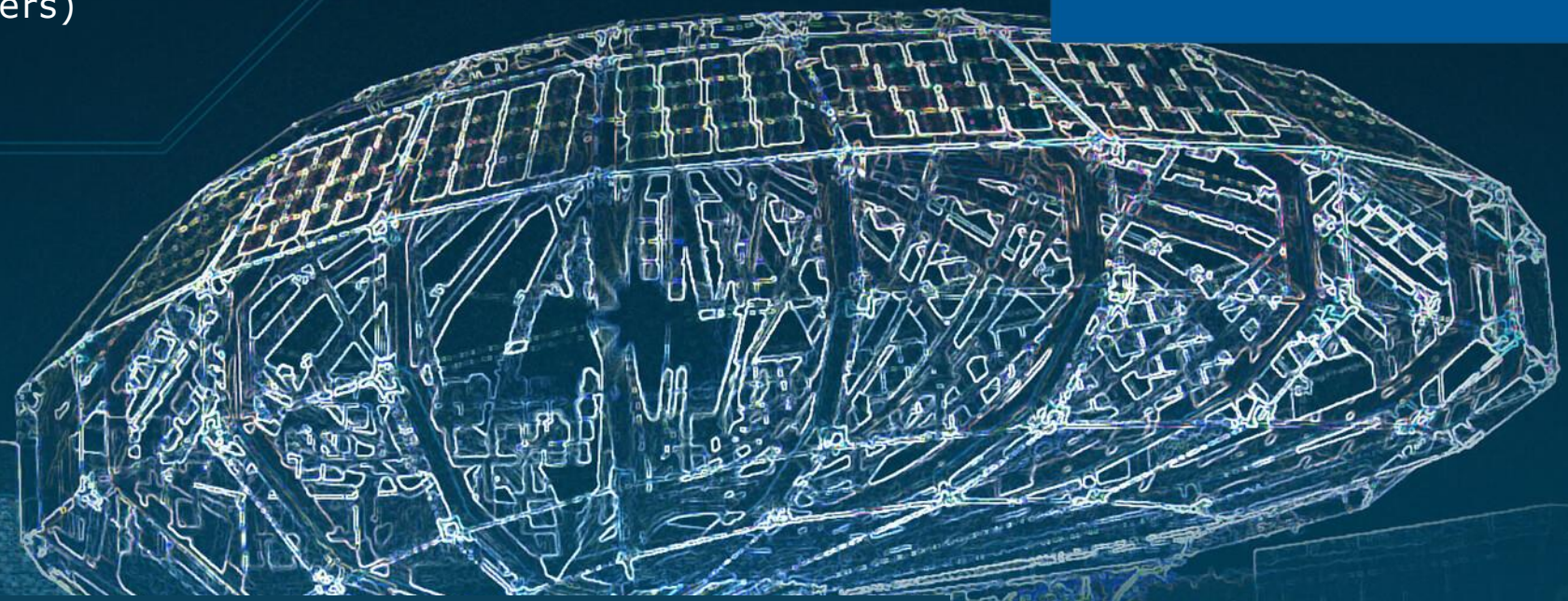
AVL List GmbH (Headquarters)



REAL DRIVING EMISSIONS (RDE)

Was steckt wirklich dahinter?

AVL M.O.V.E In-Vehicle Testsystem

Schöggl, Marco

REAL DRIVING EMISSIONS (RDE)
A REAL CHALLENGE FOR ON ROAD TESTING

RANDOMNESS

Driving style has a strong impact on the equipment – shocks and vibrations.

AMBIENT TEMPERATURE

Changing ambient temperatures can strongly impact the quality of RDE test data.

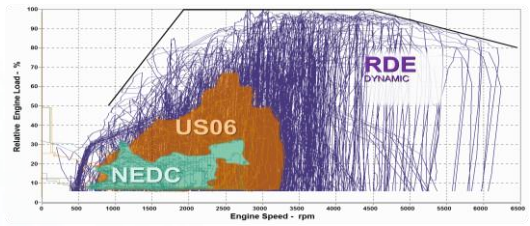
AMBIENT PRESSURE

Changing ambient pressure is the key decision criterion for the selection of PEMS analyzers..

RDE READY

Impact to Emissions

Drive Cycles:



Vehicles must be clean in a much larger area of the engine map:

- NEDC → WLTC
- Real Driving Emissions

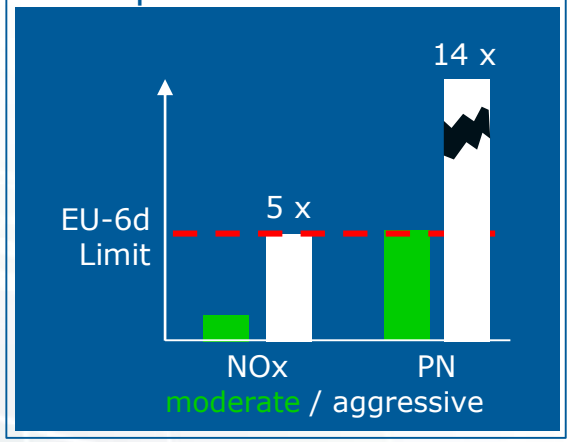
Example:

Drive Style:

Drive style has a large impact (by factors) on emission:

- aggressive
- moderate

Example:

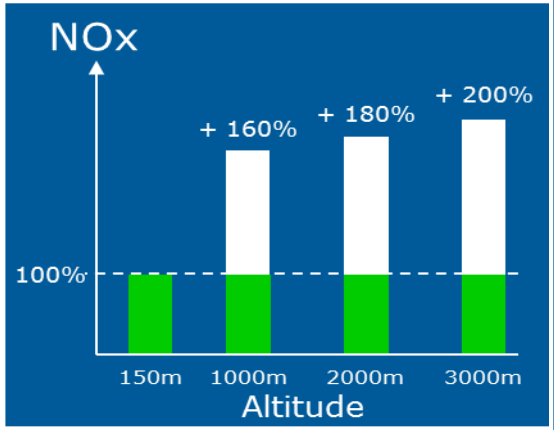


Altitude:

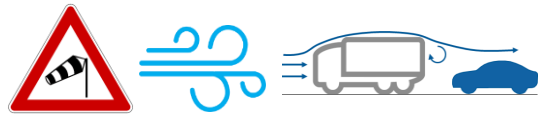
Impact of altitude:

- physical
- calibration, like when EGR is switched off

Example:



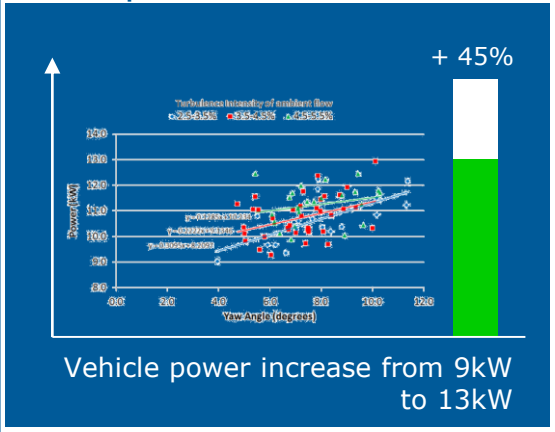
Wind:



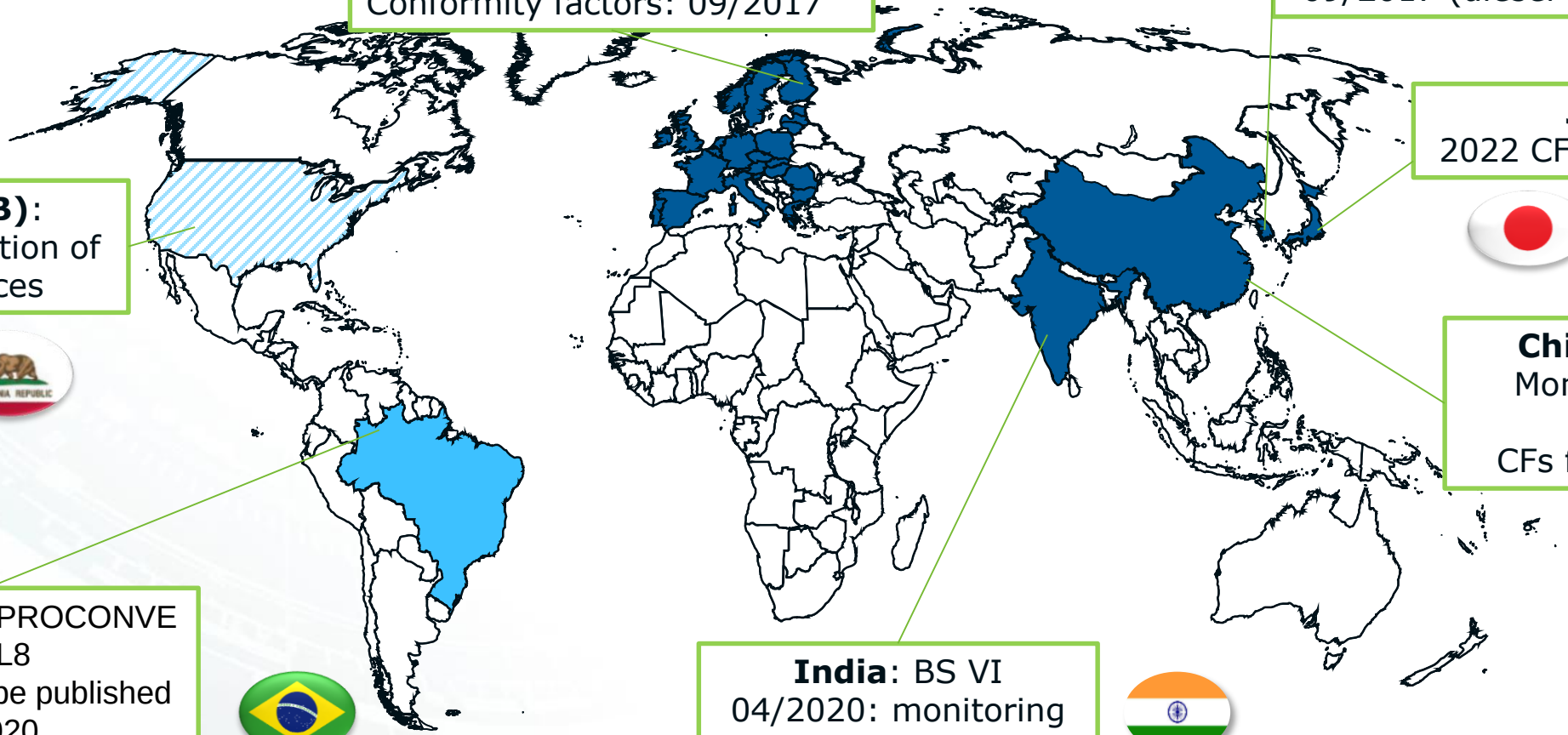
Impact of wind is:

- crosswind
- traffic turbulences
- drafting (Windschatten)

Example:



RDE IMPLEMENTATION WORLDWIDE



EU:
Monitoring: 04/2016
Conformity factors: 09/2017

South Korea:
09/2017 (diesel only)

Japan:
2022 CF 2 (diesel only)

Low Speeds

USA (CARB):
PEMS for detection of defeat devices

China: China 6
Monitoring from 07/2020
CFs from 07/2023

Up to 2.400m

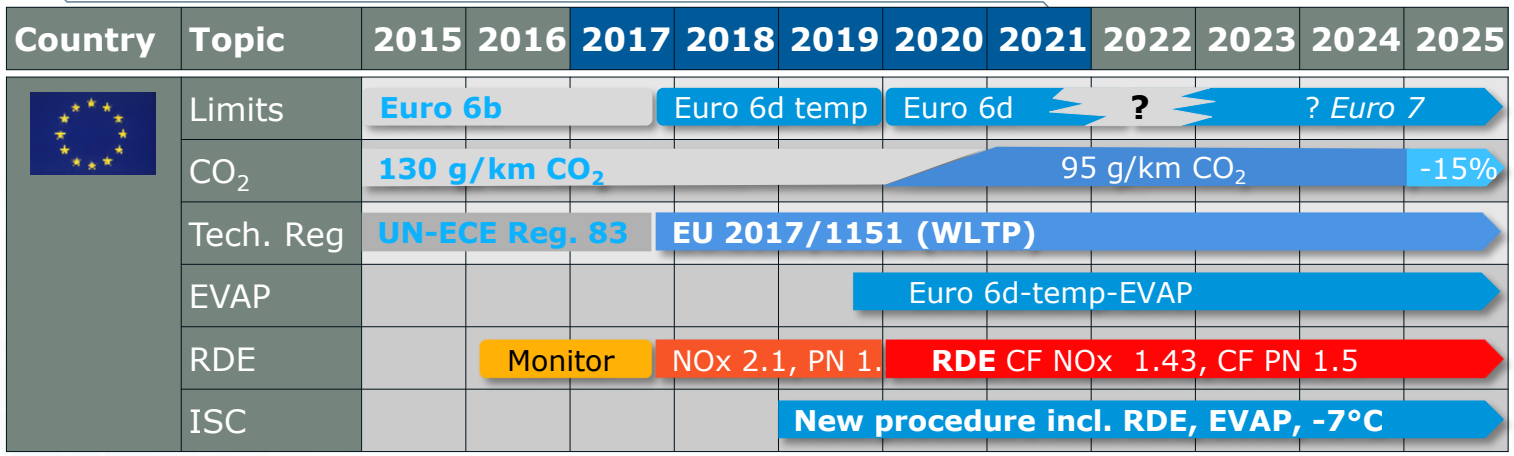
Brazil: draft PROCONVE L7, L8
Procedure to be published by 2020.
2022: monitoring?
2024/2027: CFs?

+ THC limit?

India: BS VI
04/2020: monitoring
04/2023: CFs

Low Speed & over 40°C

New characteristic of legislative development



- 04/2016 RDE Monitoring
- 09/2017 WLTP + RDE with CF-temp.
- **01/2019 New ISC Procedure**
- 09/2019 New EVAP Procedure
- 01/2020 RDE with final CF

No lead time for engineering / Last-Minute amendments

March 2018 RDE Package 4
- In Service Conformity, Member State Surveillance

3Q 2017 revised evaporative emission testing
- Canister aging, test procedures, sealed tank systems for hybrids, ...

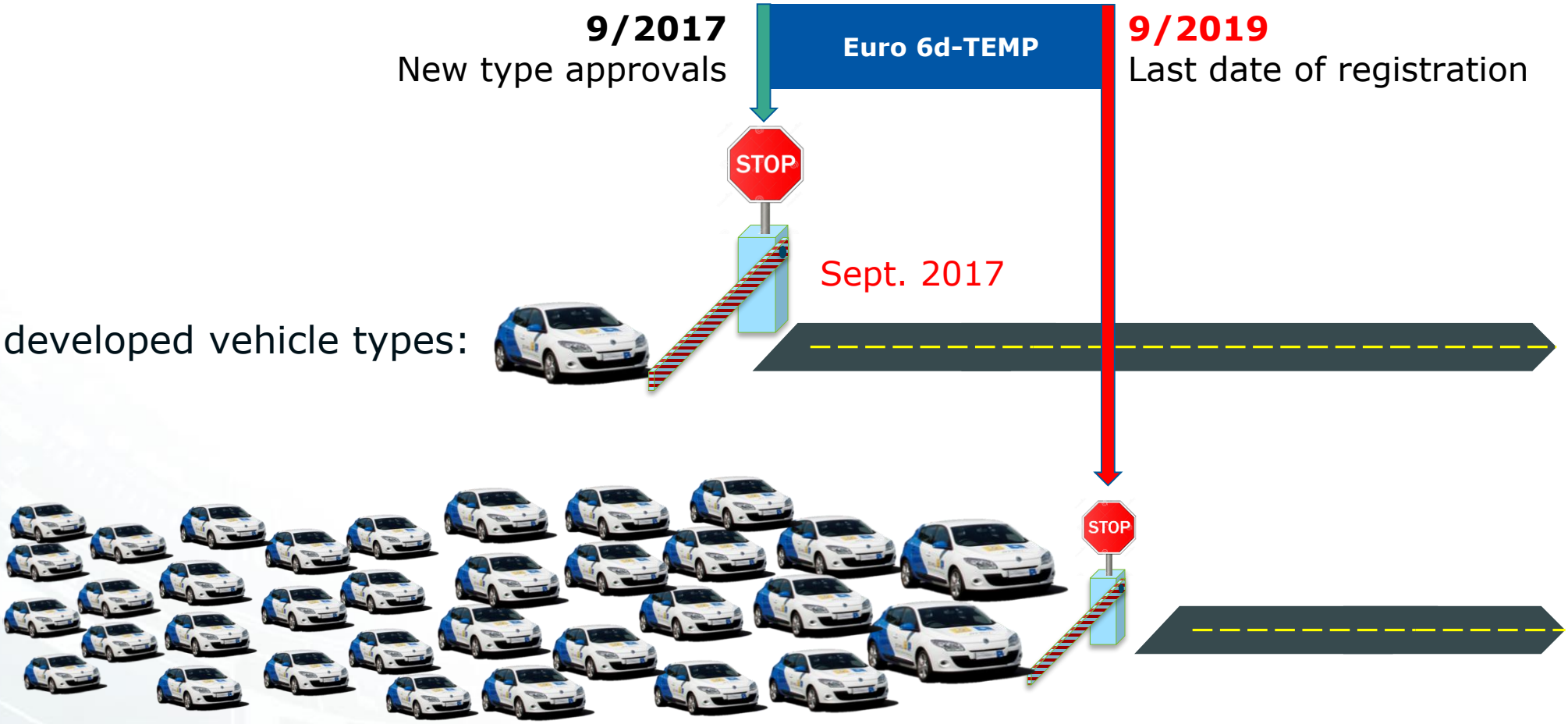
Jan. 2017 Guidance on AES and Defeat Devices
- Documentation of AES, engine protection, impact assessment, defeat device testing, ...

Dec. 2016 RDE Package 3
- PN Limit, Cold start, Hybrids

Feb. 2016 RDE Package 2
- NOx Limit, Test Boundary Conditions

2015 RDE Package 1
- Decision on PEMS, Monitoring from 2016

Euro Time line – Light Duty PC



EU – Update draft RDE Package 4

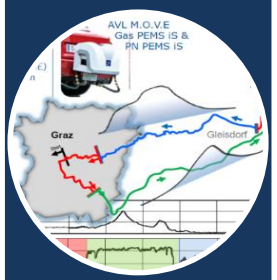
Corrections, clarifications, provisions for LCVs

CLEAR not used anymore, EMROAD only for trip normality

New emissions calculation method

Reduced NO_x margin

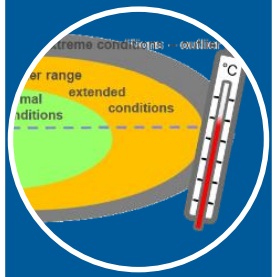
In-service conformity requirements added



Trip requirements

Urban, rural, motorway –

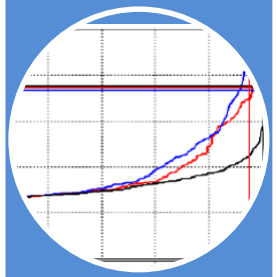
Min. and max. speed



Non-dynamic boundary conditions

Temperature

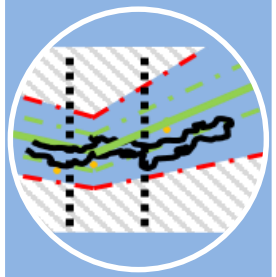
Altitude



Dynamic boundary conditions

v*apos

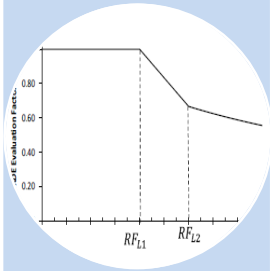
RPA



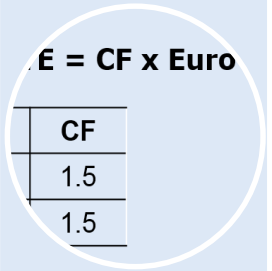
Trip normality, ~~weighting~~

EMROAD

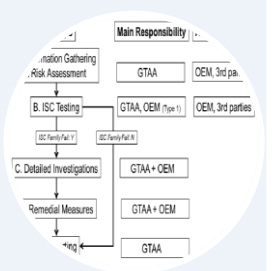
~~CLEAR~~



Calculation of final RDE emission results



Comparison of final emission results with limit



In-service conformity testing

New Appendix 6 – Calculation of the final RDE emissions results – ICE and NOVC-HEV

For valid trips, the final RDE results are calculated as follows (k = t for total trip, u for urban part):

$$M_{RDE,k} = m_{RDE,k} * RF_k$$

Index (k) refers to the category (t=total, u=urban, 1-2=first two phases of the WLTP cycle)

$m_{RDE,k}$ … pollutant emissions during RDE trip in [mg/km] or [#/km]

RF_k ….. RDE Evaluation Factor

$M_{RDE,k}$….. Final RDE result [mg/km] or [#/km]

Value of RF_k is dependent on ratio of CO_2 emissions [g/km] during RDE trip to CO_2 emissions during WLTP

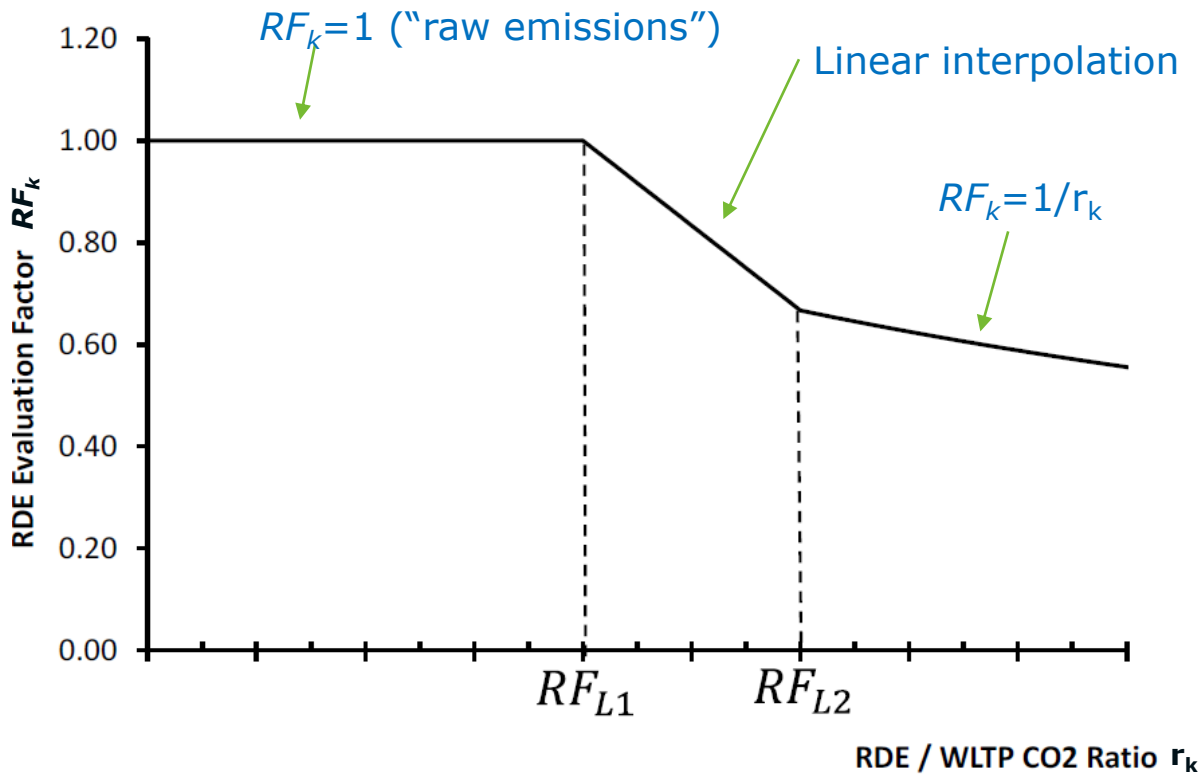
$$r_k = \frac{M_{CO_2,RDE,k}}{M_{CO_2,WLTP,k}}$$

For type approvals before 01.01.2020:

RF_{L1} = 1.20 and RF_{L2} = 1.25

For type approvals from 01.01.2020:

RF_{L1} = 1.30 and RF_{L2} = 1.50



New Appendix 6 – Calculation of the final RDE emissions results – OVC-HEV

For valid trips, the final RDE results are calculated as follows (k = t for total trip, u for urban part):

$$M_{RDE,k} = m_{RDE,k} * RF_k$$

Index (k) refers to the category (t=total, u=urban, 1-2=first two phases of the WLTP cycle)

$m_{RDE,k}$ … pollutant emissions during RDE trip in [mg/km] or [#/km]

RF_k ….. RDE Evaluation Factor

$M_{RDE,k}$….. Final RDE result [mg/km] or [#/km]

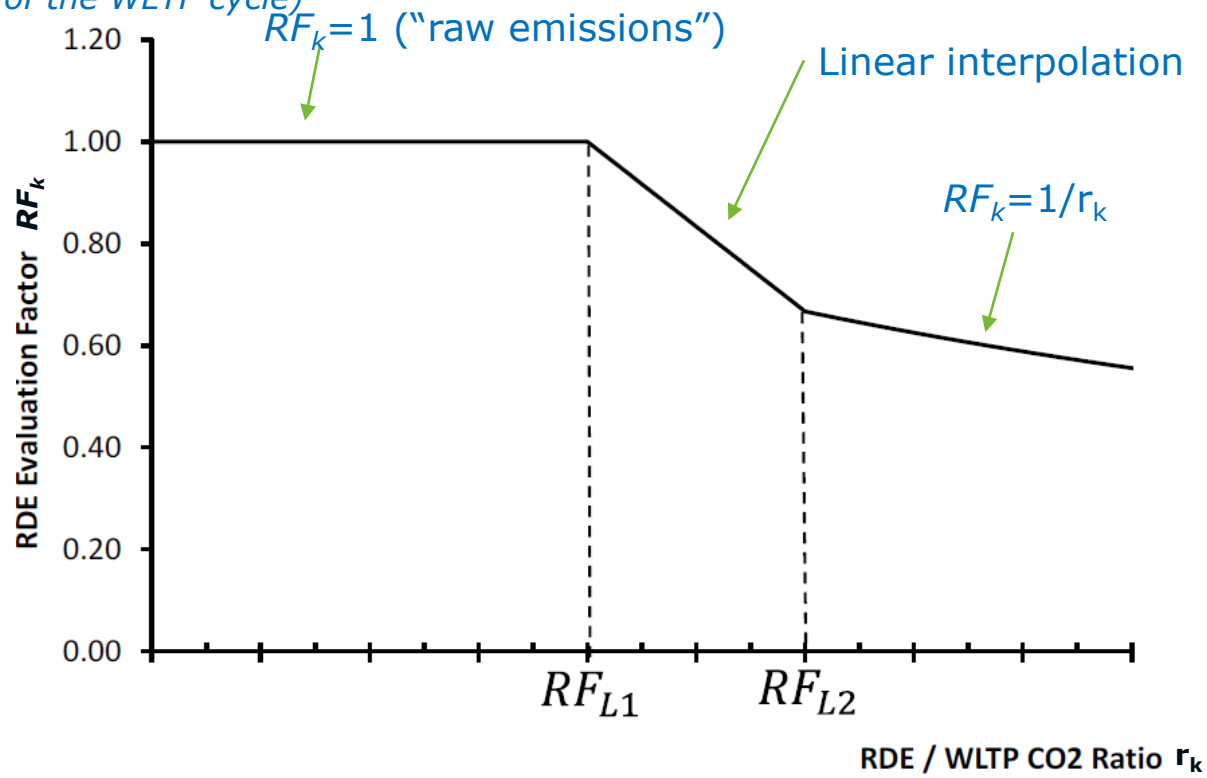
Value of RF_k is dependent on ratio of CO_2 emissions [g/km] during RDE trip to CO_2 emissions during WLTP (charge sustaining mode)

$$r_u = \frac{M_{CO_2,RDE,u}}{M_{CO_2,WLTP-CS,1-2}} * \frac{0.70}{IC_u}$$

$$r_t = \frac{M_{CO_2,RDE,t}}{M_{CO_2,WLTP-CS,t}} * \frac{0.85}{IC_t}$$

$$IC_k = \frac{d_{ICE,k}}{d_{ICE,k} + d_{EV,k}}$$

$d_{ICE,k}$ … Distance driven [km] with ICE on for OVC-HEV during RDE
$d_{EV,k}$ … Distance driven [km] with ICE off for OVC-HEV during RDE



For type approvals before 01.01.2020: RF_{L1} = 1.20 and RF_{L2} = 1.25
For type approvals from 01.01.2020: RF_{L1} = 1.30 and RF_{L2} = 1.50

AVL Solutions

(A comprehensive approach to RDE)

AVL M.O.V.E

The Industry Standard to Measure Real Driving Emissions (RDE)

COMPLETE RDE TEST SYSTEM

AVL M.O.V.E iS System

- GAS PEMS iS
- PN PEMS iS
- EFM iS
- System Control
- Concerto M.O.V.E Postprocessing

… done more than 30.000 RDE tests @ 100+ customers!

AVL M.O.V.E iS

The Industry Standard to Measure Real Driving Emissions (RDE)

AVL M.O.V.E – RDE TESTING SYSTEM

GAS PEMS iS

CO, CO2, NO, NO2, O2

PN PEMS

Particle Number

AVL M.O.V.E EFM

Exhaust Mass Flow

AVL PLUtron™

Fuel Flow

AVL Indimicro

Voltage/ amps

GPS

T, p, %

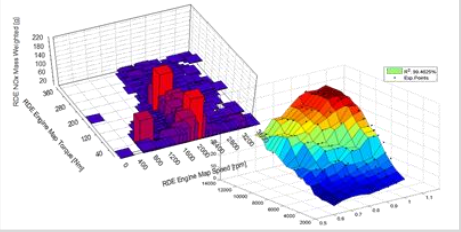
SYSTEM CONTROL

OBD II

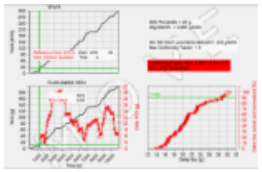
MOVE Data Toolbox

Online Tools

Advanced Analysis Tools



Reporting



Road-2-Lab Solution

RDE Testing

RDE Development

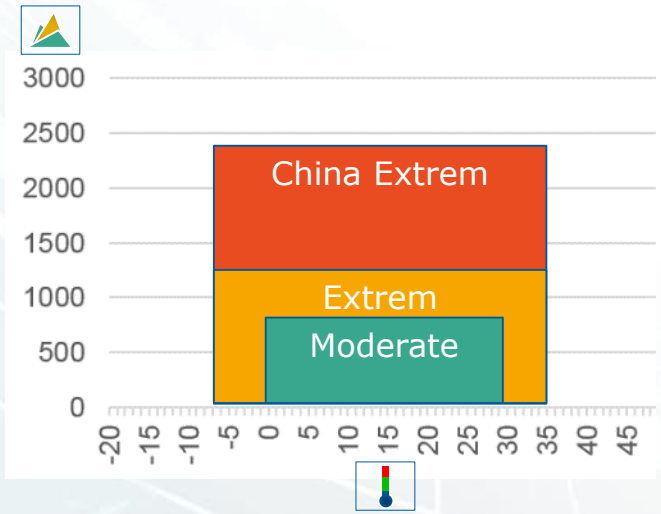
M.O.V.E – an In-Vehicle test platform which is aligned with the In-Lab test platform

RDE TEST REQUIREMENTS

Application

Standard

Real Driving Emissions (2016/427 1st package, 2016/646 2nd package, 2017/1151 3rd package, 4th package)



Light duty vehicle on Real Driving Emission testing:

- Portable E
  PN, Exhau
- Implementation: EU 2017, Korea 2018, China 2019, India 2020, Japan 2022

randomness of real driving

Limits:

- CF NOx:
- 2 calculation options, EMROAD (JRC) or CLEAR (TU Graz)

low emissions under all conditions

RDE Test requirements:

- 30min co
- RDE Drive
- 34% Urban (<60km/h), 33% Rural (60 ... 90km/h), 33% Motorway (>90km/h)
- max. Speed 145km/h (can be extended to 160km/h on test track)
- positive altitude gain < 1200m/100km
- OVC Hybrid test in Charge–Sustaining mode
- Periodical Regeneration w/o Regeneration use ki-factors

realistic testing will be tough to meet requirements

Ambient conditions:

- 0°C to 30
- up to 700

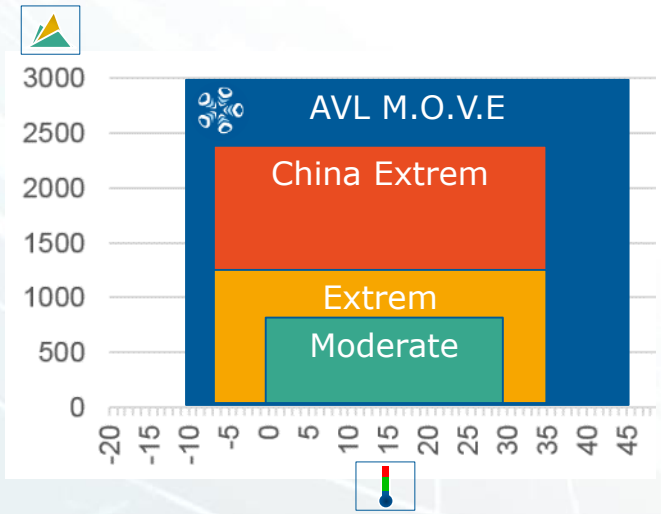
wide range of environmental conditions

RDE TEST REQUIREMENTS

Application

Standard

Real Driving Emissions (2016/427 1st package, 2016/646 2nd package, 2017/1151 3rd package, 4th package)



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realistic testing will be tough to meet requirements

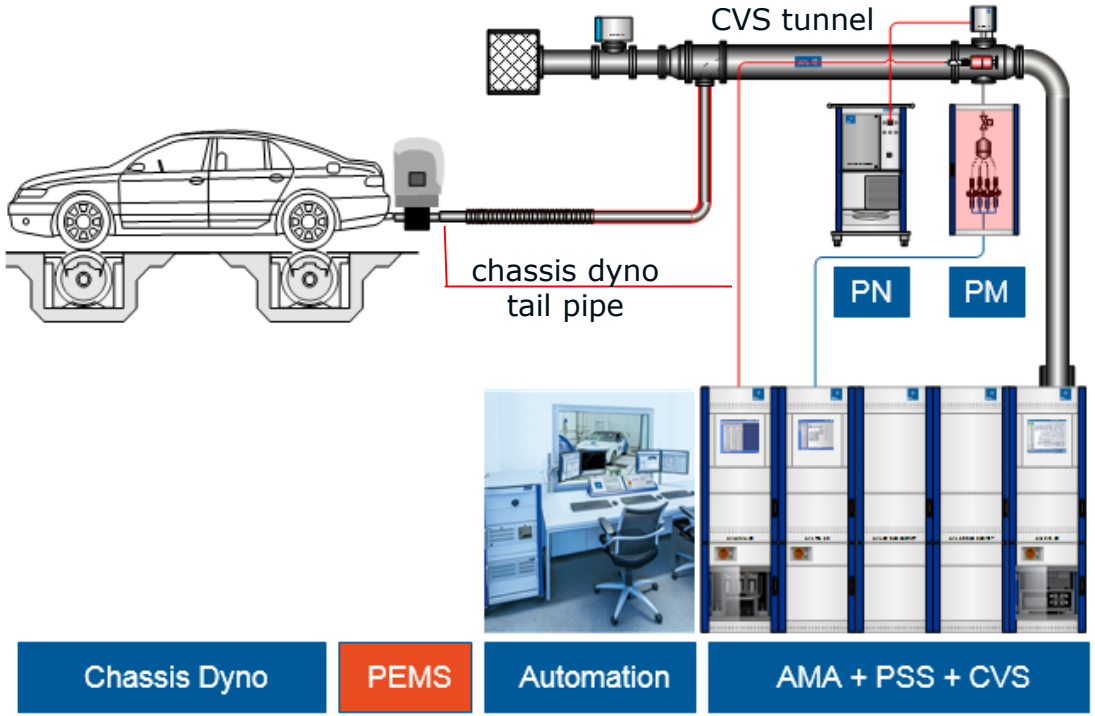
Ambient conditions:

- 0°C to 30
- up to 700

wide range of environmental conditions

RDE Chassis Dyno Validation Test
Test setup and RDE requirements

Test setup:



RDE correlation limits:

(30) in Appendix 3, in point 3.3., Table 1 is replaced by the following:
"Table 1

Permissible tolerances

Parameter [Unit]	Permissible absolute tolerance
Distance [km](1)	250 m of the laboratory reference
THC(2) [mg/km]	15 mg/km or 15% of the laboratory reference, whichever is larger
CH_4(2) [mg/km]	15 mg/km or 15% of the laboratory reference, whichever is larger
NMHC(2) [mg/km]	20 mg/km or 20% of the laboratory reference, whichever is larger
PN(2) [#/km]	$1 \cdot 10^{11}$ p/km or 50% of the laboratory reference[1] whichever is larger
CO(2) [mg/km]	150 mg/km or 15% of the laboratory reference, whichever is larger
CO_2 [g/km]	10 g/km or 10% of the laboratory reference, whichever is larger
NO_x(2) [mg/km]	15 mg/km or 15% of the laboratory reference, whichever is larger

(1) only applicable if vehicle speed is determined by the ECU; to meet the permissible tolerance it is permitted to adjust the ECU vehicle speed measurements based on the outcome of the validation test

(2) parameter only mandatory if measurement required by point 2.1 of this Annex.";

Source: Commission Regulation (EU)

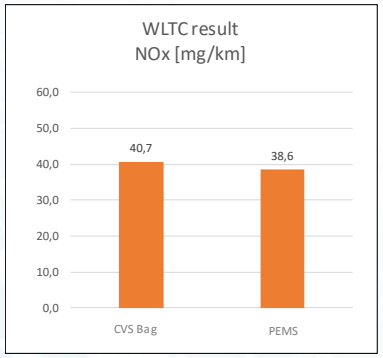
AVL M.O.V.E iS System Validation
Achieves very good agreement to CVS

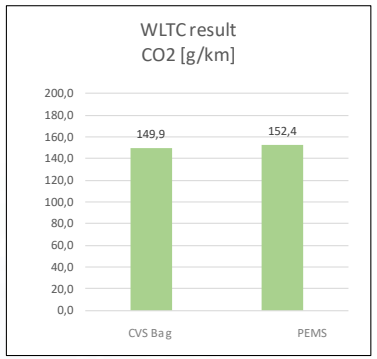
PEMS System: AVL M.O.V.E GAS iS & PN iS
Vehicle AUDI A4 1.8l TFSI

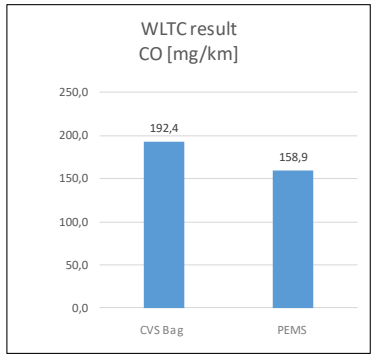
Testbed: AVL CD 401
Test Cycle: WLTC 4 Phase

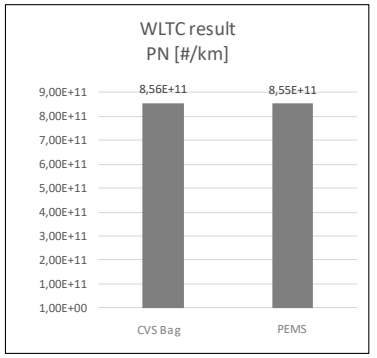
Pollutant		CVS BAG	PEMS	absolute difference (PEMS-CVS)	relative difference (PEMS-CVS)	Status	RDE correlation limits	50% Limits
Distance	km	**23,4**	**23,416**	0,016	0,9993			
CO2	g/km	**149,9**	**152,4**	2,5	1,7%	**Passed**	+/- 10g/km or 10%*	+/- 5g/km or 5%*
CO	mg/km	**192,4**	**158,9**	-33,5	-17,4%	**Passed**	+/- 150mg/km or 15%*	+/- 75mg/km or 7.5%*
NOx	mg/km	**40,7**	**38,6**	-2,1	-5,2%	**Passed**	+/- 15mg/km or 15%*	+/- 7.5mg/km or 7.5%*
PN	#/km	**8,56E+11**	**8,55E+11**	-1,62E+09	-0,2%	**Passed**	+/- 1E+11#/km or 50%*	+/- 1E+11#/km or 25%*

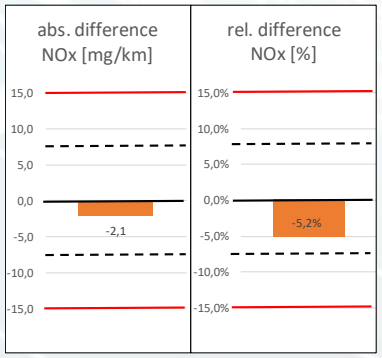
*** whichever is greater; percent of laboratory reference**

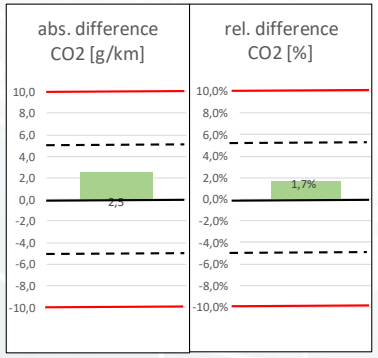


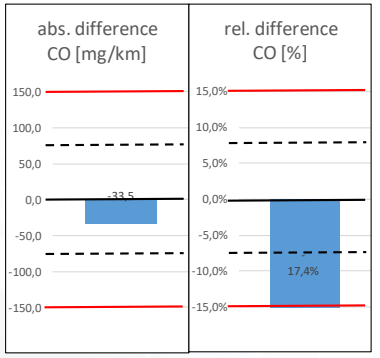


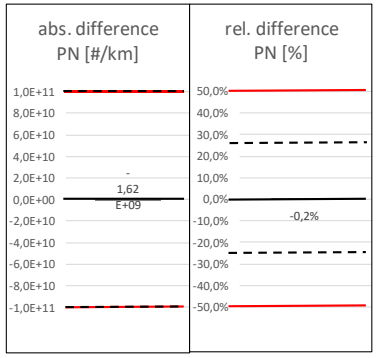


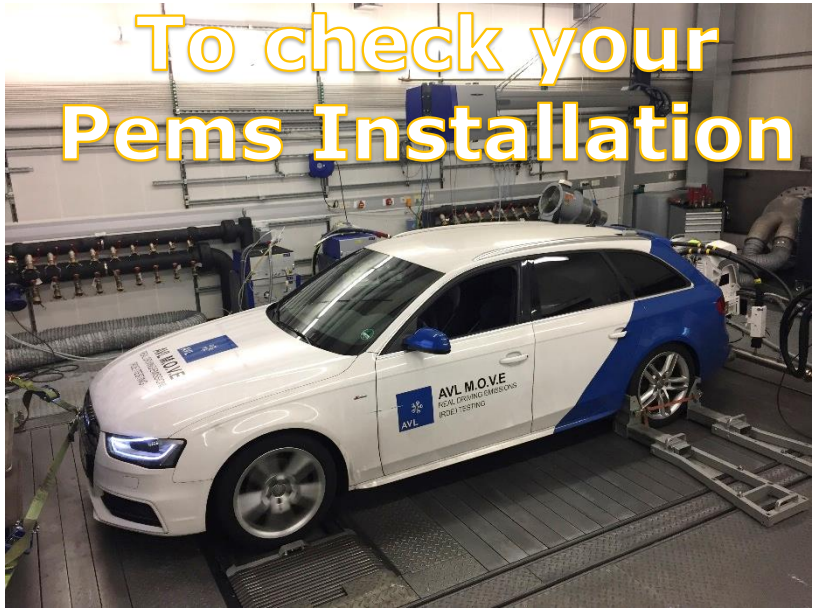








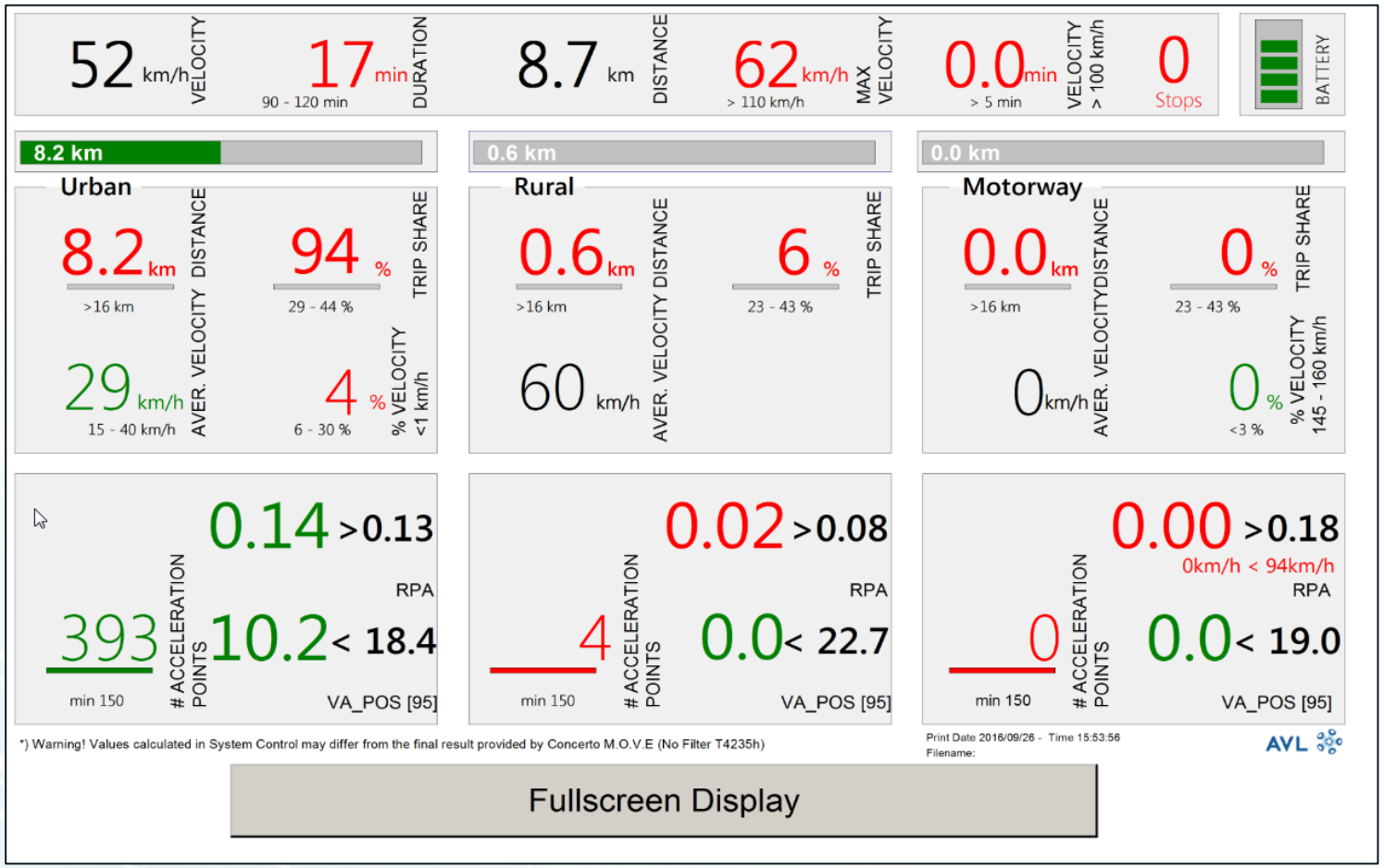




RDE limits	———
50% RDE limits	- - - - -

Passed
Passed

RDE ONLINE GUIDANCE
AVL MOVE SYSTEM CONTROL



REMOTE CONNECTION

INCREASE VALID RDE TEST DRIVE >90%

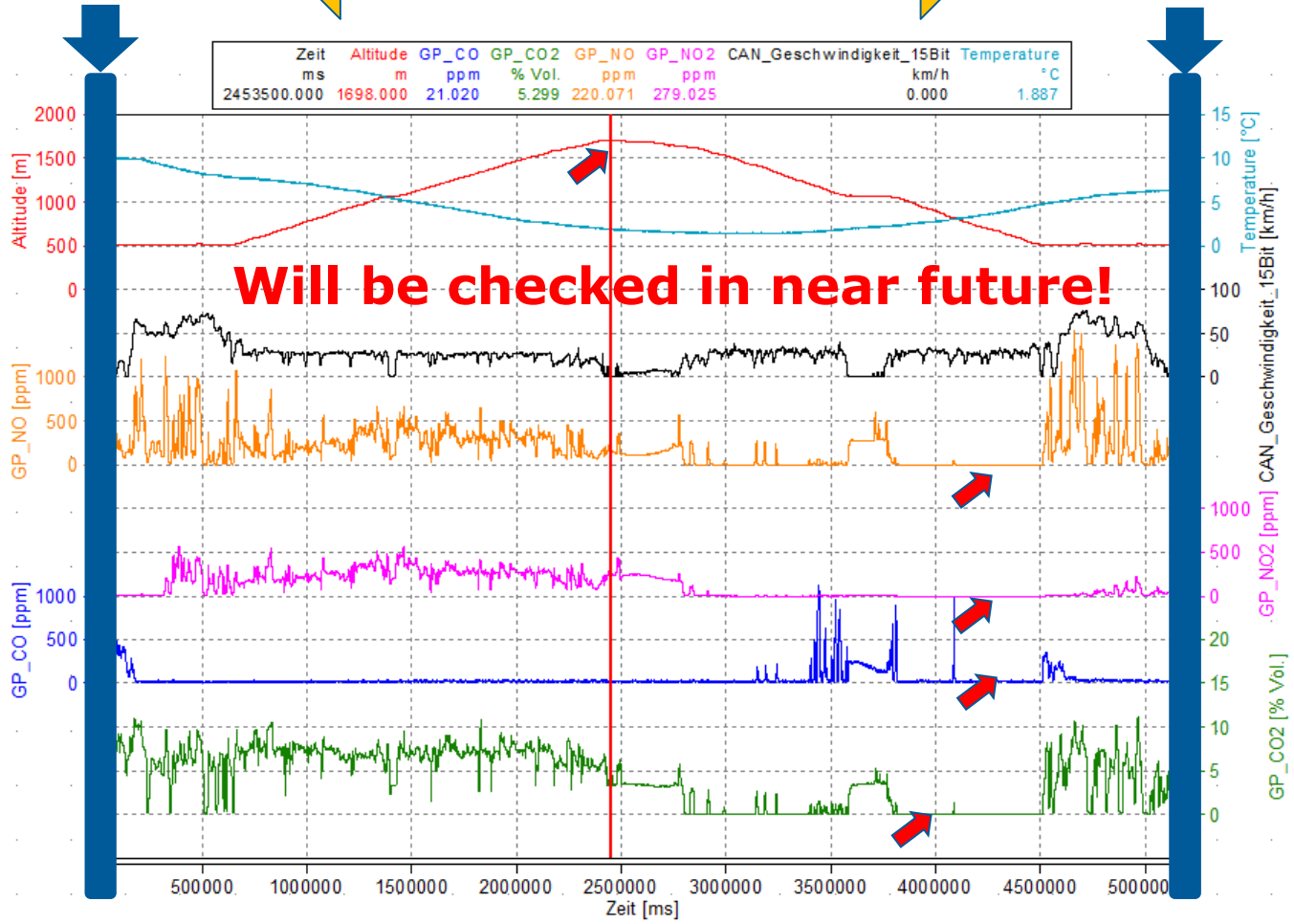
RDE PEMS Requirements will be extended
Pre vs. Post Drift Verification not enough

Pollutant	Absolute Zero response drift	Absolute Span response drift [1]
CO_2	≤2000 ppm per test	≤2% of reading or ≤2000 ppm per test, whichever is larger
CO	≤75 ppm per test	≤2% of reading or ≤75 ppm per test, whichever is larger
NO_X	≤5 ppm per test	≤2% of reading or ≤5 ppm per test, whichever is larger
CH_4	≤10 ppmC_1 per test	≤2% of reading or ≤10 ppmC_1 per test, whichever is larger
THC	≤10 ppmC_1 per test	≤2% of reading or ≤10 ppmC_1 per test, whichever is larger

Pre Test

No requirement!

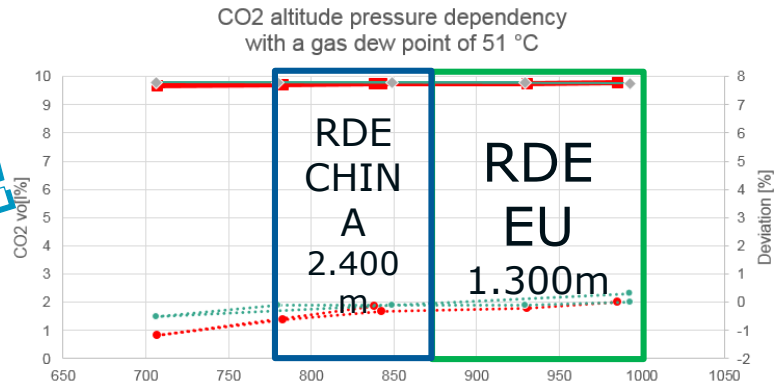
Post Test

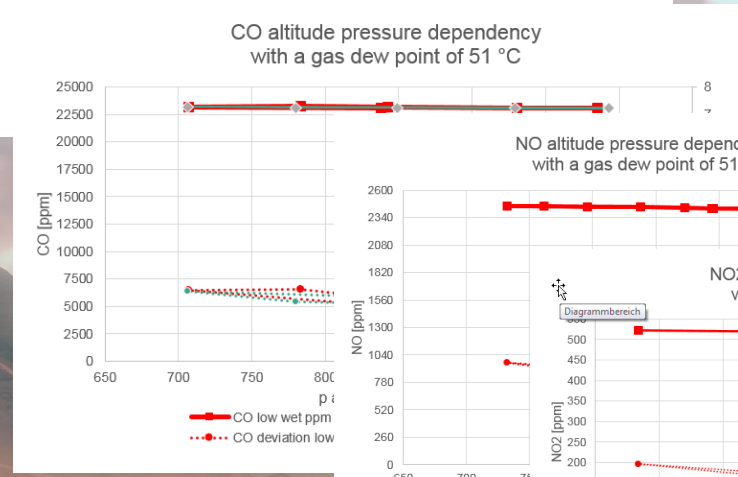


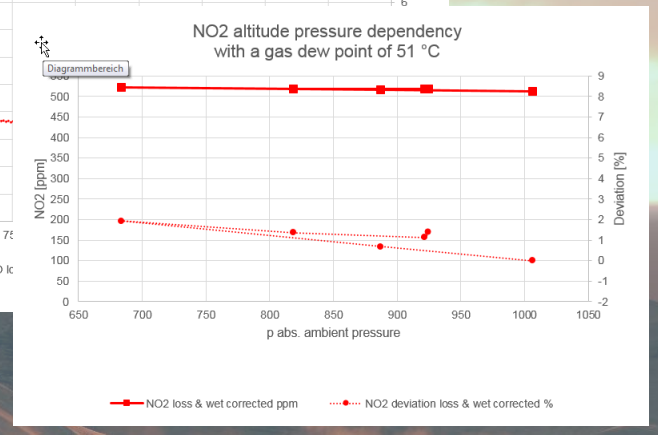
Example result for mountain road testing with the AVL GAS PEMS iS.

RDE Testing under high Altitude
Performance of GAS & PN PEMS iS (3.000m)

Robustness on the Road!!!

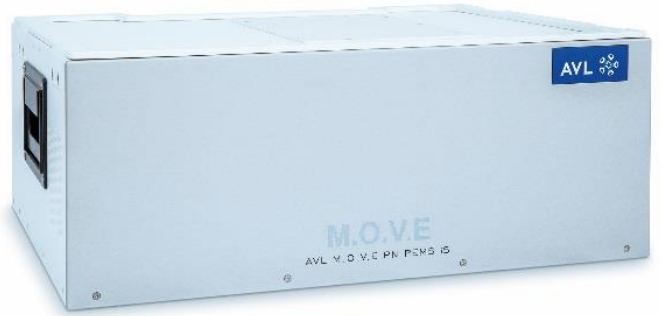






RDE Testing – M.O.V.E GAS & PN PEMS iS
More in next RDE Presentation…

AVL M.O.V.E PN PEMS iS



AVL M.O.V.E PN PEMS iS Vibration Tests

1. Measurement of the accelerations on a vehicle during a RDE test run on the road
2. Derived profile for the shaker with a representative acceleration energy density the device experience during the RDE run
3. Vibration tests on a shaker
   - APG as soot source
   - PMP-reference in parallel
   - PN PEMS installed on shaker

→ **No quantifiable effect of vibrations up to 3g was observed.**

Vibration Tests of the
AVL M.O.V.E PN PEMS iS

AVL M.O.V.E PN PEMS iS Vibration Tests

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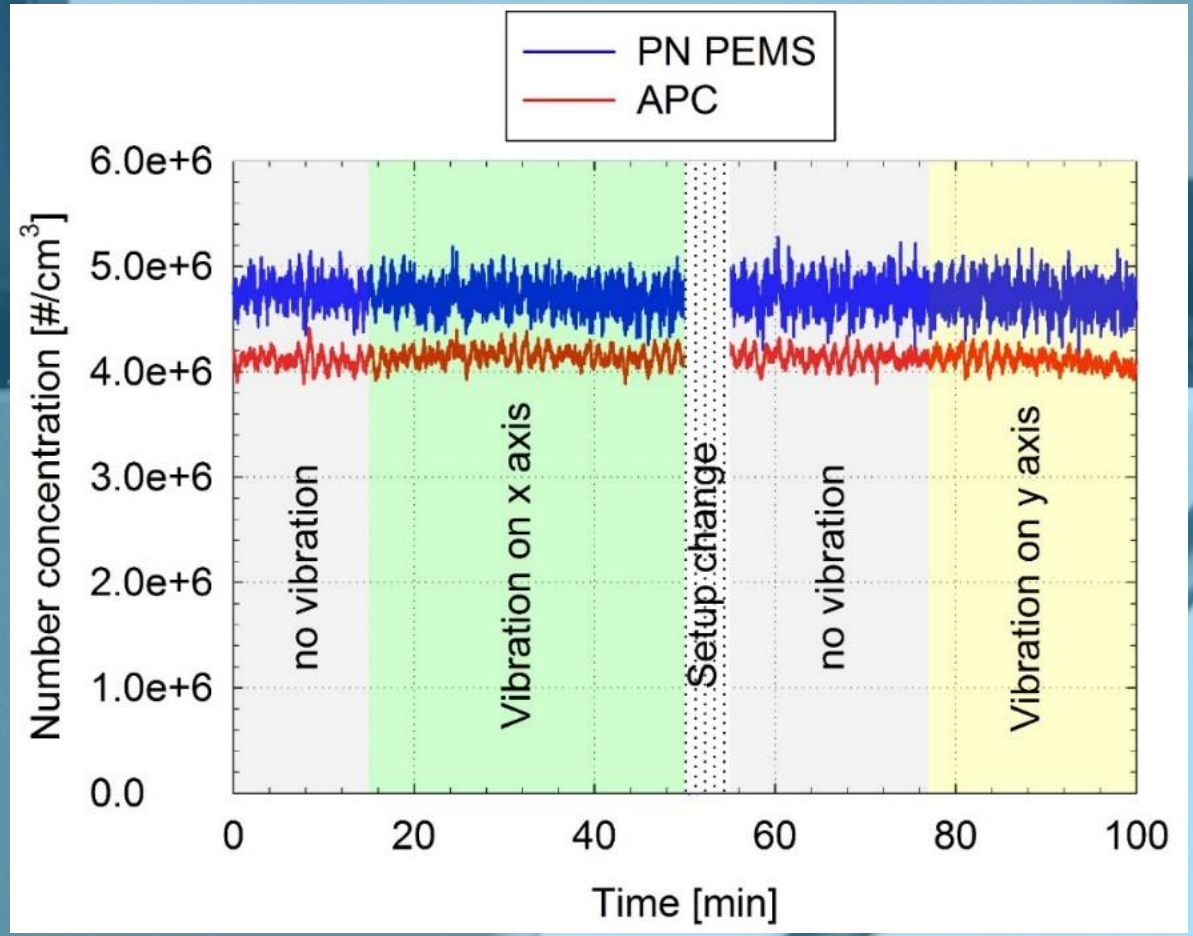
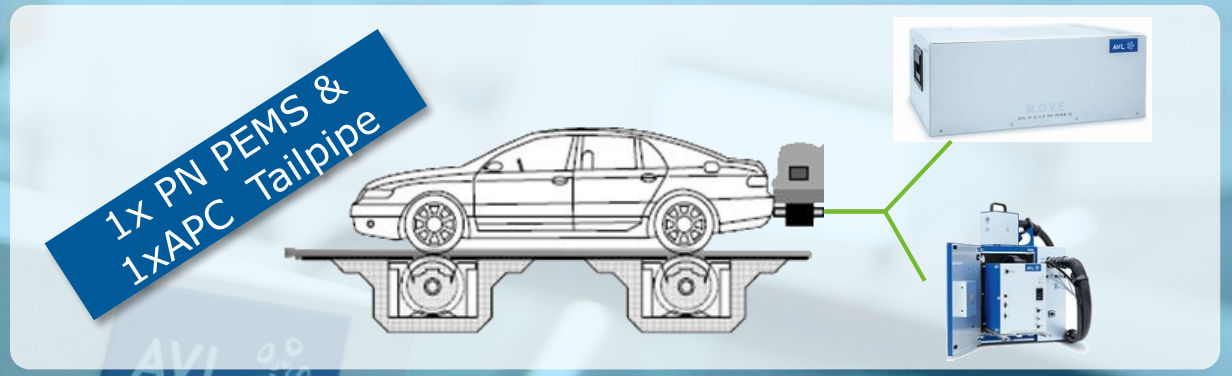
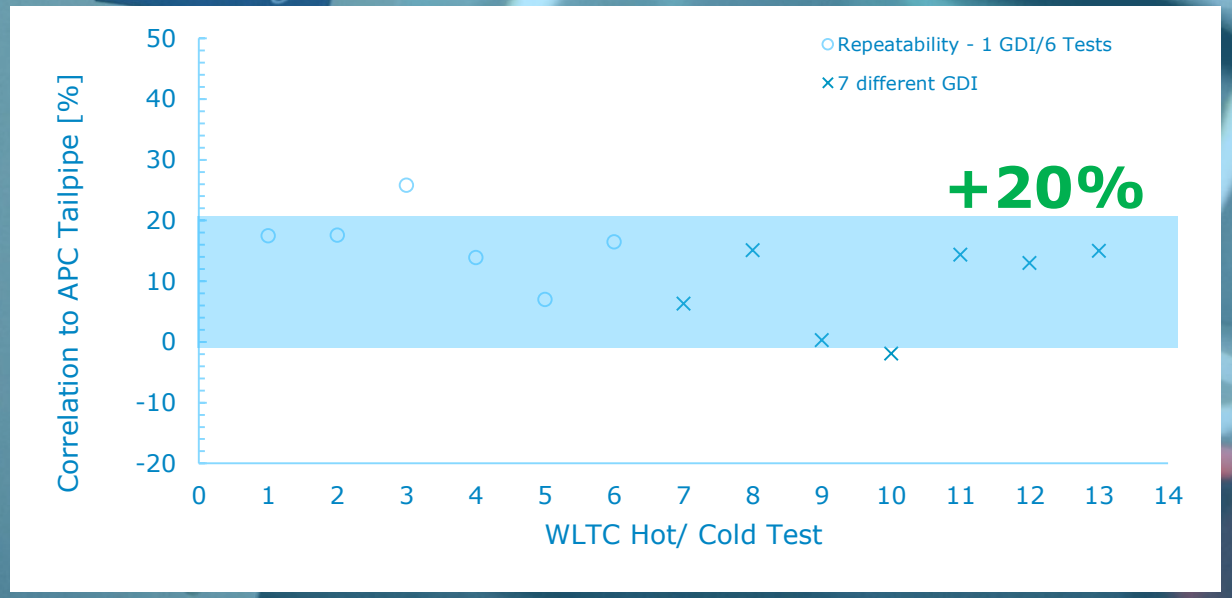


Measurement data - testbed

Measurement campaign at AVL Powertrain Engineering

- PN PEMS iS compared to an APC at tailpipe
- 6 runs with one vehicle (black) and 7 tests with different GDI vehicles (orange, cold starts)
- In total 11 WLTC hot
- Results show an excellent agreement **well below 20%**





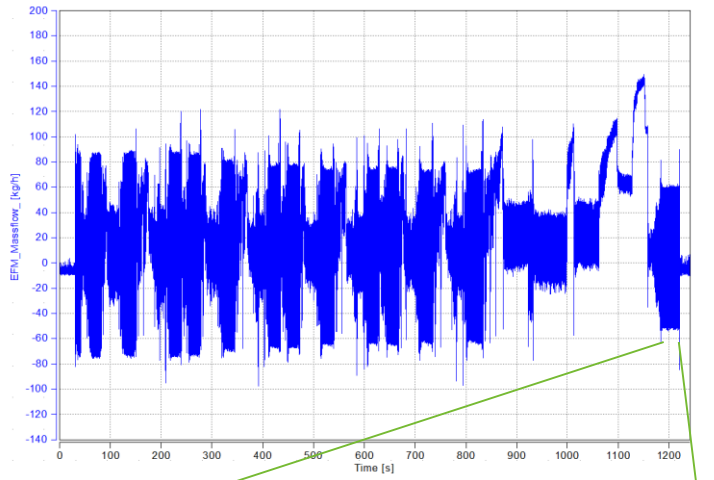
AVL M.O.V.E EXHAUST FLOW METER DESIGNED FOR…

AVL M.O.V.E EXHAUST FLOW METER

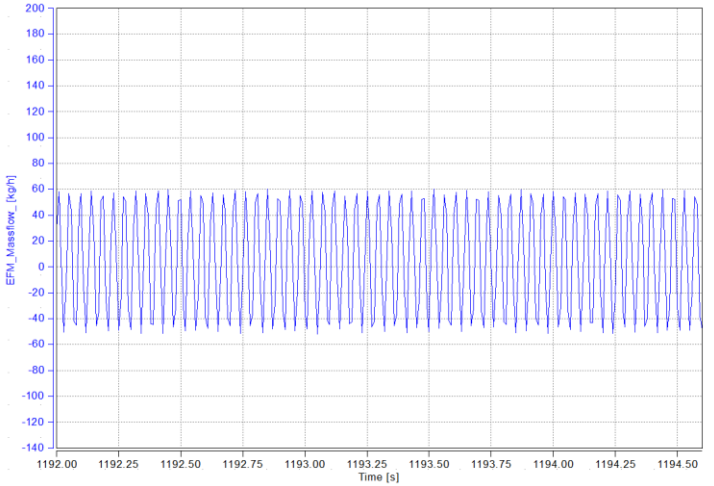
- **… fulfilling all requirements of the actual legislation (EU ISC, EU RDE, US EPA HDIUT)**
  - Sufficient lengths of the main and extension tubes
  - Linearity, accuracy, … acc. legislative requirements
- **… accurate measurements under dynamic exhaust flow conditions**
  - High-speed evaluation of the Pressure Transducers (5kHz)
- **… quick and easy integration into AVL M.O.V.E, other automation and data acquisition systems**
  - CAN out (1khz), analog out, Ethernet interface
- **… safe installation**
  - Consideration of safety aspects e. g. heat insulation blanket

Exhaust flow meter - Pitot Challenge

Small NA gasoline engines – Pulsations at low flow



Zoom



- Highest Measurement Accuracy even in low flows
- As pulsations are accurately captured at a data rate of 5 kHz!

Further Applications

AVL M.O.V.E In-Vehicle Testing

Emission Measurement

EU-4: 2016 based on UN-ECE-Regulation 40/47 and GTR-2

Introduction of PM limits for CI and GDI engines, only

EU-5: 2020 based on UN-ECE GTR-2

open discussion (Effect study) in-use conformity, off-cycle emissions and PN

USA: EPA Motorcycle Standard [g/km]

no change since 2010

USA: CARB Motorcycle Standard [g/km]

no change since 2008

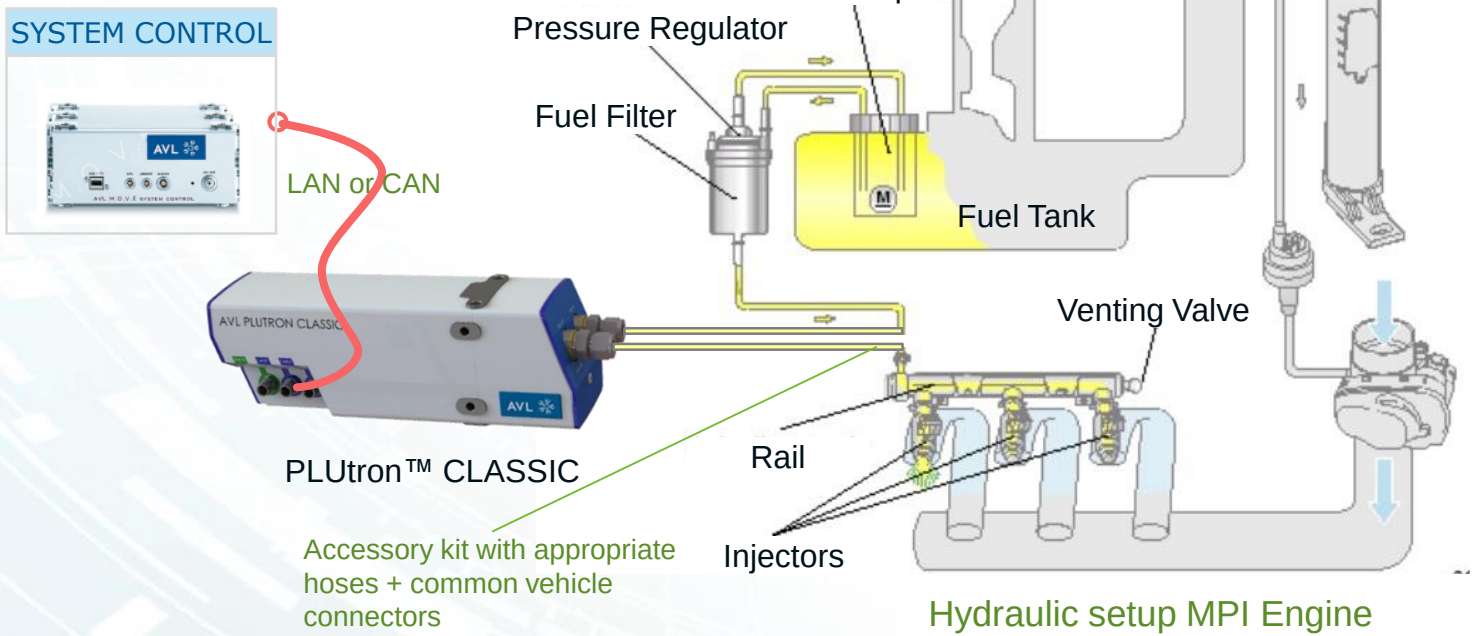
Asia (India): still Leading the MC emission regulations

Start of discussion about RDE

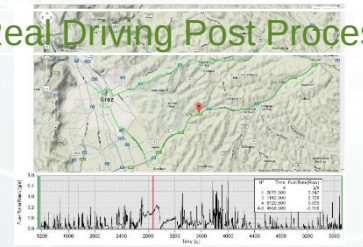
Is „Real Driving Emission“ Measurement on Motorcycles possible?

Case Study with TU Graz
Setup Motorcycle with actual RDE equipment

AVL M.O.V.E iS
CO2 Testing – Real Fuel Consumption



Real Driving Post Processing



- Fast connection to your on board fuel system
- Provides online result by l/km (also via MAP data)
- Full integration with AVL M.O.V.E and thus PEMS testing
- Highest accuracy for real driving fuel consumption at low flows

AVL M.O.V.E iS
RDE DEVELOPMENT EXTENSION

GAS PEMS iS

CO, CO2, NO, NO2, O2

PN PEMS

Particle Number

AVL M.O.V.E EFM

Exhaust Mass Flow

AVL PLUtron™

Fuel Flow

AVL Indimicro

Voltage/ amps

GPS

T, p, %

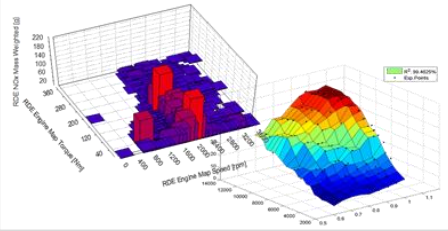
SYSTEM CONTROL

OBD II

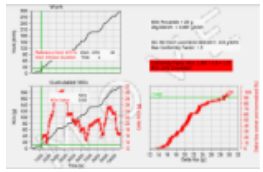
MOVE Data Toolbox

Online Tools

Advanced Analysis Tools



Reporting

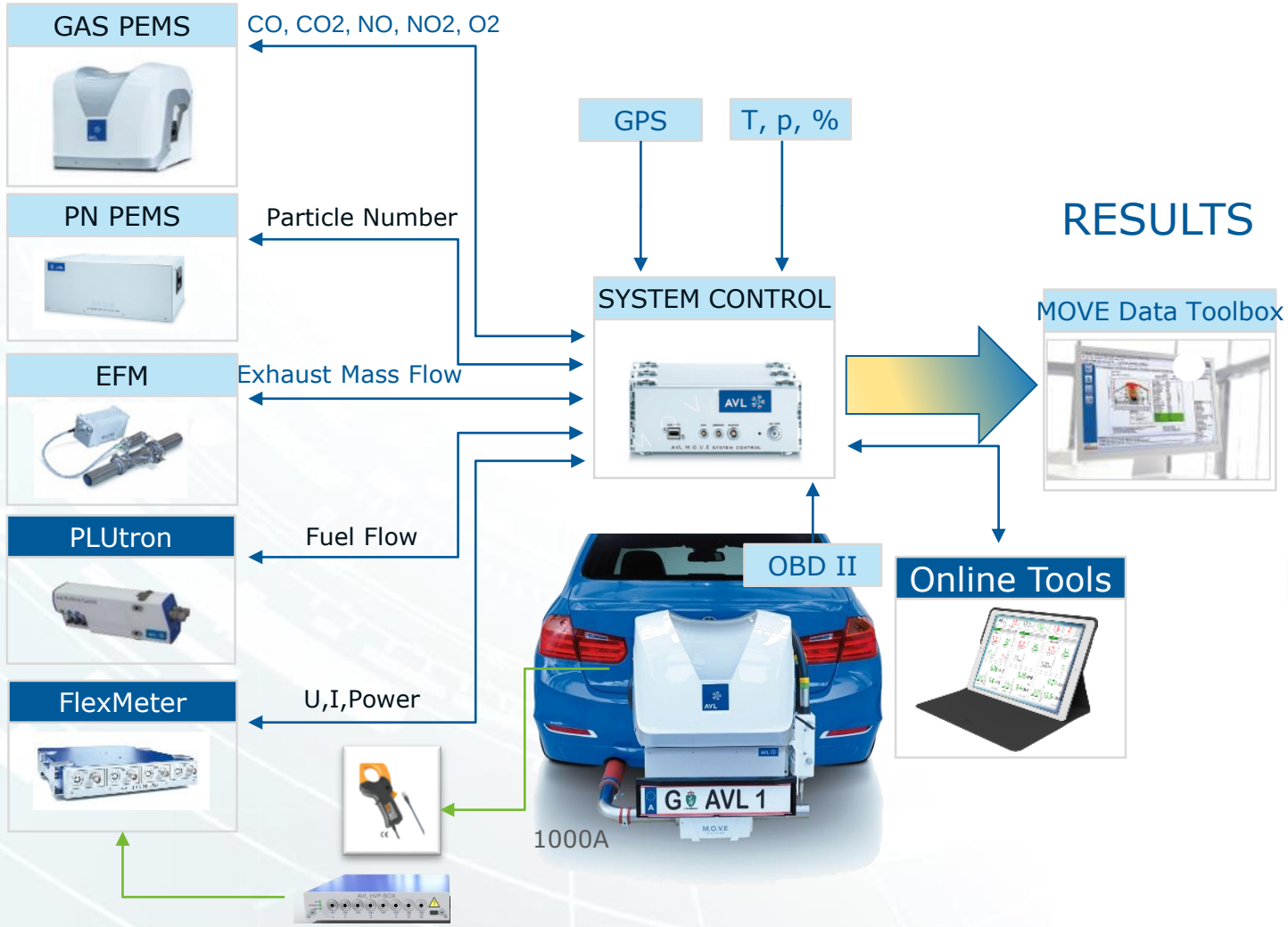


RDE Testing

RDE Development

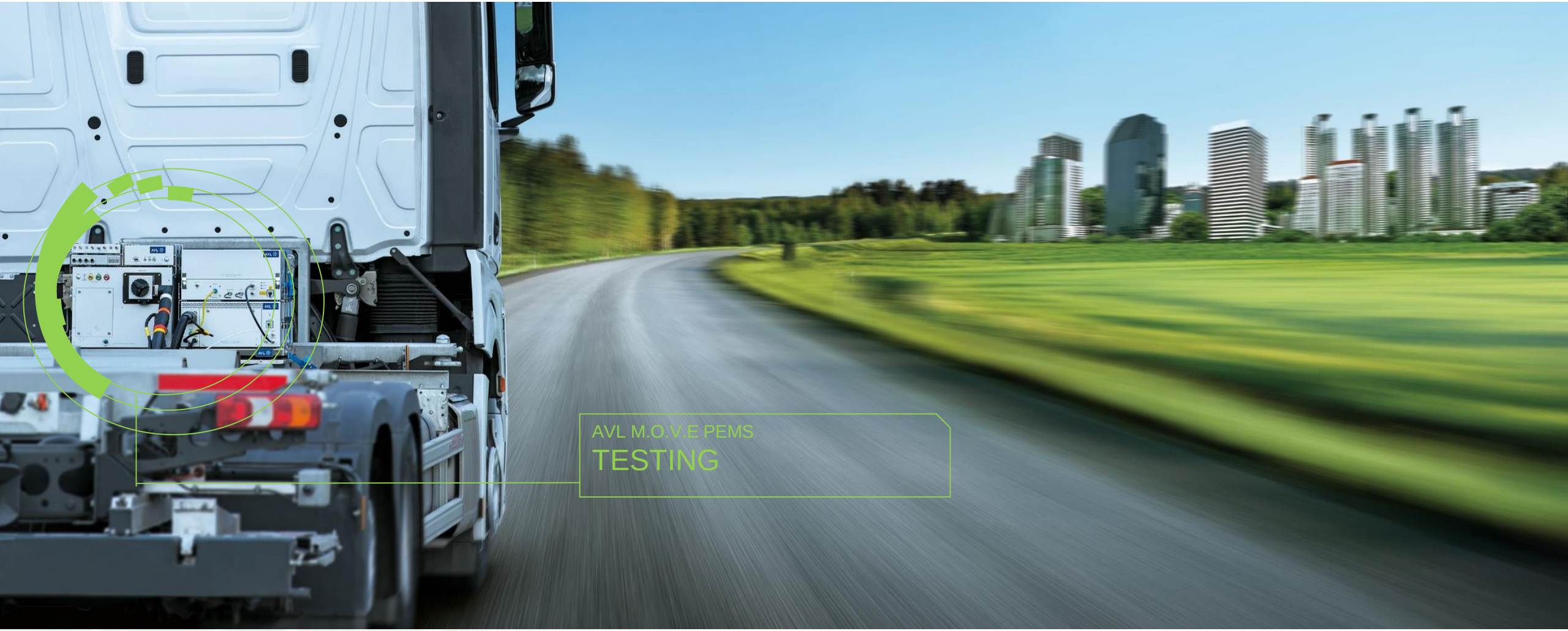
M.O.V.E – an In-Vehicle test platform which is aligned with the In-Lab test platform

AVL M.O.V.E - Energy Efficiency Evaluation CO2 & E-Power Measurement Extension



- **Easy add-on of hybrid key figures** into System Control (real fuel consumption, battery state of charge, Recuperated energy, charging modes, HCU information)
- High speed power measurement for exact **battery aging effects determination**
- Extended **Reporting of total energy efficiency** for better evaluation of vehicle strategy

AVL M.O.V.E HEAVY DUTY TESTING



Heavy duty in-service conformity with PEMS

USA and Canada

HDIUT –
In-use Testing with PEMS equipment and field-testing procedures 1 January 2005

EU

Euro VI: 1 January 2013 all new vehicle types

South Korea

Euro VI: PEMS requirements from 1 January 2016

Japan

under discussion, earliest introduction 2022

China

Phase V: 1 October 2017 all newly approved vehicle type
Phase VI *(Draft):*
1 January 2020 Phase VIa (urban vehicles)
1 January 2021 Phase Via (all vehicles)
1 January 2023 Phase VIb

Brazil

PROCONVE P-8 *(Draft): 1 January 2027*

India

Bharat VI: 1 April 2020 monitoring
1 April 2023 limitation (CF)

Singapore

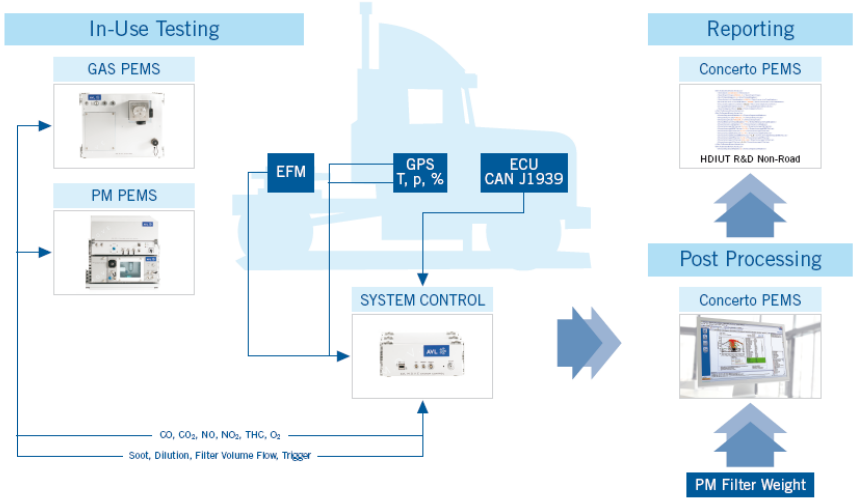
Euro VI: *1 January 2018*
PEMS only in TA

Australia

Euro VI *under discussion*

Heavy Duty – PEMS Testing

AVL M.O.V.E GAS & PM PEMS



In-Service Emissions conformity (compliance):

- "Real Life" Test on the street with PEMS (Portable Emission Measurement System). First in-service test should be conducted at the time of type approval testing
  - CO2, CO, NOx, THC, PM (PN in discussion for EU)
  - Exhaust flow rate, Speed, n, M and GPS data.

PEMS Test

- EU testing is conducted over a mix of urban (0-50 km/h), rural (50-75 km/h) and motorway (> 75 km/h) conditions, with exact percentages of these conditions depending on vehicle category.

Ambient conditions

- Temperature and Altitude as defines for off cycle emission requirements

Limits and Result calculation

- Limits are based on the laboratory limits multiplied by 1.5
- EU Result calculation by "Work based window"
- US Result calculation by NTE-Events (during ≥30seconds operation with high enough engine torque, speed and power

HDV – In Service Compliance Testing
PN Introduction

European Commission

PEMS PN procedure with conformity factors

- *The assessment of JRC in 2015 has proved a technical feasibility of the PEMS equipment to measure particulate number*
- *PEMS PN procedure will be introduced together with the 10% power threshold requirement – 1.09.2018 for new types, one year later for all new vehicles*
- *On-going tests on different vehicles*
- *Proposal to be prepared still in 2017*

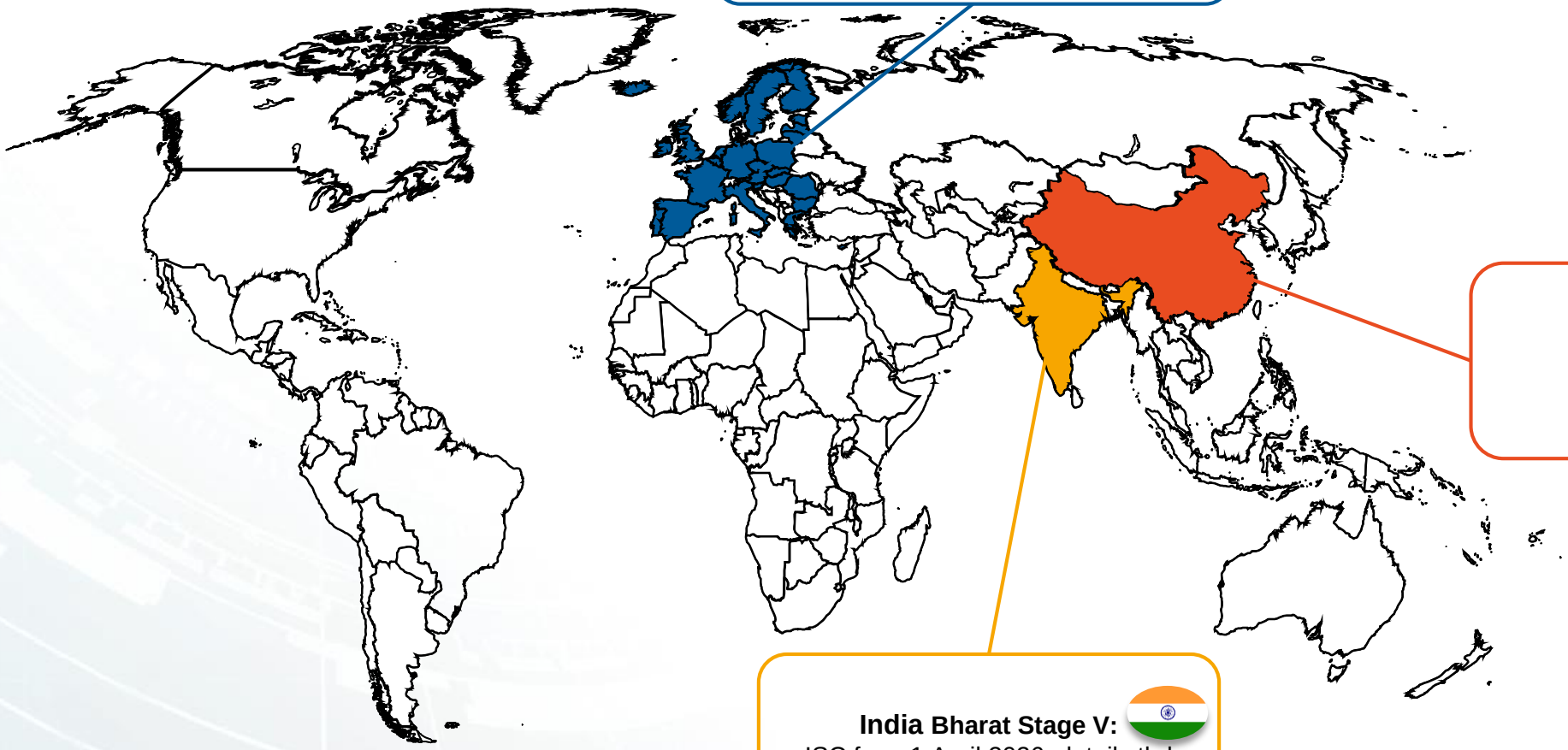
2015:
PM will be replaced by PN

PM PEMS	PN PEMS
	

2017:
PN for HDV will be introduced by 2019

NON-ROAD MOBILE MACHINERY (NRMM) IN-USE TESTING

Non-road in-service monitoring/conformity with PEMS



EU

Stage V: 1 January 2018/2019,
submission of first results: end of 2022

China

Draft China IV:
ISC from 2020
CF NO_x = 2.5

India Bharat Stage V:
ISC from 1 April 2026, details tbd

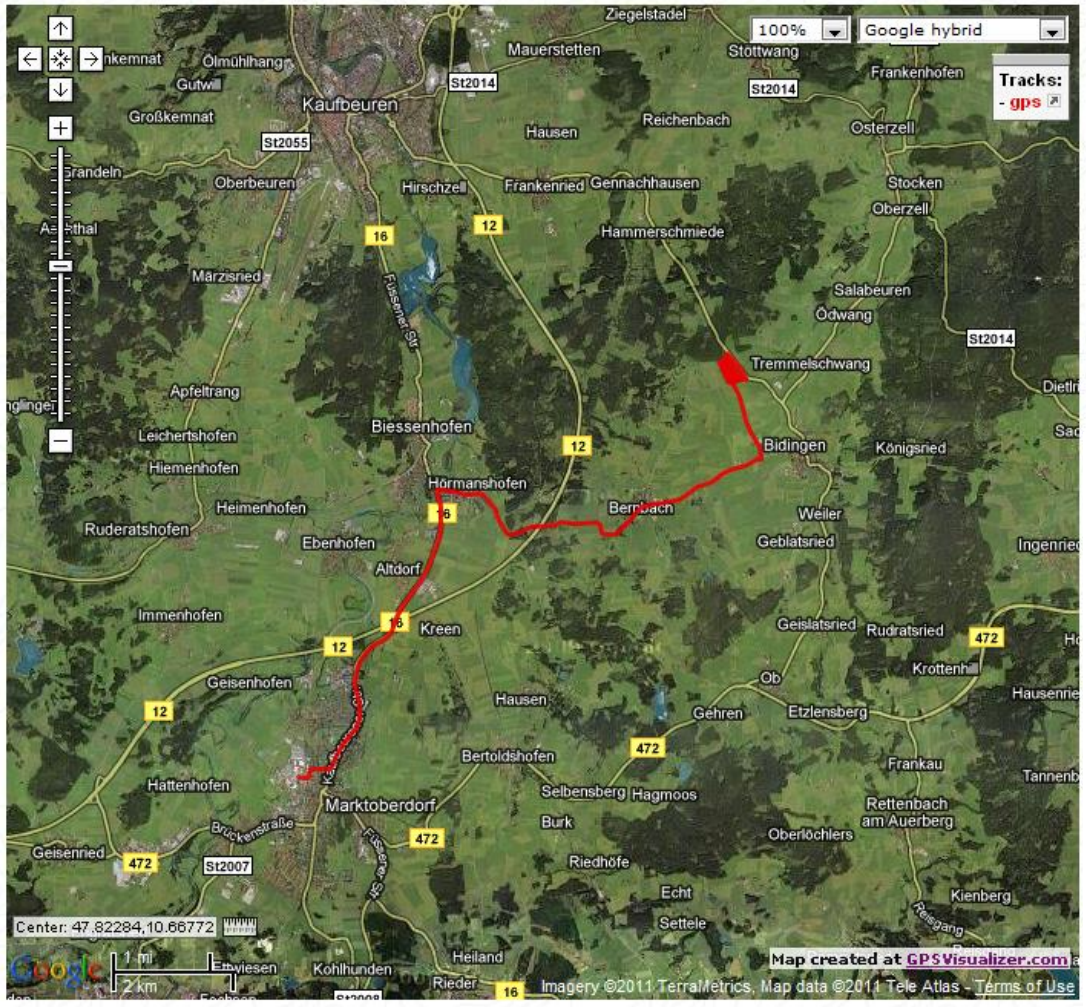
AVL M.O.V.E NRMM REFERNCE OFF-ROAD TESTING - TRACTOR FENDT

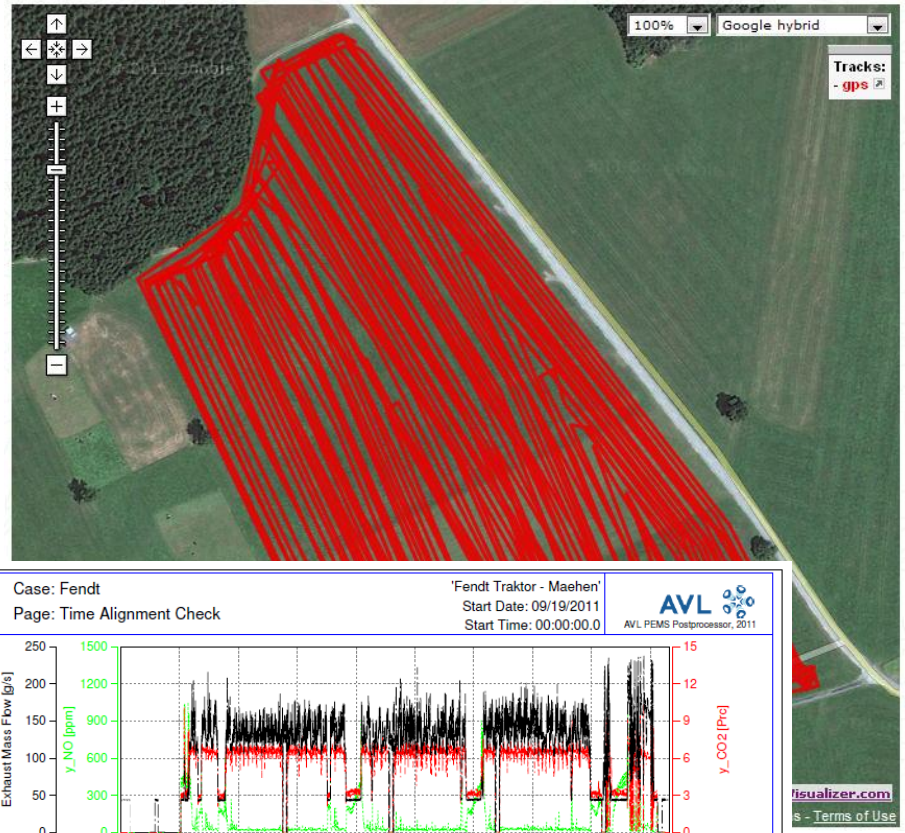
Setup consisting of

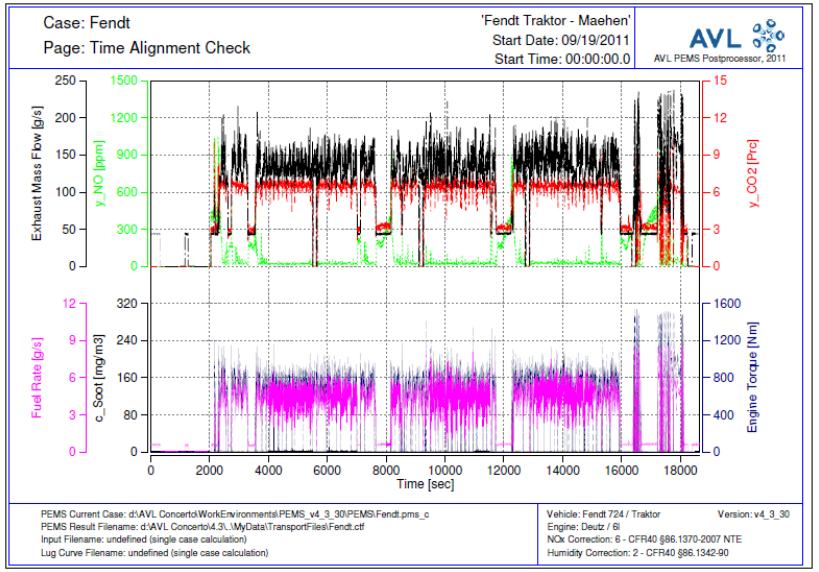
- PM PEMS
- Gas PEMS
- System Control
- Sensors EFM
- Generator
- Battery pack
- E-Box
- Rugged cases

HDIUT EXAMPLES – OFF ROAD

HDIUT EXAMPLES – OFF ROAD – RESULT DATA

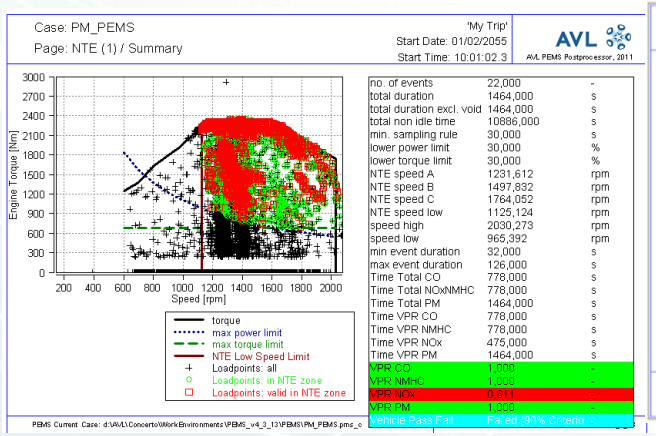


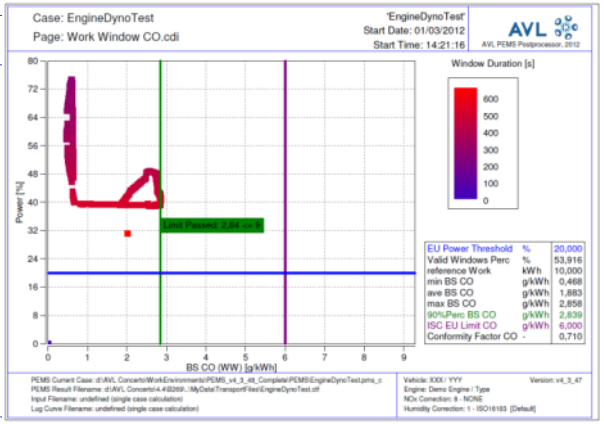


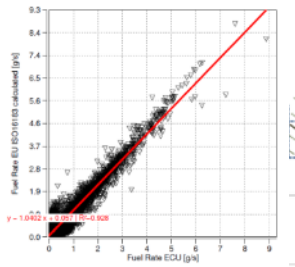


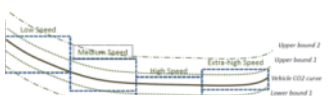

HOW TO GET A VALID TEST?
TRIP REQUIREMENTS…
KEY IS POST PROCESSING!!!

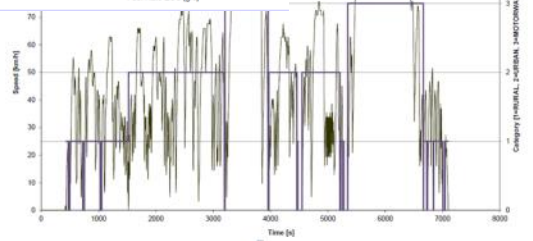
AVL CONCERTO 5™ - M.O.V.E DATA TOOLBOX LEGISLATIVE POST PROCESSING







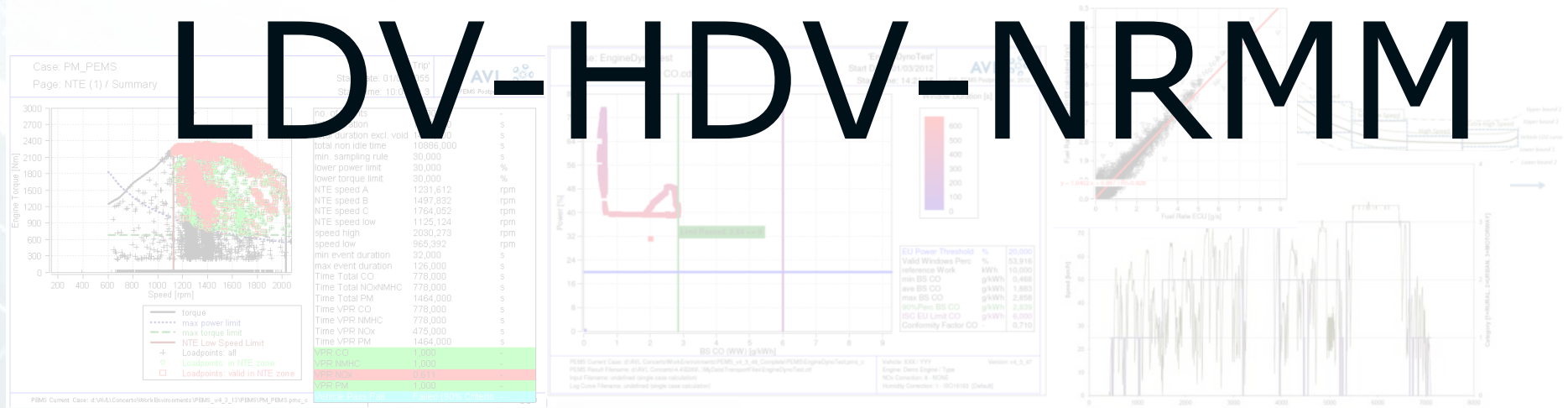




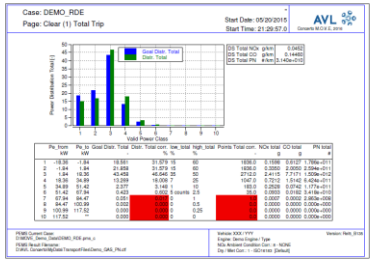
AVL CONCERTO 5™

M.O.V.E Data Toolbox

LDV-HDV-NRMM

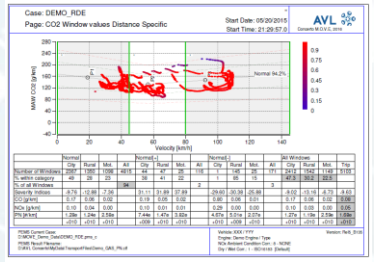


AVL CONCERTO 5™ - M.O.V.E DATA TOOLBOX
Example LDV - RDE 3 Results



TU Graz

JRC EUROPEAN COMMISSION



NEW: Quick View

Case: RDE_Demo_Data
Page: Conformity Factors

'Huntington Beach'
Start Date: 02/10/2016
Start Time: 11:16:28.0

AVL Concerto M.O.V.E, 2016

CALIBRATION	TRIP	DYNAMICS	EMROAD	CLEAR
●	●	●	●	●

Unweighted Results

		Avg. Trip	Limit
NOx	g/km	0.0068	0.800
CO	g/km	0.5667	0.500
CO2	g/km	127.9111	
PN	#/km	****	6.000e+011

JRC

		Trip	Conformity Factor			
			City	Rural	Motorway	Trip
NOx	g/km	0.0068	0.01	0.01	0.01	0.01
CO	g/km	0.3998	0.30	0.25	1.91	0.80
PN	#/km	0.000e+000	0.00	0.00	0.00	0.00

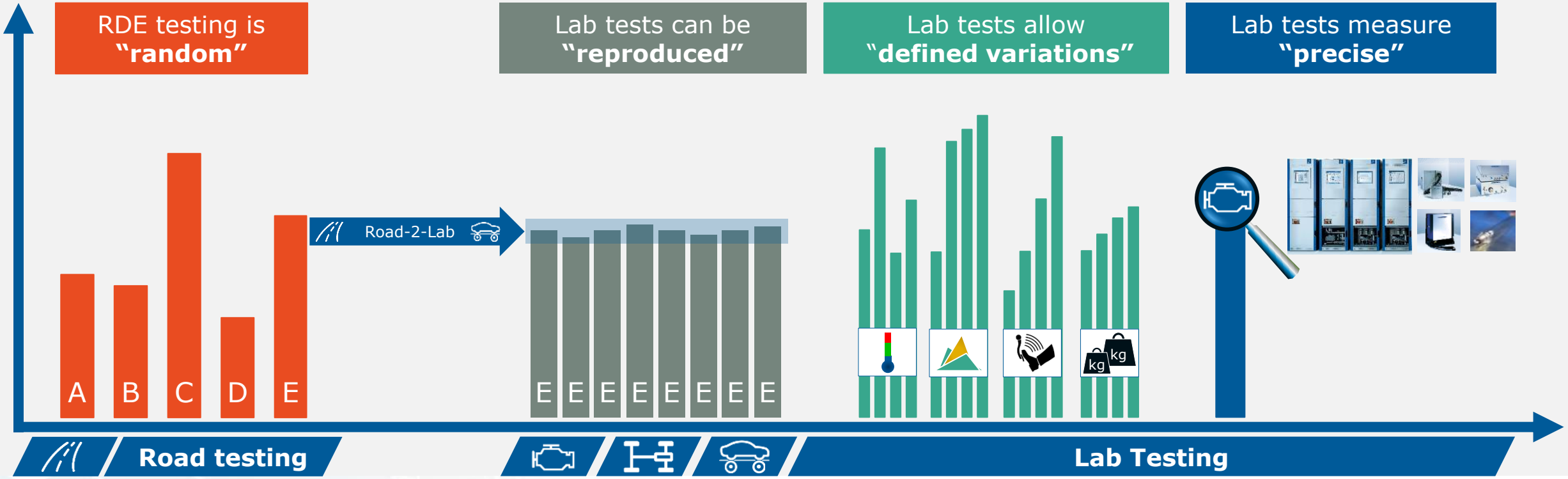
CLEAR

NOx	g/km	0.0070	0.01	0.01	0.01	0.01
CO	g/km	0.4756	0.27	0.47	2.11	0.95
PN	#/km	0.000e+000	0.00	0.00	0.00	0.00

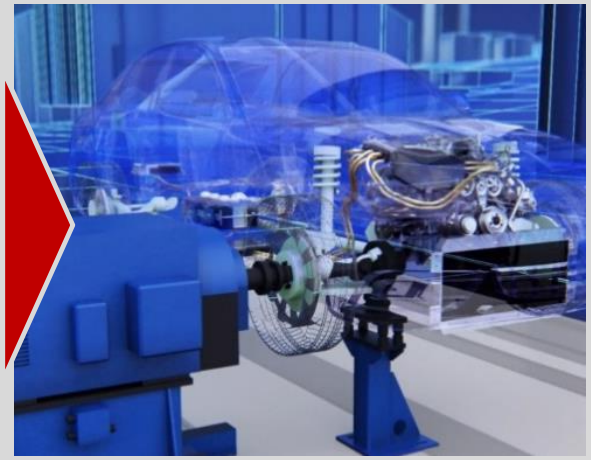
NEW: RDE TÜV Certified!

RDE Development

RDE Type Approval on the Road
R&D in the Lab



RDE Validation
Impact for Testing Environments

RDE Road Measurement	RDE Testing on Chassis Dyno	RDE Testing and Calibration on ETB	RDE Calibration on Virtual Test Bed
			

Same Results

Same Models | **Same Tests** | **Same Tools** | **Same Data Storage** | **Same Analysis**

Thank You

RDE compliance is a must

RDE legislation is implemented on global scale

RDE development focusing on boundary conditions asks for new development approach

Additional aspects will follow like Fuel Consumption & Energy Efficiency