EU7 – Herausforderungen und potenzielle Lösungsansätze für die Antriebsstrangentwicklung

EU7 general Overview
Potential Challenges and derived Solutions

AVL TechDay Deutschland 25.5.2023 in Leimen

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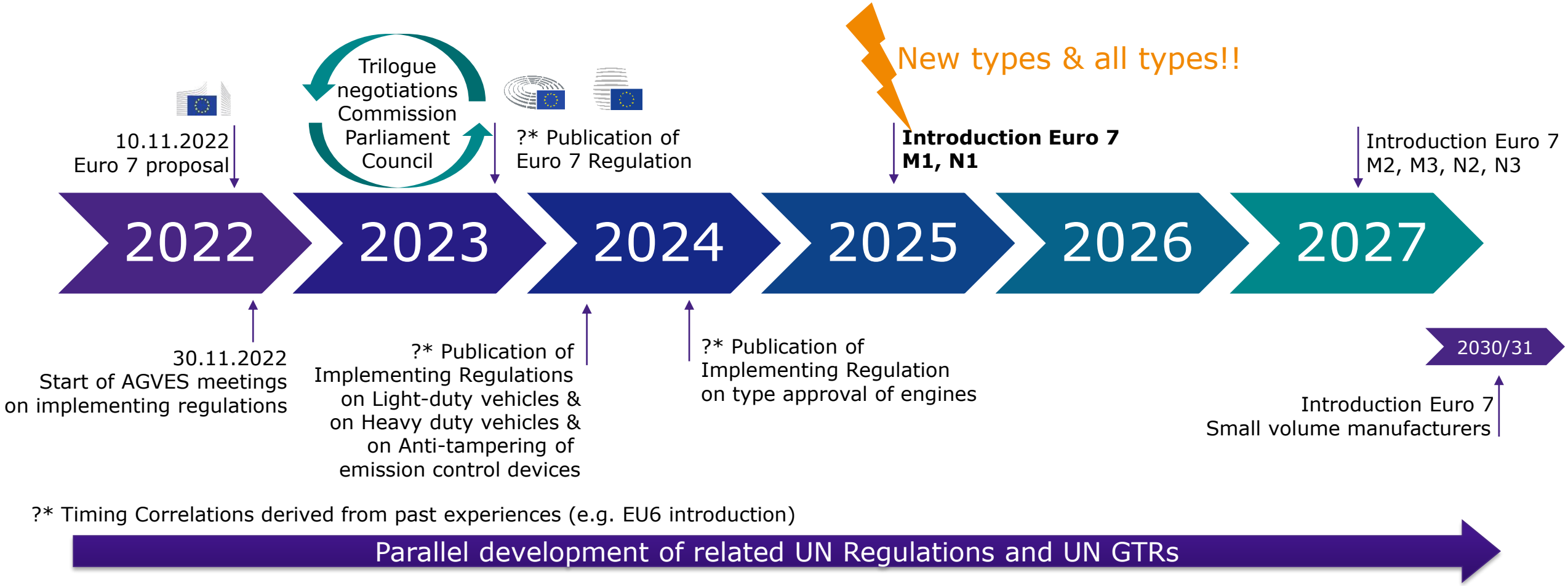
Passenger Car Powertrain Systems, Gasoline Engines

Euro 7 Legislation

Euro 7 monitoring – stay tuned

The proposal is just the beginning… **AVL Technical Legislation Services** guides you through the regulative process to come:

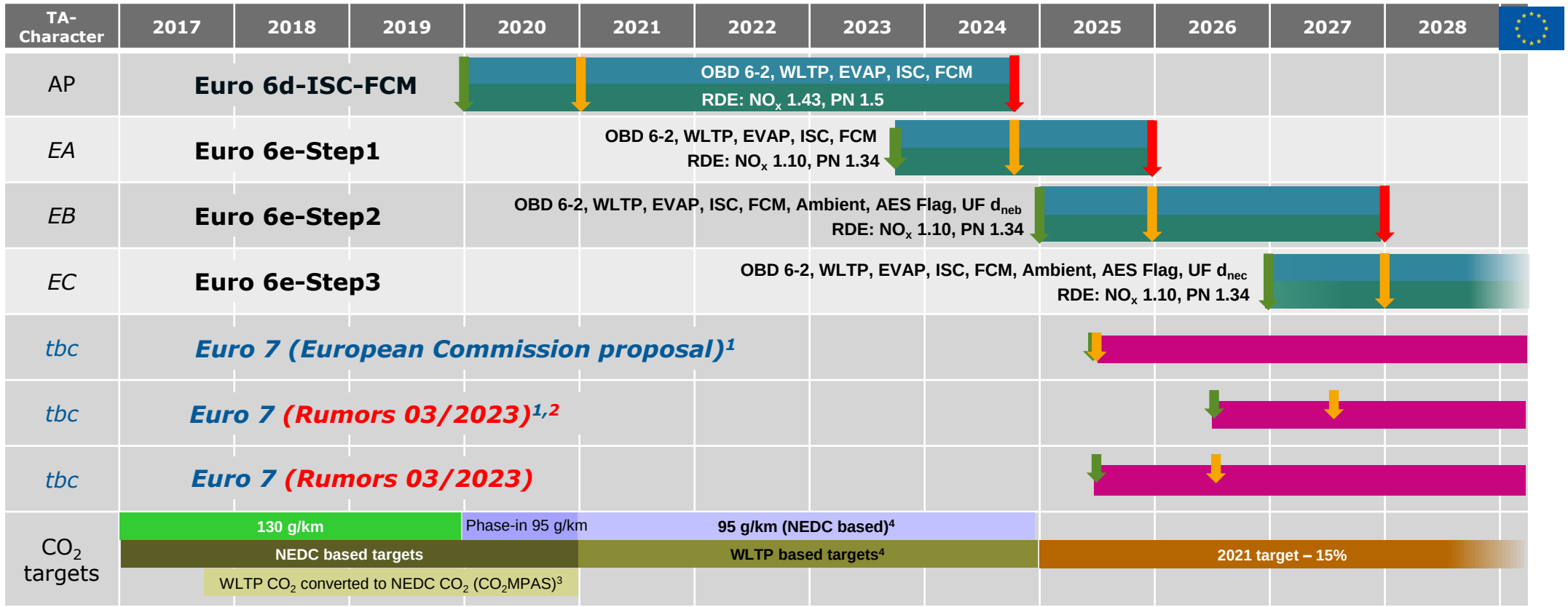


?* Timing Correlations derived from past experiences (e.g. EU6 introduction)

Parallel development of related UN Regulations and UN GTRs

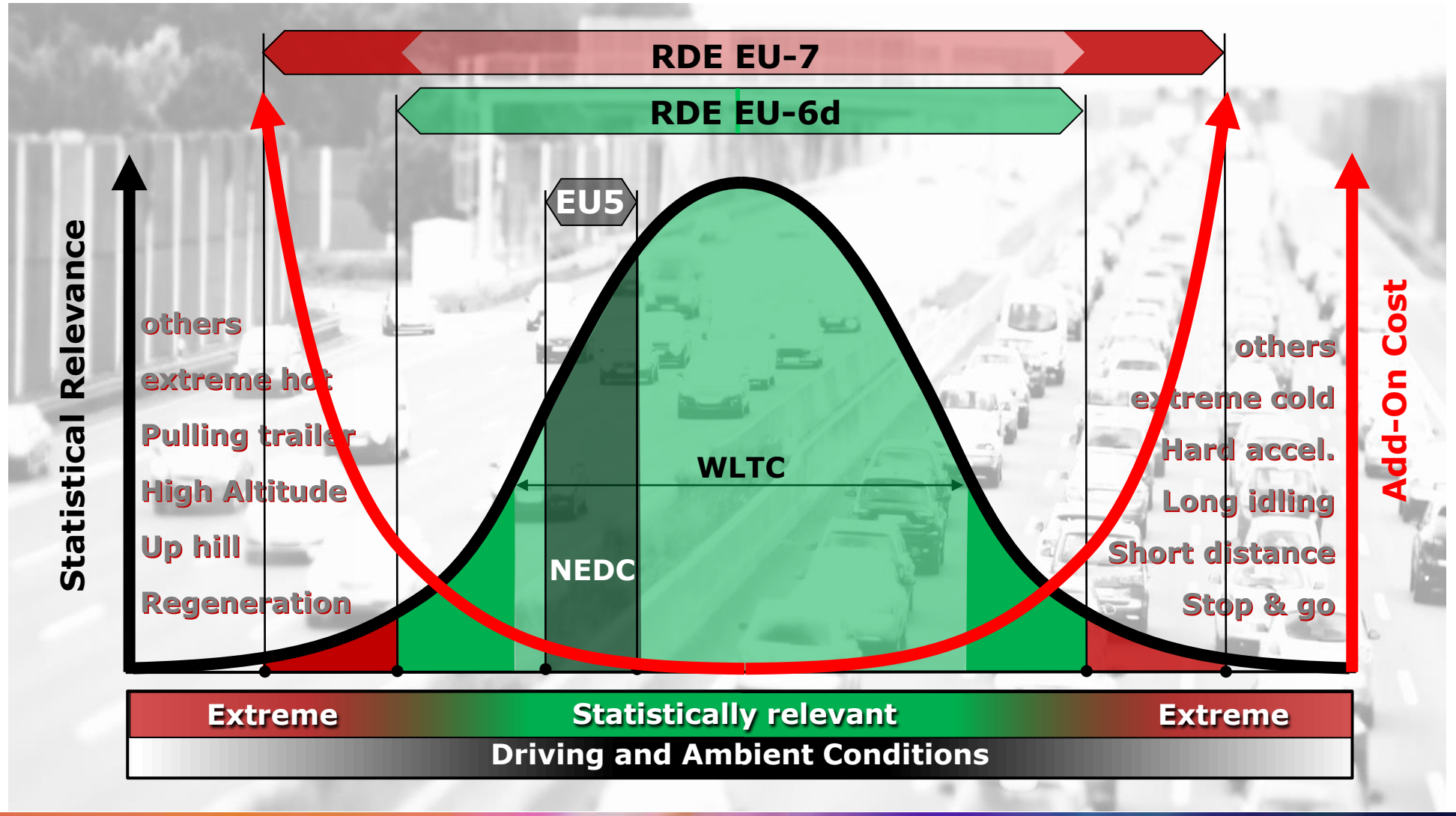
Euro 6d & 6e and Euro 7 Implementation
Passenger Cars

Latest update:
03/2023

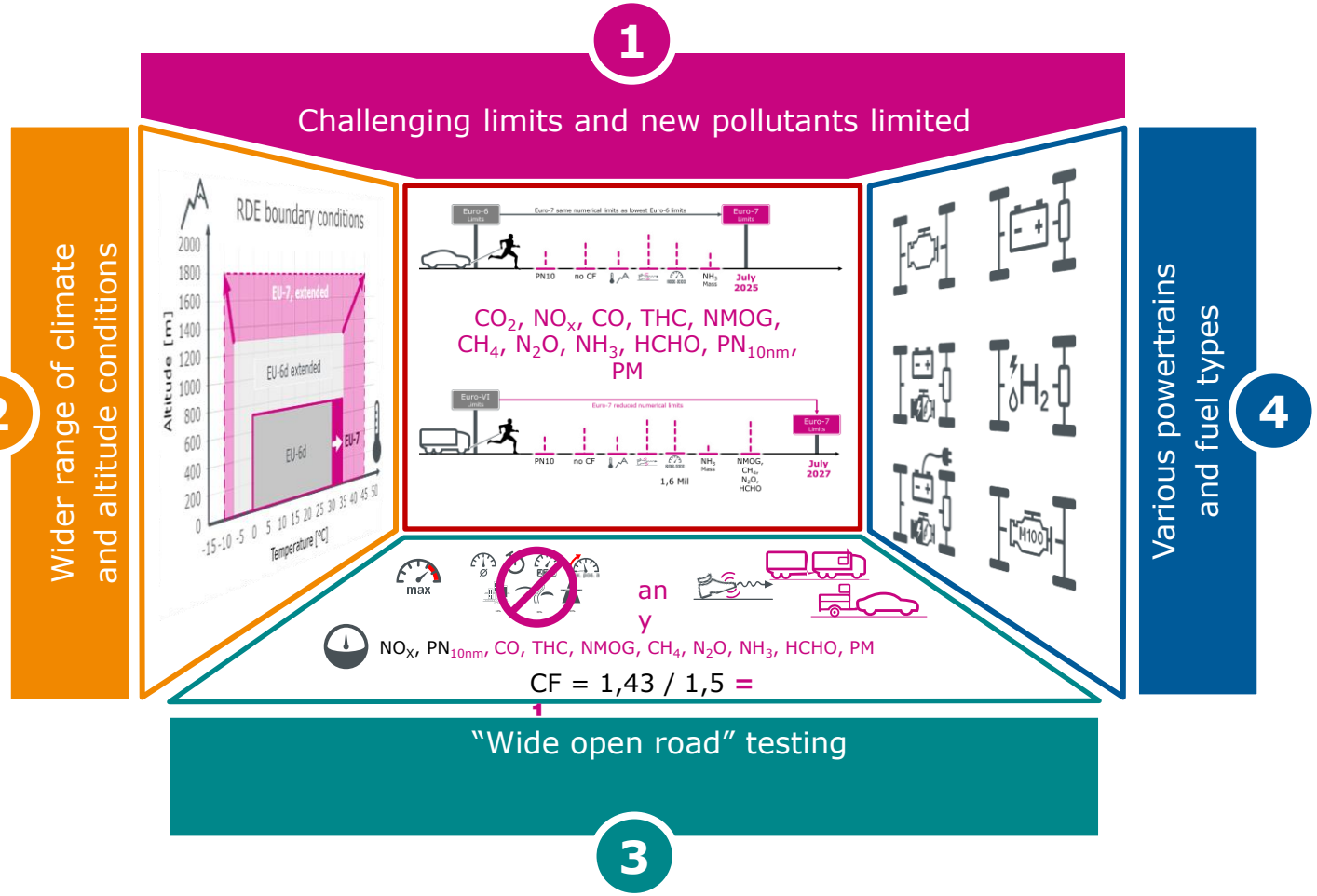


[1]Proposed Euro 7 would repeal Euro 6e
[2]based on Presidency partial compromise text, 15.03.2023. Council Working Party on Technical Harmonisation – Motor Vehicles, Meeting 22.03.2023
[3]Double testing under certain conditions
** WLTP based targets will be defined based on 2020 NEDC CO_2 values.
WLTP based targets will have comparable stringency to NEDC based 95 g/km.
Status according to Regulation (EU) 2017/1151, (EU) 2017/1154, (EU) 2017/1347, (EU) 2018/1832 and (EU) 2023/443
Ambient = increased extended ambient conditions for RDE compliance
AES flag = indicator for active AES
UF d_{neb} = updated utility factor based on d_{neb} = 2,200 km
UF d_{nec} = updated utility factor based on d_{nec} = 4,260 km

Driving Profiles
Focus on Statistical relevant areas required



Euro-7 Challenge
Mastering Complexity



- Infinitive combinations of variables.
- Impossible to physically test all.

Simulation:

	Tests per shift
SIL Simulation (easier Parallelization, faster than real time)	6000
HIL Simulation	12

Laboratory:

Engine testing	8
24/7 Powertrain testing	8
Chassis Dynamometer with RDE cycles and full environmental conditioning	2

Road:

RDE validation tests	2

SiL Application Proven in SOP Projects

GAME CHANGER 1: Availability of accurate xCU models

GAME CHANGER 2: Smart Data Management & Data Analytics

Simulation / Plant Models

Controller S/W

Simulation Models / Plant Models

Virtual xCU

Co-Simulation

Cloud Based
10.000 cycles
1.000.000 km simulated in 15h

Test Execution – SiL

Data Analytics

AVL's Engineering Analytics Platform

Base layer: AWS, MS Azure, Google Cloud

Develop | **Integrate** | **Execute** | **Post Process**

Effect of SiL in SOP 2022 Hybrid Program Use Case - Example

SiL Services

HEV

BEV

Fuel Cell

OBM

CHECK

OBM

SiL saves Hybrid-Program SOP:

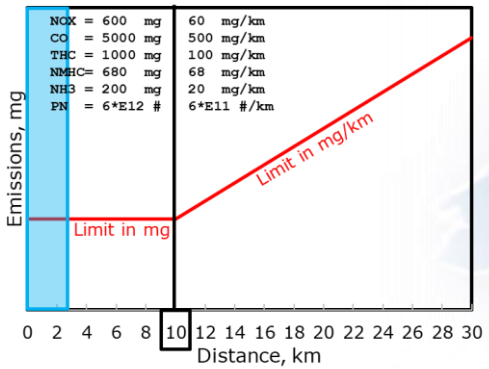
- ✓ Increased calibration speed
- ✓ Increased testing capacitiy
- ✓ Digital backoffice support
- ✓ ~130.000km Chassis Dyno testing executed on SiL (~4800 Emission Cycles)
- ✓ **40% reduction of real vehicle Chassis Dyno testing**

EU7 Emission Challenges Overview

AVL Interpretation - Main upcoming EU7 pollutant emission challenges

RDE Boundaries

- Wider RDE conditions
- Any RDE composition allowed
  → e.g. highway first
  → high load drive-offs
- Emission "budget" for the first 10km



Emission limits

- CO reduced to 50%
- NH3 introduction
- PN 10nm limit
- HC at 0/-10°C challenging
  (RDE Normal/extended)
- All Emissions limited in RDE
- New EVAP requirements
- Brake / Tyre wear

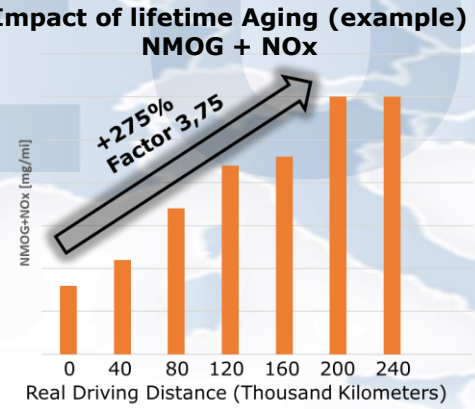
CO
reduced

PN
(>10nm)

NH_3

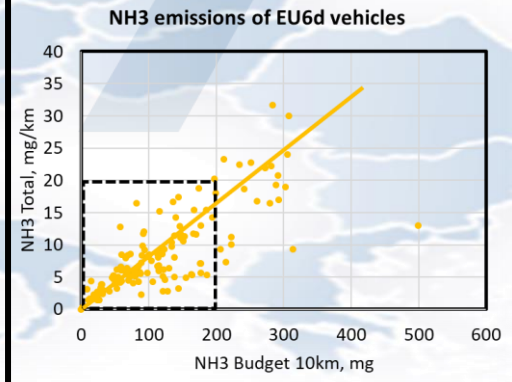
Aging Robustness

- Aging and Lifetime robustness
- Durability up to 200.000km or 10 years



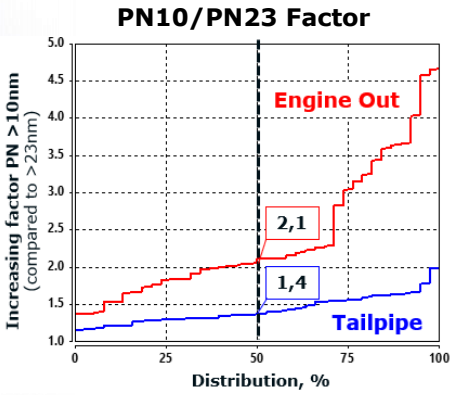
NH_3

- NH_3 produced in TWC
- 20mg/km limit discussed
- Optimization by Calibration for most cases sufficient



PN >10nm

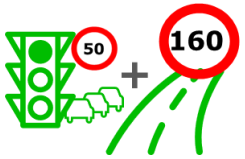
- 40-60% PN Tailpipe increase
- Limit as in EU6d
- ICE limitation, cold PN Optimization and high GPF efficiency needed



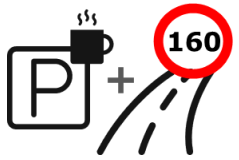
EU7 Emission Challenges
Drive-off Scenarios (Examples)

Low Speed city driving and traffic jam

Aggressive City driving (as in EU6d)

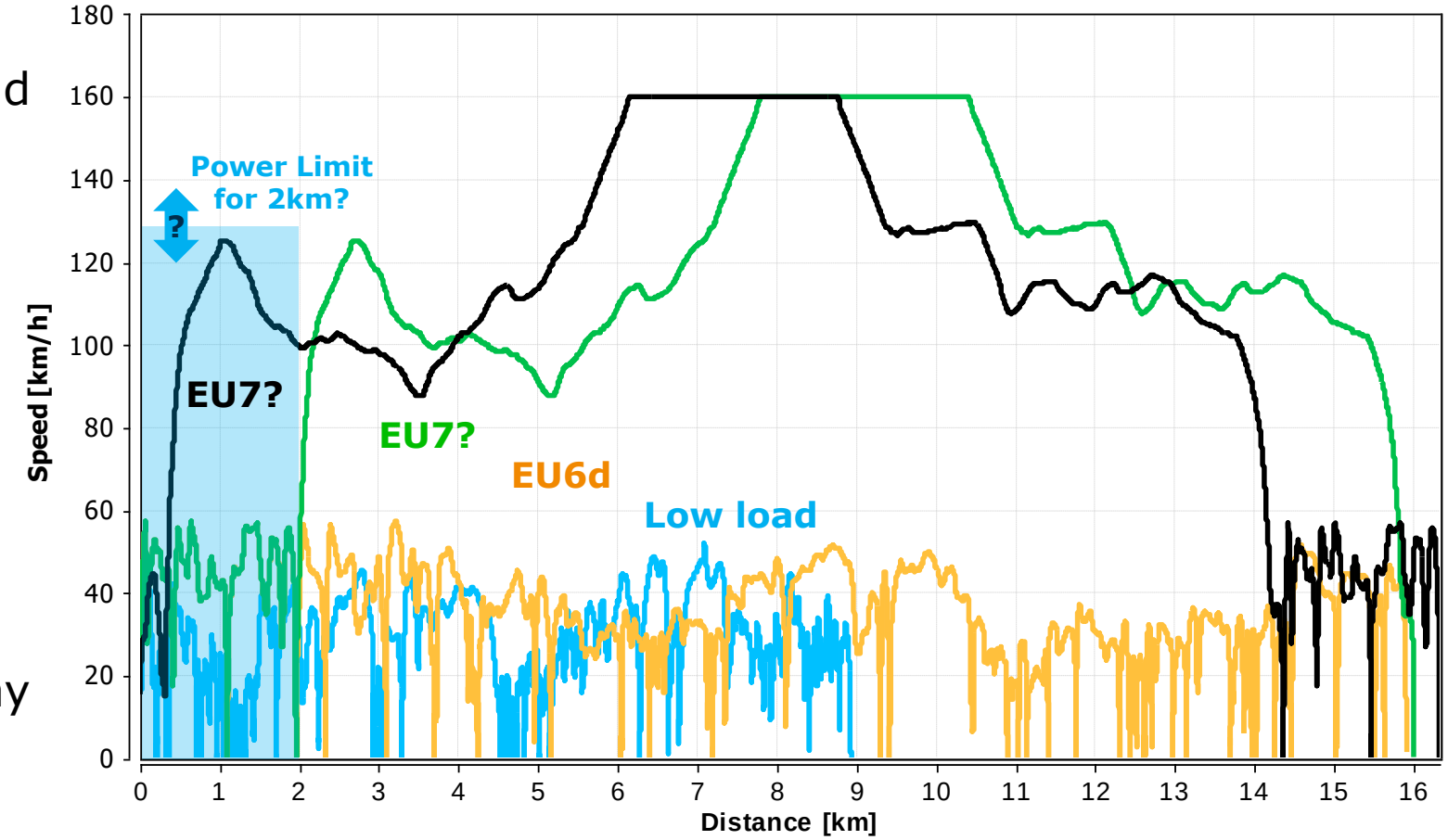


Highway after 2km



„Coffee Break" on Highway

…and other driving situations



Power Limit for first 2km. Any trip composition allowed → "highway first"?

EU7 Emission Challenges
Drive-off Scenarios

AVL Interpretation - Main upcoming EU7 pollutant emission challenges

RDE Boundaries

- Wider RDE conditions
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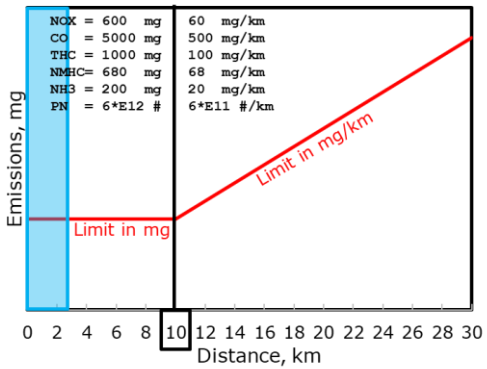
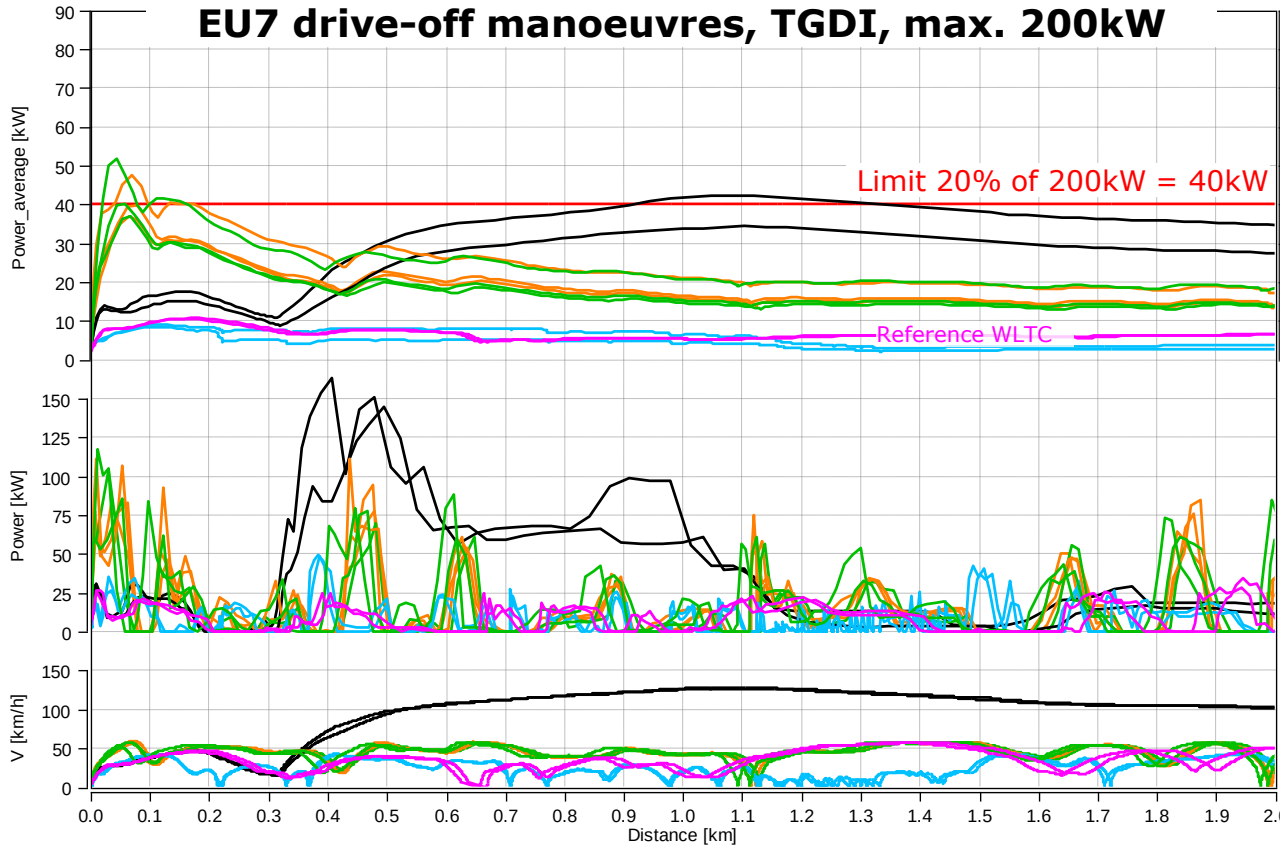
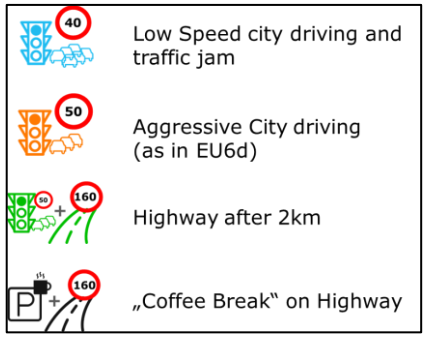
- Emission "budget" for the first 10km







Calculation method:

➔ Second-per-second average according to CLOVE in AGVES 11/2022
➔ Calculation starts at ICE-start

$$PowerMetric = \frac{P_{average\ driving}}{P_{rated,\ vehicle}} = \frac{\frac{\sum_1^{t_n}(P_{driving,tn} * \Delta t)}{t_n}}{P_{rated,\ vehicle}}$$

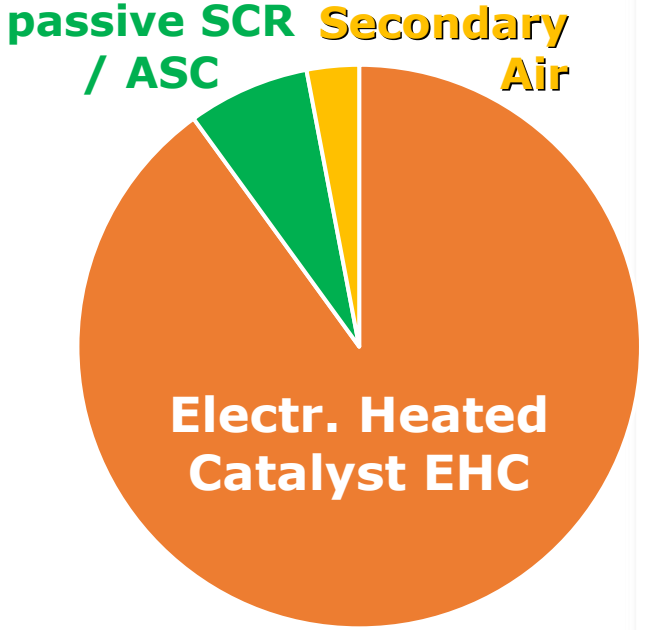
With:
- $\Delta t = 1s$
- $t_n = 1 + tn_{max}$

Gasoline vehicle partially in Extended Conditions!
First drive-off up to 160kph has significant emission impact!

Exhaust Gas Aftertreatment System
Gasoline Configuration Overview EU7

- **Less costly technology required than initially expected, however irrational timeline and missing boundaries**

10/2020: CLOVE Scenario A and B

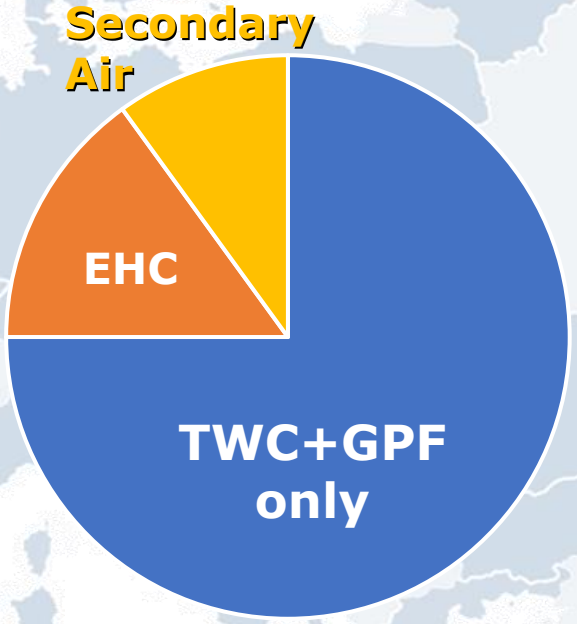


Emission Limits

CO	300/ 100	➔ 500 mg/km
NOx	30/ 10	➔ 60 mg/km
NH_3	5/3	➔ 20 mg/km
PN	$1x10^{11}$/ $6x10^{10}$	➔ $6x\ 10^{11}$

+ Budget for 10km

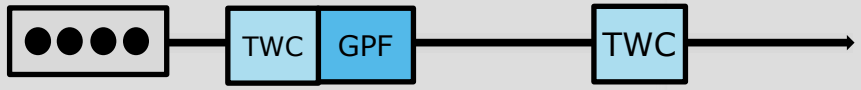
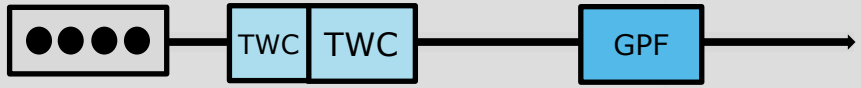
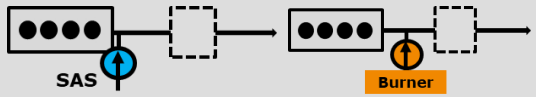
03/2023 Emission Budget Approach



Actual EU7 Technology Approaches (03/2023) de-contented versus 2020 Assumptions , however, calibration, validation and OBD /OBM effort significantly enhanced vs. EU6d

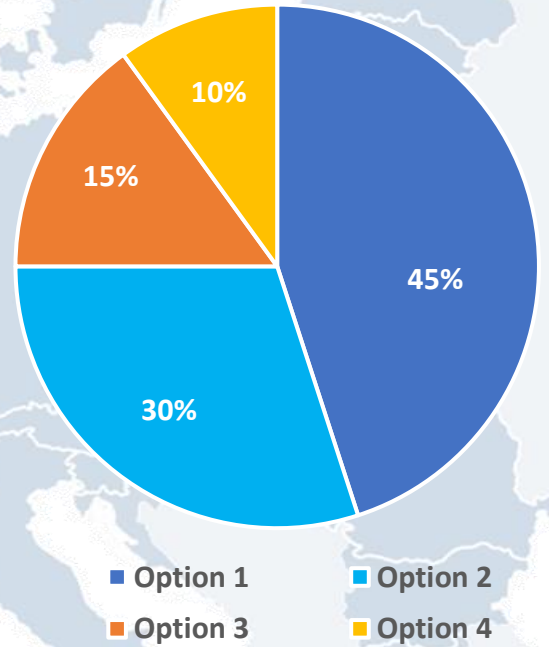
Exhaust Gas Aftertreatment System
Gasoline Configuration Overview EU7

Exhaust aftertreatment examples to be discussed in detail dependent on powertrain/vehicle concept, engine out emissions performance and final emission legislation definition

	Euro 7	Comment
1		**Options 1 and 2:** ➢ TWC1: high cell density, as close to the engine as possible → Light Off ➢ Optimized catalyst heating raw emissions ➢ NH3 reduction by calibration ➢ Underfloor TWC for aging robustness at hot / highload engine operation. Full map conversion. ➢ General trend: GPF as close as possible to enable good passive regeneration potential (heating + air from motoring phases)
2		
3	 Option **with EHC**	**Option 3:** ➢ Same statements as above ➢ Option shows very good trade-off in terms of catalyst light-off and regeneration potential and packaging.
4	 **S**econdary **A**ir **S**ystem or **Burner**	**Options 4:** ➢ SAS → in discussion, high emission potential ➢ Burner for 12V solutions, will remain a niche

Status 03/2023

EU7 (AVL Prognosis) Potential Gasoline EAS Configurations

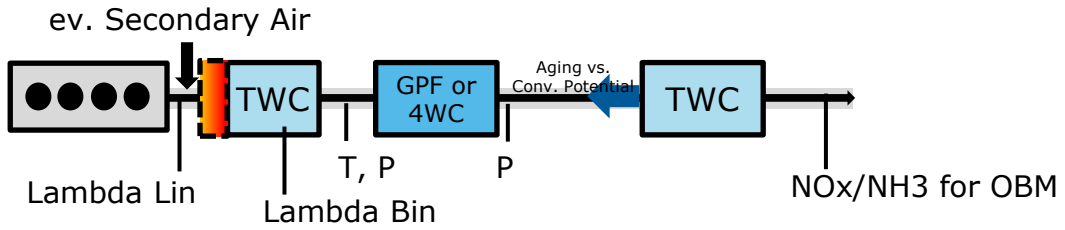


All solutions will be most likely combined with measures like torque limitation or hybrid support especially at drive off.

Technological EURO 7 requirements - Summary **Gasoline** Passenger Cars

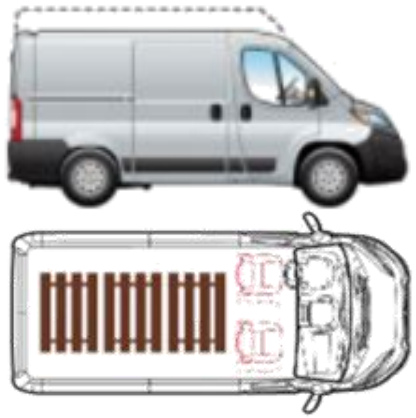
Solution elements:

- **CO** → RDE relevant → Full map Lambda = 1 engine and/or maximum Power Limit
- **NH3** → Calibration Optimization and highly accurate Lambda control in most cases sufficient
- **PN>10nm /GPF** → *ICE limitation, cold PN Optimization, >95% GPF efficiency needed* (new & regenerated GPF)
- **THC/NMHC (PN)** → Capable ICE hardware (combustion chamber, injectors, piston, charge motion...), calibration and drive-off strategy optimization required especially for T<0°C
- Full massflow capable exhaust aftertreatment volume
- Catalytic Coatings and engine operation with lowest possible influence on **lifetime aging**
- **ICE Power/Torque/Speed limitation** to fulfill emissions
- **Hybrid Support** for cold-drive-off (if applicable)
- **Secondary air and/or EHC** as efficient measure to reduce cold start emissions (if applicable)
- **OBM:** NOx/NH3 Sensor required, ECU capable Emission models / virtual sensors required (AVL expectation)

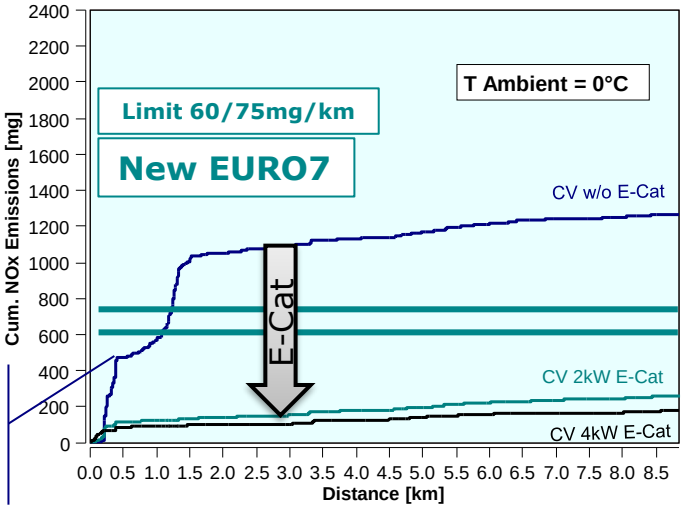


Initial EU7 System Evaluation
Diesel LCV - Standard Conditions **0°C**

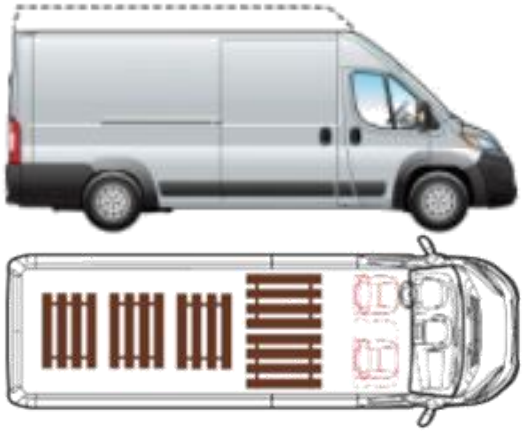
2900 kg

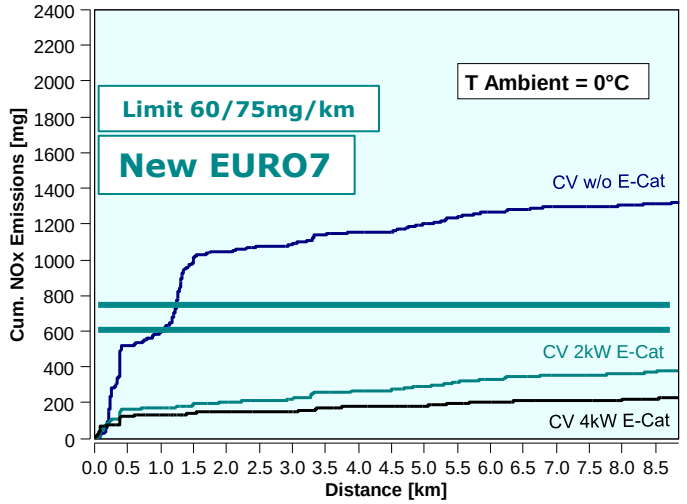


EU6 baseline
w/o spec. heat-up
strategy/devices



3400 kg

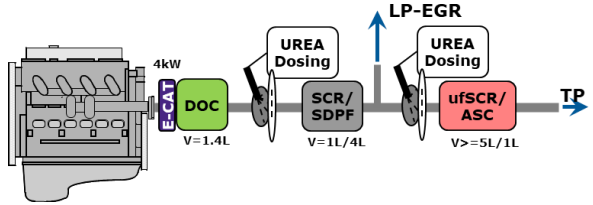




LCV Application, 2L Diesel

Operation Profile

- Low load cycle (TfL)
- 0°C @ Standard conditions



Evaluation Matrix:

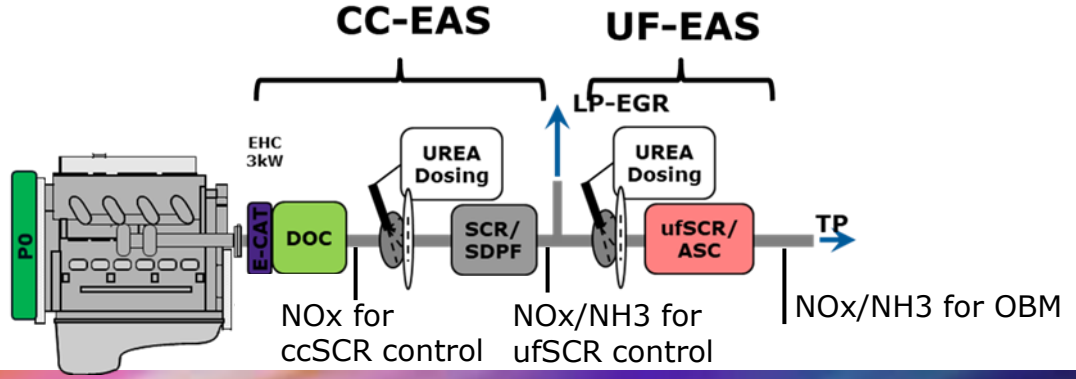
- E-Cat – Voltage and Power
- pLNT
- Torque Limitation
- Hybridisation
- Inner-Engine heat-up
- VVT – cost to benefit

➔ **Heat-up support necessary**

Technological EU7 requirements - Summary
Diesel Passenger Cars and Light Commercial N1/M1

Solution elements:

- **NH3:** Dual SCR Calibration Optimization and NH3-UI >98% in all conditions
- **NMHC/THC/CO:** Support of EHC during EAS heat up and keep warm, no active rich combustion for LNT operation
- **PN:** DPF regeneration optimization → always keep a residual Soot layer, adapting the ufSCR dosing to reduce the Urea based PN10
- **ICE Power/Torque/Speed limitation** to fulfill emissions
  - Hybrid Support for cold-drive-off if applicable
- **Aftertreatment:**
  - Catalytic Coatings and engine operation with lowest possible influence on **lifetime aging**
    → Dual SCR Dosing with specific SCR coatings (CU and CU&Fe) and "rightsized" SCR volumes
  - **EHC** as efficient measure to reduce cold start emissions and maximize the heat up potential
- **OBM:** NOx/NH3 Sensor required, ECU capable Emission models / virtual sensors required (AVL expectation)



Euro 7
OBM

Euro 7/VII
Main OBD | OBM Challenges

OBD (On Board Diagnostic)
= detecting malfunctioning systems which lead to emission exceedances in order to facilitate repairs

New system monitors required
- Component based failure detection
- Determination of root causes by detected OBM violations
- New engine / EAS components and sensors
- …

OBD development efforts will further increase!
Not part of type approval, but to be declared!

OBM (On Board Monitoring)
= detection of emissions above the emission limits due to malfunctions, increased degradation or other situations that increase emissions (incl. multiple partial degradation)

New requirements!!
- Detection of TP emissions above ETL
- Emission compliance and calibration robustness under all conditions
- **TP emissions** need to be **far below ETL/OBM** threshold limit to cover all aging effects, RDE influence factors, etc.
- Reporting of OBM information to the authorities

OBM will require calibration front-loading to VTB/HiL environment, new software development and significant increase of validation!

OBM for EU7 Challenges

AVL Interpretation - Main upcoming EU7 OBM challenges

Gas Sensors

NO_x/NH_3:

- NOx Sensors existing.
- No new sensors will be developed.
- NO_x/NH_3 Cross-Sensitivity (NOx Sensor)
- NH3/HC Cross-Sensitivity (NH3 Sensor)
- Cold start emission measurement only with preheated sensor
- Sensor Diagnosis
- Sensor Accuracy for low EU7 emissions.
- Aging

Picture Source: Vitesco Technologies

$CO/HC/CH_4$:

- No Sensors existing

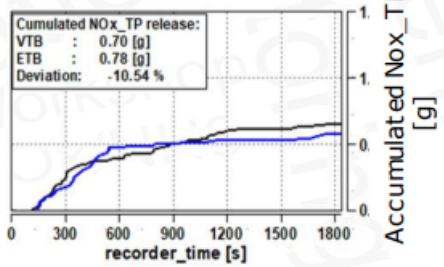
PN/PM Sensors

- No suitable sensor existing.
- OBM Feasibility unclear
- PN/PM monitoring by models very challenging
- "Advanced filter diagnostics" (GPF) with current P or T Sensors not accurate enough to fulfill the Vision of OBM.

Emission models

- Realtime capable ECU models for all emissions required.
- Emission results must be a combination of sensor values and emission models (e.g. when sensor not ready/plausible)
- Sensor plausibility / drift check with models

Measurement vs. Model



Calibration and Vehicle usage

- Model Calibration, Testing and Validation effort increases significantly (Vehicle, Virtual testbeds)
- High xCU Software development effort (models, sensor deviation, aging, poisoning)
- Learning functions for countermeasures if vehicle is close to OBM limits
- Alignment of: OBD <> OBM
- Mil on / Healing calibration
- Which part to replace in workshop / Repair Costs

Legislative Definition open

- Limit definition incl. measurement / model tolerances.
- Averaging, driving distances, # of cycles?
- Data Reporting, Data transfer, Data Analysis
- Type approval procedure (OBM PEMS Test,…)
- Responsibilities (EC, OEM, Others?)
- Consequences for high emitters?

EU7 Emission Development
OBM – Summary

- **Introduction with EU7 07/2025, no stepwise OBM introduction**
  → Introduction date to be decided by parliament & council (no comment on the timing by commission…)
- OBM will be introduced with EU7 with the goal to identify "high emitters"
- NOx/NH3 sensor is required
- Emission models, so called "virtual sensors" are required for all emissions
  - to crosscheck with sensor results (plausibility, adaptions)
  - cover cold start conditions (sensor not ready)
  - Repair pinpointing
  - Aging adaptions (sensors, EAS,..)
- PM Sensor not expected due to Sensor availability and accuracy
  - No PM Sensor existing → OBM with PM models only with higher tolerances
  - Discussed alternative: ISC RDE testing (in the laboratory) to check PM, without OBM?
- OBM Data transfer
  - During vehicle operation 1Hz data on OBD-Port
  - After vehicle operation (key-off) OBM data storage in vehicle and data transfer OTA
- S/W development for storing/handling/analyzing OBM data, EEDWS activation, inducement and repair pinpointing as one of the key challenges (lead time!)
- Significantly increased development, validation and testing effort expected in SOP calibration projects

Thank you

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