TNO Automotive
Diesel Emission Control

Introduction

New Concepts
Tools
Testing
Presentation Content

1. Introduction
2. TNO Powertrains Roadmap
3. Proposition
4. Track record
5. Wrap-up
1. **Introduction**
2. TNO Powertrains Roadmap
3. Proposition
4. Track record
5. Wrap-up
About TNO

Mission Statement
To apply scientific knowledge with the aim of strengthening the innovative power of industry and government

Key Figures
○ TNO is the Netherlands Organization for Applied Scientific Research
○ Independent Research & Technology Development
○ Founded by law in 1932
○ 4,600 employees world-wide
○ HQ in Delft, the Netherlands
○ Annual turnover approx. 400 m€
Automotive Campus / Location TNO Automotive

High Tech Automotive Campus:
- High tech automotive companies
- Facilities
- Education programmes
- Knowledge institutes
- Engineering companies
Business Unit Automotive

- Focus area’s: Integrated Safety and Powertrains
- Over 35 years of automotive experience
- Close to 200 employees
- Over 65% Master or PhD
- Located in Helmond, the Netherlands
- International customers
- Annual turnover approx. 30 m€
- Multiple expertises in one location

http://www.automotive.tno.nl
Diesel Emission Control within TNO

- Science and Industry
  - Quality of Life
  - Defense, Security and Safety
  - Built Environment and Geosciences
  - Information and Communication Technology

- Automotive (Helmond)
  - Powertrains
    - Diesel Emission Control
    - Future Automotive Fuels
    - Powertrain Testing Facilities
    - Advanced Powertrains
  - Integrated Safety
  - Homologations
Connections within TNO

Monitoring Systems

Environmental Sust. Transport (Delft)

Oil & Gas

Thermal processes (Apeldoorn)

Separation technologies (Delft)

Automotive (Helmond)

Food & Biotechnologies

Advanced concepts & products

TTAI
TÜV Rheinland TNO
Automotive International
(Helmond)

Scientific and Industry

Quality of Life

Defense, Security and Safety

Built Environment and Geosciences

Information and Communication Technology

Case examples

- Legal requirements
- Test procedures
- Traffic studies

- SCR chemistry
- CFD modelling
- Injector technology

- 2nd gen. Biofuels
- Plasma assisted gas cleaning
- Vehicle safety and crash testing
TNO Role & Position

TNO within the value chain

Market & Strategy

Concepts


Engineering

Industrialisation & Certification

Pull

Push

Automotive
Value within the Development V-cycle

Requirements, properties, specifications

Validated, certified product

Vehicle Simulation
HD / LD

to be intensified…

Vehicle Testing
LD dyno, HD climatic-altitude chamber

System Simulation
Powertrain, engine, aftertreatment

Powertrain Testing
engine, transmission dynamometers

Module
Fuel system, urea dosing system

Module Testing

Component
Sensor, injector

Component testing

Design & Development

Integration & Validation

SiL / HiL

TNO = Focus and strong areas

= Supporting
About Diesel Emission Control group

Mission Statement
To provide validated new concepts, tools & controls for meeting future diesel exhaust emission requirements by applied R&D

Model Based Control

Test Facilities
About Diesel Emission Control group

Areas of expertise
- Combustion control research
- Emission targets feasibility study
- Model based control development
- System & control strategy development
- Design of exhaust lay-outs
- Engine testing and calibration
- Pre-production programs
- Demonstration vehicles
- Vehicle field testing
- Homologation, certification
- Benchmarking, reverse engineering
1. Introduction
2. TNO Powertrains Roadmap
3. Proposition
4. Track record
5. Wrap-up
Major Challenges (1/2)

Stringent Emission Legislation

- Standards: EURO VI / 6, US2010
- Transient cycles: ETC, FTP, JE05
- Cold start impact

Focus of TNO’s “Diesel Emission Control” group

Passenger Car

<table>
<thead>
<tr>
<th>PM [g/km]</th>
<th>Euro 4 ('05)</th>
<th>NOx [g/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro 6 ('12)</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Euro 5a ('09)</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Heavy Duty

<table>
<thead>
<tr>
<th>PM [g/kWh]</th>
<th>Euro V ('08)</th>
<th>NOx [g/kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro VI ('12)</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Euro IV ('05)</td>
<td>0.02</td>
<td>3.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NOx [g/kWh]</th>
<th>0.4</th>
<th>2.0</th>
<th>3.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro VI ('12)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Major Challenges (2/2)

Energy Demand & Climate Change

- Upcoming CO₂ legislation (LD)
- Fuel costs increases
  - Pressure to reduce fuel consumption
- Diversification of fuels to bio’s, synthetics, gaseous
- Electrification of mobility: hybrids, EV’s

See also TNO’s “Advanced Powertrains” group

Additional cost

Petrol (current)
Petrol (future)
Micro hybrid
Mild hybrid
Diesel (current)
Diesel (future)
Full hybrid

Hybrid potentials based on current petrol engine

CO₂ emissions [g/km]

Oil Price $
Presentation Content

1. Introduction
2. TNO Powertrains Roadmap
3. Proposition
4. Track record
5. Wrap-up
Proposition Overview

Customer Need

Next generation solutions
Current technology application
Calibration, validation

TNO Proposition

New Concepts
Tools
Testing
New Concepts - Overview

• Integrated Powertrain Control (IPC)
  Supervisory control of engine, aftertreatment and driveline to optimize trade-off’s (fuel consumption vs. emissions vs. power output)

• Integrated Emission Management (IEM)
  Synergy between engine and aftertreatment to optimize trade-off’s (fuel consumption vs. emissions)

• Aftertreatment OBD
  Model-based OBD control for more robust performance and less calibration effort

• Closed-loop combustion control – C³
  Apply in-cylinder pressure information to minimise variations in power output and combustion phasing, avoiding misfires and knock and increasing stable operating range (HCCI/PCCI/fuels)

• TNO Euro VI SCR concept
  Future emission limits realized with limited EGR, based on maximized SCR efficiency for better fuel consumption at less costs
TNO Euro VI SCR concept

- TNO Euro VI SCR concept utilizes a close-coupled SCR catalyst
- NO\textsubscript{x} conversion is maximized by smart control, thermal management and EGR/SCR balancing
- Reduced engine complexity compared to high volume EGR solution and better fuel consumption (CO\textsubscript{2})
- Simulation and testbench validation show:
  - NO\textsubscript{x} conversion of 95% over a weighted cold and hot WHTC is possible
  - Engine out NO\textsubscript{x} emission of 7 g/kWh is low enough to meet Euro VI emission legislation
- Testbench program made possible by:

![Graph showing PM and NO\textsubscript{x} emissions over different conditions with TNO Euro VI SCR concept and DPF highlighted.]

**Graph Details:**
- PM [g/kWh] axis ranges from 0.01 to 0.03
- NO\textsubscript{x} [g/kWh] axis ranges from 0.4 to 7.0
- Key points:
  - Engine out PM
  - Tailpipe out PM
  - TNO Euro VI SCR concept marker
  - DPF marker
Example project: SCR Development 2006-2008

- Complete design & validation of SCR system (hard- and software) from concept to vehicle
- European LD OEM, US market
- Base MY 2005, Euro 4, 2.2litre turbo diesel
- Budget ~ 1.5 m€
- Issues tackled: Euro6 catalyst performance, homogeneity of urea distribution, crystallization, catalyst aging characterization for OBD
Tools - Overview

- **SIMCAT**  
  Exhaust aftertreatment modeling based on physical models

- **Fit Tool**  
  Automatic fitting of testbench data towards a validated SIMCAT model

- **Model Based Supported Calibration**  
  SIMCAT supported calibration of aftertreatment and OBD control strategies

- **DYNAMO+**  
  Control oriented dynamic engine model to predict mechanical and thermal power output and emissions

- **MACS 565**  
  Flexible and cost effective rapid control prototyping system consisting of controller and calibration tool

Tools Objective

- Achieve more in less time at less costs
- Potential within emission boundaries
- R&D&E time/costs
Diesel aftertreatment catalyst models build using actual physical models (instead of mathematical fitting) for increased result robustness.

- Real-time capability
- Reduce time in development and calibration, especially in multi-configuration applications (e.g. different power ratings)
DYNAMO+

Model-based combustion and aftertreatment control

Application examples:
- Off-line calibration tool
- Model-based control development and OBD

DYNAMO+
- Enabler of advanced combustion concepts
- Maximise combustion and aftertreatment performance
Modular Automotive Control System (MACS) is TNO’s in-house developed flexible controller for prototype systems, vehicles and small scale fleets.

MACS saves time and cost in the early phases of the development process.

After prototyping the hybrid control software can be developed into production code suited for a production controller.
Mission Statement

To provide R&D testing services in the field of combustion engines, drivetrains and vehicles
Powertrain Test Centre

- **Engine dyno’s**
  transient, 20 - 700kW

- **Transmission**
  test bed with 2 transient dyno’s

- **Chassis**
  dynamometer for LD

- **Digatron**
  electrical load simulator (750V, 300kW)

- **Emissions**
  analysis of both regulated \((\text{NO}_x, \text{CO}, \text{THC}, \text{PM}, \ldots)\) and unregulated \((\text{NO}, \text{NO}_2, \text{CH}_4, \ldots)\) emissions by CVS, FTIR, PEMS, etc.

- **Fuels**
  liquid and gaseous types, biofuels

- **Climatic - Altitude Chamber**
  engines, powertrains and complete HD vehicle testing at temperatures from –45 to +55 °C and up to an altitude of 4000m
Powertrain Test Centre

Engine dynamometer & Emission measurement equipment
Powertrain Test Centre

Climatic - Altitude Chamber
Climatic chamber application examples

- Cold start, White smoke
- Engine power, Turbo speed, Black smoke
- DPF regen.
- NO\textsubscript{x} control OBD (EU)
- ISC (EU)
- OBD (UN)
- IUPR (EU)
- Cooling, Engine-brake

Temperature [°C]

Altitude [meters]
Climatic – Altitude Chamber Specifications

- Temperature range
  -45 to +55 °C

- Altitude range
  0 to 4000 m

- Wind speed, nozzle area
  120 km/h, 1.25 x 0.7 m

- Dynamometer power, torque
  550 kW, 7000 Nm

- Regulated emissions
  NOₓ, CO, THC, CO₂

- Unregulated emissions
  NO, N₂O, O₂, NH₃

- Analysers: FTIR, particulate partial flow sampler, full flow CVS (at standard ambient conditions)

- Two direct emission lines at all ambient conditions

- Full transient hub-mounted dynamometers
1. Introduction
2. TNO Powertrains Roadmap
3. Proposition
4. Track record
5. Wrap-up
Track Record Examples

TNO Internal Research

- First SCR project from 1993 to 1996 and first SCR demonstrator truck in 1999
- Euro VI testbench demonstrator
- Closed-loop combustion control engine demonstrator. Real-time model based control

Customer Projects

Commercial vehicle

- Development of DPF soot load predictor based on pressure drop and a regeneration strategy based upon this predictor
- Full engine and SCR calibration of two HD diesel applications for Tier 4i non-road emission standard
- Calibration and certification of Euro III common rail diesel engine
- Evaluation, calibration and certification of a complete aftertreatment system for a Euro IV truck application

Passenger car

- Multiple SCR research and application projects
- Evaluation of a DPF regeneration assistance system (HC doser) and development of a production-intent control strategy
- Impact analysis of HD test procedures on a LD vehicle (van) diesel engine and aftertreatment system
1. Introduction
2. TNO Powertrains Roadmap
3. Proposition
4. Track record
5. Wrap-up
Summary

TNO Diesel Emission Control

Next generation solutions
Innovative concepts for cost-effective modelling and control of advanced combustion and exhaust aftertreatment systems

Tools for current technology
Tools to reduce time and effort in the application of available technology

Testing
State-of-the art test facilities, including a full-sized climatic-altitude chamber, to support in a wide spectrum of testing needs
• Questions?
• How to continue…
Contact Information

TNO Science and Industry
BU Automotive

Steenovenweg 1
5708 HN Helmond

P.O. Box 756
5700 AT Helmond

The Netherlands

T +31 40 265 2600
F +31 40 265 2601
E automotive@tno.nl

www.automotive.tno.nl