PASSENGER CAR EMISSION REGULATIONS

AVL-Italy Tech-Day 2014, Bologna, 21.10.2014

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AVL List GmbH

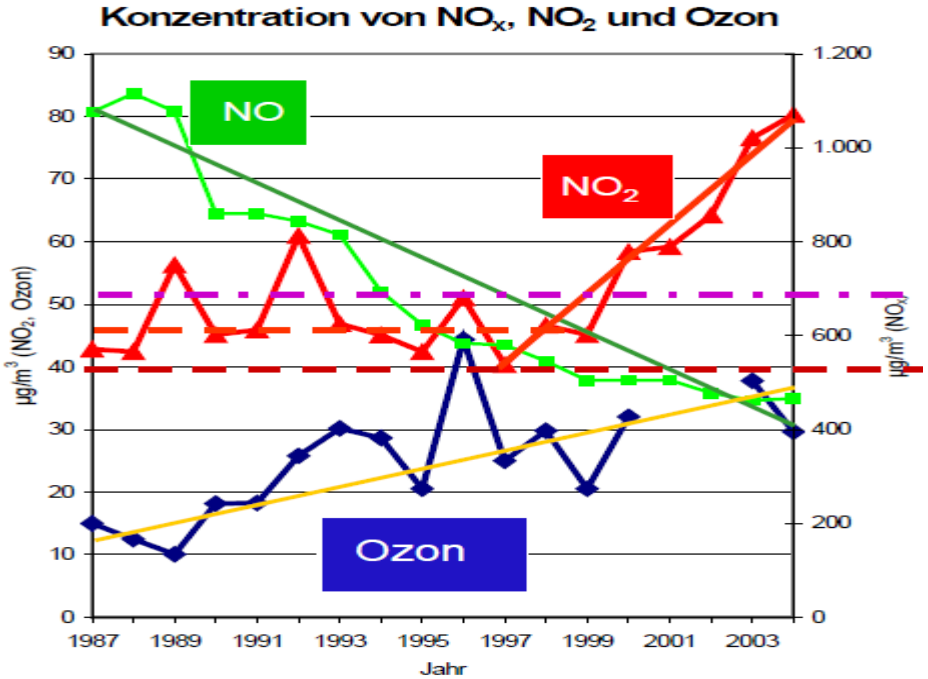
CONTENT

WHAT DRIVES EU EMISSION LEGISLATION?:

Air Quality Data:

Air quality data and transportation emission inventories don't show improvements in the last decade.

Some components, like NO2, even goes up (DPF is seen as the main reason for that)



Conclusion: **Reducing type approval limits, like in the past, does not work effectively anymore.**

Therefore the emission control process has be changed.

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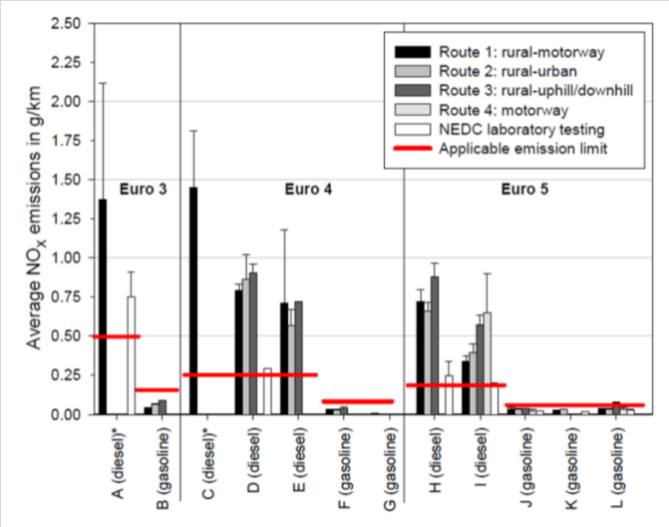
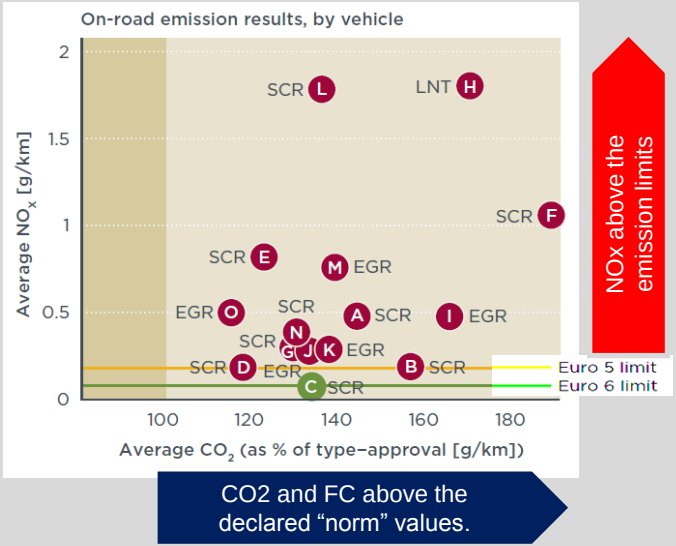
Emission measurement made on the road, showed that vehicle can have much (by factors) higher emissions, especially with the critical PM and NOx emissions.



Source: EU Joint Research Center Results – Complete trips – NOx

15 vehicles, 6 manufacturers, different NOx control technologies
In average the cars emit 7 times more NOx compared to the limit.



Source: ICCT International Council on Clean Transportation 2014
Real-world exhaust emissions from modern diesel cars a meta-analysis of PEMs emissions data from EU (Euro 6) and US (Tier 2 Bin 5/ULEV II) diesel passenger cars.

Conclusion: Reducing type approval limits, like in the past, does not work effectively anymore.

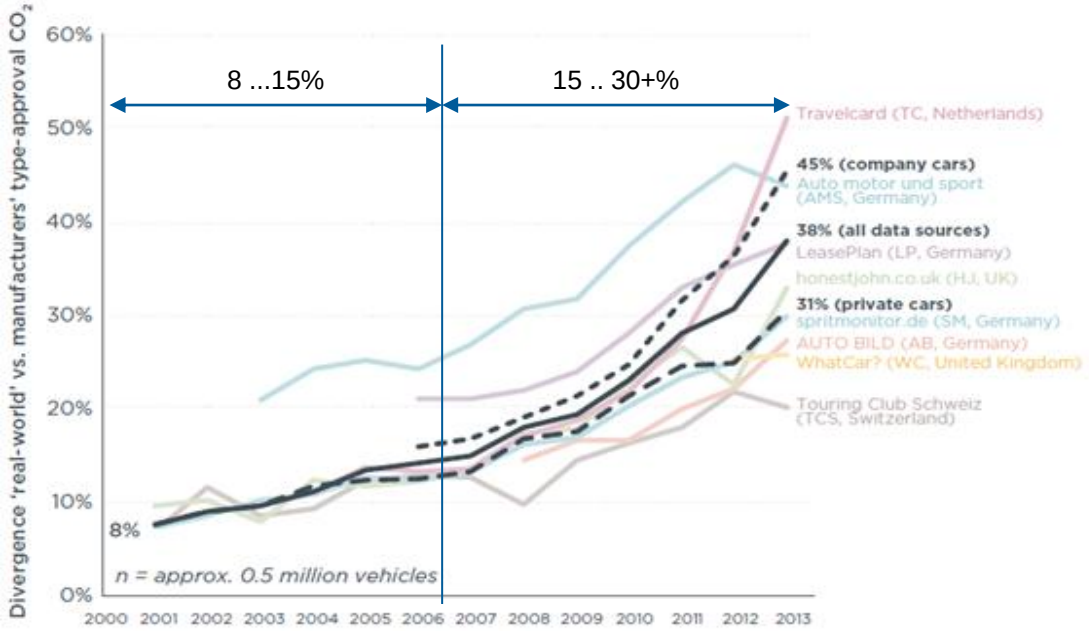
Therefore the emission control process has to be changed.

WHAT DRIVES EU EMISSION LEGISLATION?:

Real Fuel consumption and CO2 is much higher than Norm-Test results:

There was all the time some gap between lab and road, app. 10%

With the discussion about fuel consumption and the CO2 emissions with high fines the gap has increased up to 30% and more.

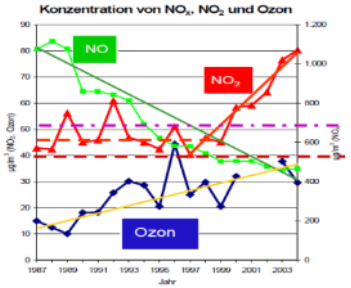


Conclusion: **Current legislations have been designed mainly for pollutant emissions measurement and were not accurate enough about CO2 and fuel testing. That was not very important at the time the current legislations were designed.**

A better definition towards fuel and CO2 testing.

Source: From laboratory to Road, White Paper International Council on Clean Transportation Sept. 2014

WHAT DRIVES EU EMISSION LEGISLATION?



Air Quality Data:

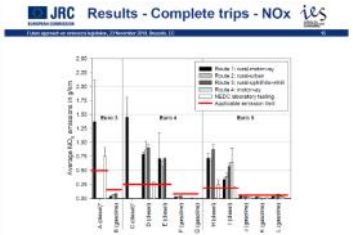
Air quality data and transportation emission inventories don't show improvements in the last decade.

Some components, like NO2, even increase (DPF is seen as the main reason for that)

Conclusion:

Reducing type approval limits only, does not anymore improve air quality. So the process of emission control must be changed.

→ RDE



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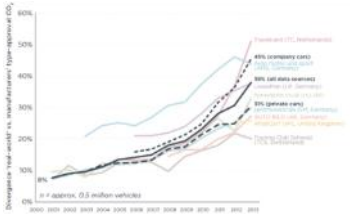

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→ GTR-15

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Motivation for emission legislation (EU)

New Legislation/Regulation structure

Euro-6 and GTR-15 (WLTP)

Real Driving Emissions

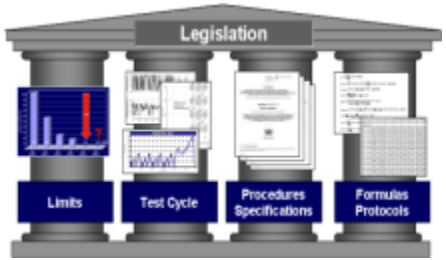
US Legislation/Regulation

Test bed layout for worldwide emission testing

Evaporative Emissions

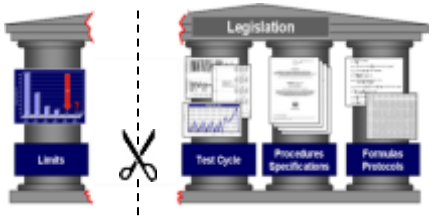
AVL Emission Testing Solutions and Products

EMISSION STANDARDS AND TECHNICAL REGULATIONS



Any Emission Control Legislation contains 4 main elements:

- Emission Limits, which define the maximum allowed tailpipe emissions
- Test cycle, how the engine or vehicle is operated
- Test procedures and specifications for the test- and measurement systems.
- Formulas and reporting defining how the final result is calculated and reported.
- In the past all 4 elements were defined in one “Book”, new legislations separate it into 2 “Books”



New European Legislation: “Split Level Approach”

- The legislation part defines the emission limits
- A global technical regulation defines how the measurement is done, including the test cycle, specifications and formulas.
- EU defines the limits and references for the technical regulation to the UN-ECE

New USA Legislation: “Standard setting part” and “Technical regulation”

- The “Standard setting part” defines the emission limits and the test cycle
- The “Technical regulation” defines how the measurement is done, including specifications and formulas.
- US-EPA (plus CARB) defines the standard setting part and the technical regulation

EMISSION STANDARDS AND TECHNICAL REGULATIONS

			EU-1	EU-2	EU-3	EU-4	EU-5a	EU-5b	EU-6b	EU-6c
			1992	1996	2000	2005	2009	2011	2014	2017
Test Cycle			ECE 15.04	ECE 15.05	NEDC	NEDC	NEDC	NEDC	NEDC	WLTC
Positive Ignition Engines (Gasoline)	CO	mg/km	2720	2200	2300	1000	1000	1000	1000	1000
	HC	mg/km			200	100	100	100	100	100
	HC + NOx	mg/km	970	500						
	NOx	mg/km			150	80	60	60	60	60
	NMHC	mg/km					68	68	68	68
	PM only GDI	mg/km					5	4.5	4.5	4.5
	PN	#/km							6E12	6E11
Compression Ignition Engines (Diesel)	CO	mg/km	2720	1000	640	500	500	500	500	500
	HC + NOx	mg/km	970	700	560	300	230	230	170	170
	NOx	mg/km			500	250	180	180	80	80
	PM	mg/km	140	80	50	25	5	4.5	4.5	4.5
	PN	#/km						6E11	6E11	6E11

no change | change | important

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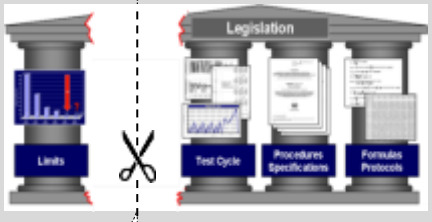

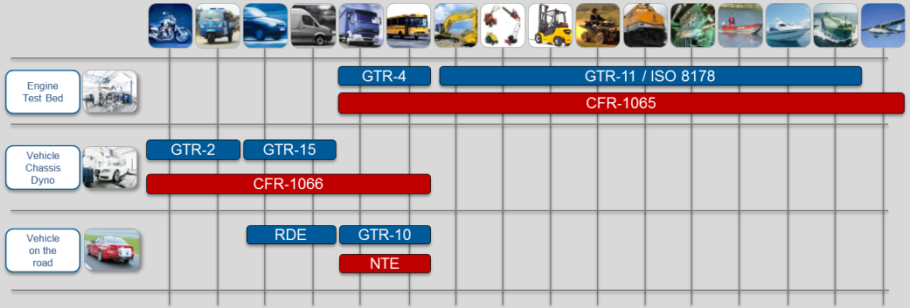

TECHNICAL REGULATIONS

Engine Test Bed

GTR-4

GTR-11 / ISO 8178

CFR-1065

Vehicle Chassis Dyno

GTR-2

GTR-15

CFR-1066

Vehicle on the road

RDE

GTR-10

NTE

Legend: Applied regulations for the emission standards of EU, UN-ECE US and CARB

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EURO-6c + GTR 15:

			EU-1	EU-2	EU-3	EU-4	EU-5a	EU-5b	EU-6b	EU-6c
			1992	1996	2000	2005	2009	2011	2014	2017
Test Cycle			ECE 15.04	ECE 15.05	NEDC	NEDC	NEDC	NEDC	NEDC	WLTC
Positive Ignition Engines (Gasoline)	CO	mg/km	2720	2200	2300	1000	1000	1000	1000	1000
	HC	mg/km			200	100	100	100	100	100
	HC + NOx	mg/km	970	500						
	NOx	mg/km			150	80	60	60	60	60
	NMHC	mg/km					68	68	68	68
	PM only GDI	mg/km					5	4,5	4,5	4,5
	PN	#/km							6E12	6E11
Compression Ignition Engines (Diesel)	CO	mg/km	2720	1000	640	500	500	500	500	500
	HC + NOx	mg/km	970	700	560	300	230	230	170	170
	NOx	mg/km			500	250	180	180	80	80
	PM	mg/km	140	80	50	25	5	4,5	4,5	4,5
	PN	#/km						6E11	6E11	6E11

no change | change | important

Euro-6:

Sept. 2014:

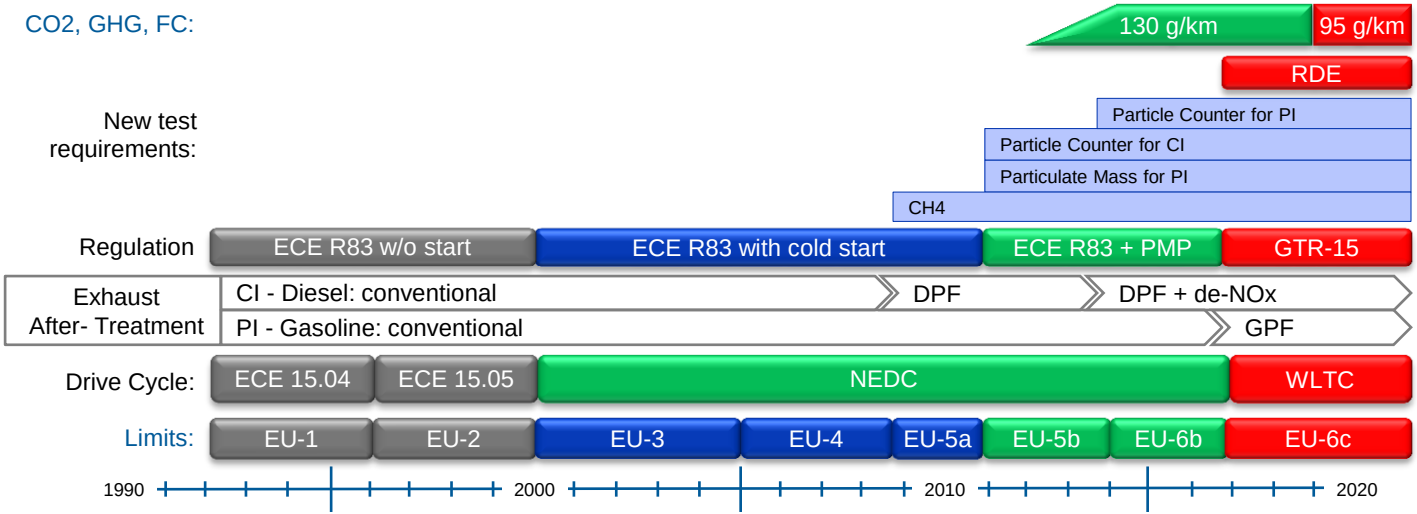
- Euro-6b starts with new lower limits and an PN limit for GDI.
- Is using the same test procedures as Euro-5b.
- Real Driving Emission (RDE) test, but without limits.

Sept. 2017:

- Euro-6c reduces the PN limits for GDI
- **GTR-15**
- RDE with limits.

- Euro-6 will result in:
  - Diesel engines with NOx exhaust aftertreatment systems (mainly SCR)
  - GDI Engines with GPF (Gasoline Particle Filter), with Euro-6c (2017)
  - RDE will ensure low emissions also under real driving conditions.

EU EMISSION CERTIFICATION: LIGHT-DUTY CARS



EU-6 Limits are not related to a cycle anymore!

GTR 15: GLOBAL TECHNICAL REGULATION NR. 15

What: It is a worldwide harmonized technical regulation how to test emissions (criteria and CO2) 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

Phase 1 (2009 - 2014)

- New drive cycle WLTC (World Lightduty Harmonized Test Cycle) by DHC group from worldwide data
  - 450.000 km von Europe
  - 153.000 km von USA
  - 98.000 km von Asia

- Test procedure for criteria compounds, CO2, fuel and energy consumption by DTP group with expert groups for:
  - Lab-Proc: Test conditions and measurement procedures of existing regulated compounds.
  - EV-HEV: Specific test and measurement procedures for electric and hybrid-electric vehicles.
  - PM-PN: Particle mass (PM) and particle number (PN) measurement
  - AP: Additional Pollutant measurements for NO2, N2O, NH3, Ethanol and Aldehydes.
  - Ref. fuels: Definition of reference fuels.

- First version of “WLTP” established as GTR-15 on 12 March 2014, Document date 12 May 2014
  - 234 pages

- Some issues have not been resolved in time,
  - therefore there is a Phase 1b and
  - an open issue list of the European Commission do be finalized for Euro-6c in 2017.

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.

Type	Description	Dyno	Auto-mation	CVS	Emission Bench	PTS	PN	Instrum-ents	SHED	Climatic Chamber
I	Average exhaust emission after a cold start	●	●	●	●	●	●			
II	CO concentration at idling speed							●		
III	Emissions of crankcase gases	●						●		
IV	Evaporation emissions (SHED - Test)	●	●						●	
V	Durability of anti-pollution devices	●	●	●	●	●				
VI	Low ambient temperature (-7°C) exhaust emission	●	●	●	●					●
OBD	Test of On Board Diagnostic Functionality	●	●	●	●	●				
	CO2 and Fuel consumption	●	●	●	●					
R24	Smoke opacity	●	●					●		

Phase 1

Phase 2

GTR-15

UN-ECE R-83

GTR-15

GTR-15 (2014-2018)

UN-ECE R-24

GTR 15: MAIN CHANGES

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	Low 1	Medium 1	Low 1	
Class 2 > 22 ≤ 34 W/kg	Low 2	Medium 2	High 2	Extra High 2
Class 3a > 34 W/kg v_max < 120 km/h	Low 3	Medium 3-1	High 3-1	Extra High 3
Class 3b > 34 W/kg v max ≥ 120 km/h	Low 3	Medium 3-2	High 3-2	Extra High 3

5 min

589 sec | 433 sec | 455 sec | 323sec

30 min

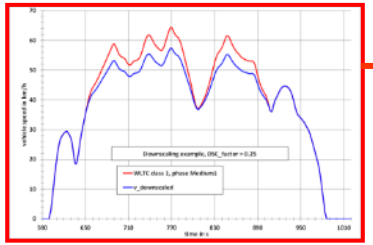
Contracting parties (i.e. Countries) may exclude the Extra-High phase, when not adequate for the local driving behavior. (like India)

WLTC: WORLDWIDE LIGHT-DUTY TEST CYCLES

Cycle modification – Downscaling:

Drivability problems may occur for vehicles with a power to mass ratios close to the borderlines between Class 2 and Class 3 vehicles or for very low powered vehicles in Class 1.

- In phases with high vehicle speed and high accelerations (Medium 1, Extra High 2, Extra High 3)
- Downscaling procedure will be applied to improve drivability
- The drive cycle will be downscaled by a mathematically method, which is specific for the individual vehicle.



$$v_{dsc,i} = v_{dsc,i-1} + a_{orig,i-1} \times t_{corr\_dec} \times 3.6 \quad (12)$$

with i = 1725 to 1762.

Determination of the downscaling factor

The downscaling factor f_{dsc} is a function of the ratio, r_{max} between the maximum required power of the cycle phases where the downscaling is to be applied and the rated power of the vehicle (P_{rated}).

The maximum required power, $P_{req,max,i}$ in kW, is related to a specific time i in the cycle trace and is calculated from the road load coefficients f_0, f_1, f_2 and the test mass TM as follows:

$$P_{req,max,i} = \frac{(f_0 \cdot v_{1,i}) + (f_1 \cdot v_{1,i}^2) + (f_2 \cdot v_{1,i}^3) + (1.1 \times TM \times \eta_{1,i} \times a_{1,i})}{3600} \quad (13)$$

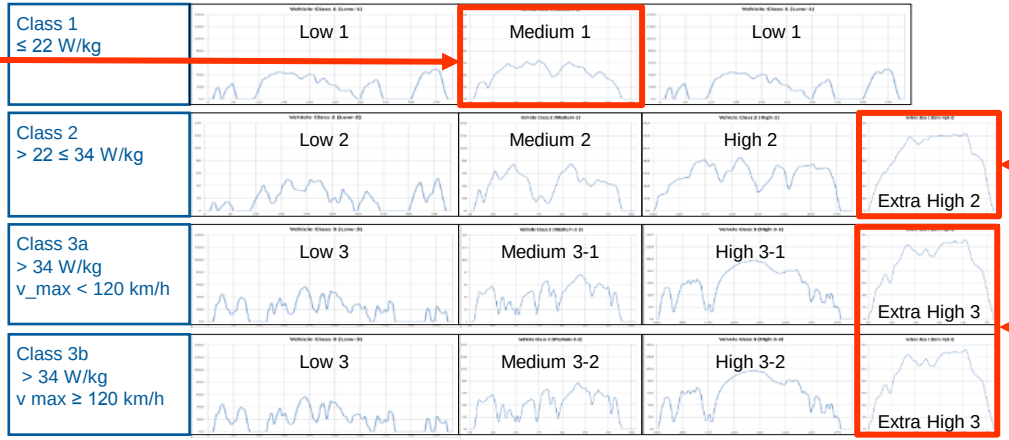
with f_0 in N, f_1 in N/(km/h) and f_2 in N/(km/h)^2, TM in kg.

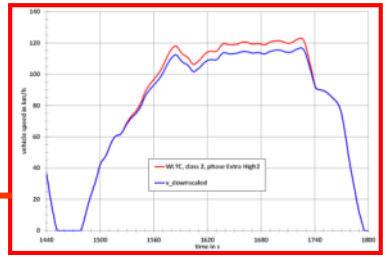
The cycle time i, at which maximum power or power values close to maximum power is required, is: 764 s for Class 1, 1574 s for Class 2 and 1566 s for Class 3 vehicles.

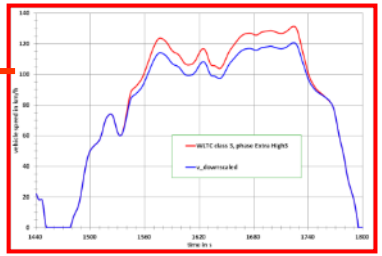
The corresponding vehicle speed values v_i and acceleration values a_i are as follows:

v_1 = 61.4 km/h, a_1 = 0.22 m/s² for Class 1,

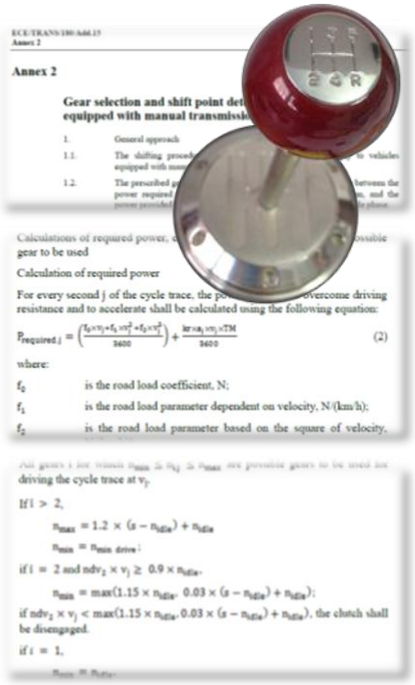
v_2 = 109.0 km/h, a_2 = 0.36 m/s² for Class 2,







WLTC: WORLDWIDE LIGHT-DUTY TEST CYCLES



Manual and Automatic Transmissions

- Manual gear shifting is all, when the “human driver” decide when the gears are shifted. Nevertheless how he does it. (Semi-automatic–transmission, or switching by buttons is all “manual”
- Automatic transmission is when a “control unit” decides when the gears are shifted.
- Testing is done in the “pre-dominant” mode, which comes up, when the car is switched on.

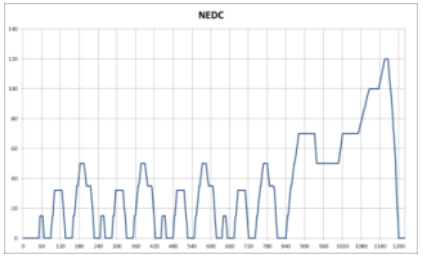
Manual gear shift point

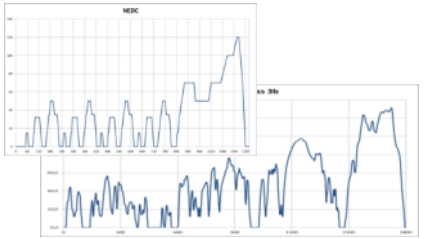
- are determined accordingly to a mathematical procedure that is based on the characteristics of the individual type vehicles, which balance between
  - power required to overcome driving resistance and acceleration requirements of the cycle and
  - vehicle mass and power provided by the engine in all possible gears at a specific cycle phase.

- Gear shift point calculation is based on:
  - Normalized engine speeds between idling speed and rated engine speed
  - Normalized full load power curves of rated power versus normalized engine speed
  - some logic conditions (If … then …), like minimum time between gear shifts

- There are no “steps” in the drive cycle for executing gear shifts, like it was in NEDC.

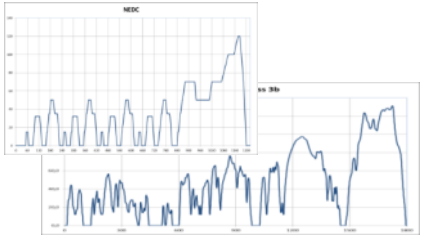
WLTC versus NEDC





	WLTP 3b:	NEDC:	Difference:	Notes:
Time [sec]:	1800	1180	35%	Test bed capacity ?
Phases	4	2	2 more	Number of CVS Bag
	Low	Urban		
	Medium	Extra-Urban		
	High			
	Extra-High			
Avg. speed [km/h]:	46	34	+ 53%	typically better fuel consumption
max. speed [km/h]:	125	120	+ 4%	
Idle	13%	27%	- 52%	less effect of engine Start/Stop
Cruse	4%	38%	- 90%	less stationary operation
Acceleration	44%	20%	+117%	more acceleration
Deceleration	40%	14%	+179%	more deceleration

WLTC versus NEDC



CO2 (Fuel consumption) Correlation NEDC versus WLTC

- Driving 10 typical diesel and 10 typical gasoline vehicles in the WLTC did not show big difference in the CO2 results. In average the difference between WLTC and NEDC were.
  - **+2% for gasoline**
  - **-2% for diesel vehicles**

			hot emissions, Diesel		hot emissions, Petrol	
region / cycle	speed part	Average speed (km/h)	CO2 emissions without idling periods (g/km)	CO2 emissions with idling periods (g/km)	CO2 emissions without idling periods (g/km)	CO2 emissions with idling periods (g/km)
WLTC	low	18.7	158.0	180.1	205.2	241.7
	medium	39.4	131.8	136.2	170.8	178.0
	high	55.8	125.2	127.1	156.1	159.2
	extra high	92.0	147.0	147.3	173.5	174.1
	total	**46.2**	**138.7**	**143.2**	**171.8**	**179.3**
		comparison with NEDC	**7.5%**	**1.9%**	**4.5%**	**-2.2%**
NECD	total		129.0	140.6	164.3	183.4

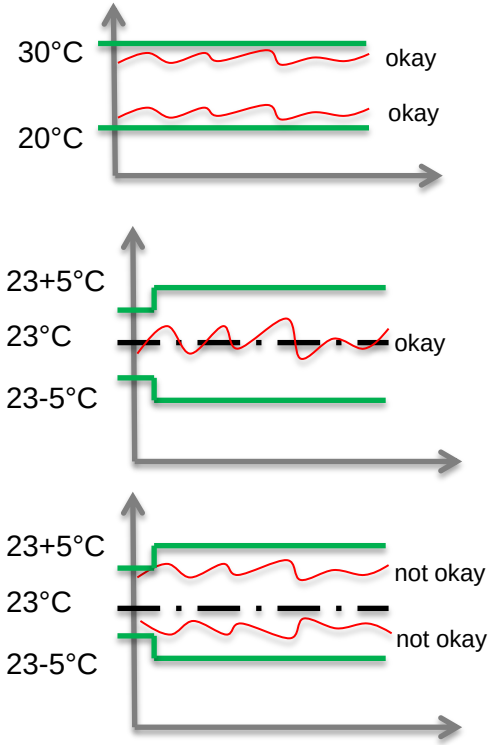
Table 3: Comparison of modeled CO2 emissions from typical diesel and gasoline vehicles.

Source: Technical report - Task 7 Europe-centric light duty test cycle and differences with respect to the WLTP cycle

Notes:

- In these tests only the drive cycle have been compared and not the associated test procedures. Both cycles were driven with the current UN-ECE R-83 test procedures, same dyno settings, vehicle preparation and conditioning.
- It is expected that using the GTR-15 test procedures will increase the CO2 results.

GTR 15: TEMPERATURE REQUIREMENTS



UN-ECE R-83: Temperature in Soak-Area and Test bed

- Temperature shall be between 20 and 30°C and relative stabile.

GTR-15: Temperature in Soak-Area and Test bed

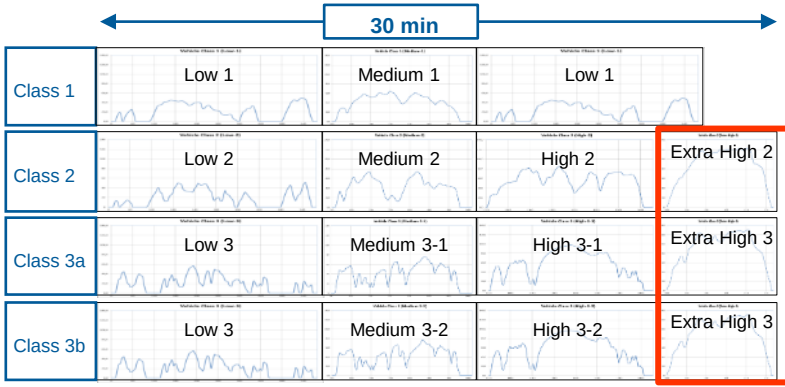
- 23°C This is a set point (296°K)
- 23°C +/-5°C Temperature soak area, on a 5 minute running average
- 23°C +/-3°C Temperature set point and tolerances during engine start
- 23°C +/-5°C Temperature set point and tolerances during test

- A set point with tolerances does not mean, that everything within the tolerance is okay. A clear Off-Set can be rejected by the Technical Service.

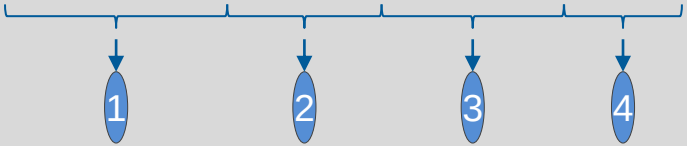
- Test cell and soak area temperatures measured and recorded with at least 1 Hz. Test cell air temperature and humidity (5.5 - 12.2g H2O/kg dry air) shall be measured at the vehicle cooling fan outlet

Note: GTR-15 defines temperatures in °K (296°K+/-5), here it is shown in °C without decimal paces, for a better understanding and in mind keeping.

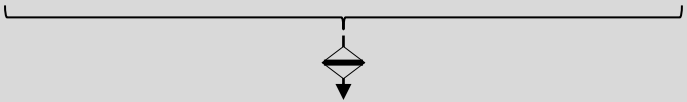
GTR-15: TEST SEQUENCE – EXHAUST SAMPLING



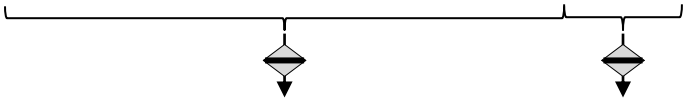
Contracting parties (i.e. Countries) may exclude the Extra-High phase, when not adequate for the local driving behavior. (like India)



Gaseous emissions are evaluated per phase. Diluted exhaust and dilution air is collected in one set of bags (ambient, exhaust) per phase.



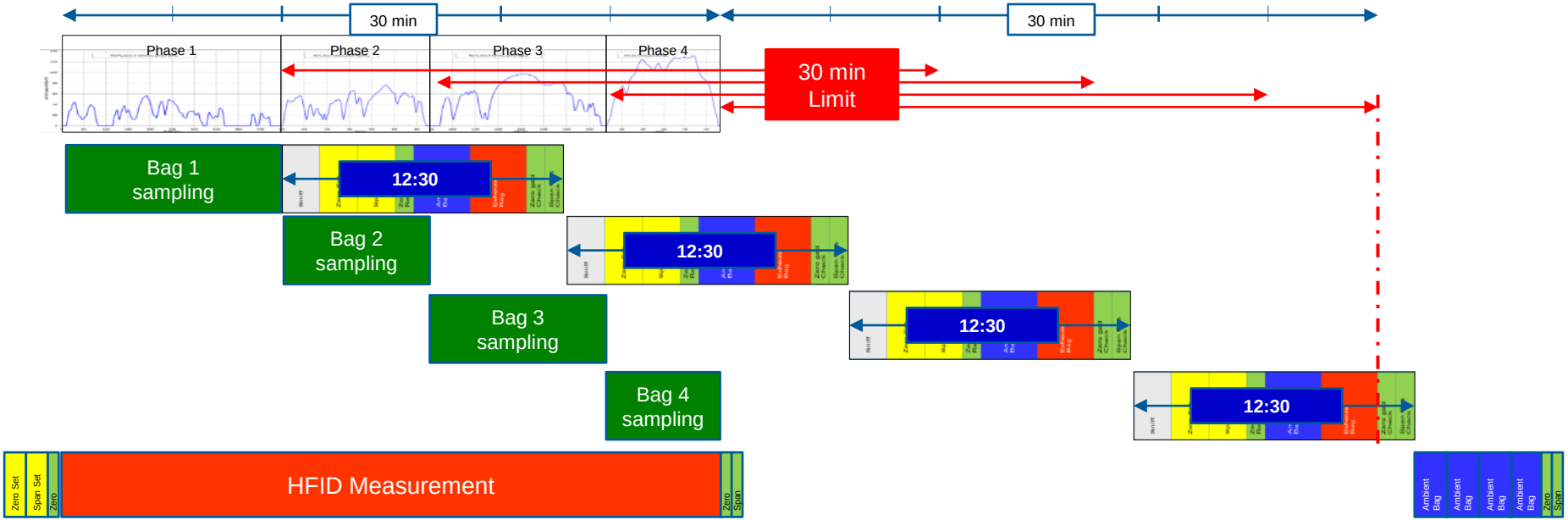
Particulate emissions are sampled on one PM-Filter for the whole test, without back-up filter.



Optional one PM-Filter can be used for Phase 1, 2 and 3, and a second PM-Filter for Phase 4. By that one 4 phase test can be executed, while calculating 2 result, one for 4 and one for 3 phases.

GTR-15: TEST SEQUENCE – BAG ANALYSIS

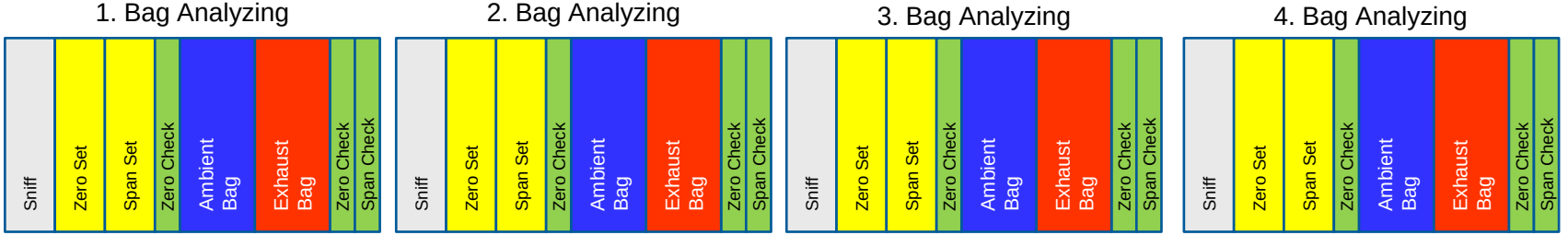
Bag Analysis in parallel to the test run.



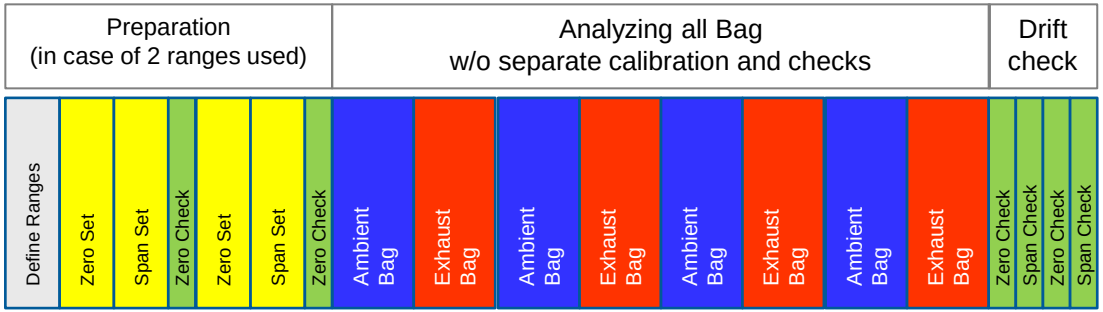
Note: Test and Bag Analysis Sequence depends on the actual emission system configuration! Therefore the here shown examples may differ from the actual possibilities:

GTR-15: TEST SEQUENCE – NEW BAG ANALYSIS

Old Bag Analysis Sequence: Sniff, Calibration and Drift check done for each phase of the test



GTR-15 Bag Analysis Sequence: It is possible to calibrate all analyzers/ranges before starting all analysis and to do the drift check only once after all bags have been analyzed

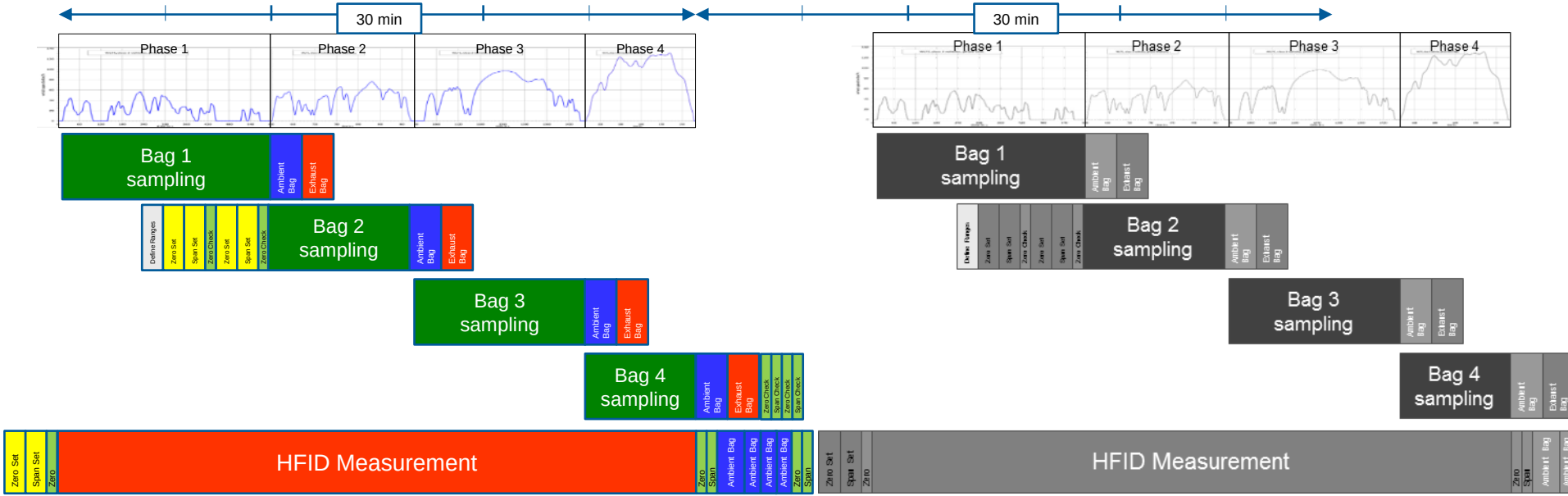


As soon as practical prior to analysis, the analyser range to be used for each compound shall be set to **zero** … The calibration curves of the analysers shall be set by means of **calibration gases** … The analysers **zero** settings shall then be rechecked …

The **samples** shall then be analysed.

After the analysis, zero and calibration points shall be rechecked using the same gases. The test shall be considered acceptable if the difference is less than 2 per cent of the calibration gas value.

GTR-15: TEST SEQUENCE – BAG ANALYSIS



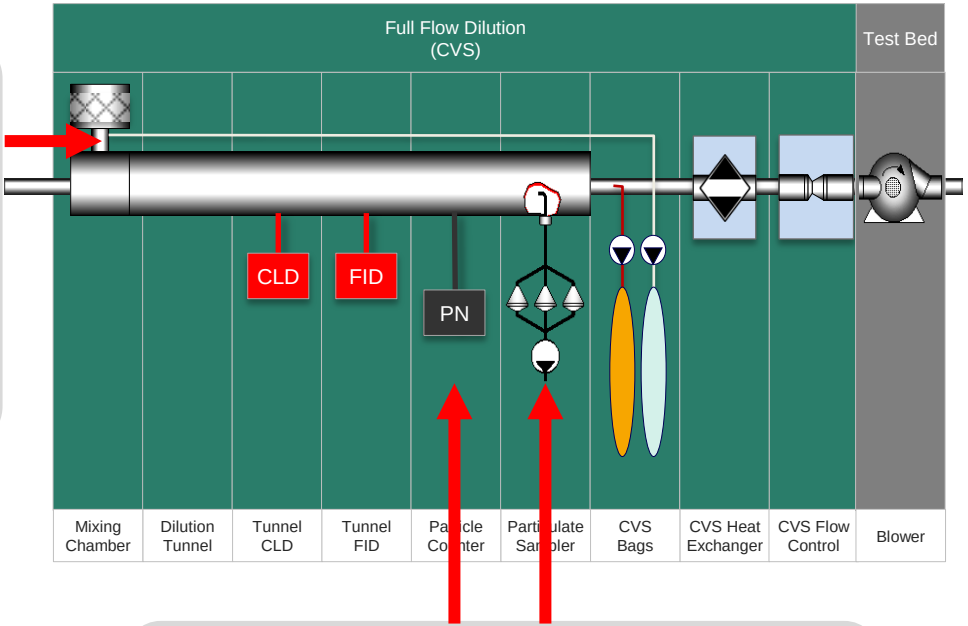
For non diesel vehicles (no HFID) the next test run could start immediately after the prior test has stopped (depending on automation system)

Note: Test and Bag Analysis Sequence depends on the actual emission system configuration! Therefore the here shown examples may differ from the actual possibilities:

GTR-15: PM/PN - BACKGROUND CORRECTION

Dilution Air PM and PN Background

Rolling average of at least 14 measurements with at least one measurement per week



PN Dilution Tunnel Background

PM Dilution Tunnel Background

One measurement performed on the day of test, either prior to or after the test.

Optional it is possible to correct for PM/PN background:

- Dilution-Air background or Dilution-Tunnel background (hang-up)
- For dilution air background there must be an additional sample point and sampling lines to the dilution air filter. For Dilution Tunnel background the PM and PN sampler can be used as for normal testing.
- Dilution Tunnel background requires one test per day and the results must be available for each test on this days (automation system).
- Dilution Air background requires a periodical task in the test bed, some data storage and calculation and the data must be available for each test (test facility management software and test bed automation.

GTR-15: ADDITIONAL POLLUTANTS DISCUSSIONS

There was a list of pollutant components, for which measurement procedures had to be defined. It was not content of the project to add new or delete components. All components are already included in a legislation, somewhere and at any engine application.

Sample method:

- All mass based emission results must be done via CVS, Bag or continuous diluted, depending on component.
- Only concentration based results, like NH3 can be measured from undiluted exhaust

NO/NO2

- Bag versus continuous diluted sampling since NO/NO2 ratio shift in Bags (discussions with Japan).

N2O

- Bag sampling

NH3 Measurement

- Sample stream and detector temperature must be the same
- 110°C to 190°C, upon manufacturer's request 110°C to 133°C (JAMA issue)
- Lost sample shall be less than 0,5% of raw exhaust. A lost-sample correction by modal-raw analysis is not accepted. If the requirement can not be fulfilled, a separate test run shall be executed for NH3 measurement only.
- TP Exhaust sample during engine-off condition in discussion

Ethanol, Formaldehyde, Acetaldehyde

- Too less validation data, too less measurement systems and expertise up to now available
- is ongoing and all feel that the CARB methods are questionable and not the preferred solution
- work shall continue

GTR 15 / WLTP: POLLUTIONS AND CO2

CO2	Carbon dioxide	regular measured compound	done	EURO-6 Limit
CO	Carbon monoxide	regular regulated compound	done	EURO-6 Limit
NOx	Nitrogen oxides	regular regulated compound	done	EURO-6 Limit
NO2	Nitrogen dioxide	because of air quality concerns in EU	done	
N2O	Nitrous oxide	from US Green-House-Gas regulation	done	
NH3	Ammonia	from EU Heavy Duty regulation for SCR	WLTP Ph1a	
THC	Total hydrocarbons (by FID)	regular regulated compound	done	EURO-6 Limit
CH4	Methane	regular measured compound	done	needed for calculation
NMHC	Non-methane hydrocarbons	regular regulated compound	done	EURO-6 Limit
C2H5OH	Ethanol	from US NMOG regulation (CARB)	WLTP Ph1a	
NMNEOG	Non-Methane Non-Ethanol Organic Gases	from US NMOG regulation (CARB)	WLTP Ph1a	
HCHO	Formaldehyde	from US NMOG regulation (CARB)	WLTP Ph1a	
CH3CHO	Acetaldehyde	from US NMOG regulation (CARB)	WLTP Ph1a	
PM	Particulate Matter	regular regulated compound	done	EURO-6 Limit
PN	Particle Number	regular regulated compound	done	EURO-6 Limit

GTR 15 / WLTP: POLLUTIONS AND CO2

CO2	Carbon dioxide	CVS Bag	NDIR	
CO	Carbon monoxide	CVS Bag	NDIR	
NOx	Nitrogen oxides	CVS Bag	CLA, NDUV	
NO2	Nitrogen dioxide	Calc. / CVS cont.	NDUV, QCL	(NOx,Bag – NO,cont.) or NO2,cont.
N2O	Nitrous oxide	CVS Bag	GC–ECD, IR-Spectr, FTIR, NDIR	FTIR, NDIR with <0,1ppm interference
NH3	Ammonia	Tailpipe	FTIR, LDD, QCL	
THC	Total hydrocarbons (by FID)	CVS Bag/Tunnel	FID, HFID	FID all fuels except Diesel, HFID all fuels
CH4	Methane	CVS Bag	GC-FID, Cutter-FID	
NMHC	Non-methane hydrocarbons	calculated		THC – CH4
C2H5OH	Ethanol	CVS	Impinger, Photo Acoustic, FTIR	Reference is CARB
NMNEOG	Non-Methane Non-Ethanol Organic Gases	calculated		
HCHO	Formaldehyde	CVS	DNPH-HPLC, FTIR	Reference is CARB
CH3CHO	Acetaldehyde	CVS	DNPH-HPLC, FTIR	Reference is CARB
PM	Particulate Matter	CVS Tunnel	PTS	
PN	Particle Number	CVS Tunnel	PNC with CPC	

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AVL Emission Testing Solutions and Products

REAL DRIVING EMISSION TESTING (RDE)

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

- Tailpipe Emissions and Evap-Emissions
- Keine Bezug auf einen „Testzyklus".
- Bezug auf "normal conditions of use"

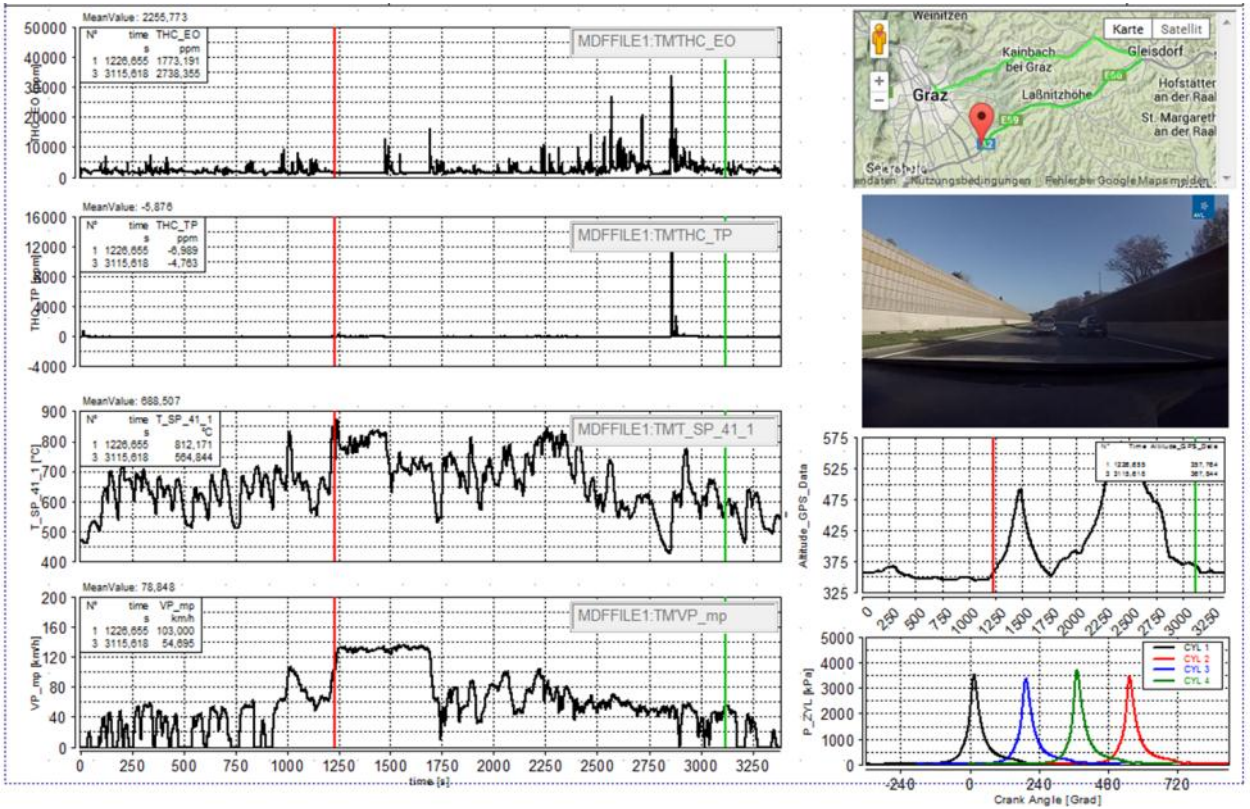
In addition, the technical measures taken by the manufacturer must be such as to ensure that the tailpipe and evaporative emissions are effectively limited, pursuant to this Regulation, throughout the normal life of the vehicles under normal conditions of use. Therefore, in-service conformity measures 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.

REAL DRIVING EMISSION TESTING (RDE)

Emissions are tested under real driving conditions:

- A Portable Emission Measurement System (PEMS) will be installed on a vehicle to measure CO2, CO, NOx and PN on the road.
- If PN measurement would not be possible, there might come a random test cycle in the test laboratory.
- Testing conditions, like fuel, temperature and altitude are still under discussion (-7 … 30°C, altitude up to 1400m)
- Calculation and Evaluation model for test result is the “CLEAR” Tool from TU-Graz or “EMROD” from JRC. (used in parallel in the next years)
- 2014-2017 no limits are required but measurement and reporting.
- 2015 the final legislation limits and procedure shall be defined.
- 2017 Limits will apply.

REAL DRIVING EMISSION TESTING (RDE)



RDE CHALLENGES:

Light Duty: most likely changes in the vehicle and exhaust aftertreatment due to RDE:

- Increase exhaust aftertreatment system (EAS) size since much higher exhaust flow rate in RDE
- Avoid cool down of EAS, due to fuel shut off during deceleration or down hill driving
- Component protection can't be made by rich combustion anymore (-> cooled exhaust manifolds ?)
- Scavening of turbo charger becomes problematic
- deactivation of EGR at higher altitude not possible (current discussion is app. 1300m (Brenner Autobahn)
- GDI most likely will need GPF
- Higher AdBlue consumption of SCR so that driver has to refill by itself. Refills aligned with service intervals not possible anymore
- NOx Storage catalysts efficiency most likely too less -> SCR
- most likely higher fuel consumption and CO2 due to above effects
- ….

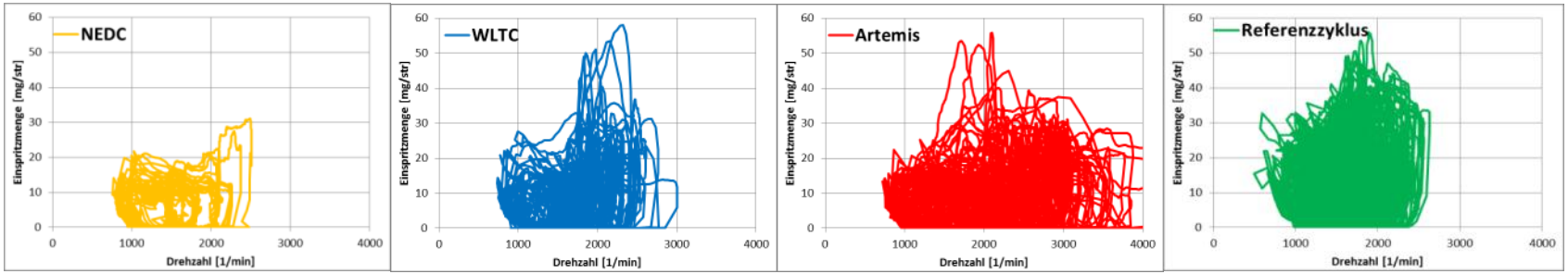
Heavy Duty: Why was RDE for HD not such a big issue?

- Heavy Duty vehicle must measure "RDE" (OCE Off Cycle Emission) already since 2013 (Euro-VI)
- Heavy Duty engine emission control had all the time to cover 100% engine load conditions
- Since 2000 (Euro-III) unknown and random engine operation points (speed/load) have been checked for emissions (NOx Screening)

RDE CHALLENGES: ENGINE MAP

Emission limit compliance with drive cycle was good enough:

- Before RDE (2017 Euro-6c) it was good enough to comply with one prototype vehicle (representing a vehicle family) with the limits in a known drive cycle (NEDC in Europe).



RDE – REAL DRIVING EMISSIONS

at the doctor | in the hospital

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

on the road | in the test bed

RDE Challenge:

- Road testing represents real world operation, but real world operation can not be reproduced.
- Analyzing and solving a problem requires:
  - Making it reproducible
  - Full capacities of all test bed types and measurement systems of a lab.
  - Virtual Pre-Simulation for front loading and validations

POWERTRAIN DEVELOPMENT PROCESS AND RDE

Reproduction und analysis of RDE tests and results

Virtual World

Models

Evaluations

Calibration Data

Test methods

Test Processes

Office Simulation

MIL/SIL Testing

HIL Testing

Battery Testing

E-Motor Testing

Engine Testing

Powertrain Testing

Chassis Dyno Testing

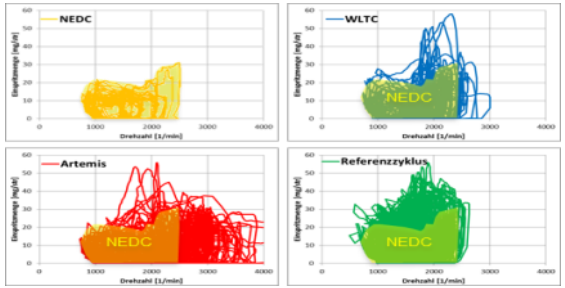
Road Testing

Production

Real World

Up-front simulation, Front loading, …

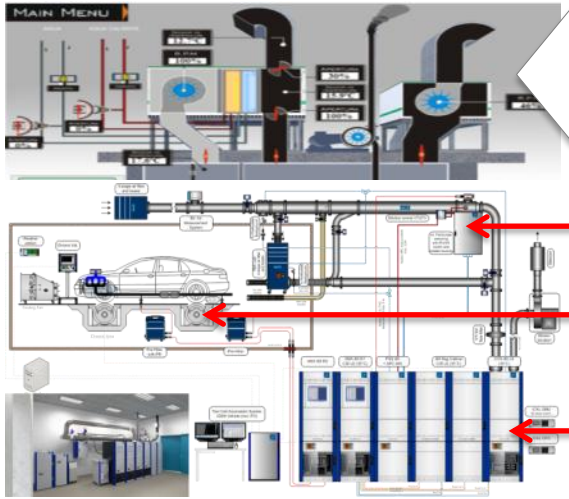
RDE VEHICLE TEST BED - REQUIREMENTS



RDE engine operation will be far above standard test cycle requirements.
The energy contained in the fuel, which is burned in a combustion engine is converted to :

- 33% to turn the wheels - Dyno must handle that
- 33% in heat - Test bed infrastructure (TGA) must handle that
- 33% heat in the exhaust - CVS and Emission Systems must handle that

plus any additional ambient condition simulation which might be requested by development



The test bed infrastructure like air-conditioning must be able to handle the additional heat produced by the vehicle. Plus any additional requirement to simulate real world temperature, pressure (altitude) and humidity conditions.

Lower dilution ratios + higher temperatures, may require double dilution for PM

Higher load requirements due to RDE, especially for high power and/or heavy vehicles, will require higher performance of the chassis dyno and cooling fan.

Larger exhaust gas flow and heat may require larger CVS or alternatives (modal diluted or raw, heated CVS, …). i.e. app. 30 m3/min CVS per 100 kW engine operation

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AVL Emission Testing Solutions and Products

TIER 3 CERTIFICATION STANDARDS (FTP, 150.000MI)

Bin	NMOG+NO_x mg/mi	PM* mg/mi	CO g/mi	HCHO mg/mi
Bin 160	160	3	4.2	4
Bin 125	125	3	2.1	4
Bin 70	70	3	1.7	4
Bin 50	50	3	1.7	4
Bin 30	30	3	1.0	4
Bin 20	20	3	1.0	4
Bin 0	0	0	0	0

* In MYs 2017-20, the PM standard applies only to that segment of a manufacturer's vehicles covered by the percent of sales phase-in for that model year.

NMOG + NOx
Fleet Average

Vehicle Category	2017*	2018	2019	2020	2021	2022	2023	2024	2025
LDV, LDT1	86	79	72	65	58	51	44	37	30
LDT2, LDT3, LDT 4, MDPV	101	92	83	74	65	56	47	38	30

* For LDVs and LDTs over 6,000 lbs GVWR and MDPVs, the fleet average standards apply beginning in MY 2018.

Source: AVL EmRep

TIER 3 PM CERTIFICATION STANDARDS (FTP, 150.000MI)

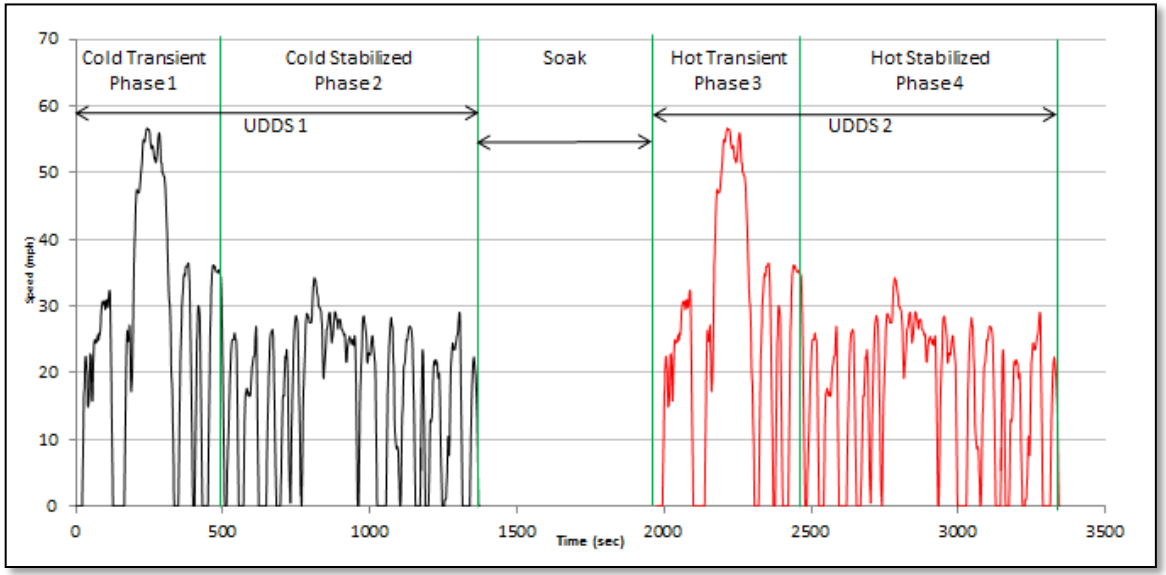
Phase-In	2017	2018	2019	2020	2021	2022
Percentage of sales	20%+	20%	40%	70%	100%	100%
Certification standard	3	3	3	3	3	3
In-use standard	6	6	6	6	6	3

* Manufacturers comply in MY 2017 with 20% of their LDV and LDT fleet under 6,000 lbs GVWR, or alternatively with 10% of their total LDV, LDT, and MDPV fleet

Source: AVL EmRep

NEW US LIGHT DUTY –EPA TIER III & CARB LEV III

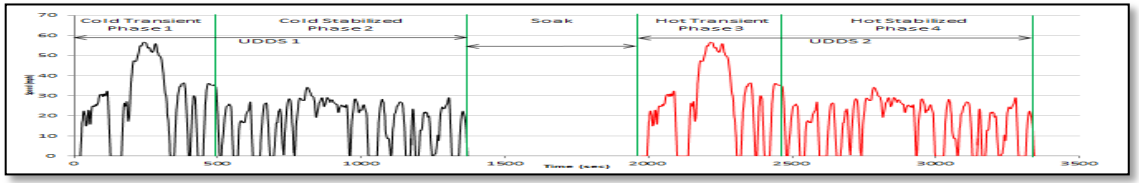
Test cycle is not part of 1066, but of the emission standard setting TIER-III & LEV-III



- Federal Test Procedure (FTP)
- FTP consists of 2 UDDS's (Urban Dynamometer Driving Schedule), cold and hot start
- Each UDDS consists of a transient phase (505 seconds) and a stabilized phase (867 seconds)
- Results are weighted
  - Cold UDDS = 43%
  - Hot UDDS = 57%

NEW US LIGHT DUTY –EPA TIER III & CARB LEV III

Test cycle is not part of 1066, but of the emission standard setting TIER-III & LEV-III

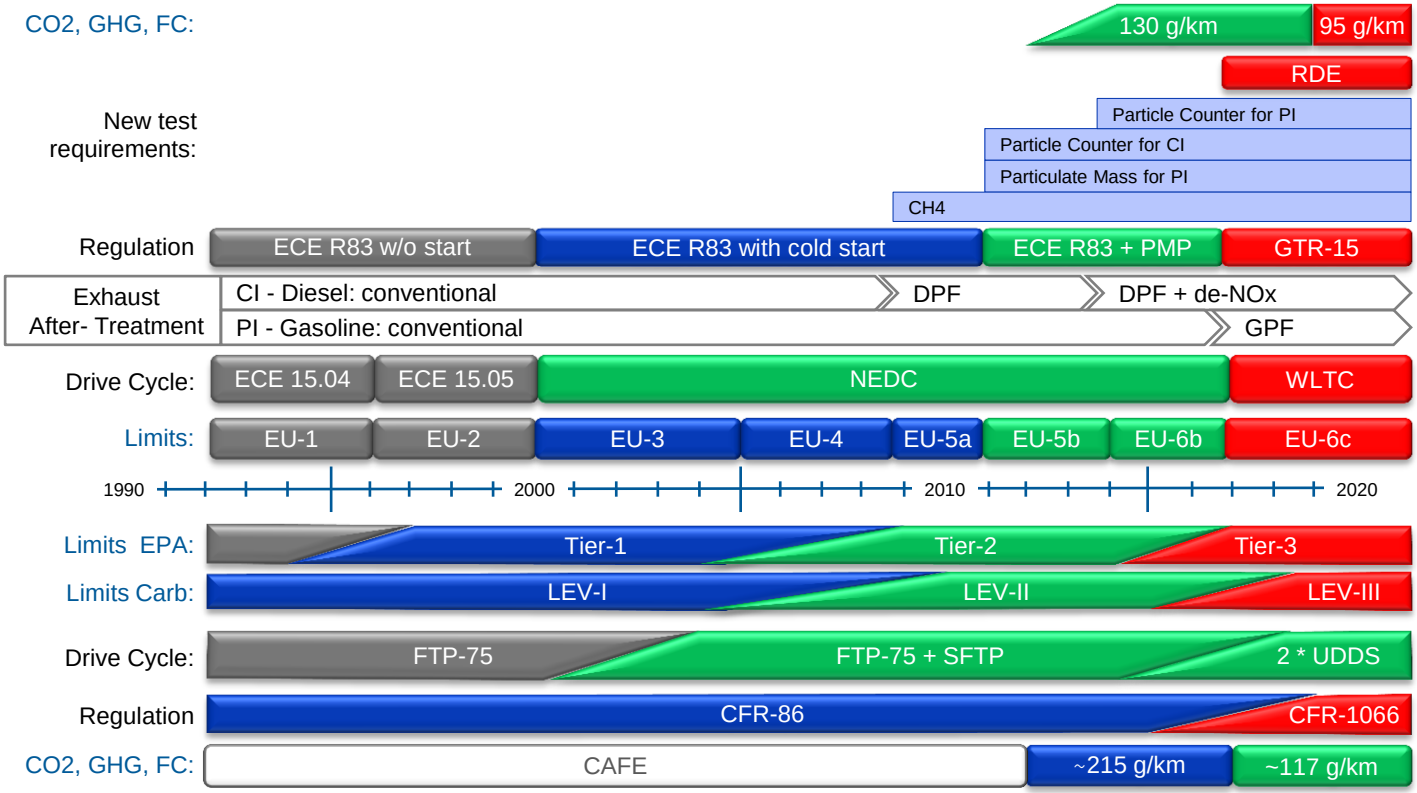


	UDDS 1			UDDS 2		
Sample Method	Cold Transient Phase 1	Cold Stabilized Phase 2	SOAK	Hot Transient Phase 3	Hot Stabilized Phase 4	COMMENT
Filter by Phase	SAMPLE 1	SAMPLE 2		SAMPLE 3	SAMPLE 4	Collect each phase independently 4 bags or filters
Filter by Phase	SAMPLE 1	SAMPLE 2		SAMPLE 3	OMITTED	Collect 3 phases and use Phase 2 (Cold Stabilized) in the calculation of the Hot UDDS. Shortens the test time by 867 seconds by eliminating sampling for Phase 4 (Hot Stabilized)
Filter by UDDS	SAMPLE 1			SAMPLE 2		Collect 1 sample for each UDDS – Will be used for Hybrid Testing
Single Filter Flow Weighted	SAMPLE 1 fw factor = 0.75			SAMPLE 1 fw factor = 1.0		Collect 1 sample for the both the cold and hot UDDS – flow weight the sample for each UDDS
Single Filter Flow Weighted	SAMPLE 1 fw factor = 0.43	SAMPLE 1 fw factor = 1.0		SAMPLE 1 fw factor = 0.57	OMITTED	Collect 1 sample over 3 phases and flow weight the sample by changing the bag fill flow rate or the pm filter face velocity. Shortens the test time by 867 seconds by eliminating sampling for Phase 4 (Hot Stabilized)

1066.815 Allowed measurements:

- 1 sample for each phase (traditional)
- 1 sample for each UDDS
- 1 sample for both UDDS's
- 1 sample for PM FTP with applying the weighting factors by adjusting the sample flow rate proportional to the weighting factor.

EMISSION CERTIFICATION: LIGHT-DUTY CARS



EU-6 Limits are not related to a cycle anymore!

Note: Due to the complexity of the US emission legislations (phase-in, credits, exceptions, EPA/Carb) a simplified flow chart can only be a rough overview.

US - TECHNICAL REGULATIONS

Applications:

Standard Setting Parts:

(40 CFR 86 SubPt. B – Light-duty vehicles)

40 CFR 1037 – Heavy-duty motor vehicles

40 CFR 1036 – Heavy-duty highway engines

40 CFR 1039 – Nonroad CI engines

40 CFR 1048 – Large Non-Road SI engines (>19 kW)
40 CFR 1054 – Small Non-Road SI engines (<19 kW)

40 CFR 1051 – Recreational engines and vehicles

40 CFR 1033 – Locomotives

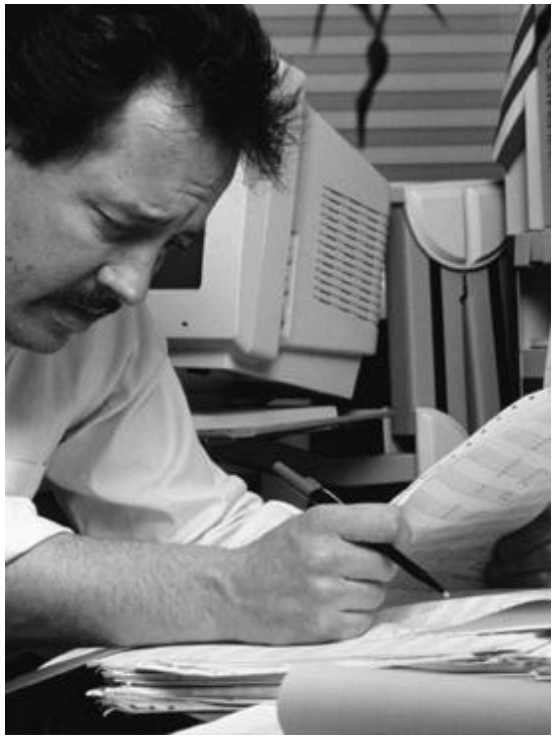
40 CFR 1045 – Marine SI engines and vessels
40 CFR 1042 – Marine CI engines and vessels
40 CFR 1043 – Marine engines and vessels (Marpol)

Technical Regulations:

CFR-1066 – Vehicle Testing

CFR-1065 – Engine testing

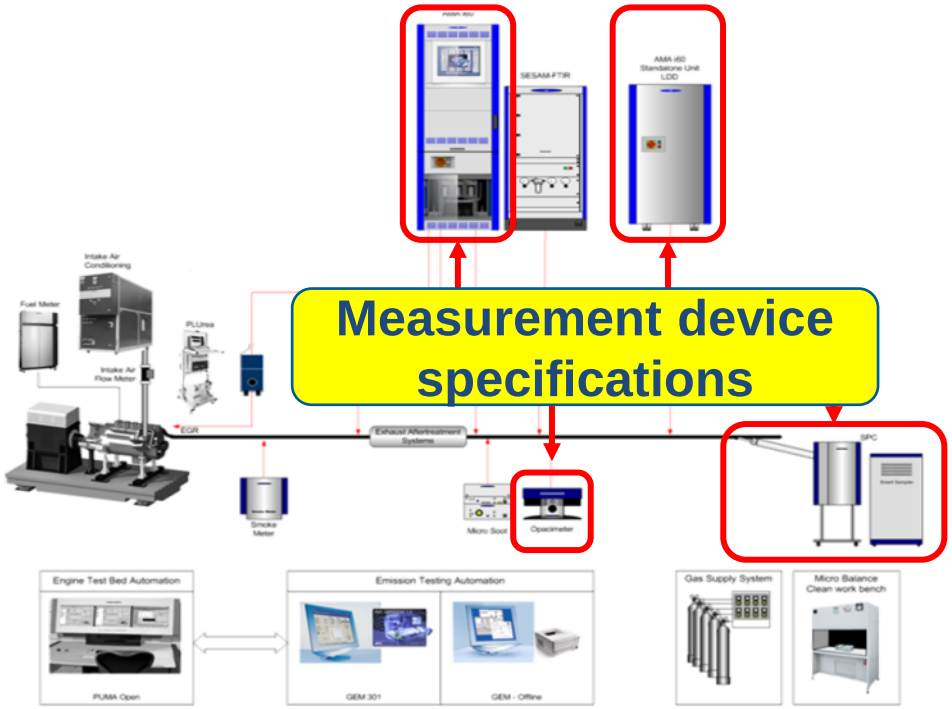
40 CFR 1065 BASIC UNDERSTANDING REQUIRED



40 CFR 1065 is a new way to specify emission testing

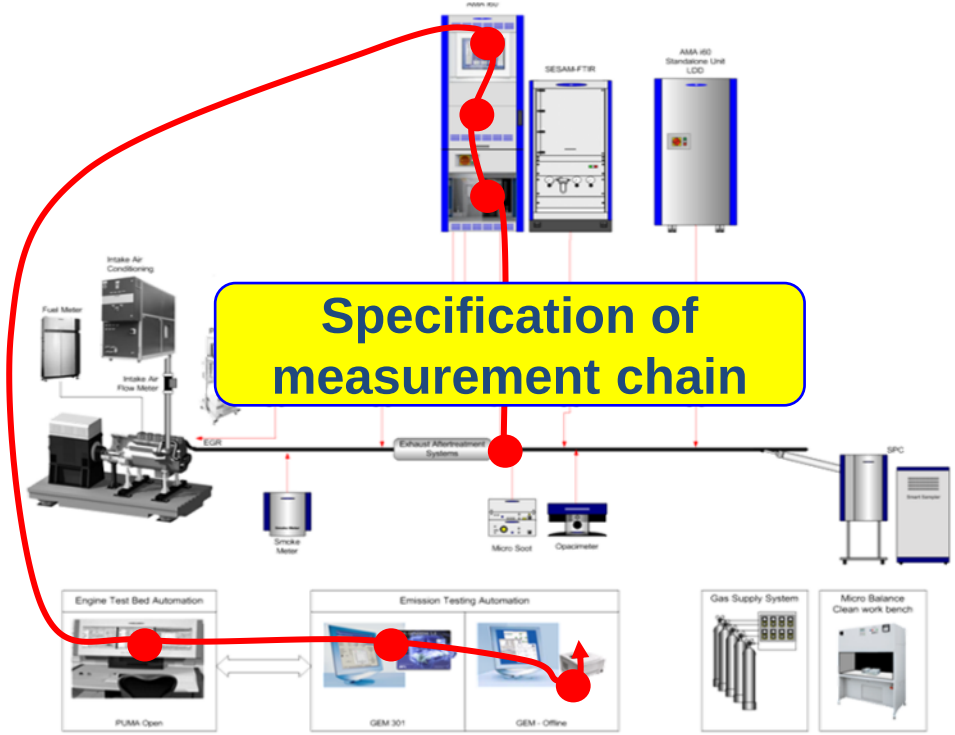
- 40 CFR 1065 is not only a new legislation, with a certain delta list, when compared to older legislations or compared to European legislations.
- It is a new way to specify emission testing.
- This new way is definitely better from a measurement quality point of view. But it is very much different as in the past.

LD US AND EU REGULATION
OLD SPECIFICATIONS BASED ON DEVICE SPECIFICATIONS



- Old US legislations and European regulation defines requirements device by device.
- Therefore it is possible to clearly say, a device is conform with legislation independent of the other systems on the test bed.

40 CFR 1065/1066 – A NEW WAY OF SPECIFICATIONS



- 40 CFR 1065/1066 specifies requirements based on the total measurement chain. From a point of view for the result quality, that is the best way.

- But, by that it is not possible to clearly say, that a device is conform with legislation independent of the other systems on the test bed. A system may be conform in one type of test bed and not conform in another.
- Example: If an analyzer can not pass certain performance criteria it might still be conform. But the bench supplier expects that the HOST system will do some compensation calculations to fix it.

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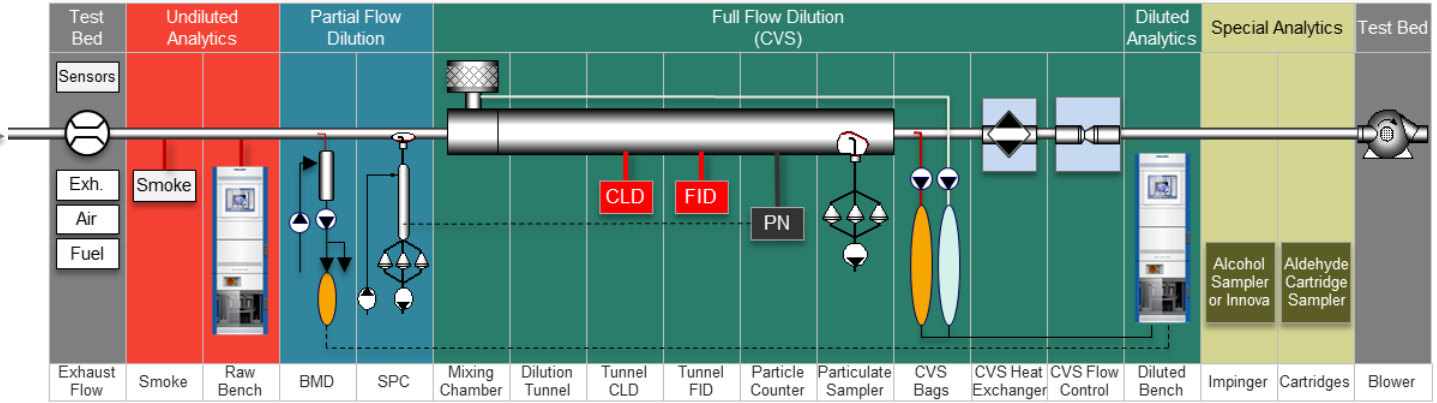
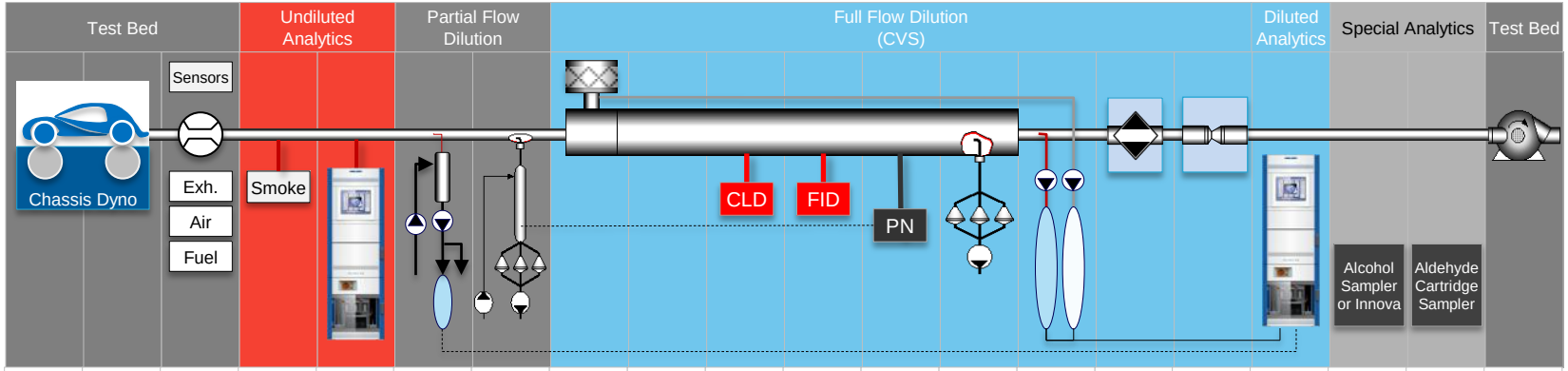
EMISSION REGELATION / LEGISLATION

Possible Emission Measurement Methods



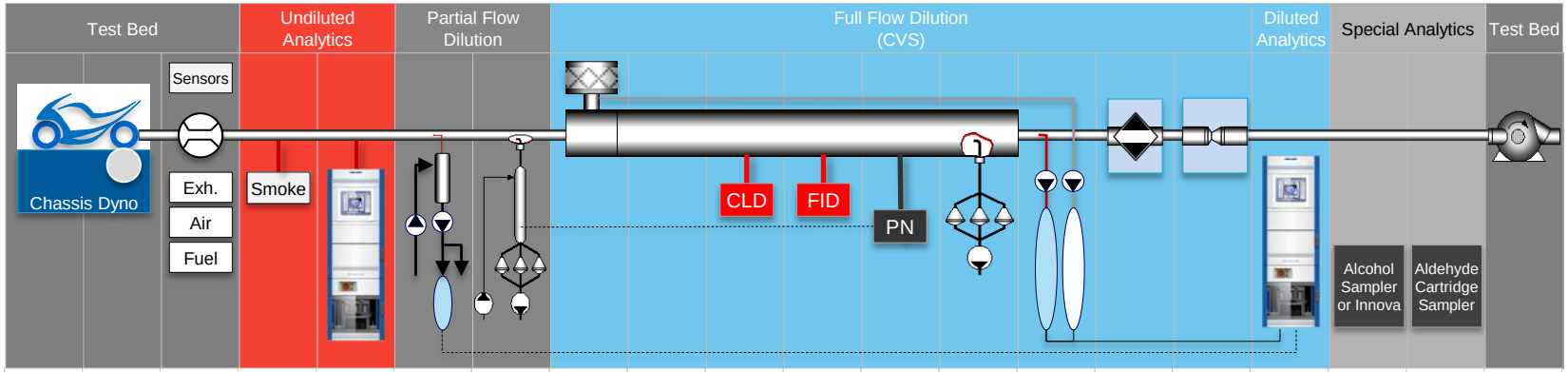
CERTIFICATION: LIGHT DUTY VEHICLES



				UUT	Load Unit	Exhaust Flow	Smoke	Raw Bench	BMD	SPC	Mixing Chamber	Dilution Tunnel	Tunnel CLD	Tunnel FID	Particle Counter	Particulate Sampler	CVS Bags	CVS Heat Exchanger	CVS Flow Control	Diluted Bench	Impinger	Cartridges	Blower	
Global	Vehicle	Chassis Dyno		✓				✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓ (9)	✓ (9)	✓	
EU	Vehicle	Chassis Dyno		✓				✓	✓		✓	✓	✓	✓		✓	✓						
USA	Vehicle	Chassis Dyno						✓	✓		✓	✓	✓	✓		✓	✓		✓	✓	✓ (9)	✓ (9)	✓	(1)
			Exh.			✓	✓													✓	✓ (9)	✓ (9)	✓	(2)
			Exh.		✓		✓														✓ (9)	✓ (9)	✓	(3)
Japan	Vehicle	Chassis Dyno						✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓			✓	

(1) USA: Configuration accordingly to CFR-86 and CFR-1066.
(2) USA: Alternative solutions with partial flow diluted gaseous and particulate measurement for upcoming (2017/2020) CFR-1066 regulation. Only accepted for the USA.
(3) USA: Alternative solutions with undiluted gaseous and partial flow particulate measurement for the upcoming (2017/2020) CFR-1066 regulation. Only accepted for the USA.
(9) USA: Alcohol and Aldehyde measurement is required, but often it is replaced by other means (like using factors or using manually chemistry laboratory sampling and analysis)

CERTIFICATION: 2- AND 3-WHEELERS



		UUT	Load Unit	Exhaust Flow	Smoke	Raw Bench	BMD	SPC	Mixing Chamber	Dilution Tunnel	Tunnel CLD	Tunnel FID	Particle Counter	Particulate Sampler	CVS Bags	CVS Heat Exchanger	CVS Flow Control	Diluted Bench	Impinger	Cartridges	Blower	
Global	Vehicle	Chassis Dyno						✓						✓		✓	✓	✓ (9)	✓ (9)	✓		
EU	Vehicle	Chassis Dyno						✓						✓		✓	✓			✓		
USA	Vehicle	Chassis Dyno						✓						✓		✓	✓	✓ (9)	✓ (9)	✓		(1)
			Exh.			✓											✓	✓ (9)	✓ (9)	✓		(2)
			Exh.		✓													✓ (9)	✓ (9)	✓		(3)
Japan	Vehicle	Chassis Dyno						✓						✓		✓	✓			✓		

(1) USA: Configuration accordingly to CFR-86 and CFR-1066.
(2) USA: Alternative solutions with partial flow diluted gaseous measurement for upcoming (2020) CFR-1066 regulation. Only accepted for the USA.
(3) USA: Alternative solutions with undiluted gaseous measurement for the upcoming (2020) CFR-1066 regulation. Only accepted for the USA.
(9) USA: Alcohol and Aldehyde measurement is required, but often it is replaced by other means (like using factors or using manually chemistry laboratory sampling and analysis)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