US Tier 2 Bin 2 Diesel Research Progress

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Light Duty Diesel technology will continue to improve and meet long term emissions and fuel economy demands

- Tier 2 Bin 2 requires major advances in Diesel engine NMOG and NOx control. These challenges are driving innovation.

- Highly Pre-mixed Cool Combustion (HPCC) enabled by air system technology can achieve 85-90% NOx reduction relative to Euro4.
  - NMOG, transient combustion noise, robustness and durability issues are being targeted in an integrated approach.

- The optimum balance between engine and aftertreatment technology is being investigated to maximise fuel economy.

- Low NOx combustion technology will be fundamental to global Diesel product strategies and CO2 reduction.
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Tier 2 Bin 2 is a major challenge for Diesel and must be achieved with improved economy and realistic cost

Approximate Relative Emissions Challenge
Eu4~6 T2B5~B2

- NOx
- HC/NMOG
- CO
- PM

Typical T2B5
Current Approach

T2B2 Research Approach

Engine
Aftertreatment

- Eu4
- Eu5
- Eu6
- T2B5
- T2B2
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# Roadmap of technologies to promote lower emissions while enhancing performance and drivability

**ACTION** = Advanced Combustion Technology for Improved engine-Out NOx

<table>
<thead>
<tr>
<th>AIR/EGR SYSTEM</th>
<th>LEVEL 2/2+</th>
<th>LEVEL 3</th>
<th>LEVEL 4</th>
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<tbody>
<tr>
<td>Variable swirl</td>
<td>Advanced EGR</td>
<td>Advanced turbo concepts</td>
<td>Assisted boosting</td>
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<tr>
<td>Advanced EGR</td>
<td>EGR bypass</td>
<td>Low Pressure EGR</td>
<td>Variable valve actuation?</td>
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<tr>
<td>COMBUSTION SYSTEM</td>
<td>16-16.5 CR</td>
<td>15.5-16 CR</td>
<td>Variable nozzle?</td>
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<td>1600-1800 bar FIE</td>
<td>&gt;1800 bar FIE</td>
<td>&gt;2000 bar FIE</td>
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<td>CONTROL SYSTEM</td>
<td>Lambda sensor</td>
<td>Combustion control (CPEMS)</td>
<td>Model based control (WAVE®RT)</td>
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<tr>
<td>EGR temperature control</td>
<td>Virtual sensors</td>
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<td>CAPABILITY</td>
<td>Euro 5 PC</td>
<td>T2 Bin 5 LDV</td>
<td>Bin5 LDT4</td>
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<tr>
<td>Euro 6 PC</td>
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<tr>
<td>T2 Bin 8 FTP LDV</td>
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</tbody>
</table>
Highly Pre-mixed Cool Combustion (HPCC)

Charge Oxygen Concentration (%) vs NOx (g/kWh)

- Euro 4
- Level 2
- Level 3

Load (bar BMEP) vs Speed (rev/min)

- Level 3 - O₂ Concentration Map
- Level 2 - O₂ Concentration Map

Numbers indicate percentage of fuel injected before start of combustion of the main injection

REFERENCE
SAE 2006-01-1145
ACTION Level 3 technology enables lower NOx and improved fuel economy

- 80-90% NOx reduction with 3-5% fuel economy gain is possible
- Low pressure EGR solution offers advantage over US06 drive cycle
Key T2B2 challenges are being targeted by technology integration

**Boost/EGR**
- High efficiency air and EGR system
  - Low pumping losses
  - Enhanced performance & drivability

**Combustion**
- HPCC combustion system
  - Low soot and good efficiency at low lambda
  - Enhanced performance

**Aftertreatment**
- HC control:
  - Fast light-off
  - HC conversion
- NOx control:
  - Low temp conversion
  - Low NOx DPF regen.

**Control Strategy**
- Advanced air path control
- CPEMS closed loop combustion control
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Research is now examining the optimum engine and aftertreatment balance for best fuel economy at T2B2.
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Engine out NOx control will be fundamental to global Diesel product strategies and CO₂ reduction
Low NOx technology will enable fuel economy gains through reduced operating speed or engine downsizing.

Brake Specific NOx Comparison - Constant Power Condition of 30kW

ACTION Level 3 Engine Brake Specific CO2

Improving Fuel Economy

5th to 6th rear at 100 kph cruise condition

FE gain by downsizing

FE gain by up shifting
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