State-of-the-art and emerging truck engine technologies

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State-of-the-art and emerging truck engine technologies for optimized performance, emissions and life-cycle-costs

- The challenge for commercial vehicles engine R&D
- Engine technology development until today
- Aftertreatment systems as emerging technologies also for commercial vehicle Diesel engines
- What will be the right technology for US MY07?
- Prerequisites to be established
Engine R&D efforts have to focus on bridging ecological and economical requirements of all stakeholders

<table>
<thead>
<tr>
<th>Ecology</th>
<th>Economy</th>
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<tbody>
<tr>
<td>Society</td>
<td>Truck Operator</td>
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<tr>
<td>- Gaseous and PM Emissions</td>
<td>- Life-Cycle Costs</td>
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<tr>
<td>- CO₂-Emissions</td>
<td>- Profitability</td>
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<td>- Noise</td>
<td>- Nation</td>
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<td>- Haulage Costs</td>
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Life-Cycle-Costs of class 8 trucks in Europe

Costs for fuel, purchase and maintenance/service are highly influenced by engine design.

- **Salary**: 30.9%
- **Fuel**: 29.3%
- **Maintenance & Service**: 14.8%
- **Tires**: 7.2%
- **Oil**: 7.3%
- **Taxes/Insurances**: 1.5%
- **Interest & depreciation**: 9.0%

**Time of use**: 4 years, mileage/year: 95,000 mls (app. 150,000 km), fuel consumption: 7.35 mpg (32.5 l/100 km)

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Worldwide emission standards and respective test cycles

For Europe, NAFTA and Japan different test cycles are mandatory with different weightings regarding engine speed and load.
Trade-off between nitric oxides ($NO_x$), fuel consumption (bsfc) and particulates (PM)

Traditional measures aiming at lower peak combustion temperature reduce fuel efficiency and increase PM- and CO$_2$-emission
European OEMs have been able to increase transport efficiency in spite of more stringent emissions regulations.
Measures to fulfill emission standards

Combustion Technologies: Injection, Combustion Chamber, Turbocharging

- Charge Air Cooling
- Electronic Engine Control
- Exhaust Gas Recirculation
- Particulate Trap
- NOx Aftertreatment

Euro 0, Euro 1, Euro 2, Euro 3, Euro 4, Euro 5

Today’s exhaust aftertreatment systems for Diesel engines

**NOx aftertreatment**
- Adsorber catalyst
- Selective Catalytic Reduction (SCR)

**PM aftertreatment**
- Continuously Regenerating Diesel Particle Filter (CDPF)
Aftertreatment systems - mode of operation
Adsorber catalyst

PHASE 1: Regular operating conditions

- Air-To-Fuel Ratio (AFR)>1
  - Storage of NOx on catalyst surface:
    - Oxidation from NO to NO₂
    - Production of nitrate (out of NO₂)
    - Storage of produced nitrate

PHASE 2: Brief enrichment (ECU controlled)

- AFR<1
  - Reduction of stored nitric oxides:
    - Back-formation of nitrate to NO
    - Reaction of NO with CO and H₂
      - \(2\text{NO} + 2\text{CO} \rightarrow 2\text{CO}_2 + \text{N}_2\)
      - \(2\text{NO} + 2\text{H}_2 \rightarrow 2\text{H}_2\text{O} + \text{N}_2\)
The SCR technology uses urea, respectively ammonia (which forms after decomposition of urea at temperatures >200°C) to convert nitric oxides (NO, NO₂) into harmless molecular nitrogen N₂ and water.

\[
\begin{align*}
\text{NO} & \quad + \quad \text{hydrogen} \quad + \quad \text{ammonia} \\
4 \text{ NO} & \quad + \quad \text{O}_2 \quad + \quad 4 \text{ NH}_3 \\
2 \text{ NO}_2 & \quad + \quad \text{O}_2 \quad + \quad 4 \text{ NH}_3 \\
\end{align*}
\]

\[
\begin{align*}
\text{nitrogen} & \quad + \quad \text{water} \\
4 \text{ N}_2 & \quad + \quad 6 \text{ H}_2\text{O} \\
3 \text{ N}_2 & \quad + \quad 6 \text{ H}_2\text{O} \\
\end{align*}
\]
Aftertreatment systems - mode of operation
Continuously regenerating Diesel particle filter

Combination of oxidation catalytic converter and soot trap

\[
\begin{align*}
2\, CO + O_2 & \rightarrow 2\, CO_2 \\
4\, HC + 5\, O_2 & \rightarrow 2\, H_2O + 4\, CO2 \\
2\, NO + O_2 & \rightarrow 2\, NO_2 \\
C + 2\, NO_2 & \rightarrow CO_2 + 2\, NO
\end{align*}
\]
Versions of particulate traps under evaluation

Sintered metal filter with a low number of filter plates

Monolith with a high number of filter channels

Courtesy Johnson Matthey

Courtesy Purem
Strategies for emission reduction for US MY07

- Increased EGR
- Status US'04
- Advanced injection timing
- SCR catalyst, adsorber catalyst
- Particulate filter
The EGR system for US’07 features approximately twice the EGR rates of US’04.

EGR rates 2002/04: 10...13%
required EGR rates for 2007: 18...25%
High EGR radiator design comparison for an axle forward truck

2002/2004 design
- crossflow radiator

2007 design
- downflow radiator
- splayed frame
- interference w/ axle forward springs
The SCR and CDPF approach

- Engine ECU
- Intercooler
- NH$_3$ sensor
- SCR catalyst
- CDPF
- aqueous urea solution tank
- Urea injection

Feedback from NH$_3$ sensor leads to engine ECU.
Timelines of different emission strategies

2002 2003 2004 2005 2006 2007 2008 2009

US
- NOx storage catalyst (adsorber catalyst) & CDPF technology with medium EGR
- SCR & CDPF technology with no EGR
- High EGR & CDPF technology

EURO4
- SCR technology

US’07
- Adv. SCR & CDPF with medium EGR

EURO5
- Adv. SCR technology

US’10
- Adv. SCR & CDPF w/ medium EGR

Europe
- SCR technology

Adv. SCR technology

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Fuel consumption and CO₂ emission of MY 07 emission strategies

- MY2004
- MY2007 High EGR & CDPF
- MY2007 SCR & CDPF

Relative fuel consumption/CO₂ emission graph showing:
- Basis: 3% penalty
- MY2007 High EGR & CDPF: 6% advantage
The SCR & CDPF technology reduces fuel consumption and life cycle costs; the cost advantage depends on the urea costs.

Life-Cycle-Cost comparison for a long haul truck
(only costs are considered, no prices that include profit and overhead)

* no costs of the truck and trailer, with oil exchange costs included
Installation of SCR & CDPF technology in a demonstrator truck
Two issues need to be resolved in order to enable the introduction of SCR:

- urea supply infrastructure
- securing that system is tamper-proof and working correctly
Urea is

- colorless
- non-toxic
- used in food, agricultural fertilizers, cosmetics, pharmaceuticals etc.
- available at required quantity; installed production capacity allows CV supply w/o additional investments

AdBlue is

- the European trade name for 32.5% aqueous urea solution
How does Europe approach the installation of a supply infrastructure for urea solution

- The urea supply industry has a major interest to establish a urea infrastructure.
- 80% of the entire heavy duty truck diesel fuel is being distributed by local fuel stations which are operated by the fleets themselves.
- Fleet owners will install urea filling stations at their places. Financial support through urea manufacturing companies is in discussion.
- Large highway truck-stops will be equipped with urea filling stations. Other fuel filling stations will install urea supply gradually.

- supply of the most important intersections
- supply along the most important routes
- area-wide supply with minimal distances
Local AdBlue filling stations

AdBlue
small filling station

AdBlue
supply unit: 265 gals (1000 l)
“Economics favor the SCR/urea technology over the NOx adsorber technology for most applications of long-haul and vocational trucks in the long-term.”

“Economics also generally favor the SCR/urea technology over the NOx adsorber technology in the near-term if early NOx adsorbers have a high fuel penalty (≈5%) and a higher initial incremental cost.”

The study furthermore states that provision of Urea is both possible and economically reasonable if “strong signals regarding manufacturers intentions to provide SCR-equipped trucks” are sent to truck operators and other stakeholders starting 3rd quarter 2003 and no later than mid-2004.

Remark: TIAX is a consulting firm which formed from Arthur D. Little‘s Technology and Innovation business.
The SCR and CDPF approach

- Engine ECU
- Intercooler
- NH₃ sensor
- SCR catalyst
- CDPF
- Temperature sensors
- Urea injection
- Aqueous urea solution tank
- Feed back from NH₃ sensor
### Emission technology comparison
preliminary estimates as of June 2003

<table>
<thead>
<tr>
<th></th>
<th>High EGR</th>
<th>SCR</th>
<th>NOx Adsorber</th>
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<tr>
<td>Fuel Economy</td>
<td>-3%</td>
<td>+6%</td>
<td>-3%</td>
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<tr>
<td></td>
<td></td>
<td>(app. 6% urea usage)</td>
<td></td>
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<tr>
<td>Cooling Requirements</td>
<td>up to 55%</td>
<td>-20%</td>
<td>0%</td>
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<tr>
<td>Power Density</td>
<td>-5%</td>
<td>+6%</td>
<td>0%</td>
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<tr>
<td>Weight</td>
<td>+50 lbs.</td>
<td>-400 lbs.</td>
<td>+200 lbs.</td>
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<tr>
<td>Oil Exchange Intervals</td>
<td>1X</td>
<td>2X</td>
<td>1X</td>
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<tr>
<td>Urea Infrastructure</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Driver’s Responsibility</td>
<td>None</td>
<td>Urea Refill</td>
<td>None</td>
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