DEER Conference 2009
Directions in Engine-Efficiency and Emissions Research

Increased Efficiency with Model Based Calibration

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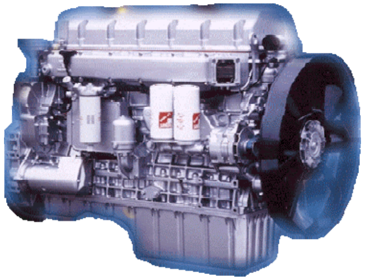
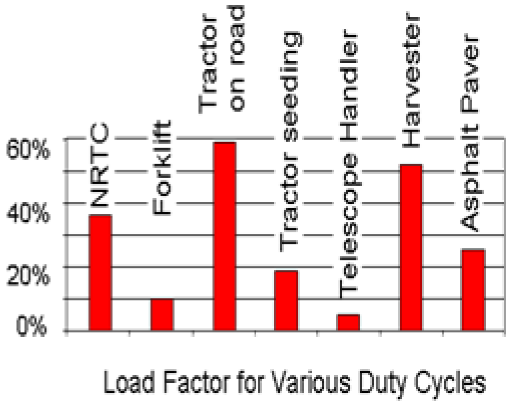
- Introduction
- Model based development process
- Application example
- Conclusion




Introduction
Development Challenges in the Off-Road Segment



One single engine type requires different power ratings for a wide range of applications, each with low annual production volumes (< 1000).



Extremely wide range of different duty cycles requiring different aftertreatment hardware and operation strategies

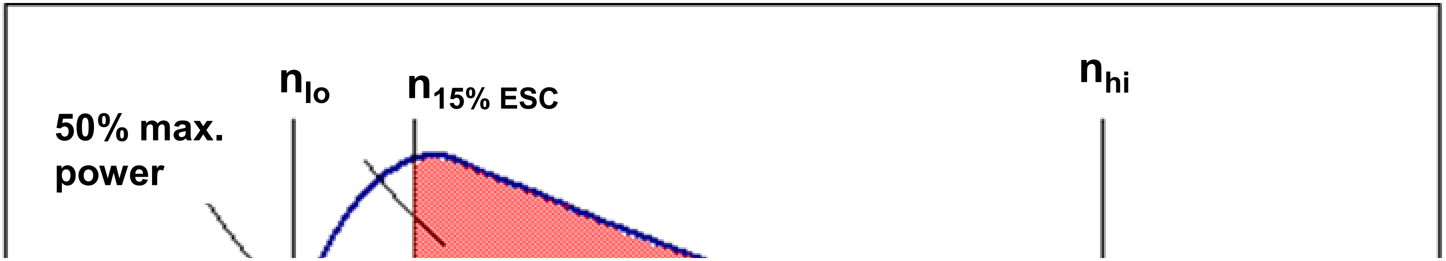
Each application has to be optimized for fuel consumption and emissions.

Introduction

De

Not-To-Exceed Standards

1.25 * Limit (1.5 * Limit if NOx < 2.5 g/kWh or PM < 0.07 g/kWh)



8

19

37

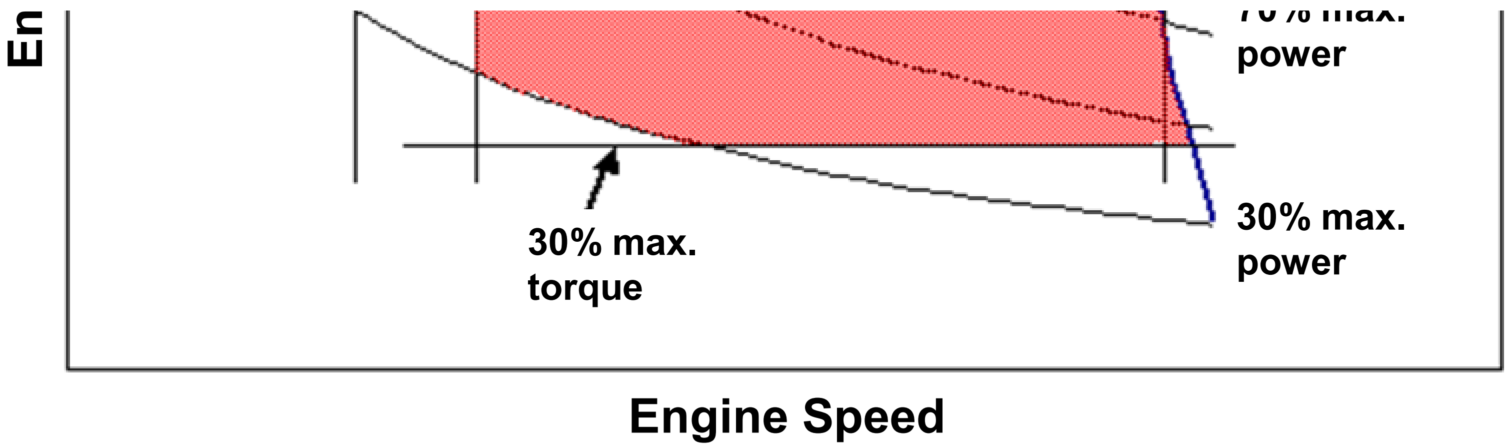
56

75

130

With Tier 4, the emission limits for non-road machinery (NRM) are similar to the most stringent on-highway legislation.

-> Increased complexity of engines and aftertreatment systems

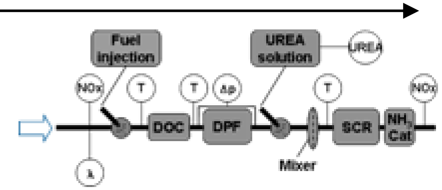


Characterized by high load and speed regimes

Introduction
Development Challenges in the Off-Road Segment

What is the optimum regarding fuel efficiency and costs?

Aftertreatment Technology



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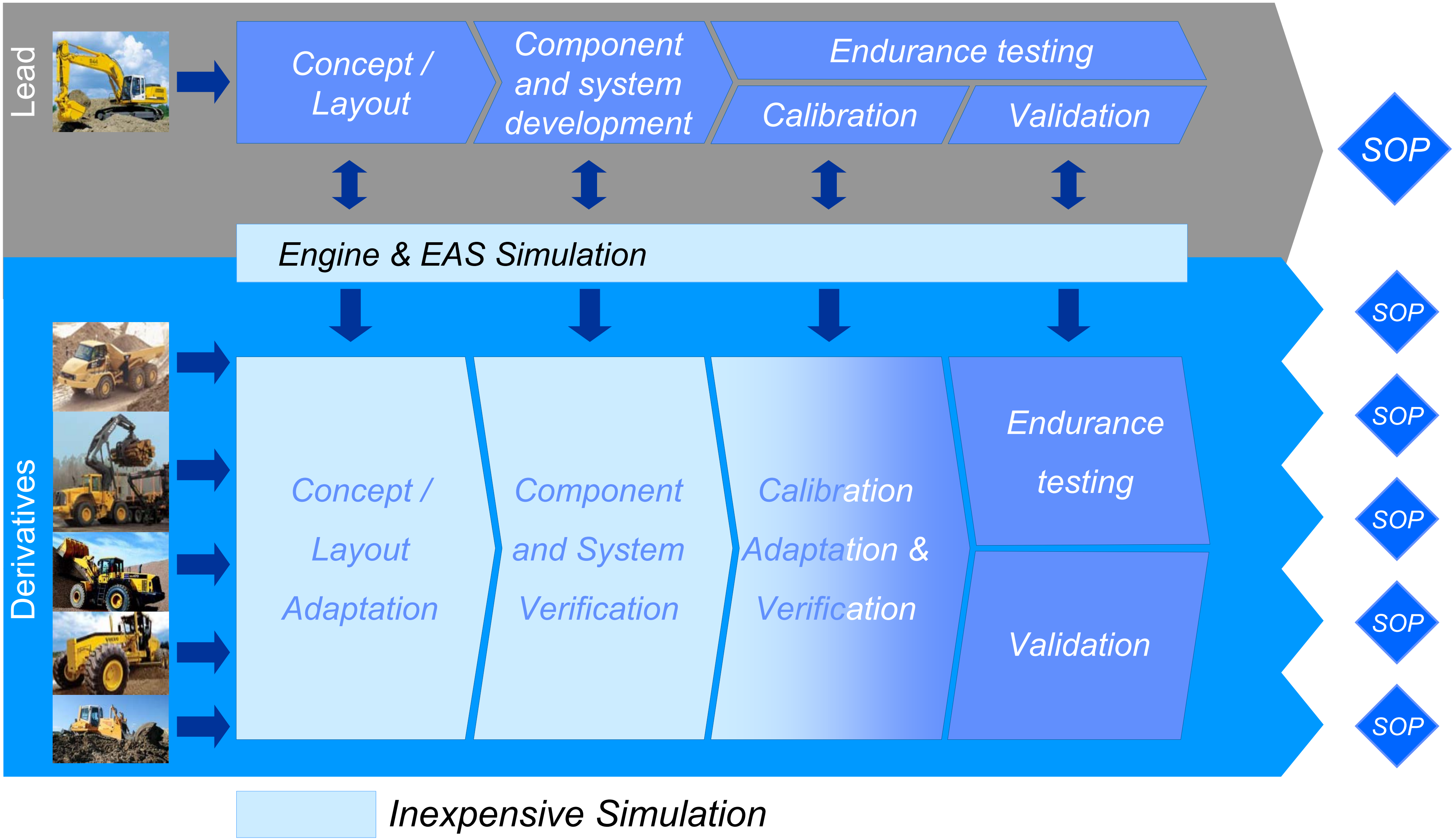
Model Based Development Process

Our solution for the challenges

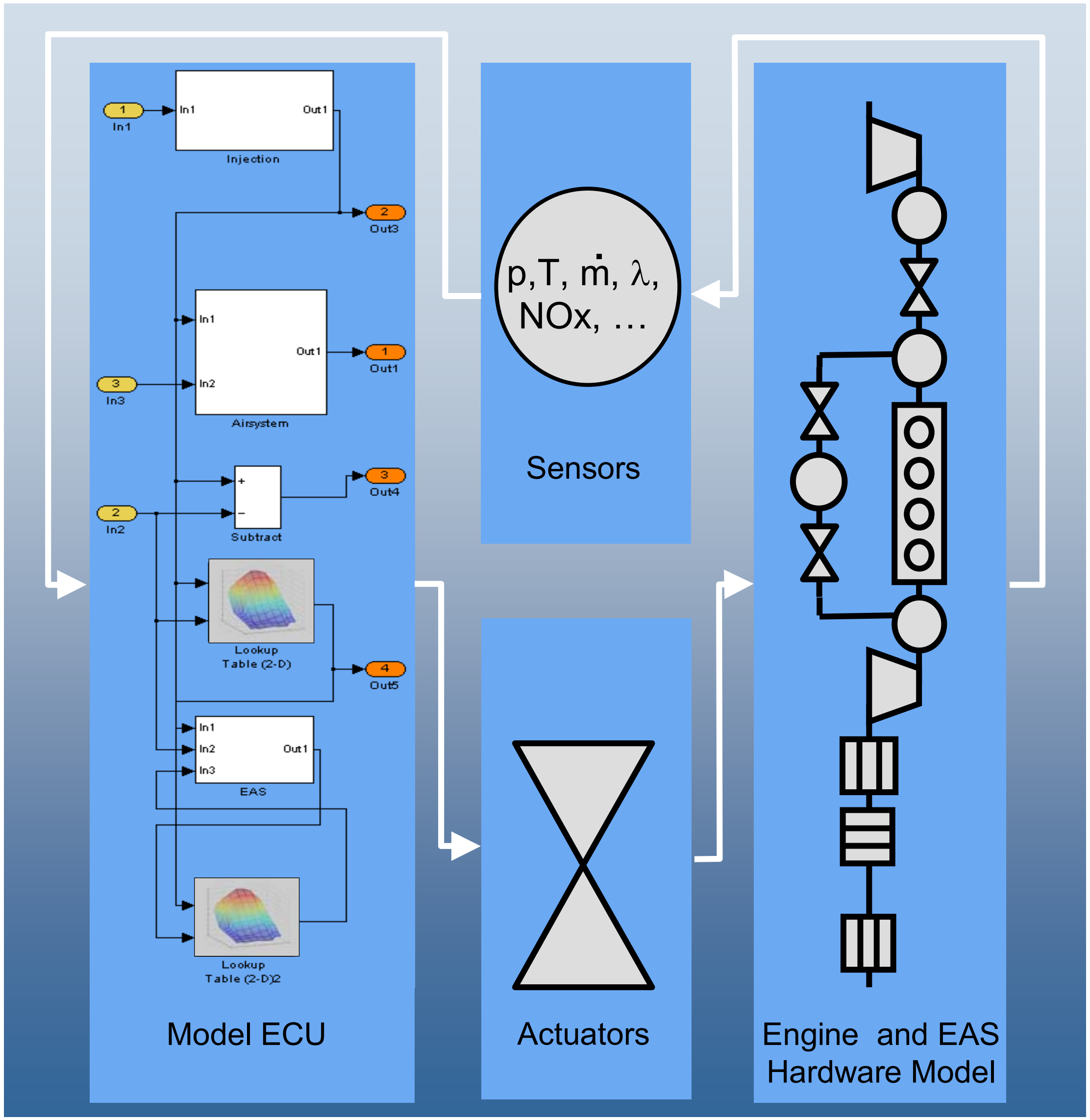


Model Concept for Simulation

IN

torque$_{dem}$

engine speed



OUT

torque

NOx, soot,

(HC, CO),

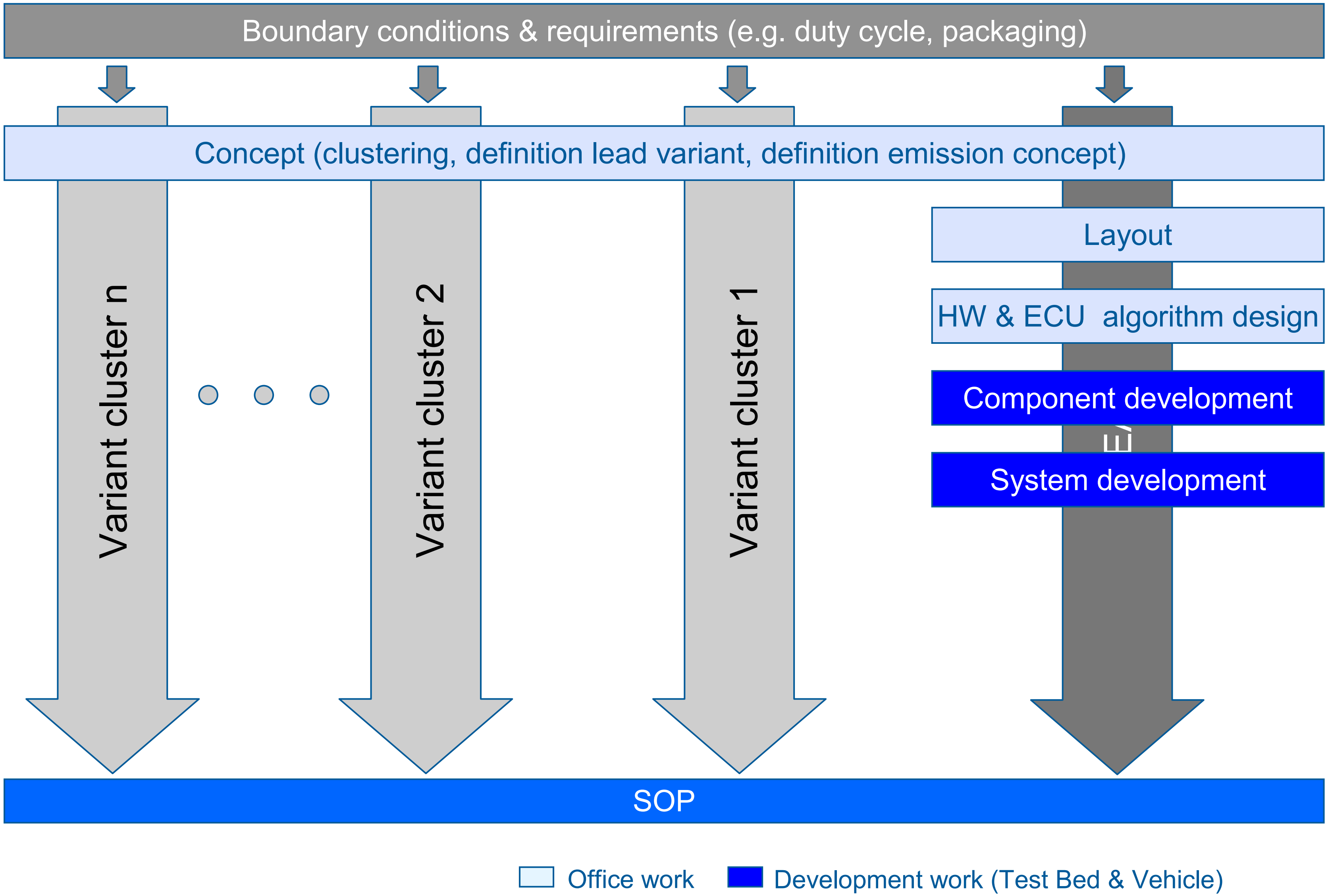
temperatures,

heat to

coolant,

BSFC

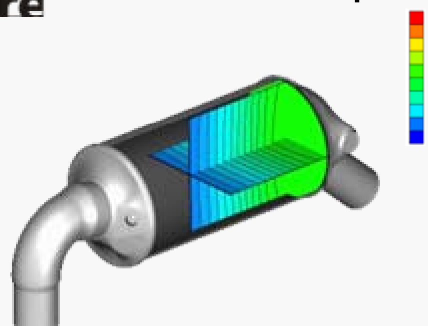
AVL Model based Development Process



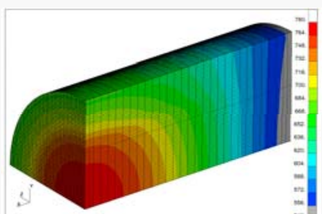
Phenomena Analysis with AVL FIRE during the Development Process

CFD Analysis of DPF Regeneration

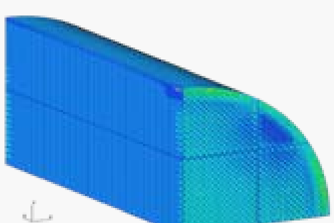
DPF Temperatures



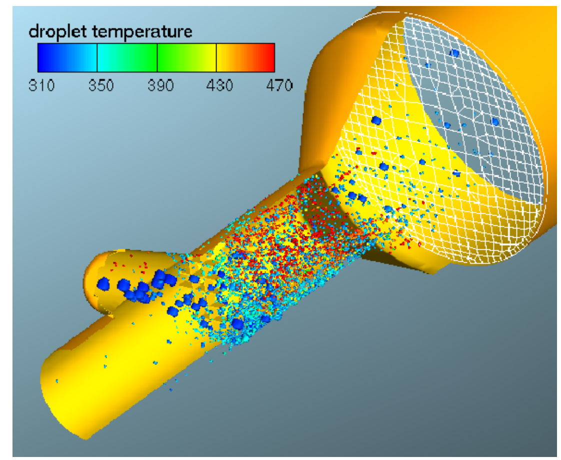
Mapping of Temperatures on FEA model



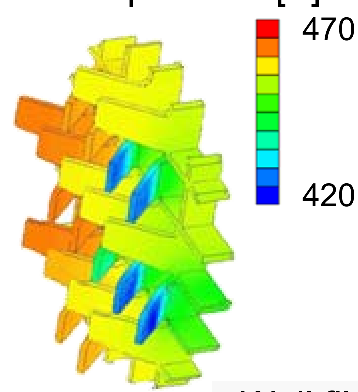
FEA Calculation of Total Stresses on DPF Substrate



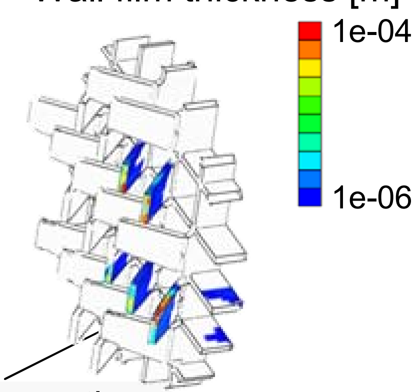
CFD Analysis of Urea Water Injection



Wall temperature [K]

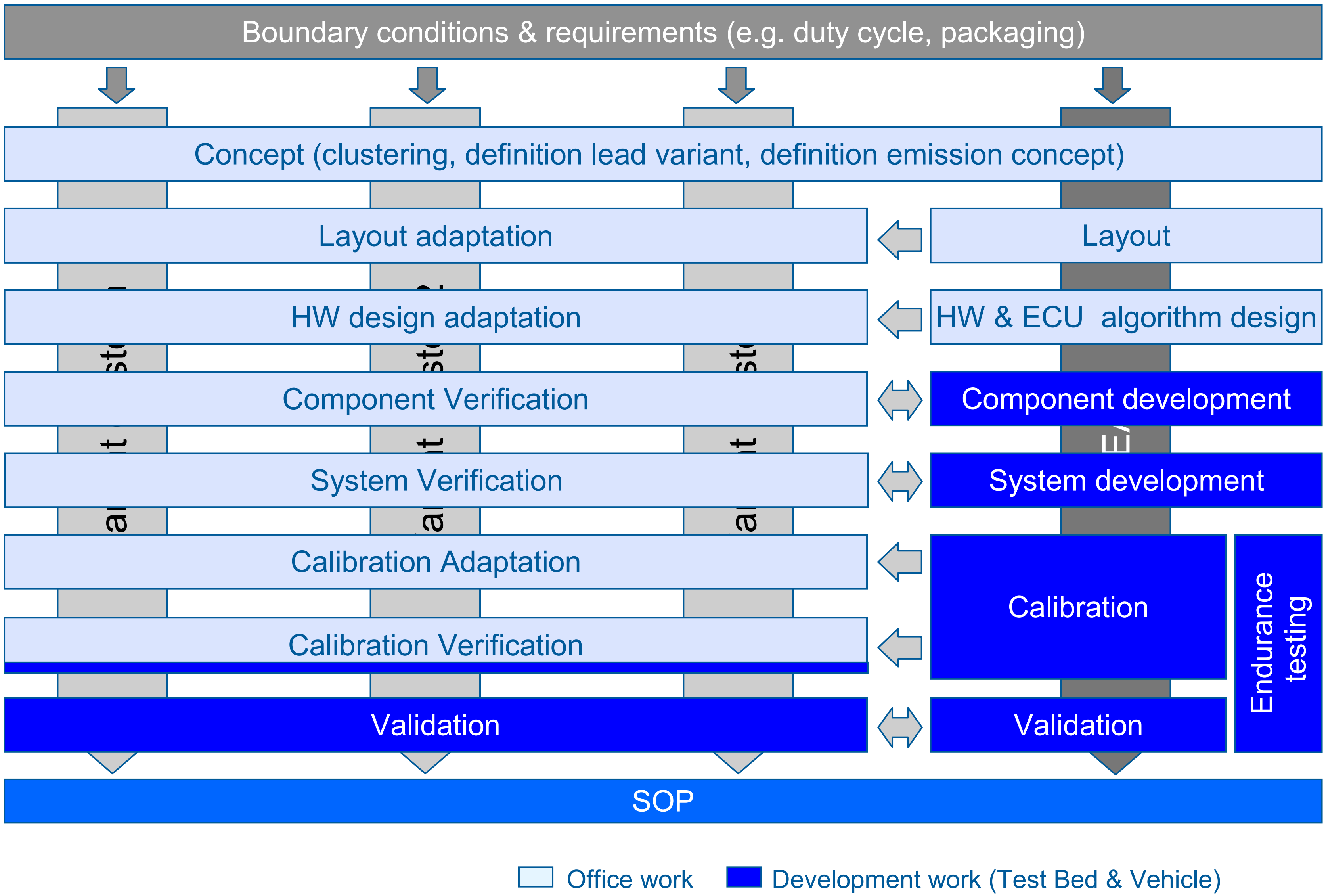


Wall film thickness [m]



Wall film formation on mixer

AVL Model based Development Process



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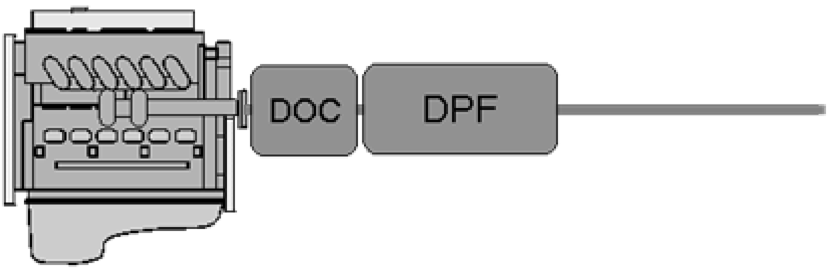
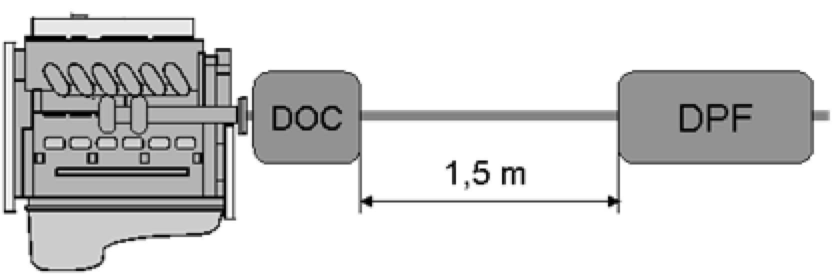
Engine and EAS Specification

Lead variant

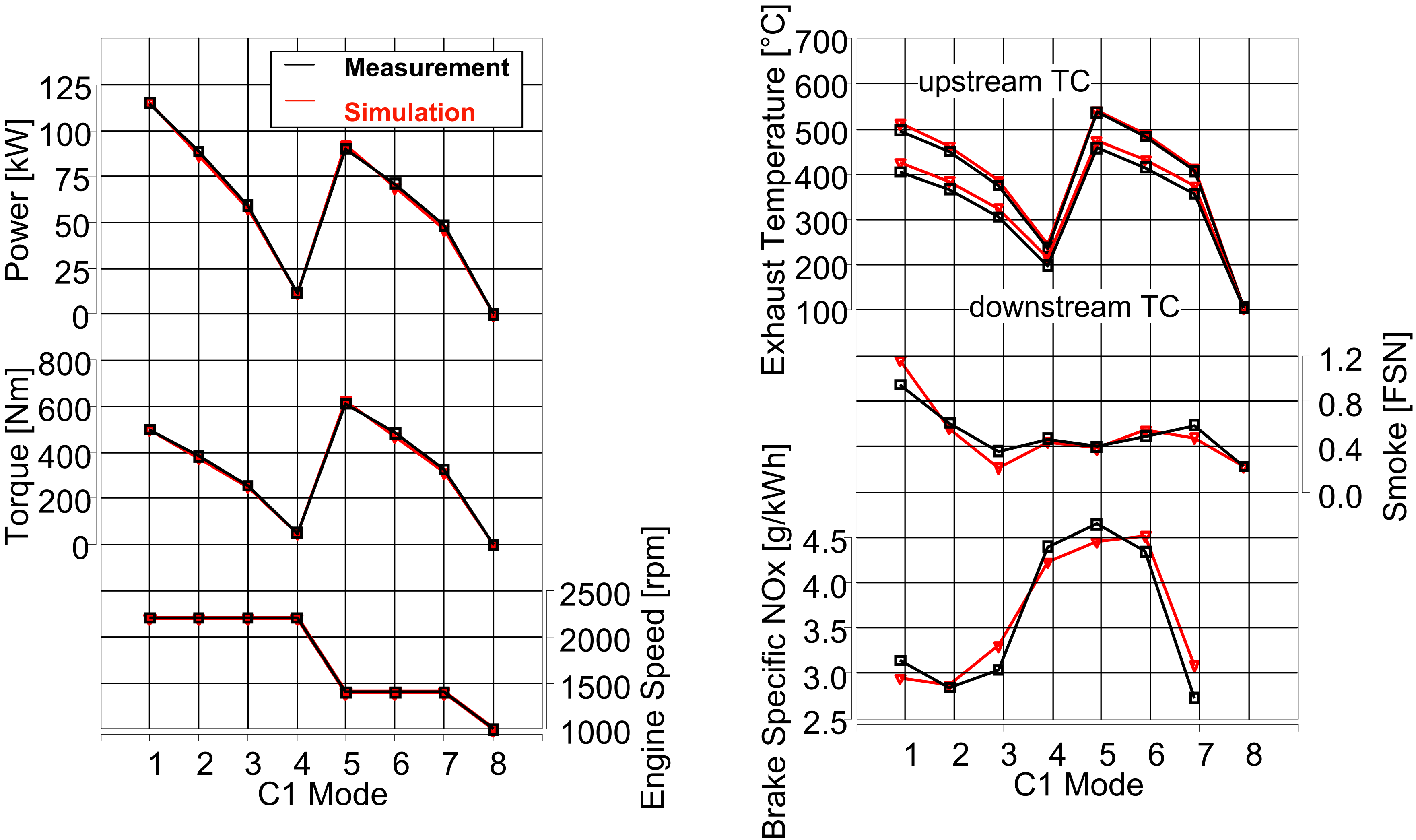


Derivative



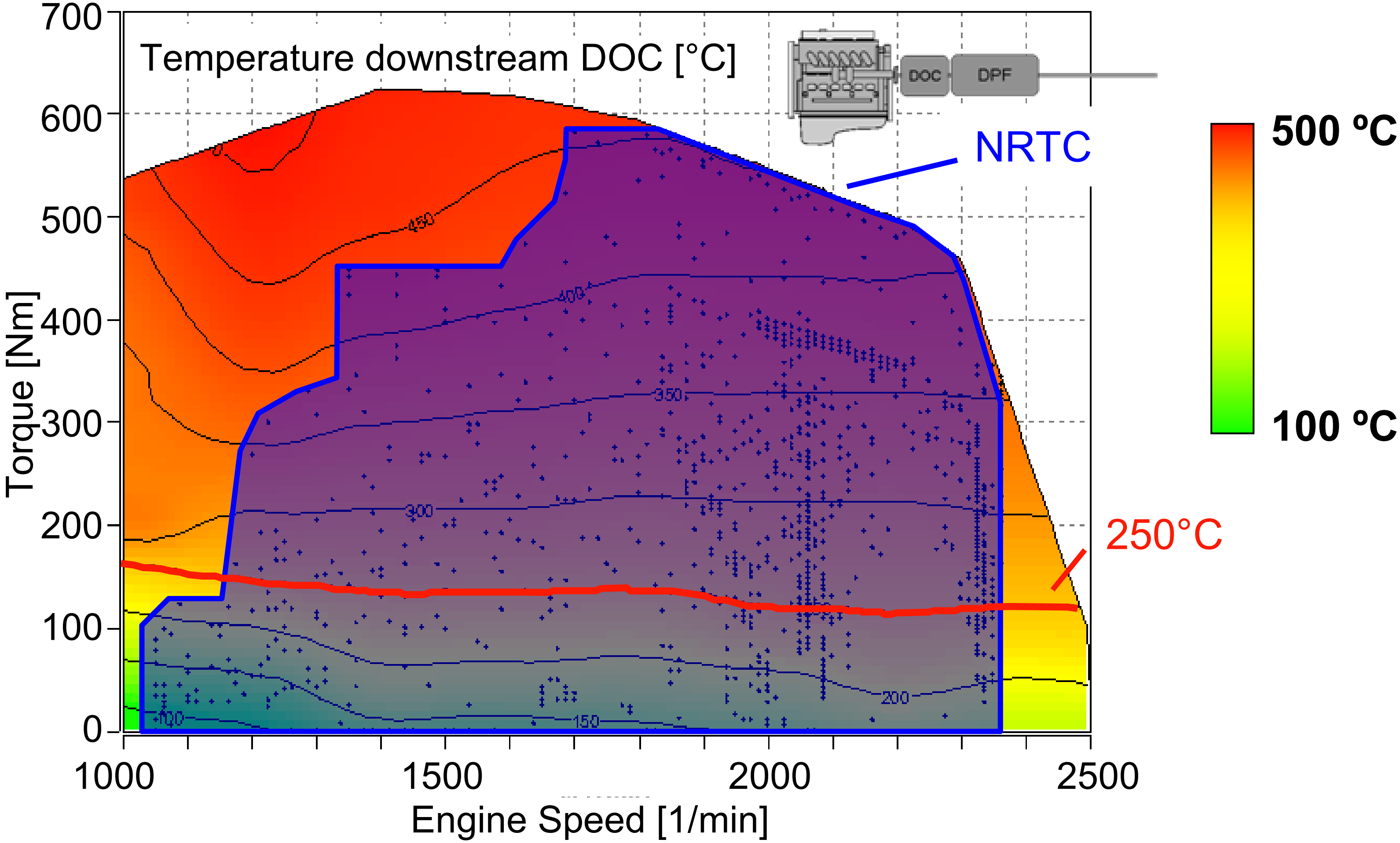
Engine	**Inline 6**	
Displacement	5 l	
Rated Power	115kW @ 2200 rpm	
Rated BMEP	12.5 bar	
Max Torque	625 Nm @ 1400 rpm	
Max BMEP	15.7 bar	
NOx Limit	3.4 g/kWh	
PM Limit	0.02 g/kWh	
EAS	**DOC**	**DPF**
Dimensions	Ø 9" x 5"	Ø 9" x 10"
Volume	5.2 l	10.4 l
Material	Cordierite	Cordierite
Cell Density	400 cpsi	200 cpsi
Wall Thickness	7 mil	12 mil
PGM Loading	50 g/ft^3	10 g/ft^3
PGM Ratio	Pt:Pd 10:1	Pt:Pd 10:1

Comparison of Measurement and Simulation Results (modified TIER 3 engine, C1 Test)



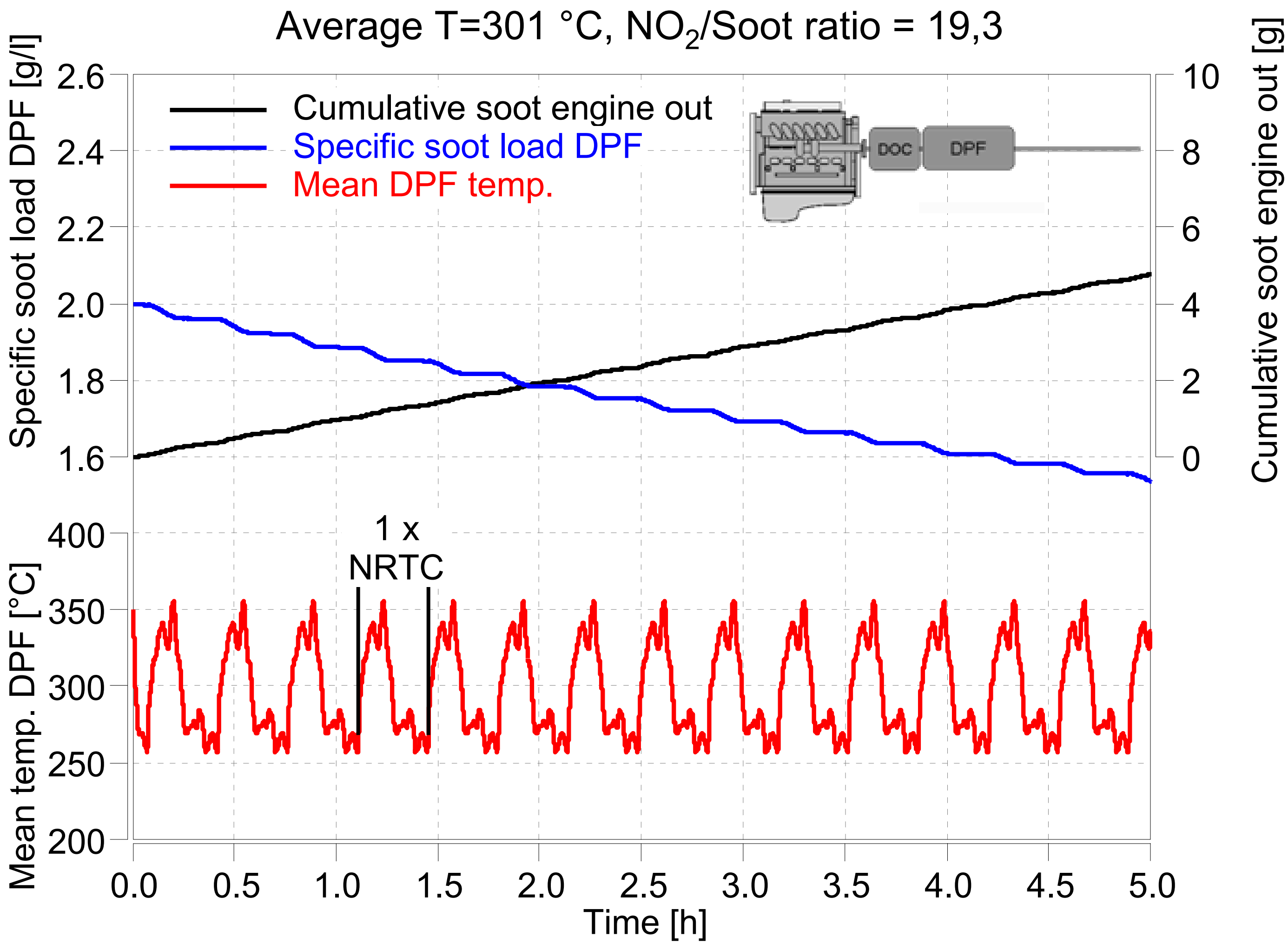
Excellent correlation measurement ↔ simulation

TIER4i Exhaust Gas Temperature downstream DOC (Baseline)



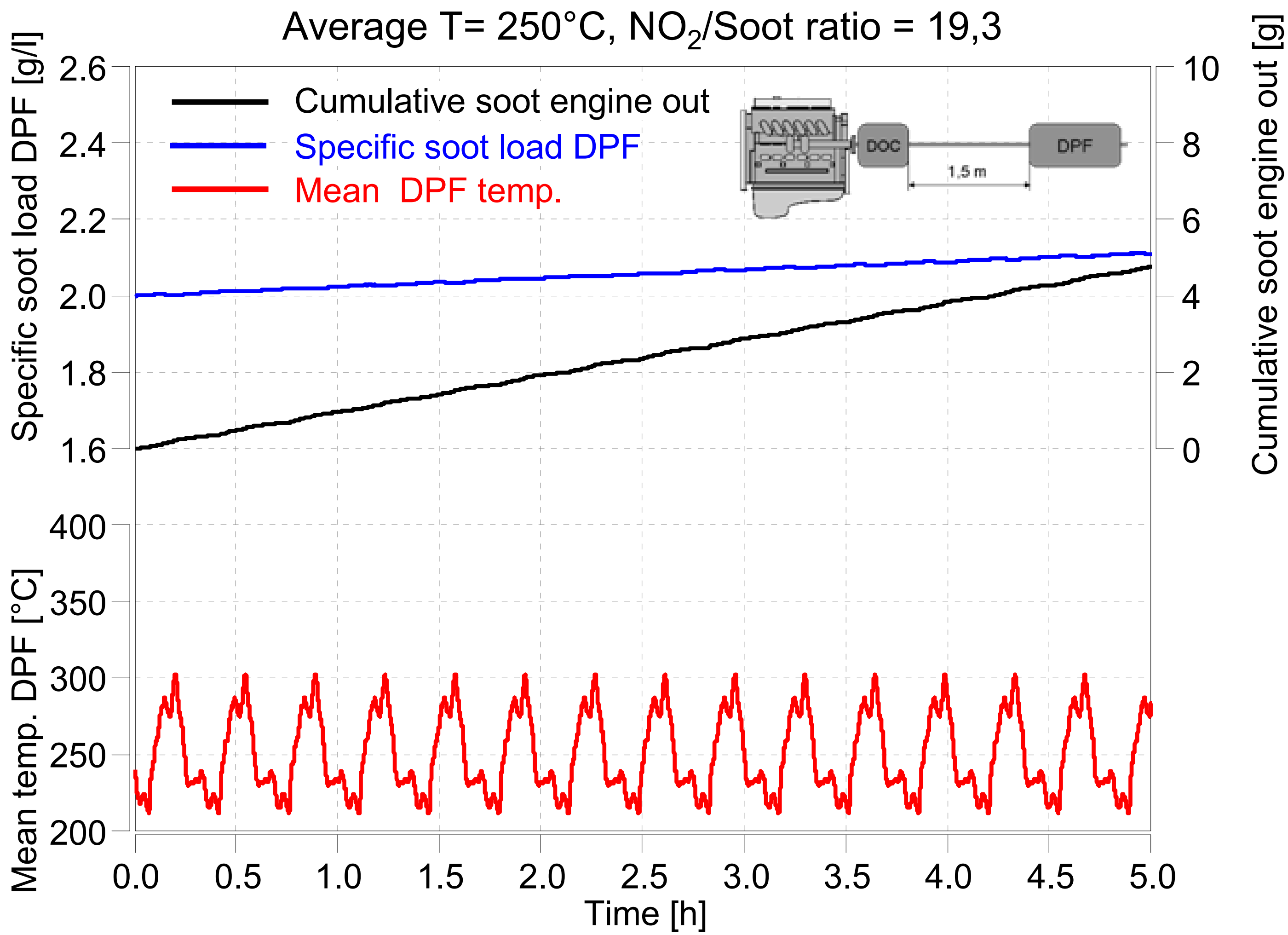
Exhaust temp. downstream of DOC is mostly above 250°C over the NRTC

Regeneration performance of the lead variant (baseline) during NRTC



Passive regeneration works well for lead variant over NRTC

Regeneration Performance of the Derivative Over NRTC



Passive regeneration insufficient!

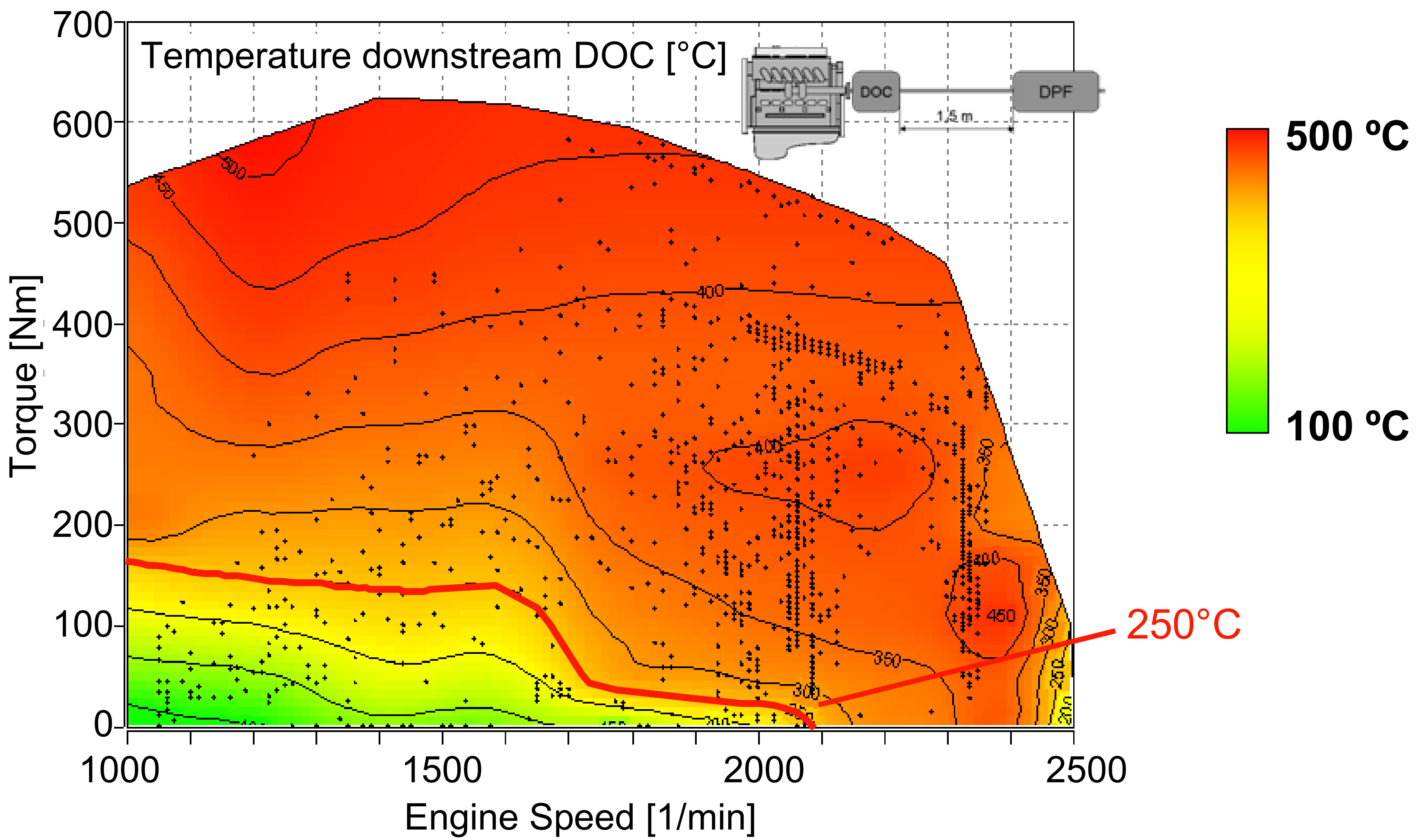
→ What would it take to keep the system strictly passive?

Initial Recalibration: Temperature Management

Increase of exhaust gas temperature

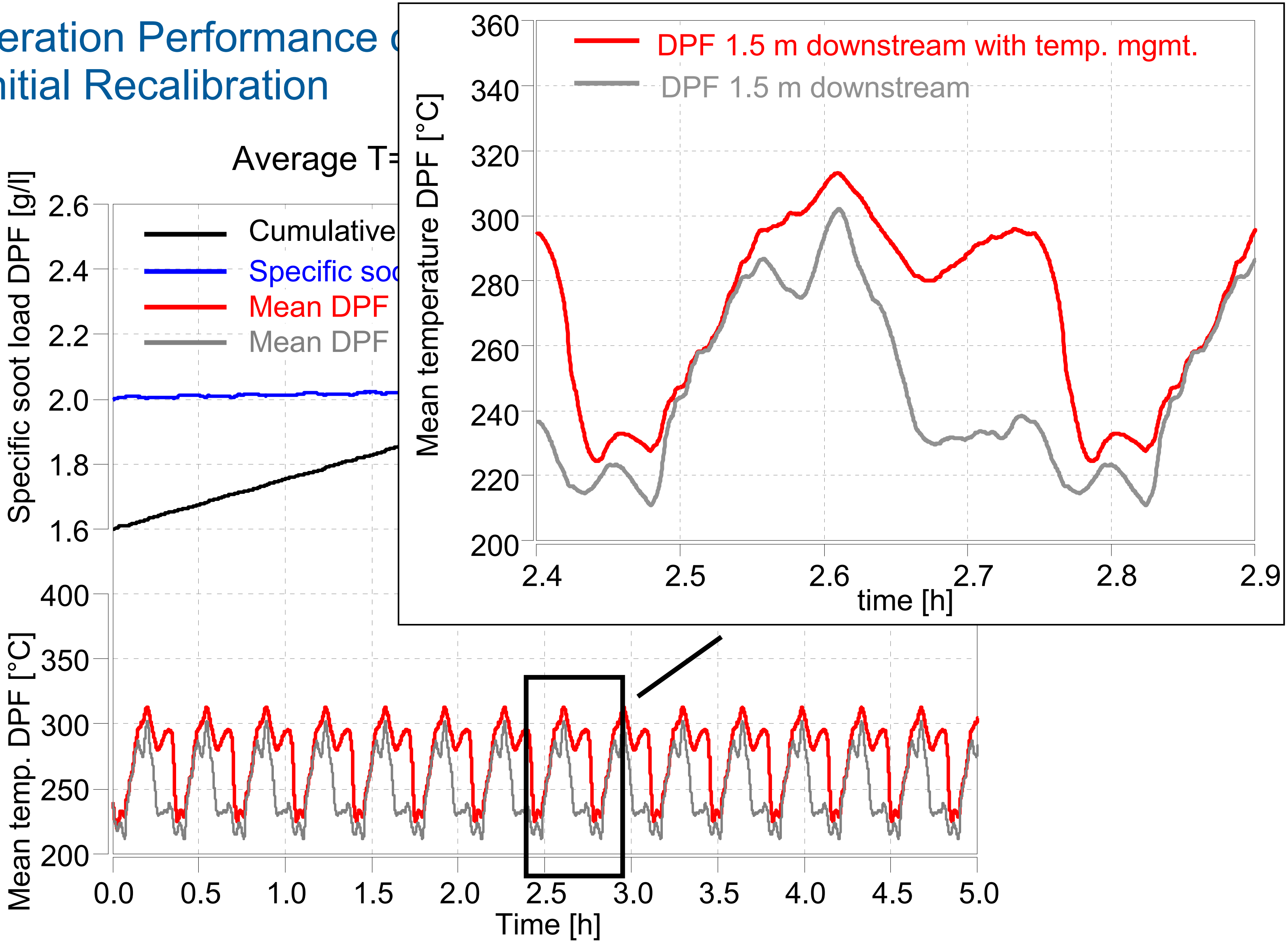
- Reduction of intake air mass (keeping diluent content similar)
- Reduction of EGR mass
- Boundary condition: constant NOx level, higher soot accepted (timing adaptation)

TIER4i Exhaust Gas Temperature downstream DOC after Recalibration



Exhaust Gas Temperature downstream DOC significantly increased

Regeneration Performance After Initial Recalibration



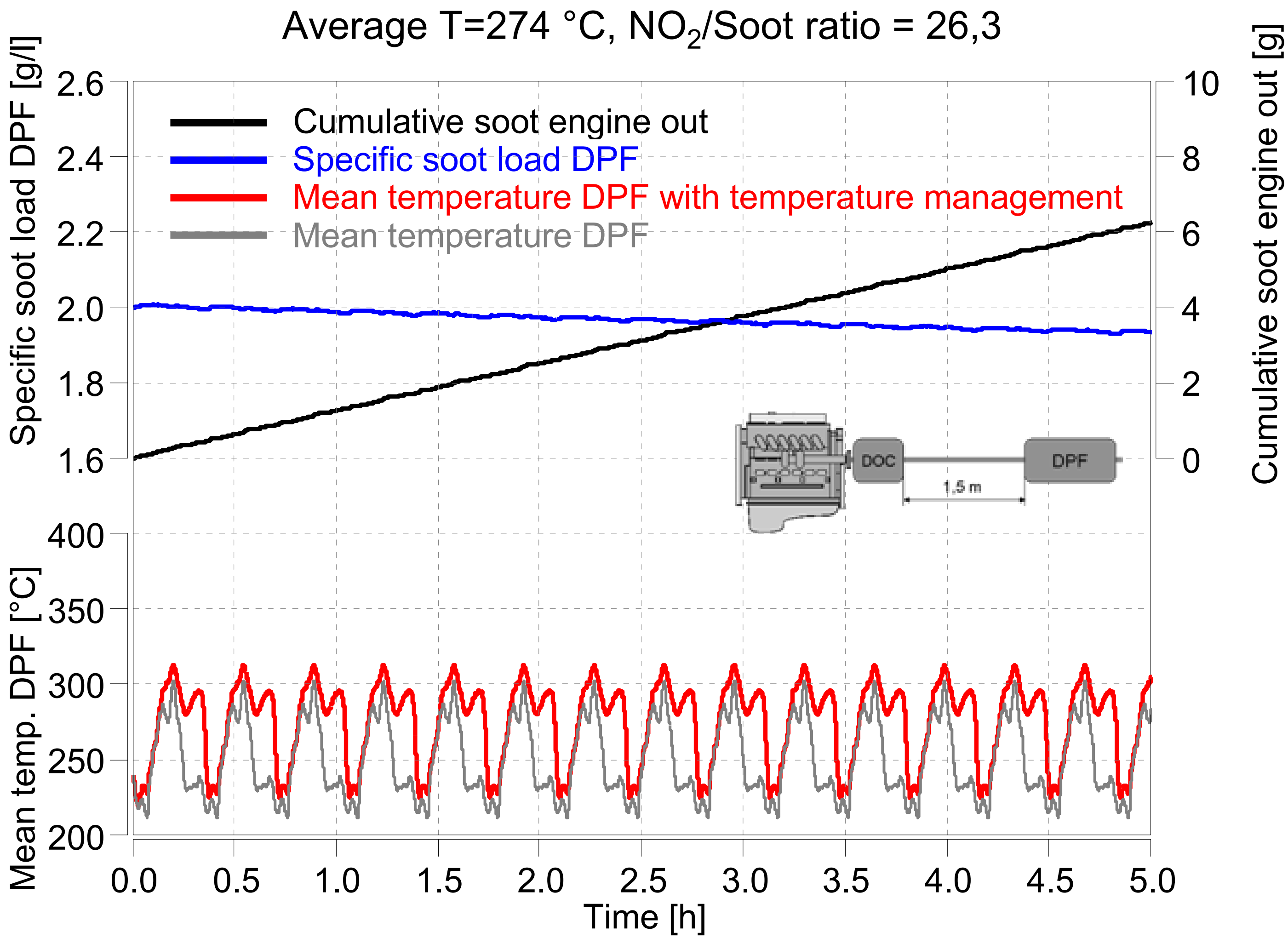
Despite exhaust temperature increase passive regeneration insufficient due to increase in engine-out emission

Final Recalibration: Soot Reduction

Reduction of engine-out soot

- Increasing injection rail pressure → higher mixing rates
- Boundary condition: no increase of NOx level and no decrease of exhaust gas temperature (timing adaptation)

Regeneration Performance of the Derivative Over NRTC After Recalibration



Recalibration resulted in acceptable passive regeneration for the derivative application but would come with a 4.6% fuel economy penalty

-> active regeneration preferable

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Conclusion

- Meeting future TIER 4 emission limits requires the integration of many new technology elements in the powertrain of non-road machinery.
- AVL's approach to handle this challenge is its new model-based development and calibration process.
- The integration of zero-dimensional semi-empirical models allows a robust system layout, avoids additional development loops, and enables concept transfer during the development phase from a lead variant to derivatives as well as efficient recalibration of derivatives.
- Consequently, a significant part of the costly facility-related development and calibration work can be shifted to low cost virtual engine testing increasing efficiency, product quality and robustness.