SCR Technology for NOx Reduction:
Series Experience and State of Development

Manuel Hesser, Hartmut Lüders, Ruben-Sebastian Henning
Robert Bosch Corporation / Robert Bosch GmbH
SCR Technology for NOx Reduction

Outline

- Necessity of NOx Exhaust Gas Aftertreatment
- Air-assisted Dosing Systems (HD applications)
- Field experience with DENOXTRONIC for MD/HD
- SCR Market Overviews
- Airless Dosing Systems (including PC/LD applications)
- Measures to optimize NOx conversion performance
- Summary
SCR Technology for NOx Reduction

MD/HD: Strategies for US10

- EGR with advanced TC
- CRS without EGR
- EGR with conventional TC

EGR Rates: 15% / 25% max at FL
Boost Pressure: 3 / 4 bar abs.
Inj. Pressure: ≤ 2400 bar
Outline

- Necessity of NOx Exhaust Gas Aftertreatment
- Air-assisted Dosing Systems (HD applications)
- Field experience with DENOXTRONIC for MD/HD
- SCR Market Overviews
- Airless Dosing Systems (including PC/LD applications)
- Measures to optimize NOx conversion performance
- Summary
SCR Technology for NOx Reduction

System layout DENOXTRONIC 1 (w/ air support)
SCR Technology for NOx Reduction

DENOXTRONIC 1- Dynamic Correction

- Speed: 1000 rpm constant
- Torque: 250 Nm to 530 Nm

Graphs showing dosing strategy with and without dynamic correction.
SCR Technology for NOx Reduction

Dosing Module

Delivery Module
SCR Technology for NOx Reduction

Outline

- Necessity of NOx Exhaust Gas Aftertreatment
- Air-assisted Dosing Systems (HD applications)
- Field experience with DENOXTRONIC for MD/HD
- SCR Market Overviews
- Airless Dosing Systems (including PC/LD applications)
- Measures to optimize NOx conversion performance
- Summary
SCR Technology for NOx Reduction

Field experience with DENOXTRONIC for HD/MD

- First SCR market introduction with Nissan Diesel in Nov. 2004 in Japan
- First SCR market introduction by Volvo-Bus at the end of 2004 in Europe
- Other OEM’s will launch first SCR vehicles in 2005 and 2006
- 1200 vehicles have been sold so far (Europe and Japan combined)
- Field test mileage with 6 OEM’s (Europe and Japan combined):
  - 14 Mio km with 200 vehicles
- Field test experience:
  - SCR is a reliable technology for automotive exhaust gas treatment
  - Solutions to technical challenges, e.g. avoiding of crystallization and heat protection at exhaust gas interface, are available.
Scr Technology for NOx Reduction

Outline

- Necessity of NOx Exhaust Gas Aftertreatment
- Air-assisted Dosing Systems (HD applications)
- Field experience with DENOXTRONIC for MD/HD

SCR Market Overviews

- Airless Dosing Systems (including PC/LD applications)
- Measures to optimize NOx conversion performance
- Summary
SCR Technology for NOx Reduction

SCR in Europe

Drivers:

- Benefits in specific fuel consumption and reliability
- Early compliance with Euro 5 emission standards
  ➔ Highway tax incentives, e.g. Germany 0.02 €/km until 2009
SCR Technology for NOx Reduction

Urea / AdBlue Infrastructure in Europe

► 3 Companies provide AdBlue through their filling station networks

► At present:
  - 20 filling stations with pumps
  - 650 filling stations offer canisters (>1500 stations by the end of 2005)

► Various companies offer the distribution of:
  - On-site tanks and pumps
  - Bulk loads
  - Intermediate bulk containers and cans
SCR Technology for NOx Reduction

SCR in Japan

- **HD/MD**
  - Reducing agent infrastructure is being prepared with cans, on-site tanks and public filling stations (~700).
  - Driver: Compliance with ‘New Long Term Regulations’ (2g/kWh NOx)

- **PC/LD**
  - Market potential is expected to increase as the AdBlue infrastructure expands.
SCR Technology for NOx Reduction

SCR in North America

→ **HD/MD**
  - For 2007 industry is focused on EGR and DPF
  - SCR is seen as potential technology for US10 combined with EGR/DPF
  - No definitive technology path determined yet (LNT ↔ SCR)

→ **PC/LD**
  - SCR seems to be the preferred solution with regard to lifetime performance, effective temperature range, fuel consumption and costs
  - OEM’s are in discussion with EPA for a potential SCR introduction in 2008/09.
SCR Technology for NOx Reduction

Outline

- Necessity of NOx Exhaust Gas Aftertreatment
- Air-assisted Dosing Systems (HD applications)
- Field experience with DENOXTRONIC for MD/HD
- SCR Market Overviews
  - Airless Dosing Systems (including PC/LD applications)
  - Measures to optimize NOx conversion performance
  - Summary
SCR Technology for NOx Reduction

System layout for HD/MD, non-air assisted
SCR Technology for NOx Reduction

PC/LD: Strategies for Tier 2 Bin 5 (FTP)

- Switchable EGR, optimized Cooling and Distribution
- Optimized Turbocharger
- High-end Injection Systems
- Reduced ε, optimized Injection and Glow Strategies, low T
- Exhaust Gas Treatment for heavy Vehicles

1. Diesel Particulate Filter
2. NOx Storage Catalyst or Selective Catalytic Reduction
3. Bin 5, Tier 2 Bin 8

Half Useful Life    Full Useful Life
SCR Technology for NOx Reduction

FTP75 Test Cycle – 120k aged / Non-air assisted

TP ammonia slip is lower than TP NH3 from equivalent gasoline production vehicle.

Total Conversion Efficiency: 88%

Tailpipe NOx 0.049 g/mi

Test Wt: 5250; 1:1 SCR-Engine Volume Ratio
SCR Technology for NOx Reduction

US06 Test Cycle – 120k aged / Non-air assisted

![Graph showing NOx emissions and efficiency during the US06 test cycle.](image)

- Engine CUM NOX
- TP Cum wtd NOx, 1:1 Vol Ratio
- TP Cum wtd NOx, 2:1 Vol Ratio
- Total System NOx Eff, 1:1 Vol Ratio
- Total System NOx Eff, 2:1 Vol Ratio
- Test Cycle

NOx Eff’y - 76% 1:1 SCR: Engine Vol Ratio
92% 2:1 SCR: Engine Vol Ratio

Tailpipe NOx 0.07 / 0.2 g/mi

4k mile US06 Std

Test Wt: 5250

Roll spd [mph], NOx Eff [%]
**SCR Technology for NOx Reduction**

**Urea Flow Requirements**

![Urea Flow, FTP & US06 Test Cycle Histogram](chart.png)

*Primary flow is at or under 50 g/hour on FTP. Dosing system range from 30 – 1500 g/hr is needed.*

Primary flow is at or under 50 g/hour on FTP. Dosing system range from 30 – 1500 g/hr is needed.
SCR Technology for NOx Reduction

Prototype System Layout for PC/LD

- AdBlue Pipe
- Tank with integrated Supply Module
- Engine Control Unit*
- ECU Control Line
- Dosing Module

*DCU functions integrated, separate DCU available
SCR Technology for NOx Reduction

Challenges and potential Solutions for PC/LD

**Challenges:**
- Minimize refilling and reducing agent consumption
- Minimize reducing agent tank volume (mass)
- Cold climate operation (below -11 °C)
- Low temperature performance (Catalyst Light-off)

**Solutions:**
- Minimize NOx raw emissions
- System heating or freeze resistant reducing agent
- “Rapid-heat up“ (engine measures) and advanced catalyst technologies
SCR Technology for NOx Reduction

Refilling options currently under consideration

A.) During regular service
   ➔ Driver is not involved with refilling  ☃ preferred initial solution
   ➔ Independent of infrastructure status
   ➔ Tank volume ≥ 20 liters (oil change interval)

B.) Do it yourself
   ➔ Driver is involved with refilling  ☹ not customer friendly
   ➔ Reduced tank volume possible

C.) Co-fueling
   ➔ Involvement of driver is minimized  ☃ preferred future solution
   ➔ Co-fueling equipment at filling stations necessary
SCR Technology for NOx Reduction

Outline

- Necessity of NOx Exhaust Gas Aftertreatment
- Air-assisted Dosing Systems (HD applications)
- Field experience with DENOXTRONIC for MD/HD
- SCR Market Overviews
- Airless Dosing Systems (including PC/LD applications)
- Measures to optimize NOx conversion performance
- Summary
SCR Technology for NOx Reduction

The NOx Conversion Maximization Process

- SCR catalyst
  - Wash Coat

- DOC
  - Location cc/under floor
  - Precious metal content
  - Volume

- Fuel, Lube Oil
  - Sulfur Content

- Exhaust Temp
  - Insulated pipes
  - Light-off, thermal Mgmt

- Space Velocity
  - Volume

- Catalyst Position
  - Location pre/post DPF
  - Inlet Flow Distribution
  - Thermal Mgmt

- Flow Pattern
  - Droplet Entrainment
  - Mixer usage

- Dosing Strategy
  - Closed/open Loop
  - NH₃ Storage Model
  - NH₃ Slip

- Spray Pattern
  - Droplet size distribution
  - Spray Shape
  - Dosing Rate

- Reductant mass flow
  - Dosing Qty

- Volume

- Location cc/under floor
- Precious metal content
- Volume

- Insulated pipes
- Light-off, thermal Mgmt
- Volume

- Closed/open Loop
- NH₃ Storage Model
- NH₃ Slip

- Wash Coat
- Sulfur Content

- Light-off, thermal Mgmt
- Volume

- NH₃ Storage Model
- NH₃ Slip
- Volume

- Insulated pipes
- Light-off, thermal Mgmt
- Volume

- Wash Coat
- Sulfur Content

- Light-off, thermal Mgmt
- Volume

- NH₃ Storage Model
- NH₃ Slip
SCR Technology for NOx Reduction

The NOx Conversion Maximization Process

- Catalyst Supplier
- Oil Industry
- Fuel, Lube Oil
- Vehicle / Engine and Suppliers
- Exhaust Temp
- Space Velocity
- Brake
- Flow Pattern
- Dosing Strategy
- Spray Pattern
- Reductant mass flow

NOx conversion maximization requires close cooperation of all partners!
SCR Technology for NOx Reduction

Outline

→ Necessity of NOx Exhaust Gas Aftertreatment
→ Air-assisted Dosing Systems (HD applications)
→ Field experience with DENOXTRONIC for MD/HD
→ SCR Market Overviews
→ Airless Dosing Systems (including PC/LD applications)
→ Measures to optimize NOx conversion performance

→ Summary
SCR Technology for NOx Reduction

Summary

- NOx Aftertreatment required to meet future emission legislation (EU, J, US)
- SCR is currently the most robust and long-term stable NOx reduction technology.
- Challenges (e.g. Infrastructure, in-use compliance, urea freezing) are identified and addressed
- SCR is expected to become the prime NOx reduction technology for HD/MD in Europe and Japan. High potential for US.
- SCR is very promising for PC/LD applications requiring highest NOx conversion rates over lifetime.
- Bosch offers SCR Technology which enables compliance with stringent future emission regulations for PC/LD, MD and HD applications.
Thank you!