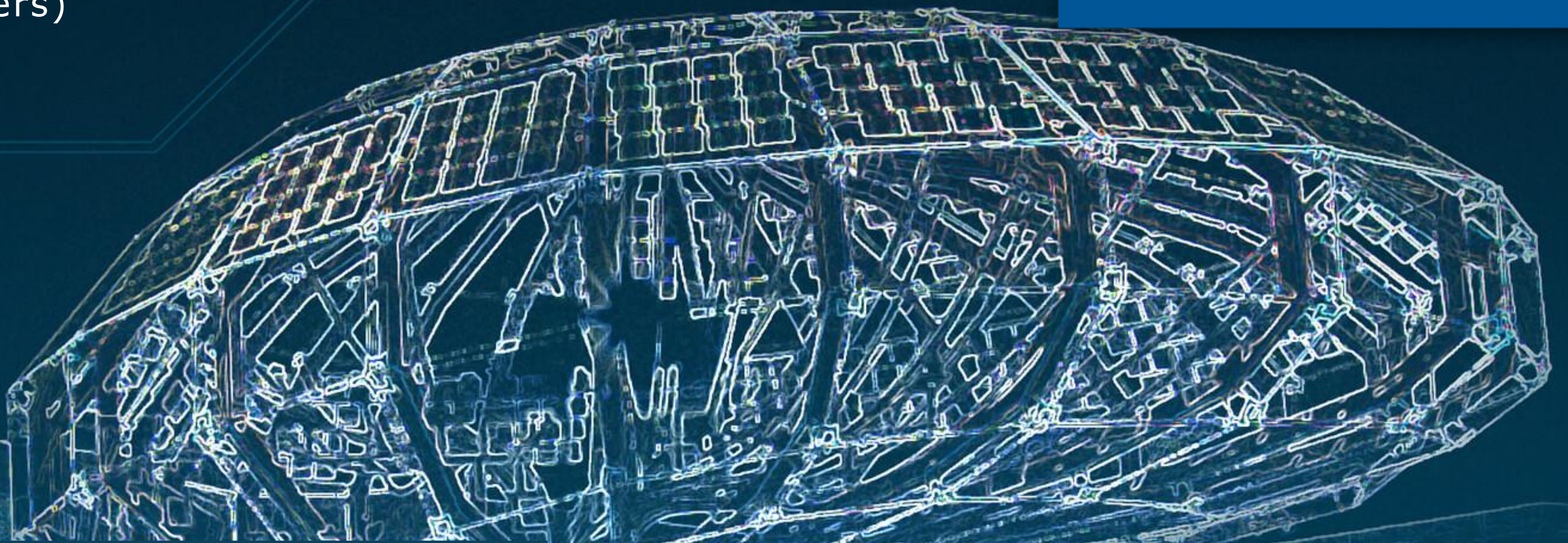
AVL List GmbH (Headquarters)



Bharat Stage VI Emission Challenges

Transition from test bed to real world vehicle emission compliance

Kusumba, Manoj
Graf, Gernot

Enterprise Development Automotive

RESEARCH 10%
of turnover in-house R&D

INNOVATION 1500
granted patents

STAFF

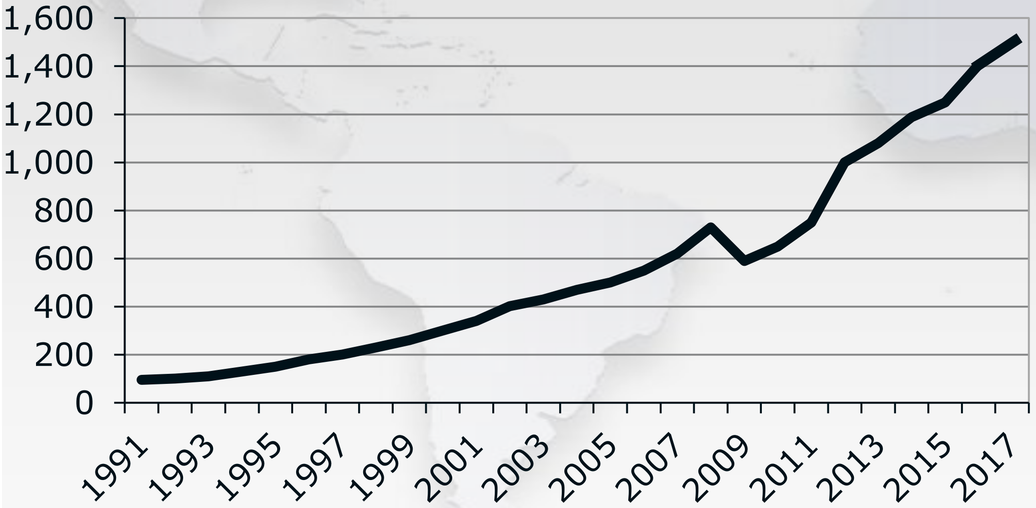
9.500 employees

65% engineers and scientists

GLOBAL FOOTPRINT

30 engineering locations
- **>220** testbeds
- Global customer support network

GROWTH



SALES

1995:
0.15 billion €

2017:
1.55 billion €

Plan 2018:
1.71 billion €

EXPERIENCE
70 years !

5 powertrain elements

ONE
PARTNER

AVL Powertrain –
A Network Of Technical Centers



HQ Graz, **AUT**


Steyr, **AUT**

Graz, **AUT**


Budapest, **HUN**


Paris, **FRA**


Reggio Emilia**, ITA**


Neuenstadt, **GER**


Regensburg, **GER**


Remscheid, **GER**


Munich, **GER**


Södertälje,**SWE**


Istanbul, **TUR**


Basildon, **UK**


Coventry, **UK**


Ingolstadt, **GER**


Stuttgart, **GER**


Gotenborg, **SWE**


Haninge, **SWE**

Europe
Austria*
France
Germany
Great Britain
Italy

Hungary
Sweden
Turkey


Plymouth, **USA**

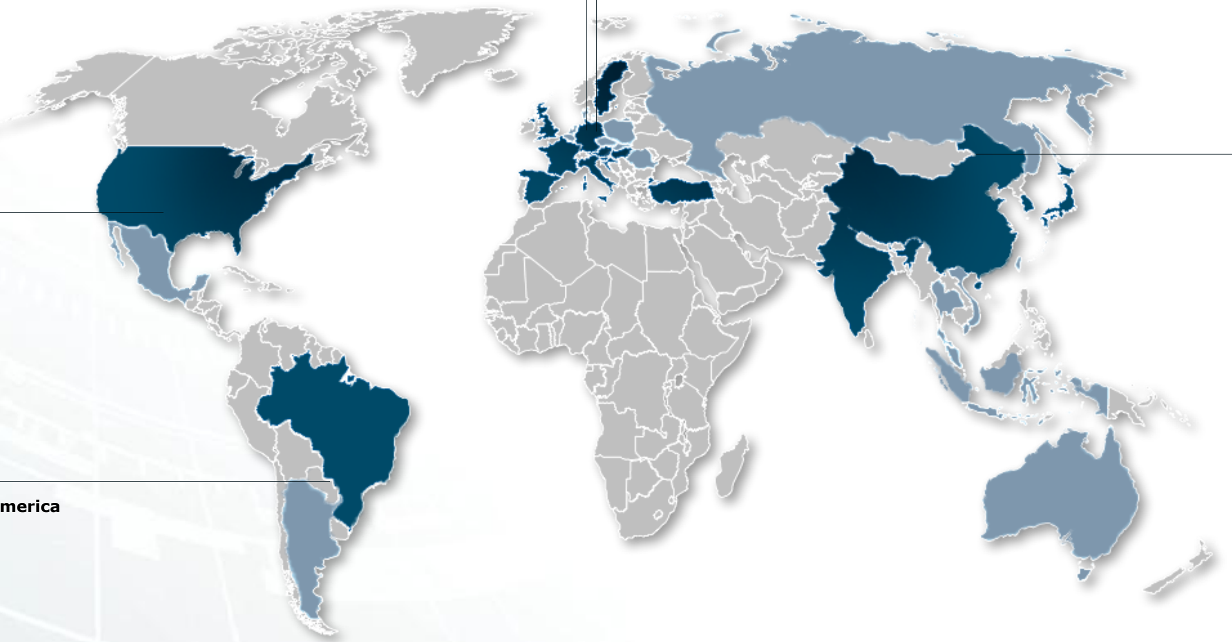
Lake Forest, **USA**


Ann Arbor, **USA**


Sao Paulo, **BRA**

North America
USA

South America
Brazil



Asia
China
India
Japan
Korea

Delhi-Gurgaon, **IND**


Shanghai, **CHN**


Tianjin, **CHN**


Seoul, **KOR**


Tokyo, **JPN**

+ another
13 Engineering
Offices

*Headquarters in Graz

- Legislative Requirements
- Boundary conditions in India
- Implications on Engine and Aftertreatment layout
- Technical trends

Bharat Stage VI Challenges

Cold transient test, to be considered with weighting factors for Hot & Cold test cycles

Wider engine map and non standard ambient conditions covered

Test Cycle operating points in real world speed area

ISC – Real Driving Emission (until end of useful life)

Bharat Stage VI 2020 (2023) – Overview

<table>
<tr><th>Parameter</th><th>Content</th><th>Remarks</th></tr>
<tr><td>Emission limits</td><td>

	CO (g/kWh)	THC (g/kWh)	NOx (g/kWh)	NH_3 (ppm)	PM (g/kWh)	PN (#)
WHSC	1.50	0.13	0.40	10	0.01	$8.0 * 10^{11}$
WHTC	4.00	0.16	0.46	10	0.01	$6.0 * 10^{11}$
WNTE*	2.00	0.22	0.60	-	0.016	-

</td><td>Test procedures according to draft AIS 137 as on 1 Jan. 2017.

* Under various ambient conditions</td></tr>
<tr><td>Deterioration factors</td><td>

	CO	THC	NOx	NH_3	PM	PN
WHSC/ WHTC	1.3	1.3	1.15	1.0	1.05	1.0

Useful life: 700.000 / 300.000 / 160.000 km
</td><td>Alternatively min. service accumulation period (km):
160,000: N1 & M2 vehicles
188,000: N2, N3<16T, M3<7.5T
233,000: N3>16T, M3>7.5T</td></tr>
<tr><td>OBD limits</td><td>

NOx (g/kWh)	PM (g/kWh)
1.5 (1.2)	Performance Monitoring (0.025)

</td><td>Including malfunction classification</td></tr>
<tr><td>In Service Conformity (ISC)</td><td>At type approval – emission measurements on vehicle using PEMS shall be carried out for data collection (CF CO, THC and NOx not for PM/PN)</td><td>CF factor tbd for 2023</td></tr>
<tr><td>$IUPR_m$</td><td>- (0.1)</td><td>OBD relevant, not applicable</td></tr>
</table>

Legislative Requirements

Boundary conditions in India

Implications on Engine and Aftertreatment layout

Technical trends

INDIA Climate Requirements

Proposed WNTE Requirements

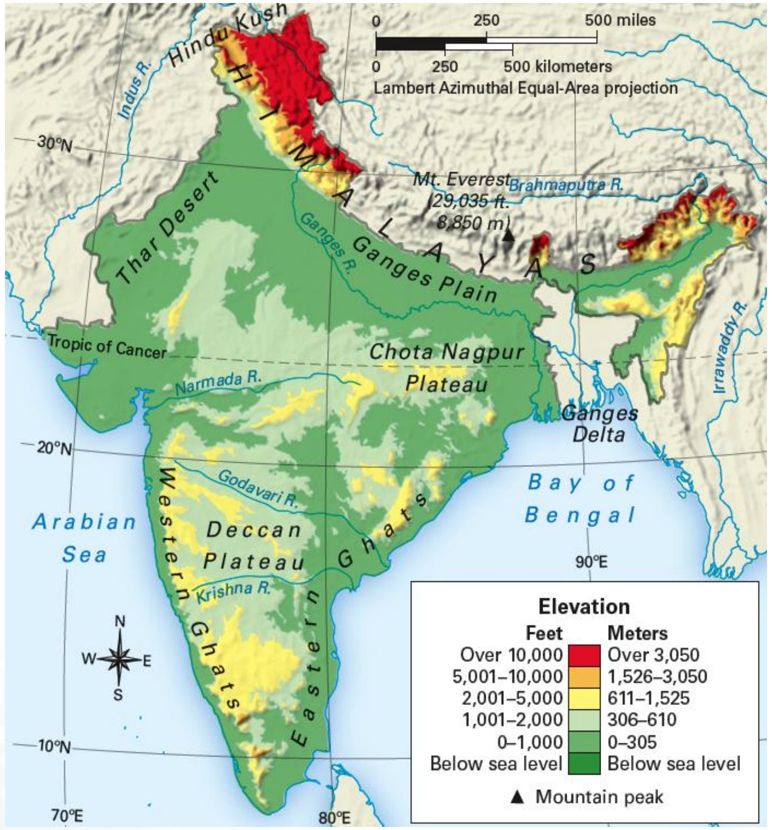
Ambient conditions:

Altitude up to **~1680m**
Temperature ≥ **-7°C**
Temperature ≤ 38°C (at sea level)

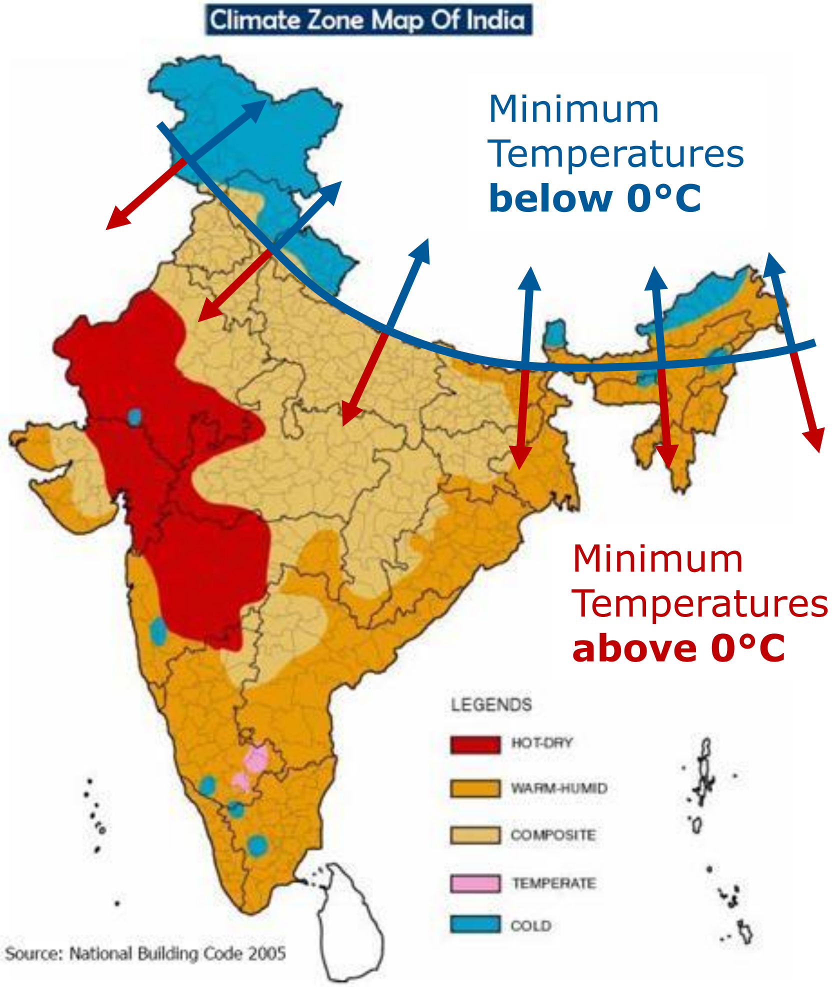
Requirement for demonstration:
Part of certification
Test bed data (3 grids)

AVL Climate test bed

Altitude

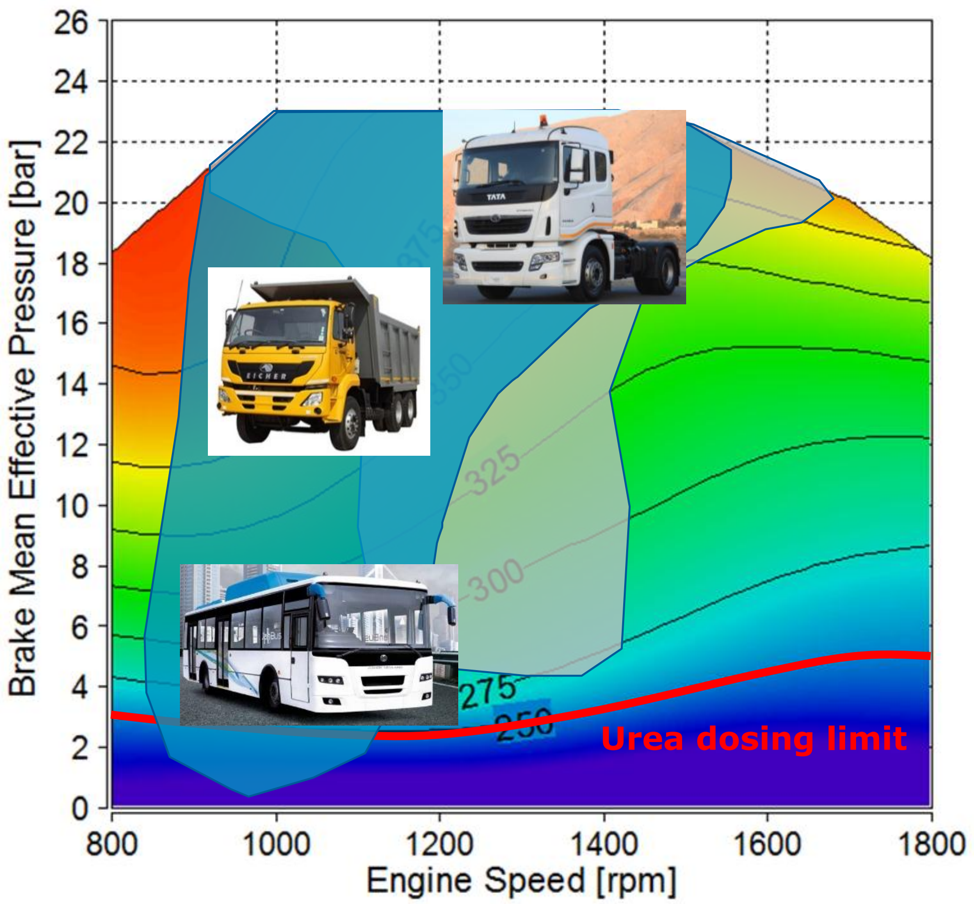


Temperature distribution



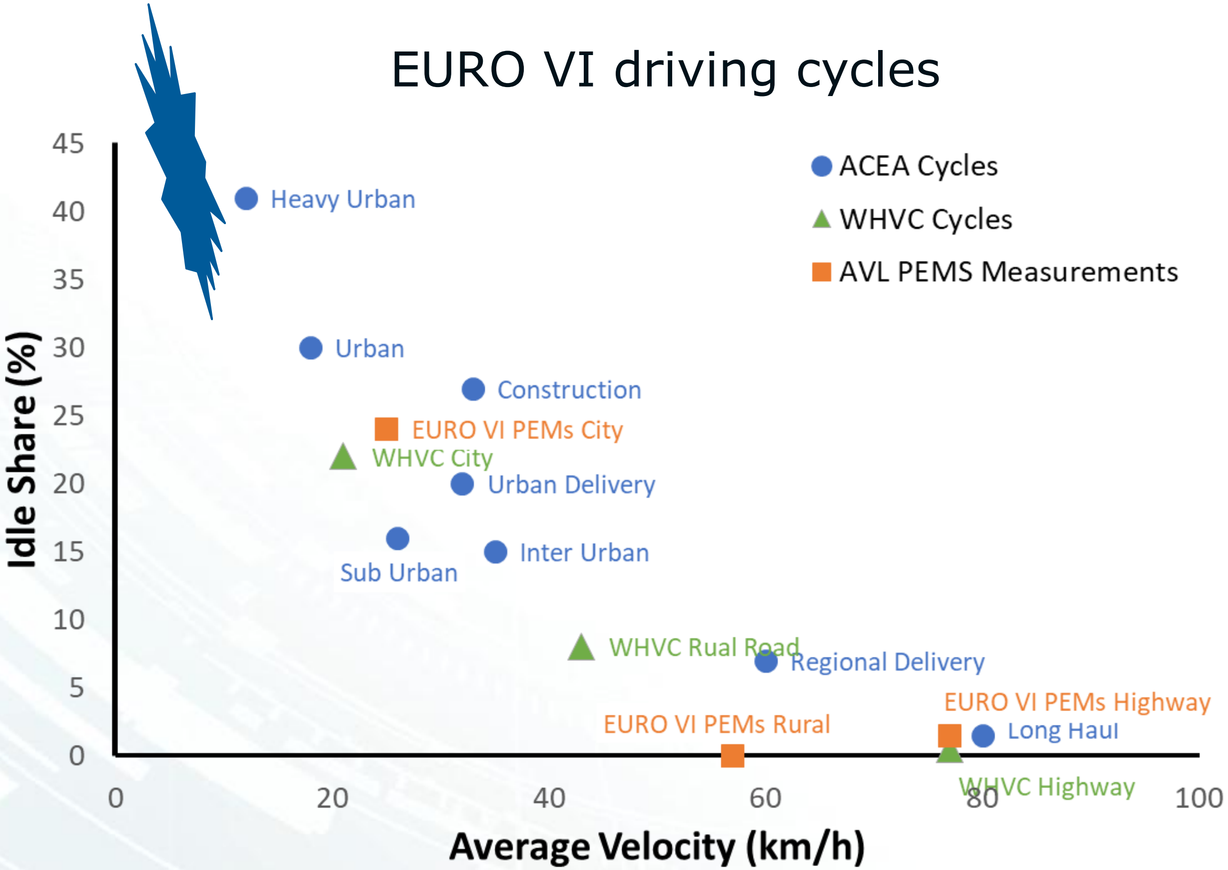
Typical Indian Applications

Exhaust Temperature Map [°C]



- Low heat rejection potential at high ambient temperatures and overload
- One engine to cover all applications and duty cycles
- India service network
- Considering temporary use of high sulfur fuels

Driving cycles



Bangalore traffic trend

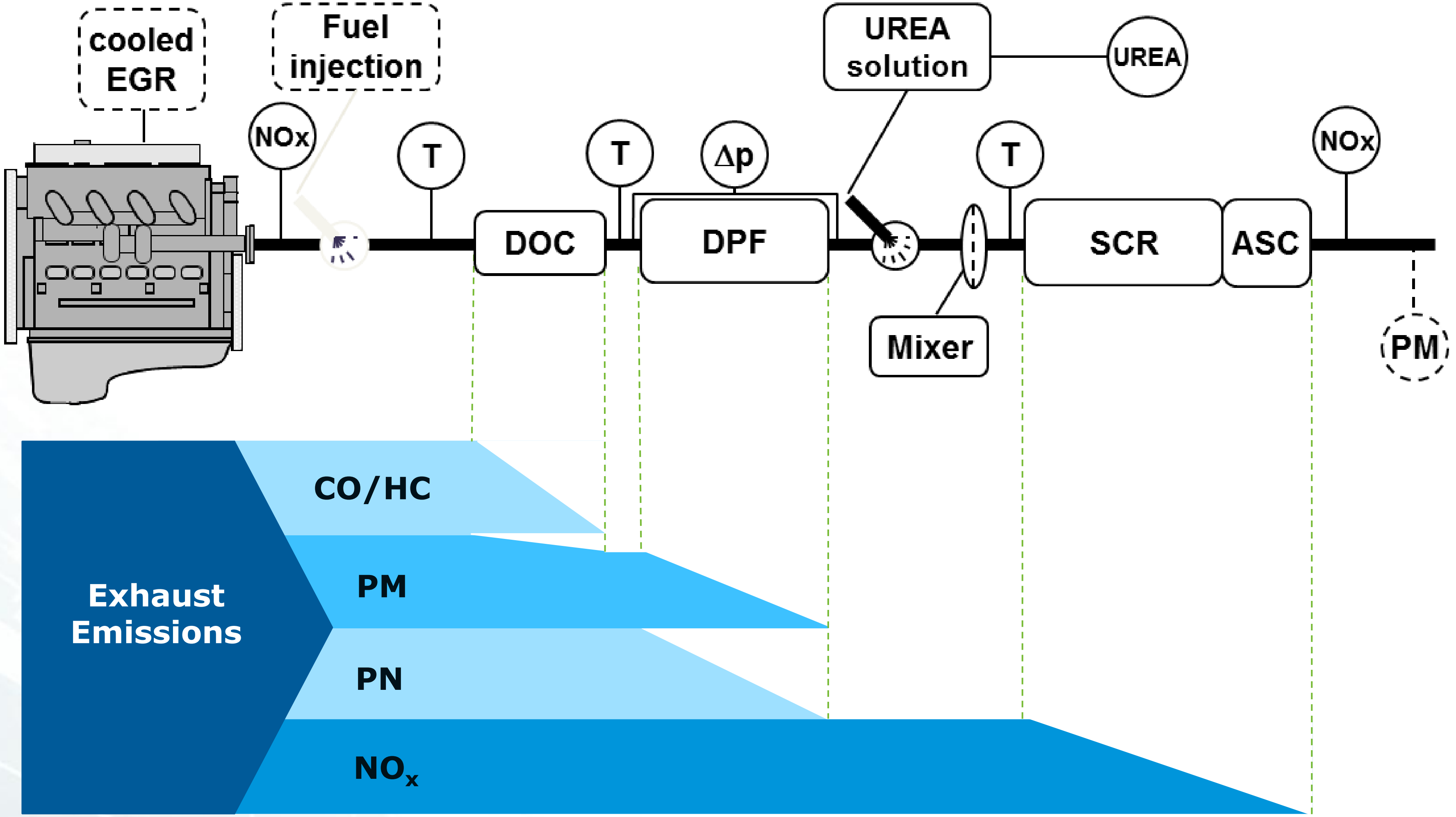
AVERAGE SPEED OF VEHICLES IN CITY

35 kmph	2005
20 kmph	2010
10 kmph	2014
7 kmph	2014
On MG Road (20 kmph in 2010)	
5 kmph	2020 (expected)

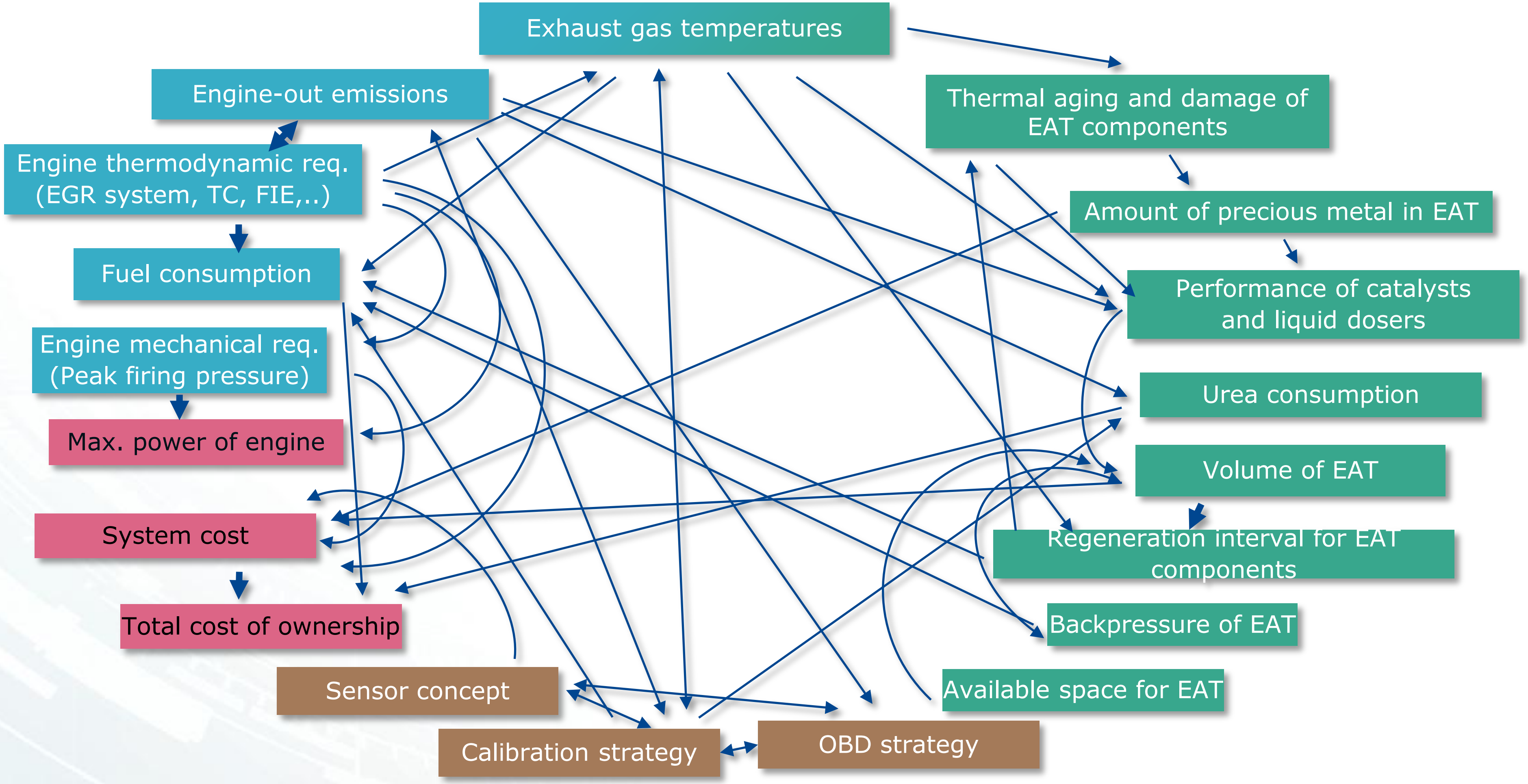
Traffic conditions in India differ from Europe. Therefore the boundary conditions for the EAS layout are significantly different between EURO VI and BS VI.

- Legislative Requirements
- Boundary conditions in India
- Implications on Engine and Aftertreatment layout
- Technical trends

Overview of Emission reduction path in the exhaust system



Mutual dependencies between Engine and EAS FOR BS VI application

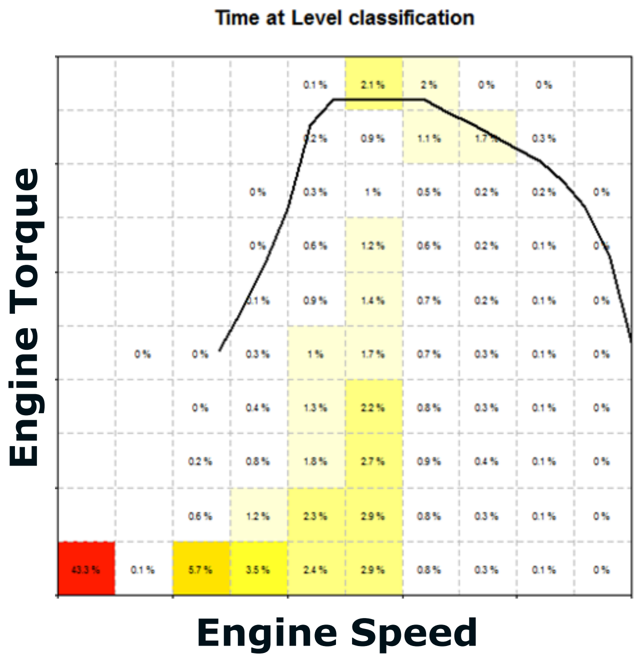


A system approach is mandatory in order to find the optimum balance between conflicting targets. A separated optimization of engine and EAS leads to sub-optimal system results.

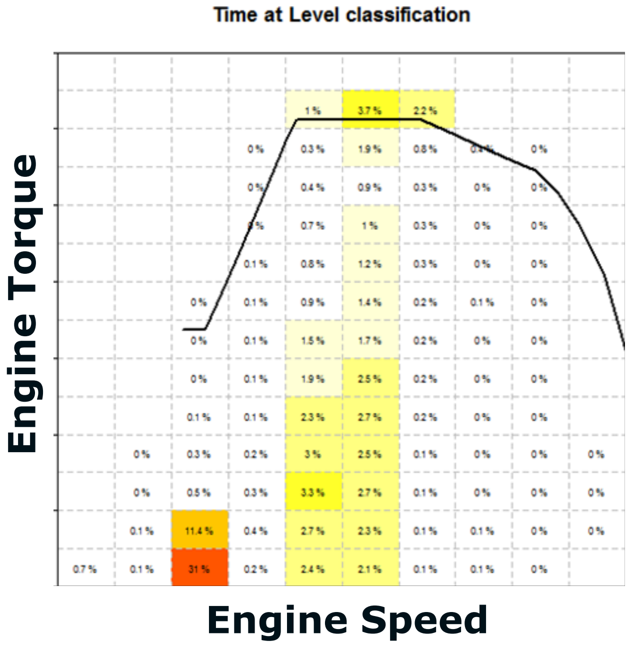
Influence of Duty cycle on exhaust temperature

AVL

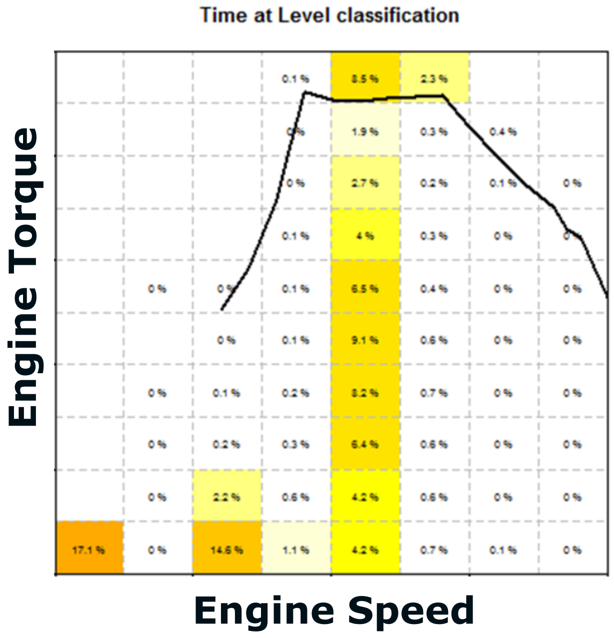
City Bus



Urban Transportation

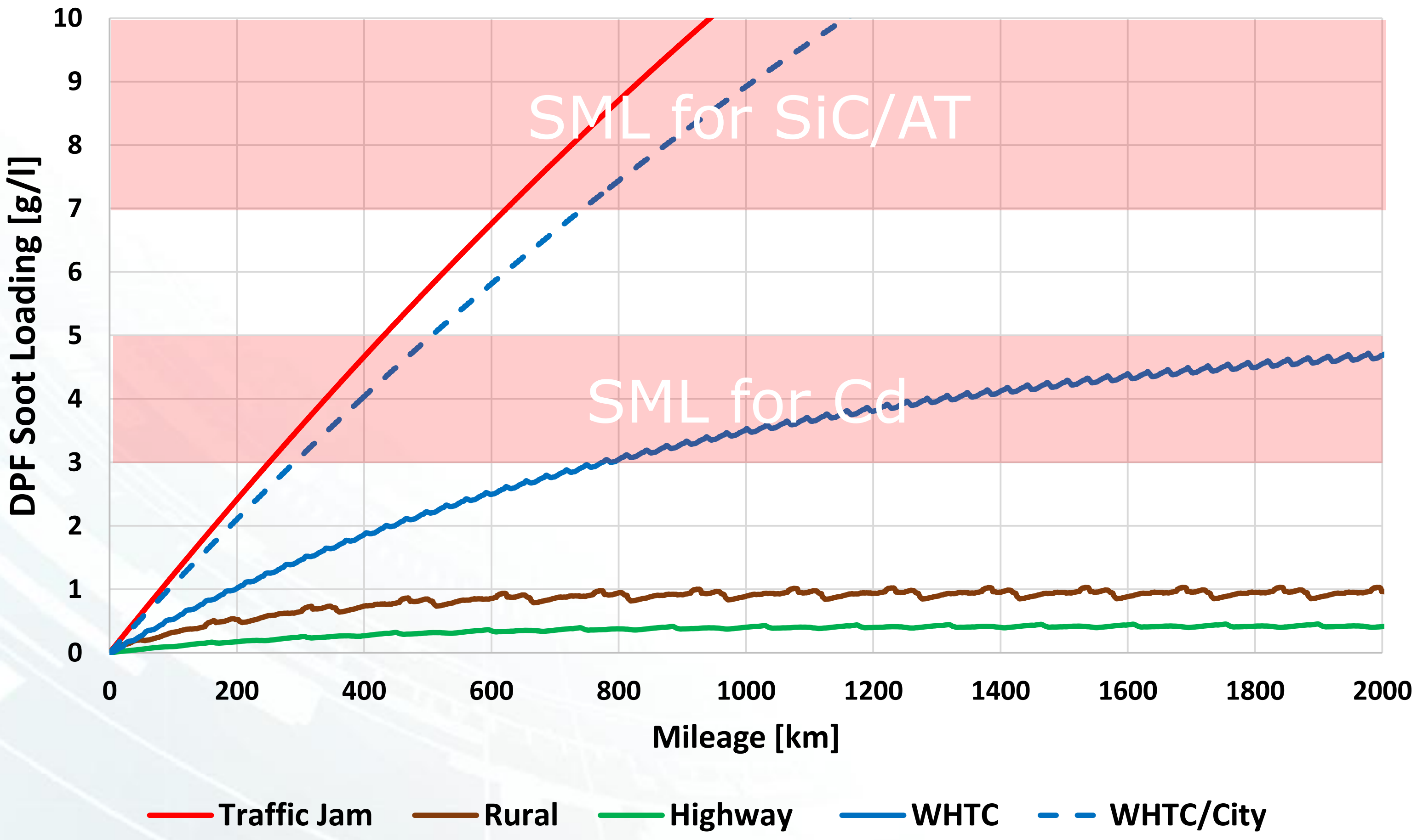


Highway Transportation



Exhaust Temperature in Duty Cycle

DPF soot loading of reference LCV engine in different load cycles



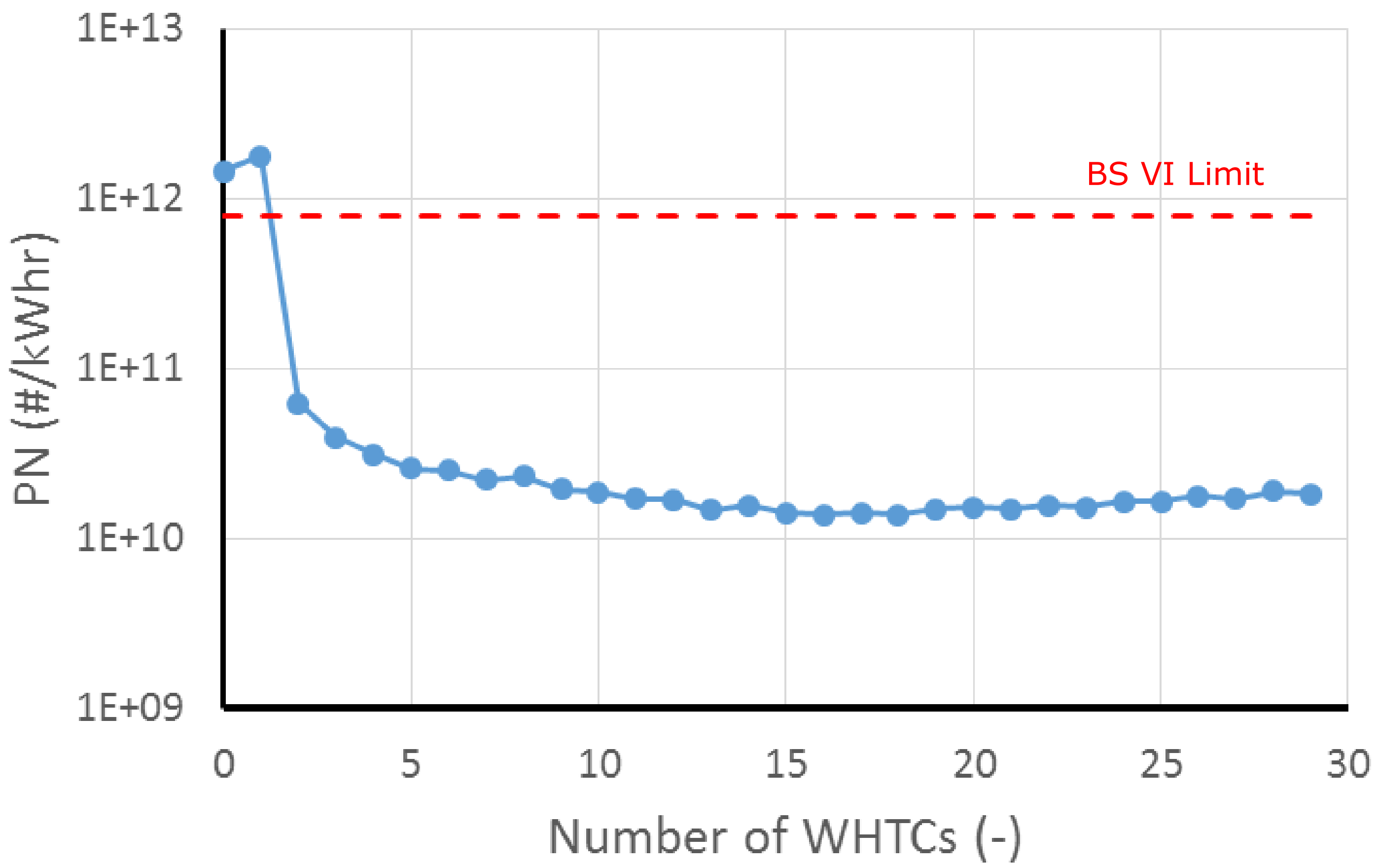
Strong dependency of DPF soot loading on driving profile.

DPF regeneration frequency has impact on:

- Fuel consumption
- HC doser application
- Oil change interval
- Catalyst ageing
- DOC, DPF & SCR coating selection
- Urea deposit formation

DPF regeneration frequency at WHTC might differ significantly from target application.

PN Number limit



DPF is mandatory for fulfilling PN targets.

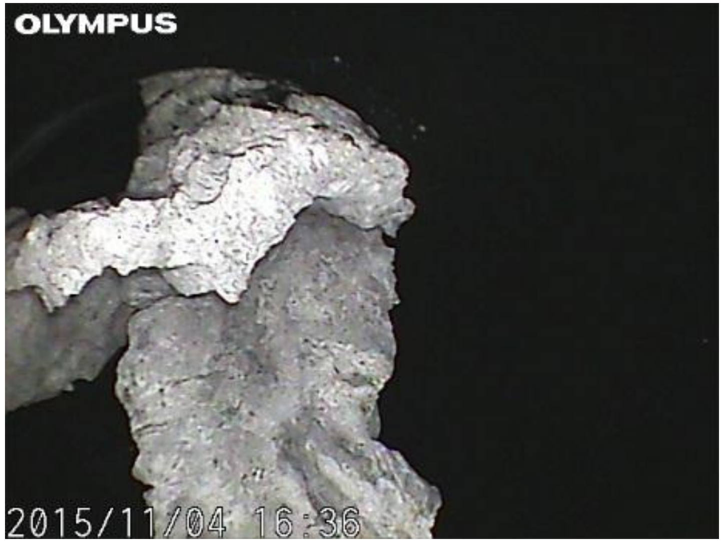
Additionally sufficient soot loading on the DPF is required to achieve PN filtration efficiency.

Open Crankcase ventilation requires specific blow-by oil separation

Urea Deposits

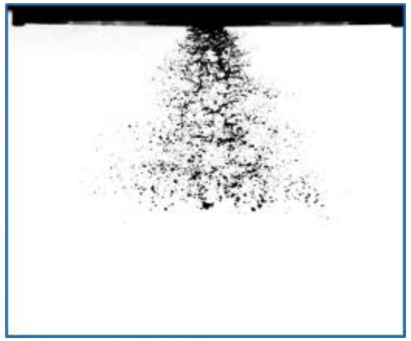
ISC requires reliable urea dosing also in city driving

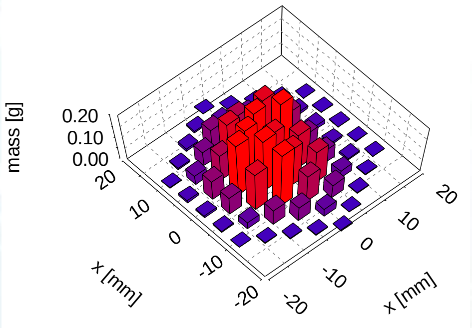
- ISC (PEMS) and WNTE are significantly extending the areas in the engine map were urea dosing is required. –> Dosing start around 180°C is required
- Low exhaust temperatures are critical for deposit build
- Smart mixer design which avoid deposit build up are required
- Further engine thermal measures needs to be applied in order to avoid deposits



Optimization of NH_3 generation

Flow Rig

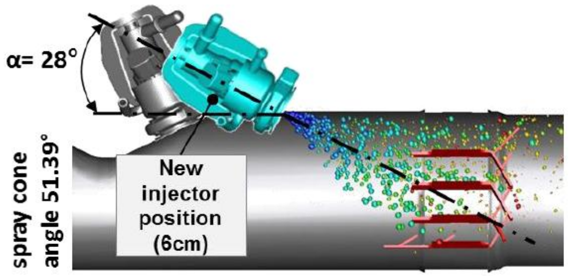


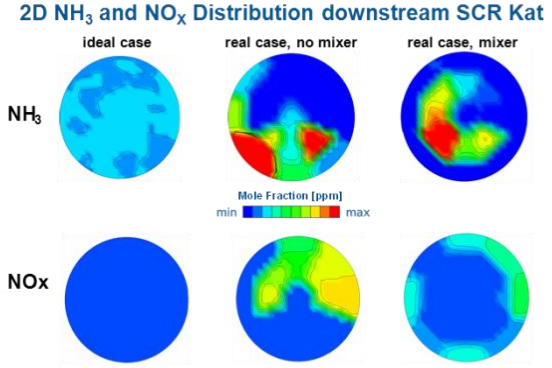


Measurement of:
- AdBlue massflow distribution
- Droplet size distribution
- Droplet velocity

Generation of input data for CFD

CFD Simulation

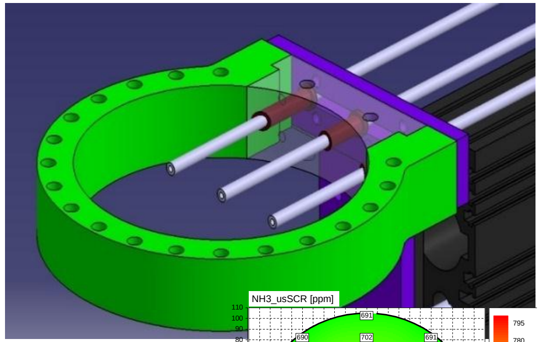




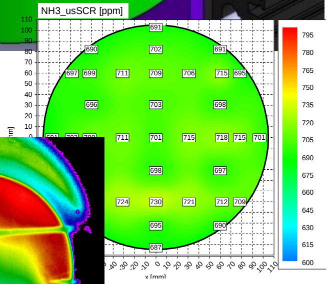
Optimization of:
- EAS backpressure
- Mass flow distribution
- NH3 concentration distribution

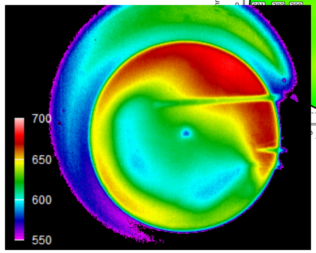
Risk reduction for urea deposit formation

Flow validation



Measurement flange

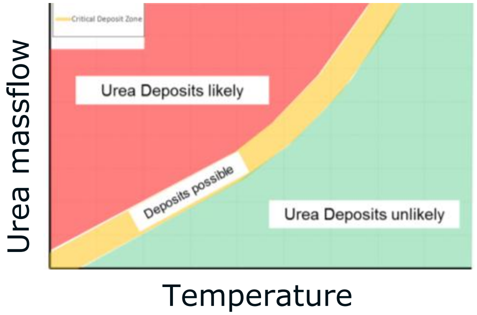


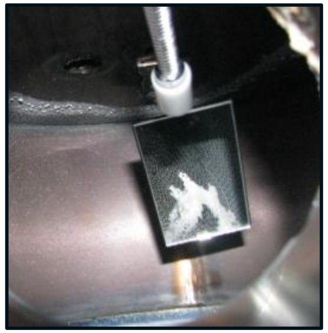


Thermografic measeuments

Validation of:
- NH3 distribution
- Temperature distribution
- Mass flow distribution

Deposit testing





Visual inspection

Identification of critical operation points for deposit formation
Calibration of dosing release conditions
Durability testing in real driving conditions.

EAS Emission validation overview
6 Pillars of EAS Performance validation

STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6
EAS System and Requirements definition	**Synthesis Gas Bench Catalyst testing (fresh and aged)**	**EAS Hardware verification on test bed**	**EAS Hardware validation on test bed**	**EAS System performance prediction**	**Vehicle calibration validation and Fleet monitoring**

STEP 1
- Target vehicles
- Fluids (fuel, AdBlue, oil)
- Markets
- User profiles
- Validation targets
- Aging conditions

…

STEP 2
- Catalyst characterization (e.g. fresh and aged)
- Injector characterization

…

STEP 3
- Functional test (e.g. ammonia UI)
- Legislative cycles
- DPF balance point

…

STEP 4

Low Load runs:
- Calibration Validation (e.g. DPF Soot loading models)
- EAS Failure modes:
  - Urea deposits
  - HC deposits
  - Face plugging

High Load runs:
- Calibration Validation
- EAS Failure modes:
  - Thermal aging
  - Chemical aging

DF runs:
- DF rehearsal

...

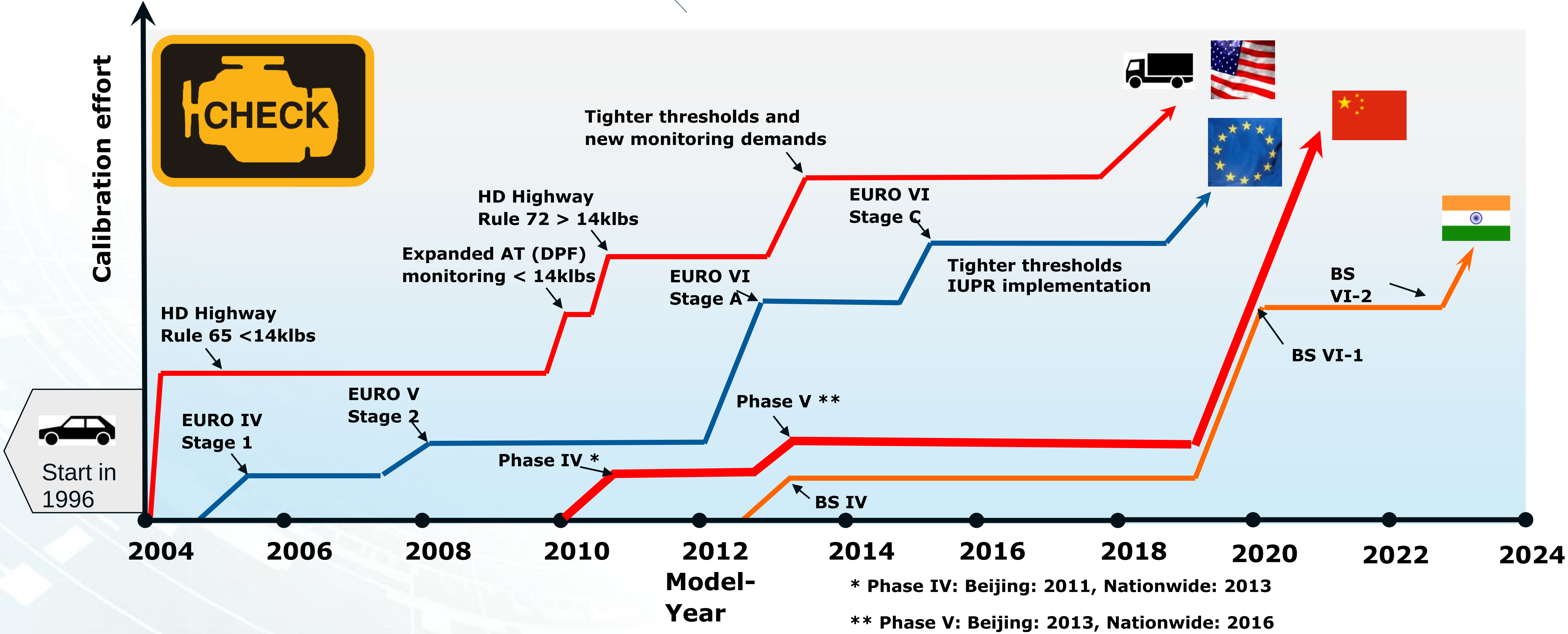
STEP 5
- Thermal Ageing Model
- Chemical Ageing Model
- Prediction of End-of-Life Emission Performance

…

STEP 6
- Vehicle calibration validation testing
- Cold / high altitude trip
- Hot / high altitude trip
- Fleet Validation and failure mode reporting
- Frequent ISM / PEMS measurements

…

Historic Development in OBD Requirements



BS VI represents a big step in OBD requirements compared to BS IV

Legislative Requirements

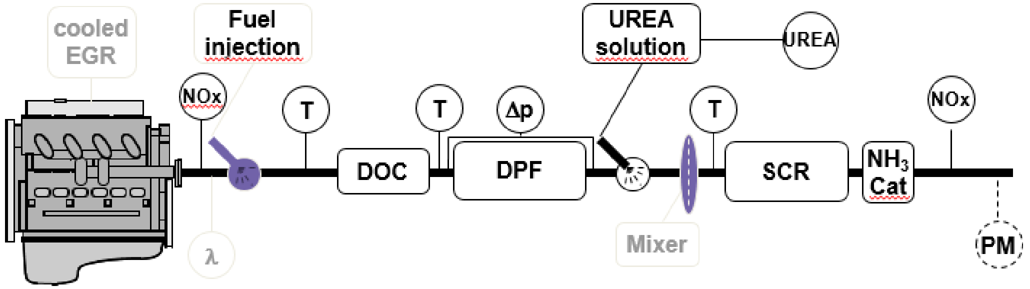
Boundary conditions in India

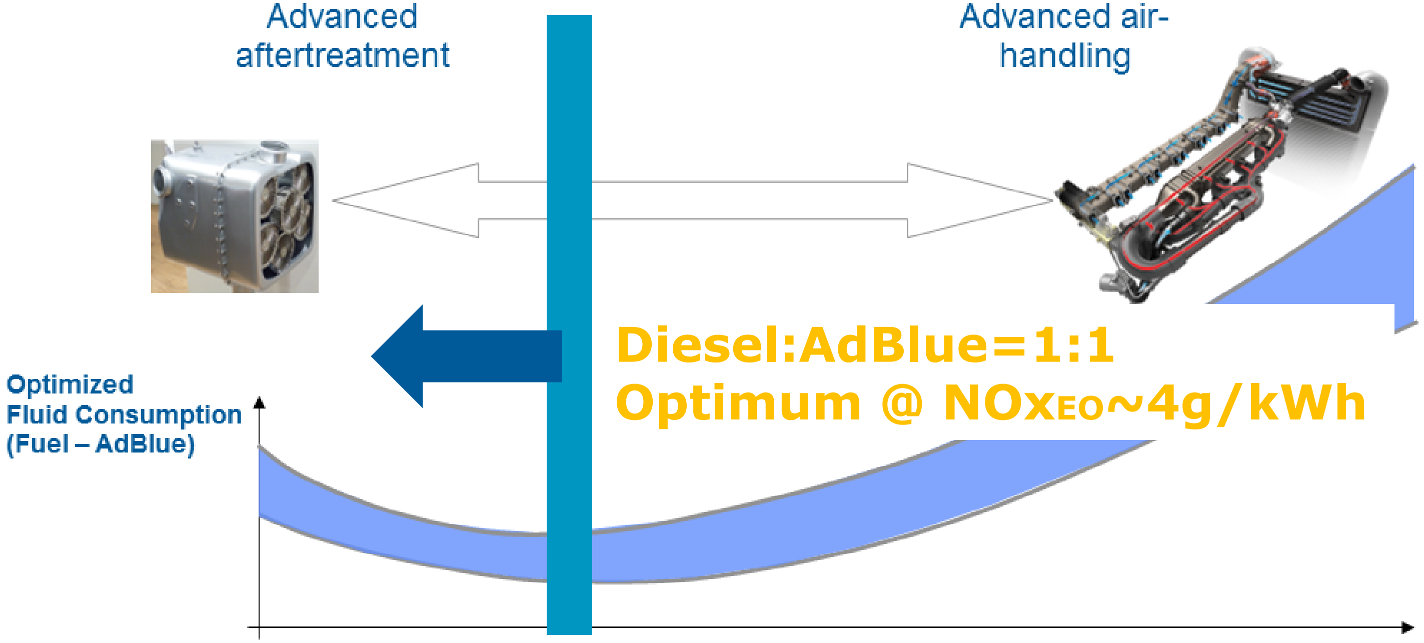
Implications on Engine and Aftertreatment layout

Technical trends

Emission strategies for BSVI

	STRATEGY I	STRATEGY II	STRATEGY III	STRATEGY IV	STRATEGY V
NOx reduction by	SCR only	SCR & EGR	SCR & EGR	SCR & EGR	EGR
PM / PN reduction by	DPF, passive Regeneration	DPF, passive Regeneration	DPF, passive Regeneration	DPF, passive Reg. (DPF, active Regeneration)	DPF, active Regeneration





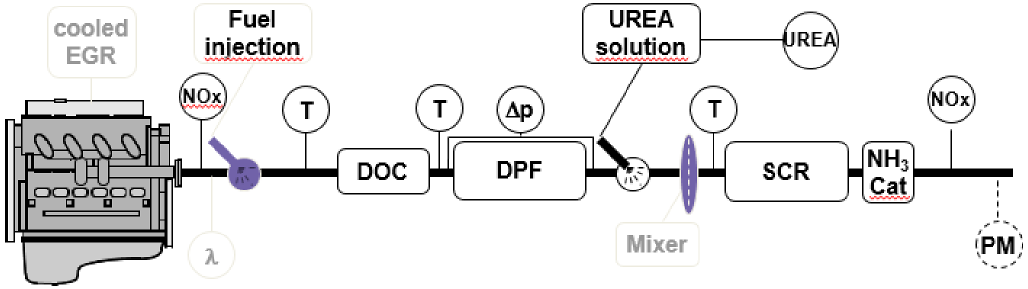
Diesel Price ↑

AdBlue Price ↓

NOxEO ↑

Emission strategies for BSVI

	STRATEGY I	STRATEGY II	STRATEGY III	STRATEGY IV	STRATEGY V
NOx reduction by	SCR only	SCR & EGR	SCR & EGR	SCR & EGR	EGR
PM / PN reduction by	DPF, passive Regeneration	DPF, passive Regeneration	DPF, passive Regeneration	DPF, passive Reg. (DPF, active Regeneration)	DPF, active Regeneration
Required aftertreatment efficiency [%] (weighted hot + cold) for					
NOx [%]	> 97	< 95	< 95	≤ 90	-
PM / PN [%]	~85 / > 99,9	~90 / > 99,9	~92 / > 99,9	~95 / > 99,9	~98 / > 99,9
Engine-out limit²⁾ for: EU 6 NOx WHSC/WHTC = 0,4 / 0,46 g/kWh					
NOx [g/kWh]	8.5	3.5 / 4.5	2.5 / 3.5	1.5 / 2.0	0.3 / 0.4
PM [g/kWh]	< 0.03	< 0.05	< 0.06	< 0.1	~ 0.2
	Challenges: • SCR eff. • applic. variety • temp. managem. • fluid consumpt. • emission durability	advanced SCR efficiency mandatory	main technology route with limited temp. management	conservative technology route w/o temp. management	Challenges: • heat reject. • fuel cons. • trans. NOx • turbocharg. • trans. performance • DPF limits



η_{EATS} ↑↑ (>95%)

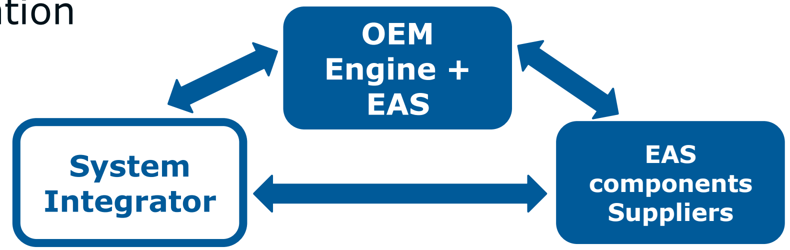
$€_{EATS}$ ↓↓

Less costly, more efficient emissions strategy for India

System engineering
EAS integration

OEM should have full control of complete system, thus includes the EAS integration

- EURO VI / (DOC/DPF/SCR) accounts for up 30% of engine cost
- “Off-The-Shelf” EAS box restricts engine operation
- High knowledge of system interaction is required for smart EAS integration



Benefits of having full control of EAS

- Cost focusing product needs optimization on system level (engine + EAS)
- CO2 reduction takes place on system level
- Flexibility to source component (coating, substrate, dosing,…) from different suppliers (cherry picking)

AVL can take over role of **EAS integrator** to support OEM during BS VI ramp-up

- Highly experienced on System Engineering
- Special EAS Test Facilities (e.g. Synthesis Gas Bench)
- EAS Software Controls Development
- Experience with all suppliers


BS VI emission legislation
AVL
Solutions available