ECMA International Conference

BSVI and Real Driving Emissions

Major Step Towards Cleaner Environment

25th October 2018

K Senthur Pandian

Associate Chief Engineer

Head - Diesel Powertrain

Mahindra and Mahindra Limited

Engine & After Treatment Solutions

Major Drivers – Indian Automotive Industry

Legislative Requirements

- Emission 2020 Ph 1
- IRDE
- Emission 2023 Ph 2

1

CAFE

CO_2 Ph I & Ph II

2

Customer Desire

- Driveability
- Performance
- NVH & FE

3

Technology Developments & Challenges

4

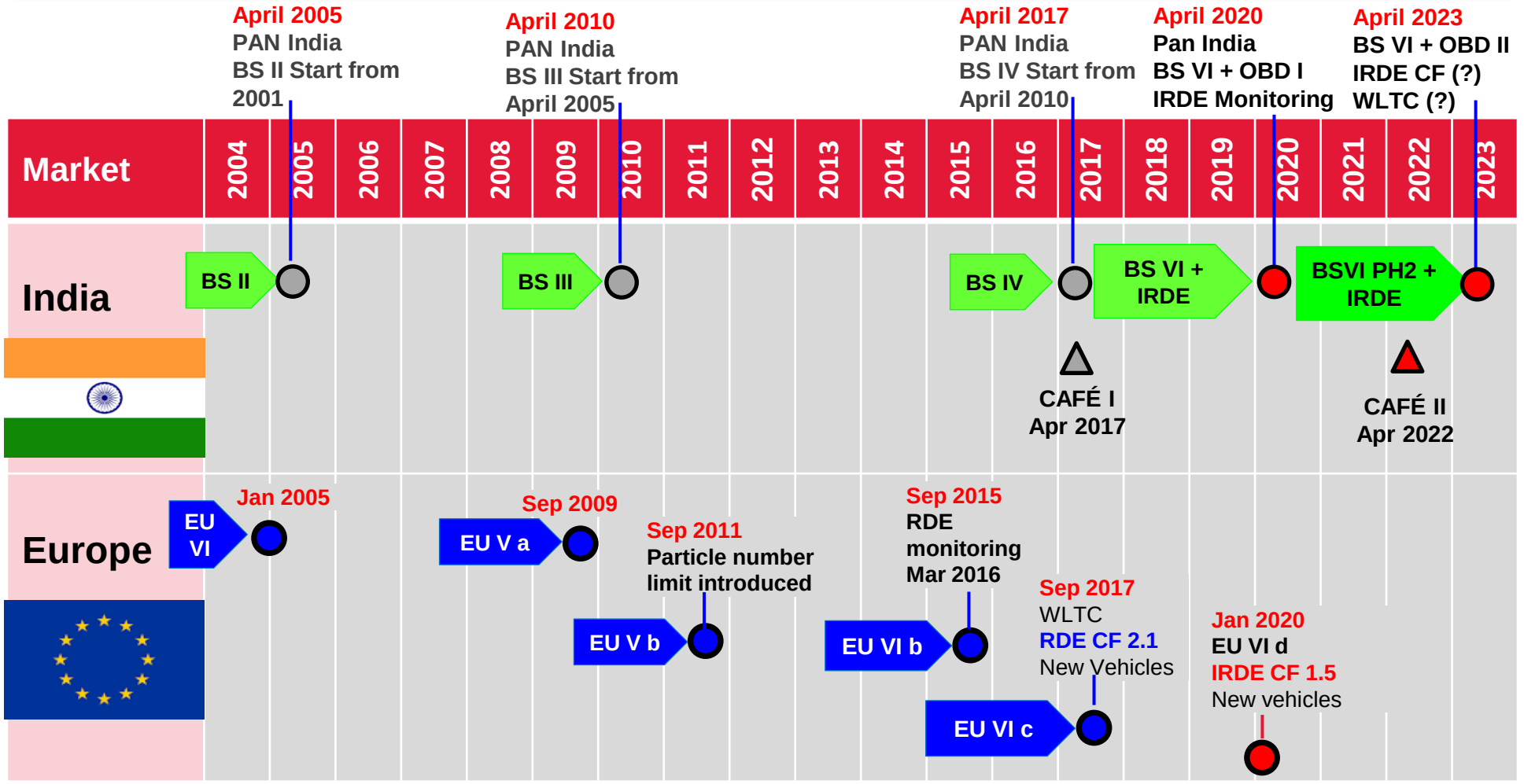
Emissions Legislations

1

BS6, IRDE Legislations

Emissions Legislations

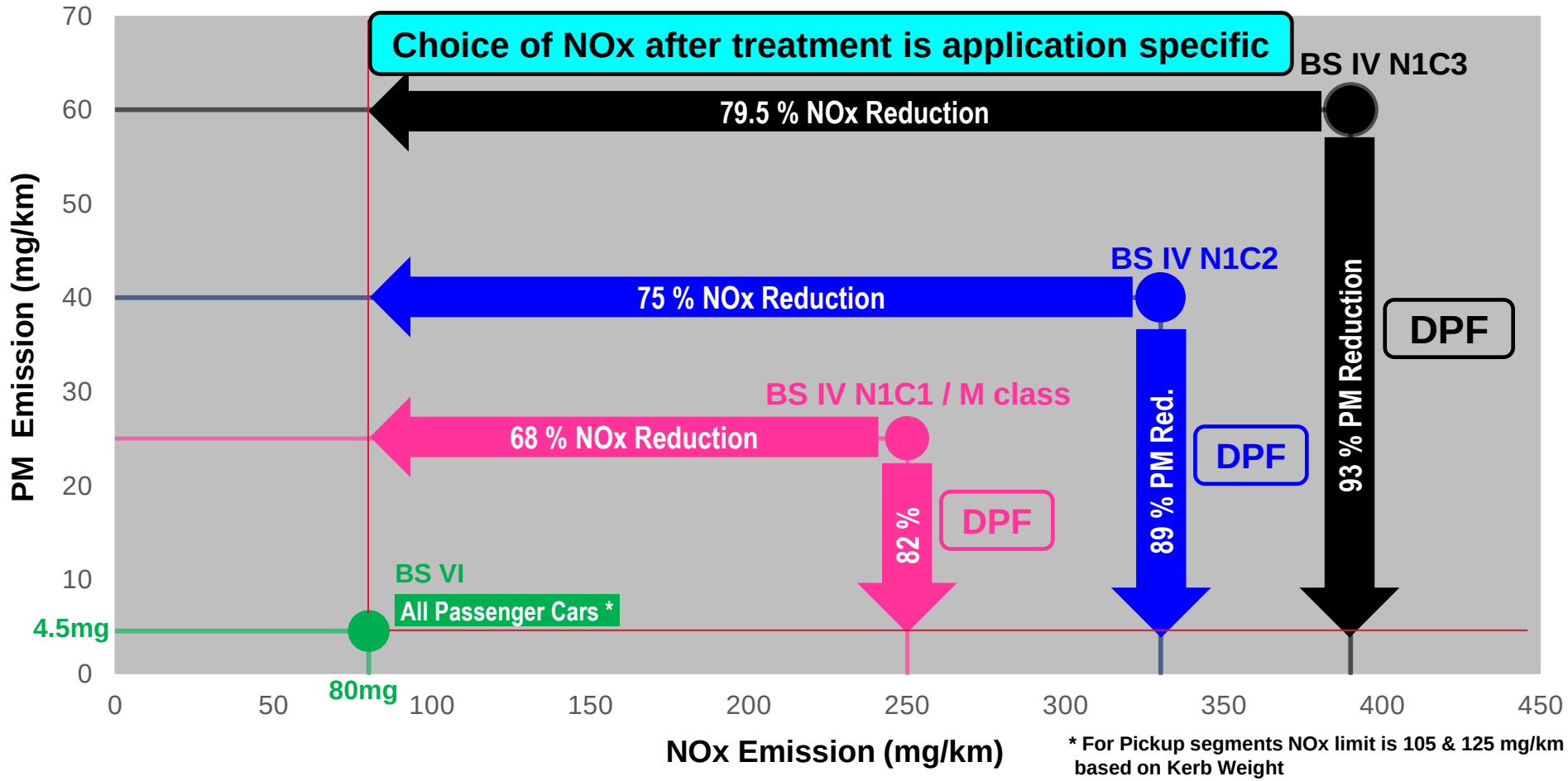
Legislation Overview at a Glance



- Pan India BS IV was 12 years after EU4; BS V1 is only 4.5 years behind
- BS6 implementation before CAFÉ Ph 2 make the targets even more tougher

Emission Legislations

Emission Limits at a Glance



* For Pickup segments NOx limit is 105 & 125 mg/km based on Kerb Weight

- Two Step Emission Reduction from BS4 to BS6 in one go – Quite ambitious move
- DPF and LNT/SCR Technology adaption in ~ 3 years timeframe

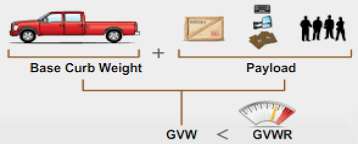
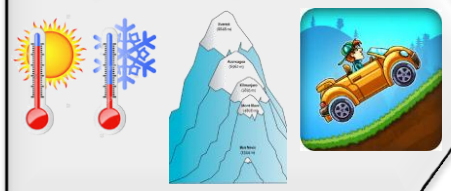
Emission Legislations

Emission Certification Cycles – Global & Indian Scenario

Country	Certification Cycle	Supplementary Cycle in Chassis Dyno	On Road Testing
	• FTP 75	• US06 : High speed & High Aggressive • HWFET : High speed & Less aggressive • SC03 : Mid speed cycle, AC ON & solar load 35° C • FTP75 : 1609 m , Standard Ambient • Cold FTP 75 : at -7° C ambient	• Not Applicable
	• NEDC 120 / WLTC	• Not Applicable	• Well Established • CF 2.1 : 2017 • CF 1.5 : 2020
	• JC 08	• Not Applicable	• Not Applicable • 2020 onwards
	• MIDC 90	• Not Applicable	• Europe RDE framework is baselined.

Overview – IRDE

Indian Real Driving Emission (IRDE)

	EUROPE	IRDE (Almost Final)
Vehicle load 	**Driver + witness (if needed) + Test equipment - Max 90% of pay load** **Air Condition – As used by consumer in real world**	←
Temperature / Altitude 	**Ambient Temperature / Altitude** Moderate: 0° C to 30° C; < 700 m Extended: -7° C to 35° C; < 1300 m **Cold Start:** Immediate after start (RDE3) **Altitude gain: <** 1200m / 100km	**Ambient Temperature / Altitude** Moderate: **10°C to 40°C** ; < 700 m Extended: **8°C to 45°C** ; < 1300 m **Cold Start**: RDE with cold start **Altitude gain: <** 1200m / 100km
Trip share / Dynamics / Limits 	**Urban:** 0 to 60 km/h; share 34% (±10%) ; but min 29%; min 16 km **Rural:** 60-90 km/h; share 33% (±10%); min 16 km **Motorway:** > 90km/h; share 33% (±10%); min 16 km **Duration:** 90 to 120 min **Max speed:** 160 km/h (<3% above 145 km/h)	**Urban: 0 to 45 km/h**; share 34% (±10%) ; min 16 km **Rural: 45-65 km/h**; share 33% (±10%) ; min 16 km **Motorway: > 65km/h**; share 33% (±10%); min 16 km **Duration:** 90 to 120 min **Max speed: 100kmph** (<3% above 100 and below 120 km/h)

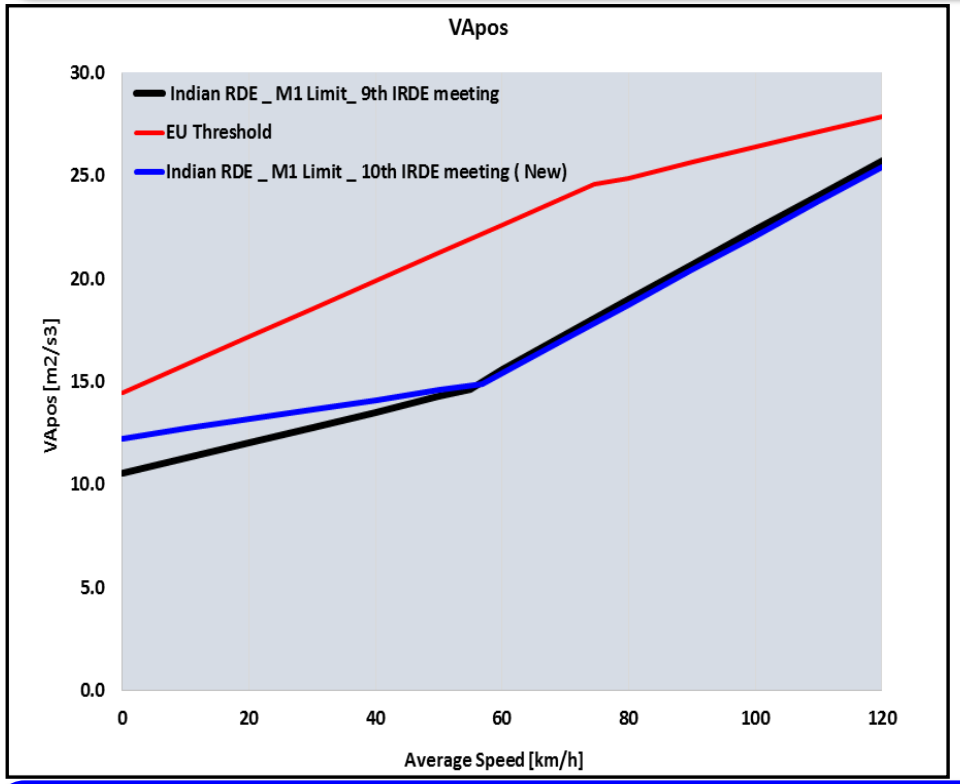
Overview – IRDE

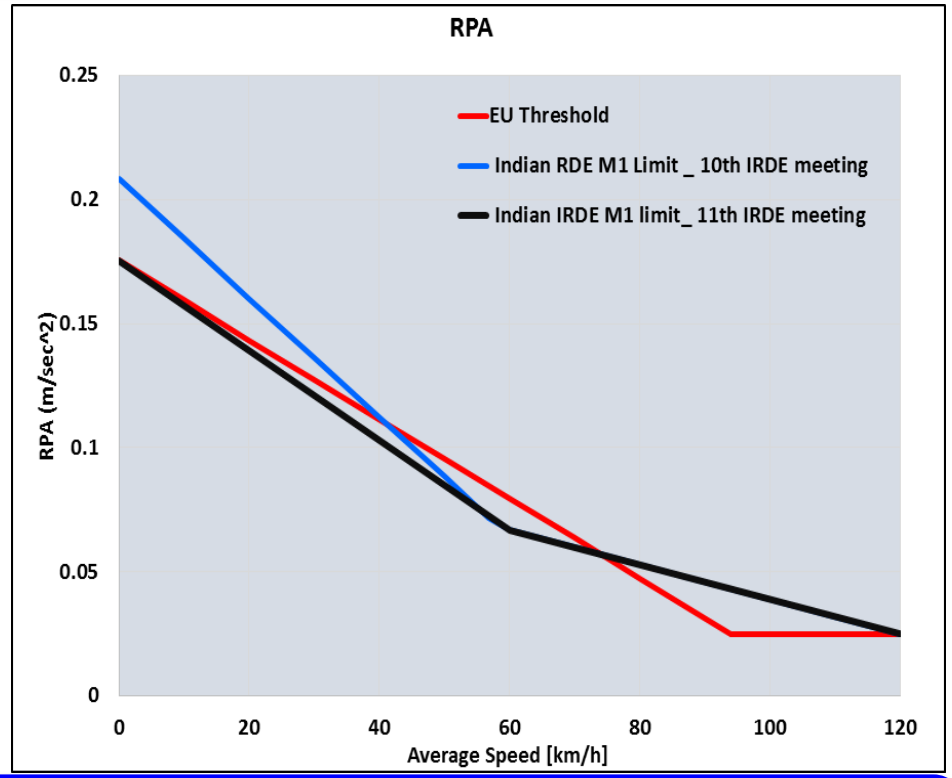
Indian Real Driving Emission (IRDE)

	EUROPE	IRDE (Almost Final)
Drive aggression limit	Upper limit & lower limit for drive aggression is defined based on vehicle speed vs acceleration (VAPos & RPA)	VAPos & RPA Customization – Under Discussion
Conformity factor calculation	• CO_2 moving average window method • Power binning method • WLTC forms the reference for both methods	Procedure is being worked out
Conformity factor limit	▪ C.F. Phase 1 – 2.1 ▪ C.F. Phase 2 – 1 + 0.5	▪ C.F. Phase 1 (2020) – Monitoring ▪ C.F. Phase 2 (2023) – For discussion

IRDE – V * APos & RPA

- Calculated for every phase – defines the aggression of drive
- A suitable limit is derived based on multiple vehicle / segment data; even if in one phase the value lies outside the limit then the test is considered invalid.
- Lower limit is defined by Relative Positive Acceleration (Passive Drive)





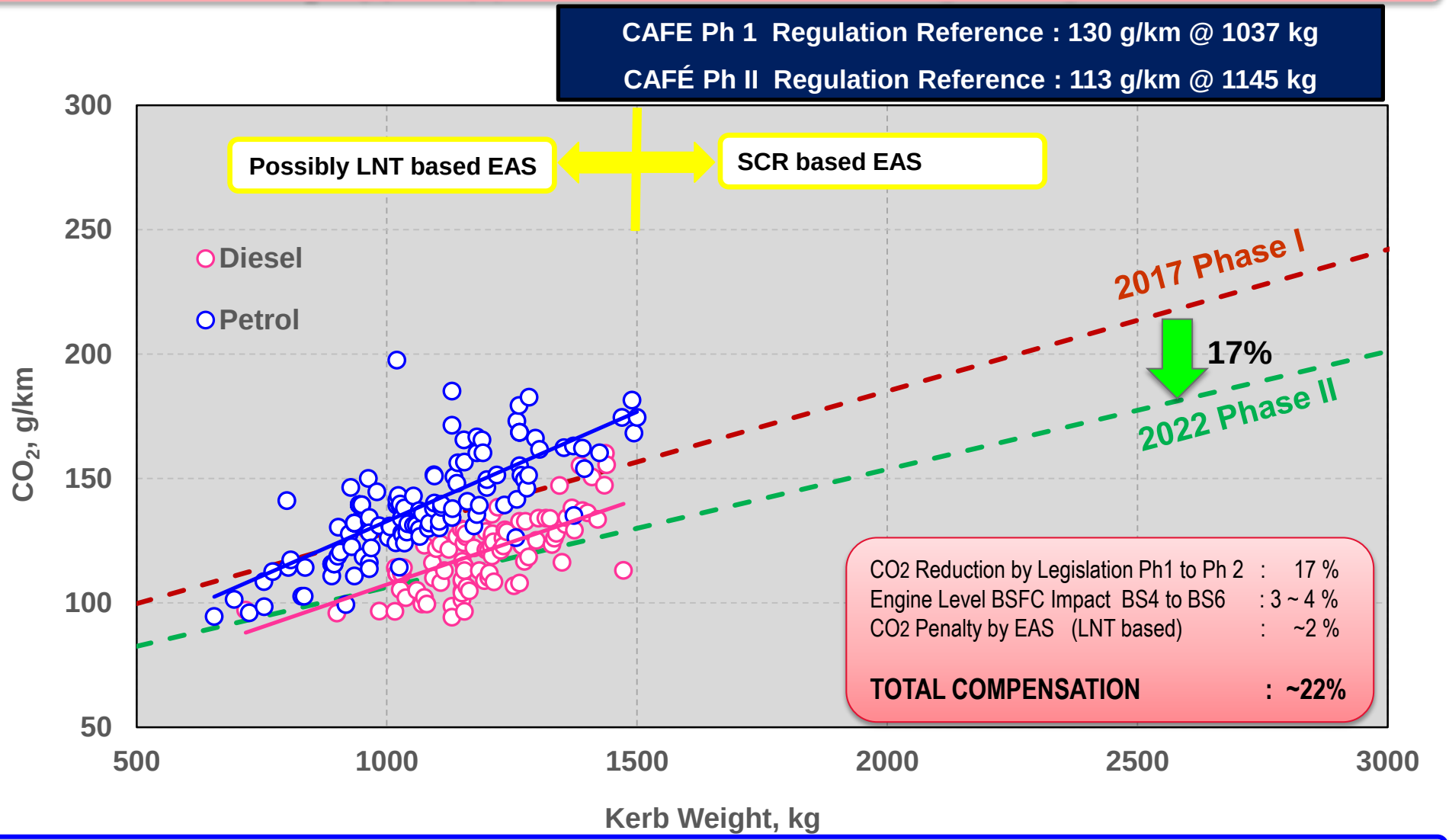
Scatter of multiple vehicles driven in Major Cities like Delhi, Chennai and Pune with more than 100 trips & 20 vehicles from major OEMS (M1, N1 and M1/N1 Low powered vehicles) to derive RDE boundary condition for Indian Traffic condition. (Trip share & Trip Dynamics). Data split in to City, Rural and Highway phase

2

CAFÉ CO_2 Regulation

Overview – CAFE

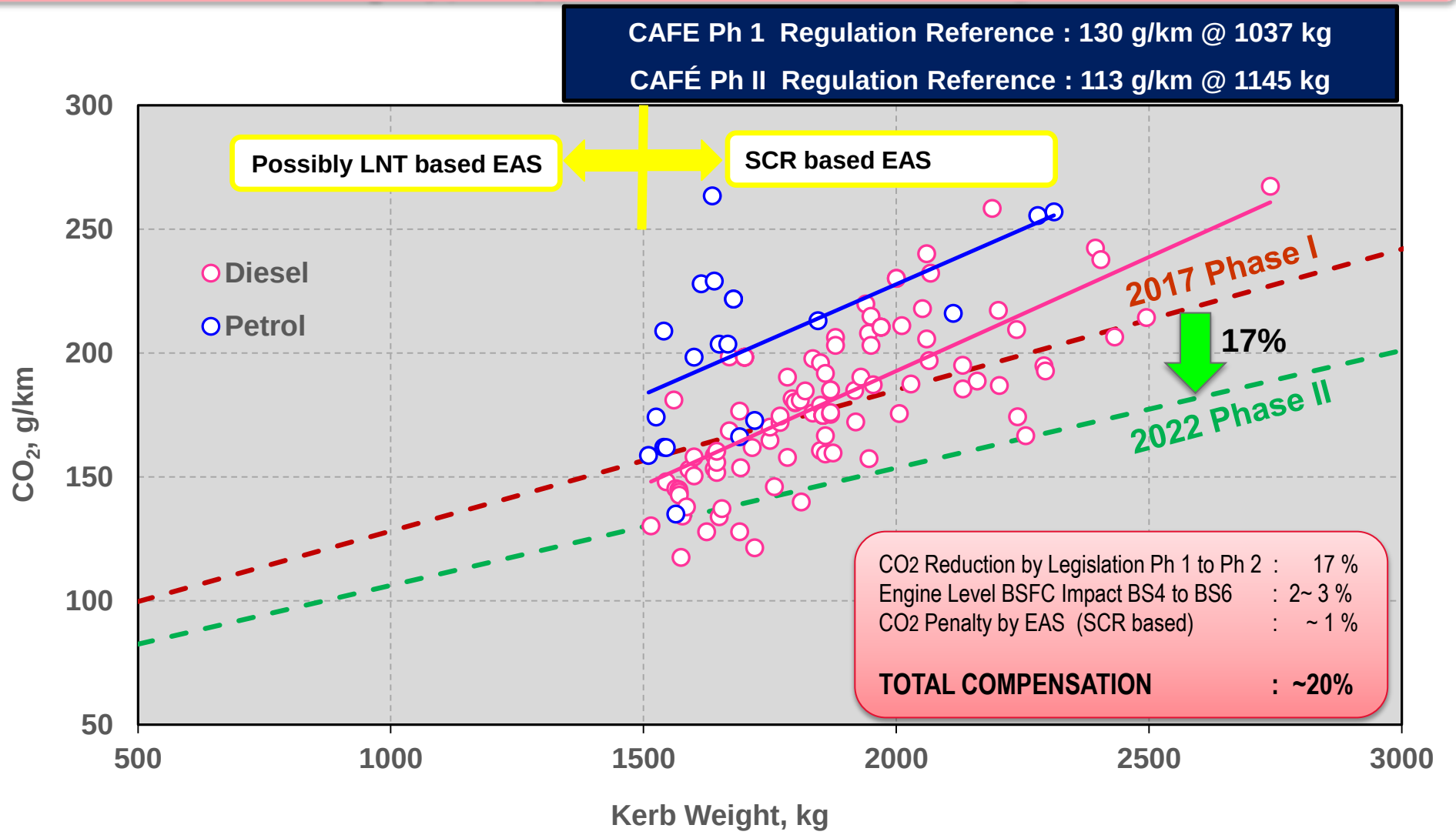
CO_2 Type Approval Values – Passenger Segment



- **BS6 Introduction adds more challenges !**

Overview – CAFE

CO_2 Type Approval Values – SUV Segment



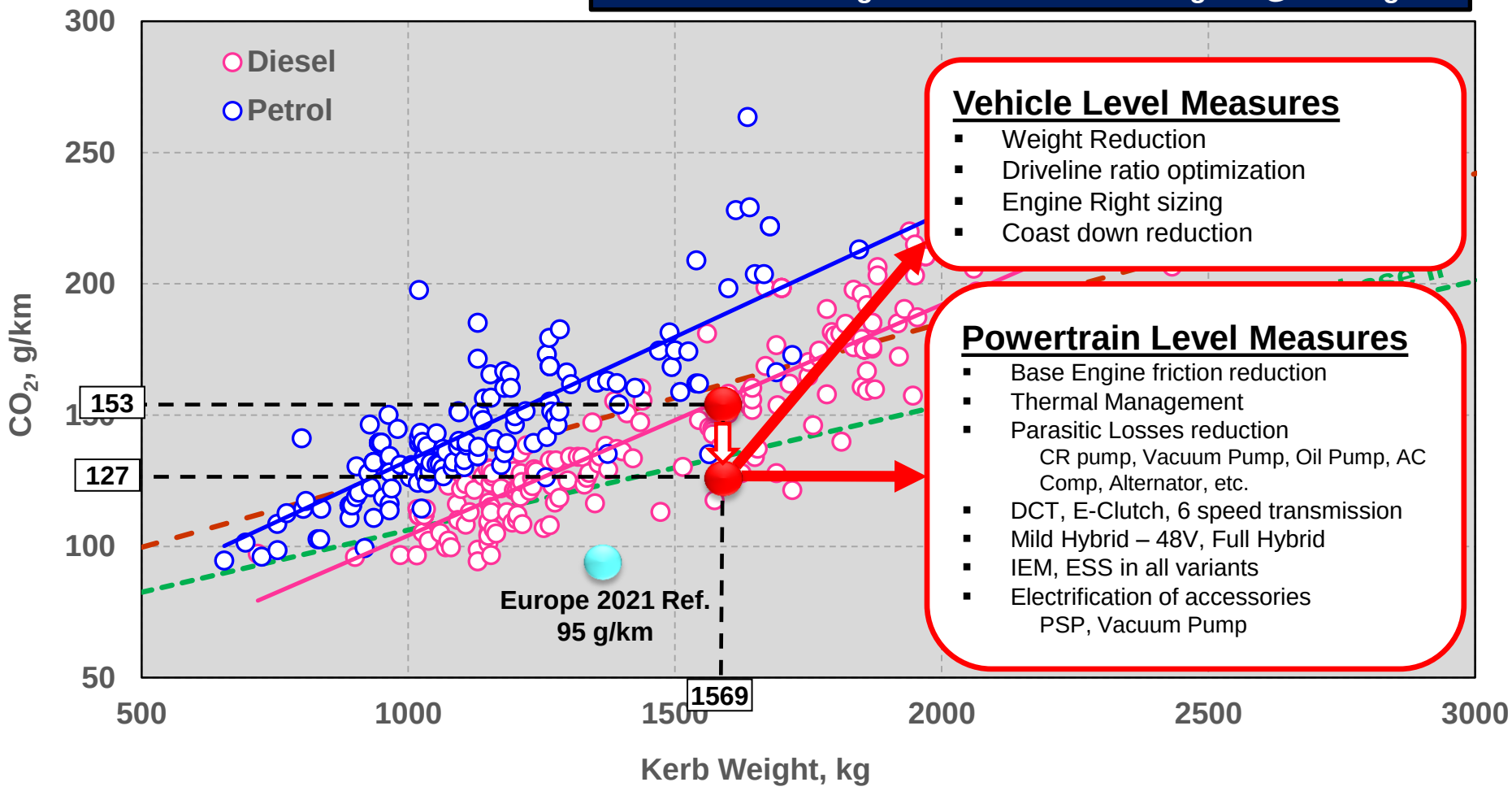
- **BS6 Introduction adds more challenges !**

Overview – CAFE

CO_2 Type Approval Values – All Segments

CAFE Ph 1 Regulation Reference : 130 g/km @ 1037 kg

CAFÉ Ph II Regulation Reference : 113 g/km @ 1145 kg



Vehicle Level Measures

- Weight Reduction
- Driveline ratio optimization
- Engine Right sizing
- Coast down reduction

Powertrain Level Measures

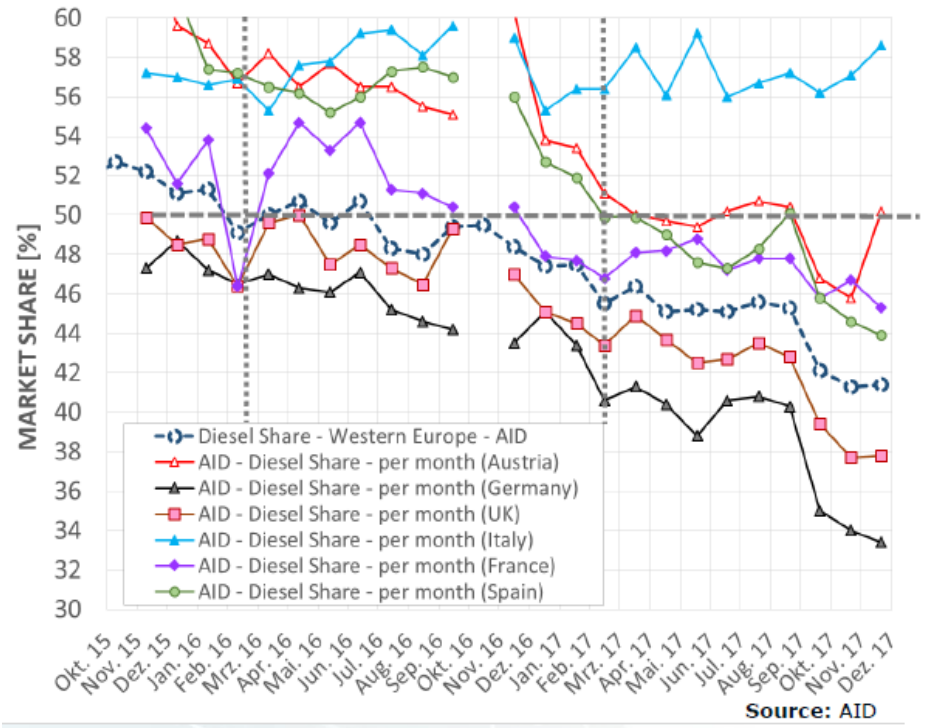
- Base Engine friction reduction
- Thermal Management
- Parasitic Losses reduction
  - CR pump, Vacuum Pump, Oil Pump, AC Comp, Alternator, etc.
- DCT, E-Clutch, 6 speed transmission
- Mild Hybrid – 48V, Full Hybrid
- IEM, ESS in all variants
- Electrification of accessories
  - PSP, Vacuum Pump

- **Diesel has advantage of about 25% CO_2 over equivalent Gasoline**

Overview – CAFE

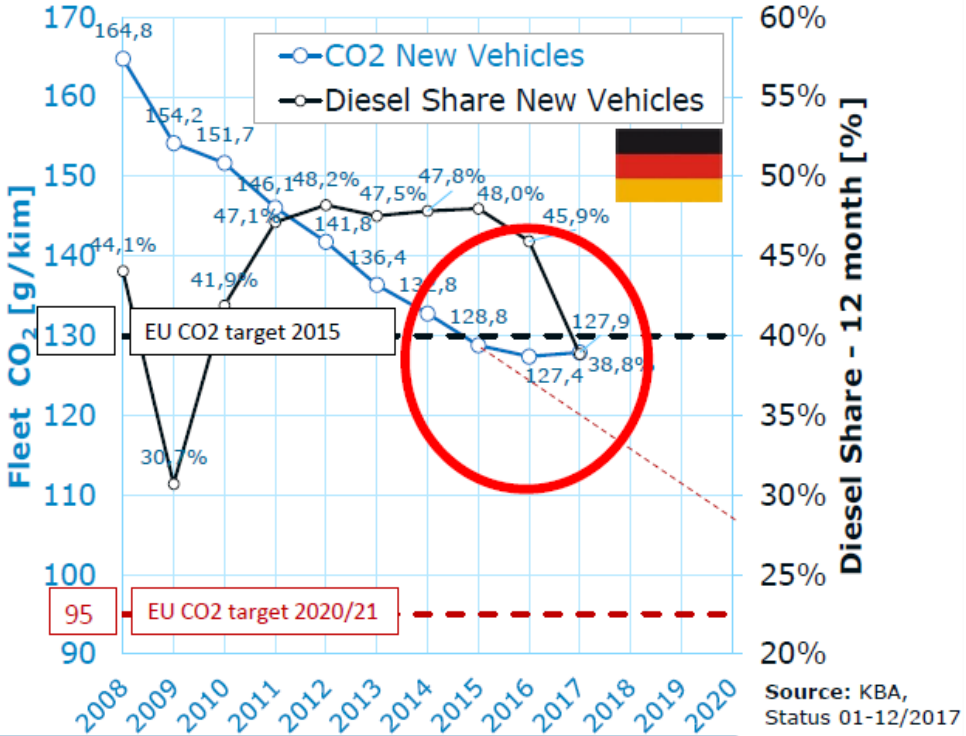
Europe CO_2 Situation

Diesel Share W.EUR, AUT, GER, UK, I, FRA



Source: AID

Diesel Share Germany, Fleet CO_2 Germany



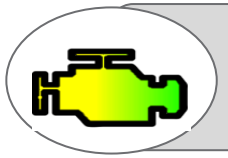
Source: KBA, Status 01-12/2017

➔ **Reduced Diesel Share Increases Fleet CO_2**

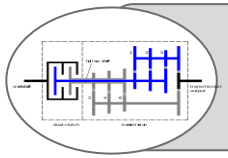
- **Diesel Share is Key for CO_2 balance**
- **Electrification / Hybridization needs more incubation time – Infrastructure & affordability**

Overview – CAFE

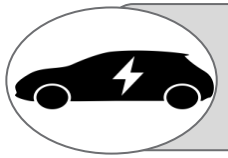
FE Improvement Technologies



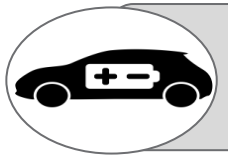
Engine Measures



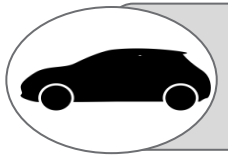
Transmission Measures



Hybridization



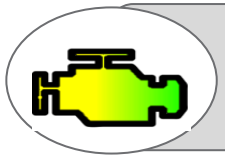
Electric Vehicles



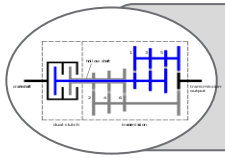
Vehicle Improvements – Weight, Coast Down, DTL

Overview – CAFE

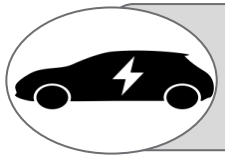
FE Improvement Technologies



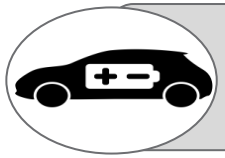
Engine Measures



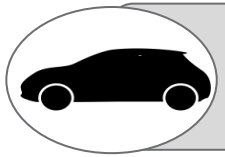
Transmission Measures



Hybridization



Electric Vehicles



Vehicle Improvements – Weight, Coast Down, DTL

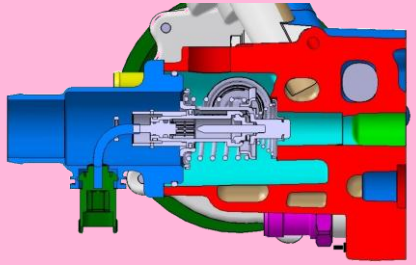
Overview – CAFE

Non – Hybrid CAFÉ Measures– DIESEL ENGINES

Variable Oil Pump

FE Benefit : 1 – 1.5 %

Map Controlled TS



FE Benefit : 0.5%

LP EGR

FE Benefit : 2 – 2.5 %

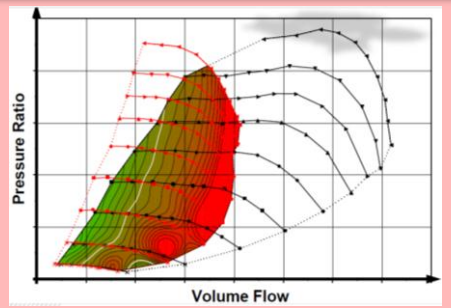
Map Controlled PCJ

FE Benefit : 0.5 - 1 %

Switchable Water Pump

FE Benefit : 0.5 to 1.0 %

Ball Bearing Turbo



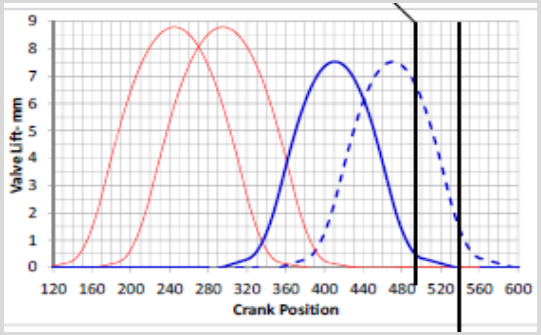
FE Benefit : 1 - 2 %

- **Total FE Benefit Potential : 5.5 - 8 %**

Overview – CAFE

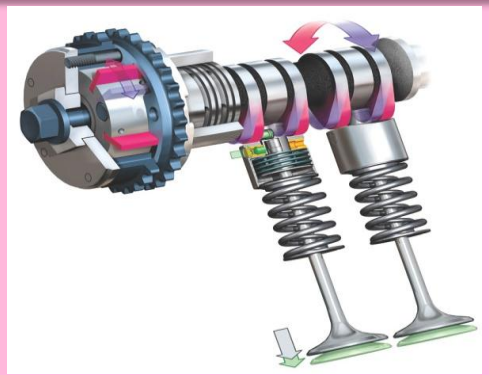
Non – Hybrid CAFÉ Measures– GASOLINE ENGINES

Only Miller Cycle
(Torque & Power limitation)



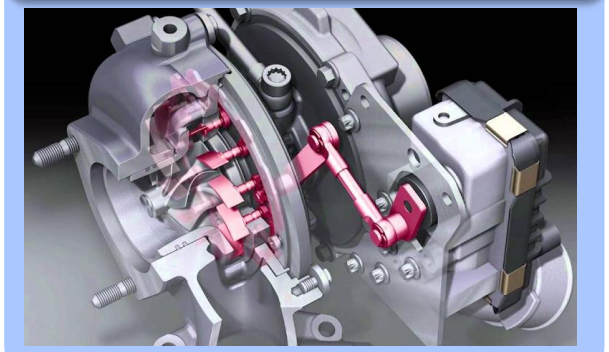
FE Benefit : 3 - 4 %

Miller + CVVT



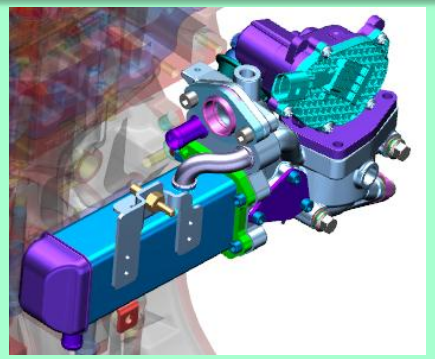
FE Benefit : 6 - 8 %

Turbocharger - VGT



FE Benefit : 1 to 2 %

Cooled EGR



FE Benefit : 1 to 1.5 %

- **Total FE Benefit Potential : 8 to 11.5 %**

Non – Hybrid CAFÉ Measures – e Clutch

Only 2 pedals – Drive Comfort

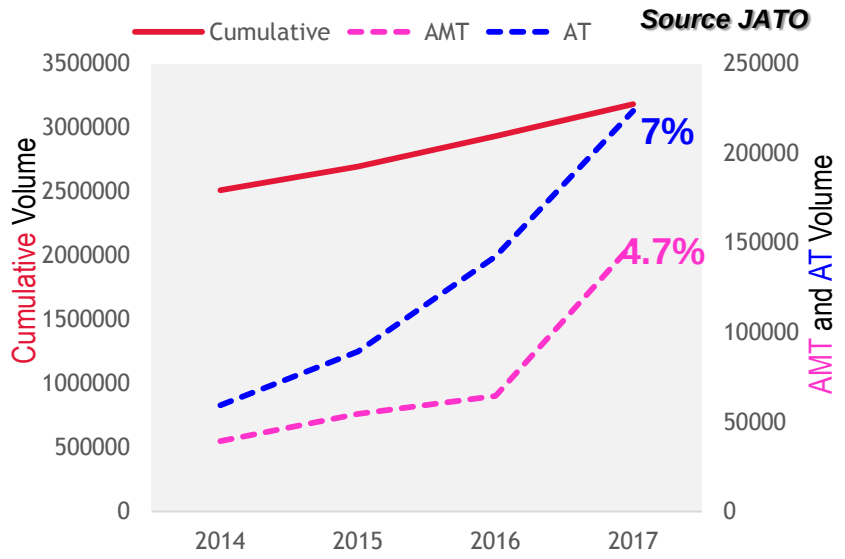
Start-stop sailing function – FE benefit

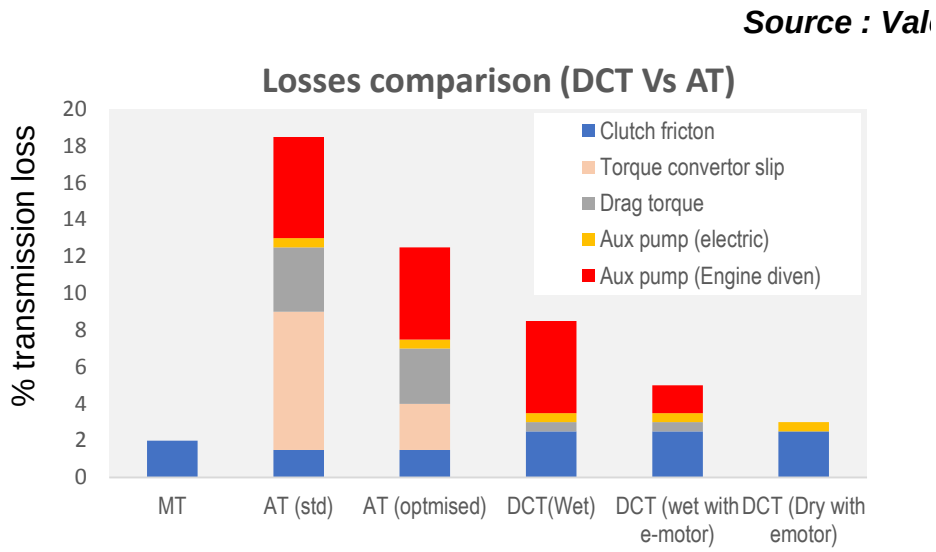
- FE benefit Potential

  1 % in NEDC

  3`% in real world

Non – Hybrid CAFÉ Measures – DCT





- **Automatic volume is growing rapidly. AT and AMT make 11.7% of total volume in 2017.**
- **Losses in new generation of Automatics have come down.**
- **However DCT still has an edge on lower transmission losses**
- **1.0% FE improvement for every 2.5% Transmission loss reduction**

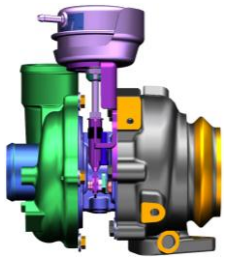
3

Technology Development

Emission Development

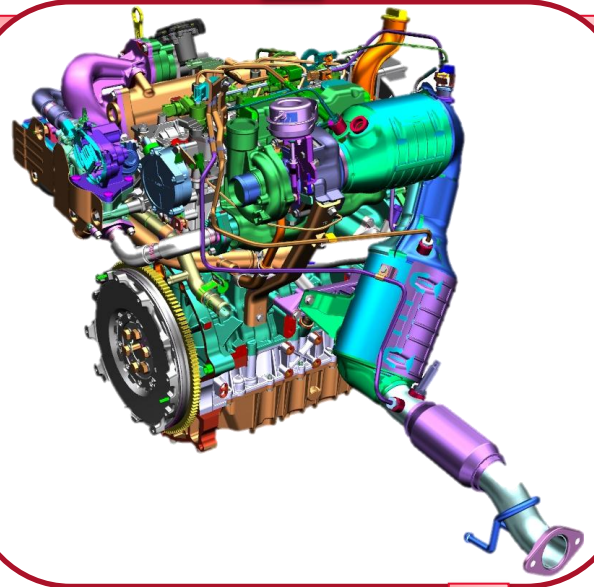
Engine Out | NOx After Treatment | PM After Treatment

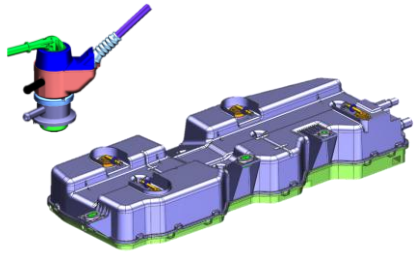
Major New Technologies



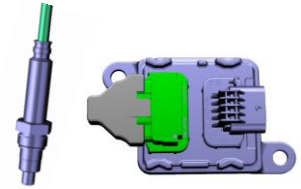
Advanced TC

Throttle Valve

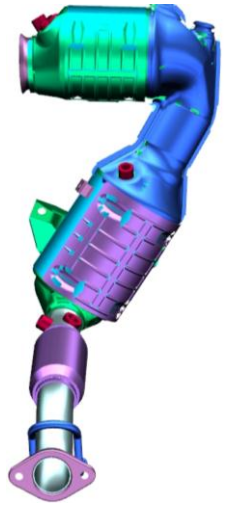




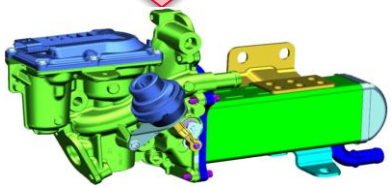
Urea Tank Assy & Dosing Module



NOx Sensor & ECU

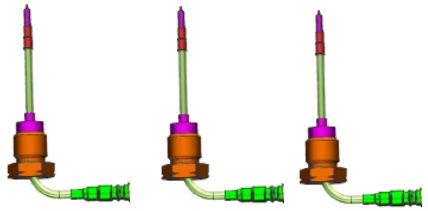


DOC-SPF



EGR cooler Module

ECU with advanced software controls



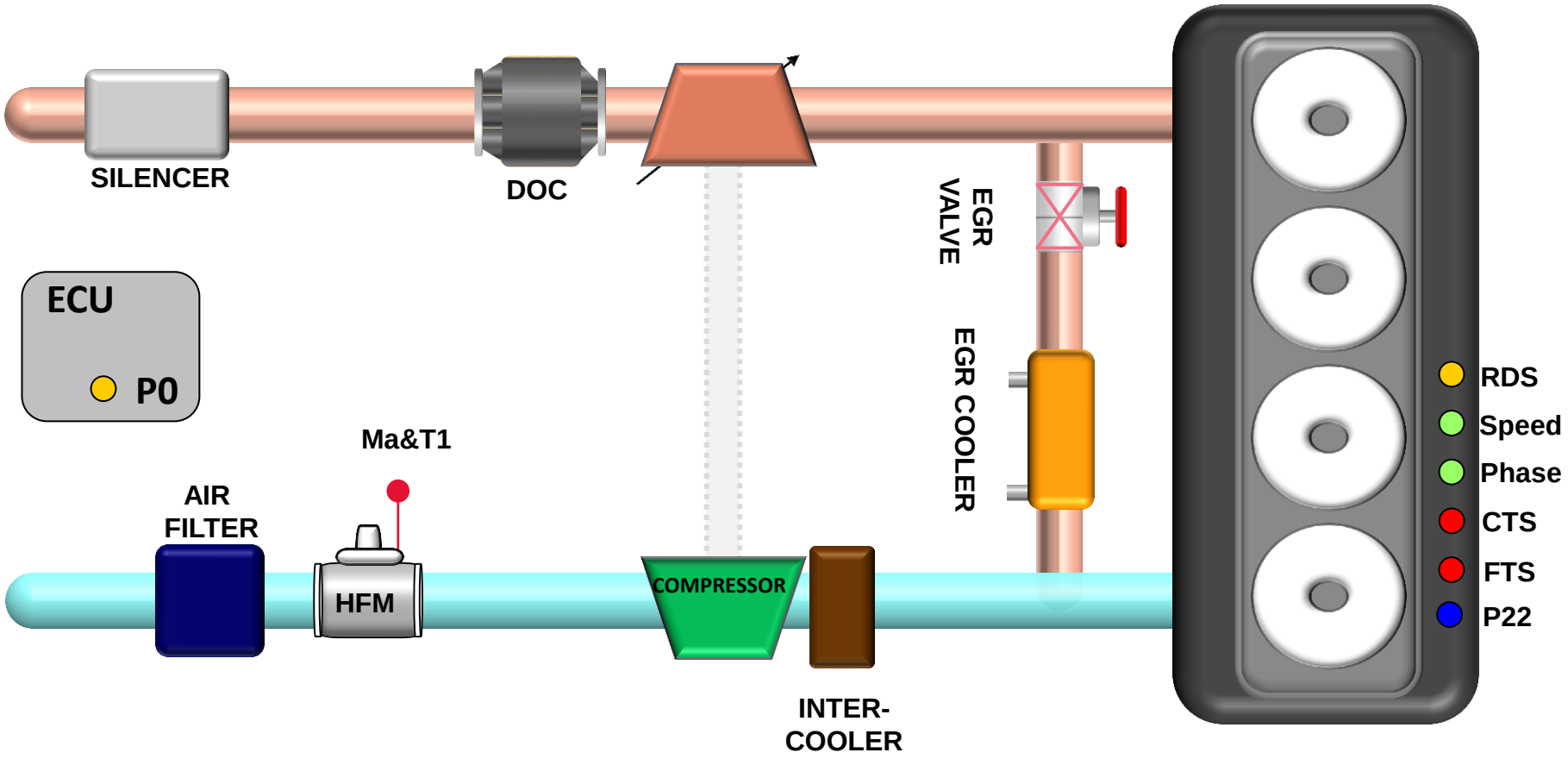
T3 T4 T5

High Temperature Sensors

Emission Development

Engine Out | NOx After Treatment | PM After Treatment

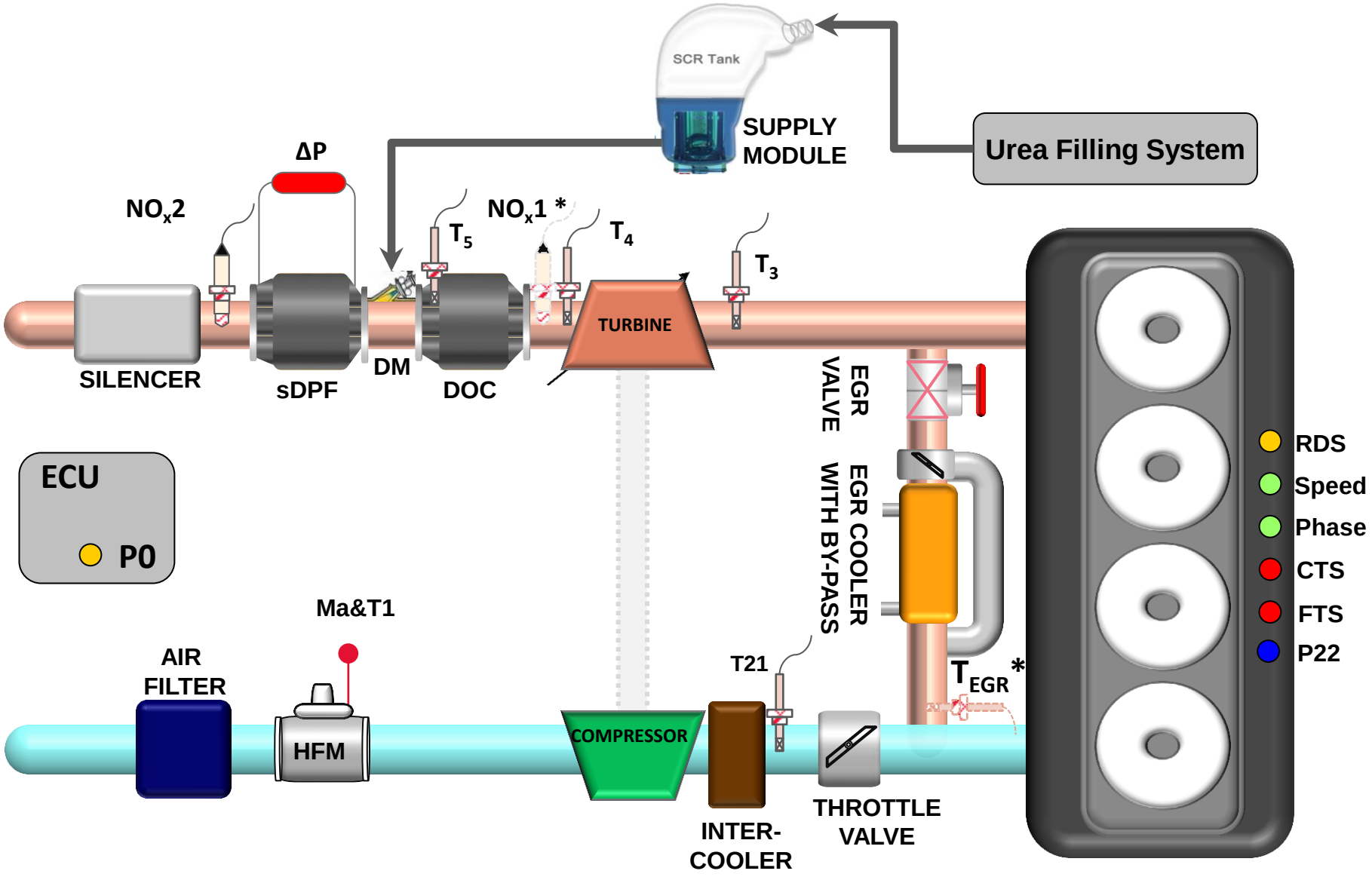
Typical BS6 Layout – Typical BS4



Emission Development

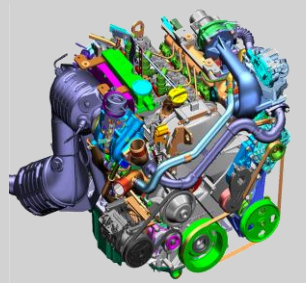
Engine Out | NOx After Treatment | PM After Treatment

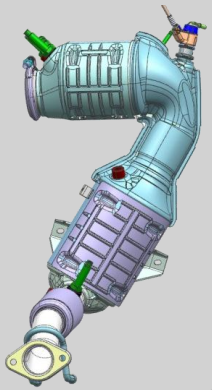
Typical BS6 Layout – SCR Based



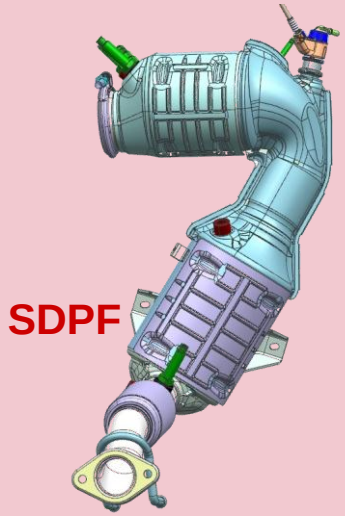
Technology Development

- BS6 Development
- Engine Out Development
- NOx After Treatment
- PM After Treatment





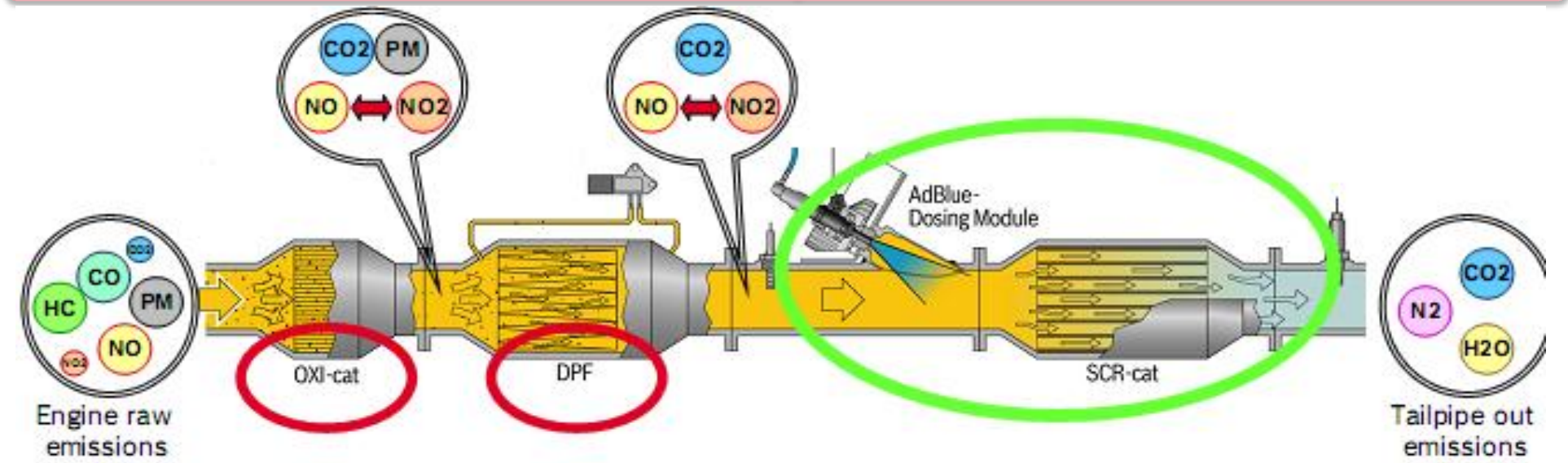
NOx After Treatment



Emission Development

Engine Out | NOx After Treatment | PM After Treatment

Selective Catalytic Reduction



Urea Decomposition

Thermolysis (160 – 180 ° C)

$H_2N – Co – NH_2 \rightarrow NH_3 + NHCO$

Hydrolysis (180 – 200 ° C)

$HNCO + H_2O \rightarrow NH_3 + CO_2$

Std.: $4\ NH_3 + 4\ NO + O_2 \rightarrow 4\ N_2 + 6\ H_2O$

NO_2/NO_x <50%

"Fast": $4\ NH_3 + 2\ NO + 2\ NO_2 \rightarrow 4\ N_2 + 6\ H_2O$

NO_2/NO_x = 50%

"Slow": $4\ NH_3 + 3\ NO_2 \rightarrow 3.5\ N_2 + 6\ H_2O$

NO_2/NO_x > 50%

SCR reactions starts above 180 °C

Emission Development

Engine Out | **NOx After Treatment** | PM After Treatment

Selective Catalytic Reduction

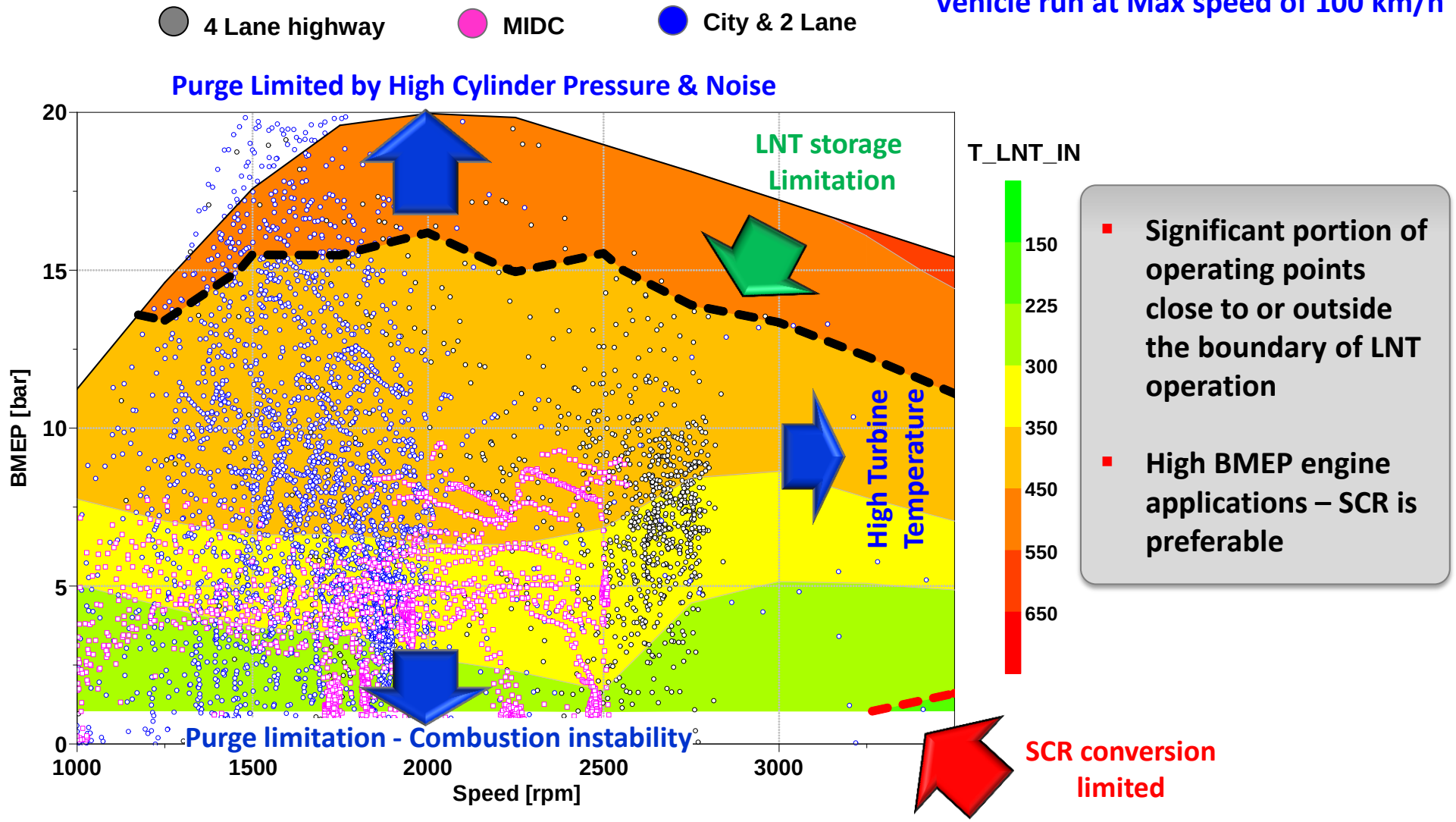
Frequent low temperature operation increases the risk of urea deposition

Emission Development

Engine Out | NOx After Treatment | PM After Treatment

Lean Operation – High BMEP / without Speed Limitation

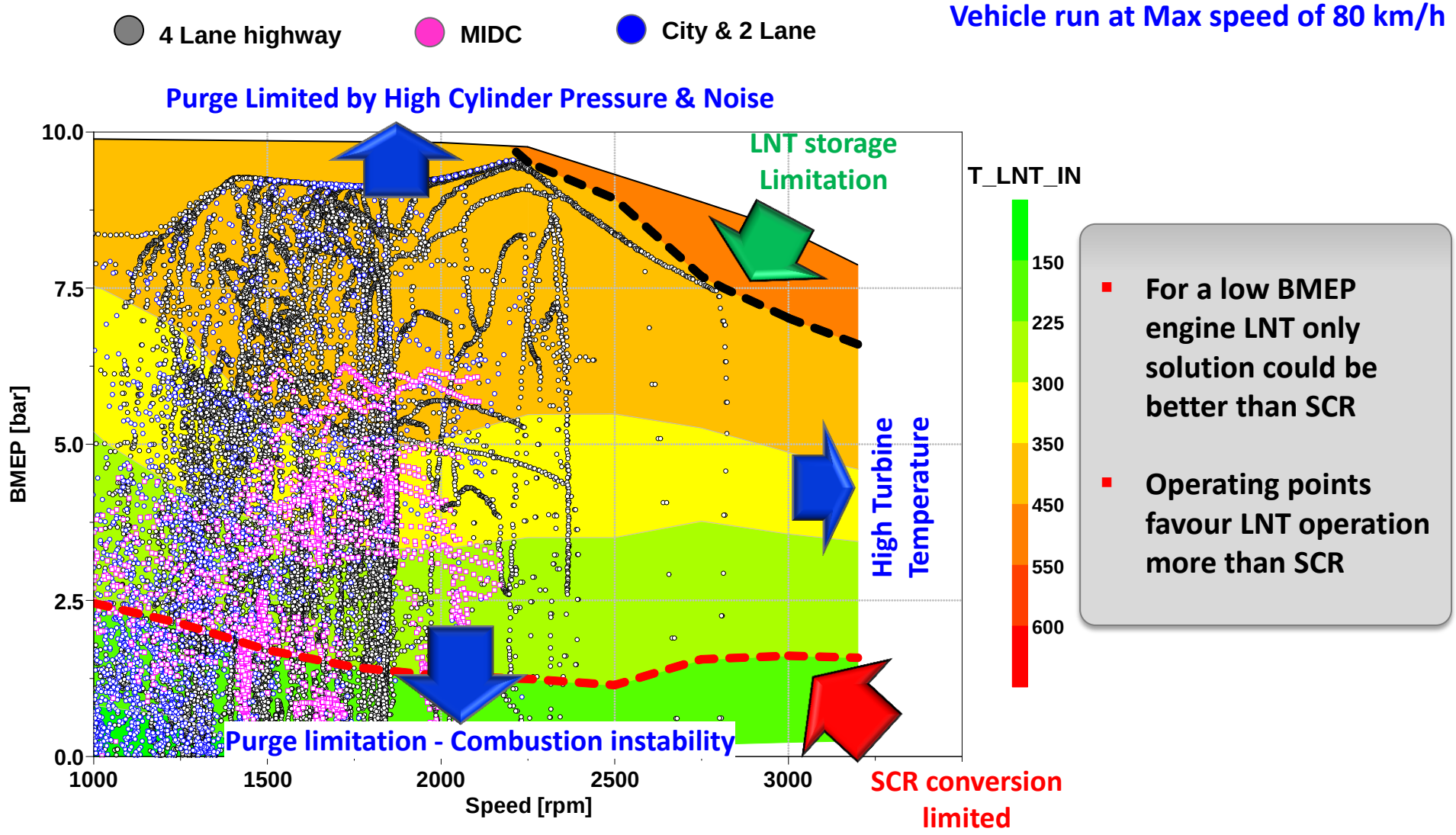
Vehicle run at Max speed of 100 km/h



- Significant portion of operating points close to or outside the boundary of LNT operation
- High BMEP engine applications – SCR is preferable

Lean Operation – Low BMEP / with Speed Limitation

Vehicle run at Max speed of 80 km/h

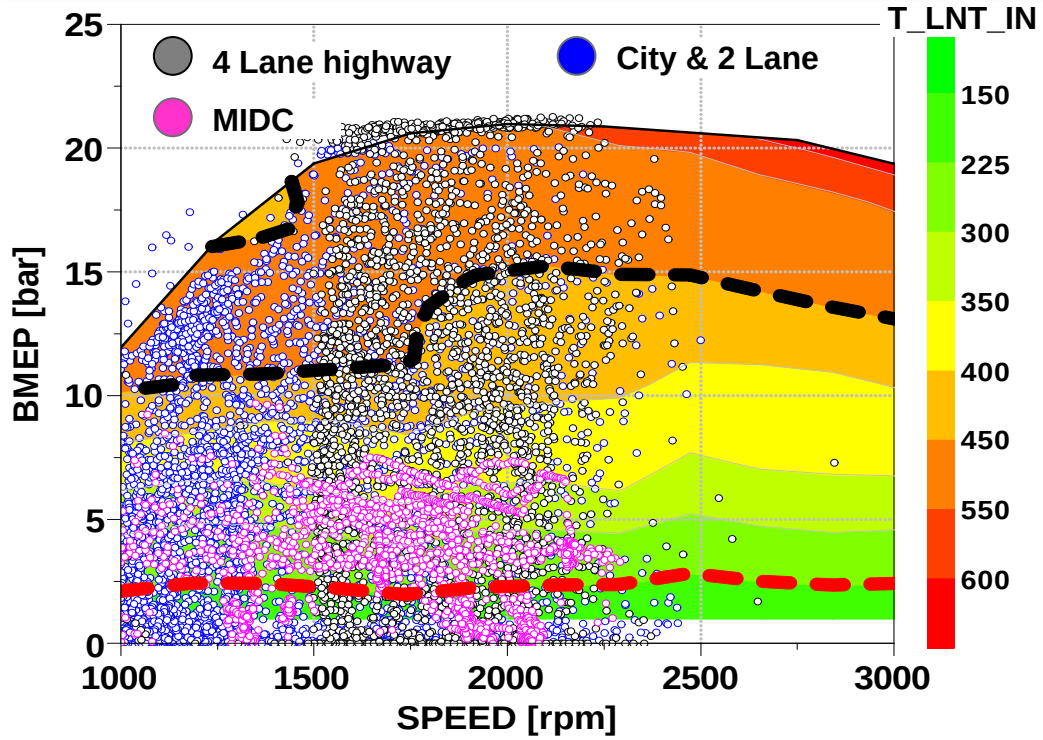


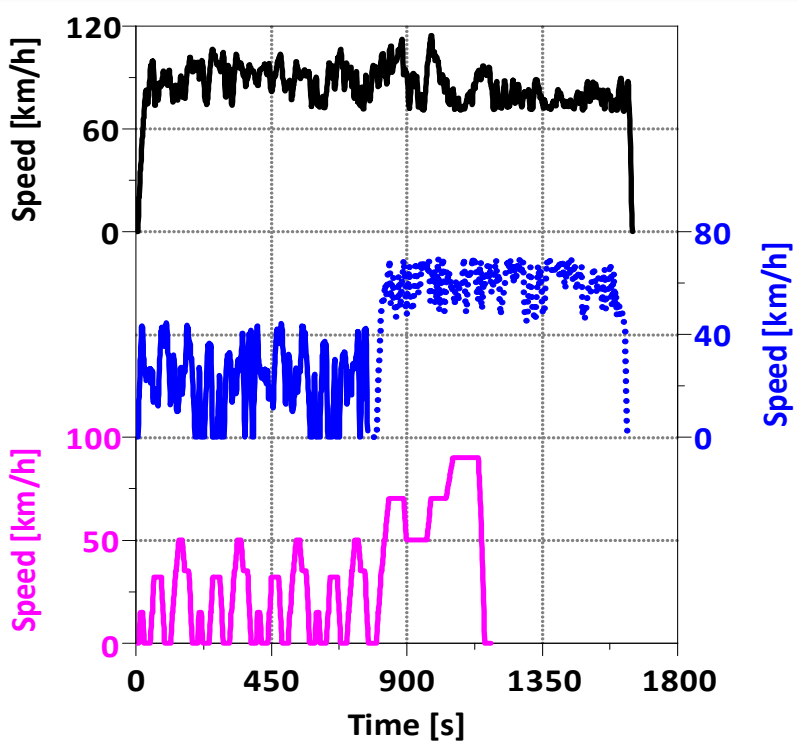
- For a low BMEP engine LNT only solution could be better than SCR
- Operating points favour LNT operation more than SCR

Emission Development

Engine Out | NOx After Treatment | PM After Treatment

LNT Vs SCR : High BMEP Engine





Cycles	LNT		SCR
	FE Penalty	RP / 100 km	AdBlue Cons.
MIDC	2.5%	8	0.4%
City	4.0%	17	1.46%
Rural (2 Lane)	11.1%	50	4.24%
Highway (4 Lane)	7.8%	46	3.78%

Emission Development

Engine Out | NOx After Treatment | PM After Treatment

LNT Vs SCR : High BMEP Engine

Parameter	SCR	LNT
Cycle Emissions Compliance	+ +	+
IRDE Compliance Voluntary Monitoring Phase	+ +	- -
In-service Emission Compliance	+ +	- -
HC Slip	0	-
Fuel Sulphur Poisoning (> 10 ppm)	+ +	- -
FE Penalty compared to BS4	-	- -
Customer Convenience Factor (Urea Filling @ service interval)	-	0
Service Convenience	-	0
Packaging Complexity	- -	+ +
Calibration Complexity	-	- -
Cost	- -	-

- SCR Vs LNT is purely depending on cc/weight, EO emissions, FE, CF & Cost
- Integration & Application complexity has different scale for each technology

Emission Development

Engine Out | NOx After Treatment | PM After Treatment

LNT Vs SCR : Low BMEP Engine

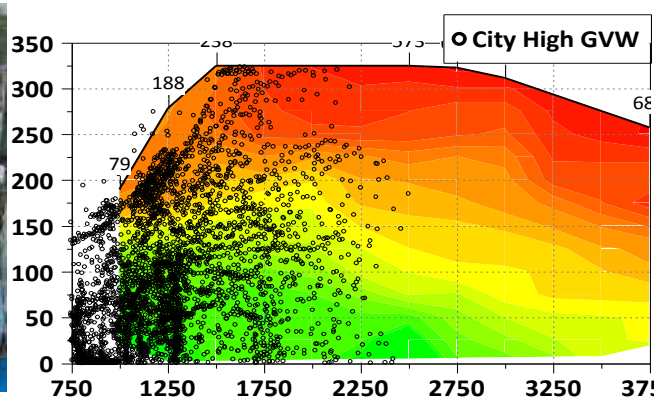
Parameter	SCR	LNT
Cycle Emissions Compliance	-	+ +
IRDE Compliance Voluntary Monitoring Phase	+	+
In-service Emission Compliance	+	+
HC Slip	0	+
Fuel Sulphur Poisoning (> 10 ppm)	+ +	- -
FE Penalty compared to BS4	- -	- -
Customer Convenience Factor (Urea Filling @ service interval)	-	0
Service Convenience	-	0
Packaging Complexity	- -	+ +
Calibration Complexity	-	- -
Cost	- -	-

- SCR Vs LNT is purely depending on cc/weight, EO emissions, FE, CF & Cost
- Integration & Application complexity has different scale for each technology

PM After Treatment

DPF

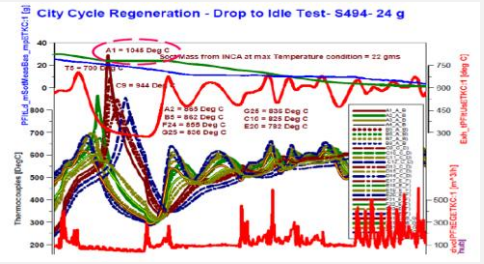
DPF – Challenges in Indian Market

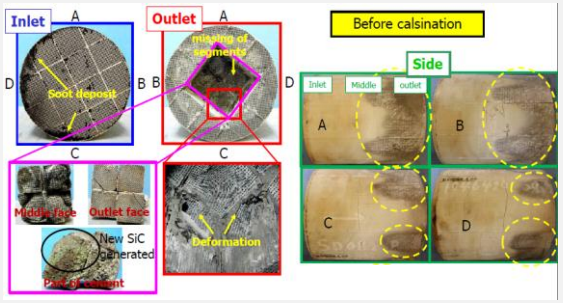


- Thick Road Traffic, extended idle : Critical for DPF Regeneration
- Extreme operations : 0 ~ 5500 m, + 52 °C, low city avg speed of ~ 6 kmph
- Low engine speed / high load driving behavior

DPF – Challenges in Indian Market

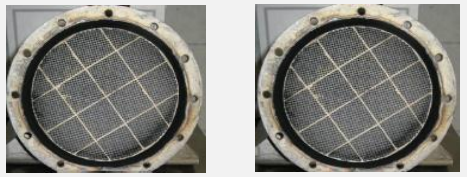
High Temperature & Thermal Stress



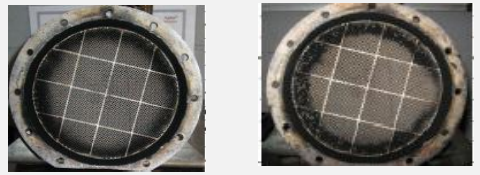


Oil Dilution

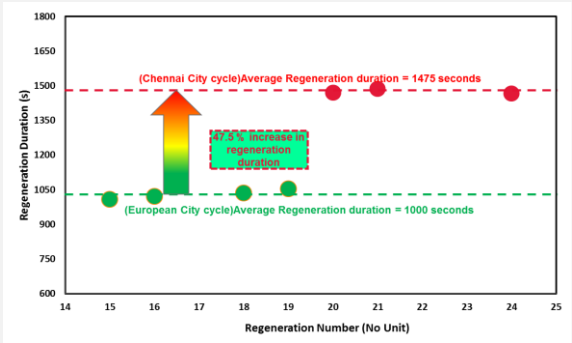
Increased Regeneration Frequency
Extended Regeneration duration



European city cycle regeneration

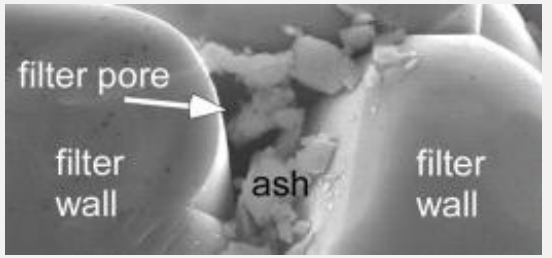


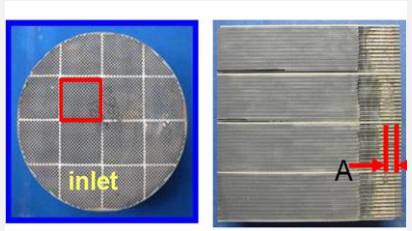
Chennai city cycle regeneration



Ash Deposition

Fuel & Oil Quality





To Summarize …

- Two Step Emission change with RDE Monitoring in one go – A big Step
- New inputs for legislation boundary conditions – Late input is a risk
- CAFÉ readiness and Customer TCO. Hybrid yet to shape-up
- Country specific Technology Adaption is a challenge
- Right time fuel availability to enable adequate fleet test for robustness
- High cost of Ownership, Technology incubation cost & investments
- Anti – Diesel Sentiments, though clean with technology & key for CO_2
- Latent need of customers for refinement & object of desire

Unique Challenges Across Industry !!!

Thank You

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