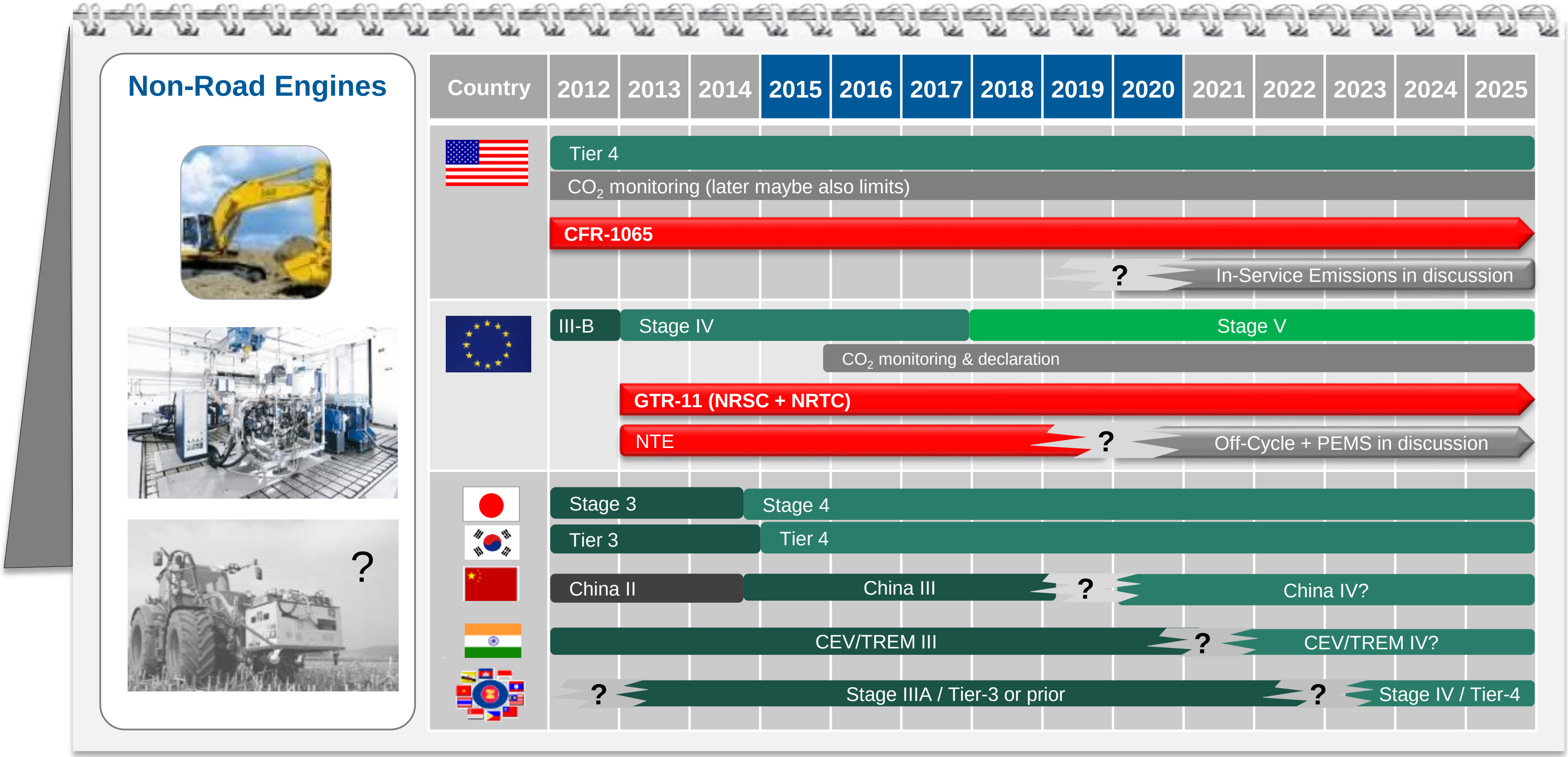
- For hybrid powertrains the total powertrain, energy storage and powertrain control units must considered.
- In order to avoid testing on a chassis dynamometer, a HILS (Hardware-in-the-loop simulation) was developed in Japan. In the WHVC cycle, the influence of the hybrid components on the engine operation is tested. 2 Variants exists:
  1. By HILS an engine test cycle is generated and tested on an engine testbed.
  2. The whole hybrid powertrain is tested on a powertrain testbed



CO2 and Fuel consumption

- Contrary to exhaust emissions, fuel consumption and CO2 emissions are not part of the GRPE mandate. Therefore, regional regulations are under development.
- EU: develops a vehicle based procedure, based on transport work and a simulation tool VECTO (TU-Graz) with 5 different test cycles representative for different vehicle categories.
- USA: Green House Gas rule developed by EPA and NHTSA. There are separate limits values for engine and vehicle. CO2 and FC are calculated with a simulation tool GEM.
- Japan: starting 2015 fuel economy limits are based on a simulation approach. FC is calculated from engine testbed data and vehicle class generic vehicle parameters on base of the JE05 and a motorway cycle.
- China: regulates on base of a modified WHVC to be run on a chassis dyno.

EMISSION TIMELINE – NON-ROAD 130-560KW



EMISSION TIMELINE – LIGHT DUTY

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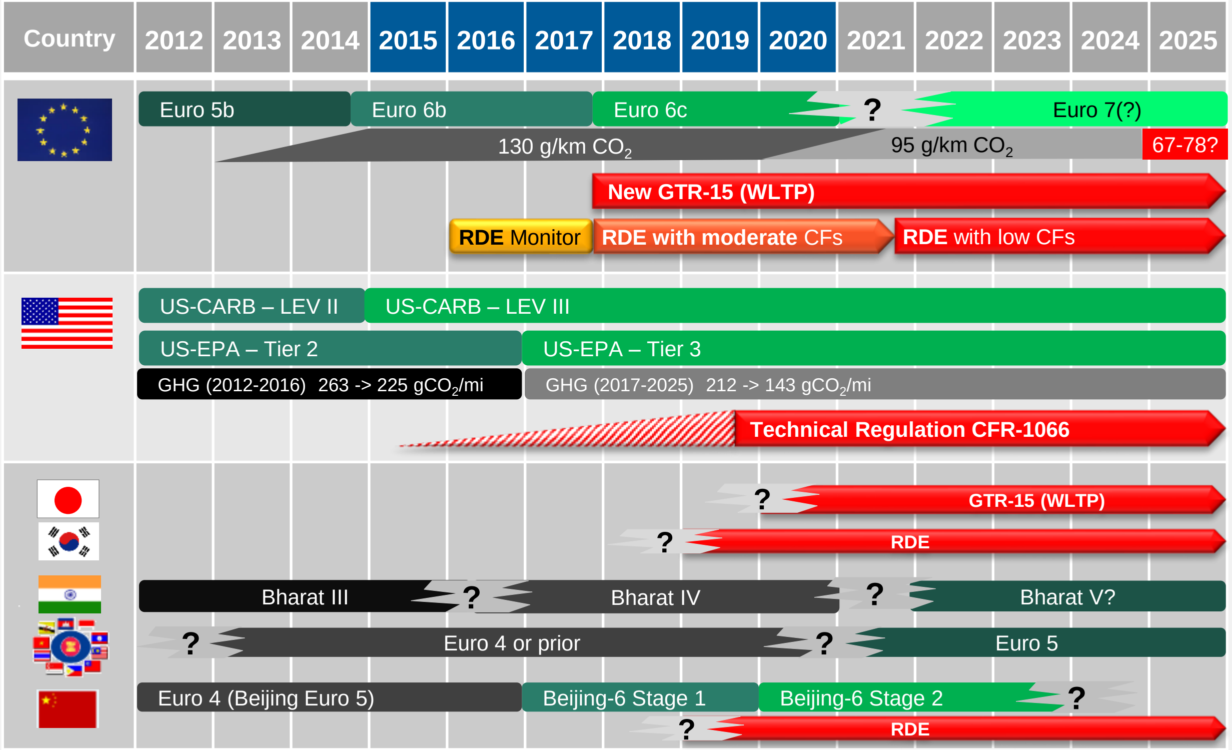
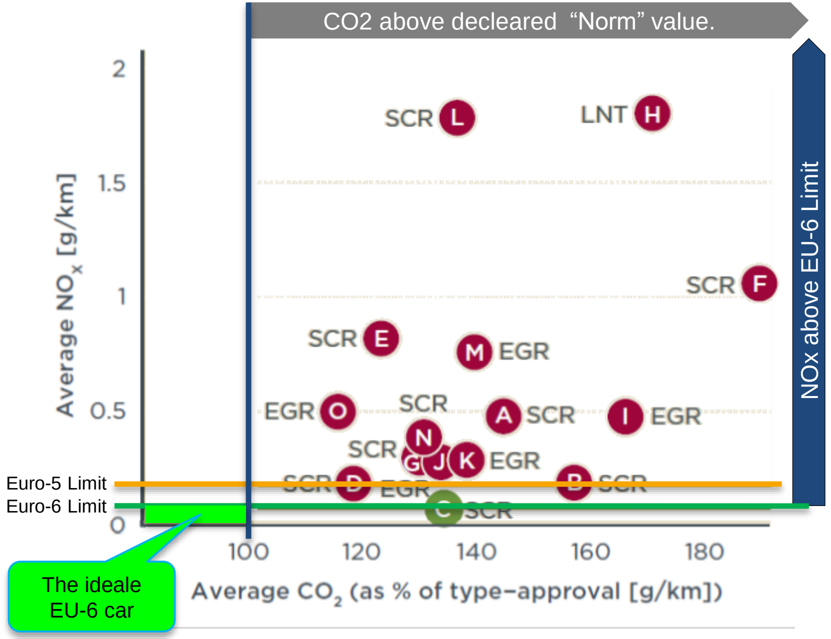
Light Duty Vehicles

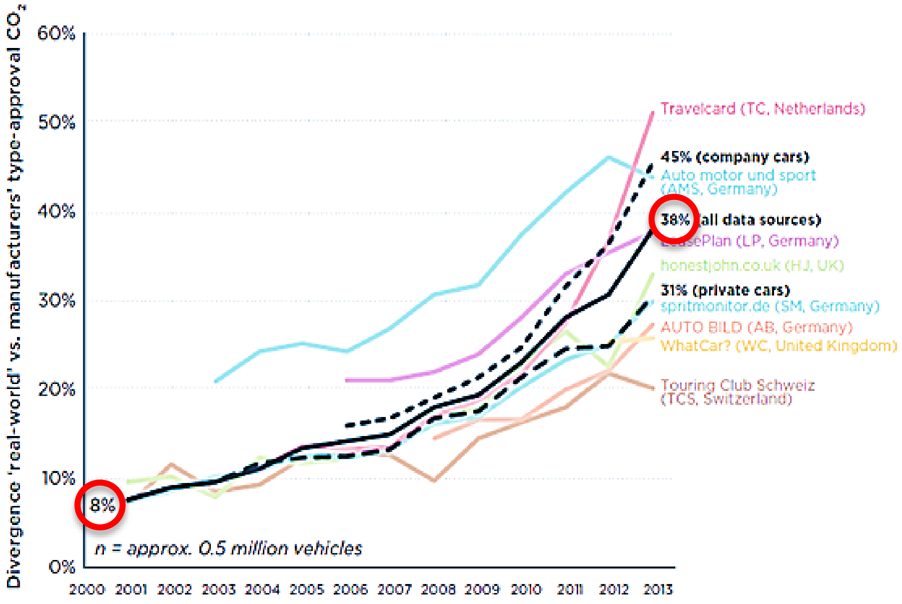


WHAT DRIVES EU EMISSION LEGISLATION?

Real-world exhaust emissions (PEMS) from modern diesel cars:
15 vehicles, 6 manufacturers with different NOx control technologies
All calibrated for EU (Euro 6a) or US (Tier 2 Bin 5/ULEV II)

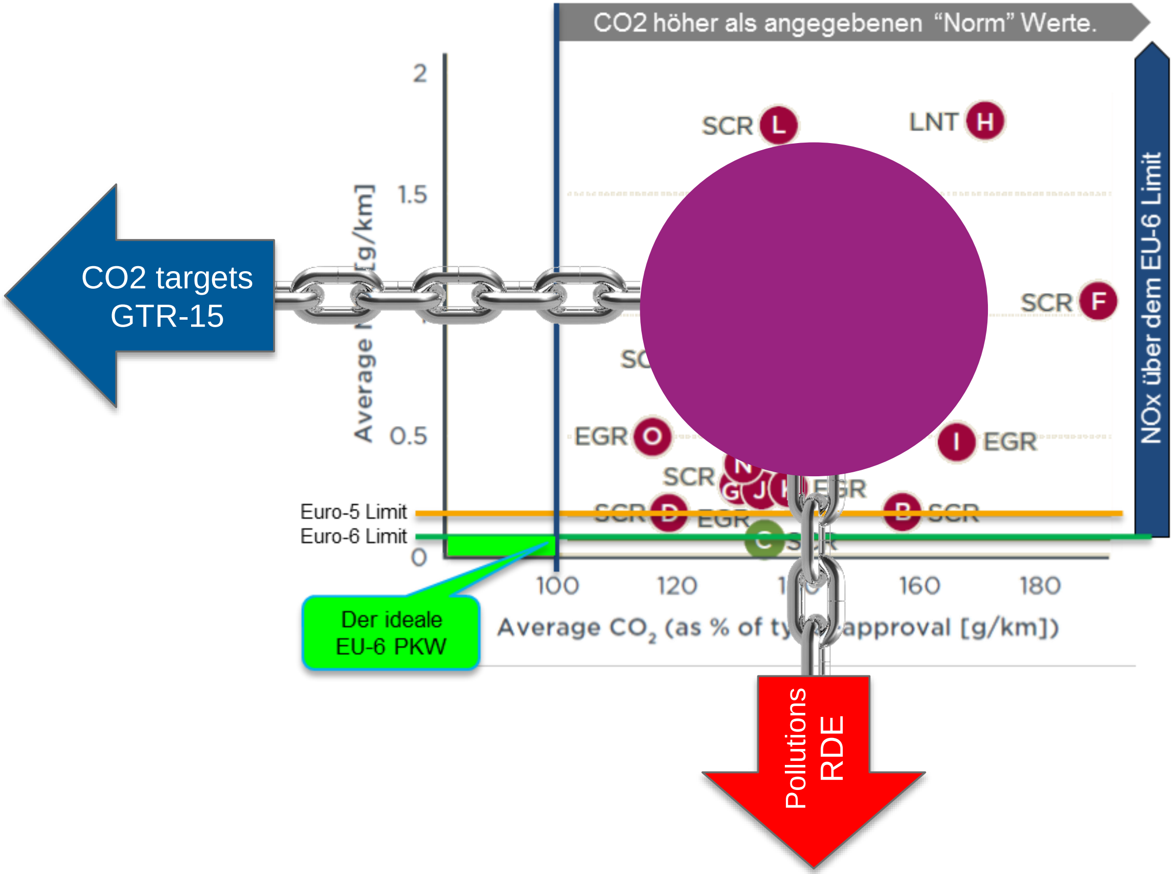


Source: ICCT International Council on Clean Transportation 2014



Source: ICCT International Council on Clean Transportation 2014

WHAT DRIVES EU EMISSION LEGISLATION?



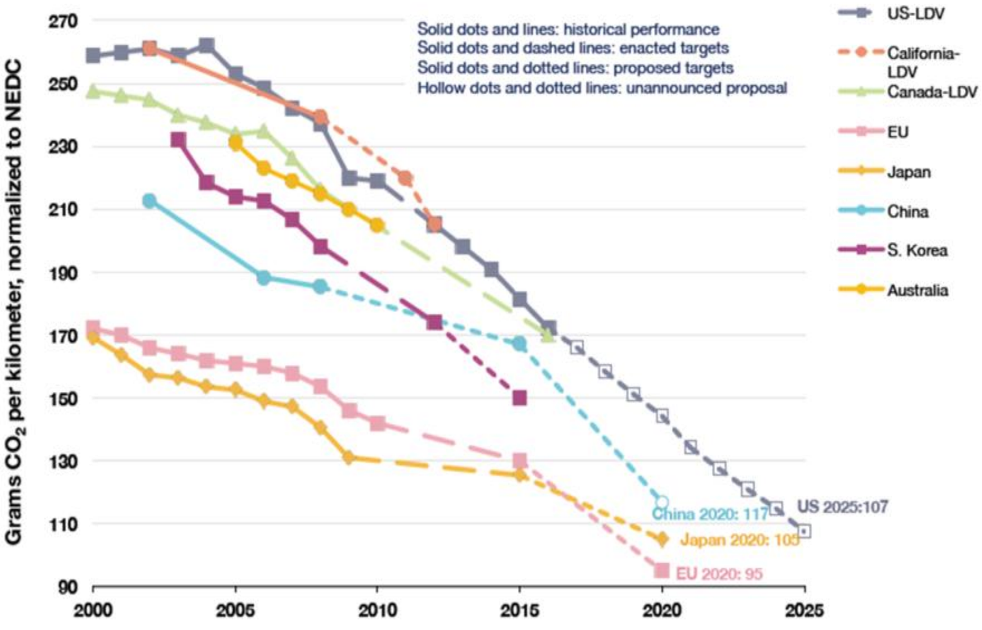
Technical Issue:

In the technical realization in a vehicle RDE and CO2 are very much linked together. Often what is a positive effect on CO2 is a negative effect on RDE (like engine downsizing). Therefore a trade off between RDE and CO2 is a technical challenge.

Political Target:

While technical wise RDE and CO2 are very much linked together. As a political target they are independent targets.

GREEN HOUSE GAS EMISSIONS



[1] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be lower.
[2] US and Canada light-duty vehicles include light-commercial vehicles.

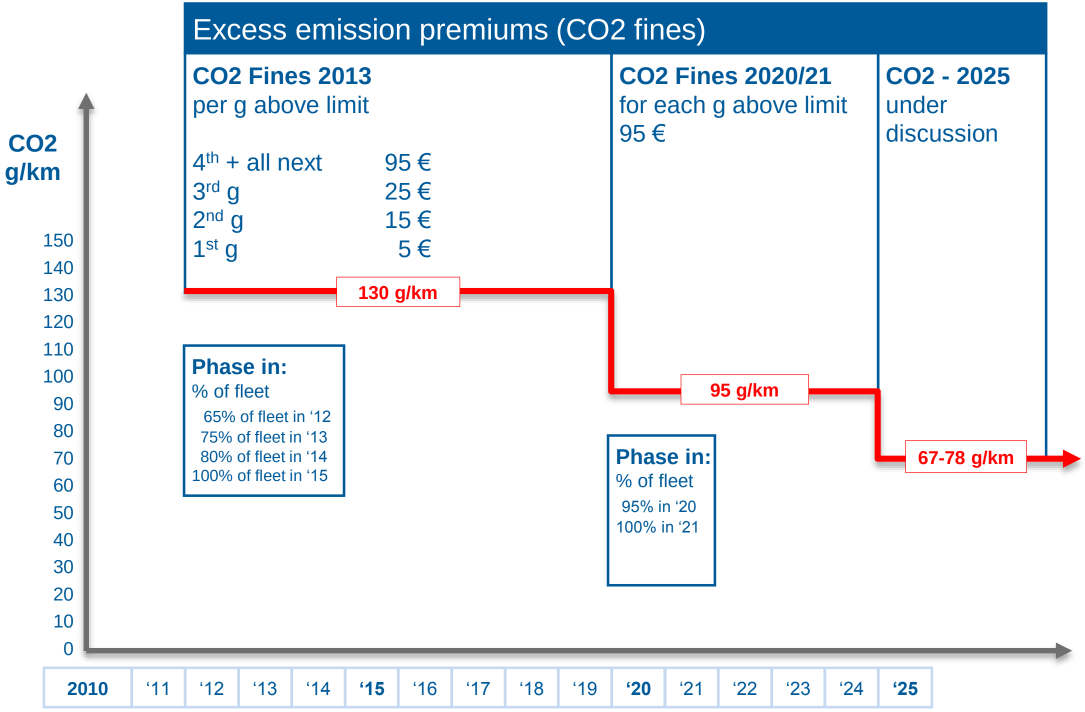
	2014 CO_2 Ranking		Registrations 2014	Average CO_2 2014	Average CO_2 2013	Improvement Ranking		2013-14 % change
↑	1	Peugeot-Citroën	1,360,773	110.1	115.7	1	Nissan	-12.1%
↑	2	Toyota	538,732	112.8	116.5	2	Peugeot-Citroën	-4.8%
↓	3	Renault	1,246,046	113.6	114.6	3	Mazda	-4.4%
↑	4	Nissan	469,203	115.0	130.9	4	Daimler	-3.9%
↓	5	Fiat	671,767	116.4	116.6	5	Volvo	-3.3%
↓	6	Ford	941,009	121.7	121.6	6	Toyota	-3.2%
↓	7	Suzuki	153,500	123.8	126.9	7	Honda	-2.8%
↓	8	Volkswagen	3,159,286	125.8	128.8	8	Suzuki	-2.4%
→	9	Volvo	231,915	126.5	130.8	9	Volkswagen	-2.3%
↑	10	Mazda	159,729	128.2	134.1	10	BMW	-2.2%
↓	11	Hyundai	756,435	130.5	130.0	11	General Motors	-1.7%
↓	12	General Motors	897,024	130.5	132.8	12	Renault	-0.9%
↑	13	Daimler	686,590	131.5	136.8	13	Fiat	-0.2%
↓	14	BMW	798,543	131.7	134.6	14	Ford	0.1%
→	15	Honda	126,106	133.9	137.8	15	Hyundai	0.4%
		All Manufacturers	12,546,165	123.4	126.8		All Manufacturers	-2.6%

Source: An analysis of carmaker progress towards EU CO2 targets in 2014, T&E – European Federation for Transport and Environment AiSBL

EU: CO2 EMISSIONS

CO2 Targets

If a manufacturer's fleet average is above the CO2 target, he still is allowed to sell the vehicles. But he must pay the Excess Emission Premium (CO2 fines). Depending on how much he exceeds the target it converted to € and multiplied by the number of registered cars per year.



Credits

- Incentives for vehicles with less than 50g/km, by counting it such a car as 3,5 cars in 2013 and 1,5 in 2015
- E85 credits (5% less CO2), for such cars in countries where at least 30% of the fuel stations offer E85 (only Sweden)

Eco-innovations

Innovative technologies, which can not show the CO2 reduction in the type-approval test procedure, like LED lights, can reduce up to 7gCO2/km if agreed by the authorities.

Specific emissions target per manufacturer

Each manufacturer has its individual annual CO2 target. That is calculated on the basis of the average vehicle mass of the manufacturer's fleet and a reference mass, which is defined on base of the average vehicle mass of the whole EU fleet.

Derogations

- Niche-Derogations for OEM's selling 10.000 to 300.000 cars
- OEM's selling less than 10.000 cars per year

EU: CO2 EMISSION MONITORING REPORT

Table 3.6 Main specific emission statistics for the largest car manufacturers (> 100 000 registrations per year)

Note: These are total number of registrations in the EU-27, not the registrations used for the calculation of the target and of the average emissions.

Manufacturer	Registrations 2013 ([a])	Average mass (kg) 2013	Average CO_2 (g CO_2/km) 2013	2012	2011	2010
Renault SAS	793 063	1 262	110	121	129	134
Automobiles Peugeot	723 688	1 349	115	121	128	131
Fiat Group Automobiles SPA	646 554	1 145	116	117	118	125
Toyota Motor Europe Nv SA	513 116	1 315	116	122	126	129
Automobiles Citroen	587 544	1 356	116	123	126	131
Seat SA	280 310	1 231	119	127	125	131
Ford-Werke GmbH	891 562	1 342	122	129	132	137
Skoda Auto AS	480 748	1 268	125	132	135	139
Automobile Dacia SA	289 150	1 200	127	137	143	145
Volkswagen AG	1 486 282	1 382	127	133	135	140
Kia Motors Corporation	285 340	1 320	128	129	137	143
Volvo Car Corporation	203 165	1 700	131	142	151	157
Nissan International SA	411 702	1 399	131	137	142	147
Adam Opel AG	804 117	1 443	132	133	134	140
Audi AG	650 995	1 554	133	138	145	152
Bayerische Motoren Werke AG ([b])	758 186	1 560	134	138	144	146
Mazda Motor Corporation	133 183	1 422	134	142	147	149
GM Korea Company	135 379	1 405	136	141	142	144
Daimler AG	661 356	1 577	137	143	153	160
Hyundai Motor Manufacturing Czech SRO ([c])	220 348	1 426	138			
Jaguar Land Rover Limited ([d])	131 530	2 049	182			

-23% to 89 g/km (*) in 2020/21

1g CO2 above **62 Mil.€** per year @ 650.000 cars

Source: European Environment Agency (EEA) Technical report No 19/2014.

(*) Note: Manufacturer specific CO2 target values depend on manufacturer fleet average vehicle mass and over all average vehicle mass. The targets are redefined every second year.

USA: GREEN HOUSE GAS (GHG) EMISSIONS

AVL

TABLE IV–1—FIRST MODEL YEAR FOR GHG REPORTING REQUIREMENTS

Engine category	CO_2	N_2O[a]	CH_4
Highway Heavy-Duty (engine and vehicle)	2011	2013 or NO_X AT	2012
Nonroad Diesel	2011	2013 or NO_X AT	2012
Marine Diesel (other than C3)	2011	2013 or NO_X AT	2012
C3 Marine	2011	None	None
Locomotives	2011	2013 or NO_X AT	2012
Small Spark-Ignition	2011	2013 or NO_X AT	2012
Large Spark-Ignition	2011	2013 or NO_X AT	2012
Marine Spark-Ignition	2011	2013 or NO_X AT	2012
Snowmobiles	2011	2013 or NO_X AT	2012
Highway Motorcycles	2011	2013 or NO_X AT	2012
Off Highway Motorcycles/ATVs	2011	2013 or NO_X AT	2012
Aircraft[b]	2011	None	None

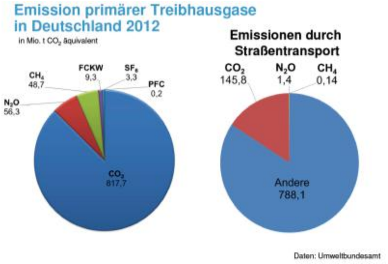
[a] N_2O reporting for new engines begins in 2013 or when the manufacturer introduces NO_X aftertreatment technology, whichever is later.
[b] Applies to all turbofan and turbojet engines in production in 2011 with a rated output greater than 26.7 kilonewtons. Reporting of NO_X also required.

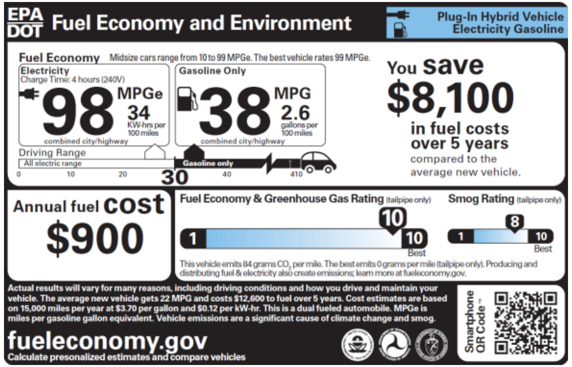
TABLE III.A.3–1—PROPOSED INDUSTRY-WIDE GREENHOUSE GAS EMISSIONS STANDARDS

Standard/covered pollutants	Form of standard	Level of standard	Credits	Test cycles
CO_2 Standard[117]: Tailpipe CO_2	Fleetwide average footprint CO_2-curves for cars and trucks.	See footprint—CO_2 curves in Figure I.C–1 for cars and Figure I.C–2 for trucks.	CO_2-e credits[118]	EPA 2-cycle (FTP and HFET test cycles), with separate mechanisms for A/C credits.[119]
N_2O Standard: Tailpipe N_2O	Cap per vehicle	0.010 g/mi	None	EPA FTP test.
CH_4 Standard: Tailpipe CH_4	Cap per vehicle	0.030 g/mi	None	EPA FTP test.

USA implemented a GHG Emission legislation including CO2, CH4 and N2O

It is unlikely that EU also would include CH4 and N2O, since the EU emission inventories show only 0,9% from N2O and 0,1% from CH4 already calculated as CO2 äquivalent.





Information

about vehicles to the final customer about smoke (pollutant emissions) and fuel efficiency and GHG emission rating.

Penalty:

In case of violating GHG regulations.

Example: Hyundai and Kia Clean Air Act Settlement from November 3, 2014.

Hyundai and Kia will pay a $100 million civil penalty for selling 1.2 million vehicles, that will emit appr. 4.75 million tons of greenhouse gases (GHG) in excess of what the automakers certified.

Plus forfeit GHG emission credits of $200 million collected by these violations.

Plus implement measures ($50 million) to prevent future violations.

GTR 15: GLOBAL TECHNICAL REGULATION

What: It is a worldwide harmonized technical regulation how to test emissions (criteria and CO_2) and fuel and energy consumption of light duty vehicles. It is published by the UN-ECE and therefore agreed by all members of the United Nations. Earlier it was better known under the project name “WLTP”.

Why: Up-date and improvements of the current regulation (UN-ECE-83) for a

- better representativeness of test bed results of real world driving
- better reproducibility of the results

How:

- New Drive Cycle – WLTC (Worldwide harmonized Light duty Test Cycle).
- New Test Procedures - Road load determination, equipment, specifications, fuels, …)
- However “Harmonization” (global) and “Representativeness” (local) is always a trade-off.
- GTR-15 doesn’t define the emission limits and which components have to be measured.

When and Where:

- **Sept. 2017 it will start in Europe with Euro-6c.**
- Over time it will be implemented in most of local light duty emission legislations.
- Japan will implement it mid term, too. (GTR-4 for Heavy Duty is already implemented)
- USA will not implement it, and will use the technical regulation CFR-1066.

GTR 15 / WLTP: PROJECT

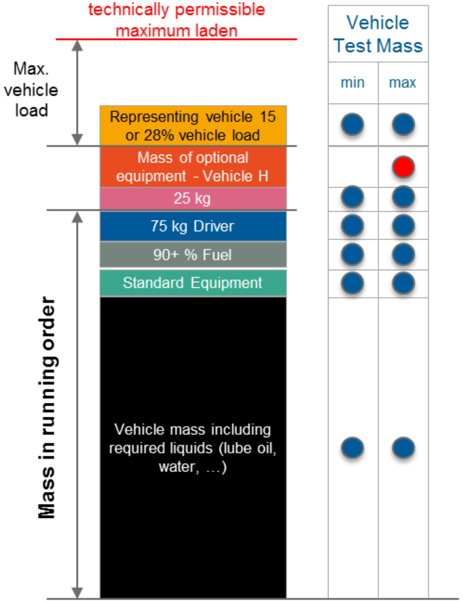
What is new:

With Phase-1 not everything in the European light vehicle emission type approval will be changed. GTR-15 will replace the Type-I test of UN-ECE R-83 and UN-ECE R101.

The definition of the other test types will still be following UN-ECE R-83 specifications, but most likely replacing in this types the NEDC cycle with the WLTC cycle.

Emission Type Approval Test Types		Phase 1	Phase 2
Type-I	Average emission after a cold start	GTR-15	GTR-15 (2015-2018) Low temperature High altitude test Durability In-service conformity On-board diagnostics Air conditioning Energy efficiency OCE and RDE
Type-IA	Real Driving Emission (RDE)	→ RDE	
Type-II	CO Idle test	UN-ECE R-83 (NEDC->WLTC)	
Type-III	Crankcase emission		
Type-IV	Evaporative Emission		
Type-V	Durability test		
Type-VI	-7°C low temperature emission test (like Type-I testing but at -7°C)		
OBD	On Board Diagnostic		
CO2 + FC EC + E-Range	CO2 + Fuel Consumption, Energy consumption and electric range for E-Vehicles	GTR-15	
Reg-24	Smoke Opacity for compression ignition engines	→ UN-ECE R-24	

GTR 15: GLOBAL TECHNICAL REGULATION



Main changes for emission testing:

- A new drive cycle with 4 Phases and 30 minutes long.
- Drive cycle is different for different vehicle classes C1, C2, C3a and C3b, which depends on the Power/Weight ratio of the vehicle and the max. velocity.
- Manual gear shifting point are calculated individually for each vehicle.

- More detailed definition of the road load measurement, road load simulation on the chassis dynamometer and vehicle weight and options.
- Definition of vehicle preparation, conditioning before and during the test (temperature, battery charging, ...)

- More accurate definition of the temperature 23°C +/-5°C, during soak , engine start (+/-3°C) and test execution (+/-5°C).
- Changes in test and measurement sequences
- Electric energy flow evaluated for the 12V vehicle battery and batteries must not be loaded during soak time
- …

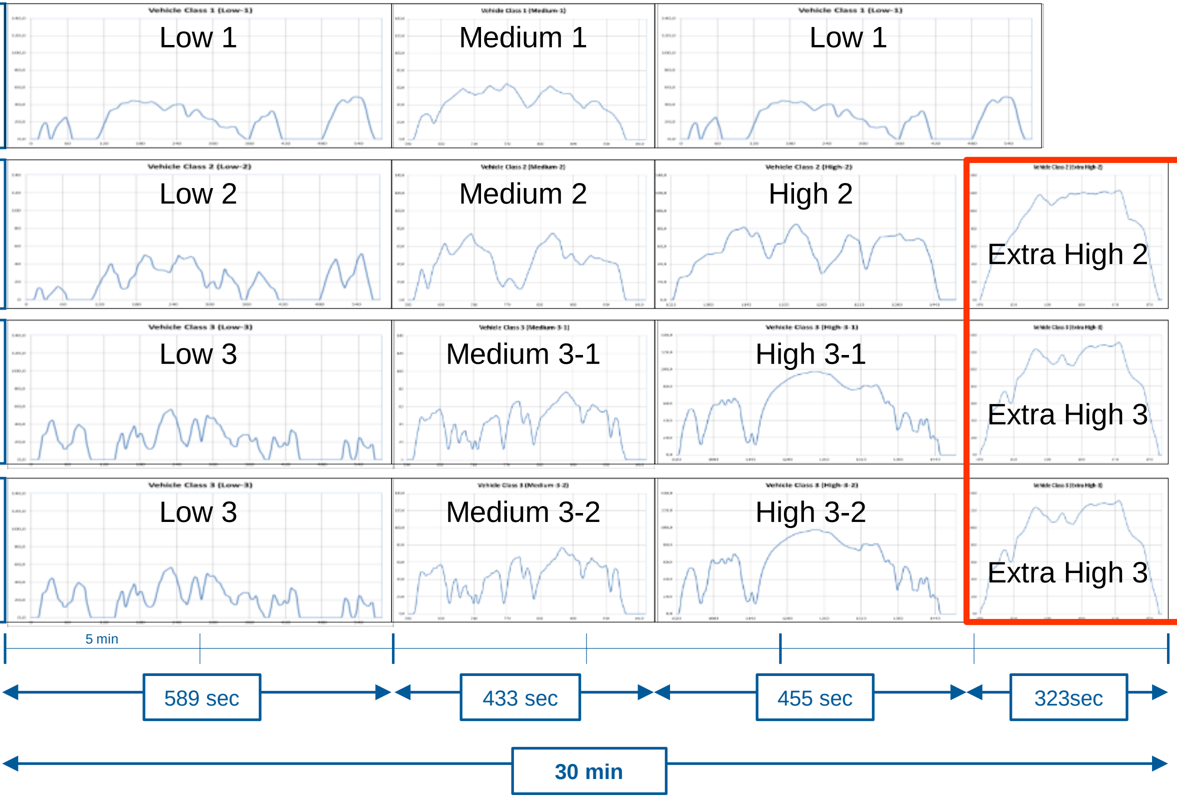
WLTC: WORLDWIDE LIGHT-DUTY TEST CYCLES

Class 1
≤ 22 W/kg

Class 2
> 22 ≤ 34 W/kg

Class 3a
> 34 W/kg
v_max < 120 km/h

Class 3b
> 34 W/kg
v max ≥ 120 km/h



Contracting parties (i.e. Countries) may exclude the Extra-High phase, when not adequate for the local driving behavior. (like India)

Manual gear shifting is set individually for each vehicle, based on cycle power requirements versus vehicle mass and power

RDE SHOULD BE KNOWN SINCE 2007 (EU-5)

Regulation (EC) 715/2007 Chapter II, Article 4:

- Tailpipe Emissions and Evap-Emissions
- No reference to a known driving cycle anymore
- But emission requirements for “normal conditions of use”

In addition, the technical measures taken by the manufacturer must be such as to ensure that the tailpipe and evaporative emissions are effectively limited, pursuant to this Regulation, throughout the normal life of the vehicles under normal conditions of use. Therefore, in-service conformity measures shall be checked for a period of up to five years or 100 000 km, whichever is the sooner. Durability testing of pollution control devices undertaken for type approval shall cover 160 000 km. To comply with this durability test, the manufacturers should have the possibility to make use of test bench ageing, subject to the implementing measures referred to in paragraph 4.

VEHICLE EMISSION TESTING REQUIREMENTS

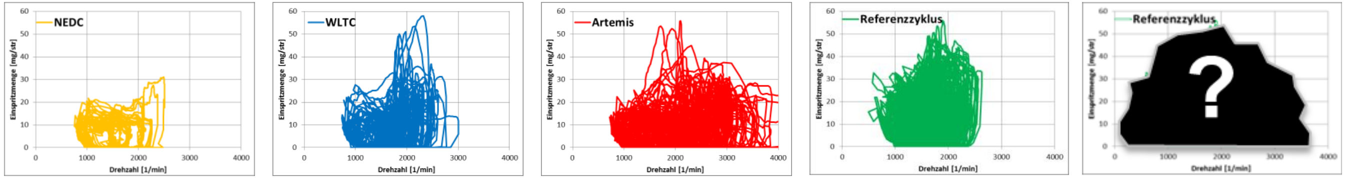
Emission Test Types		SI – Vehicle inclusive Hybrids									CI-Vehicle inclusive Hybrids		Pure Electric	H2 Fuel cell
	Fuel System =	Mono-Fuel				Bi-Fuel			Flex-Fuel		Mono Fuel	Flex Fuel		
	Fuel Type =	Gasoline	LPG	NG	Hydrogen	Gasoline LPG	Gasoline NG	Gasoline Hydrogen	Gasoline Ethanol	NG H2NG	Diesel	Diesel Bio-Diesel		
Type-I	Average Emission	✓	✓	✓	✓	✓ both fuels	✓ both fuels	✓ both fuels	✓ both fuels	✓ both fuels	✓	✓ both fuels		
Type-IA	Real Driving Emission	✓	✓	✓	✓	✓ both fuels	✓ both fuels	✓ both fuels	✓ both fuels	✓ both fuels	✓	✓ both fuels		
Type-II	CO Idle test	✓	✓	✓		✓ both fuels	✓ both fuels	✓ Gasoline	✓ both fuels	✓ NG				
Type-III	Crankcase emission	✓	✓	✓		✓ Gasoline	✓ Gasoline	✓ Gasoline	✓ Gasoline	✓ NG				
Type-IV	Evaporative Emission	✓				✓ Gasoline	✓ Gasoline	✓ Gasoline	✓ Gasoline					
Type-V	Durability test	✓	✓	✓	✓	✓ Gasoline	✓ Gasoline	✓ Gasoline	✓ Gasoline	✓ NG	✓	✓ both fuels		
Type-VI	-7°C low temperature	✓				✓ Gasoline	✓ Gasoline	✓ Gasoline	✓ both fuels					
OBD	On Board Diagnostic	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
CO2 + FC Energy + Range	CO2 and FC E-energy cons. and electric range	✓	✓	✓	✓	✓ both fuels	✓ both fuels	✓ both fuels	✓ both fuels	✓ both fuels	✓	✓ both fuels	✓	✓
Reg-24	Smoke Opacity										✓	✓		

Note: Gasoline includes E5/E10 and Diesel includes B5/B7 and NG includes Bio-methane

RDE - IMPACT

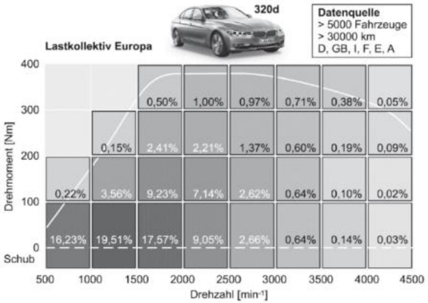
Emissions must be low in a much wider range of vehicle operation:

- Larger engine map area must be covered, compared to NEDC cycle



How is "normal condition of use" defined:

- Is it based on vehicle categories, size, rated power, driver behavior, ….



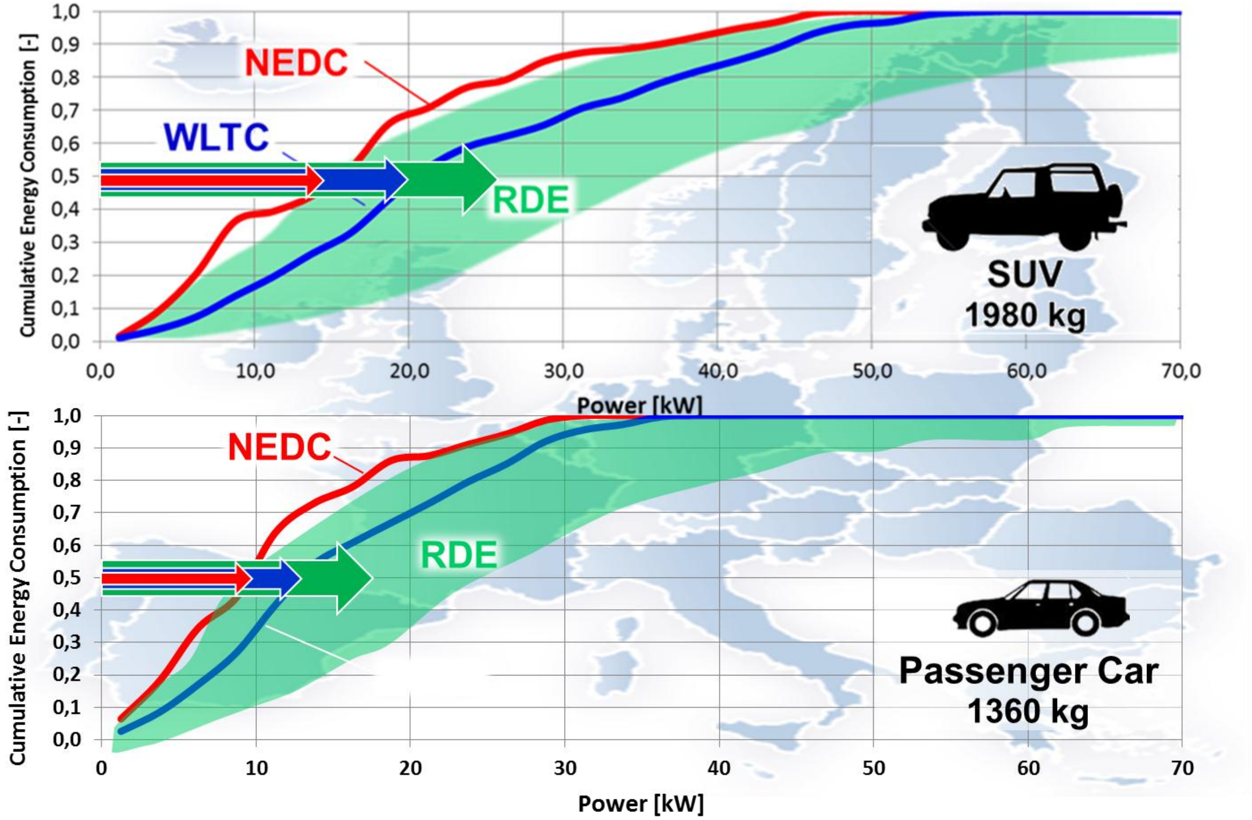
Average engine speed/load map collective of a BMW 320d by customers on the road.

FAD Conference 2014, RDE-Anforderungen und Lösungen aus OEM-Sicht. Hans-Jürgen Brüne, Andreas Bittermann, Thomas Fortner, BMW Motoren GmbH

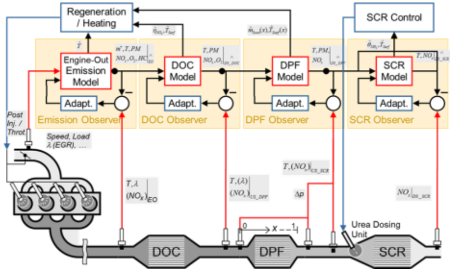
Emissions must be low in a much wider range of street and ambient conditions:

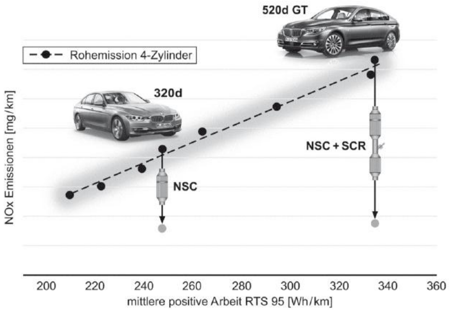
- Temperature, humidity, slope and altitude, curves, …

RDE - IMPACT


1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
Cumulative Energy Consumption [-]
NEDC
WLTC
RDE
SUV
1980 kg
0,0
10,0
20,0
30,0
40,0
50,0
60,0
70,0
Power [kW]
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
Cumulative Energy Consumption [-]
NEDC
RDE
Passenger Car
1360 kg
0
10
20
30
40
50
60
70
Power [kW]

RDE: POSSIBLE IMPACTS ON VEHICLES





Possible impacts of RDE on engine design:

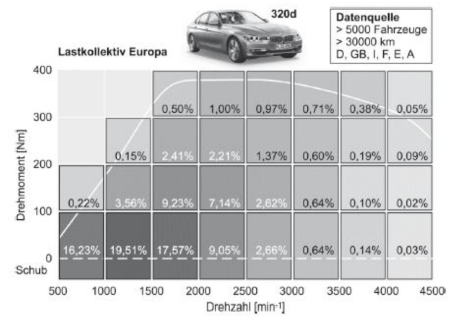
- Emission optimization on a wide engine map area
- Component protection (like turbo charger, catalysts, … cooling) can't be made by rich combustion anymore (-> cooled exhaust manifolds)
- Scavening of turbo charger becomes problematic
- ….

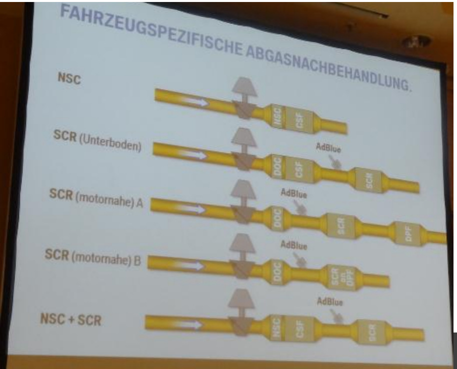
Possible impacts of EU-6c and RDE on Exhaust Aftertreatment Systems (EAS)

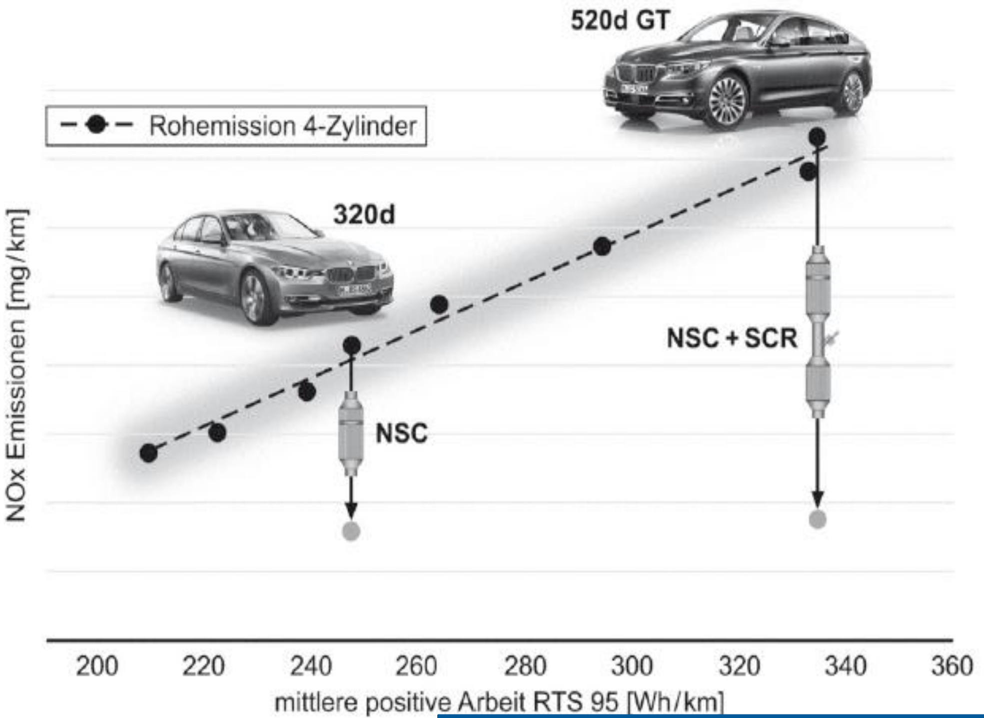
- Increased volumes of EAS to accommodate high exhaust flow under "normal condition of use"
- Avoid cool down of EAS, due to fuel shut off during deceleration or down hill driving
- **Gasoline:**
  - GDI most likely with Gasoline Particulate Filter (GPF) since EU-6c PN limit reduction and RDE). If not now, then EU may test PN down to 10nm PN instead of 28nm.
- **Diesel:**
  - Deactivation of EGR at higher altitude (up to 1350m) not possible
  - NOx Aftertreatment mandatory, since (EU-6b and RDE)
    - Lean NOx Traps (LNT) most likely not efficient enough
    - Mainly SCR systems or even SCR in combination with LNT (to cover wide exhaust temperature range and reduction of AdBlue consumption)
    - Higher AdBlue consumption of SCR so that driver has to refill by itself. Refills aligned with service intervals not possible anymore
- ….

VW will have in 2017 50 models with SCR for EU-6c & RDE

Source: VW Presentation, Dr. Dorenkam
FAD conference, Dresden 2014





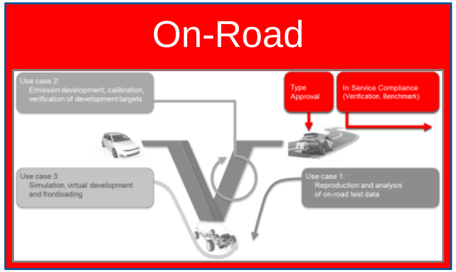


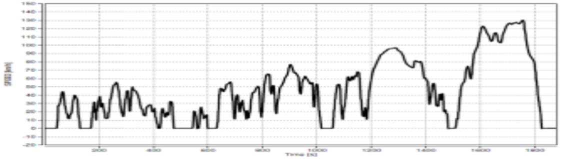
AVL

BMW will have NSC plus SCR on board for EU-6c & RDE

Source: BMW Presentation, H-J Brüne
FAD conference, Dresden 2014

RDE – ON THE ROAD



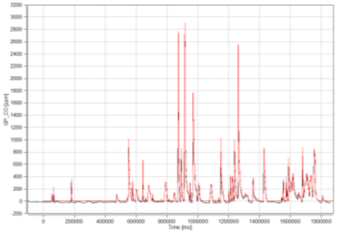


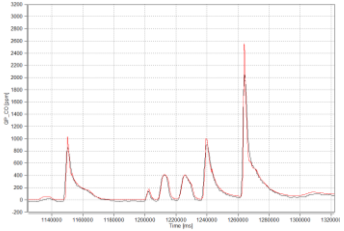
PEMS versus chassis dyno emission laboratory results validation:

- In general for data plausibility and quality reasons
- If ECU data are used as exhaust flow rate, which is possible for R&D and In-Service conformity testing (not allowed for type approval testing)

1. Correlation of <u>emission concentrations</u>, only.:

- A first test comparing only the concentrations between a PEMS and an emission laboratory emission analyzer bench, shows the correlation of the analytical systems, excluding exhaust flow rate determination, time alignment and modal mass calculations.





2. Correlation of <u>total mass emission</u>:

- Only a full correlation between PEMS and an emission laboratory emission mass results will prove the correctness of PEMS measurements. Permissible tolerance for ISC are:
  - THC +/- 10 mg/km or 10% of lab. result, whichever is larger
  - CO +/- 150 mg/km or 30% of lab. result, whichever is larger
  - NOx +/- 15 mg/km or 20% of lab. result, whichever is larger
  - CO2 +/- 5 mg/km or 8% of lab. result, whichever is larger

RDE – ON THE ROAD

AVL

Institute for Internal Combustion Engines and Thermodynamics

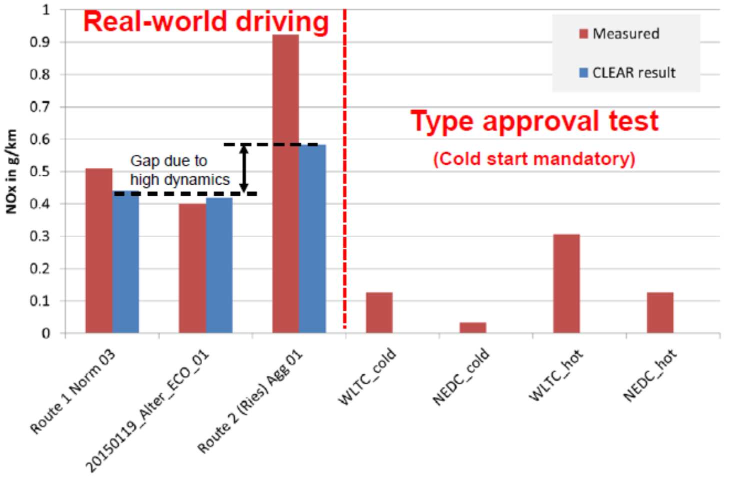
TU Graz

How do actual EU 6 diesel cars behave in RDE?

Example one a EURO 6 diesel car tested in 2 routes in the area of Graz

→ Aggressive driving with high dynamics can not fully be corrected by the CLEAR method (CLEAR compensates for abnormal distribution of power but not for abnormal dynamics)

→ Aggressive driven route would be invalid due to exceedance of v*a threshold (note: not decided if such a threshold will come into force)



Stefan Hausberger RDE test procedure

Result of CLEAR (from TU-Graz) :

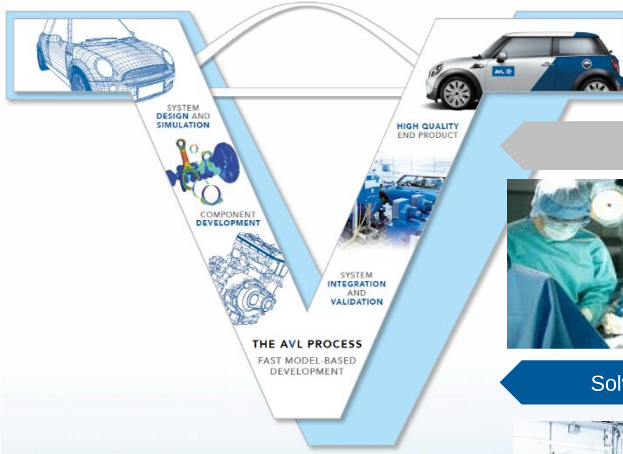
- The Real-world driving shows the effect of the CLEAR tool. The read bar shows the measured NOx emission mass and the blue bars show the result after applying the CLEAR tool.
- On Route 2 a high downscaling effect of high emission of a high dynamic drive is significant.

Result of CLEAR (from TU-Graz) :

- The increase of the test bed type approval emission results from the NEDC drive cycle to the WLTC drive cycle and procedures.
- That hot start emissions are significantly higher than cold start emissions. That is the opposite to the real physical behavior of an engine and exhaust aftertreatment systems. But the result of an emission optimization for the official type approval test specifications.

Source: Prof. Hausberger, TU-Graz @ Research Networking Day 2015, Graz

RDE: DEVELOPMENT WORKFLOW



Sick in the hospital | Sick at the doctor | Sick at home



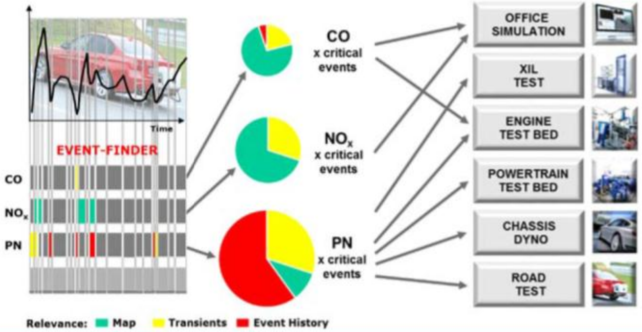

Solving the problem | Analyzing the problem | Validation of Problem | Indication of a problem



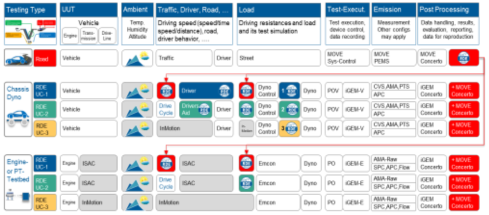

All types of test beds (Engine-, Powertrain-, Chassis Dyno) | Chassis Dyno | on the road

RDE: DEVELOPMENT WORKFLOW

Development process → Identification of potential risk areas "EVENT-FINDER" → Evaluation and classification of potential risk events → Test definition & allocation to optimum test environment → Validation & robustness assessment → **Testing Environment**



Simulation

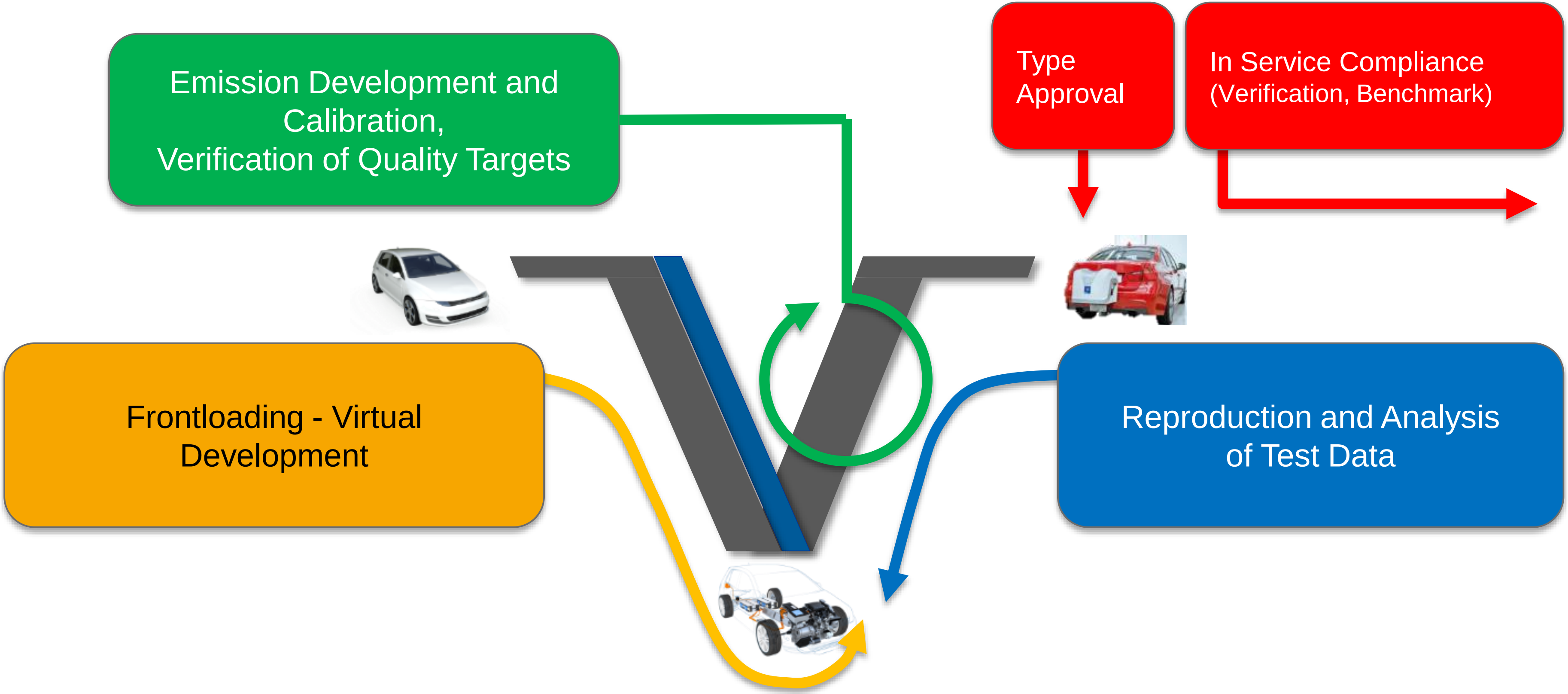


	GASOLINE	DIESEL
Engine map (stationary)	• Enrichment • Scavenging • Cat space velocity	• EGR • Injection Timing • SCE Dosing
Transient effects	• Transient fuelling (metering / mixture formation)	• EGR transient control • Air path
Event history	• Catalyst temperature • Engine temperature	• Conditioning EAS (Loading,temperature) • Engine temperature

TEST CELL – RDE READY CONFIGURATIONS

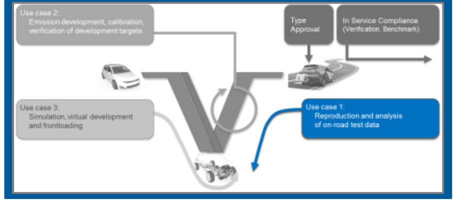
Testing Type		UUT		Ambient	Traffic, Driver, Road, …			Load			Test-Execut.		Emission	Post Processing	
		Vehicle Engine / Trans-mission / Drive-Line		Temp. Humidity Altitude	Driving speed (speed/time speed/distance), road, driver behavior, ….			Driving resistances and load and its test simulation			Test execution, device control, data recording		Measurement Other configs may apply	Data handling, results, evaluation, reporting, data for reproduction	
	Road	Vehicle			Traffic		Driver	Street			MOVE Sys-Control		MOVE PEMS	MOVE Concerto	RDE READY
Chassis Dyno	RDE UC-1	Vehicle			RDE READY	RDE Controler		RDE READY	Dyno Control 1	Dyno	POV	iGEM-V	CVS,AMA,PTS APC	iGEM Concerto	+ MOVE Concerto
	RDE UC-2	Vehicle			Drive Cycle	Drivers Aid	Driver	RDE READY	Dyno Control 2	Dyno	POV	iGEM-V	CVS,AMA,PTS APC	iGEM Concerto	+ MOVE Concerto
	RDE UC-3	Vehicle			InMotion		Driver	In-Motion	Dyno Control 3	Dyno	POV	iGEM-V	CVS,AMA,PTS APC	iGEM Concerto	+ MOVE Concerto
Engine- or PT-Testbed	RDE UC-1	Engine	ISAC		RDE READY	ISAC		RDE READY	Emcon	Dyno	PO	iGEM-E	AMA-Raw SPC,APC,Flow	iGEM Concerto	+ MOVE Concerto
	RDE UC-2	Engine	ISAC		Drive Cycle	ISAC		RDE READY	Emcon	Dyno	PO	iGEM-E	AMA-Raw SPC,APC,Flow	iGEM Concerto	+ MOVE Concerto
	RDE UC-3	Engine	InMotion		InMotion				Emcon	Dyno	PO	iGEM-E	AMA-Raw SPC,APC,Flow	iGEM Concerto	+ MOVE Concerto

HOW TO DEVELOP FOR RDE?



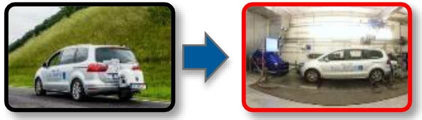
RDE – REPRODUCTION AND ANALYSIS

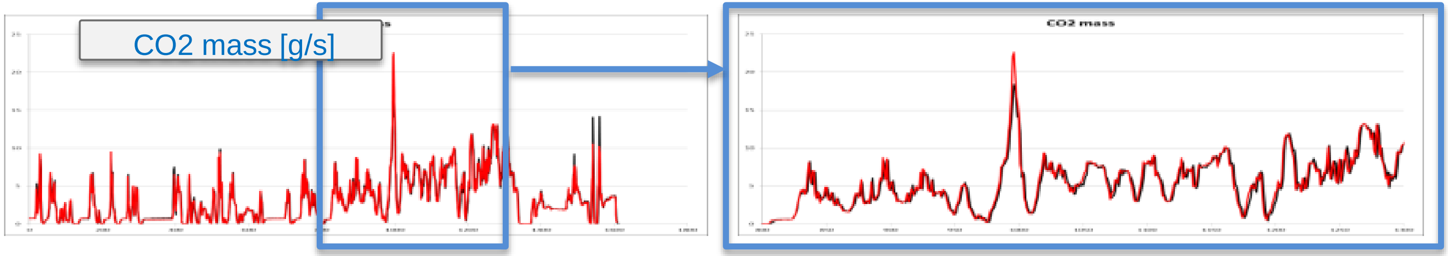
Reproduction



Results of AVL RDE reproduction development work:

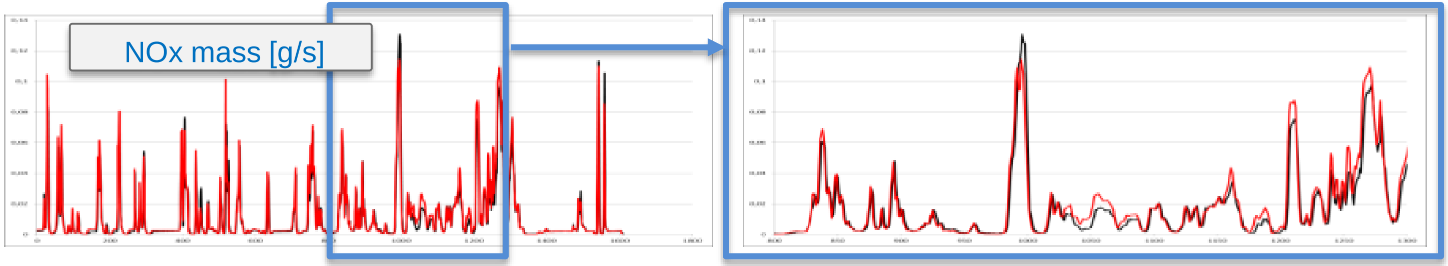
- Euro-5 Diesel passenger car with DOC, SCR and DPF.
- These data were measured during preliminary tests of a new test methodology under develop. It can not be expected that the here shown good correlation can always be achieved.





CO2 mass

Road	178,1 g/km
Lab.	177,9 g/km
Deviation	-0,1 %

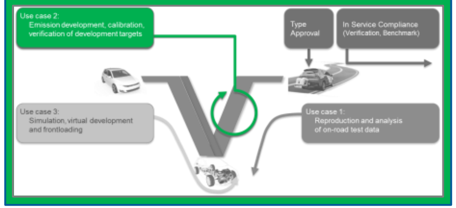


NOx mass

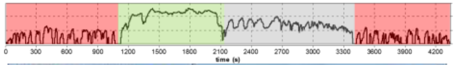
Road	0,633 g/km
Lab.	0,692 g/km
Deviation	+9,3 %

RDE – CONVENTIONAL REFERENCE DRIVE CYCLES

Conventional



Distance/Time	52,6km	4300s
City	20%	47%
Highway	43%	23%
Interstate	37%	30%



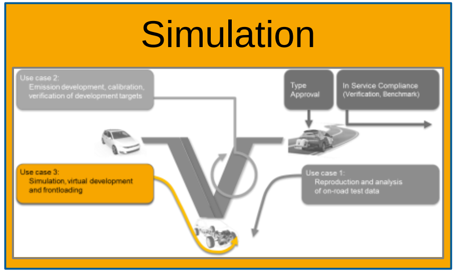
Conventional drive cycle testing but with RDE "Reference" cycles:

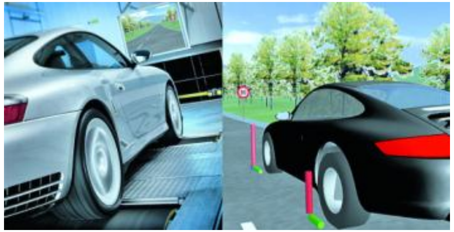
- The current development methodology , which is mostly based on standard reference cycles, is extended by already known or newly developed "RDE Reference Cycles".
- These include variations of velocity, road gradient, curve radius, ambient conditions, …
- Reproducible and comparable results, also between different vehicles

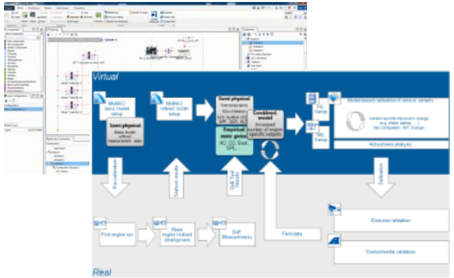
Drive Cycle based development:

- Beside the well known emission cycles, like WLTC, NEDC or FTP75 also other known cycles will be used. Like
  - Artimis (also known as CADC), which was used in the past mainly for emission modeling and emission inventory estimations
  - Standardized Random Test Sequence, like RTS95 ("aggressive")
  - Specific "RDE Reference cycles" which are generated by an OEM specificly for its vehicle types.
  - Drive cycles generated by a "Random Cycle Generator", like the one developed by TNO on base of the WLTC data base.
  - or specific drive cycle maneuver elements combined to a test sequence like a "finite element approach".

REAL DRIVING EMISSION







Simulation technologies to:

- address the "**infinite variables involved in real world driving**"
- master todays "**large number of vehicle models and variants**".

Virtual Integration and Front-Loading Calibration:

- Virtual simulation of random driving maneuvers with full variability of ambient conditions, driver types, vehicle variants, connected powertrain, …
- from pure simulation, Hardware in the Loop (HIL) to conventional test beds
- Evaluation of powertrain and vehicle concepts, definition of solutions and engineering targets, calibration in non standard ambient conditions

Implementation:

- Based on InMotion
- Engine- or Powertrain test beds
- 4x4 Chassis dyno test beds with individual wheel dynos.
- up to GPS Emulation on chassis dyno testbed for car to infrastructure integration

Innovation Adoption:

- Simulation approach, especially for "classic" emission development and testing groups, require still a high willingness and ramp up time to adopted to such innovations.

RDE CHALLENGES ESTIMATIONS – TEST CAPACITY

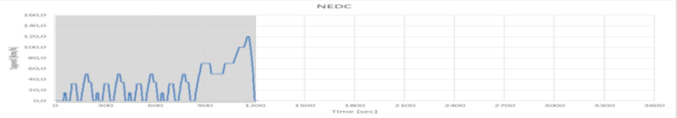
• Number of development chassis dyno testbeds	=	10 Chassis dynos
• 5 days/week, 50% in 1 and 50% in 2 shift operation, 7 tests/shift, 49 weeks/year	=	2.600 Tests per year per CD testbed
• **Total test capacity**	**=**	**26.000 Tests per year**

Effects on test bed capacity caused by:

• Reduction of number of tests by longer test time (NEDC 20min -> WLTC 30min)	=	3.700 Tests per year must be compensated

TEST RUN TIME INCREASE BY NEW LEGISLATION

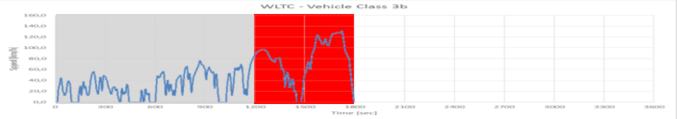
NEDC



20 min NEDC

Including pre- and post test activities one NEDC vehicle tests requires typical 60 min.

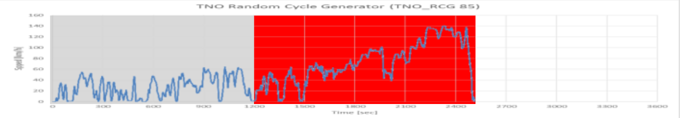
WLTC



+ 10 min

At a chassis dyno that would already reduce the number of tests per shift from typical 7 to 6.

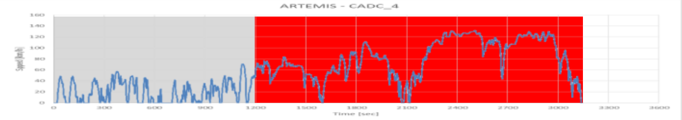
TNO Random Cycle Generator



+ 22 min

TNO Random cycle generator is based on the WLTC data base, same as the RDE evaluation tools CLEAR and EMROD.

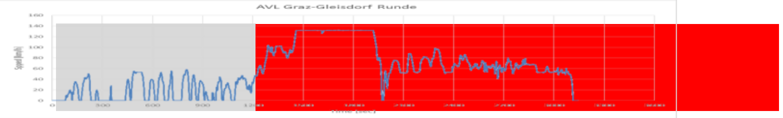
ARTEMIS CADC_4



+ 32 min

Artemis is used for emission inventor estimations in the EU, therefore it is seen to be quite representative for average vehicle driving within Europe.

RDE Reference Cycle (AVL Gleisdorf Runde)



+ 52 min

Typical every manufacturer, engineering service supplier and technical service has its own RDE reference road and test cycle

RDE Road Test Reproduction

RDE road test shall be between 90 to 120 min long

+70 … 90 min

For further analysis and development RDE tests on the road will be reproduced on a test bed.

RDE CHALLENGES ESTIMATIONS – TEST CAPACITY

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• 5 days/week, 50% in 1 and 50% in 2 shift operation, 7 tests/shift, 49 weeks/year	=	2.600 Tests per year per CD testbed
• **Total test capacity**	**=**	**26.000 Tests per year**

Effects on test bed capacity caused by:

• Reduction of number of tests by longer test time (NEDC 20min -> WLTC 30min)	=	3.700 Tests per year must be compensated
• additional 50 chassis dyno tests needed since RDE		
@ 20 models each in 10 EU variants tested in the next 3 years until 2018	=	3.300 Tests per year should be added
• **Additional needed test capacities**	**=**	**7.000 Tests per year**

+27% more, but what ?

- More test beds,
- Higher Efficienciy,
- Other test bed types (Powertrain- , Engine, HIL, …) or/and
- more effective development methods and tools (simulation, front loading

RDE READY – CLOSING THE GAP'S