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# DIESEL ENGINE EMISSION CONTROL CONCEPTS FOR ROBUST COMPLIANCE WITH INDIAN RDE LEGISLATION

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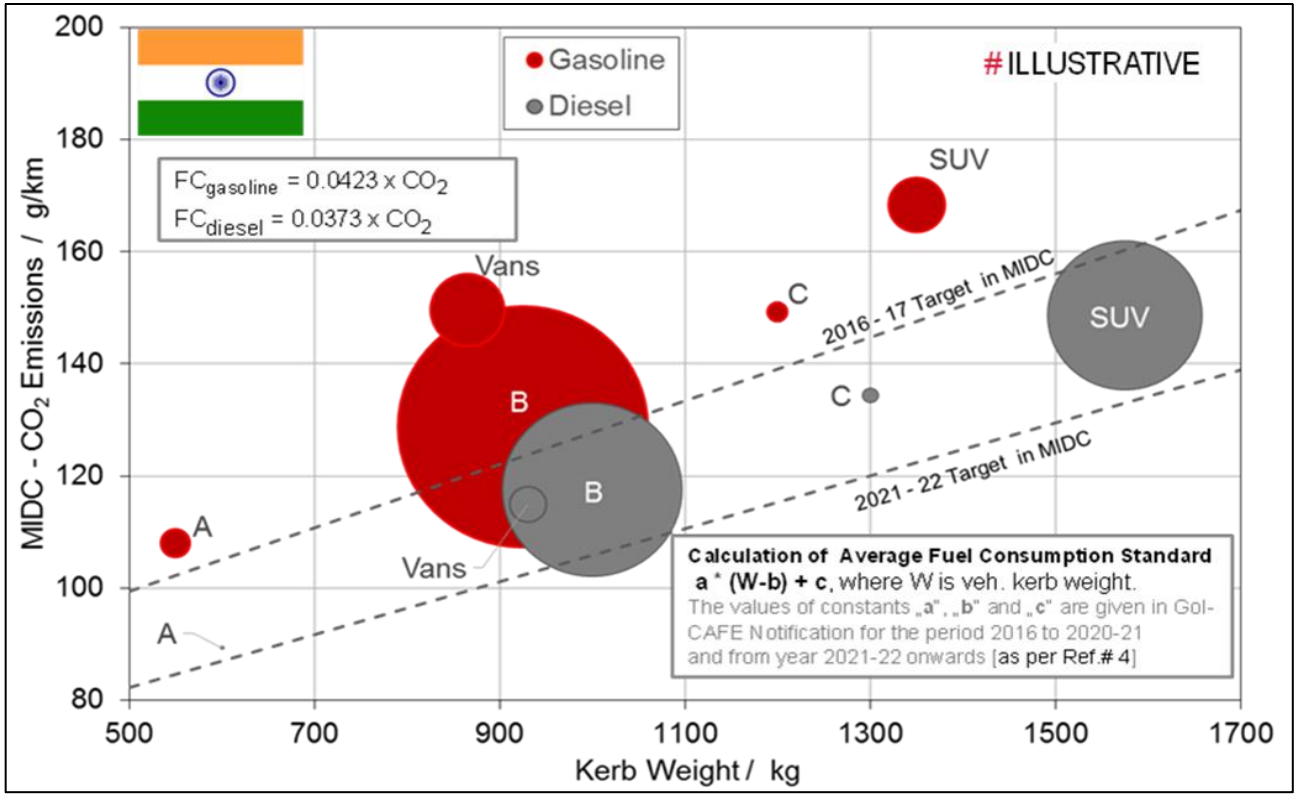
FEV Author's : O.P Bhardwaj, Th. Korfer, S. Arora, M. Panda

HJS Author's : C. Menne

# Agenda

- Introduction and Background
- Methodology and Approach
- Results
  - Passenger Car
- HJS's Capabilities Overview
- Results
  - Heavy Duty Application
- Summary and Outlook

# Introduction & Background



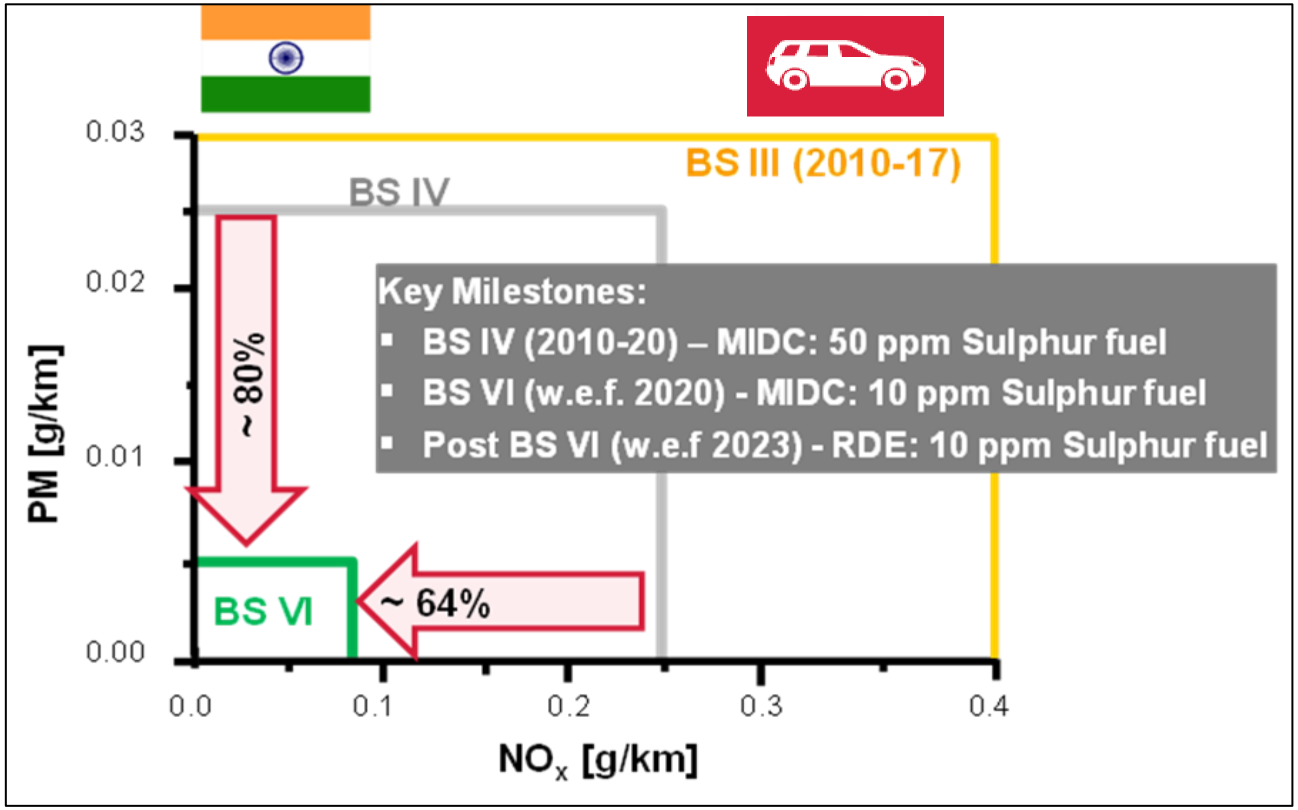

» **Diesel powertrains are 15 – 20% more efficient compared to gasoline powertrains, quite comparable to the situation in EU**

- Figure shows the kerb weight dependent CO2 emission in the MIDC cycle for gasoline and Diesel PC applications
- Small PC segment is mainly dominated by Gasoline vehicles
- The heavier segment is mainly dominated by Diesel powertrains with the market share 80 – 90 %

* Size of the bubble indicates the sales volume

# Introduction & Background

## INDIAN LEGISLATION




» **Leapfrogging to the higher legislation is major driver for the technological upgradation in existing engines / powertrains**

- The leap-frogging to BS VI will require > 80 % reduction in tailpipe PM mass emissions and ~ 64% reduction in tailpipe NOx emissions
  - 2020 : BS VI with MIDC certification
  - 2023 : BS VI with RDE (PEMS certification) – Conformity Factors will become mandatory

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# Methodology & Approach

SUV APPLICATION

# BEST PRACTICE

## Test Set-up & Model Validation

### Mean Value Engine Model Setup & Validation

**Vehicle**
- SPORT UTILITY VEHICLE (SUV)
- UTILITY VEHICLE (UV)

**Powertrain**

2.0 L CLASS DIESEL ENGINE WITH MT6

**Test Cycle**
- MIDC:1930 KG
- WLTC (TMH):2150 KG
- RDE-IND: 2270 KG.
- RDE-95MOD: 2270 KG

**EATS**

UREA SCR BASED SYSTEMS

## Optimization Strategies

### Integrated Engine and EATS Optimization

IMPACT OF WLTC & RDE DRIVING CYCLES ON A BSVI (MIDC) COMPLIANT BASE ENGINE

STRATEGY FOR OPTIMIZATION:
- ENGINE CALIBRATION
- MULTIPLE EGR SYSTEMS (HPE & LPE)
- EATS LAYOUT OPTIMIZATION

» **Optimized Engine Calibration (Air & Fuel Path) and EATS Strategy**

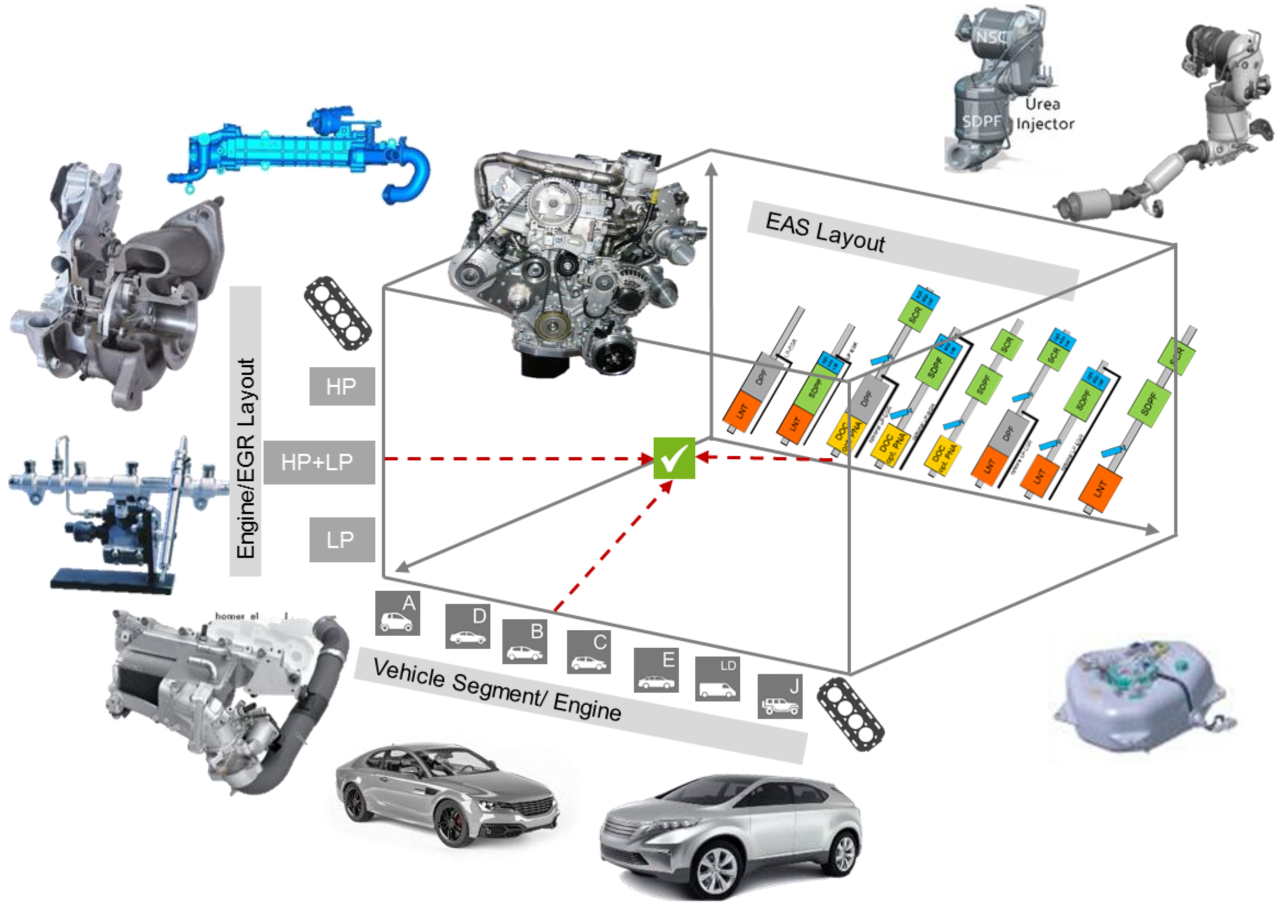
## Comparision of Strategies

### Comparative Assessment of Different Emission Control Pathways

- TAILPIPE $NO_X$
- CONFORMITY FACTORS OF RDE
- DPF REGEN. INTERVAL
- FUEL CONSUMPTION / $CO_2$

» **Robust Emission Compliance along with Efficient Operation in Real Driving Conditions**

# 0-D POWERTRAIN SIMULATION MODEL




- Nearly 800 different combinations are theoretically conceivable
- Detailed and comprehensive Emission Controls System analysis considering
  - Vehicle segment and characteristics
  - Engine features, Air system and EGR layout
  - After-treatment system configuration and specification
- Extension is possible, such as incorporation of 48V technology and HV-based hybridization

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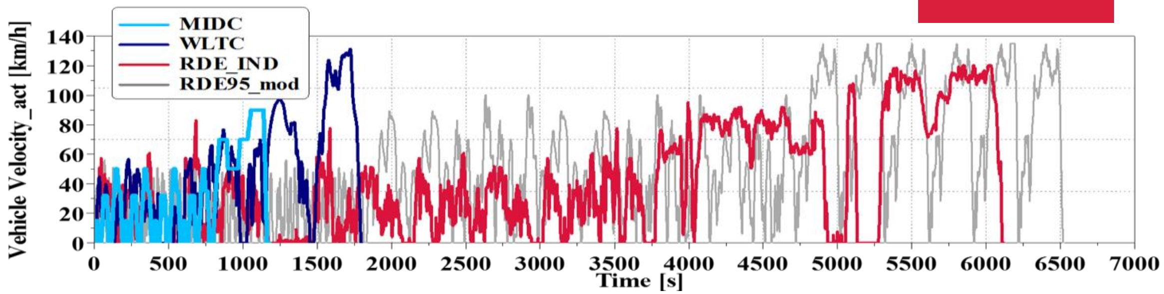
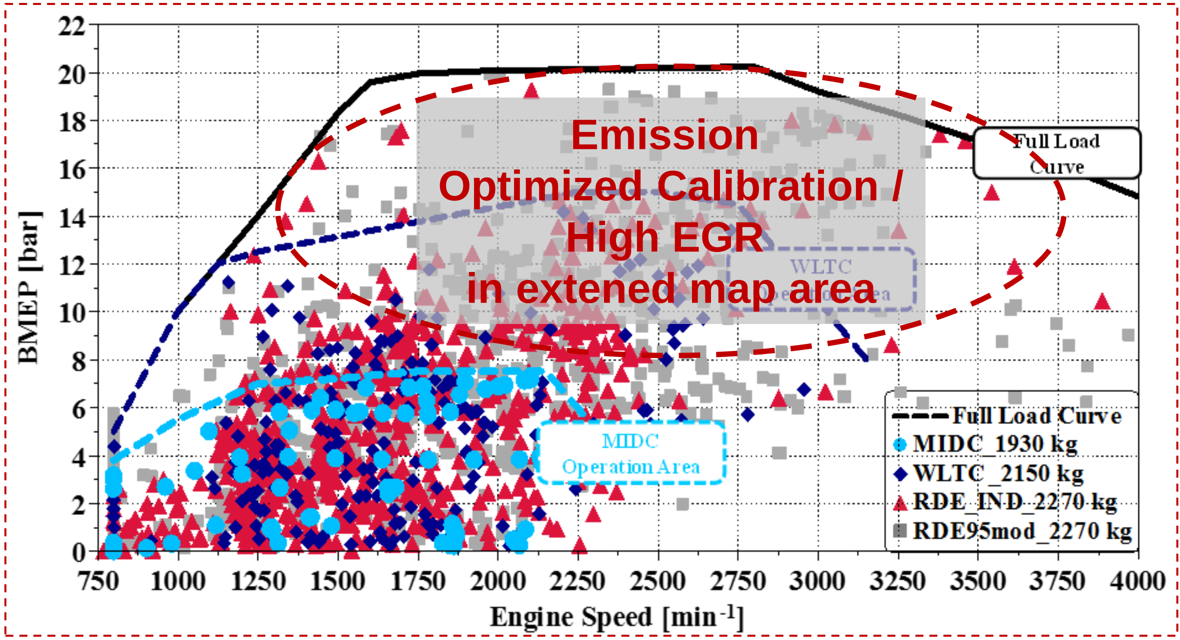
# Test Cycles

## SUV APPLICATION

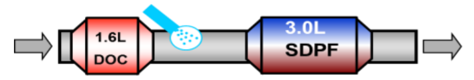
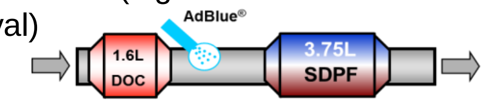
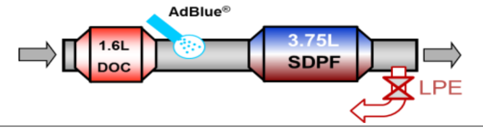
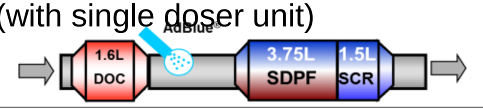



- **MIDC** represents more of the stationary conditions with a high low load/low speed driving (with high idle phase) & **WLTC** is high transient with max. speed 130 kmph
- **RDE-IND** was generated by running the vehicle in a cosmopolitan city considering key regulatory requirements such as: *Altitude*, *Amb*. *T*, *Trip share*, *acceleration*, *av. speed*, *max speed* etc.
- The **specific cycle work (KJ/km)** comparision wrt **MIDC (IWC:1930 kg):**
  - **WLTC (TM: 2150 kg): ~ 50 % higher**
  - **RDE –IN (TM: 2270 kg): ~ 60 % higher**
  - **RDE-95 mod (TM: 2270 kg): ~ 100 % higher (double)**

# Technical Strategies

## TEST MATRIX: SUV APPLICATION

<table>
<tr><th></th><th>Engine Measures</th><th>EATS* Measures</th></tr>
<tr><td>Baseline Tests<br>(with MIDC BS VI base calibration)</td><td>Impact of driving cycle (WLTC, RDE) on:<br>– NOx (raw and tailpipe) & C.F<br>– Soot Emissions / DPF Regn. Interval<br>– F.E / $CO_2$ emissions</td><td>EATS same as BS VI MIDC (year 2020)<br><br></td></tr>
<tr><td>Case Study - A<br>(step towards BS VI RDE)</td><td>Reducing the engine out NOx<br>■ Extension of the HP EGR upto Full Load<br>■ Enhanced EGR Cooler Capacity (~ 25%)</td><td>Bigger SDPF (higher NOx conv. Eff. and regn. Interval)<br><br></td></tr>
<tr><td>Case Study – B<br>(step towards BS VI RDE)</td><td>Further minimization of engine out NOx<br>■ Implementation of cooled LP EGR<br>■ Uncooled HP EGR</td><td>with Low Pressure EGR<br><br></td></tr>
<tr><td>Case Study – C<br>(step towards BS VI RDE)</td><td>Engine calibration same as case study - A<br><br>Potential of elimintation of LP EGR system (Cost / Robustness)</td><td>Enhanced SCR functionality using the passive SCR (with single doser unit)<br><br></td></tr>
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***EATS**: Exhaust Gas Aftertreatment System

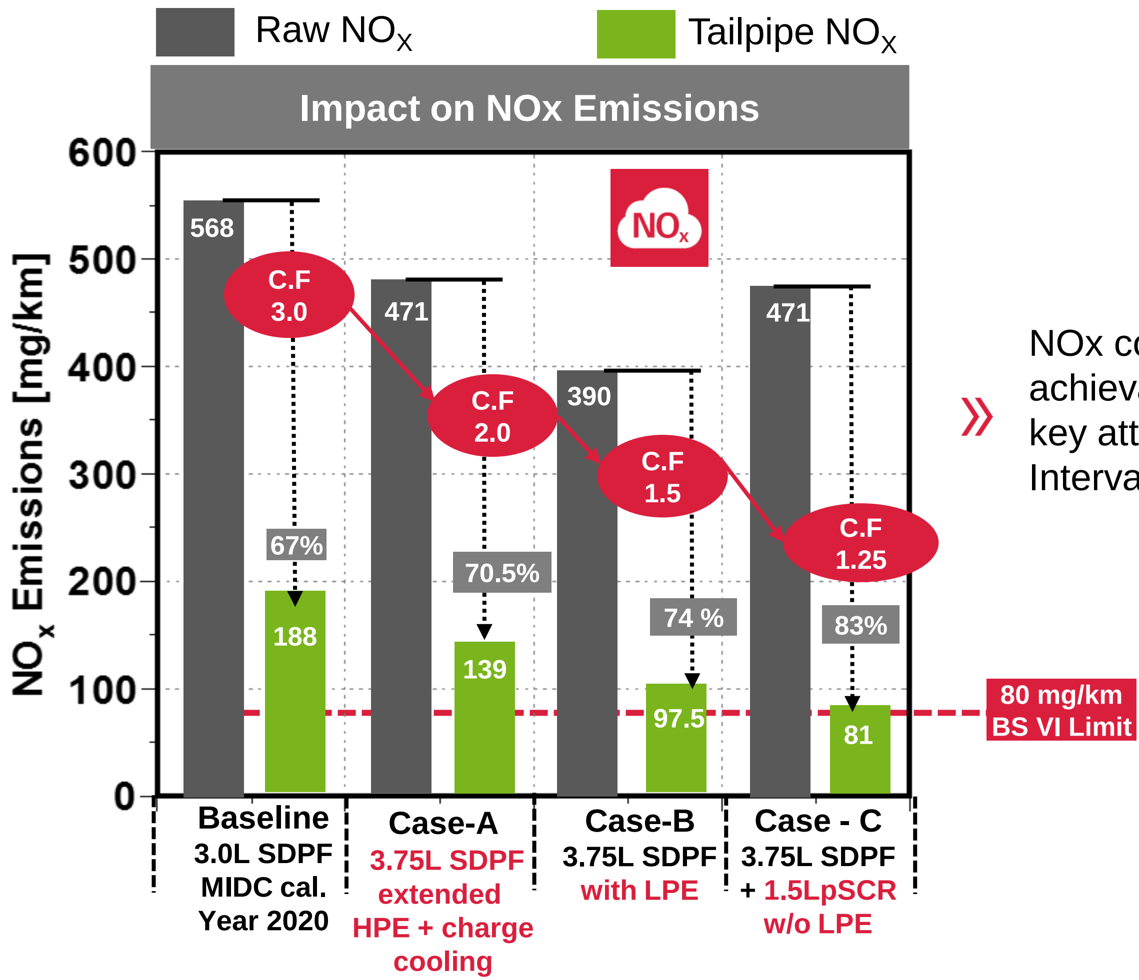
Note: the conversion perf. of EATS corresponds to **~ 160,000 kms aged system**



# Key Results – Indian Real Driving Cycle

## TEST RESULTS: SUV APPLICATION

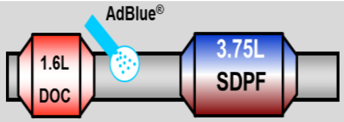
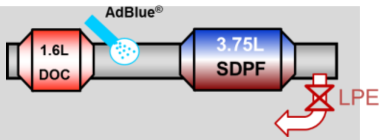
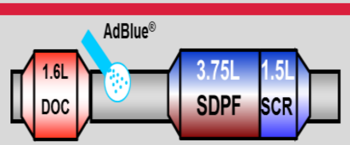



» NOx conformity factor (C.F) ~ 1.25 is achievable in RDE, while still satisfying other key attributes like fuel economy, DPF Regn. Intervals and performance, etc.

# Summary – Comparative Analyses of different path ways

## SUV APPLICATION

| | Technology Measures / EATS | Low T | High T | NOx – C.F | CO2 / F.E | AdBlue | Sensitivity to Fuel Quality | Complexity / Robustness | System Costs |
|---|---|---|---|---|---|---|---|---|---|
| Case – A DOC+SDPF |  | + | + | - | + | + | 0 | + + | + + |
| Case – B DOC+SDPF |  | + | + | + | + + | - - | - | - | - - |
| Case – C added pSCR |  | + | + + | + + | + + | + | 0 | + + | + |

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# HJS's Capabilities Overview

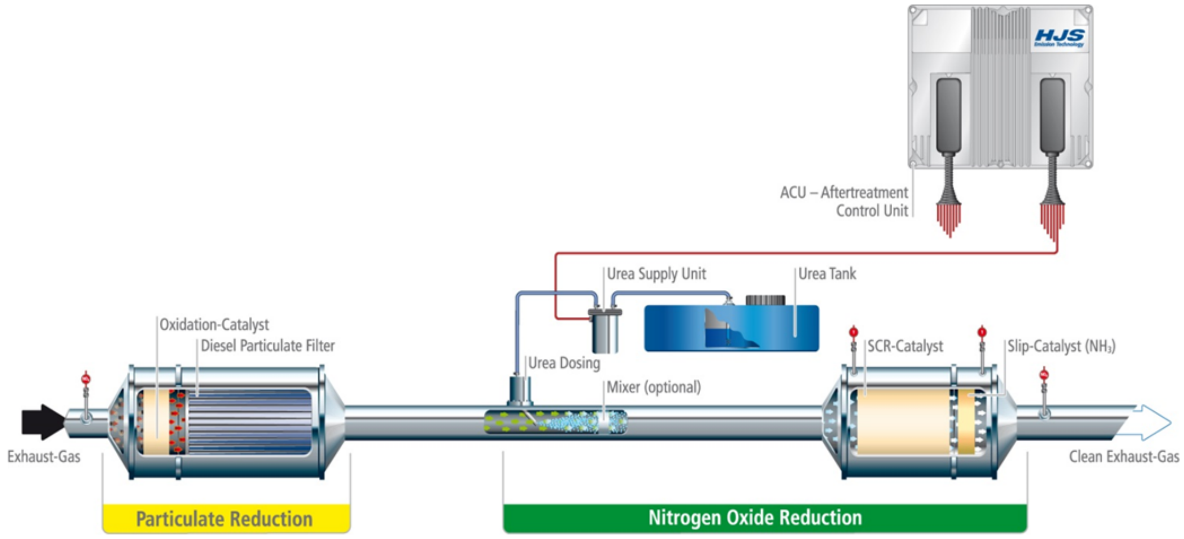
HJS EXHAUST GAS TREATMENT TECHNOLOGY FOR MEETING EMISSION LEVELS IN INDIA

- HJS specialises in Sinter metal filter (SMF) to filter PM/PN
- Partial SMF filters from HJS are being used in the Indian market for BS IV applications
- **Now, HJS brings you the closed SMF to meet BS VI emission legislation!**

# HJS System layout for typical heavy duty application

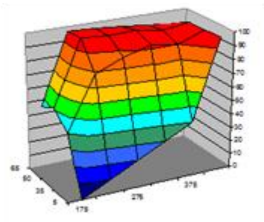
## TECHNICAL SOLUTION FOR BS VI LEGISLATION REQUIREMENTS

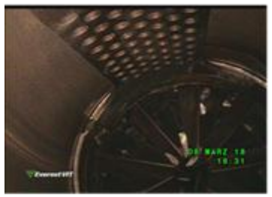



- **DOC:** for active and passive regeneration → increase of temperature by fuel dosing or/and measures
- **DPF:** to achieve PN / PM requirements, coated to provide NO2/NOx ratio for SCR
- **SCR:** for $NO_x$ reduction → replace Va-cats by Cu-zeolites if active thermal regeneration is planned , slip catalyst
- **ACU:** **HJS A**ftertreatment **C**ontrol **U**nit Complex EATS monitoring & control for OBD II (up to 4,000 parameters)

**>> System set up for BS VI requirements, also available as stand alone solution!**

# HJS's Capabilities Overview





| SCR System Major Development Tasks | HJS Facilities |
|---|---|
| SCR catalyst characterisation | - Catalyst test bench<br>- Engine test bench |
| Check of urea dosing system stability | - Injection test bench<br>- Component test bench |
| Optimisation of urea injection | - CFD calculation<br>- Component test bench |
| Optimisation of ammonia distribution upstream SCR catalyst | - CFD calculation<br>- Component test bench |
| Analysis of deposit formation / secondary emissions | - Chemical lab |
| Sensor layout and verification | - test bench investigations<br>- vehicle tests |
| SCR dosing strategy development | - Rapid prototyping system |
| SCR system calibration | - Off-line calibration<br>- Steady-state & transient test bench<br>- vehicle |
| SCR system verification | - Vehicle chassis roller dyno tests<br>- Vehicle on-road tests |

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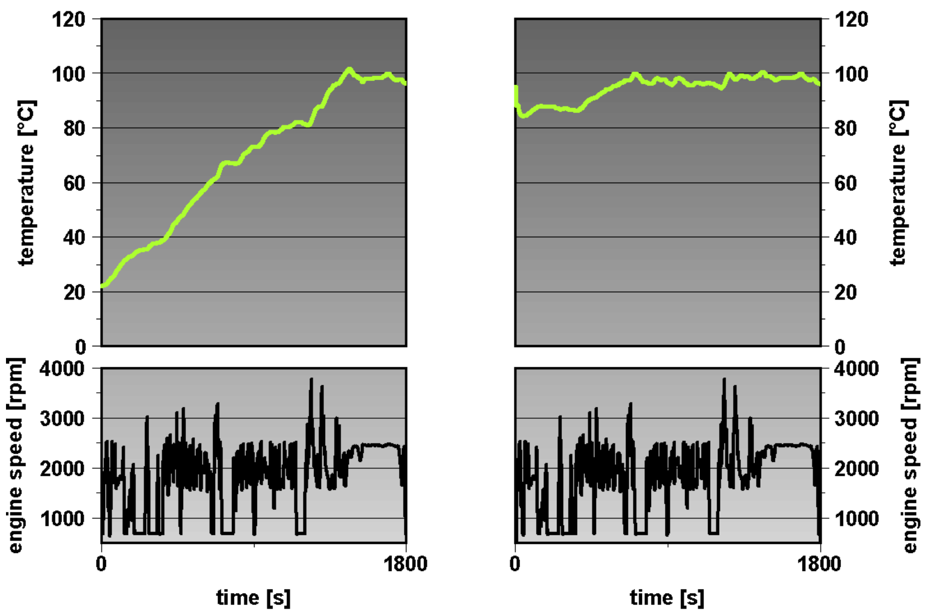
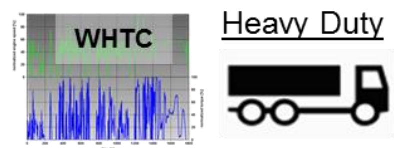
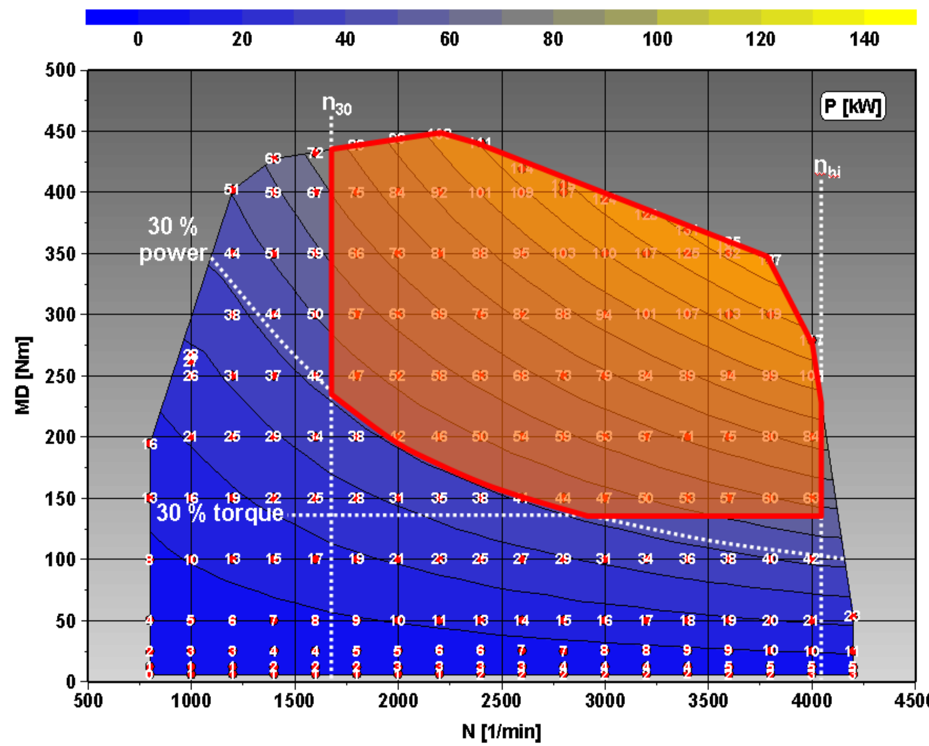
# Heavy duty investigation

## TEST CYCLE OVERVIEW – HEAVY DUTY







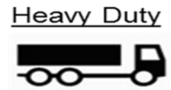





# Heavy duty legislation

## EMISSION LIMITS : WHTC/WHSC




### EURO VI engine emission

| Cycle | CO | THC | NMHC | $CH_4$ | NOx[1] | $NH_3$ | PM mass | PM number[2] |
|---|---|---|---|---|---|---|---|---|
| | mg/kWh | | | | | ppm | mg/kWh | #/kWh |
| **WHSC (CI)** | 1500 | 130 | | | 400 | 10 | 10 | $8 \times 10^{11}$ |
| **WHTC (CI)** | 4000 | 160 | | | 460 | 10 | 10 | $6 \times 10^{11}$ |
| **WHTC (PI)** | 4000 | | 160 | 500 | 460 | 10 | 10 | [3] |

PI = positive ignition

CI = compression ignition

[1] The admissible level of $NO_2$ component in the NOx limit value may be defined at a later stage.

[2] A new measurement procedure shall be introduced before 31 December 2012.

[3] A particle number limit shall be introduced before 31 December 2012.

- weighted average from cold start test and hot start test

$$e = \frac{0.14 \cdot m_{cold} + 0.86 \cdot m_{hot}}{0.14 \cdot W_{act,cold} + 0.86 \cdot W_{act,hot}}$$

- where

| | |
|---|---|
| $m_{cold}$ | emission of cold start test, g/test |
| $M_{hot}$ | emission of hot start test, g/test |
| $W_{act,cold}$ | actual cycle work of cold start test, kWh |
| $W_{act,hot}$ | actual cycle work of hot start test, kWh |



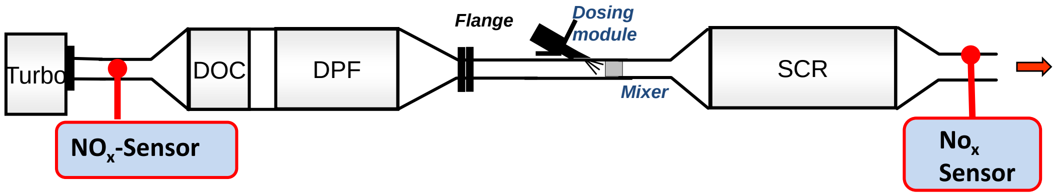
# EATS Investigated layout

## EAS SETUP : HEAVY DUTY APPLICATION

Heavy Duty

**Test Engine : 7.0L Diesel**

- After-treatment system
  - DOC + cDPF + SCR




- Test Cycle : WHTC
- Catalyst Sizes
  - DOC = 6.5 Lit.
  - DPF = 12 Lit.
  - SCR = 19.5 Lit.

- 7.0L class on Road HD Diesel was used for the investigations to meet BS VI legislation
- A classical SCR based EATS was investigated

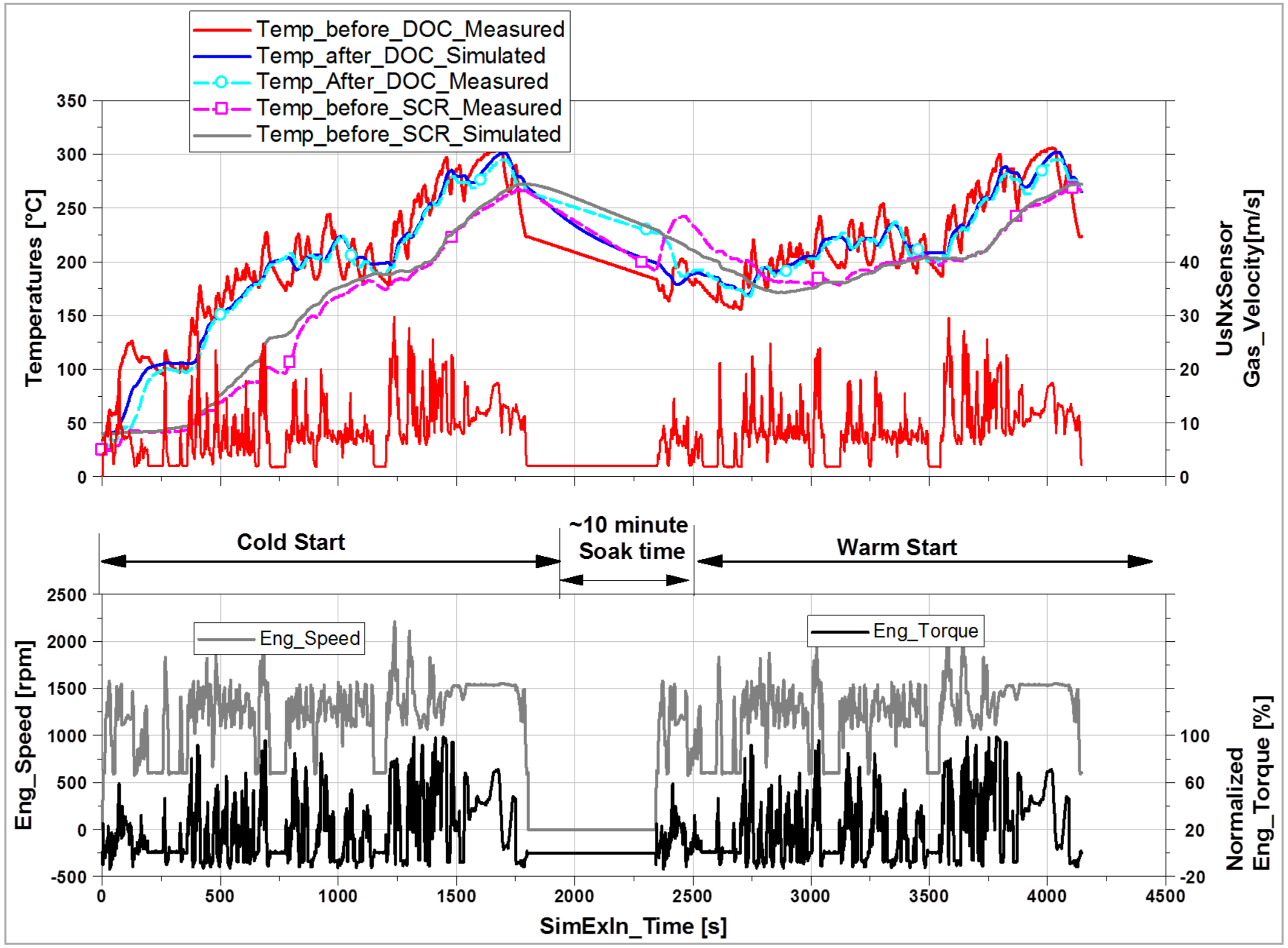


# Key Results – Temperature model validation

Heavy Duty

## WHTC : BASE MODEL SETUP – EXHAUST TEMPERATURE VALIDATION

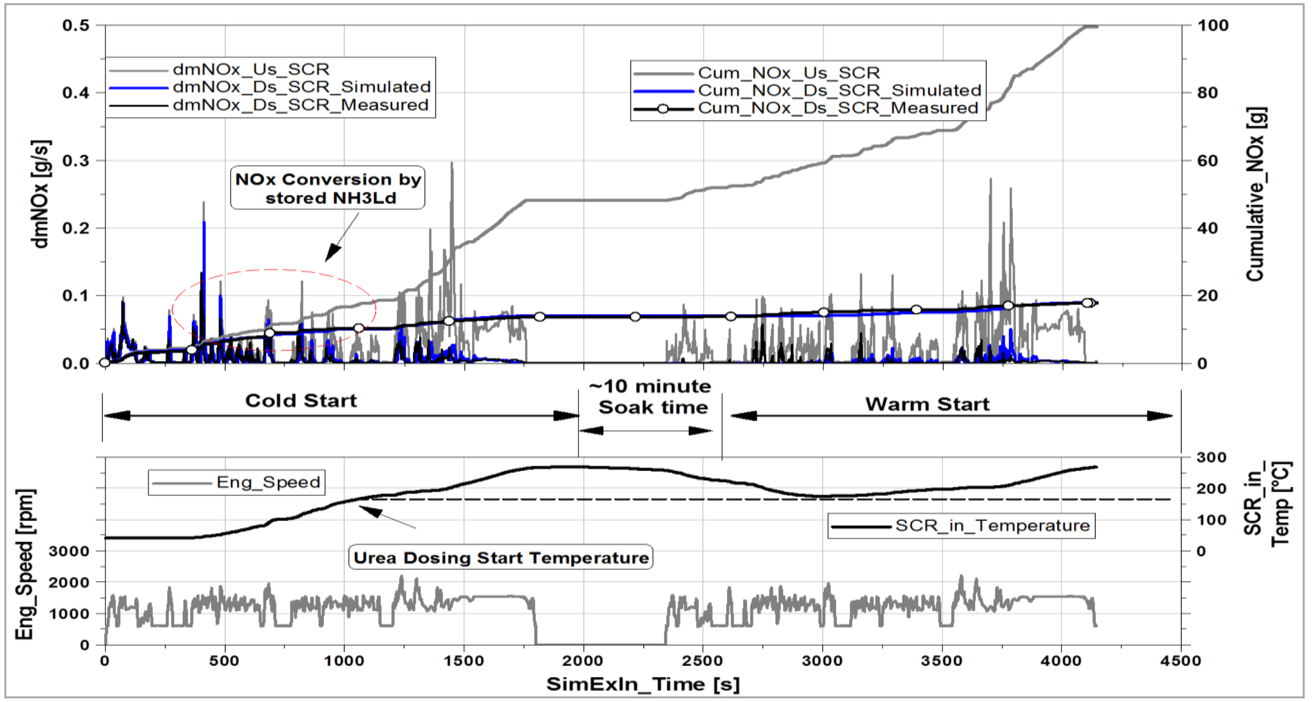



- SimEx temperature model was validated against measured WHTC temperature traces at different positions in the exhaust system.
- SimEx temperature profiles corresponds very well with the measured profiles at the engine test bench.
- The validated model results correspond well with the engine bench measurements

# Key Results – NOx tailpipe validation

Heavy Duty

## WHTC : VALIDATION OF NOX CONVERSION MODEL




| Raw NOx g/kWh | $Tp\_NO_x$ g/kWh | $\eta_{scr}$ % |
|---|---|---|
| Weighted | Weighted | 89.5% |
| 3.52 | 0.36 | |

- The exhaust after treatment system was calibrated to meet the WHTC cycle emission legislation for NOx emissions (EU 6 Limit: 0.46 g/kWh).
- With an engineering target set at ~ 80% of the legal obligation the emission target, the set-up was calibrated to give Tail pipe NOx of ~ 0.36 g/kWh
- The simulated NOx emissions show a good correspondence w.r.t the measured tailpipe NOx traces

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# Summary and Outlook

- Diesel engines offer substantial potential concerning global $CO_2$ reduction strategies while meeting stringent local air quality requirements worldwide
- Based on the passenger car optimized results, it could be concluded that a base BS VI MIDC engine can be upgraded for robust RDE compliance with C.F ≤ 1.25  (the final aim is to achieve C.F <1), while keeping the F.E / $CO_2$ at lowest level.
- With regards to heavy duty application, It was demonstrated that FEV´s powertrain simulation tool-chain along with HJS´s well engineered SCR based exhaust after-treatment systems could enable robust BSVI emission compliance.
- Thanks to the advanced, model-based, rule-governed and interlinked SW functionalities, as the key for maximal usage of individual emission control related sub-system capabilities ( □ optimal system layout with lowest dev. costs & time)
- Depending upon the local conditions & application specific boundaries, a combination of several innovative technologies is possible to meet legal compliances and performance requirements