The Compliance of BS VI

Sustainable Approach

02nd Nov 2017

K Senthur Pandian

Associate Chief Engineer

Head - Diesel Engines (Automotive)

Mahindra and Mahindra Limited

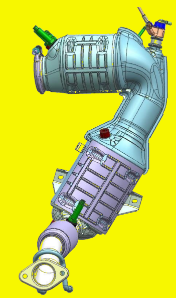
Sustainability Challenges & Emerging Trends

Major Drivers – Automotive Powertrain

Upcoming Legislations

- CO_2 Ph I & Ph II
- Emission 2020, IRDE
- Safety 2019

Technology Overview



Real World Fuel Economy

Cost of Ownership

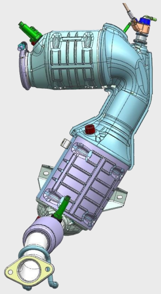
Sustainability Challenges & Emerging Trends

Major Drivers – Automotive Powertrain

Upcoming Legislations

- CO_2 Ph I & Ph II
- Emission 2020, IRDE
- Safety 2019

Technology Overview



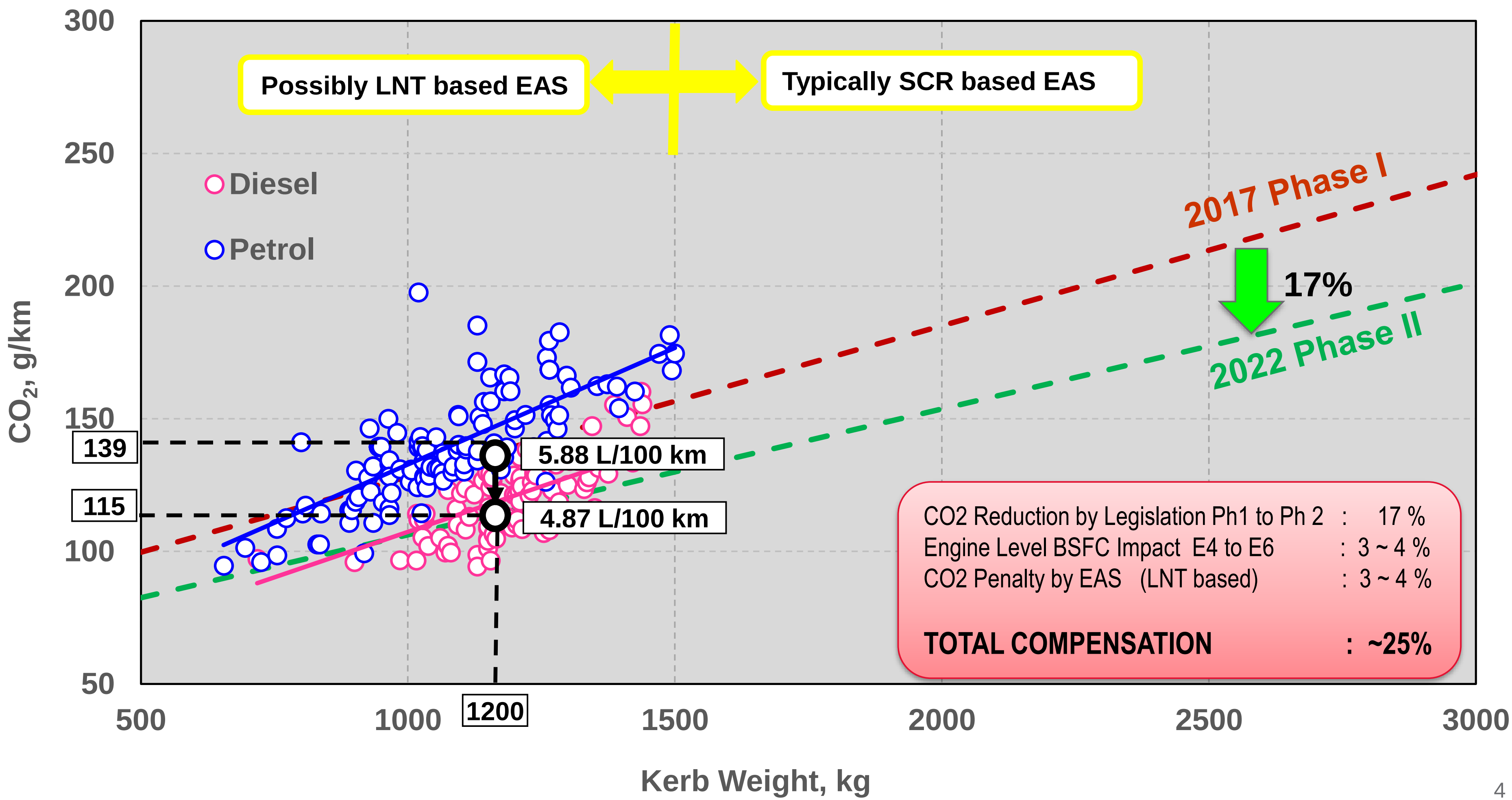
Real World Fuel Economy

Cost of Ownership

Sustainability Challenges & Emerging Trends

Upcoming Legislations | Technology Over view | Rear World Fuel Economy | Cost of Ownership

CO_2 Type Approval Values – Passenger Segment (India)

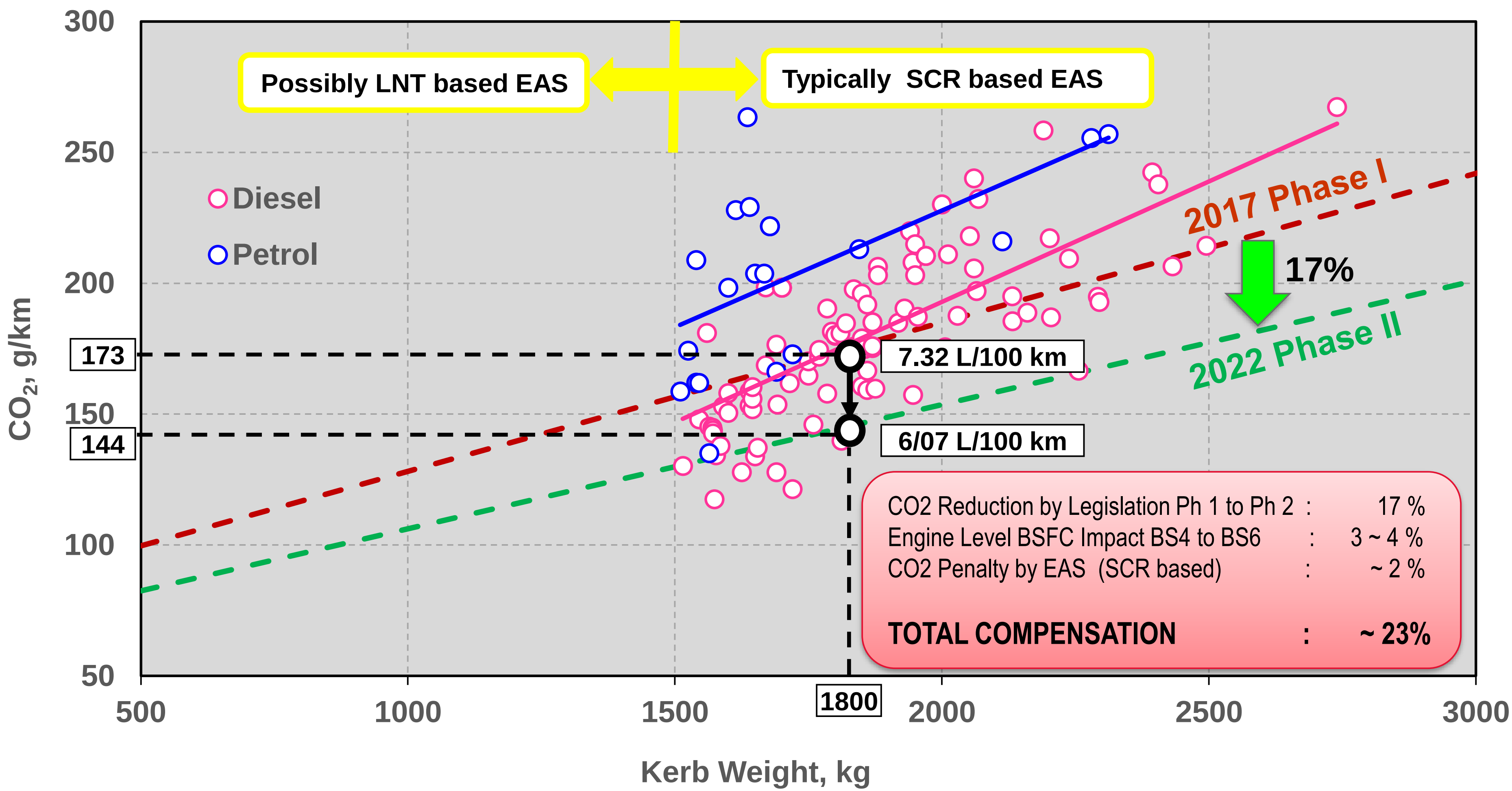


CO2 Reduction by Legislation Ph1 to Ph 2	:	17 %
Engine Level BSFC Impact E4 to E6	:	3 ~ 4 %
CO2 Penalty by EAS (LNT based)	:	3 ~ 4 %
TOTAL COMPENSATION	**:**	**~25%**

Sustainability Challenges & Emerging Trends

Upcoming Legislations | Technology Over view | Rear World Fuel Economy | Cost of Ownership

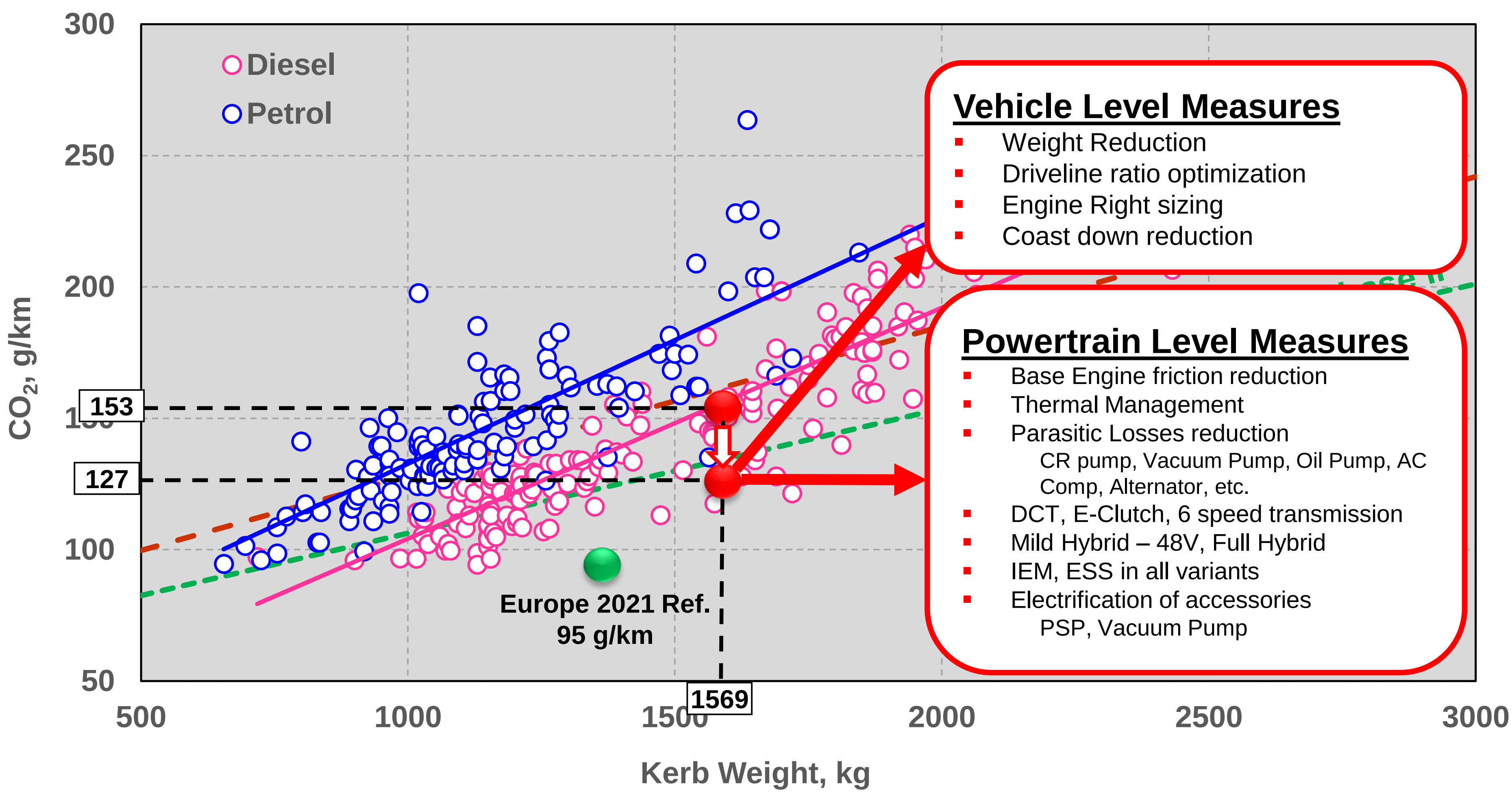
CO_2 Type Approval Values – SUV Segment (India)



Sustainability Challenges & Emerging Trends

Upcoming Legislations | Technology Over view | Rear World Fuel Economy | Cost of Ownership

CO_2 Type Approval Values – All Segments (India)



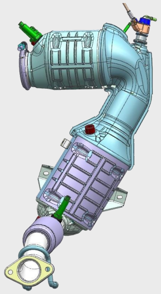
Sustainability Challenges & Emerging Trends

Major Drivers – Automotive Powertrain

Upcoming Legislations

- CO_2 Ph I & Ph II
- Emission 2020, IRDE
- Safety 2019

Technology Overview



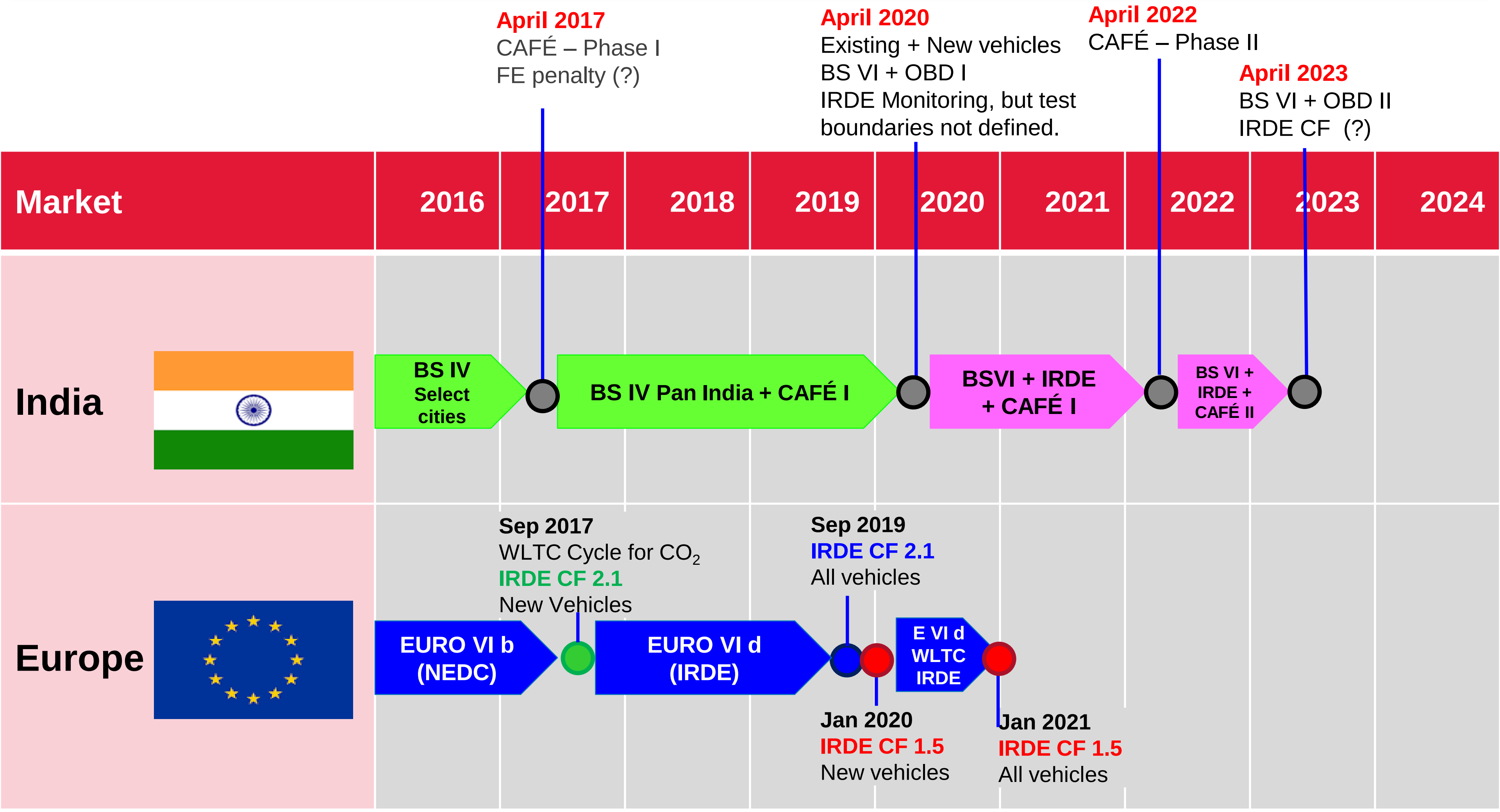
Real World Fuel Economy

Cost of Ownership

Sustainability Challenges & Emerging Trends

Upcoming Legislations | Technology Over view | Rear World Fuel Economy | Cost of Ownership

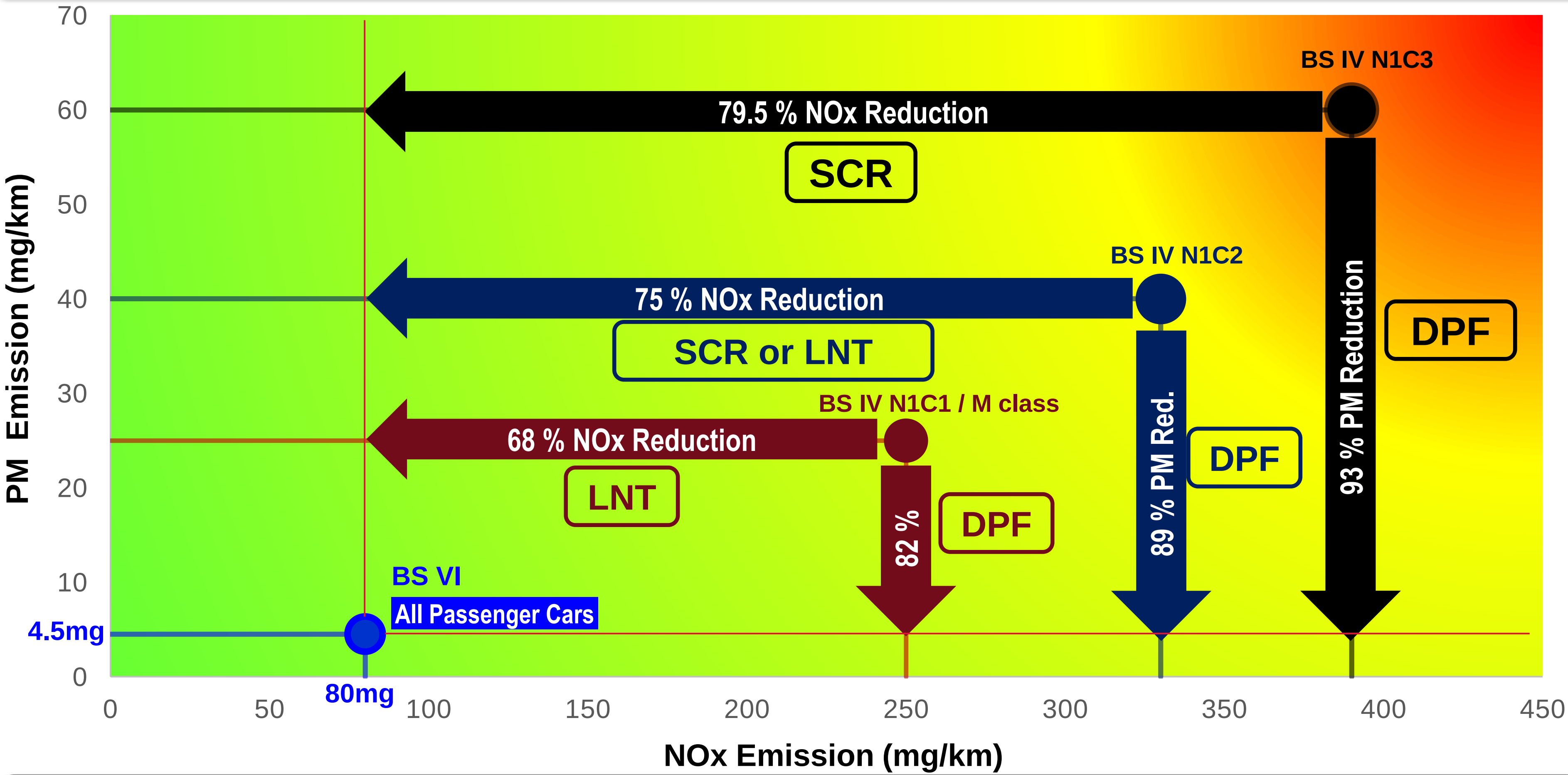
Legislation Overview in India



Sustainability Challenges & Emerging Trends

Upcoming Legislations | Technology Over view | Rear World Fuel Economy | Cost of Ownership

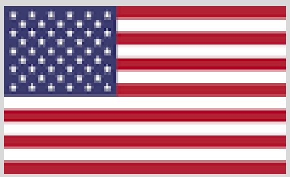
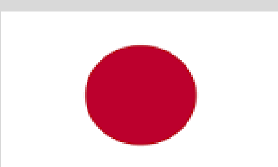
BS VI Emission in India – April 2020



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

Sustainability Challenges & Emerging Trends

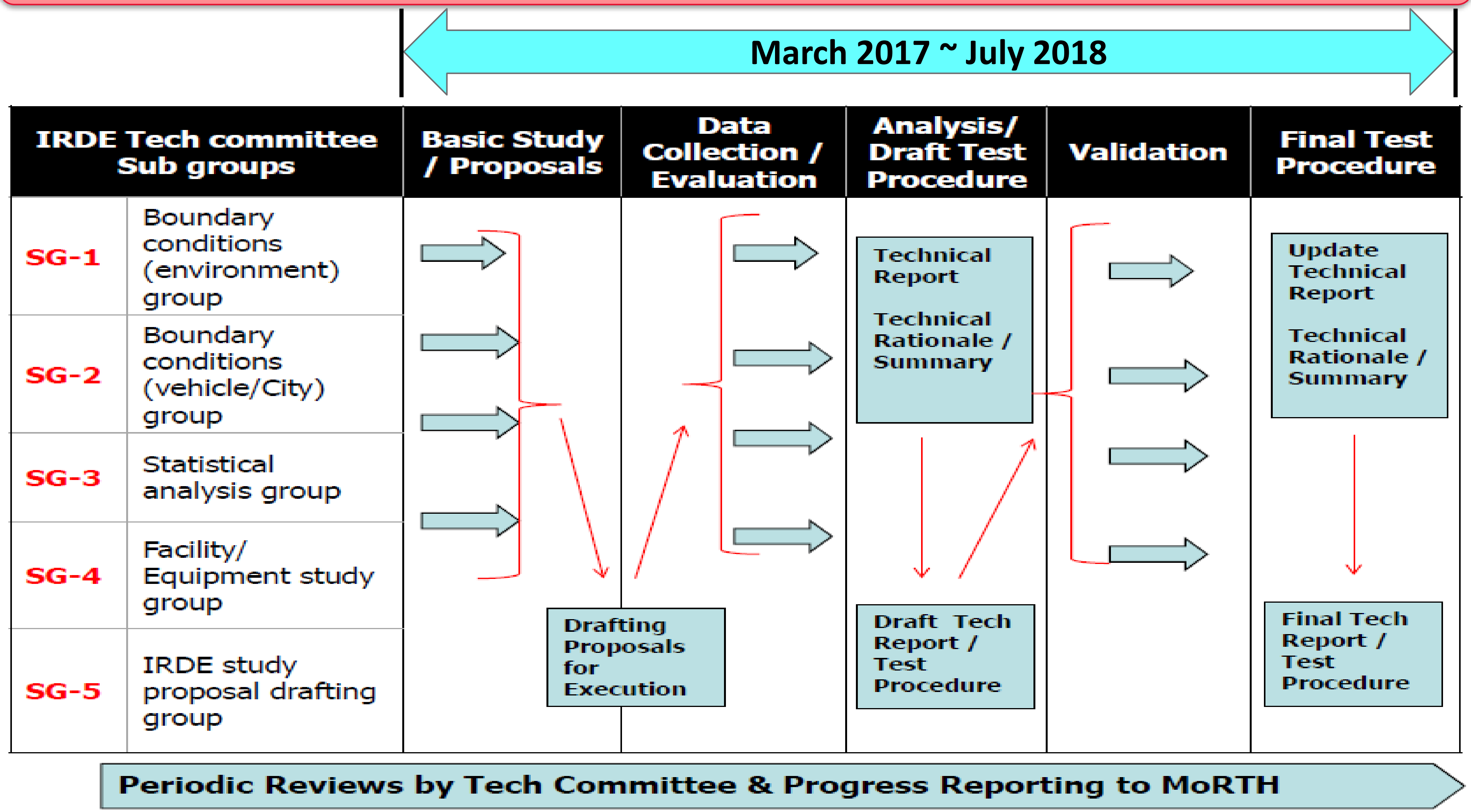
Indian Real Driving Emission (IRDE)

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	• Not Applicable	• Well Established • CF 2.1 : 2017 • CF 1.5 : 2020
	• JC 08	• Not Applicable	• Not Applicable
	• NEDC 90	• **Approach 1** • Random cycles with dynamic temperature and ambient pressure	• **Approach 2** • To derive from Europe

Sustainability Challenges & Emerging Trends

Upcoming Legislations | Technology Over view | Rear World Fuel Economy | Cost of Ownership

Indian Real Driving Emission (IRDE)

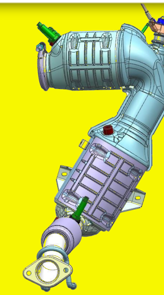


Sustainability Challenges & Emerging Trends

Major Drivers – Automotive Powertrain

Upcoming Legislations
- CO_2 Ph I & Ph II
- Emission 2020, IRDE
- Safety 2019

Technology Overview



Real World Fuel Economy

Cost of Ownership

Sustainability Challenges & Emerging Trends

Upcoming Legislations | **Technology Over view** | Rear World Fuel Economy | Cost of Ownership

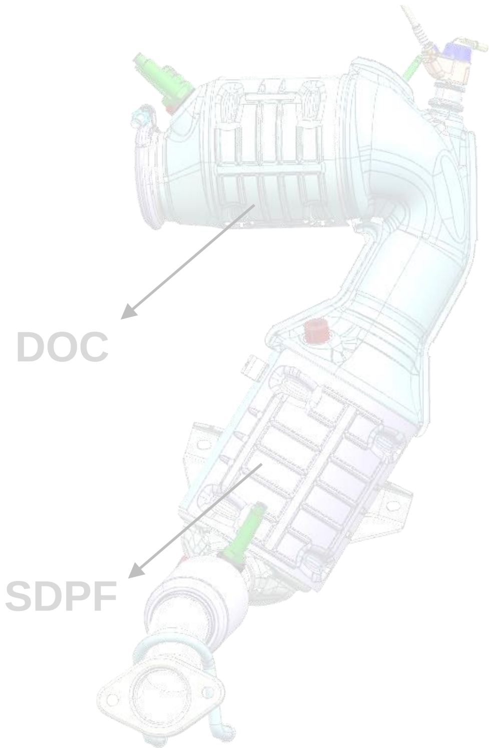
Exhaust After-treatment - Challenges

PM Reduction

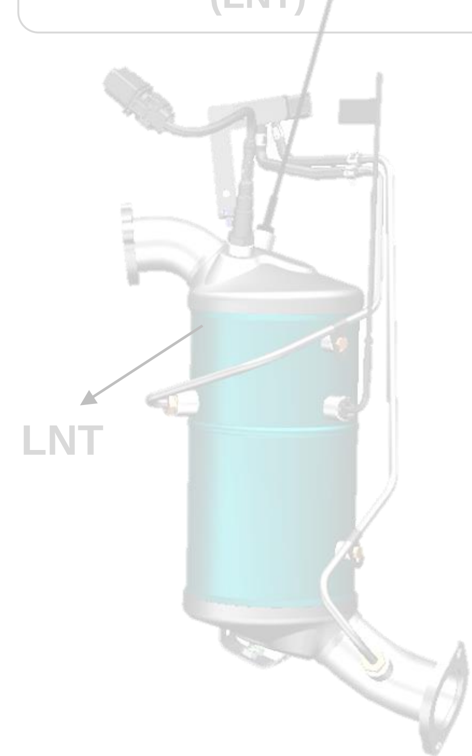
Diesel Particulate Filter (DPF)

NOx Reduction

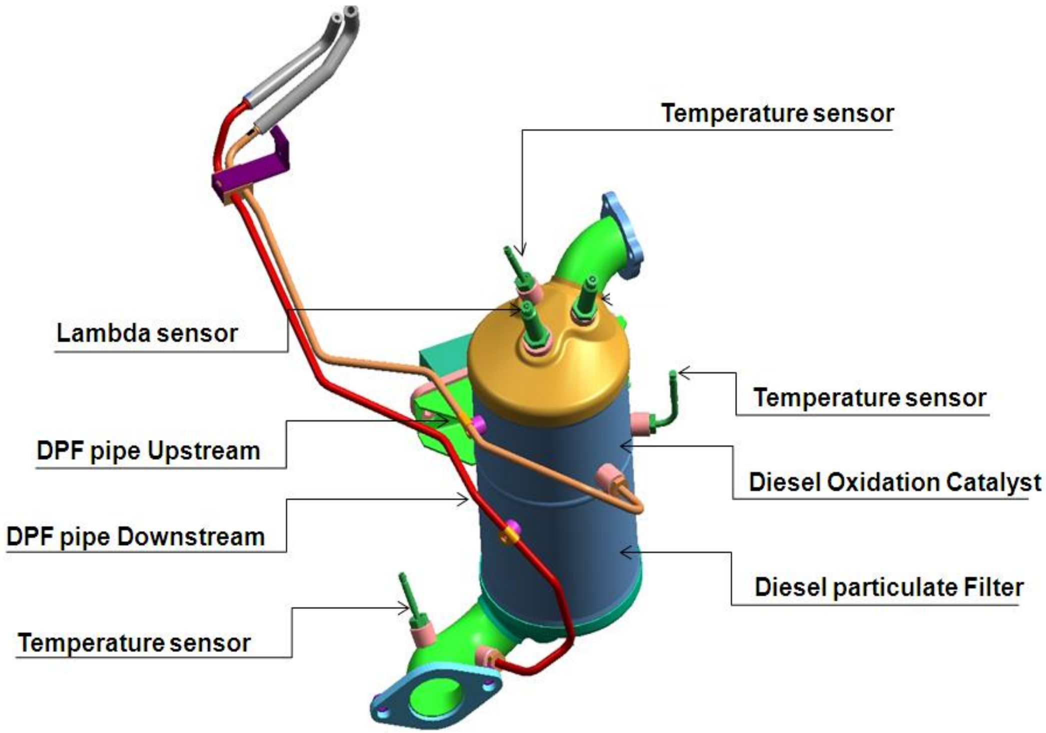
Selective Catalytic Reduction (SCR)



Lean NOx Trap (LNT)



DPF – An Overview



Sensors

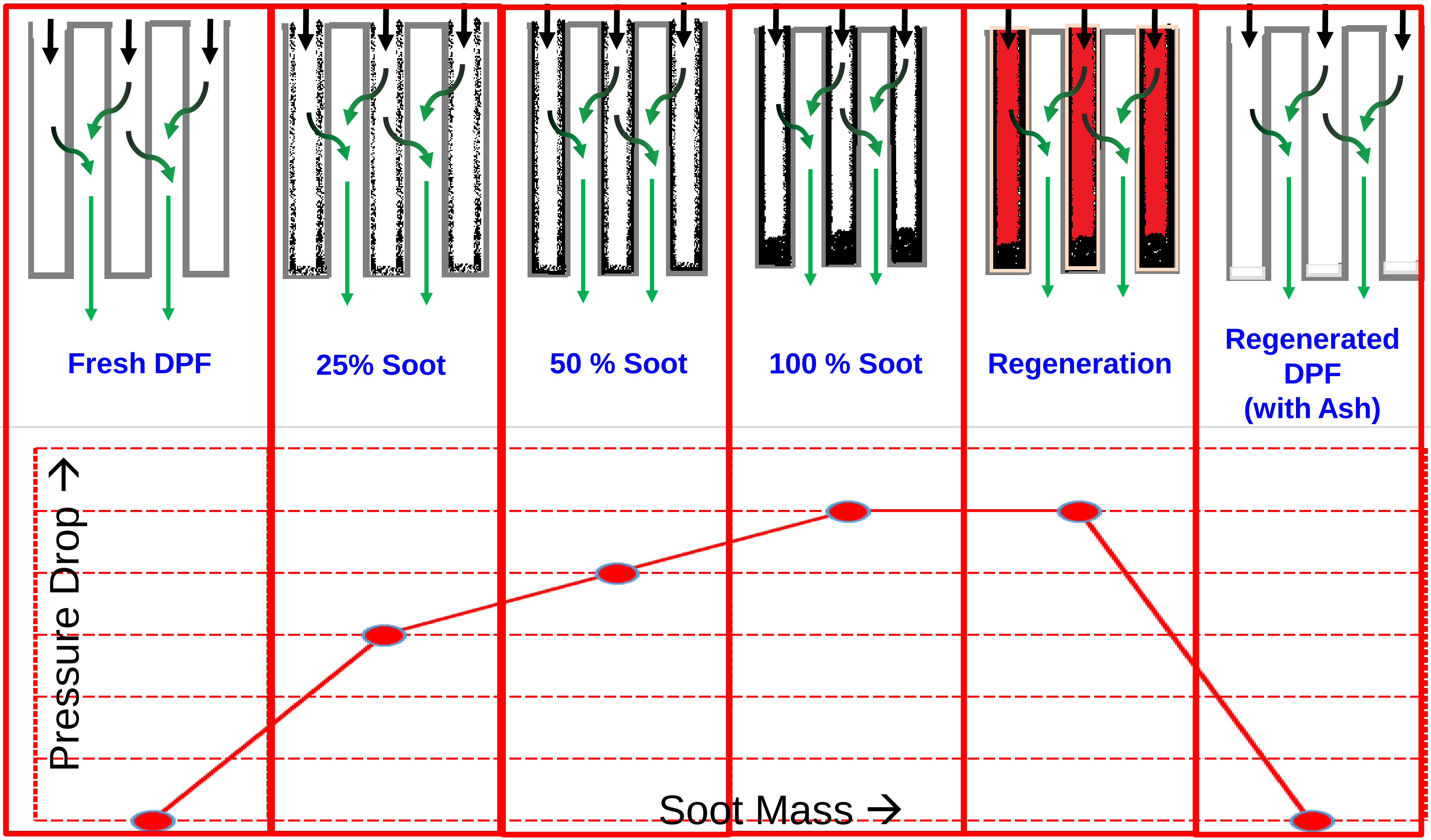
- Exhaust Temperature sensor (Before Oxidation catalyst)
- Exhaust Temperature sensor (Before particulate filter)
- Differential pressure sensor
- Lambda sensor

DPF is mandatory for emission norms BSV and beyond

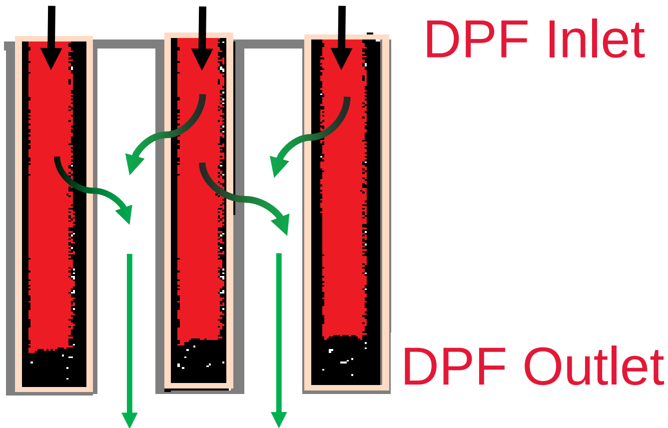
Sustainability Challenges & Emerging Trends

Upcoming Legislations | **Technology Over view** | Rear World Fuel Economy | Cost of Ownership

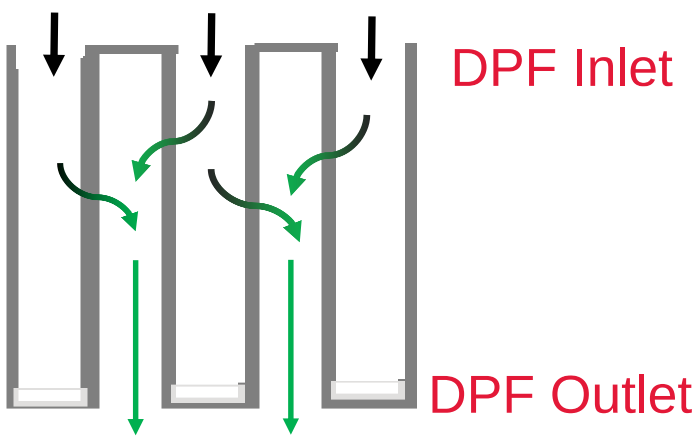
DPF – An Overview



DPF – An Overview



Before Regeneration

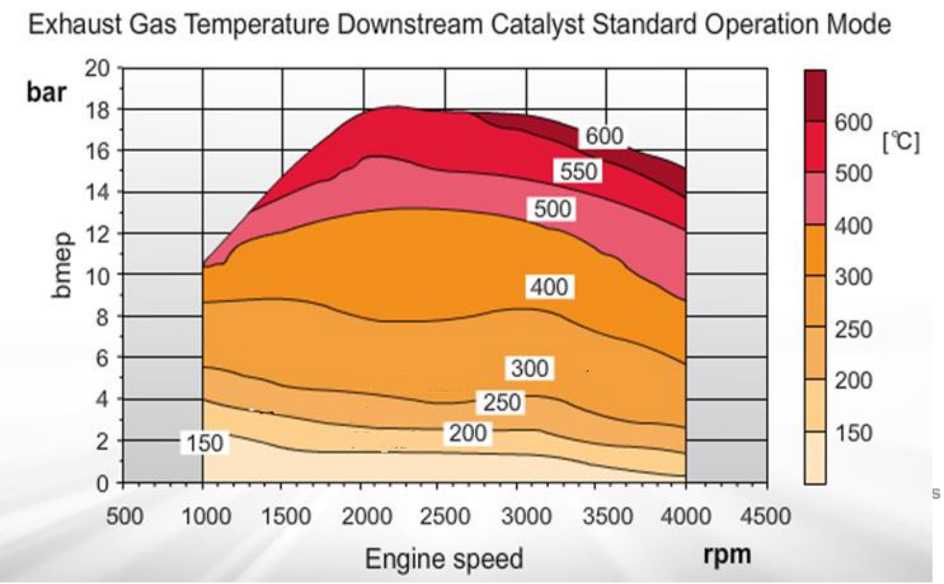


After-Regeneration

- **The process of burning the particulates accumulated in the DPF is called "Regeneration"**
  - **$C + O_2 \rightarrow CO_2$ (Active Regeneration)**
  - **$C + 2NO_2 \rightarrow CO_2 + 2NO$ (Passive Regeneration)**
- **Active regeneration needs temperatures ~600 Deg C in the presence of O_2**
- **Passive regeneration required temperatures are 250 ~450 Deg C with the presence of NO_2**

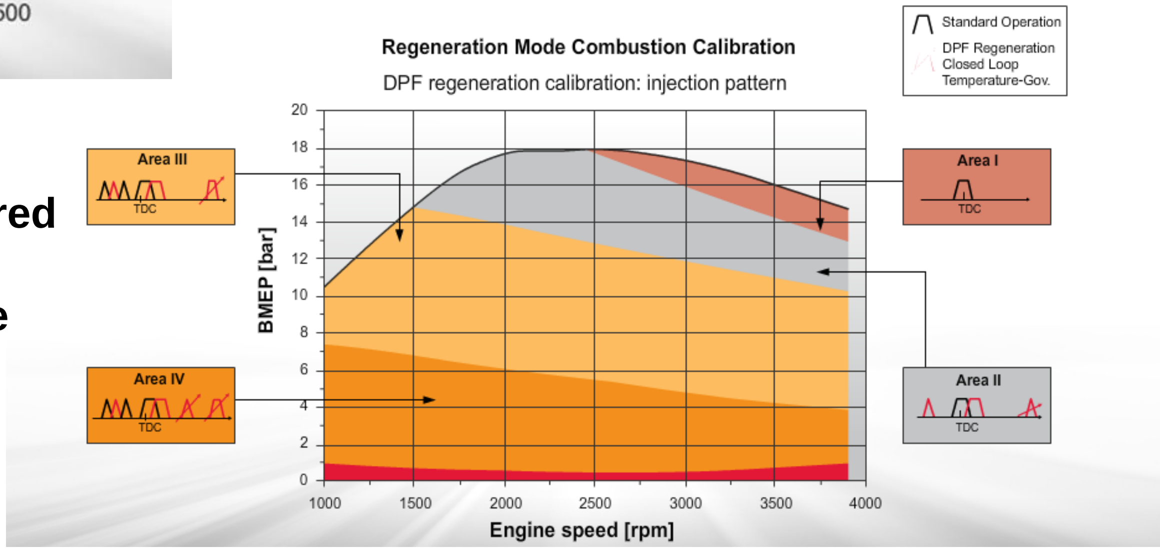
Sustainability Challenges & Emerging Trends

DPF – An Overview



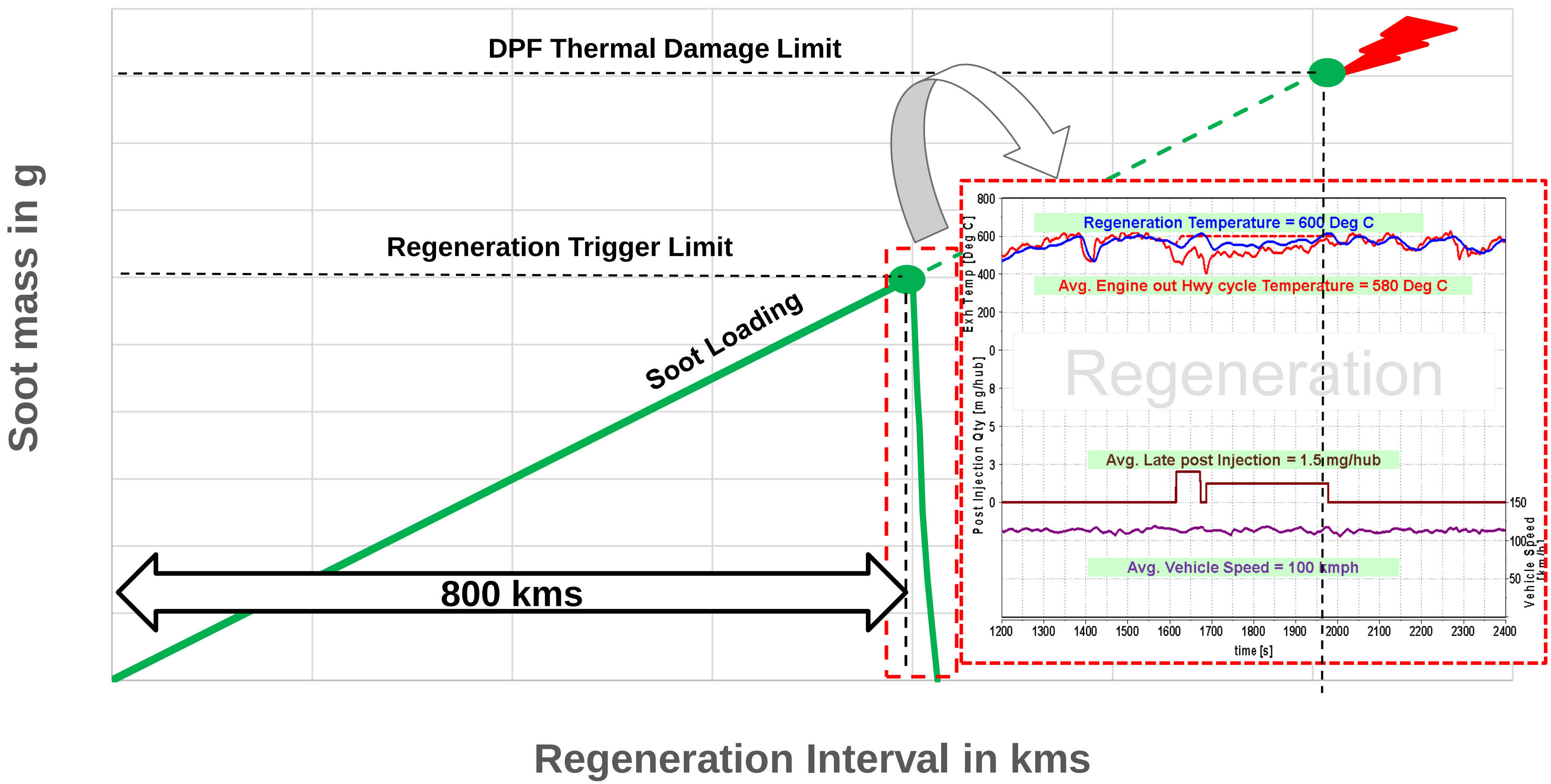
- Need for high regeneration Interval
- To maximize CRT effect
- Thermal Regeneration at high loads

- Lambda of Exhaust > 1.05 preferred
- Low EGR levels to control smoke
- Optimal Injection Strategy



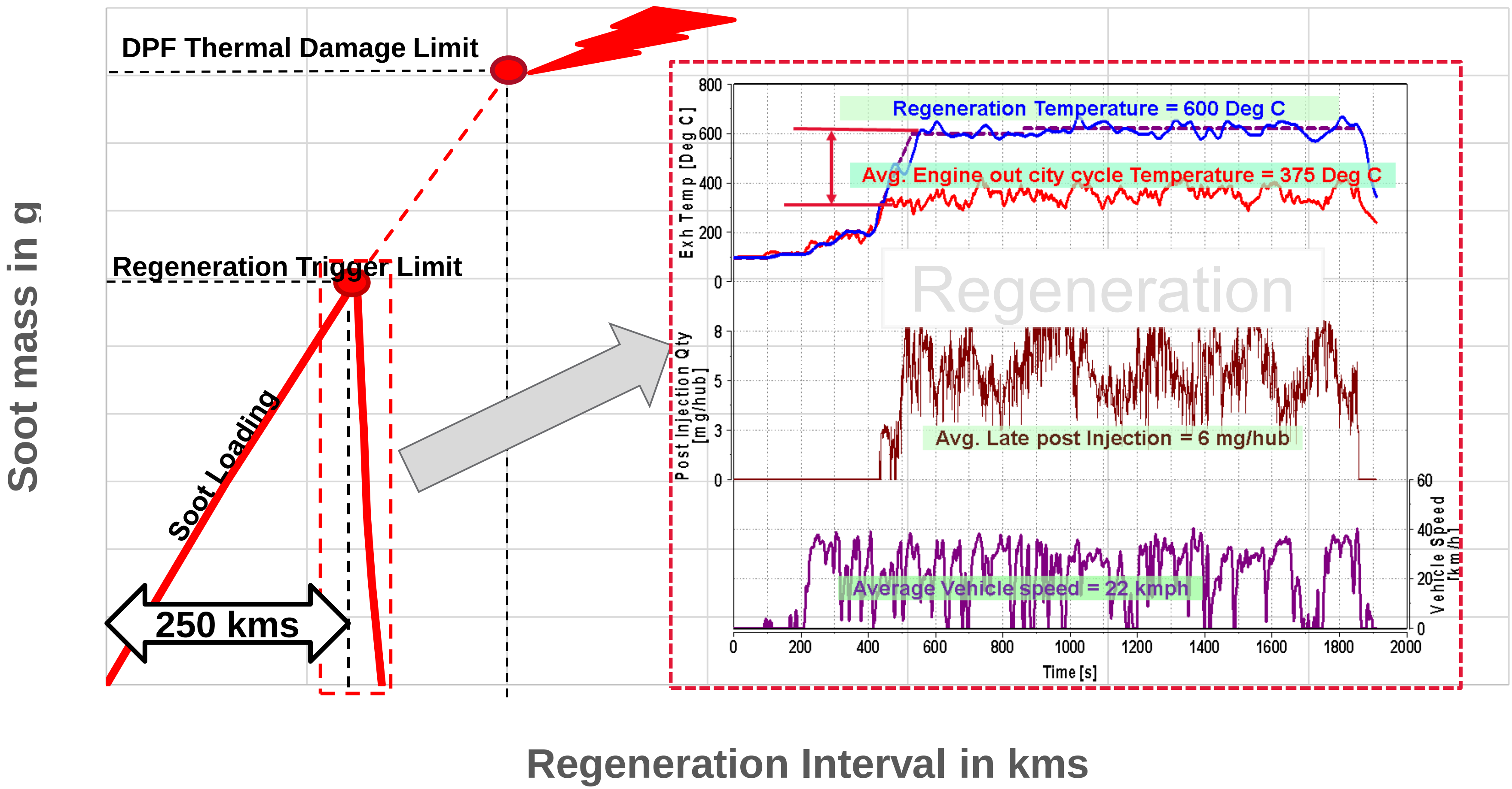
DPF – An Overview

Highway Cycle

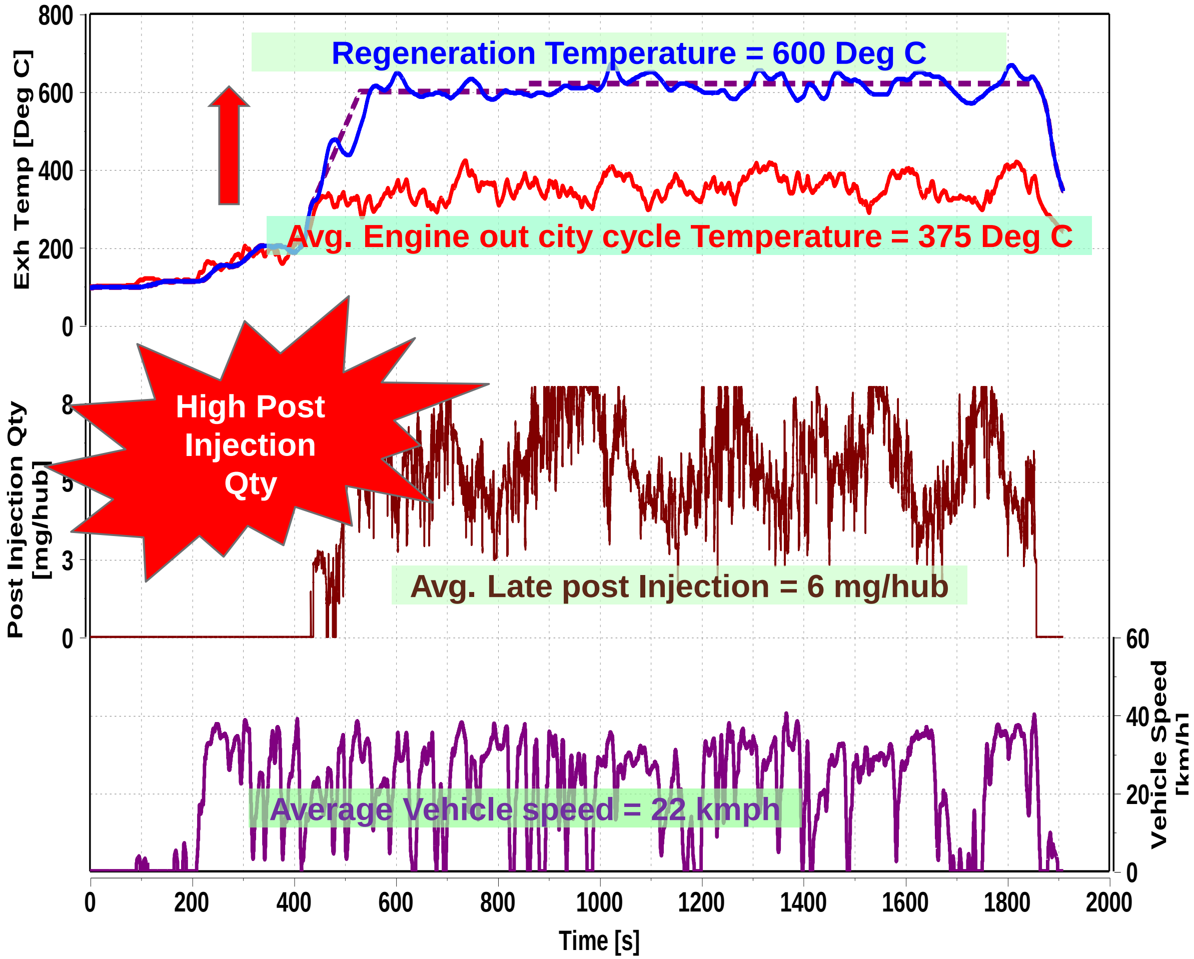


DPF – An Overview

City Cycle



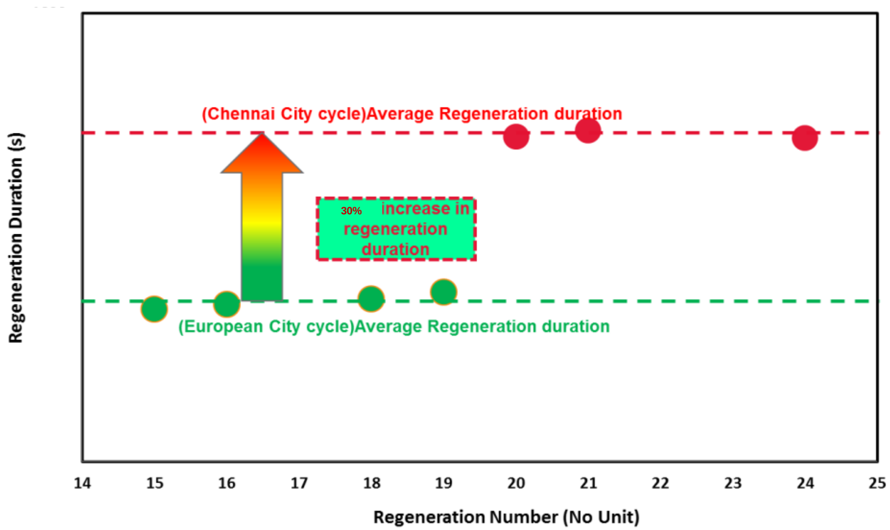
DPF – An Overview



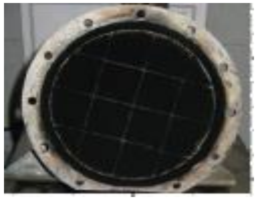
- In the city cycle, the engine out temperatures are lower due to the Lower engine load points. Temperature is about 375 Deg C
- To Increase the temperatures to Regeneration temperatures a technology called "**Late Post Injection**" needs to be adapted
- This late post injection is a " Cat-burner"
- Late Post Injection in the magnitude of 6 mg/hub is sufficient to burn the soot in the DPF
- In city cycle regeneration, the risks of poor regeneration efficiency is higher leading to higher oil Dilution.

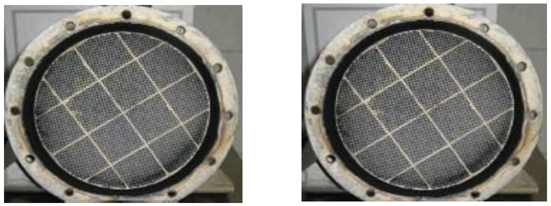
Sustainability Challenges & Emerging Trends

DPF – An Overview

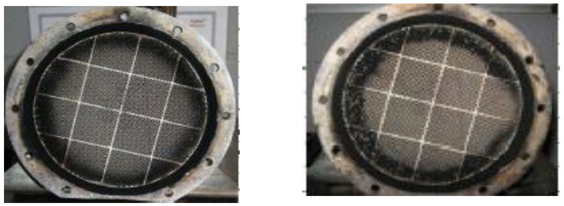


Before Regeneration

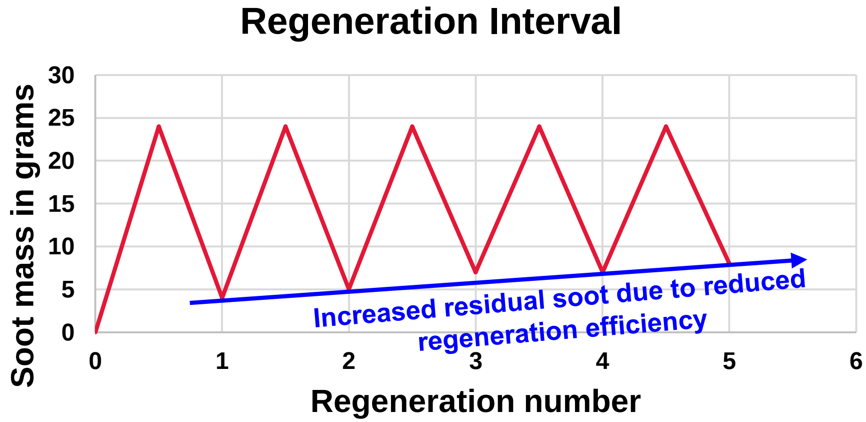




European city cycle regeneration



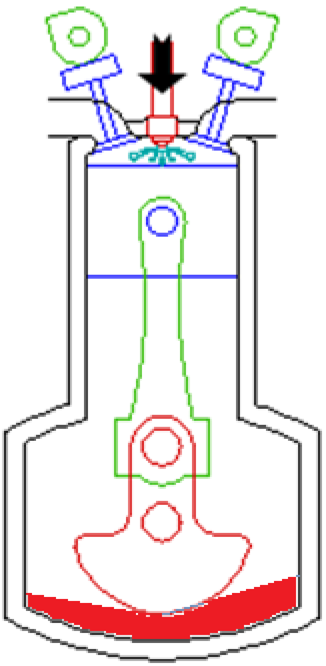
Chennai city cycle regeneration



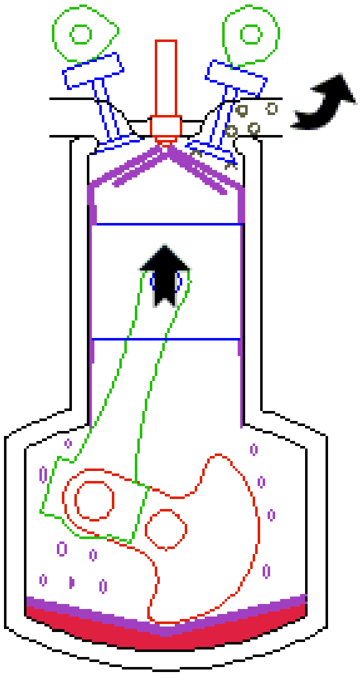
- Indian driving conditions require ~ 30% more regen duration than Europe
- In spite of High regeneration duration, still soot is not fully burnt

DPF – An Overview

Oil Dilution Phenomenon



Conventional Injection targeted to hit the Combustion bowl

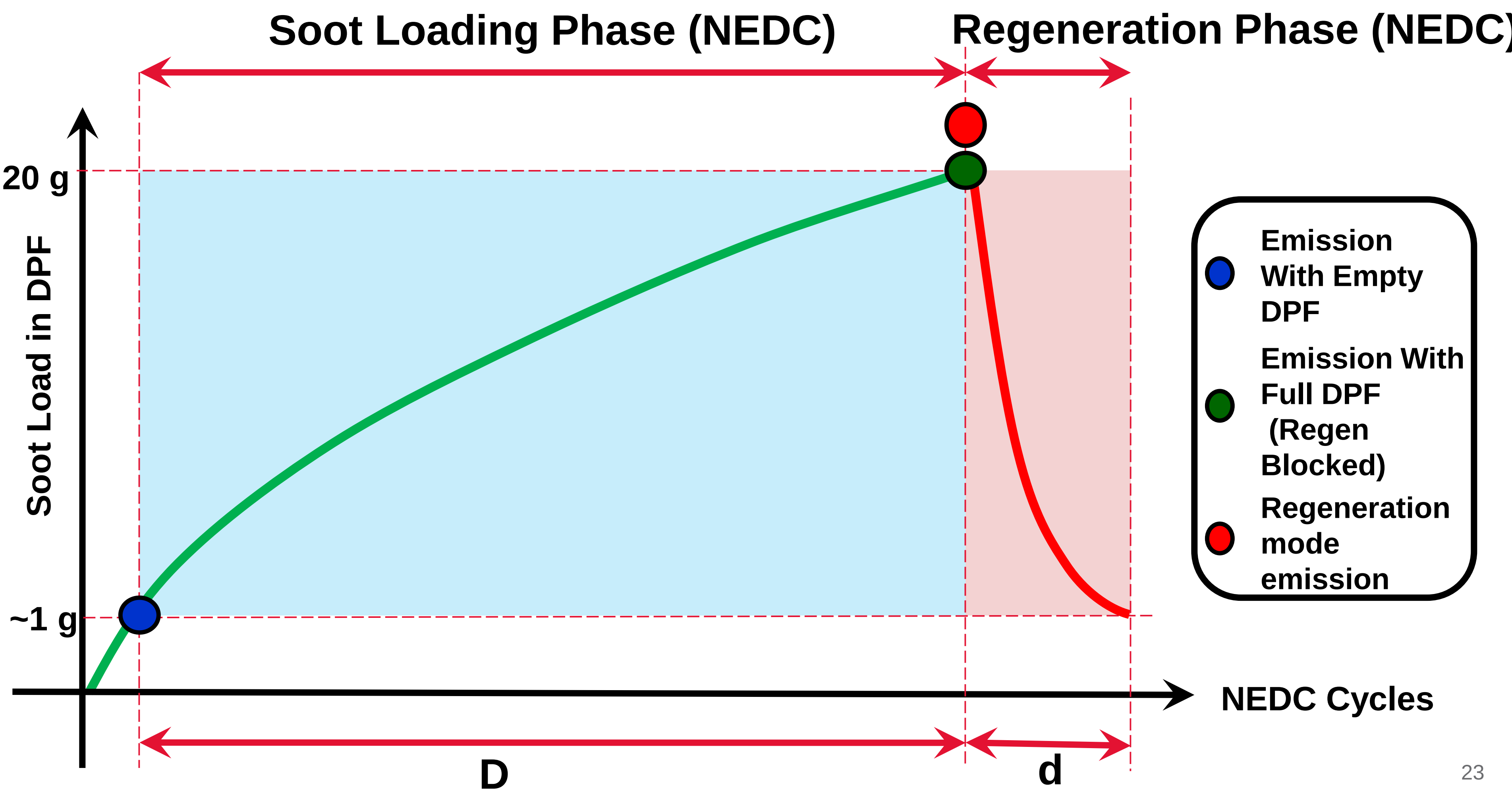


Late Post Injection impinging on the cylinder walls

- In the conventional diesel engine combustion the injection is targeted to hit the combustion bowl where it is expected to get combusted.
- In the late post injection concept the diesel injector injects at a very retarded timing, thereby the Hydro-carbons are released into the exhaust for increasing the exhaust temperatures via the Diesel Oxidation catalyst by exothermic.
- As the injection impinges on the cylinder walls, the diesel dribbles through the piston rings and gets accumulated in the oil Sump.
- This results in the phenomenon of "**Oil Dilution**" where the engine lube oil gets mixed with diesel fuel.
- With increase in the number of regenerations the diesel level mixing with the lube oil increases leading to diesel carry over into the intake pipe through the crankcase blow-by system. This results in un-intended acceleration of the engine due to the fuel vapors. This phenomenon is called **"Self-acceleration"**

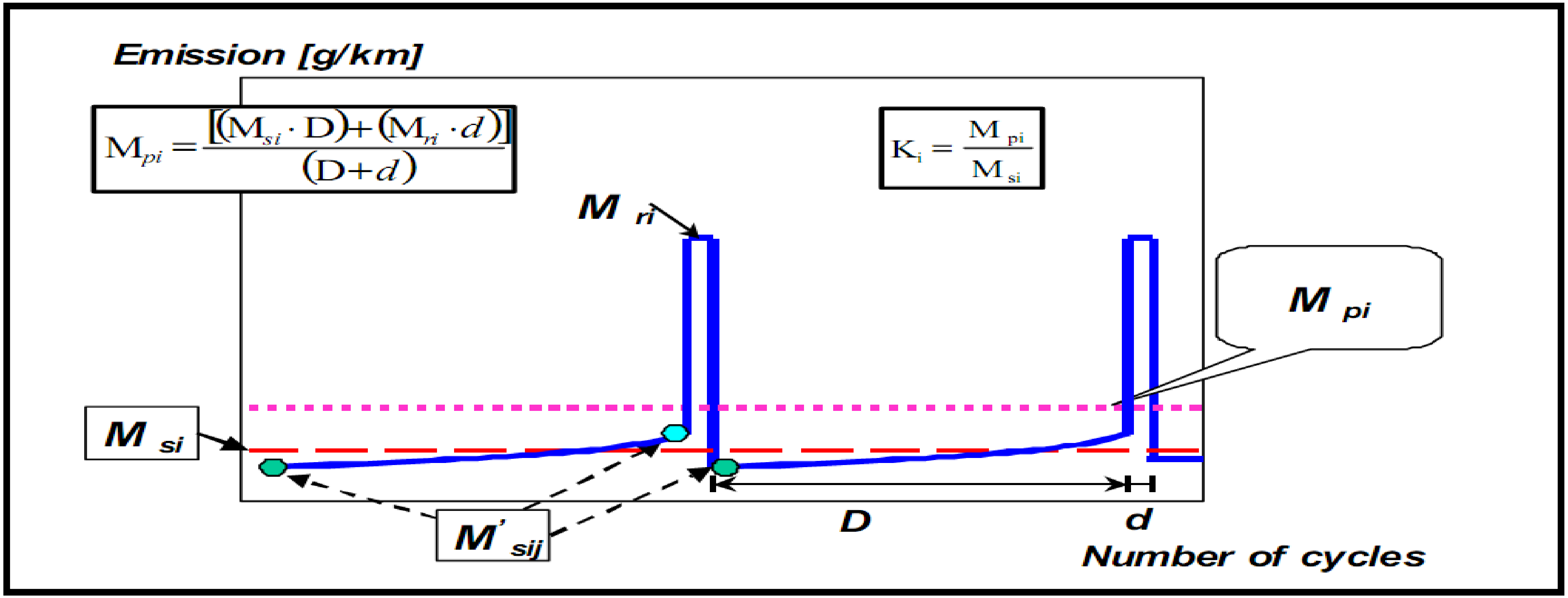
DPF – An Overview

- **Description of parameters used to identify soot loading**



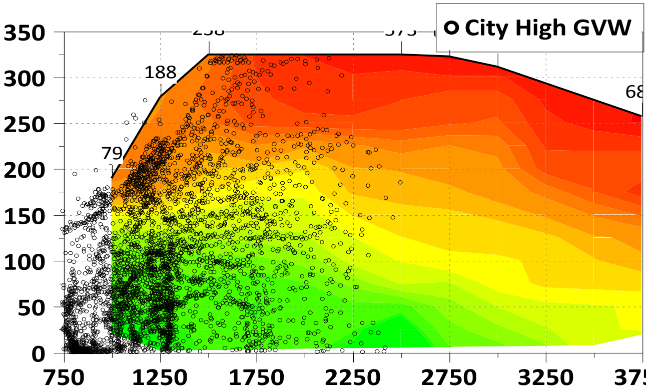
DPF – An Overview

- **Procedure and Formulae to be followed as per standard R83**



M_{si} – Emissions measured in Normal mode in g/km
M_{ri} – Emissions measured in regeneration mode in g/km
D - Number of NEDC cycles completed in Normal mode from '0'g soot loading to Fully soot loaded DPF
d – Number of NEDC cycles completed in Regeneration Mode

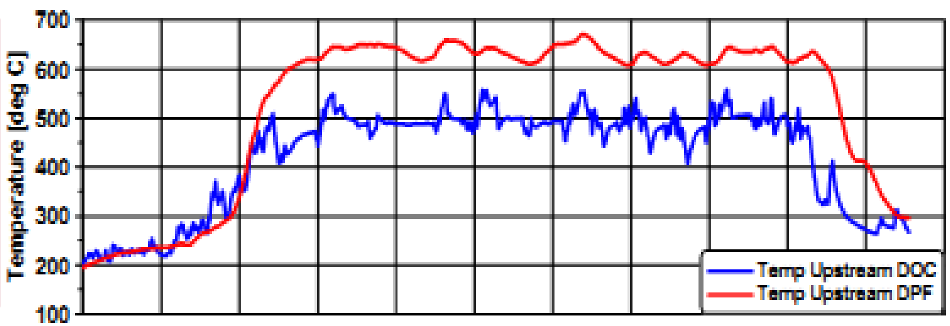
DPF – Challenges in Indian Market



- Thick Road Traffic, extended idle : Critical for DPF Regeneration
- Extreme operations : 0 ~ 5500 m, + 52 °C, low city avg speed of ~ 8 kmph
- Low engine speed / high load driving behavior

DPF – Challenges in Indian Market

Regeneration Requirements

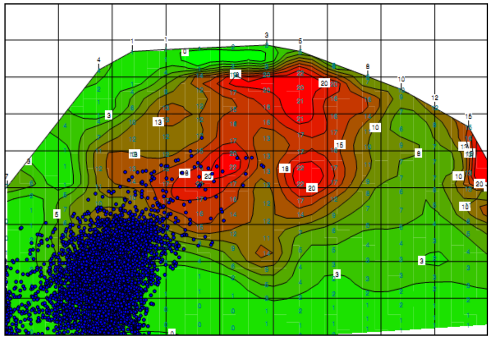


- **Regeneration Needs**
  - Exhaust Temperature ~ 600°C
  - O2 Content in Exhaust ~ 5%
  - Irrespective of climatic condition
  - Irrespective of cycles & altitude

Traffic Conditions

- **Traffic Condition**
  - Very low average speed - 6 kmph
  - High Idle duration
  - Very transient Driving behavior
  - Extreme temperature & altitude

DPF Challenges



- **Unfavorable DPF Regen.**
  - Extended Long Regen. duration
  - Low Exh. Mass flow
  - Risk of Temp. Over shoot DTIT
  - High Oil Dilution

Sustainability Challenges & Emerging Trends

Upcoming Legislations | Technology Over view | Rear World Fuel Economy | Cost of Ownership

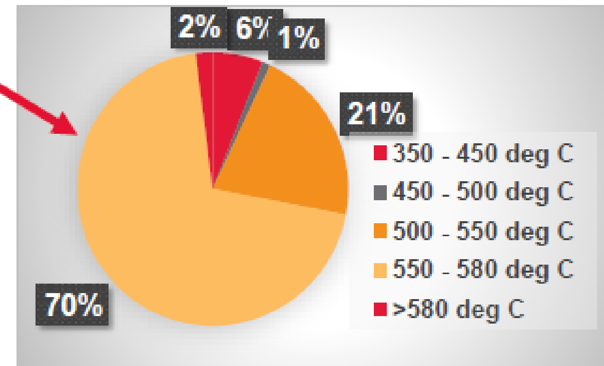
DPF – Challenges in Indian Market

- **Typical City operation & DPF scenario**

Data from Chennai City cycle

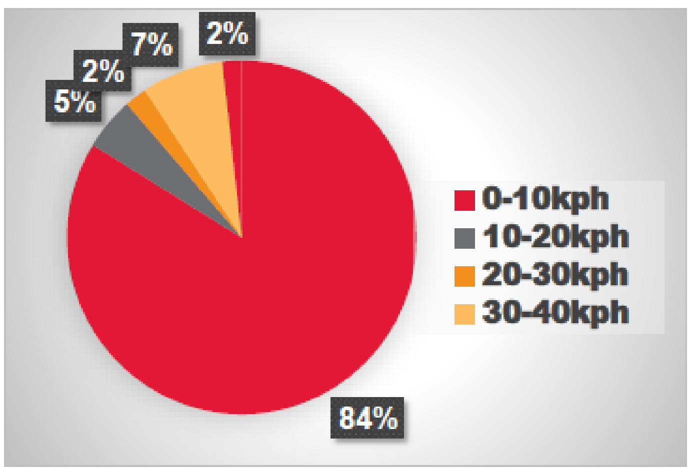
Even with POI 1 qty of 8 mg/hub, actual T5 temp. always 50 deg C less than the desired T5 demanded by ETCtl

T5 distribution when vehicle speed between 0 and 10 kmph

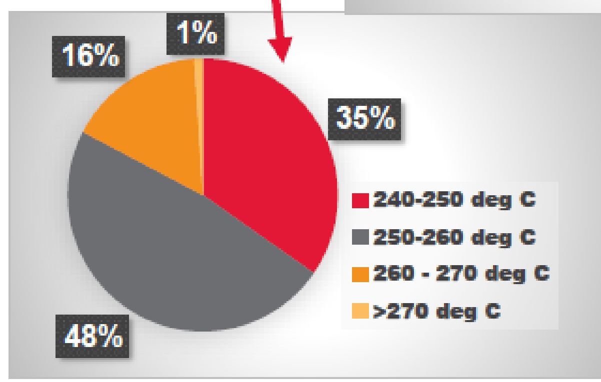


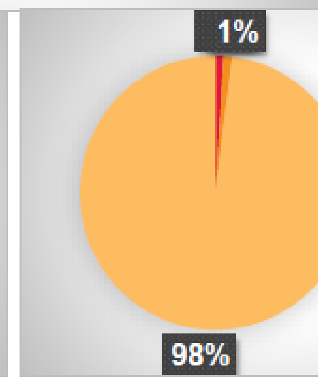
POI1 qty when vehicle spped between 0 to 10 kmph

Vehicle velocity distribution



T4 distribution during vehicle speed of 0- 10 kmph



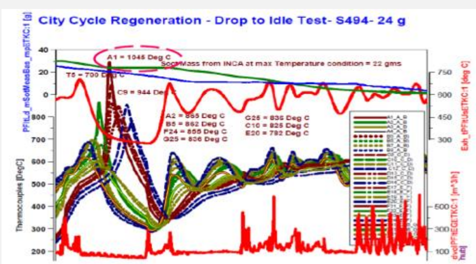


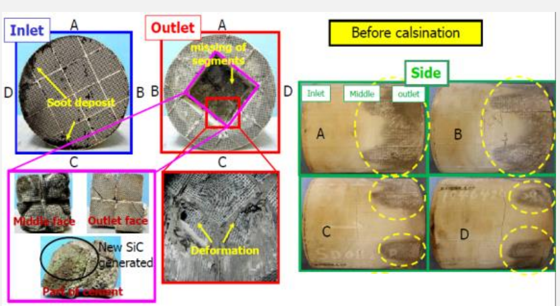
POI 1 > 7mg risky for oil dilution

- 35% higher Regeneration frequency
- 30% extended Regeneration duration
- Risk of high oil dilution - unintended self acceleration, a safety concern

DPF – Challenges in Indian Market

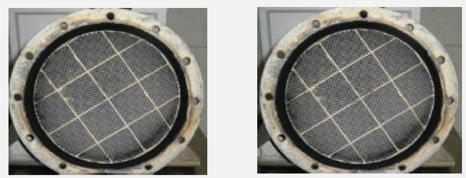
High Temperature & Thermal Stress



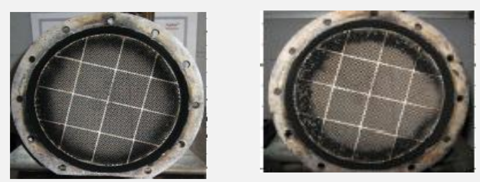


Oil Dilution

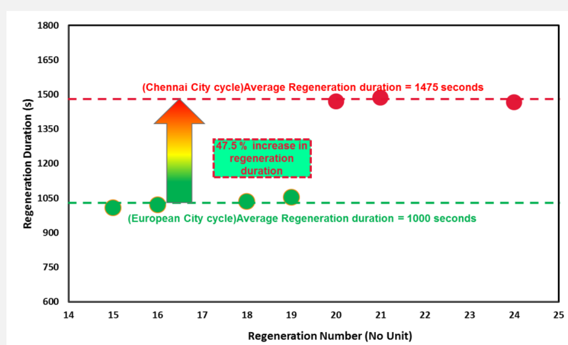
Increased Regeneration Frequency
Extended Regeneration duration



European city cycle regeneration

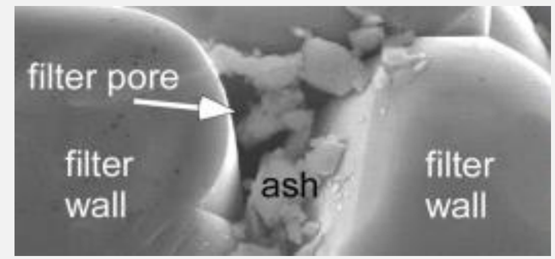


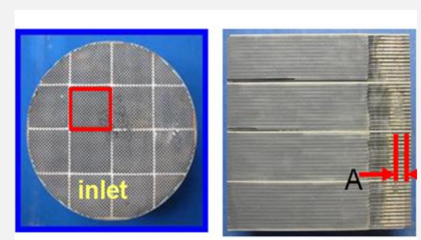
Chennai city cycle regeneration



Ash Deposition

Fuel & Oil Quality



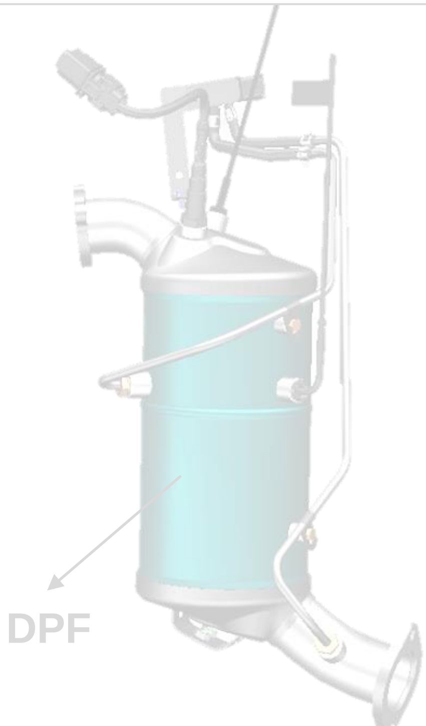


Sustainability Challenges & Emerging Trends

Technologies to meet BS VI in Diesel

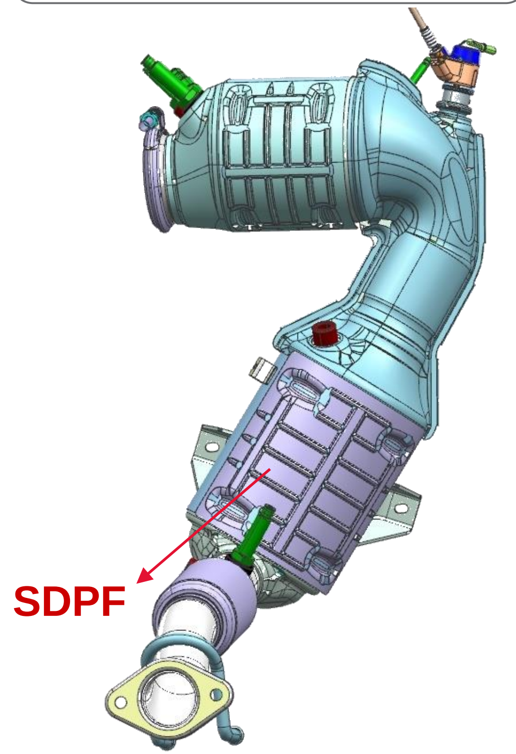
PM Reduction

Diesel Particulate Filter (DPF)

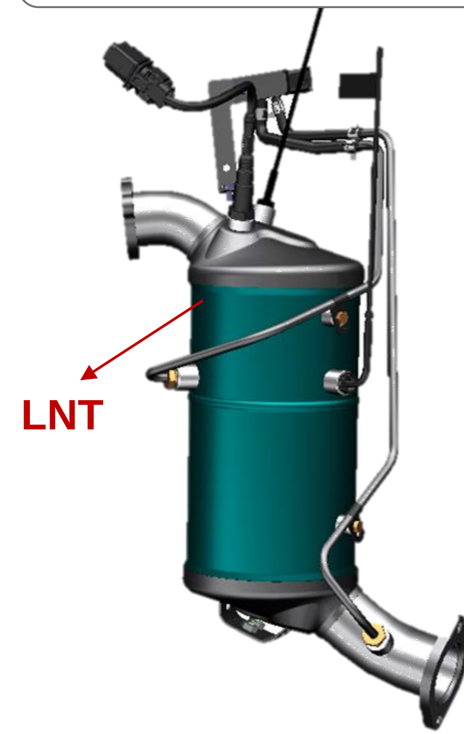


NOx Reduction

Selective Catalytic Reduction (SCR)

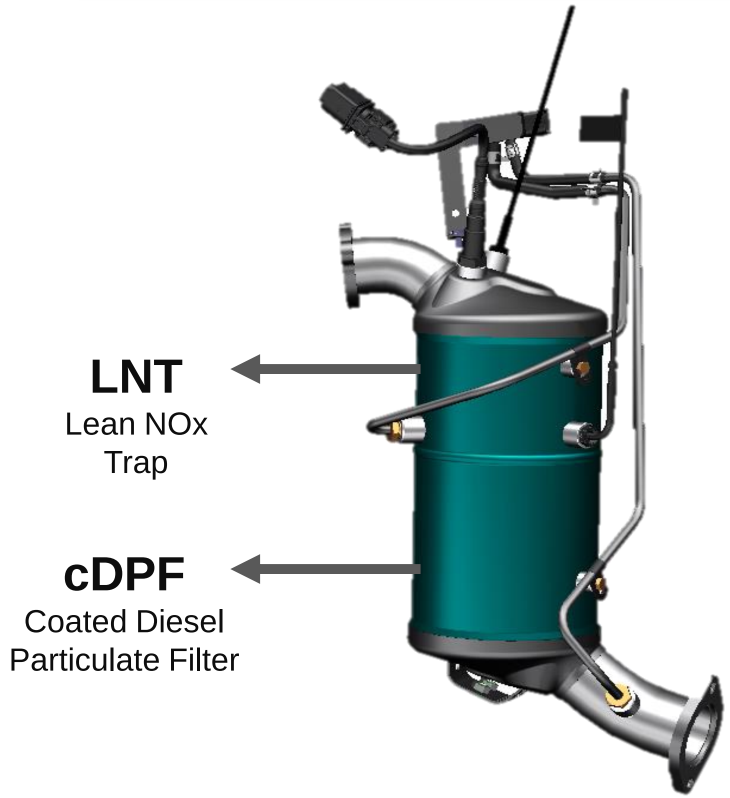


Lean NOx Trap (LNT)



LNT – An Overview

Lean NOx Trap (LNT)



- Chemical Based filter for Nox
- Stores the NO_2 in lean phase
- NO_2 gets reduced to N_2 in Rich Phase
- Performance is dependent on
  - Exhaust Temp
  - Space Velocity
  - NOx Pre Load
  - NOx Concentration

System Requirements

- 2 Lambda Sensors – 1 US and 1 DS
- Temperature US and DS LNT
- Well Calibrated Air system for Lean - Rich transition

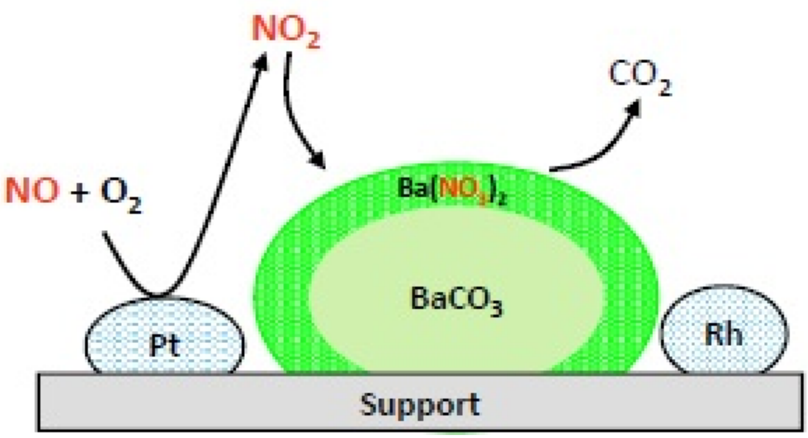
Sustainability Challenges & Emerging Trends

Upcoming Legislations | **Technology Over view** | Rear World Fuel Economy | Cost of Ownership

LNT – An Overview

NOx Storage Mode

LNT – Lean Operation (λ > 1)

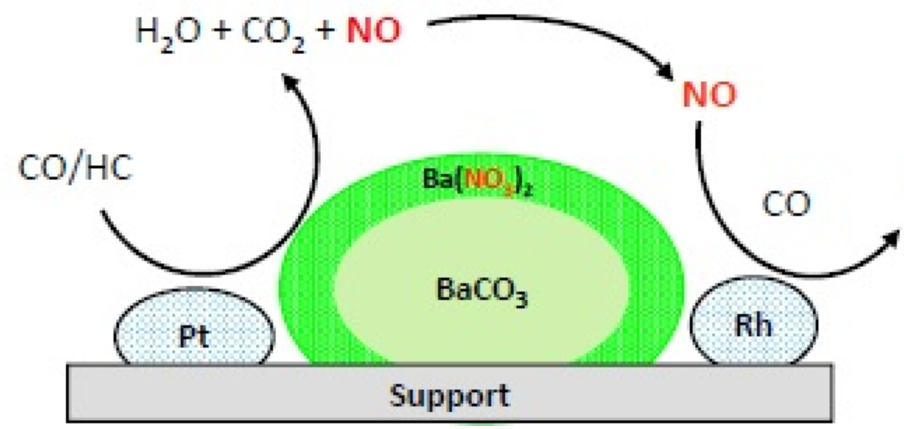


- NOx Oxidation & Storage
- 99% of cycle time

- $2NO + O_2 \xrightarrow{Pt} 2NO_2$
- $6NO_2 + 2BaCO_3 \rightarrow 2Ba(NO_3)_2 + 2CO_2 + O_2$
- $6NO_2 + 2BaO \rightarrow 2Ba(NO_3)_2 + O_2$

NOx Regeneration Mode

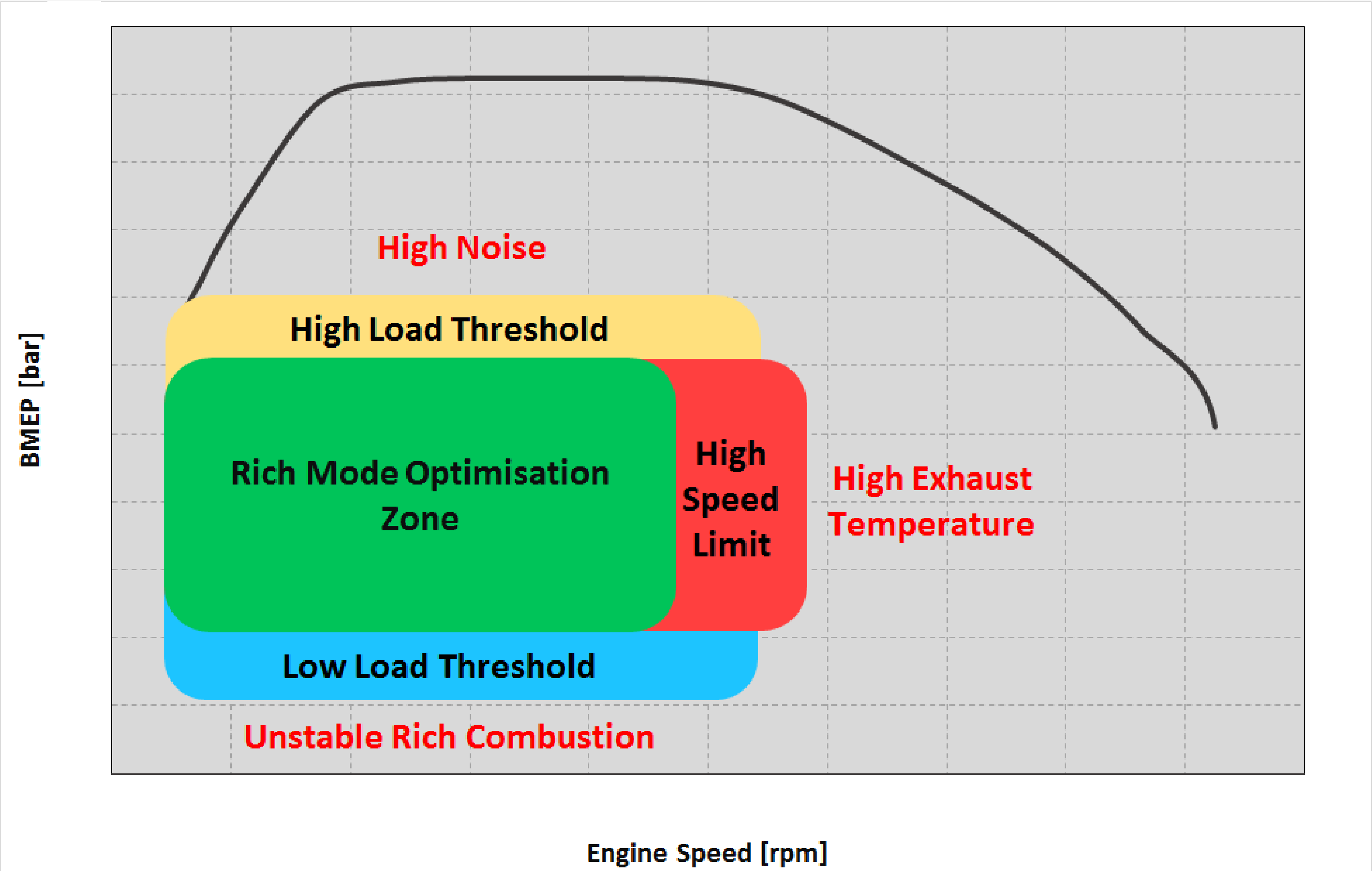
LNT – Rich Operation (λ < 1)



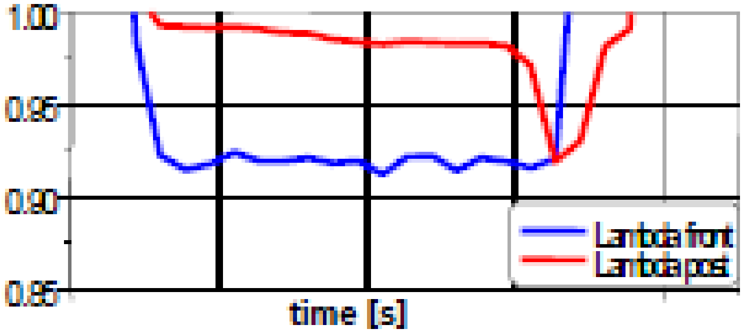
- NOx Release & Reduction
- 1% of cycle time (8 ~ 10 Sec)

- $Ba(NO_3)_2 + CO \xrightarrow{Rh} BaCO_3 + 2NO_2$
- $2NO_2 + 4CO \xrightarrow{Rh} N_2 + 4CO_2$
- 10NO2+ 2C3H8 → 5N2 + 6CO2 + 8H2O

LNT – An Overview



LNT – An Overview



Targets of Rich Mode:

- Should have no change in torque when mode change over happens.
- No change in Noise.
- FE penalty should be as minimum as possible.
- Smoke values during rich pulse should be as minimum as possible as it will impact the DPF Regen interval.

Requirements of Rich Pulse

- CO > 2%
- HC < 0.8 %
- O2 < 0.8 %
- Smoke as less as possible

Trigger Point for Rich Pulse

- Engine out Nox Integral
- Target Tail Pipe emissions
- Ageing of the LNT
- Sox Load

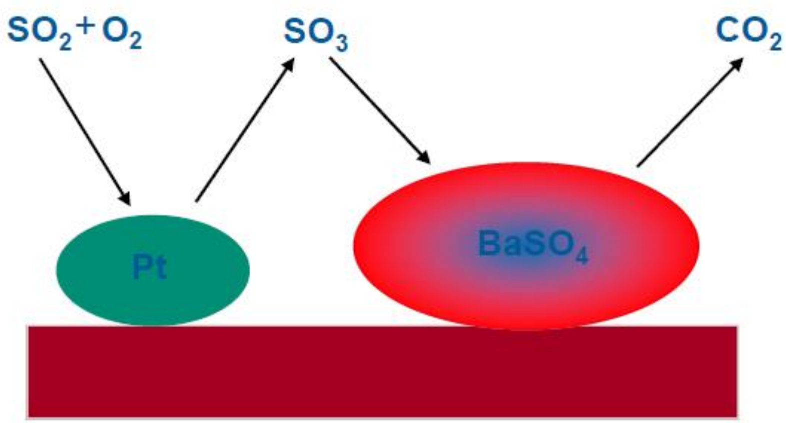
Detection of End of LNT Regen

- When the down stream Lambda sensor turns to rich and crosses upstream sensor value.

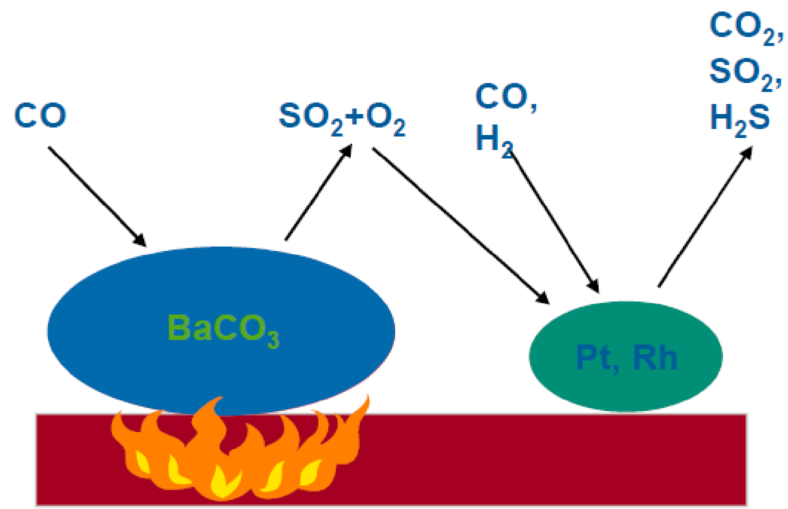
Sustainability Challenges & Emerging Trends

LNT – An Overview

LNT – Lean Operation (λ >1)



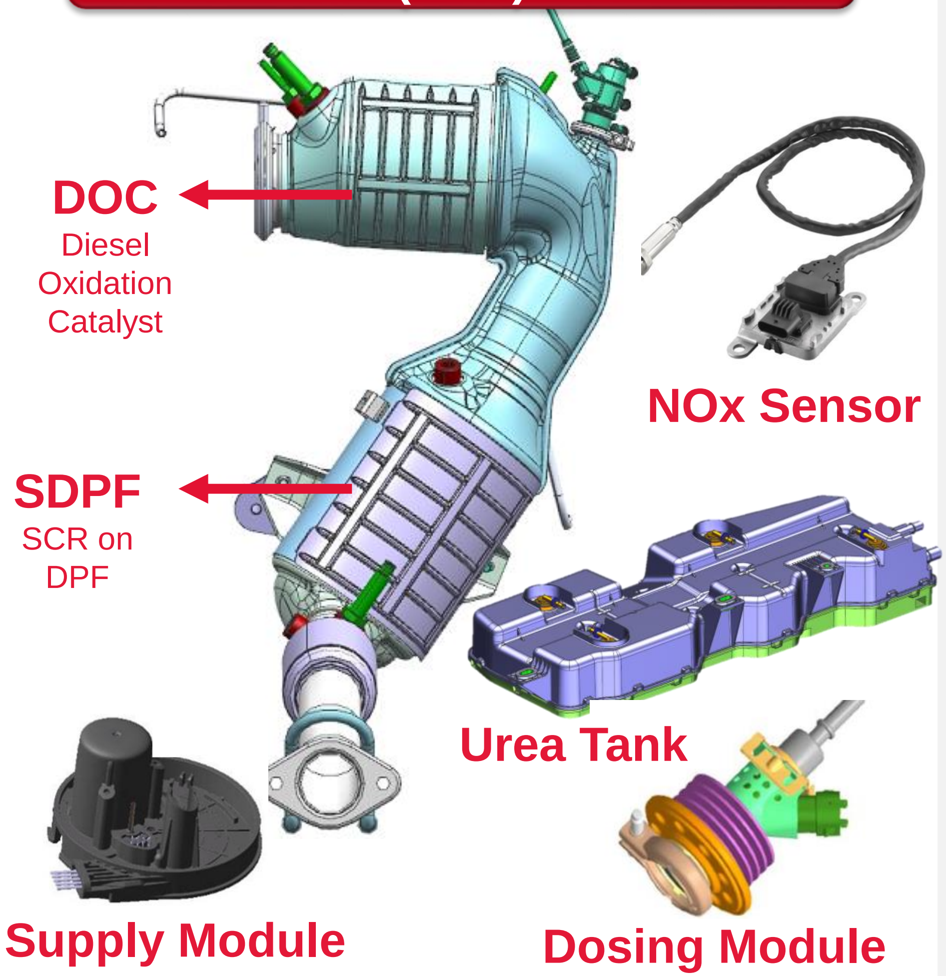
LNT – Rich Operation (λ <1)



- Fuel Sulphur poisons NOx Storage sites by forming Sulphates.
- De-sulphation needed to activate poisoned sites
- Frequency : ~ 800 km to 1000 km with 10ppm Sulphur fuel
- 600ºC to 750ºC with λ<1 to avoid LNT damage.

SCR – An Overview

Selective Catalytic Reduction (SCR)



- **High Efficiency**
- **Wide range function**
- **Independent of engine system**
- **Modular / Sizable Technology**
- **Sulphur Resistive**
- **Higher System Price**
- **Extremely Complex System**
  - **Urea tank & Filling System**
  - **Supply Module**
  - **Dosing Module**
  - **Urea Mixer**
  - **Urea Warning System**

SCR – An Overview

- **SCR needs aqueous urea solution for NOx reduction.**
- **Mixer for uniform distribution of urea into catalyst.**
- **Metallic zeolites (Mainly Copper & Iron) in wash coat.**
- **Higher NOx conversion from ! 200 °C onwards**
- **Aqueous urea freezes below -11 Deg C**

Urea Decomposition

Thermolysis (160 – 180 ° C)

H2N – Co – NH2 → NH3 + NHCO

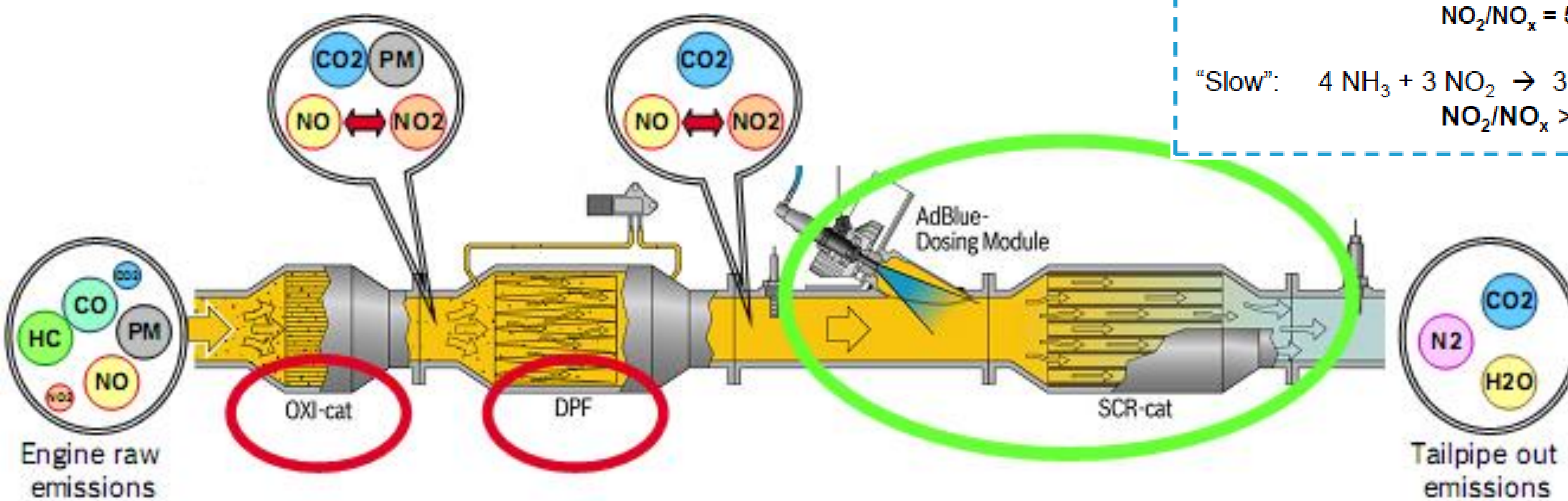
Hydrolysis (180 – 200 ° C)

HNCO + H2O → NH3 + CO2

Std.: $4\ NH_3 + 4\ NO + O_2 \rightarrow 4\ N_2 + 6\ H_2O$
NO_2/NO_x <50%

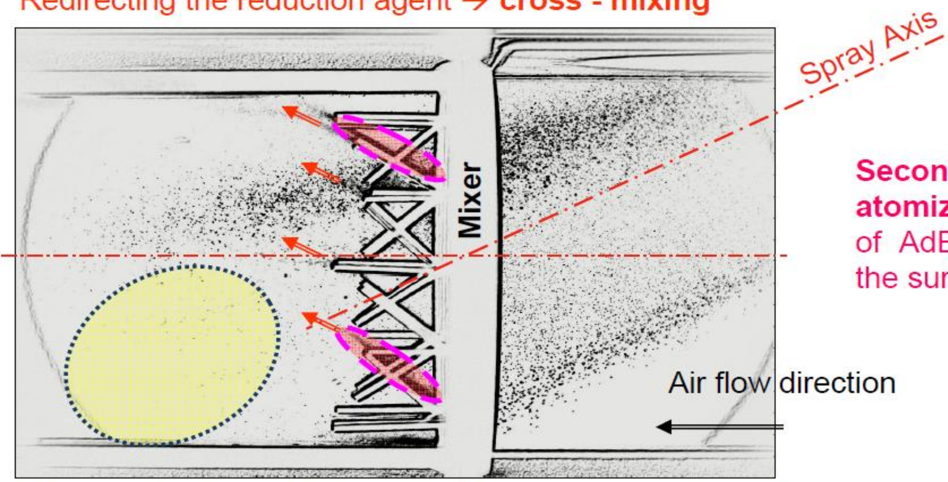
"Fast": $4\ NH_3 + 2\ NO + 2\ NO_2 \rightarrow 4\ N_2 + 6\ H_2O$
NO_2/NO_x = 50%

"Slow": $4\ NH_3 + 3\ NO_2 \rightarrow 3.5\ N_2 + 6\ H_2O$
NO_2/NO_x > 50%



SCR – An Overview

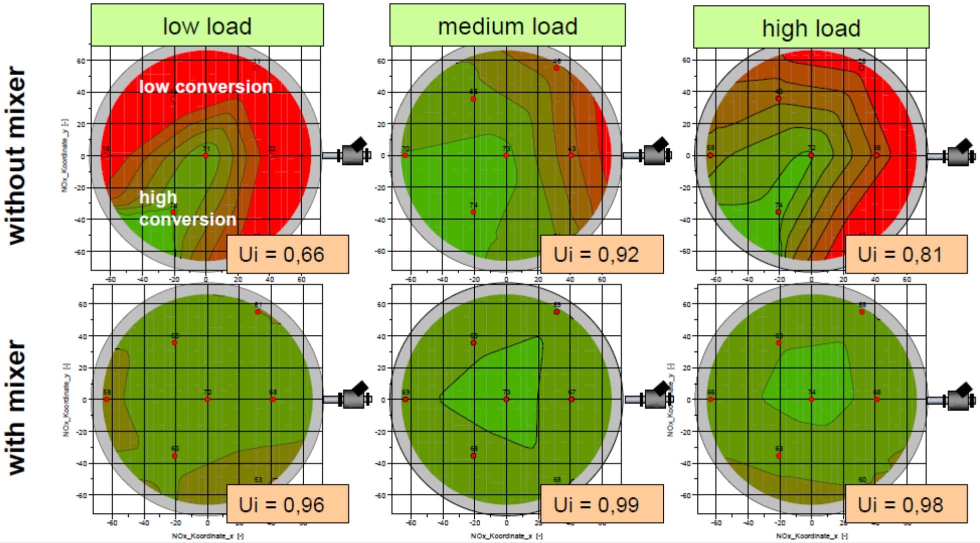
Redirecting the reduction agent → **cross - mixing**



No more droplets visible → Liquid evaporate on the surface

- **Mixer Design is critical**
- **Particle tracking simulation**
- **Risk of Urea Crystallization**

Mixer selection: local NO_x conversion, uniformity index $U_{i\_afterSCR}$



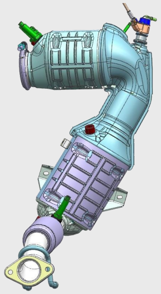
- **To maximize UI & NH_3 Distribution**
- **Use of NH_3 slip CAT, if required**
- **Urea consumption is critical**

Sustainability Challenges & Emerging Trends

Major Drivers – Automotive Powertrain

Upcoming Legislations
- CO_2 Ph I & Ph II
- Emission 2020, IRDE
- Safety 2019

Technology Overview



Real World Fuel Economy

Cost of Ownership

Sustainability Challenges & Emerging Trends

Measures to improve Real World Fuel Economy

Base Engine

- Friction reduction
- Right-sizing
- Turbo optimization
- VVL

48V Hybrid

- Belt starter Generator
- E-Boost
- Accessory electrification

Rolling Resistance

- Low rolling resistance tires
- Wheel bearing
- Drive shaft joints

Thermal Management

- Demand controlled cooling
- Fast heat-up
- Insulation
- Efficient climate control

Aerodynamics

- Optimized vehicle shape
- Active aerodynamics
- Optimized wheel/wheel-house
- Air curtain
- Underbody design

Transmission

- DCT
- No of speeds 6 → 8
- Efficiency Improvement
- Wider gear spread

Plug-in Hybrid

- P0 & P4 concept
- High Voltage systems
- Accessory Electrification

Weight Reduction

- Mild, medium, strong
- High strength steel
- Light-weight materials
- Composites

BSVI Compliance Approach

To Summarize …

- Two step emission upgrade, Short Development time
- On-time right fuel availability for fleet validation
- Clarity on IRDE, decides selection of appropriate technology
- Country specific EAS Technology adaption challenges
- High Cost of Ownership, Technology incubation cost
- CO_2 Challenges, Hybrid & BEV Technology yet to shape-up

Unique challenges ahead …

Thank You

Disclaimer

Mahindra & Mahindra herein referred to as M&M, and its subsidiary companies provide a wide array of presentations and reports, with the contributions of various professionals. These presentations and reports are for informational purposes and private circulation only and do not constitute an offer to buy or sell any securities mentioned therein. They do not purport to be a complete description of the markets conditions or developments referred to in the material. While utmost care has been taken in preparing the above, we claim no responsibility for their accuracy. We shall not be liable for any direct or indirect losses arising from the use thereof and the viewers are requested to use the information contained herein at their own risk. These presentations and reports should not be reproduced, re-circulated, published in any media, website or otherwise, in any form or manner, in part or as a whole, without the express consent in writing of M&M or its subsidiaries. Any unauthorized use, disclosure or public dissemination of information contained herein is prohibited. Unless specifically noted, M&M or any of its subsidiary companies is not responsible for the content of these presentations and/or the opinions of the presenters. Individual situations and local practices and standards may vary, so viewers and others utilizing information contained within a presentation are free to adopt differing standards and approaches as they see fit. You may not repackage or sell the presentation. Products and names mentioned in materials or presentations are the property of their respective owners and the mention of them does not constitute an endorsement by M&M or its subsidiary companies. Information contained in a presentation hosted or promoted by M&M is provided “as is” without warranty of any kind, either expressed or implied, including any warranty of merchantability or fitness for a particular purpose. M&M or its subsidiary companies assume no liability or responsibility for the contents of a presentation or the opinions expressed by the presenters. All expressions of opinion are subject to change without notice.