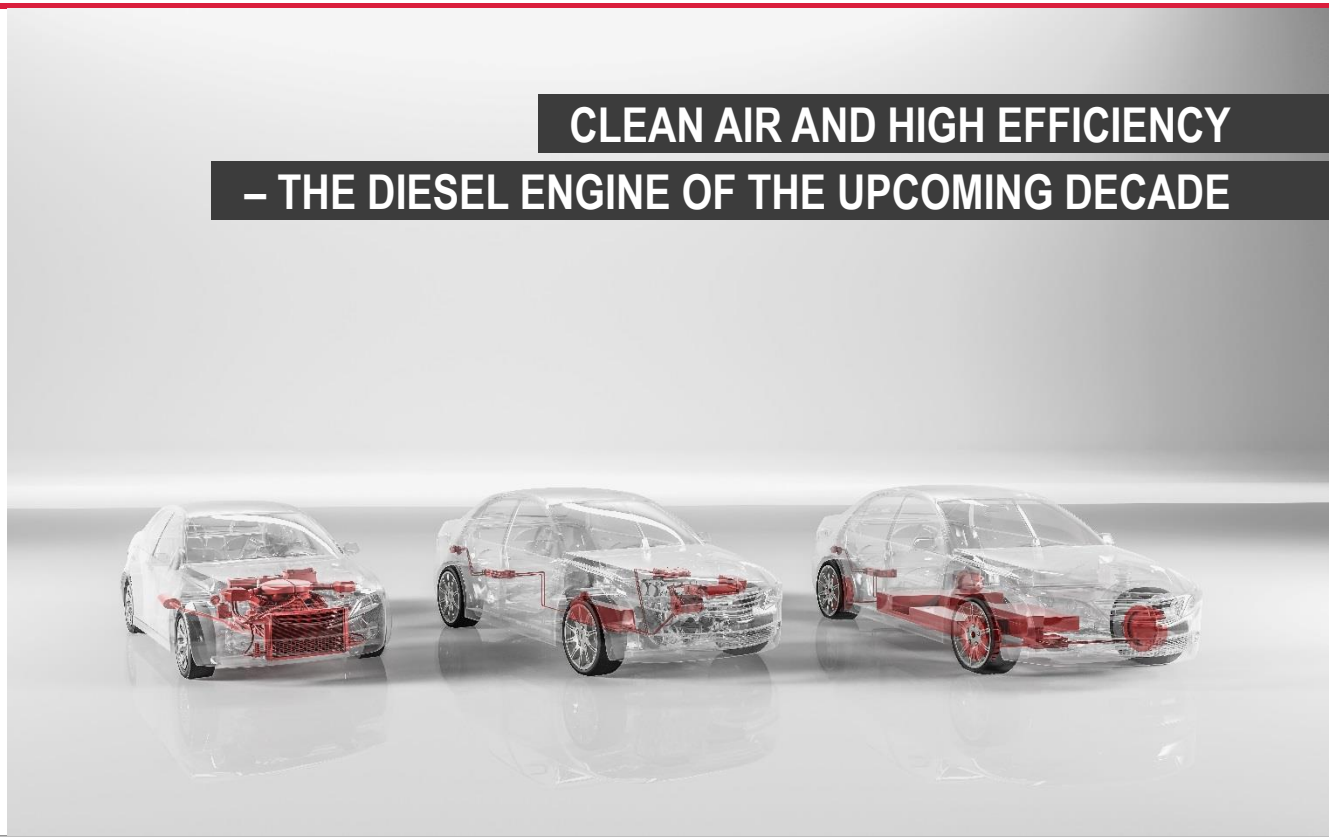
CAR2017
MOBILITY ENGINEERING and ENVIRONMENT



CLEAN AIR AND HIGH EFFICIENCY – THE DIESEL ENGINE OF THE UPCOMING DECADE

University of Pitesti, November 8th 2017
Dr.-Ing. Christoph Menne

Director Vehicle Application Diesel Powertrains

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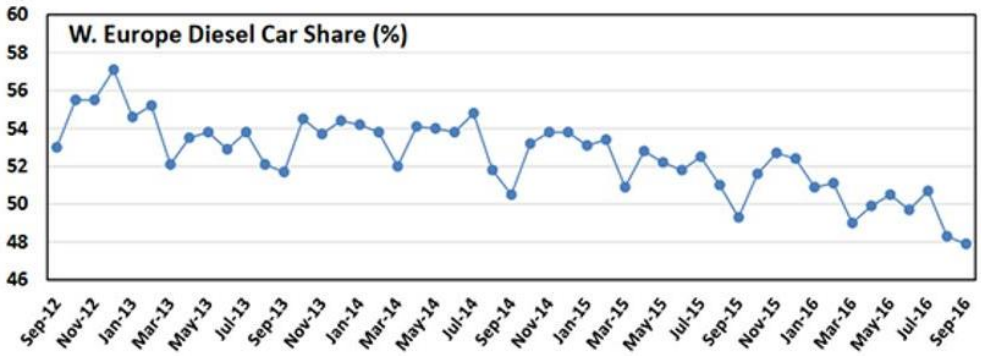
Challenges for Diesel Engines
Diesel under pressure

GERMAN “BILD“ (02.03.2017)



No Diesel vehicles in German city centres?

~~Clean~~ Diesel ?

2020 – no Diesel in Paris?

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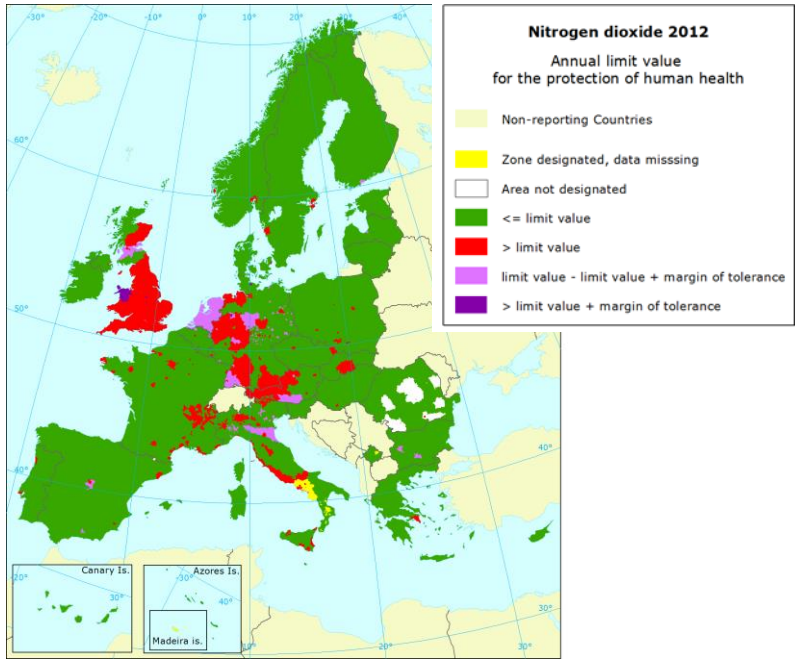
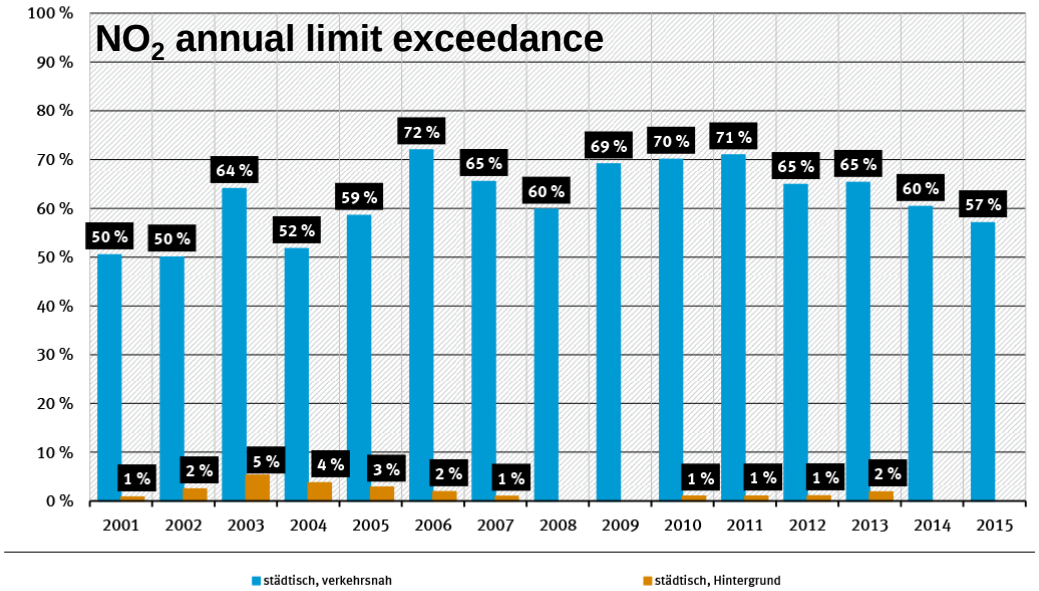
Challenges for Diesel Engines
Air Quality

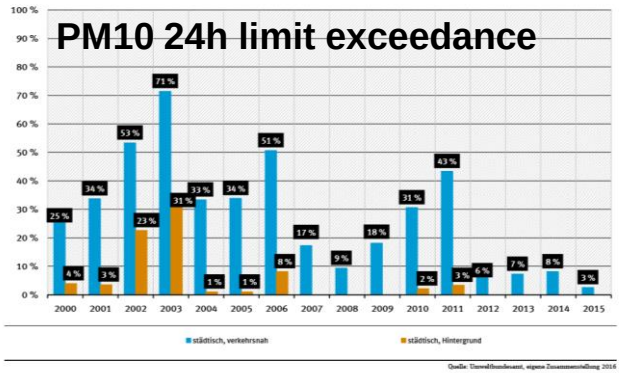


Prozentualer Anteil der Messstationen mit Überschreitung des Stickstoffdioxid-Jahresgrenzwertes (40 µg/m³) bezogen auf den jeweiligen Stationstyp



Quelle: Umweltbundesamt, eigene Zusammenstellung 2016

Prozentualer Anteil der Messstationen mit mehr als 35 Überschreitungen des 24-h-Grenzwertes (50 µg/m³ PM10), bezogen auf den jeweiligen Stationstyp



- NO_2 limits exceeded at urban measurement points
- Reduction in the last years but >50% of German urban measurement stations above annual average limit in 2015
- Particulate (PM10) exceedance at significantly lower level

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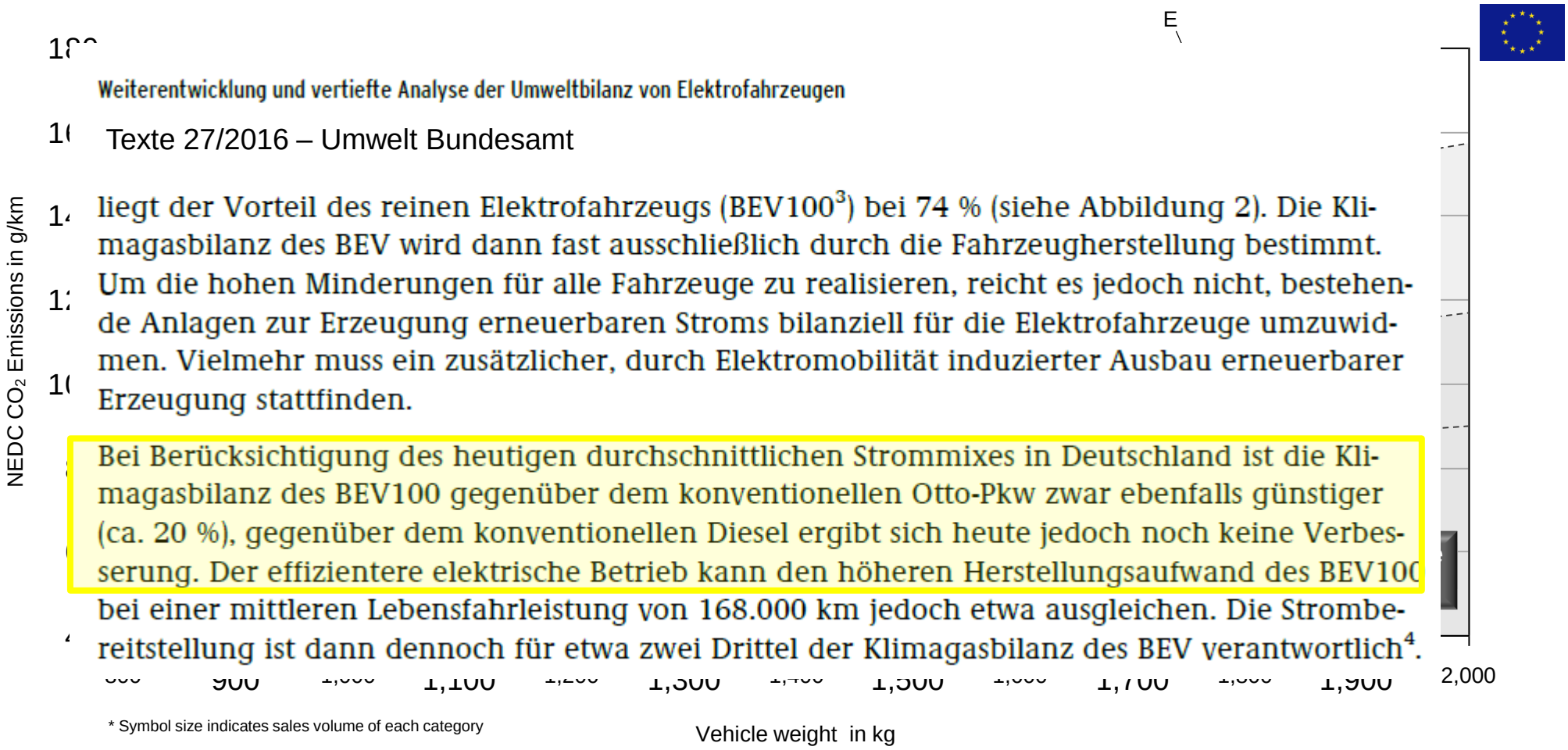
Market split of Diesel and Petrol engines in EU* - Diesel cars emit ~15 to 20% less CO_2 than Petrol counterparts and can meet strict CO_2 standards



Weiterentwicklung und vertiefte Analyse der Umweltbilanz von Elektrofahrzeugen

Texte 27/2016 – Umwelt Bundesamt

liegt der Vorteil des reinen Elektrofahrzeugs (BEV100[3]) bei 74 % (siehe Abbildung 2). Die Klimagasbilanz des BEV wird dann fast ausschließlich durch die Fahrzeugherstellung bestimmt. Um die hohen Minderungen für alle Fahrzeuge zu realisieren, reicht es jedoch nicht, bestehende Anlagen zur Erzeugung erneuerbaren Stroms bilanziell für die Elektrofahrzeuge umzuwidmen. Vielmehr muss ein zusätzlicher, durch Elektromobilität induzierter Ausbau erneuerbarer Erzeugung stattfinden.

Bei Berücksichtigung des heutigen durchschnittlichen Strommixes in Deutschland ist die Klimagasbilanz des BEV100 gegenüber dem konventionellen Otto-Pkw zwar ebenfalls günstiger (ca. 20 %), gegenüber dem konventionellen Diesel ergibt sich heute jedoch noch keine Verbesserung. Der effizientere elektrische Betrieb kann den höheren Herstellungsaufwand des BEV100 bei einer mittleren Lebensfahrleistung von 168.000 km jedoch etwa ausgleichen. Die Strombereitstellung ist dann dennoch für etwa zwei Drittel der Klimagasbilanz des BEV verantwortlich[4].

- Diesel Engines are extremely important to achieve ambitious CO_2 target

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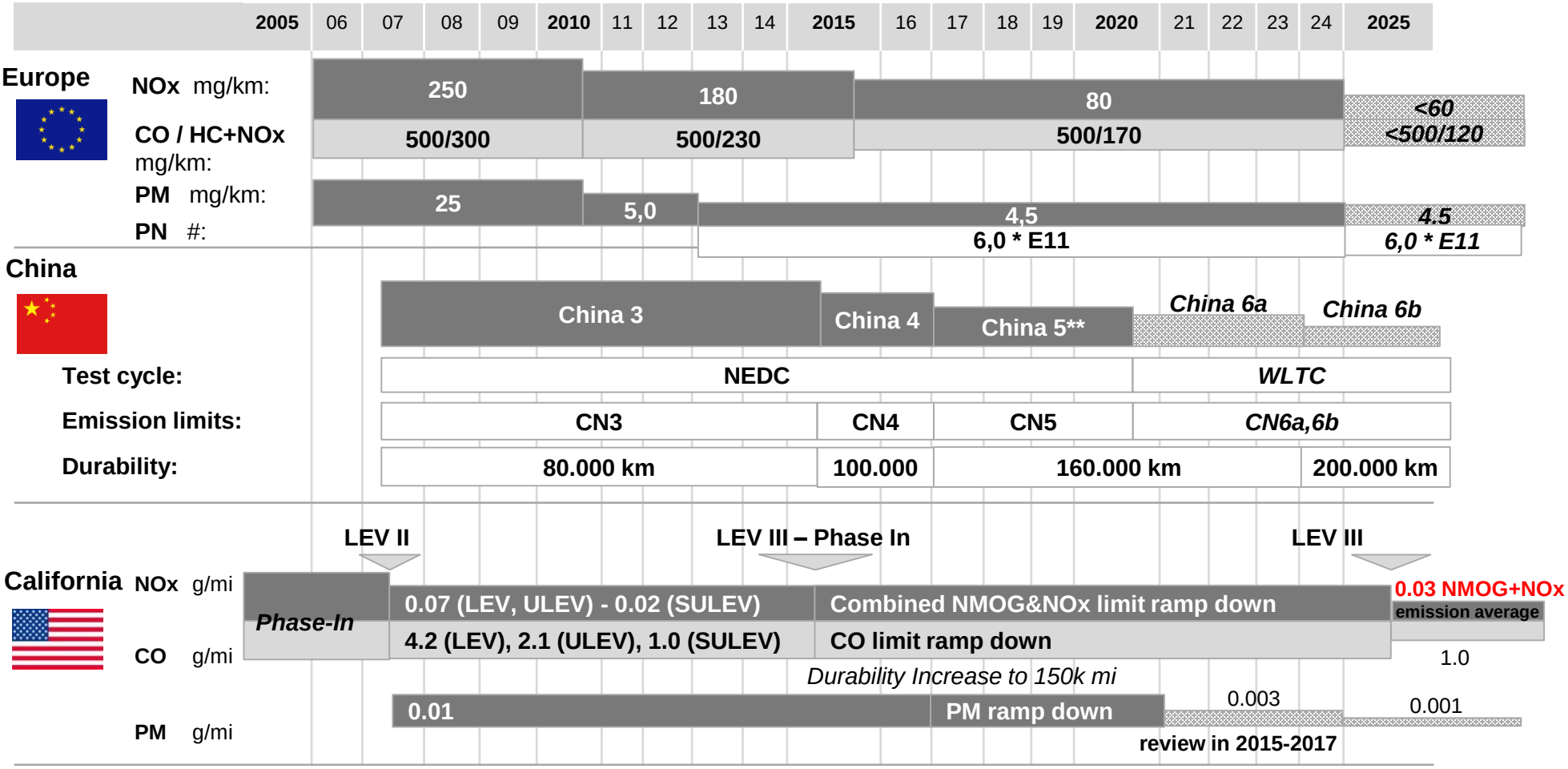
Continuous tightening of emission standards for all major markets

LIGHT DUTY DIESEL LEGISLATION



**: China 5 standard is nearly equivalent to the Euro 5b standard

Source: FEV, Delphi

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Emission Limits need to be realised under real world conditions
RDE Test Procedure and Boundary Conditions (EU6d_temp/EU6d)

Test Procedure

Vehicle Mileage: from 3000 to 160000 km

Drive at least 30 min

Park from 6 to 56 h

Doors, bonnet closed, engine off

Soak within moderate or extended conditions

Check avg temperature over last 3 h before the test

Extended

Divide pollutant emissions by 1.6

Moderate

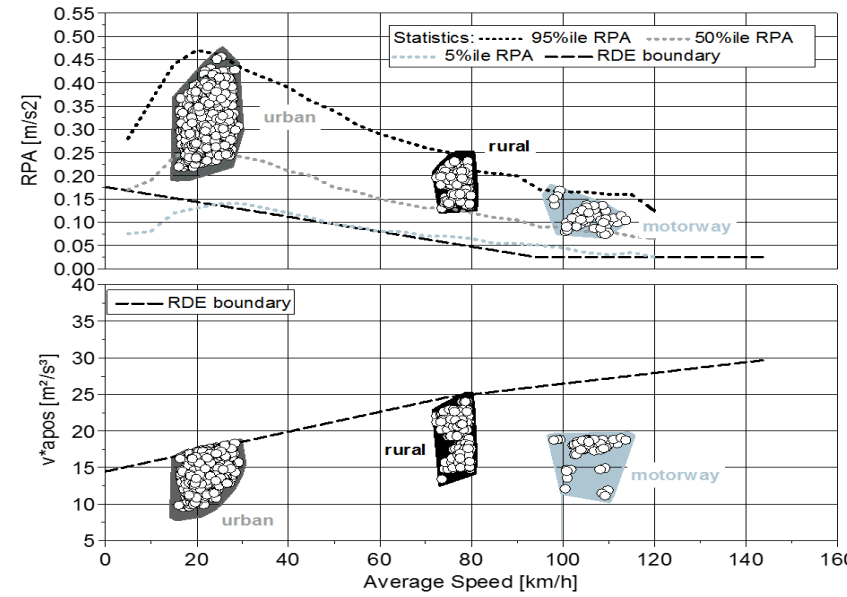
RDE Result incl. Cold start

Boundary Conditions

Moderate Ambient Conditions
0°C <= T <= 30 °C
h <= 700 m

Extended Ambient Conditions
T > - 7°C & T < 35 °C
700 m < h < 1300m

Extremely big variety of driving scenarios within RDE limits possible:



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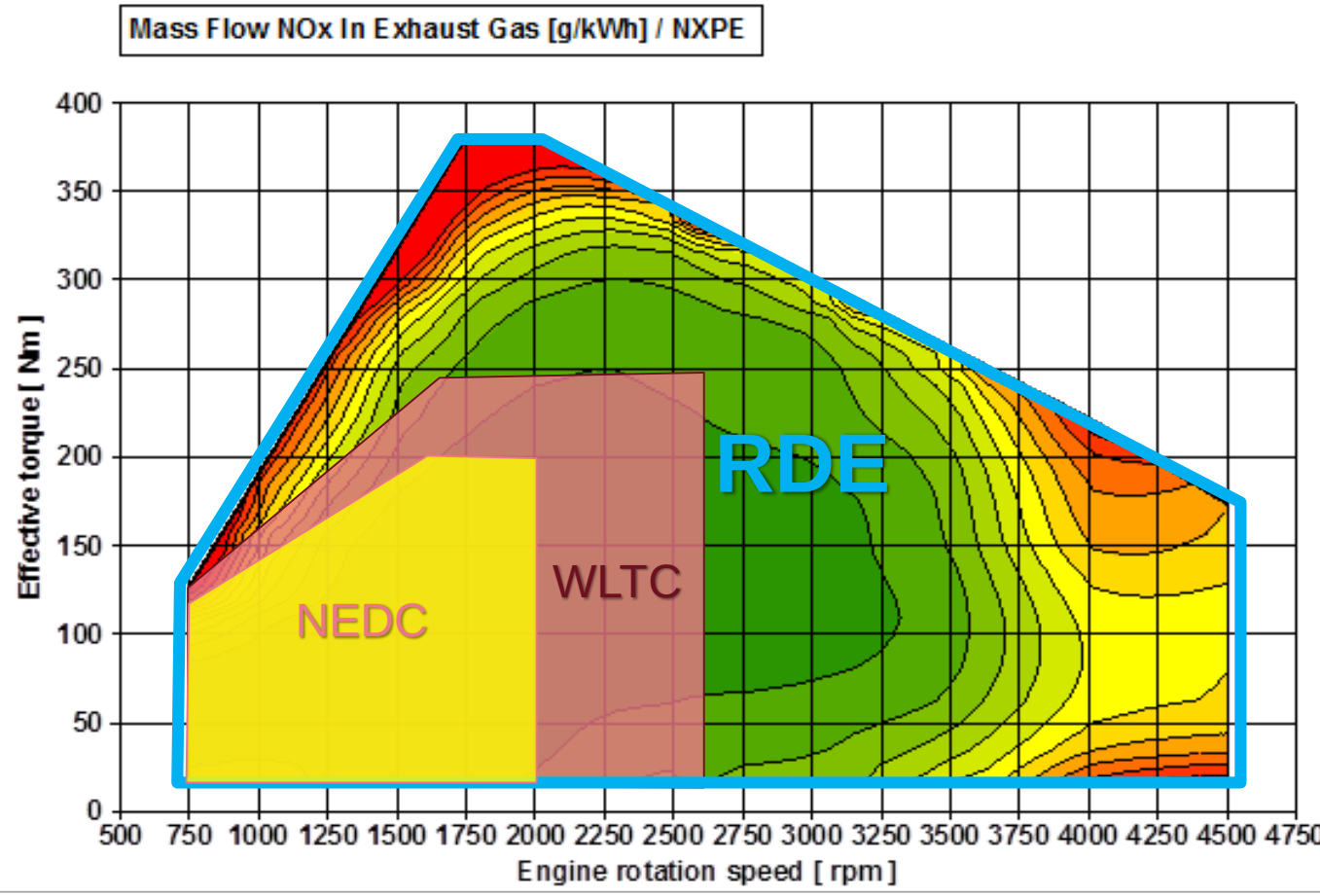
Enlargement of emission relevant map area to full map requires tailored technology upgrade and optimization for engine/aftertreatment hardware

Application Package Challenges Migrating from EU6b to EU6d

Operating Range Extension from NEDC → WLTC→ RDE



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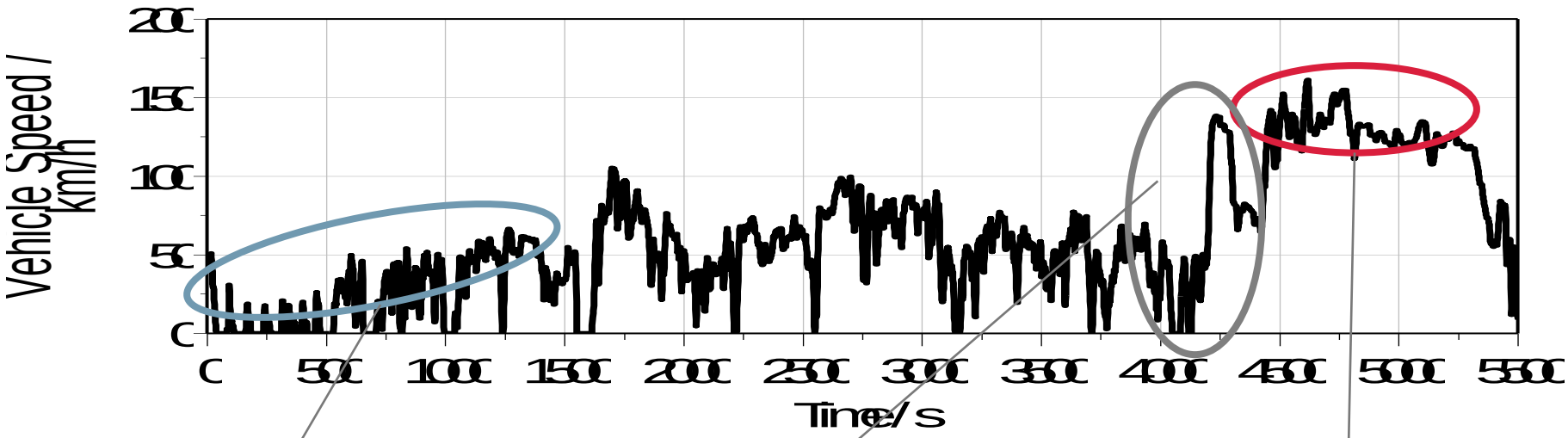
Robust compliance with lowest NOx-emission targets requires a technology combination covering various operating conditions



City driving (Not to exceed CF!)	Transient driving	Motorway driving
■ Rapid heat up of aftertreatment ■ Lowest possible engine out emissions ■ Electrically heated catalyst ■ Close-coupled NOx-aftertreatment	■ Engine-out NOx control ■ Highly Capable aftertreatment ■ Highly accurate, model-based engine and aftertreatment control	■ Engine out emission control for high loads and engine speeds ■ Highly efficient aftertreatment system for high temperatures and massflows

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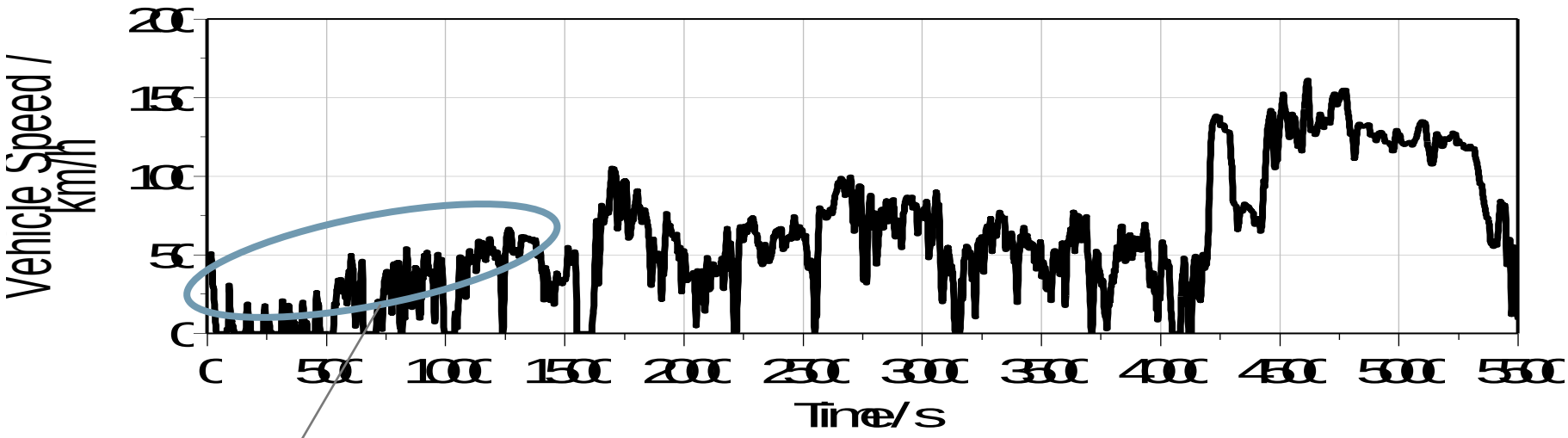
Urban Driving with low exhaust temperatures



City driving

- Rapid heat up of aftertreatment
- Lowest possible engine out emissions
- Electrically heated catalyst
- Close-coupled NOx-aftertreatment

- Increase of exhaust temperature/enthalpy with min. CO_2 impact
- Minimisation of engine out emissions
- Close-coupled NOx-aftertreatment
- Air gap insulated exhaust system components
- Variable valvetrain
- Electrically heated catalyst
- E-drive / load leveling

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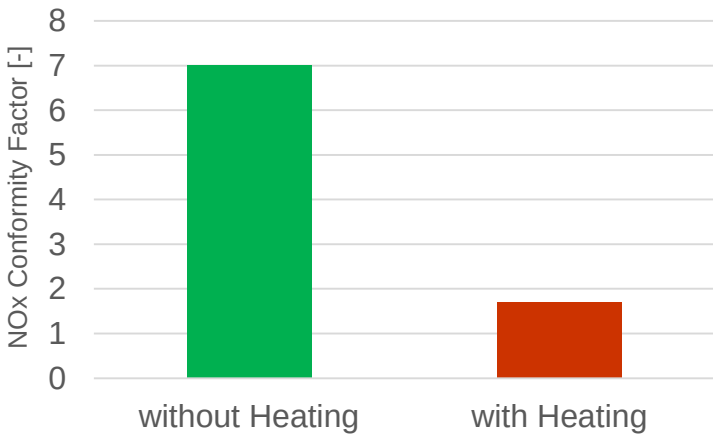
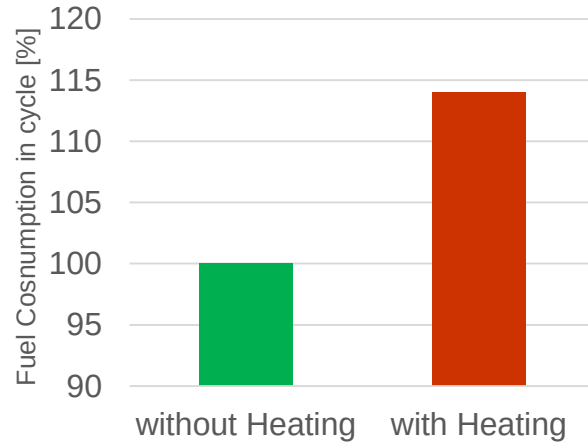
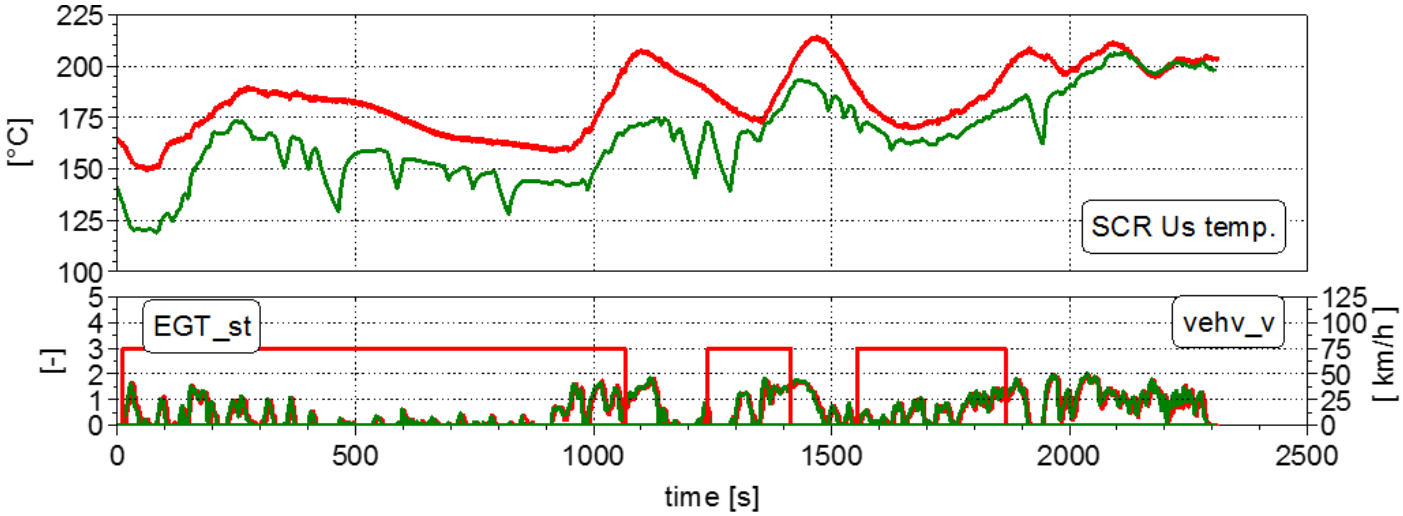
Impact of a Heating Strategy in Transport for London slow city cycle
Example of underfloor SCR application







- Significantly reduced NOx tailpipe emissions with heating
- Temperature increase of 25-45°C
- Fuel Consumption degradation of ~15% in shown cycle
- Negative impact on soot emissions for transients
- “Traditional“ heating measures:
  - Throttling and reduced boost pressure level
  - Retarded center of combustion
  - Increased post injection quantities after DOC light off

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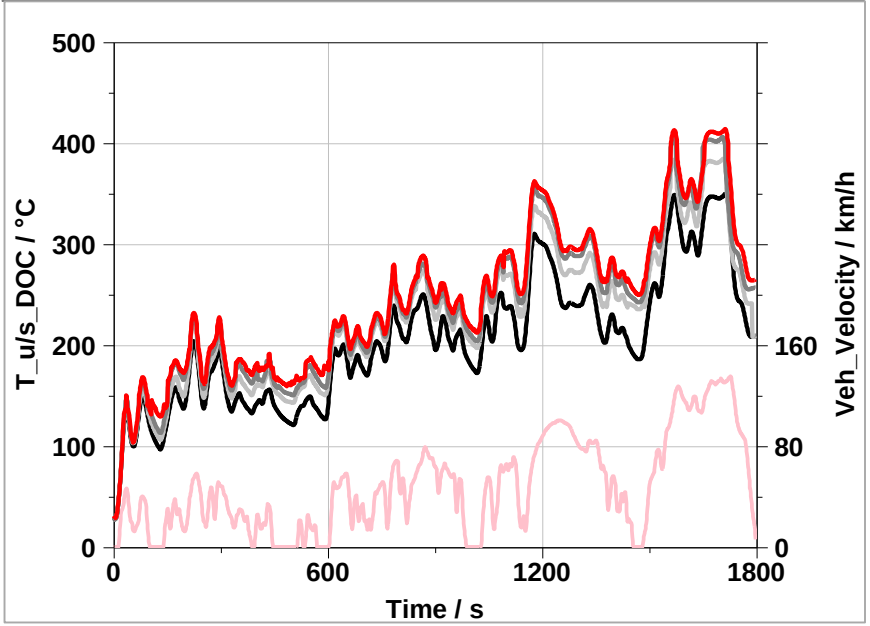
Reduced exhaust temperature losses to improve aftertreatment efficiency
Insulation Measures

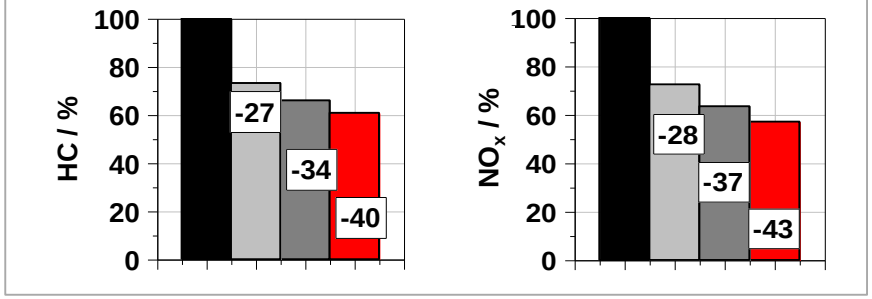
Impact on exhaust temperature in WLTC

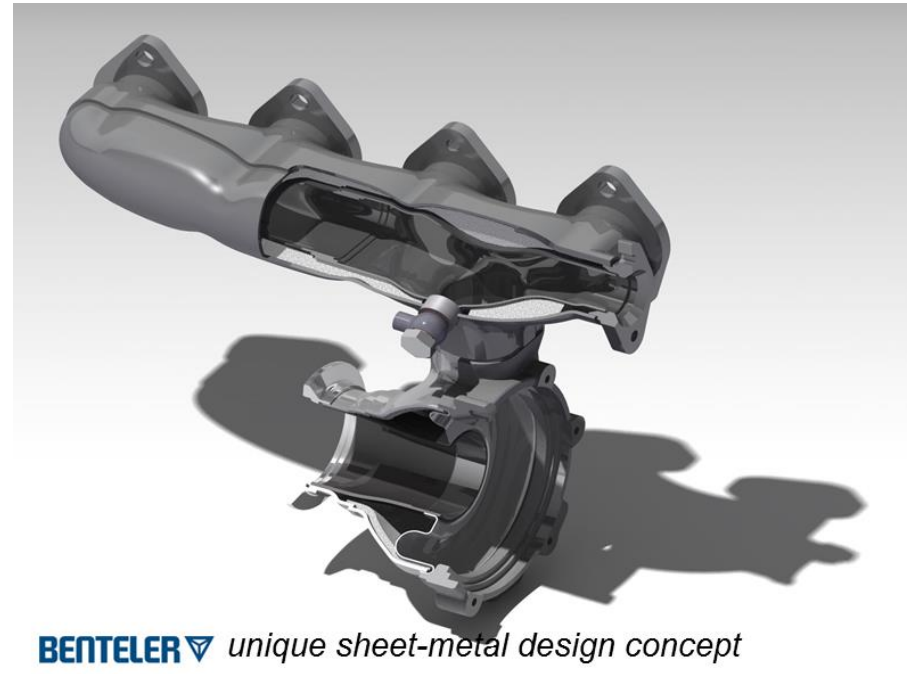


*AGI - Air Gap Insulation

- **Cast Manifold + Cast Turbine Housing**
- **AGI Manifold + AGI Turbine Housing**
- **AGI Manifold + AGI Turbine Housing**
- **AGI Manifold + AGI Turbine Housing + int. Mat Insulation**

Improvement of pollutant conversion





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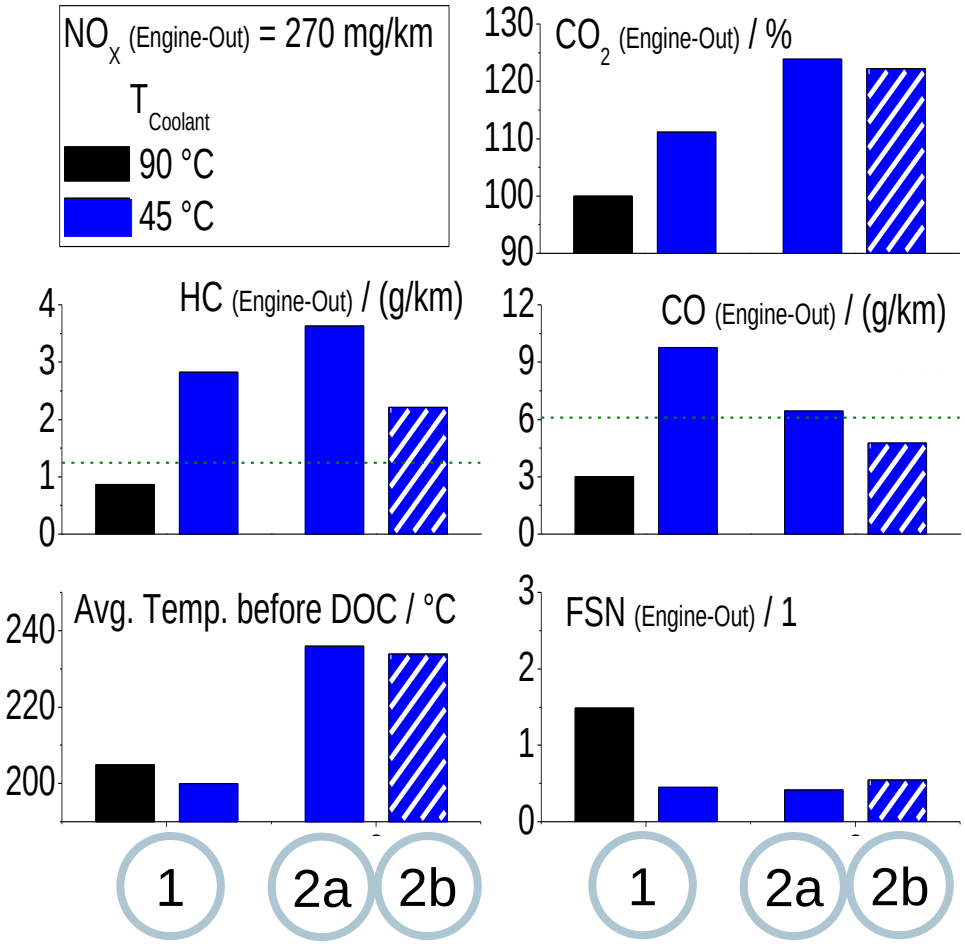
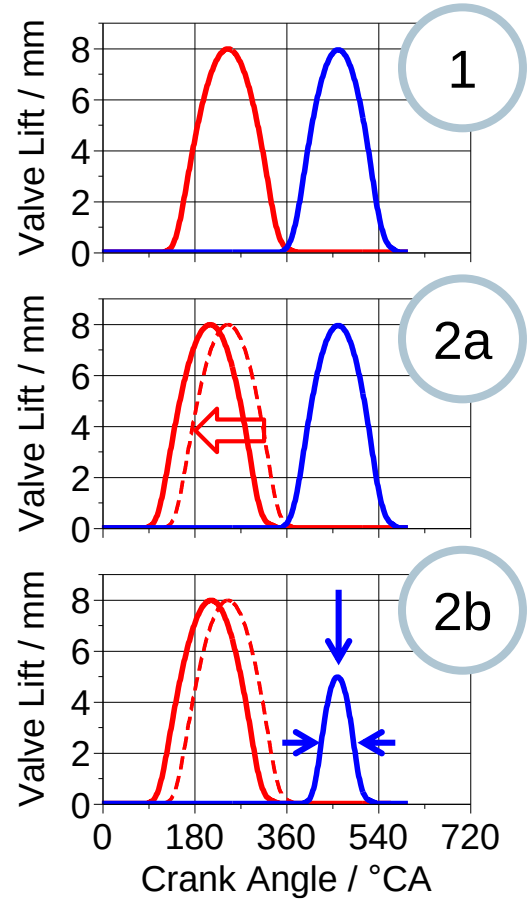
Heating Measures
Valvetrain Variabilities

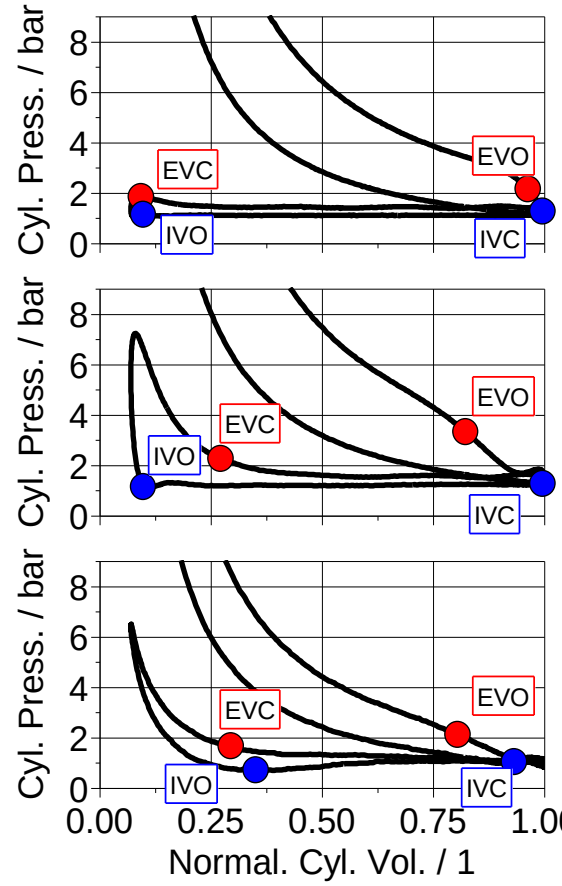
WLTC PHASE 1 RESULTS (TRANSIENT TEST BED)



Valve Timing



Gas Exchange



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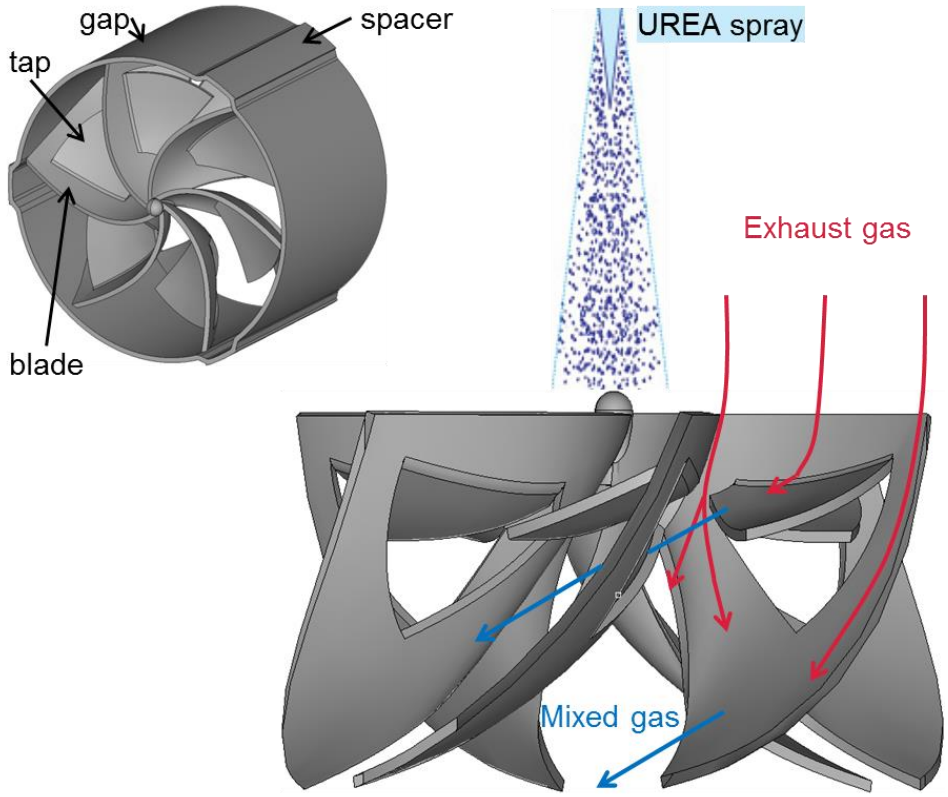
Close coupled LNT & SDPF + underfloor SCR with twin dosing

System Layout



Challenges

+ High conversion efficiency at low temperatures (minimised LNT usage) due to close coupled SDPF
+ High conversion efficiency for highly transient operation and high temperatures due to full utilisation of underfloor SCR
+ Underfloor SCR to be optimised for high temperatures and space velocities
+ Limitation of NH3 slip due to dual dosing and precise control
+ Reduced NH3 into LP EGR path
- Backpressure of two mixers and SCRF
- Minimsed CRT / fast soot loading

➔ Careful optimisation of SDPF, dosing and mixers required

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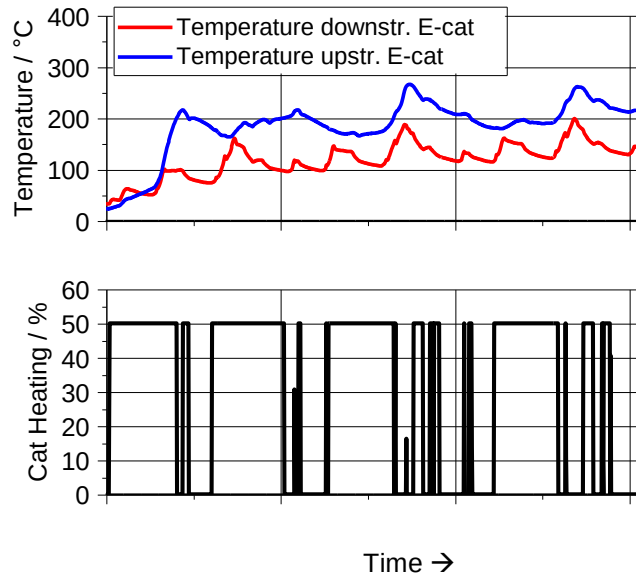
Challenging catalyst light-off; electrically heated catalyst as a possible option for 48V MHEV vehicles?



- With increased degree of electrification (48V or HV-hybrid), the use of electrically heated catalysts is an option
- Relatively small electric catalyst slice to achieve light off but to limit electric power demand
- Careful balance between rapid heat-up and slow cool down of catalyst is required in order to limit the electric energy demand
- “Precious“Electric energy rather to be used for propulsion

Source: FEV, Continental

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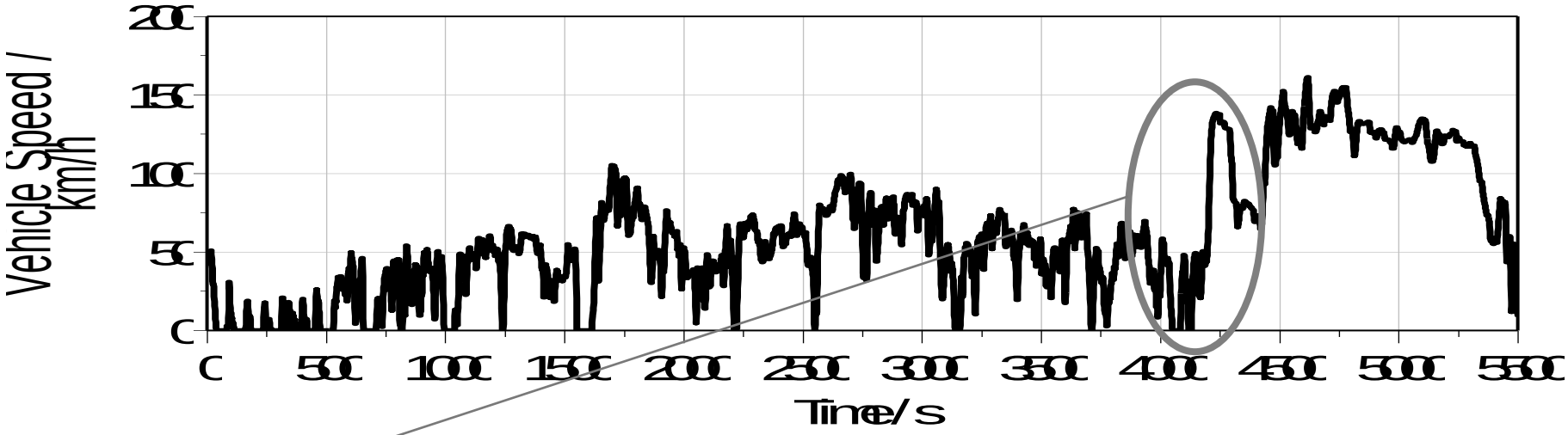
Transient Driving



Transient driving

- Engine-out NOx control
- Highly Capable aftertreatment
- Highly accurate, model-based engine and aftertreatment control

- Cooled low pressure and high pressure EGR
- Fast and accurate EGR control
- Improved NOx/PM tradeoff
- Minimisation of clogging / fouling of air path components
- Transient engine out and aftertreatment NOx control
- Electric boosting

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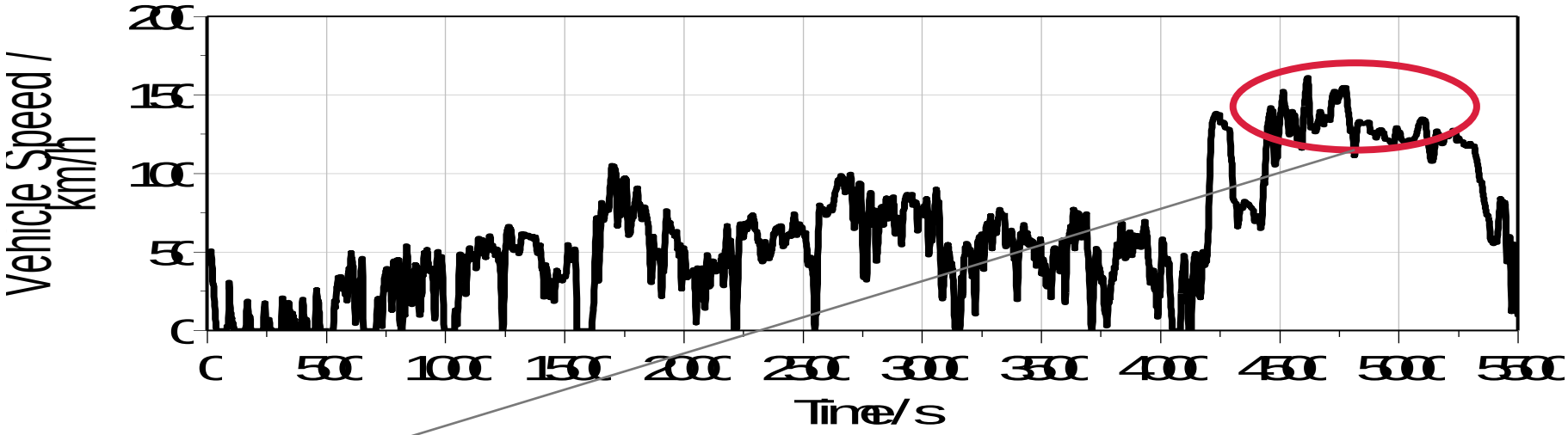
Motorway Driving



Motorway driving

- Engine out emission control for high loads and engine speeds
- Highly efficient aftertreatment system for high temperatures and massflows

- Improved SCR formulations for high temperatures and mass flows
- High load EGR capability adapted turbo charger matching
- Variable compression ratio

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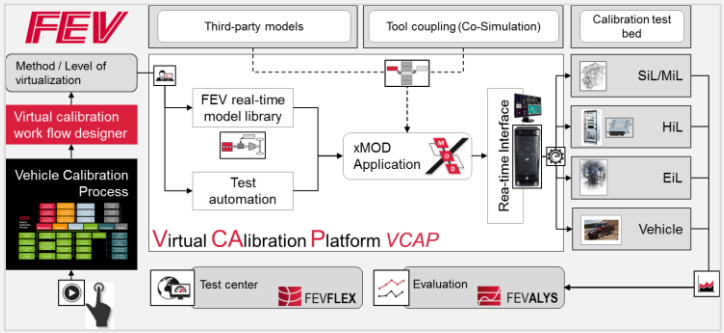
FEV Solution for XiL calibration environment

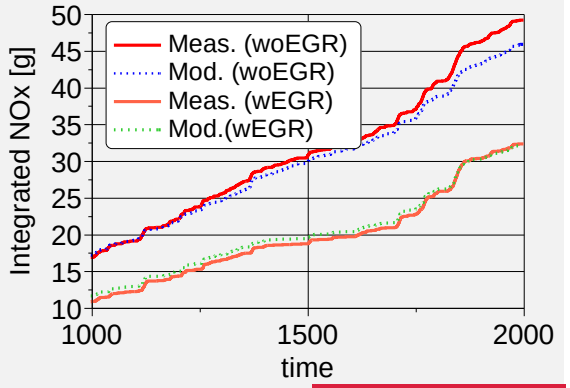
XiL based Virtual Calibration Process & robust RDE Sign Off

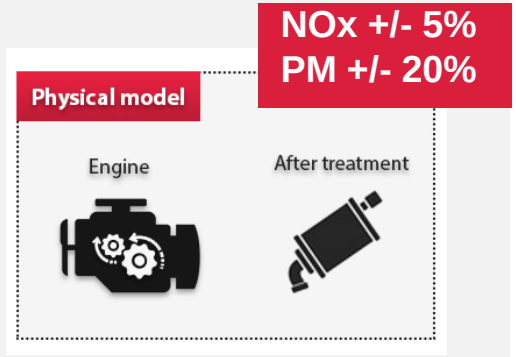
SMART CALIBRATION AND VALIDATION APPROACHES TO HANDLE COMPLEXITY

Virtual Calibration X-in-the-Loop

- Complete Model in the loop calibration
- Real time simulation of virtual vehicle with real hardware ECU
- HiL-based virtual calibration approach designed for series development







In Use Performance Validation

- Statistical evaluation of customer-relevant vehicle usage
- Robustness with regards to:
  - RDE
  - Aftertreatment capabilities
  - Model adaptations

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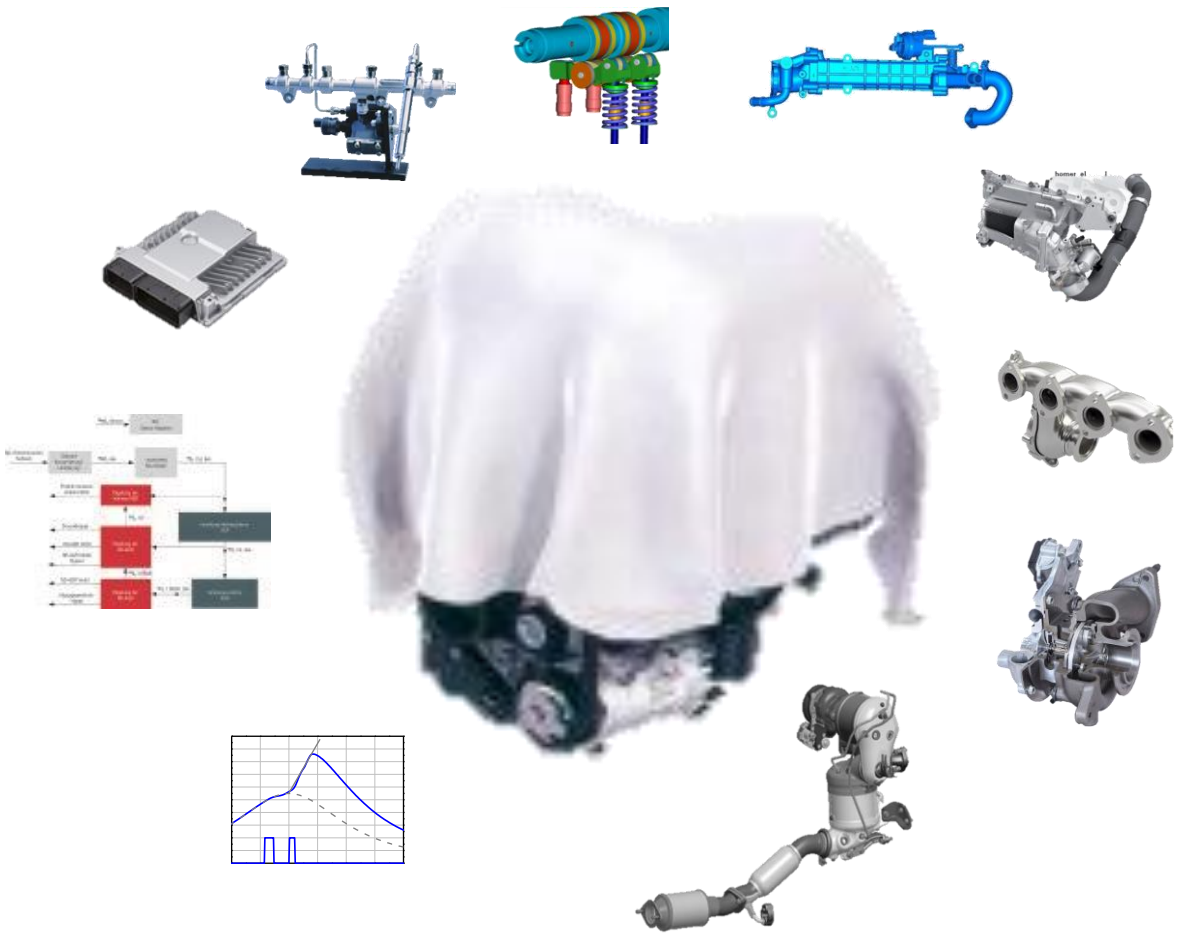
Technology package for the robust fulfillment of the EU6-d requirements for 2020+

NEXT GENERATION DIESEL ENGINE FOR COMPREHENSIVE EMISSION COMPLIANCE



- Refined combustion system with optimised matching of charge motion, spray pattern and piston bowl
- Upgraded FIE with >2500bar inj. pressure
- Enhanced boosting with WCAC and high load EGR capabiltiy
- Cooled low pressure and high pressure EGR
- Valvetrain variabilities
- Variable compression ratio
- DOC/LNT+ccSDPF+ufSCR

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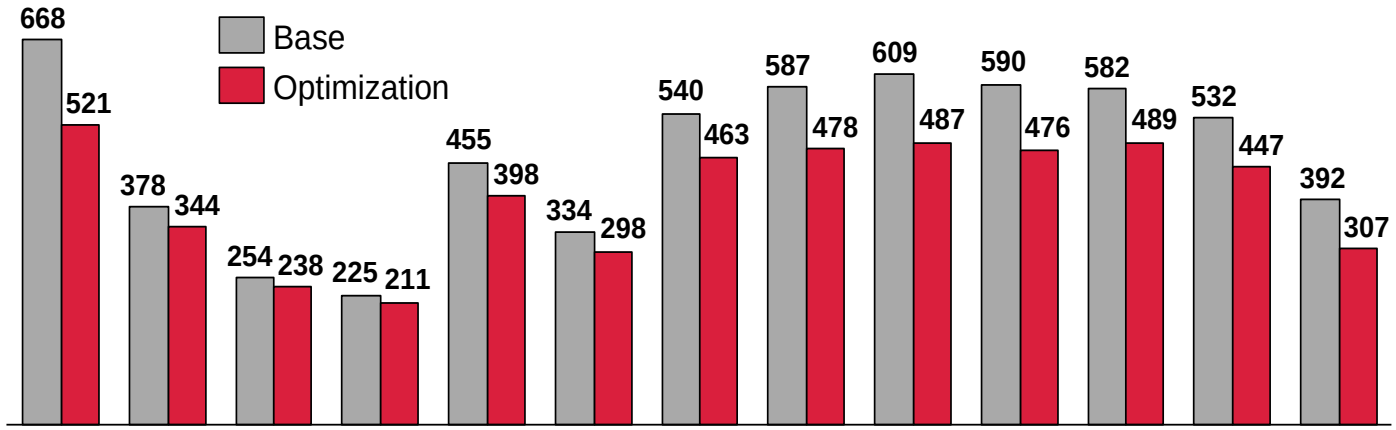
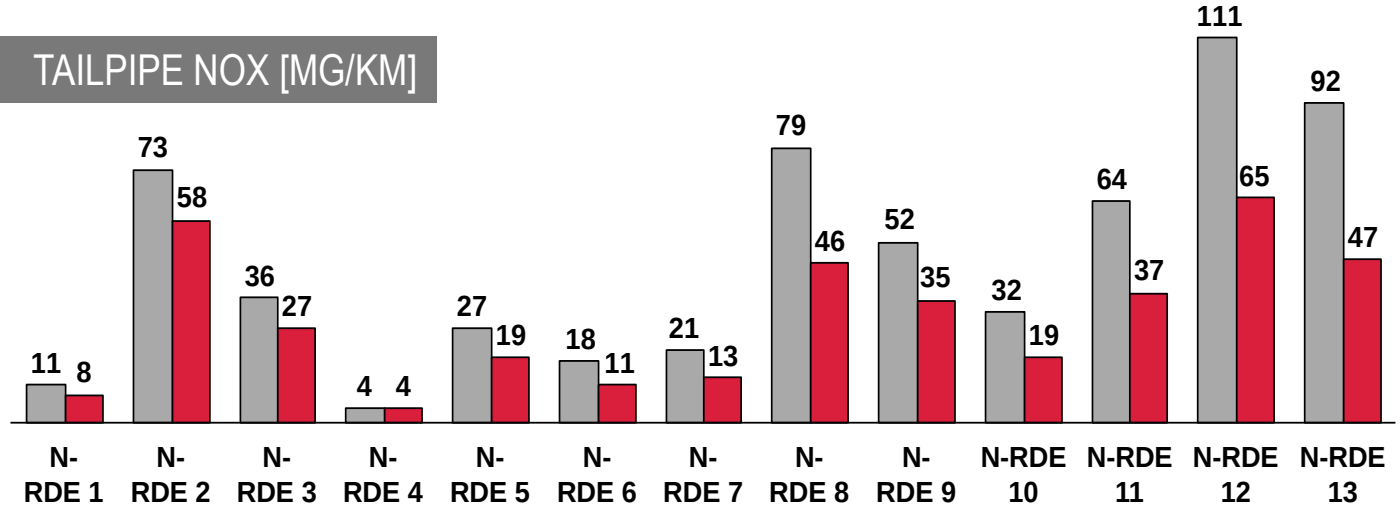
Emission results for several ambient conditions and drives
RDE moderate & extended → low tailpipe values achievable

ENGINE OUT NOX [MG/KM]



TAILPIPE NOX [MG/KM]



Description

- D-segment vehicle **with advanced ~2l engine, featuring opt. combustion, VVT functionalities, exhaust insulation, enhanced cooled HP/LP-EGR system and combined LNT, SDPF, SCR aftertreatment**
- Advanced base engine calibration realizing low engine out NOx in complete engine map
- Active LP-EGR during DPF regeneration

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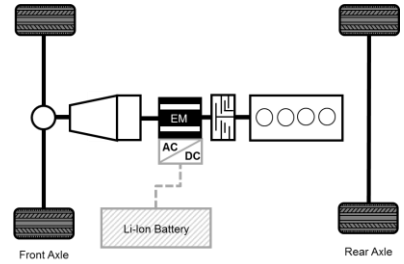
Possible access restrictions for inner city regions and continuously tightened efficiency requirements drive the motivation for Diesel PHEV's

Customer benefits

- Fuel economy improvement
  - Low fuel consumption in short distance driving due to electric recuperation and boosting
  - Low fuel consumption on highway and in long distance driving due to high efficiency of Diesel engine
- Local emission free driving
  - PHEV can cover distances of up to ~50 km in urban traffic with purely electric propulsion
- Enhancement of Performance
  - Better launch behavior
- More refinement and comfort
  - Seamless start/stop



Limitation of add-on costs

- The conventional powertrain can be designed out for more stationary operation in a smaller area of the engine map.
- Transient and low load operation can be covered or supported by the electric system.
- Simplification of EGR-system, boosting system, EATS and T/M is possible and can partly compensate the cost increase due to the hybrid system.
- Further reduction of add-on costs is expected in the next years due to higher production figures and lower costs of hybrid components.

Source: FEV

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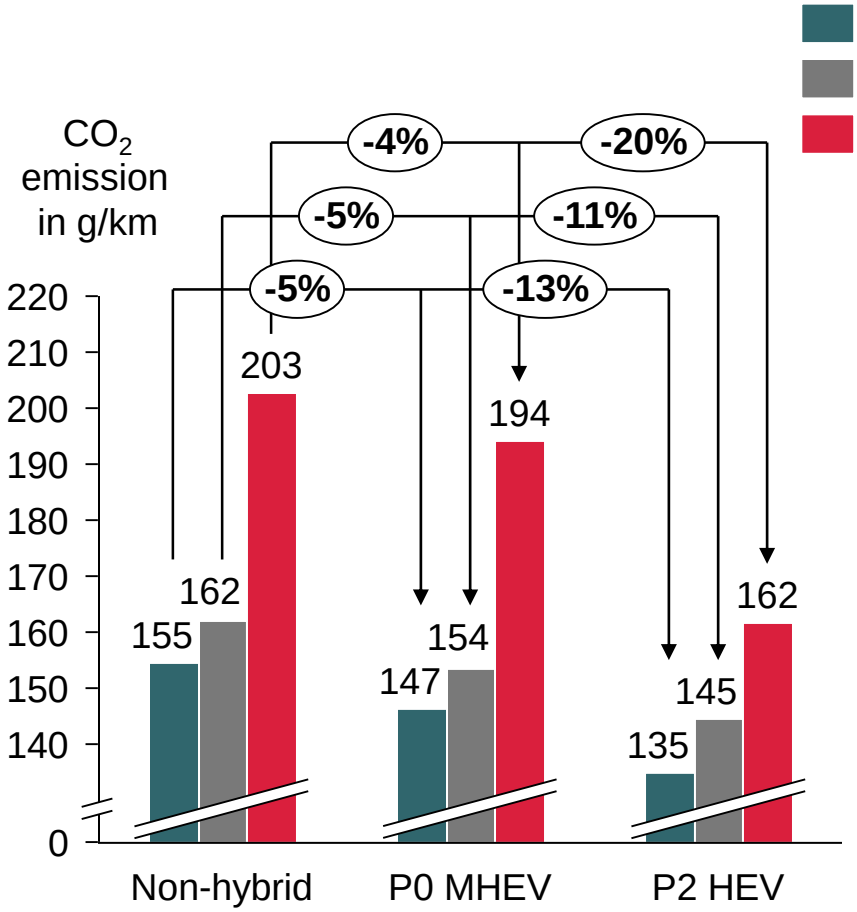
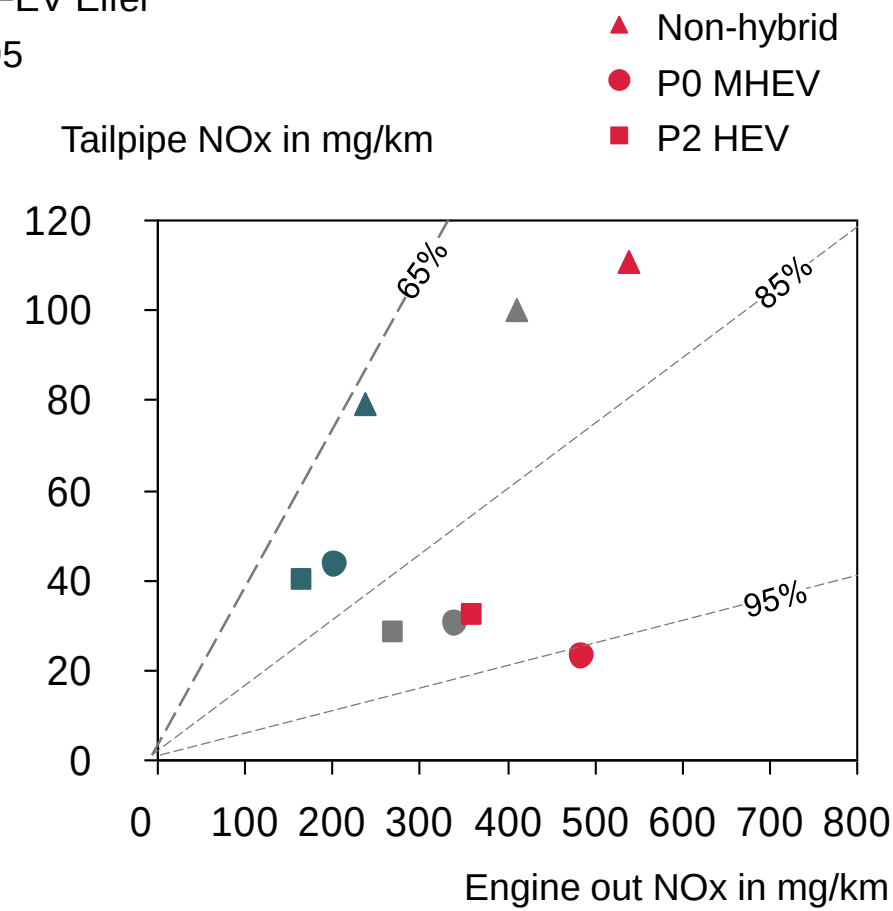
Diesel Hybrid SUV
Results overview (P0: 12kW; P2: 50kW)





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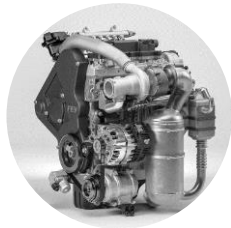
Diesel Hybrid Powertrains – Low Emissions Meet High Efficiency

WHITE ECO DIESEL

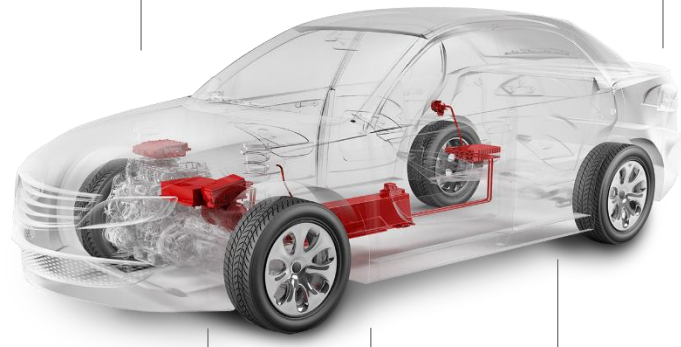


HIGH POWERTRAIN EFFICIENCY AND LOW TCO

LOCALLY EMISSION FREE

Umwelt ZONE

COST OPTMIZATION BY TAILORED POWERTRAIN

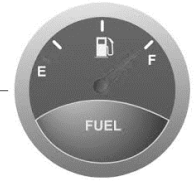


ELECTRIFICATION FACILITATES NOx REDUCTION

LOWEST REAL WORLD CO2

SECURED ENERGY SUPPLY AND FAST REFILL

UNCONSTRAINED USAGE/VERSATILE POWERTRAIN



HIGH MILEAGE

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Engineering Services at a Glance

BRINGING INNOVATION
TO THE STREET

HYBRID POWERTRAIN CONCEPT OPTIMIZATION AND SIMULATION	OPERATING STRATEGY AND ENERGY MANAGEMENT	ENGINE-IN-THE-LOOP TESTING
ANALYSIS OF LEGISLATIVE REQRUIREMENTS AND MARKET TRENDS	**DIESEL HYBRID POWERTRAIN SERVICES**	DEMONSTRATOR SET-UP
DIESEL HYBRID POWERTRAIN BENCHMARKING	NON-ELECTRIC HYBRID POWERTRAINS	POWERTRAIN CALIBRATION

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