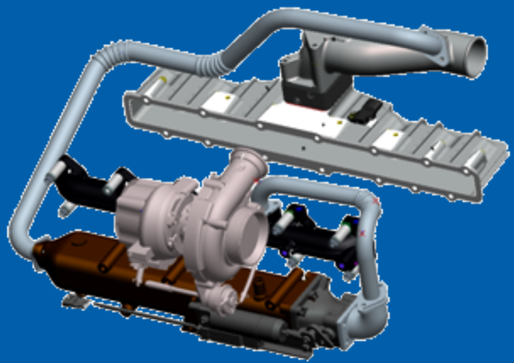
engineexpo2010

AdBlue
vs
Add-nothing Debate



Anirudh Jaipuria

Deputy Manager, Engine R&D

ASHOK LEYLAND

Contents

- Heavy Duty Diesel Emission Norms
- Emission Technology Overview
- Ashok Leyland Engines
- Effect on Cooling Requirements
- Engine and Vehicle layout
- Performance And Emission
- Engine durability
- Oil Requirements & Life
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- Feasibility of SCR & EGR for future norms
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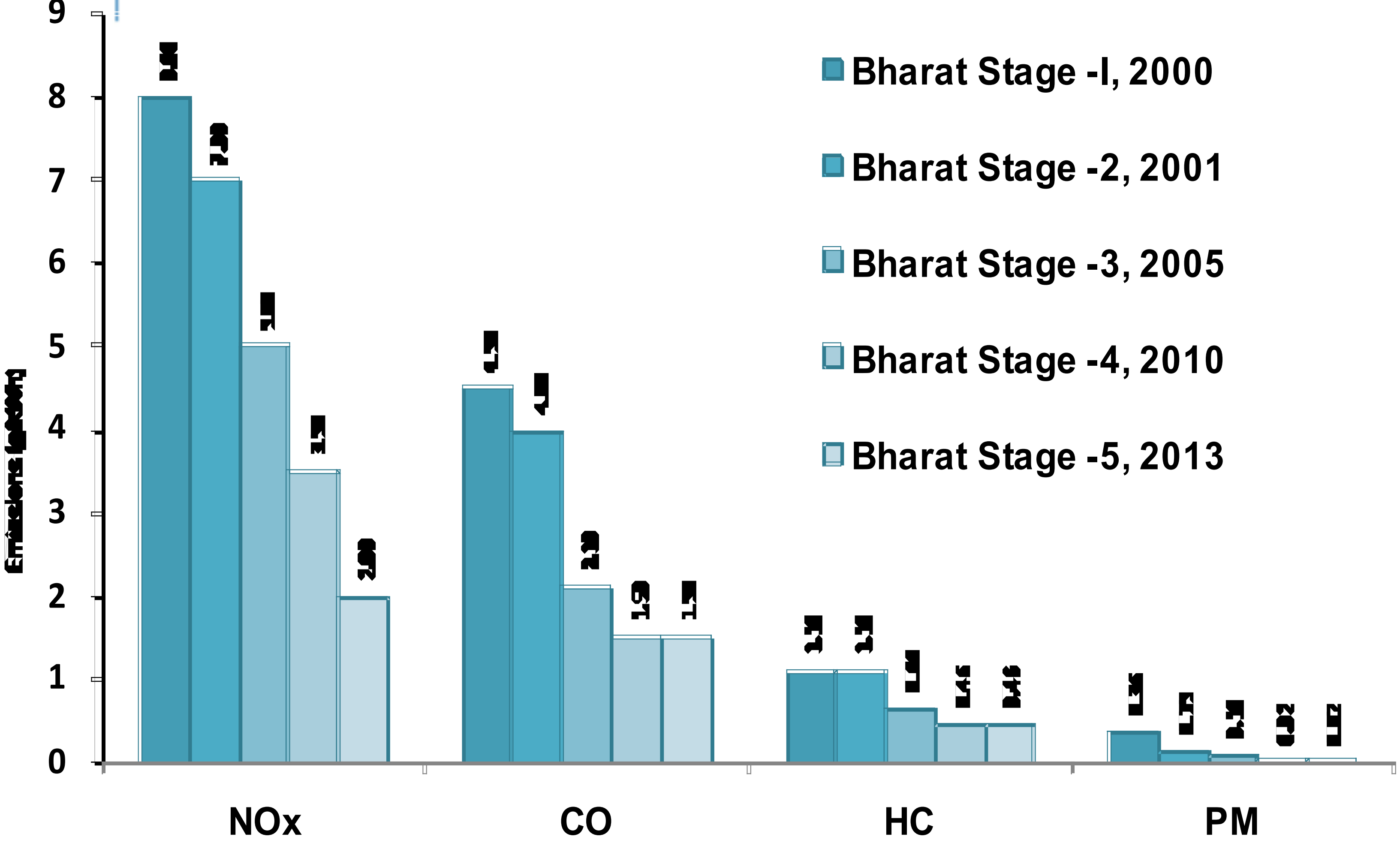
Evolution of Indian Emission Norms



*Bharat Stage-5 Norms have not been drafted, quoted are expected values

Evolution of Emission Test Cycles

Legislation / Test Cycle	Bharat Stage I	Bharat Stage II	Bharat Stage III	Bharat Stage IV	Bharat Stage V
R49	✓	✓	-	-	-
ESC	-	-	✓	✓	✓
ETC	-	-	-	✓	✓
ELR	-	-	✓	✓	✓
FAS	✓	✓	✓	✓	✓
OBD	-	-	-	OBD-I	OBD-II

- **Low Temperature ETC Cycle & On Board Diagnostics introduced for Bharat Stage-IV & Beyond**

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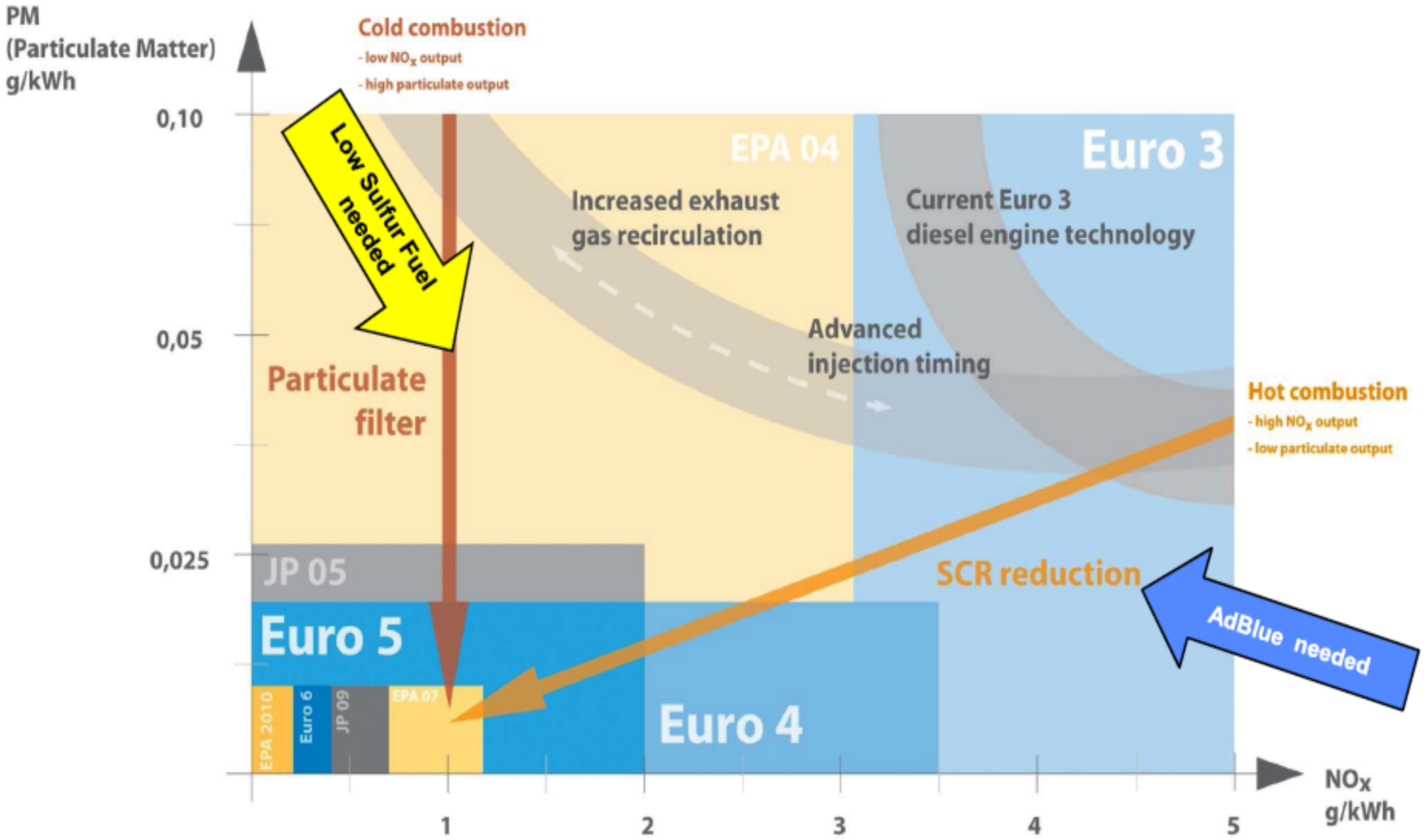
Technology Options for Emission Reduction

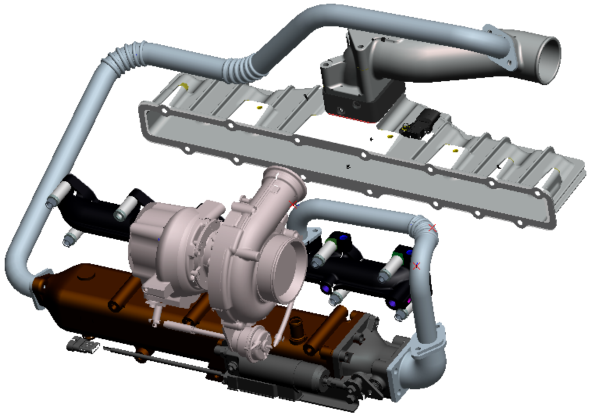


Exhaust Gas Recirculation (EGR)

- In EGR Technology, a portion of the exhaust gas is cooled and recirculated to the oxygen rich intake air

- EGR helps reducing in-cylinder NOx production by reducing maximum instantaneous temperature during Combustion
  - ✓ but increases the PM emissions

- To reduce PM, typically a DPF/DOC+POC is incorporated in the Exhaust system



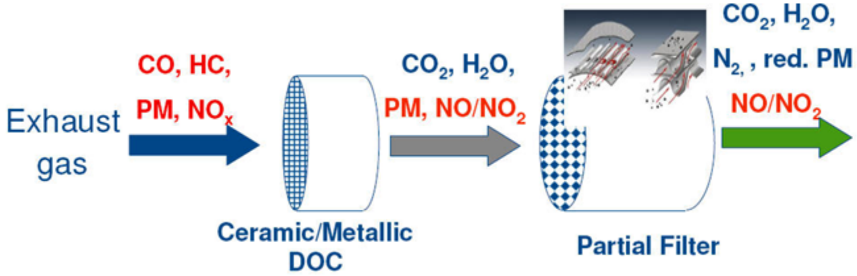
After-Treatment for EGR Engines

Particulate After Treatment

Diesel Particulate Filters (DPF)

- ❑ 90% PM conversion
- ❑ Can be combined with DOC for higher filtration efficiency
- ❑ Catalyzed for continuous regeneration
- ❑ Needs active regeneration if non-catalyzed

Partial Flow Filters (POC)



- ❑ 40-60% PM conversion with DOC
- ❑ Lower Light-off temperature when combined with DOC
- ❑ Self re-generating

Selective Catalytic Reduction

- Selective Catalytic Reduction (SCR) is a method to reduce nitrogen oxides (NOx) outside the cylinder
- SCR Engines are operated at advanced injection timings for Soot optimized combustion
- Nitrogen oxides are converted to nitrogen and water on the surface of a catalyst by adding ammonia to the exhaust gas

Reactions

$$4NH_3 + 4NO + O_2 \longrightarrow 4N_2 + 6H_2O$$
$(NO:NO_2 = 9:1)$

$$2NH_3 + NO + NO_2 \longrightarrow 2N_2 + 3H_2O$$

$$4NH_3 + 2NO_2 + O_2 \longrightarrow 3N_2 + 6H_2O$$

Source of NH_3 - Urea Solution (Adblue)

- Urea Solution
  - Urea Solution injected upstream of SCR catalyst, which undergoes thermolysis and hydrolysis to form NH_3

$$(NH_2)_2CO(aq) \longrightarrow (NH_2)_2CO(s)$$

$$(NH_2)_2CO(s) \longrightarrow HNCO + NH_3 \text{ (Thermolysis)}$$

$$HNCO + H_2O \longrightarrow CO_2 + NH_3 \text{ (Hydrolysis)}$$

Other Sources of NH_3: **Anhydrous Ammonia, Ammonium carbamate (NH_2COONH_4)**

AdBlue Specification

AdBlue	
Chemical Formula	$CO(NH_2)_2$
Molecular Weight	60.06 kg/mole
Urea Concentration	32.5% by mass (eutectic)
Freezing Point	-11°C
Appearance	Colorless
Hazards	Non-Toxic Non-Explosive
Density (@20°C)	1087-1092 kg/m^3
Quality Standard	ISO 22241-1:2006
Testing Method	ISO 22241-2:2006
Handling, Transportation and Storing Standard	ISO 22241-3:2008

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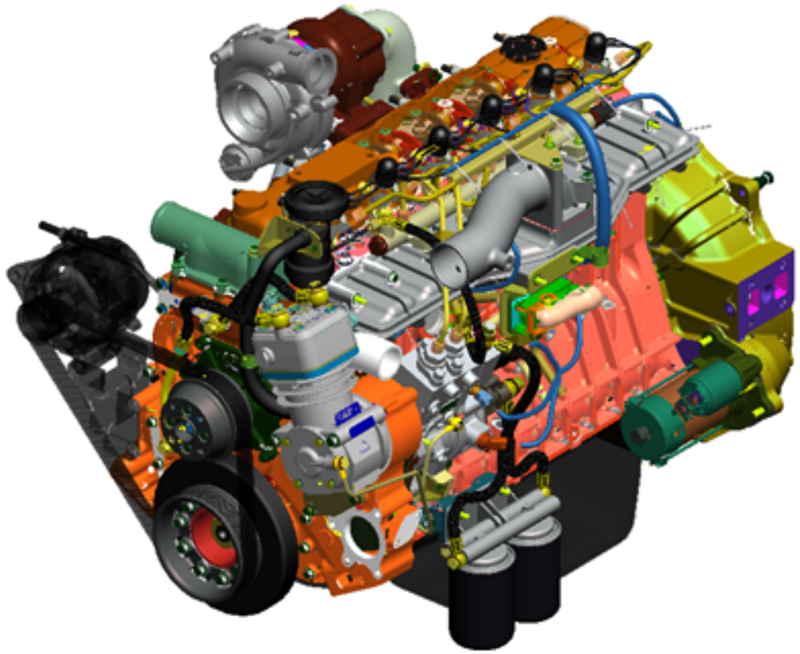
Ashok Leyland BS-3 Base Engine

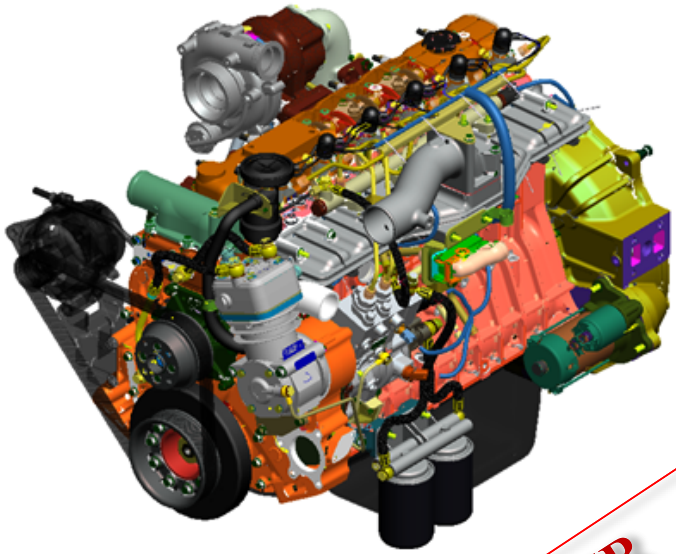
ENGINE SPECIFICATION	
Configuration	6 Cylinder TCIC, Direct Injection
Bore x Stroke	104 x 113 mm
Valves per cylinder	2
Max. Power	152 kW @ 2500 rpm
Max. Torque	700 Nm @ 1200-1800 rpm
Fuel Injection System	Gen 2,Common Rail, 1600 bar
Peak Cylinder Pressure	135 bar
Emission Norm	**Bharat Stage-3**



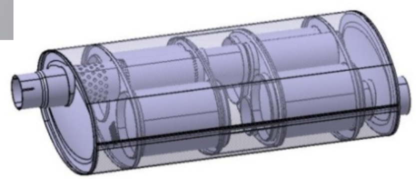
BASE

Ashok Leyland SCR Engine

ENGINE SPECIFICATION	
Configuration	6 Cylinder TCIC, Direct Injection
Bore x Stroke	104 x 113 mm
Valves per cylinder	2
Max. Power	152 kW @ 2500 rpm
Max. Torque	700 Nm @ 1200-1800 rpm
Fuel Injection System	Gen 2,Common Rail, 1600 bar
Peak Cylinder Pressure	135 bar
After-Treatment	NOx Selective Catalytic Reduction Vanadium Based catalyst, without Oxicat & Slip catalyst
Emission Norm	**Bharat Stage-4**

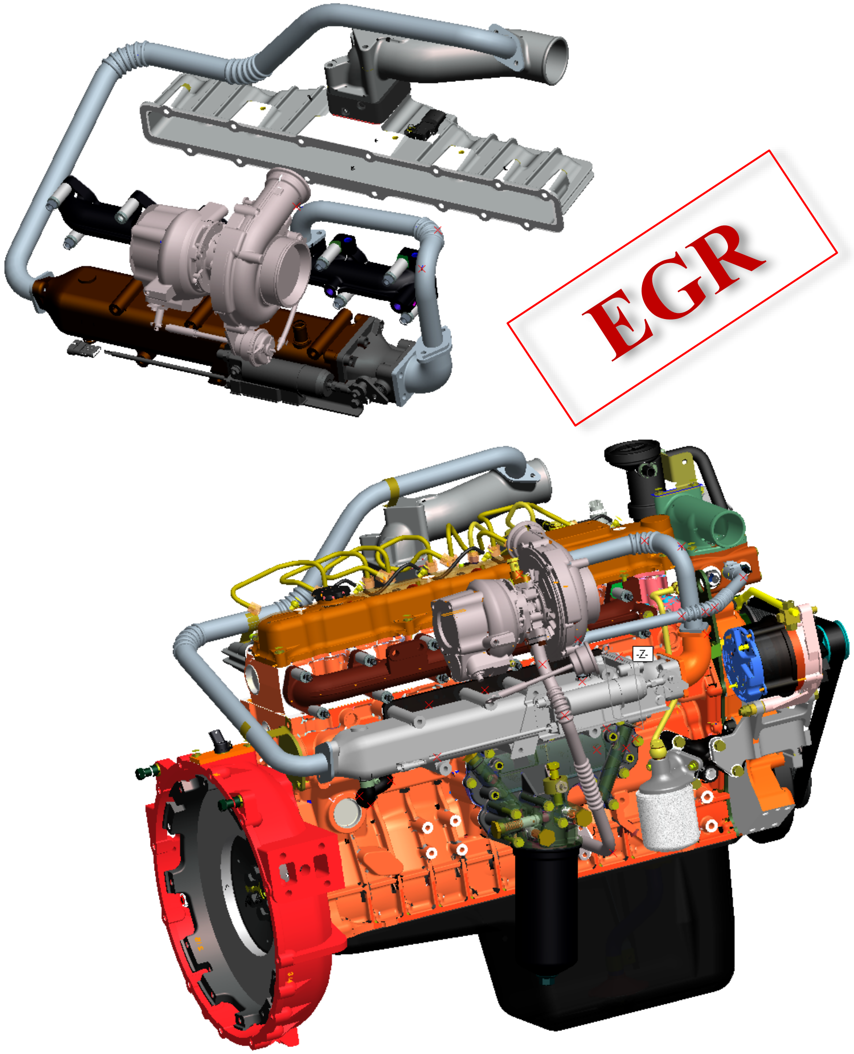


SCR After-Treatment



Ashok Leyland EGR Engine

ENGINE SPECIFICATION	
Configuration	6 Cylinder TCIC, Direct Injection
Bore x Stroke	104 x 113 mm
Valves per cylinder	2
Max. Power	140 kW @ 2400 rpm
Max. Torque	700 Nm @ 1200-1800 rpm
Fuel Injection System	Gen 2,Common Rail, 1600 bar
Peak Cylinder Pressure	135 bar
Recirculation	High Pressure Cooled EGR
After-Treatment	Partial Flow Filter (DOC+POC)
Emission Norm	**Bharat Stage-4**



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Effect on Cooling Requirements

SCR

- Cooling requirement same as BS-3

EGR

- 15% Higher heat rejection to coolant due to heat load of recirculated exhaust gas
- Higher coolant flow for cooling recirculated exhaust gases

Effect on Cooling Requirements

SCR

- ❑ Cooling requirement same as BS-3

EGR

- ❑ 15~20% Bigger radiator size
- ❑ 15~20% higher fan flow

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Engine Layout

SCR

- Engine Layout
  - No additional layout requirement on Engine

EGR

- Engine Layout
  - Packaging of EGR cooler and EGR valve
    - Oversized EGR Cooler to counter fouling due to soot deposition (f=0.001)
  - Heat shield for EGR valve
    - to avoid valve drift due to temperature (if near heat source like exhaust manifold)

Engine Layout

SCR

- Engine Layout
  - No additional layout requirement on Engine

EGR

- Engine Layout
  - Routing of EGR pipe to intake manifold
  - Larger coolant pump dimensions
  - May call for use of Turbocharger with asymmetric turbine

Engine and Vehicle Layout

SCR

- Vehicle Layout
  - Additional space on chassis for AdBlue Tank
  - Larger silencer with integrated SCR catalyst
  - Routing of AdBlue pipe from Dosing Module
  - Additional nozzle and temperature sensors in exhaust pipes

EGR

- Vehicle Layout
  - Additional space for larger radiator/fan
  - Packaging space for DPF/Partial filters

Engine and Vehicle Layout

- For larger engines producing < 20 kW/l or smaller engines < 2 l
  - SCR Catalyst needs to be packaged very close to the turbocharger
  - Oxidation catalyst required for achieving higher NOx conversion at lower light-off temperatures
  - Insulation of exhaust pipes to reduce heat loss due to convection

- ❑ Heavy Duty Diesel Emission Norms
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Performance & Emissions

SCR

- Superior fuel economy compared to BS-3

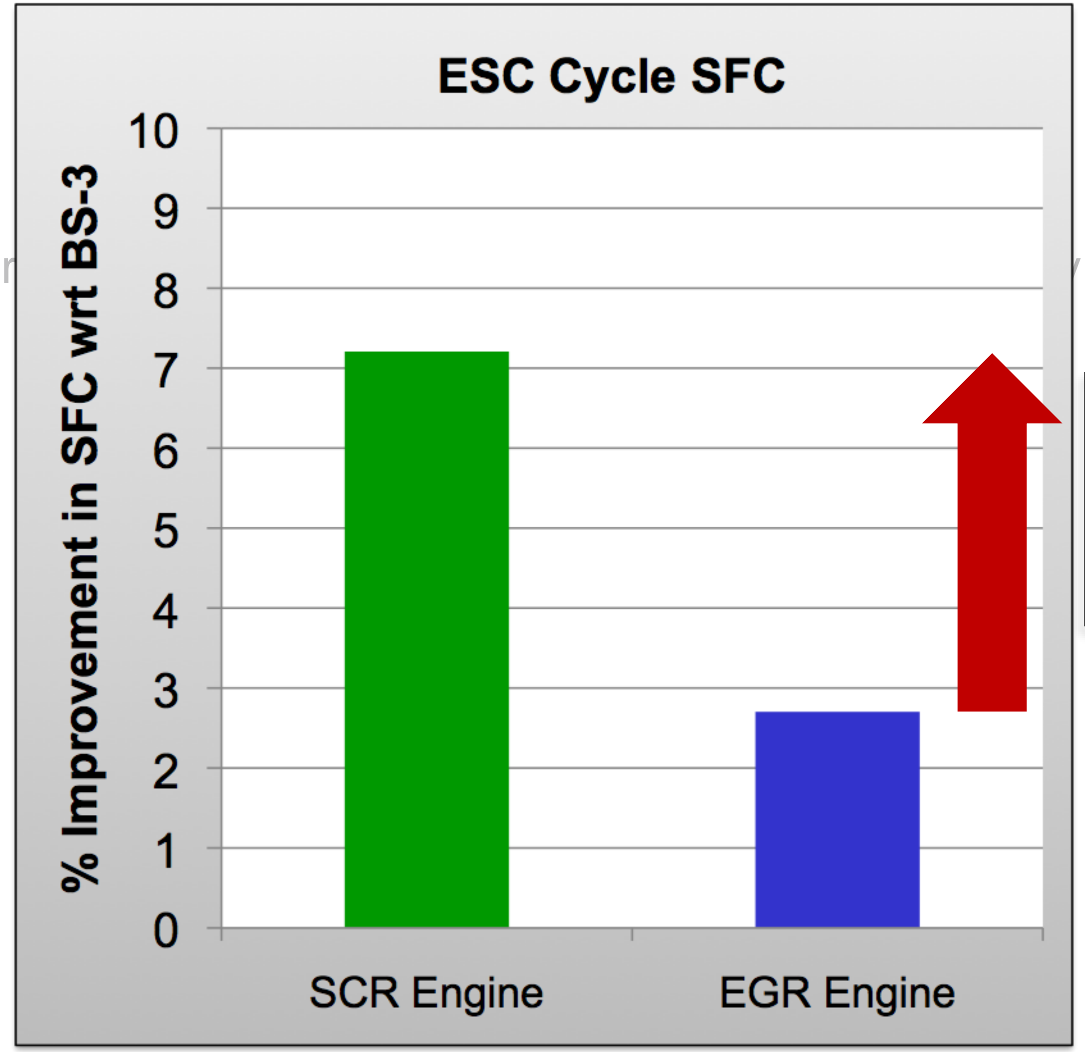
EGR

- Fuel economy marginally better than BS-3

Performance & Emissions

SCR

- Superior … at par with BS-3 BS-3



5% Improvement in SFC with SCR

Same Peak Firing Pressure

Performance & Emissions

SCR

- Superior fuel economy compared to BS-3
- No change in power for the same Peak Cylinder Pressure

EGR

- Fuel economy marginally better than BS-3
  - 15% drop in engine power for the same Peak Cylinder pressure

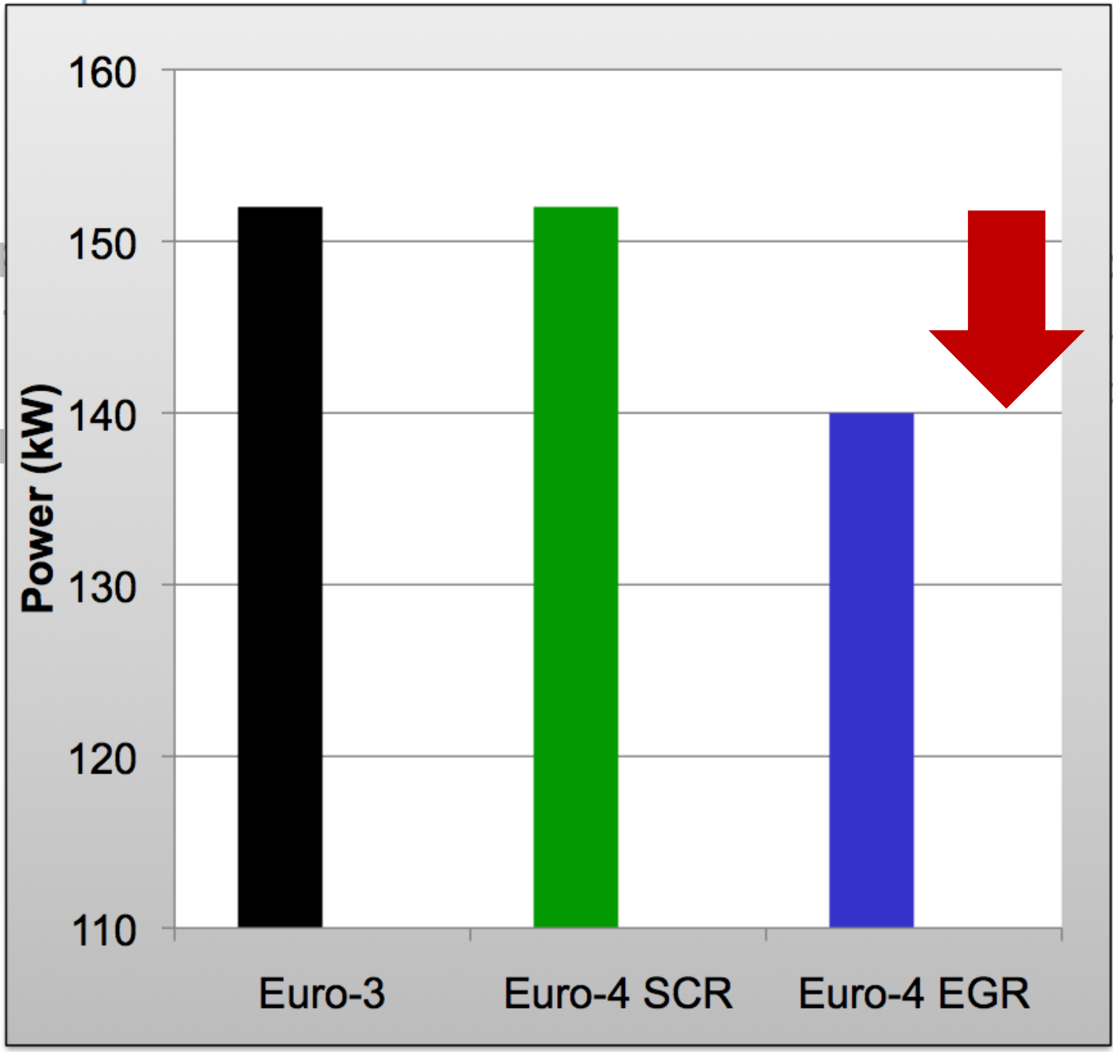
Performance & Emissions

SCR

- Su... BS...
- No... Cy...

...my at par with BS-3

...op in engine power for the ...Peak Cylinder pressure



8% Lesser Power with EGR

Same Peak Firing Pressure

Performance & Emissions

SCR

- Superior fuel economy compared to BS-3
- No change in power for the same Peak Cylinder Pressure
- No effect on Emission with change in Back Pressure of the system

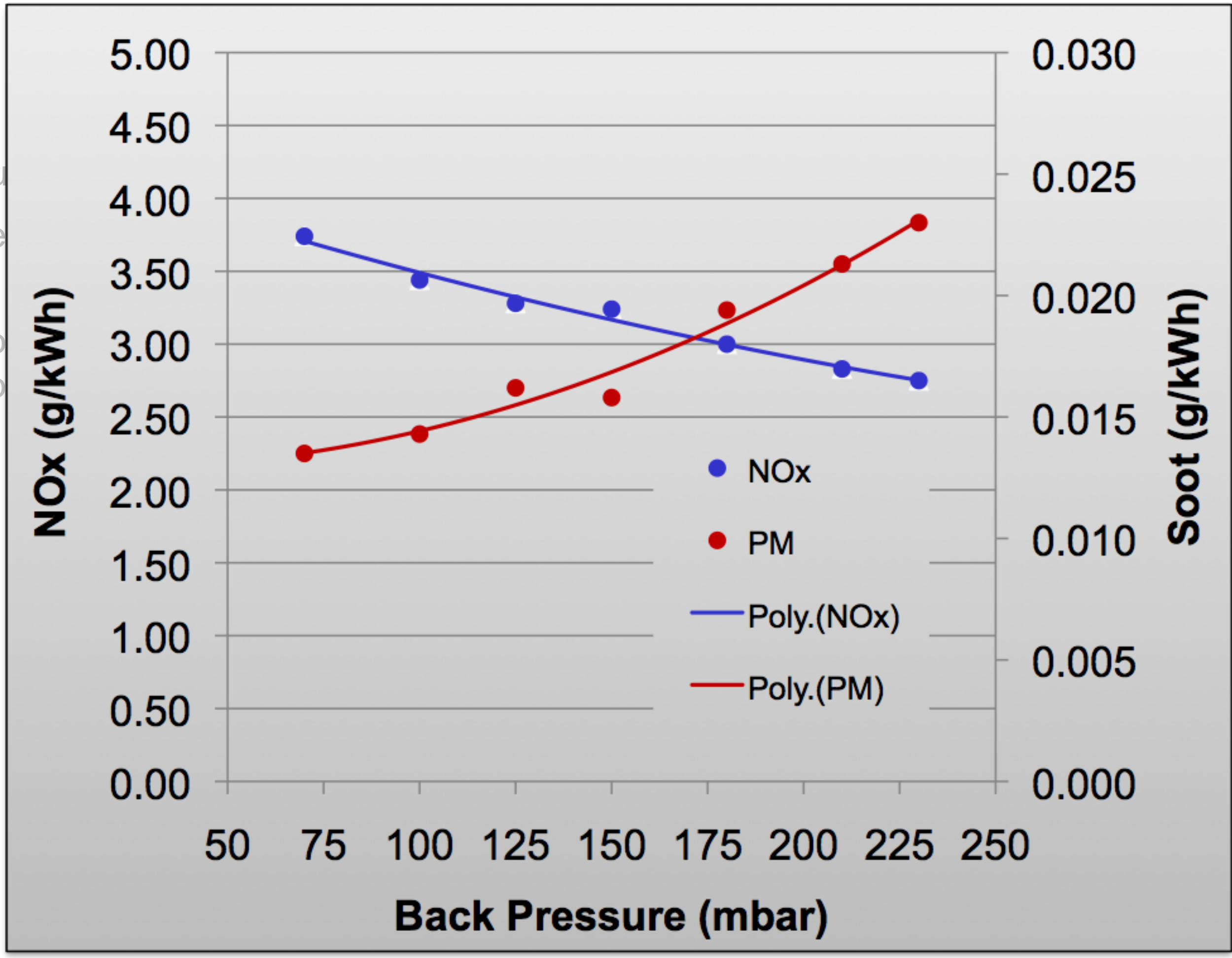
EGR

- Fuel economy marginally better than BS-3
  - 15% drop in engine power for the same Peak Cylinder pressure
  - Reduction in EGR Flow with reduction in back pressure, consequently
    - Increase in NOx emissions (lesser back-pressure)
    - Increase in PM emissions (higher back pressure)

Performance & Emissions

SCR

- Superior fu … ro-3
- No change … er for the same Peak Pressure … -3
- No effect o … with reduction in Pressure o … ently
  - … (lesser back-pressure)
  - … igher back pressure)



Performance & Emissions

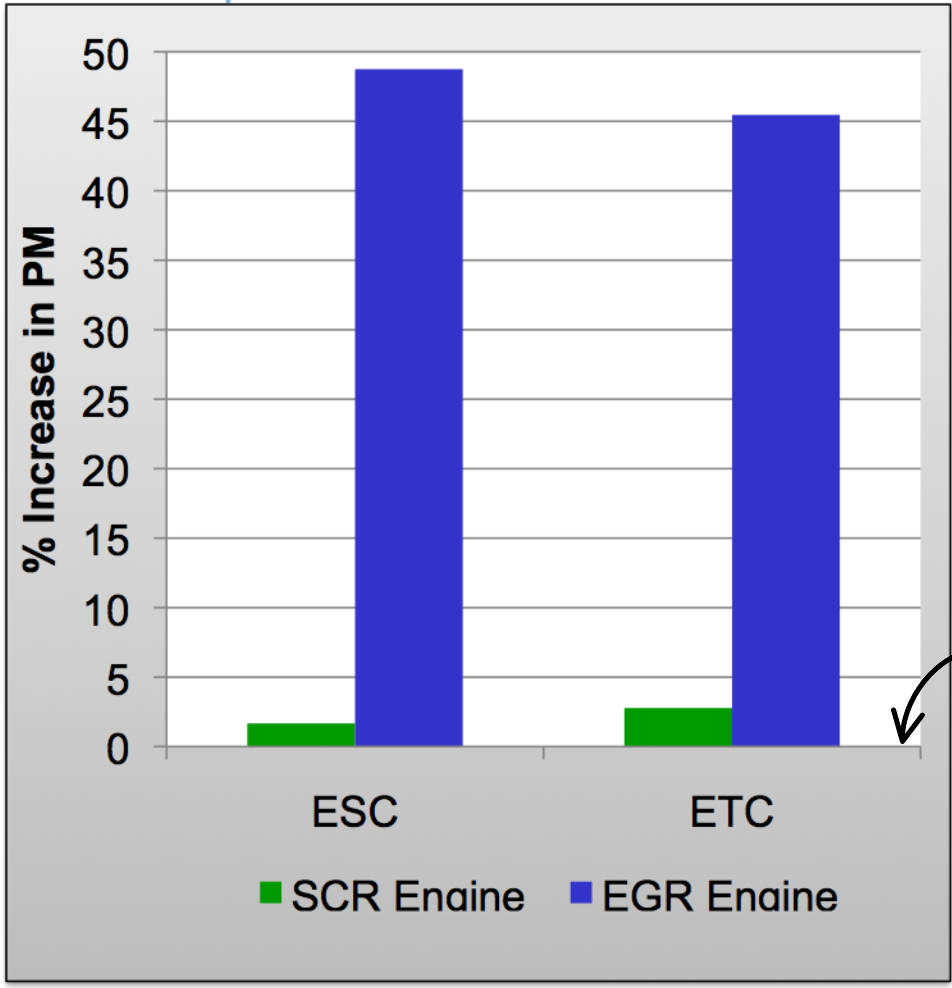
SCR

- ❑ Superior fuel economy compared to Euro-3
- ❑ No change in power for the same Peak Cylinder Pressure
- ❑ No effect on Emission with change in Back Pressure of the system
- ❑ Marginal increase in PM emissions with high sulphur fuel

EGR

- ❑ Fuel economy marginally better than Euro-3
  - ❑ 15% drop in engine power for the same Peak Cylinder pressure as BS-3
  - ❑ Reduction in EGR Flow with reduction in back pressure, consequently
  - ➢ Increase in NOx emissions (lesser back-pressure)
  - ➢ Increase in PM emissions (higher back pressure)
  - ❑ Drastic increase in PM Emissions with high sulphur fuel

Performance & Emissions



High Sulphur Fuel
Euro-3 Commercial Diesel
(350 ppm Sulphur)

Base Fuel
Euro-4 Commercial Diesel
(38 ppm Sulphur)

EGR

- Fuel economy at par with Euro-3
- % drop in engine power for the same Peak Cylinder pressure as BS-3
- Reduction in EGR Flow with reduction in back pressure, consequently
  - Increase in NOx emissions (lesser back-pressure)
  - Increase in PM emissions (higher back pressure)
- Drastic increase in PM Emissions with high sulphur fuel

*EGR Engine with DOC+POC after-treatment

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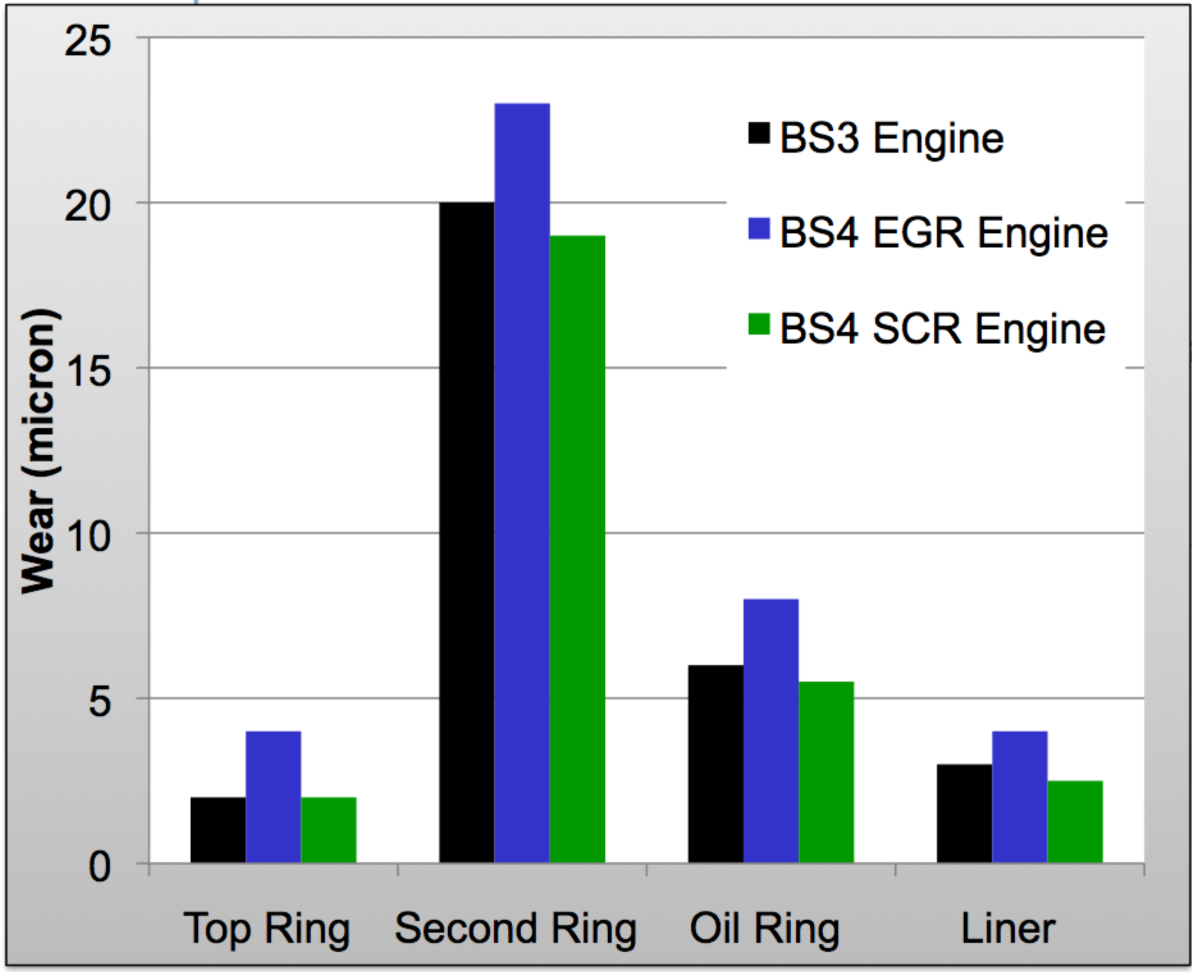
Engine Durability

- Engine durability can be studied majorly in terms of
  - Piston Ring Wear & Liner Wear
    - Liner and ring-pack material
    - Combustion Chemistry
      - More soot in oil in case of EGR engines than for SCR engines
    - Peak cylinder pressure
    - Oil Grade
  - Wear of Bearings & Valve train components
    - Depends on peak cylinder pressure, material of parts in contact, Oil Grade

Engine Durability



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Component wear for EGR Engine found well within acceptable limits

***Component Wear Analysis after 500 h Endurance on Test-Bench**

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Oil Requirements & Life

Effect on Oil Parameters

SCR

- Reduced soot loading on oil

EGR

- Higher soot loading
  - ✓ dispersants additives
- Increase in oil viscosity
- Increase in oil Acid Number (TAN)
  - ✓ over-based detergent additives
- Increase in oil Oxidation Number
  - ✓ antioxidants (AO)

Oil Requirements & Life

Effect on Oil Parameters

SCR

- ❑ Reduced soot loading on oil

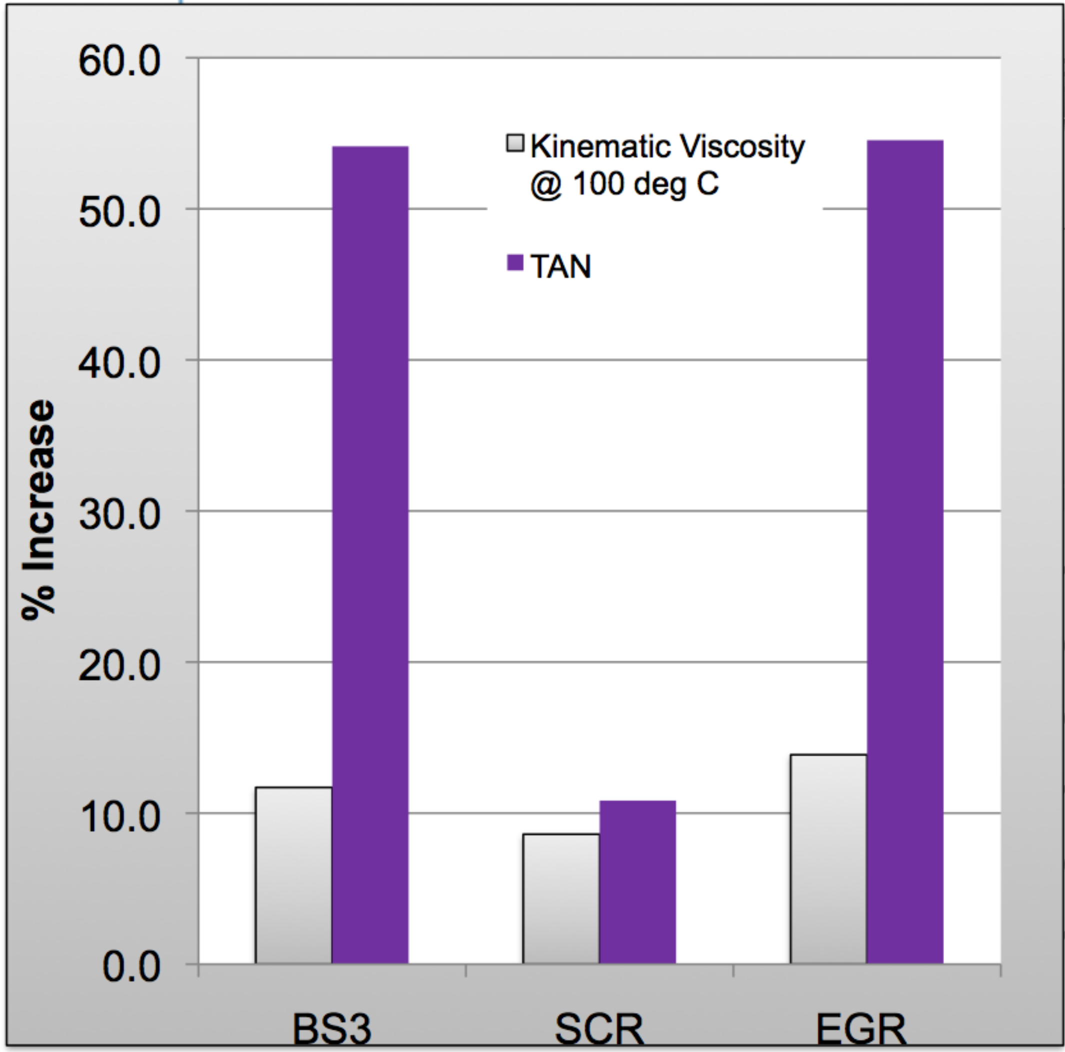
CH4 API Grade Sufficient

EGR

- ❑ Higher soot loading
  - ✓ dispersants additives
- ❑ Increase in oil viscosity
- ❑ Reduction in oil Base Number (TBN)
  - ✓ over-based detergent additives
- ❑ Increase in oil Oxidation Number
  - ✓ antioxidants (AO)

CI4 or Higher API Grade Recommended

Oil Requirements & Life



EGR Oil Drain Intervals at par with BS3

eters

EGR

gher soot loading

dispersants additives

crease in oil viscosity

crease in oil Acid Number (TAN)

over-based detergent additives

crease in oil Oxidation Number

antioxidants (AO)

BS3 Engine : CH4
BS4 SCR Engine: CH4
BS4 EGR Engine: CI4+

***Oil Analysis after 500 h Endurance on Test-Bench**

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Vehicle Running Cost

❑ SCR Operating cost

- Fuel consumption
  - ➢ 6% lower than BS-III engines
    - o (Based on Test data from 5 vehicles in field)
- AdBlue consumption
  - ➢ 5% of engine fuel consumption
    - o (Based on Test data from 5 vehicles in field)
- Net operating cost
  - ➢ 3-4 % lower than BS-III engines

    (Assuming Cost of AdBlue = 50% of Diesel)

❑ EGR Operating cost

- Fuel consumption
  - ➢ 2% lower than BS-III engines
    - o (Based on Engine Test-Bench data)
- AdBlue consumption
  - ➢ Nil
- Net operating cost
  - ➢ 2 % lower than BS-III engines

Vehicle Running Cost

- SCR Operating cost
  - Fuel consumption
    - 6% lower than BS-III e
      - (Based on Test d
        vehicles in fie
  - AdBlue co
    - 5% of
      con
  - Cos ation
    - 50% of diesel cost (assumed)
  - Net operating cost
    - 3.5 % lower than BS-III engines

- EG cost
  - tion
    - an BS-III engines
      - d on Engine Test-Bench
        ta)
  - ue consumption
    - Nil
  - Net operating cost
    - 2 % lower than BS-III engines

Return on investment with SCR technology is less than 1-year for a vehicle running 700 km/day

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Feasibility of SCR & EGR for future norms

SCR

- BS-V/ Euro-5 Legislation
  - No additional engine structural requirement
  - Fuel economy at par with BS-IV Engine
  - No additional cooling requirement
  - Recalibration of in-cylinder combustion not required
  - Oil drain period at par with BS-IV
  - With increased dosing and marginally larger catalyst, Euro-5 can be achieved
  - Lesser development cost and time

EGR

- BS-V/ Euro-5 Legislation
  - Heavier engine structure to maintain same AF ratio and Power
  - Upto 7-8 % loss of fuel economy is expected if only EGR is to be used with full flow DPF
  - More load on cooling system due to Higher EGR Rates
  - In-cylinder combustion calibration needs to be repeated
  - Shorter oil drain intervals due to higher EGR rates, soot loading
  - Resizing of DPF, PM-Kat after combustion calibration
  - More development cost and time

Feasibility of SCR & EGR for future norms

SCR

- OBD-II
  - Requirement of Urea quality sensor/NOx sensor for OBD-II is yet to be decided
  - OBD Calibration would be costlier due to additional sensors
  - Reliability and Cost of NOx sensor
    - Subject to the decision on NOx sensor for the OBD

EGR

- OBD-II
  - No requirement of Urea quality sensor/NOx sensor for OBD-II
  - OBD Calibration can be done by feed-forward algorithm
  - Reliability of EGR valve

Feasibility of SCR & EGR for future norms

SCR

- World Harmonized Cycle (WHC)
  - For meeting low cycle temperature of WHC special low temperature catalyst, Oxidation catalyst would be required
    - If combined with DPF with active regeneration, the catalyst should have capability of withstanding high temperature
  - Cost of low temperature catalyst is higher

EGR

- World Harmonized Cycle (WHC)
  - Active regeneration of DPF would be required
  - Active regeneration would lead to 1-2% poor fuel economy

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Summary

- SCR gives upto 5% Superior fuel economy compared to EGR (for BS-4)
- For same structural strength Engine power density reduces with EGR
- Lower grade oil can be used for SCR Engines
- Equal oil drain intervals can be achieved for EGR with API CI4 Grade oils (for BS-4)
- SCR catalyst is tolerant to High Sulphur Diesel
  - ✓ Ideal for countries with dual norms
- Engine Durability for both SCR & EGR are comparable
- SCR is cost competitive for larger engines
  - ✓ Cost can be recovered in one year for a truck running 700 km/day
- Engines with EGR ask for complicated modifications to the engine design than for SCR engines
- SCR is more promising for Euro-5 and beyond

Thank You