Richard Dorenkamp

12th Diesel Engine-Efficiency and Emissions Research (DEER) Conference
August 20-24, 2006, Detroit, Michigan

LNT or Urea SCR Technology:

Which is the right technology for TIER 2 BIN 5 passenger vehicles?

Diesel Engine Development, Volkswagen AG, Wolfsburg

Agenda

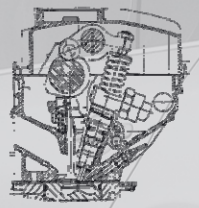
- Engine Program and Demands
- Current Emission Results in Europe and NAR
- Engine Reduction Potential
- Comparison LNT and SCR Technique
- Conclusion

VW Diesel Engine Program

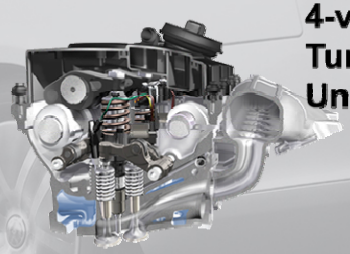
1976 1.5l-SD 50 HP
1978 2.0l-SD 71 HP
1978 2.4l-SD 75 HP
1981 1.6l-SD 54 HP
1982 1.6l-TD 69 HP
1982 2.0l-TD 83 HP
1983 2.4l-TD 102 HP
1987 1.3l-SD 45 HP
1989 1.6l-TD 80 HP
1989 1.6l-TD 60 HP
1990 1.4l-SD 48 HP
1990 1.9l-SD 68 HP
1990 2.4l-SD 78 HP
1992 1.9l-TD 64 HP
1993 1.9l-TDI 90 HP TIER1
1995 1.9l-SDI 64 HP
1995 1.9l-TDI 110 HP
1996 2.5l-TDI 102 HP
1998 1.9l-TDI-PD 116 HP
1999 2.5l-TDI 150 HP
1999 1.2l-TDI-PD 61 HP
1999 1.9l-TDI-PD 90 HP
1999 1.4l-TDI-PD 75 HP
2000 1.9l-TDI-PD 100 HP BIN10
2000 1.9l-TDI-PD 130 HP
2000 1.9l-TDI-PD 150 HP
2002 2.5l-TDI-PD 310 HP
2003 2.5l-TDI-PD 174 HP
2003 2.0l-2V-TDI-PD 136 HP BIN10
2003 2.0l-2V-TDI-PD DPF 136 HP
2003 2.0l-4V-TDI-PD 136 HP
2004 2.0l-4V-TDI-PD DPF 140 HP
2005 2.5l-TDI-Common Rail 136 HP
2006 5.0l-TDI-PD DPF 310 HP BIN10
.... 2.0l-4V-TDI Common Rail 140 HP BIN5

Cylinder head
naturally aspirated diesel(SD)

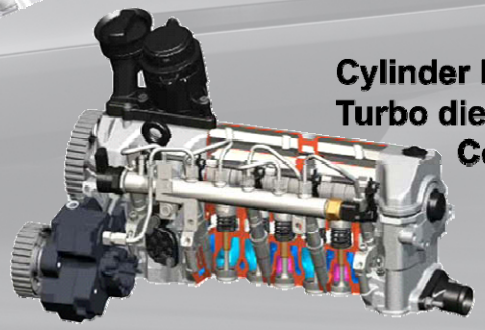
Cylinder head
Turbo diesel Direct Injector (TDI)



Cylinder head
Turbo diesel Direct Injector
Unit-Injector (TDI-PD)



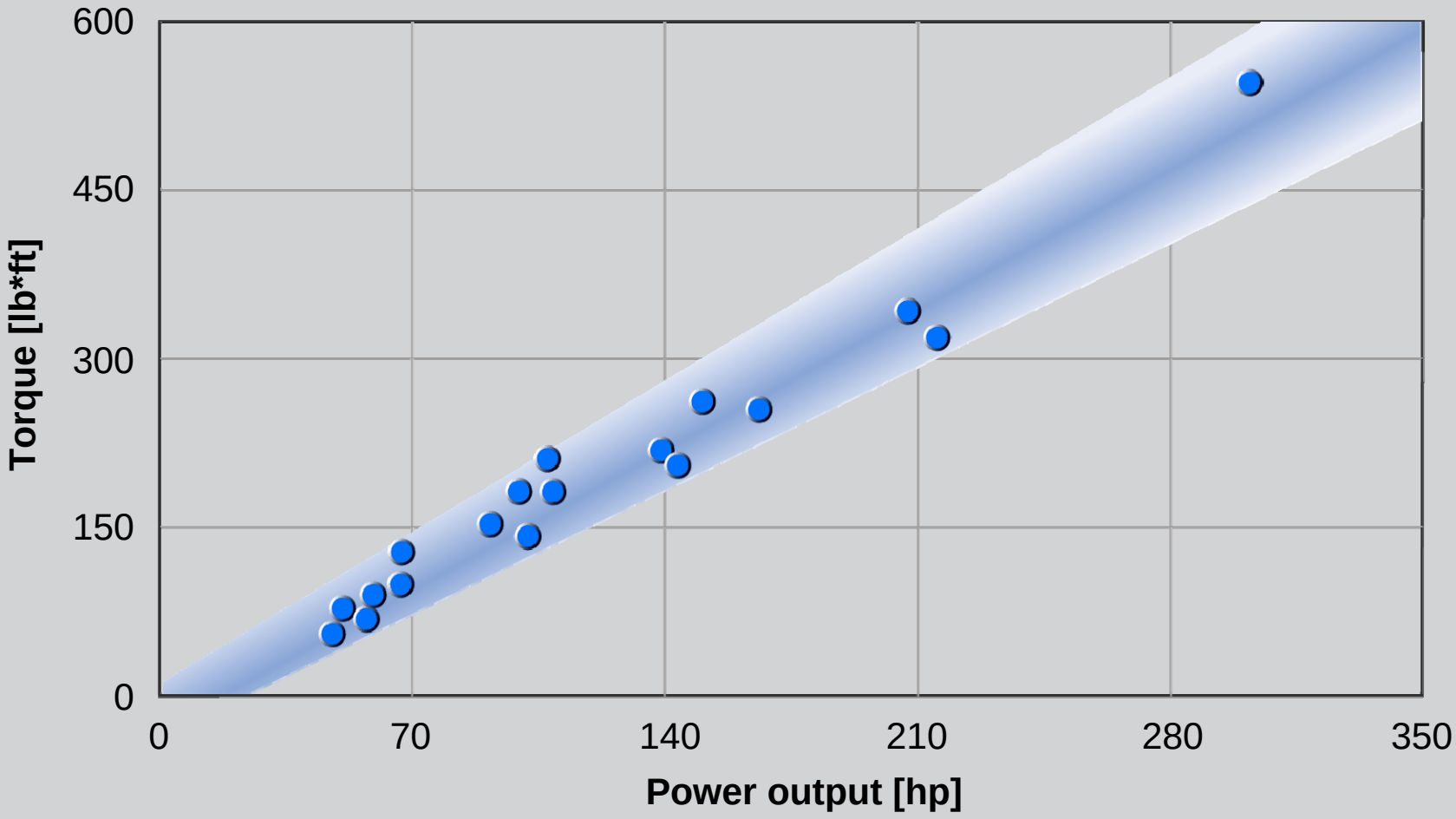
4-valve-cylinder head
Turbo diesel Direct Injector
Unit-Injector (TDI-PD)



Cylinder head
Turbo diesel Direct Injector
Common Rail (TDI-CR)

VW Diesel Engine Program

VW Diesel Engine Program



Global Markets: Future Demands and Developments

North America

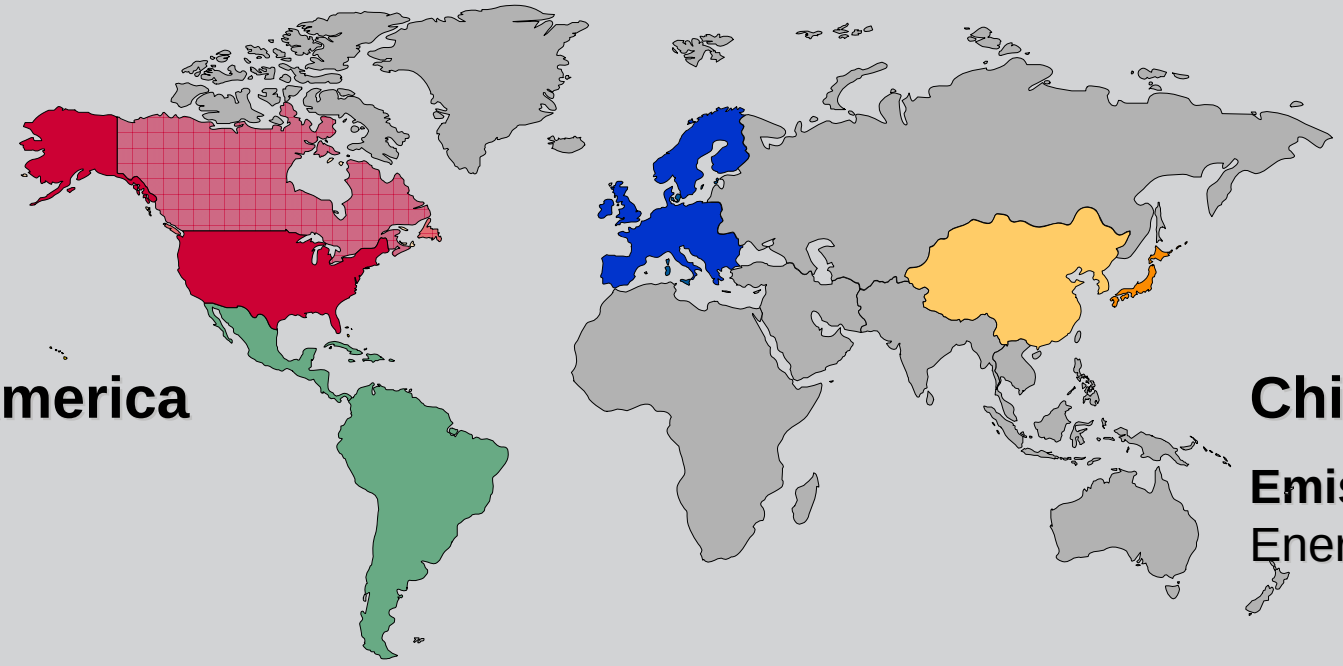
Emissions,
Performance,
Consumption

Europe

Emissions,
Consumption,
CO_2

Japan

Emissions,
Consumption,
Comfort



Latin America

Costs,
Mobility

China

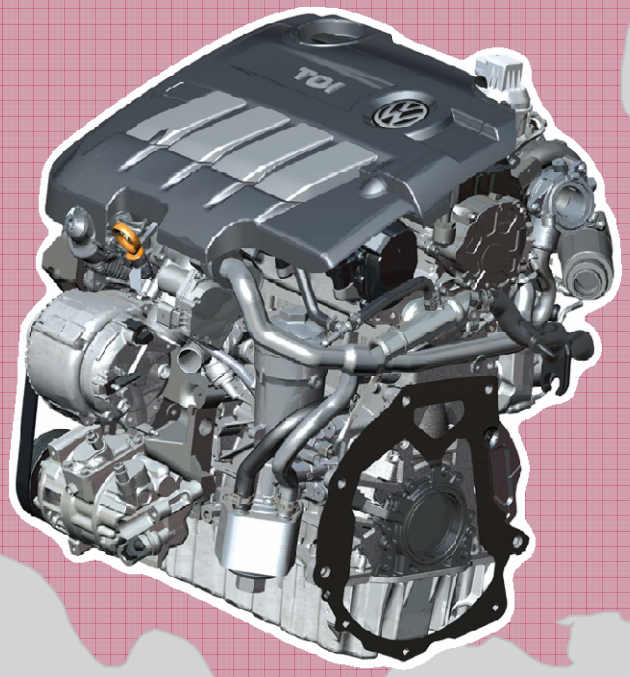
Emissions,
Energy

Customer Demands on Modern Diesel Engines

Sufficient power output / torque

Low fuel consumption

Low emissions (noise, smell, exhaust gas)



High comfort (low vibrations)

Low consumption of lubricants

Good operability

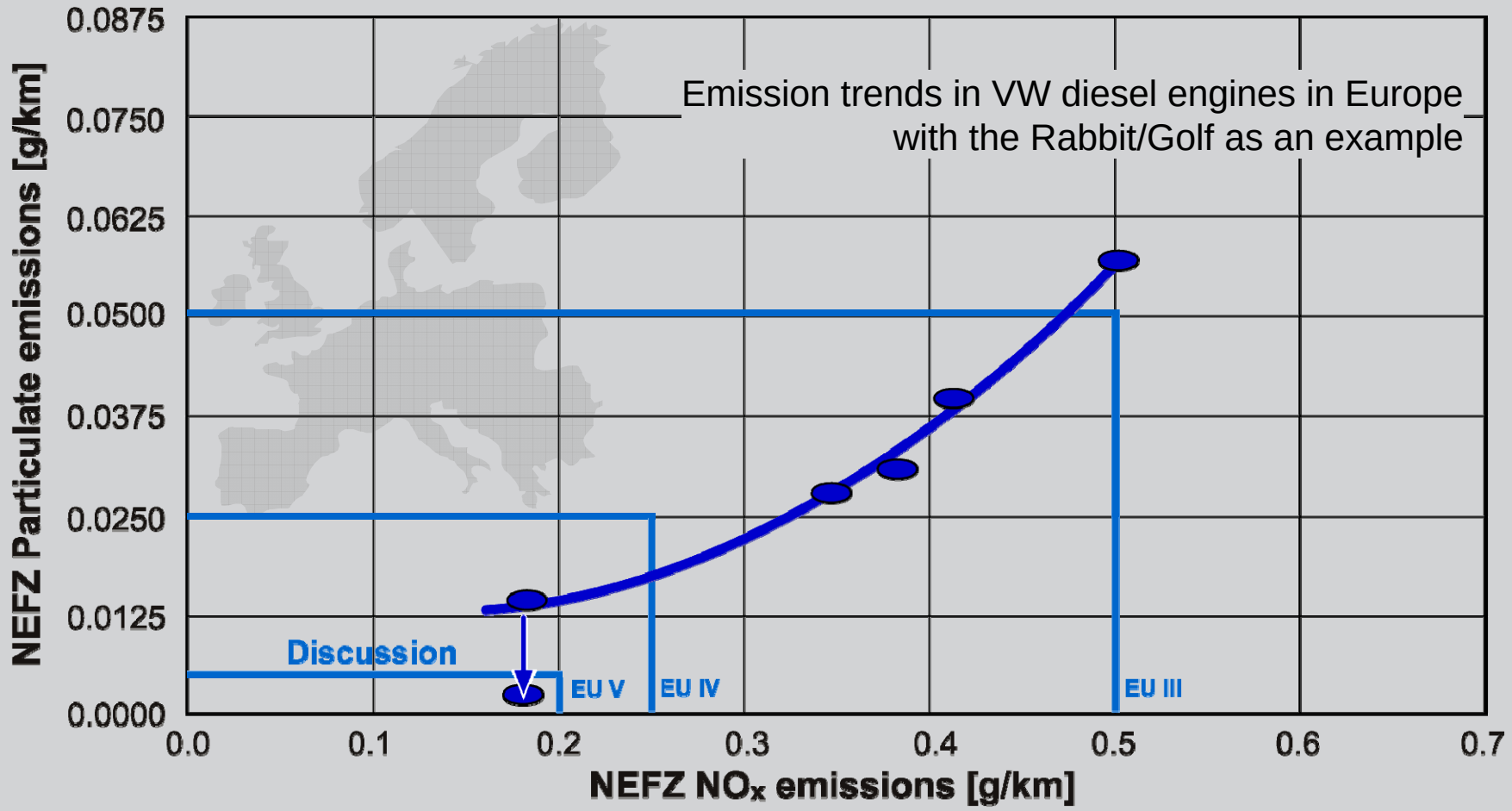
Compatible with biogenic fuels

Long service life

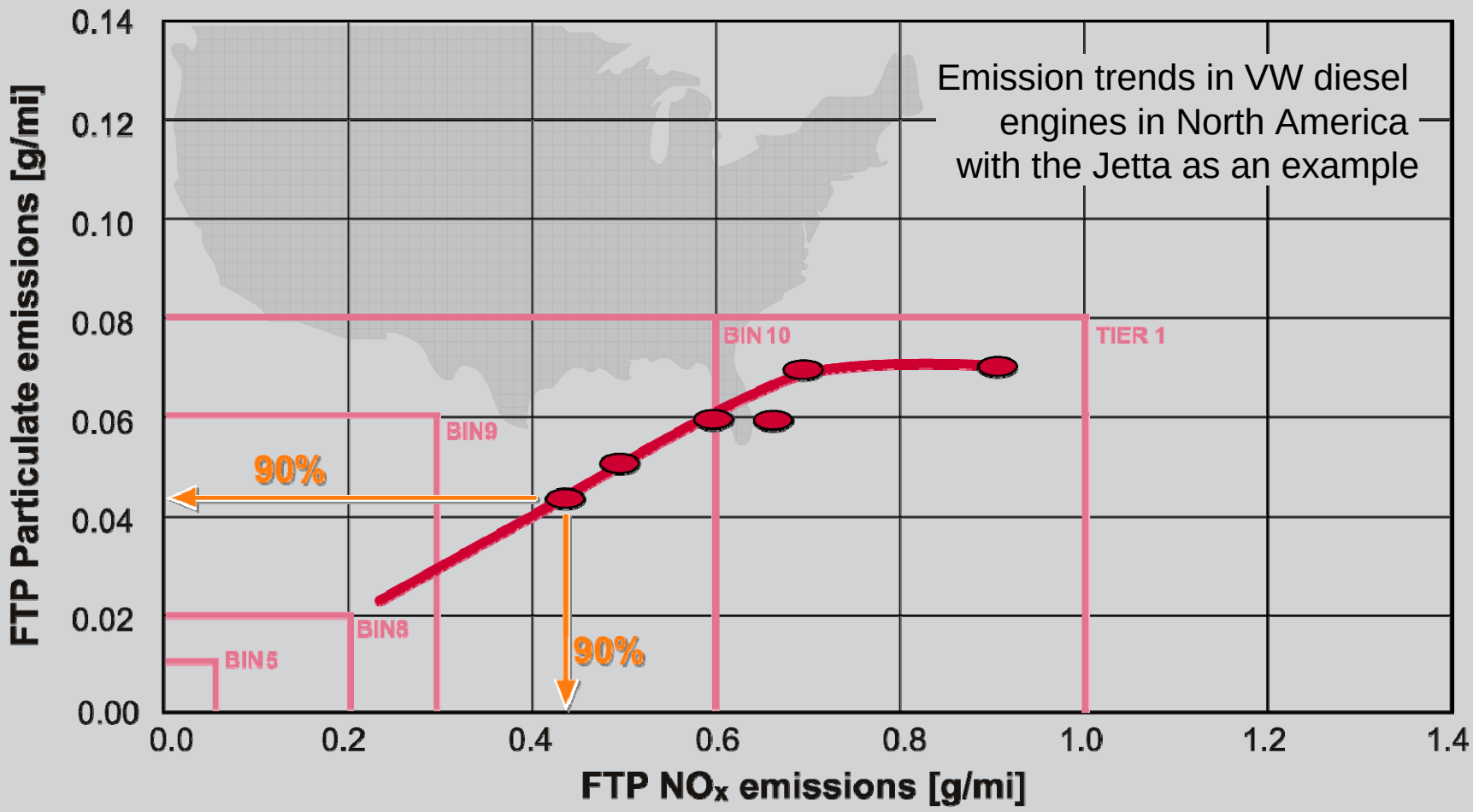
Low production costs

Low service costs

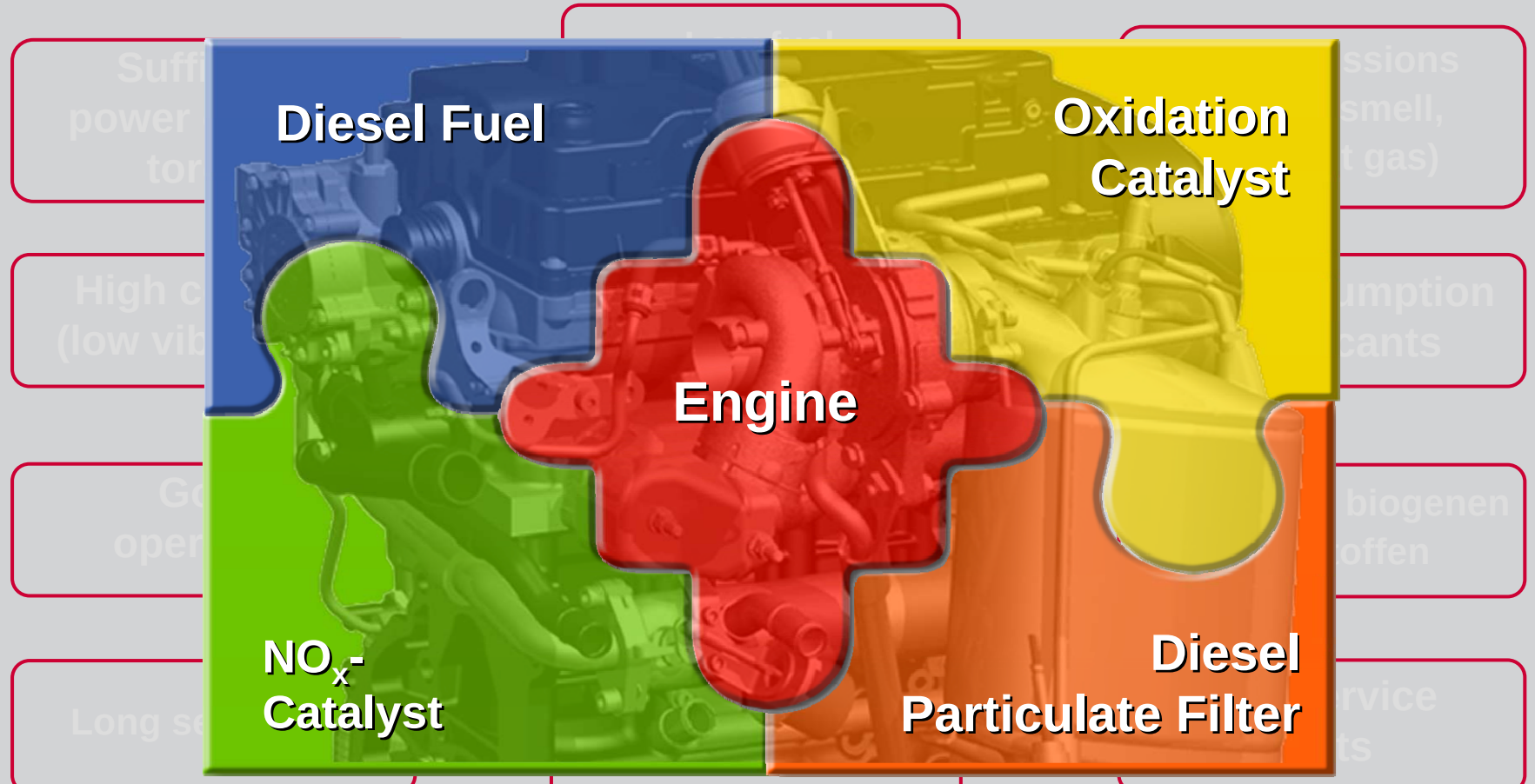
European Emission Results



North America Region Emission Results



Components of Diesel Development



Measures on the Engine

Injection

Combustion

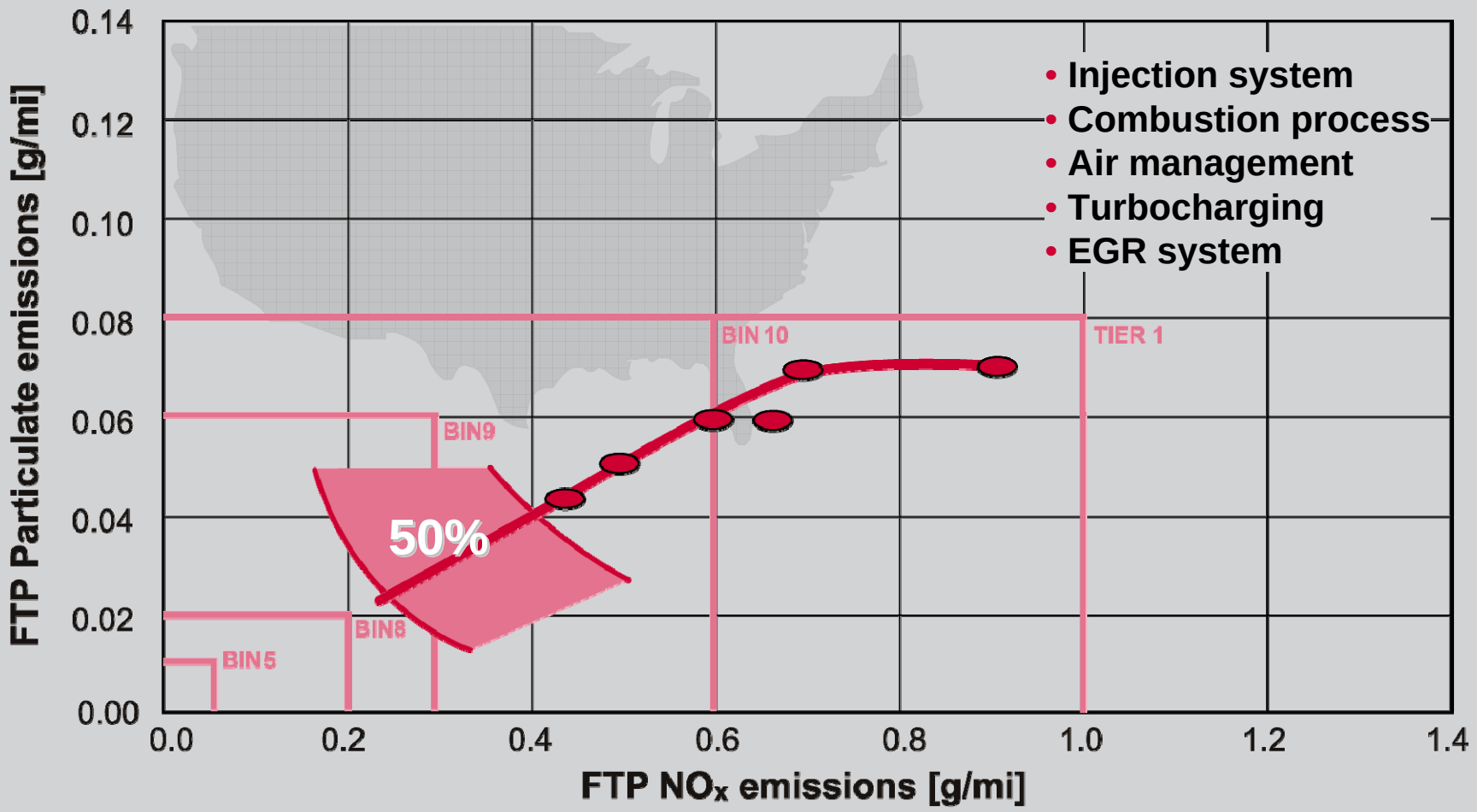
Turbocharging

Temperature management

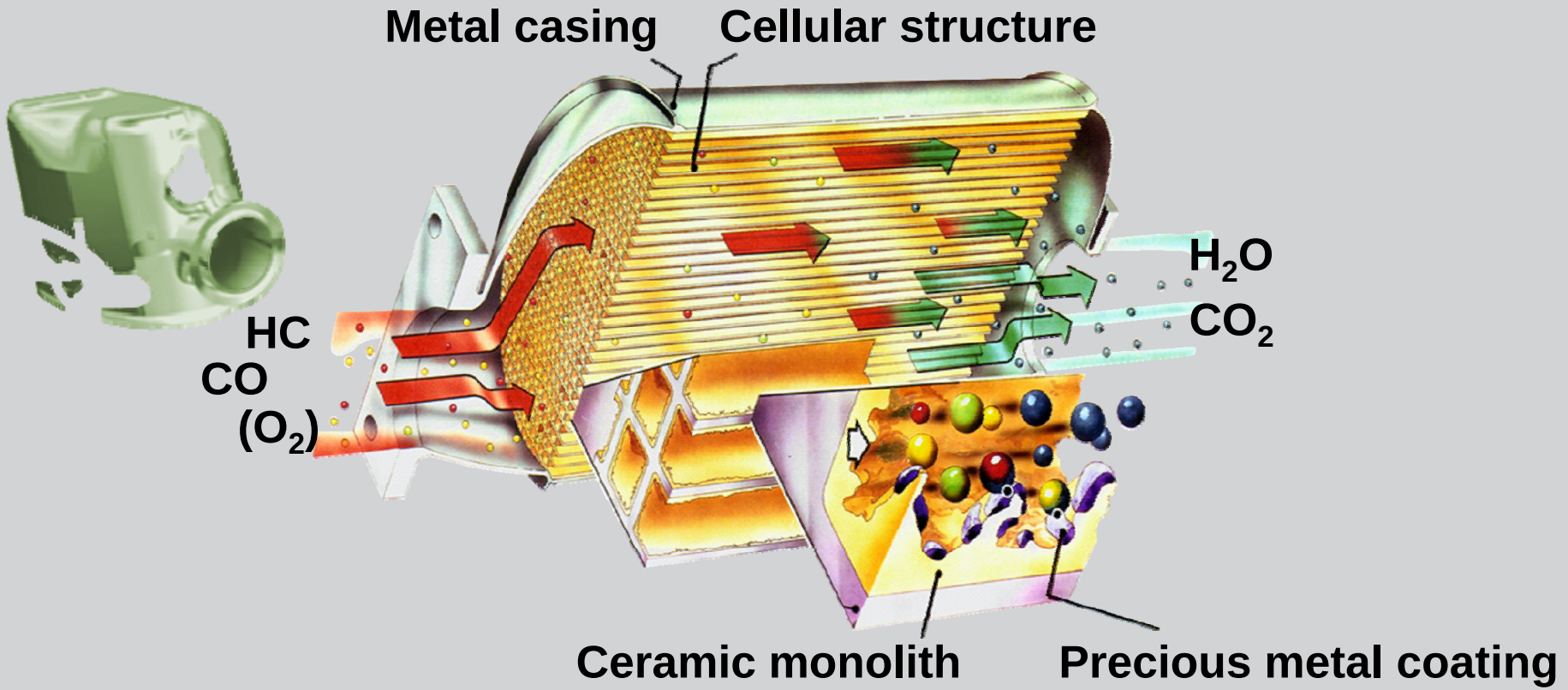
Exhaust gas recirculation

Homogenization

Engine Improvements

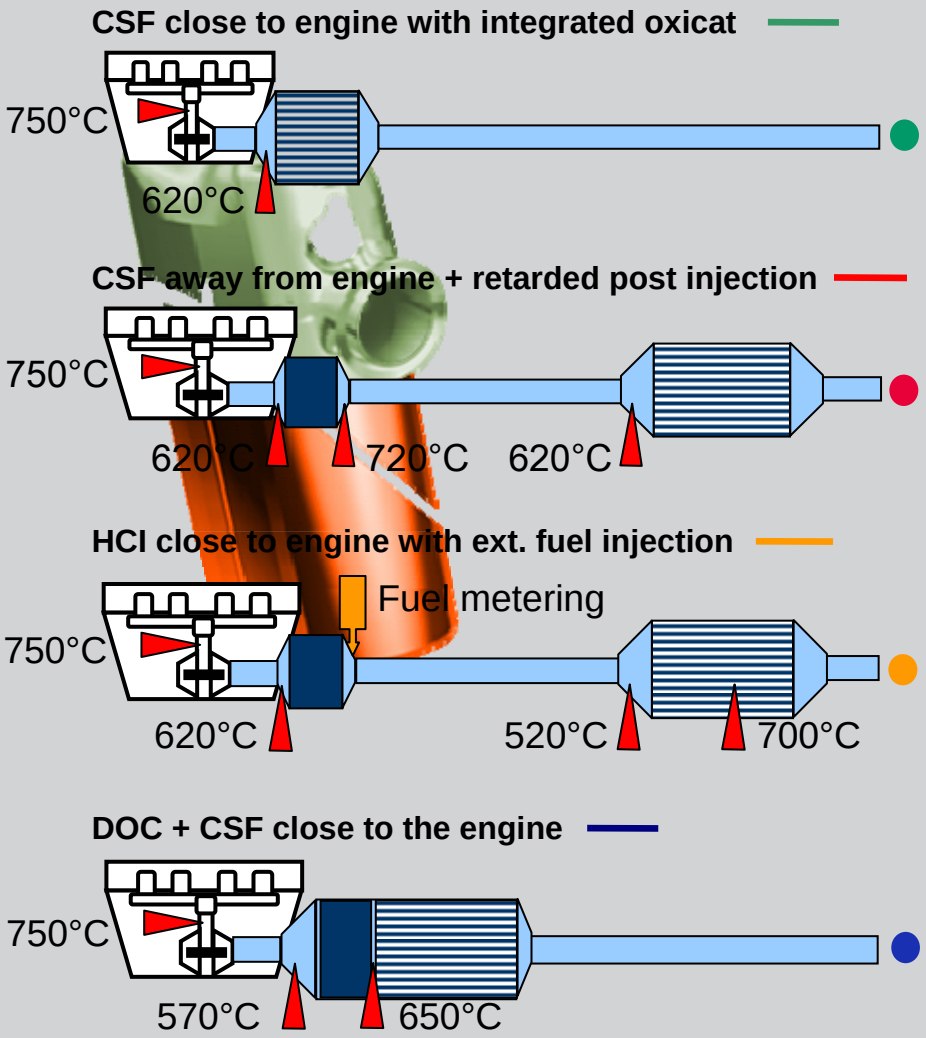


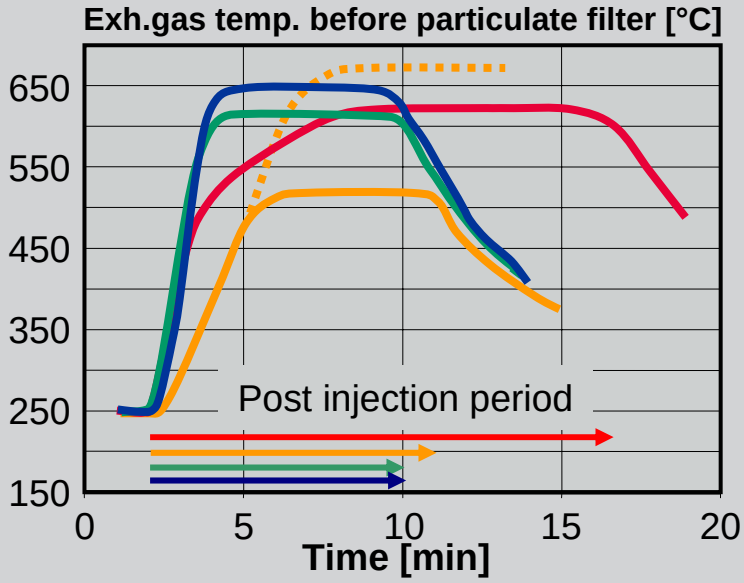
Oxidation Catalyst Principle



- HC- CO- conversion at low temperature
- Exotherme in exhaust gas system (necessary for PM trap NSC)

Different Particle Traps





General Conditions for NO_x Catalytic Converter Systems

1. **NO_x-storage catalytic converter (discontinuous)**

   $\lambda > 1$: NO_x storage (formation of Nitrates)

   $\lambda < 1$: NO_x release and reduction

   - Low sulfur fuel (S < 10 ppm) necessary
   - Additional fuel consumption as a result of catalytic converter regeneration

2. **Urea SCR catalytic converter (continuous)**

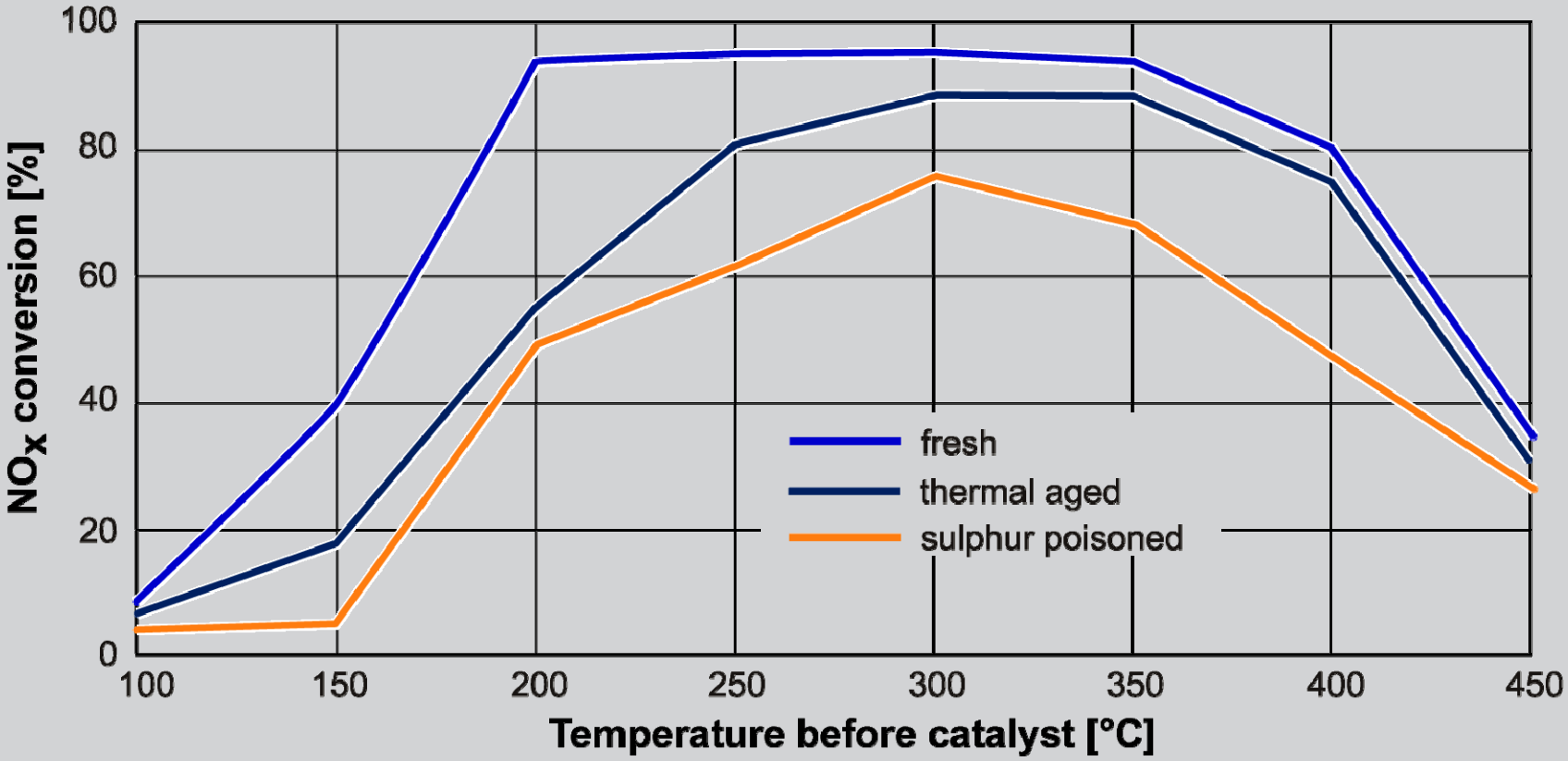
   - Hydrolysis and thermolysis of urea → formation of NH_3
   - Reduction of NO_x in the SCR catalyst using NH_3

   - Logistics necessary for the reduction agent, urea
   - Customer-friendly topping up of urea at filling stations

Impacts on NO_x Efficiency for NO_x Storage Cat

- Catalyst temperature
- Space velocity
- Current NO_x load
  - Regeneration frequency ($\Leftrightarrow$ fuel consumption)
- Thermal ageing
- Sulphur poisoning

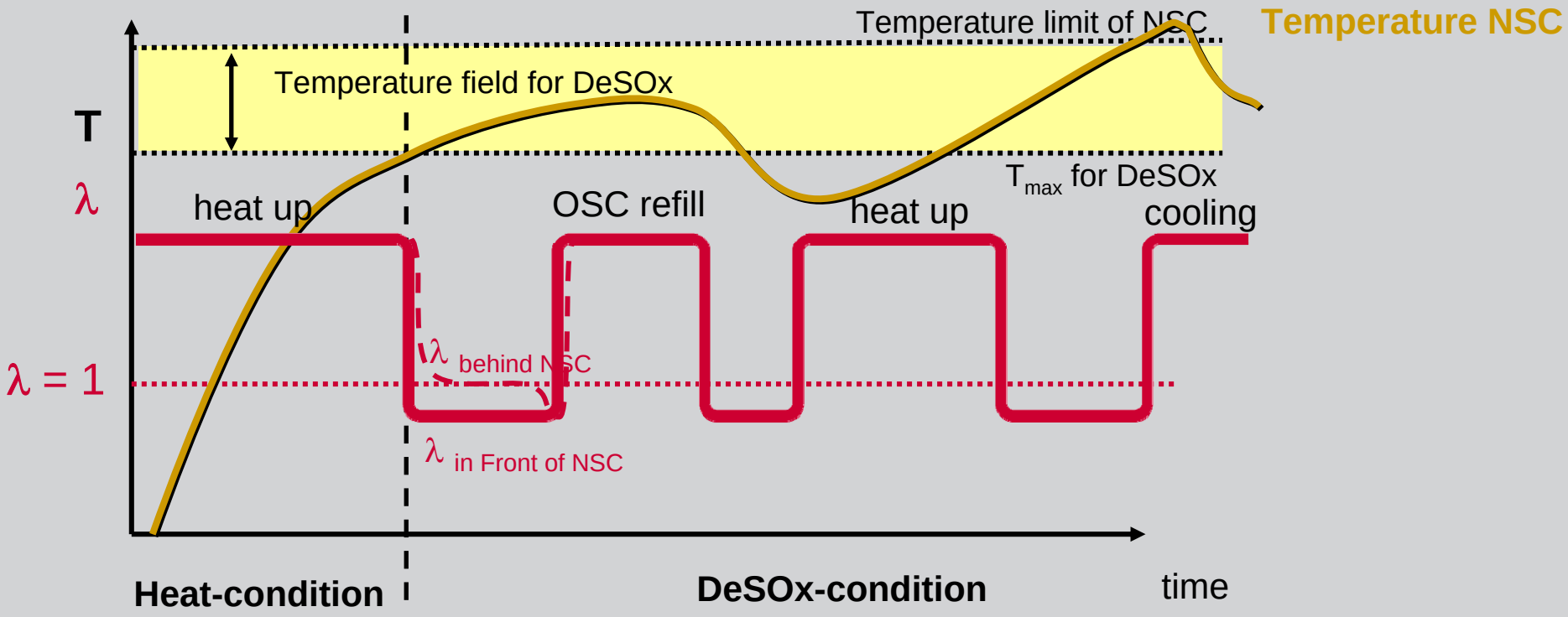
Impacts: Thermal Ageing and Sulphur Poisoning



Desulphation ($DeSO_x$)

Requirements for desulphation

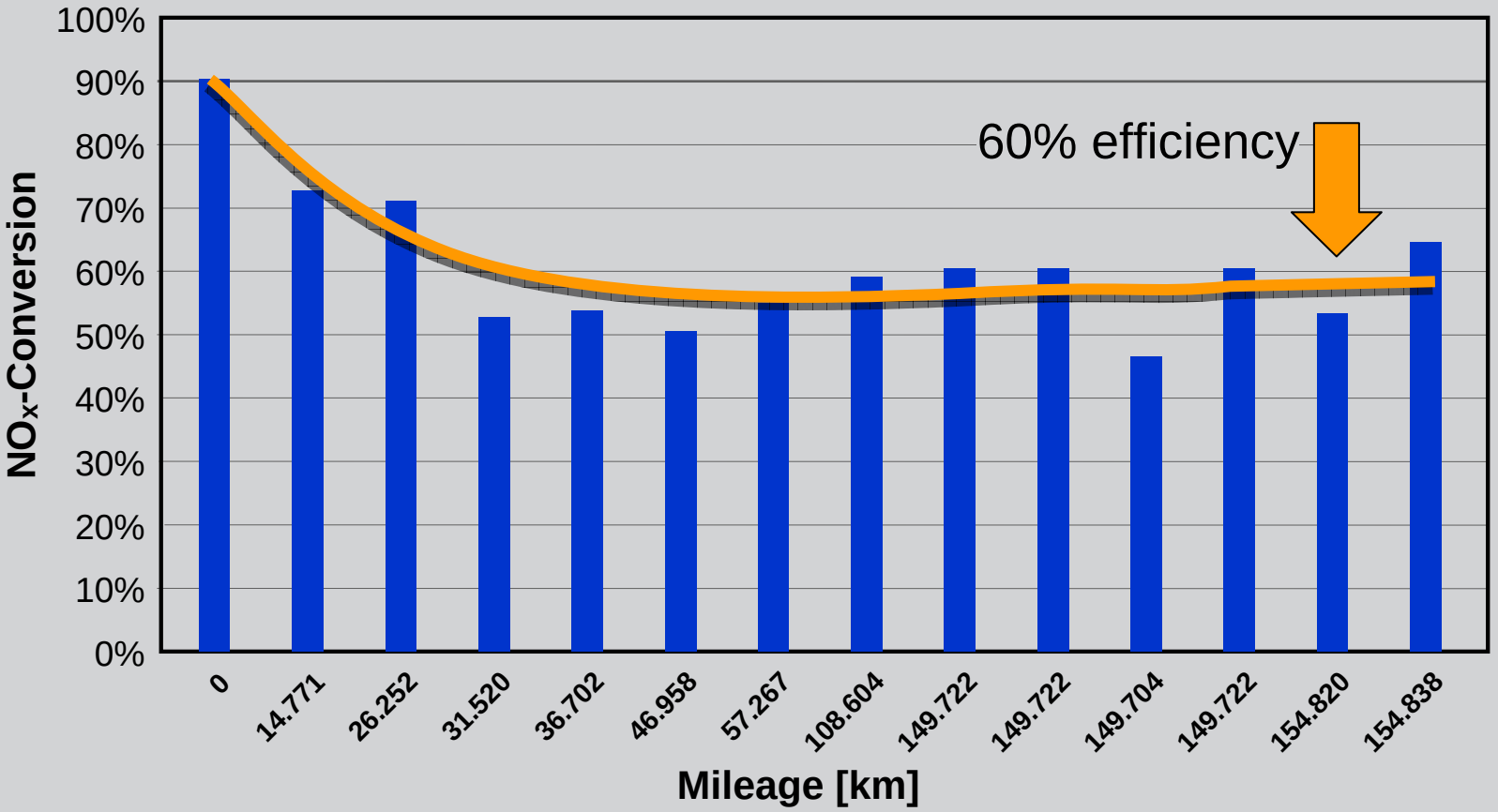
- **catalyst temperature (600°C < T < 750°C)**
- **$\lambda \leq 1$**
- **secondary emissions (λ-control)**



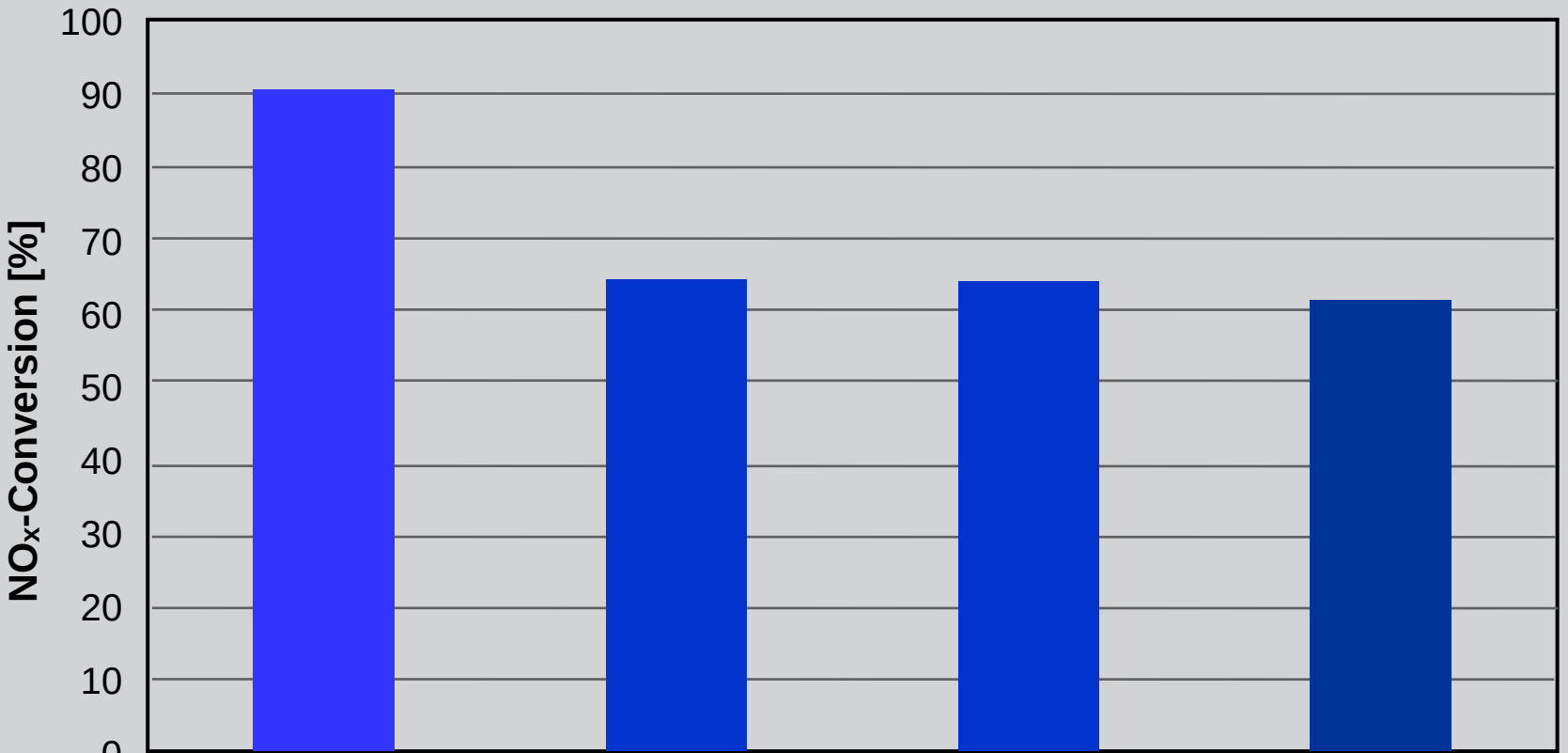
Durability Run with Desulphation

Touran 74 kW EU4 (4000 lbs) with CSF cc + NSC underfloor

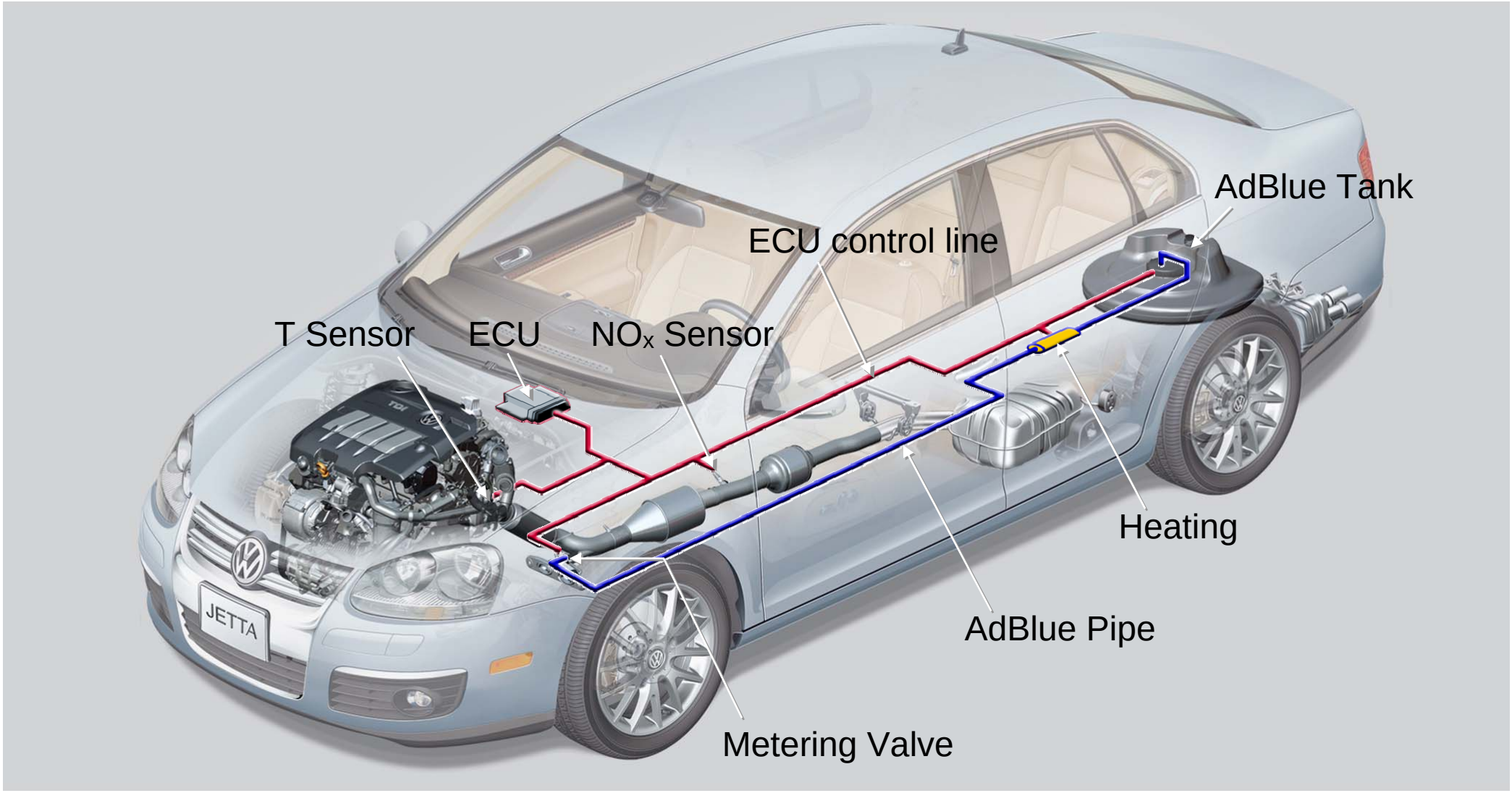
NO_x Conversion at FTP cycle (engine out NO_x 0.35 g/mi)



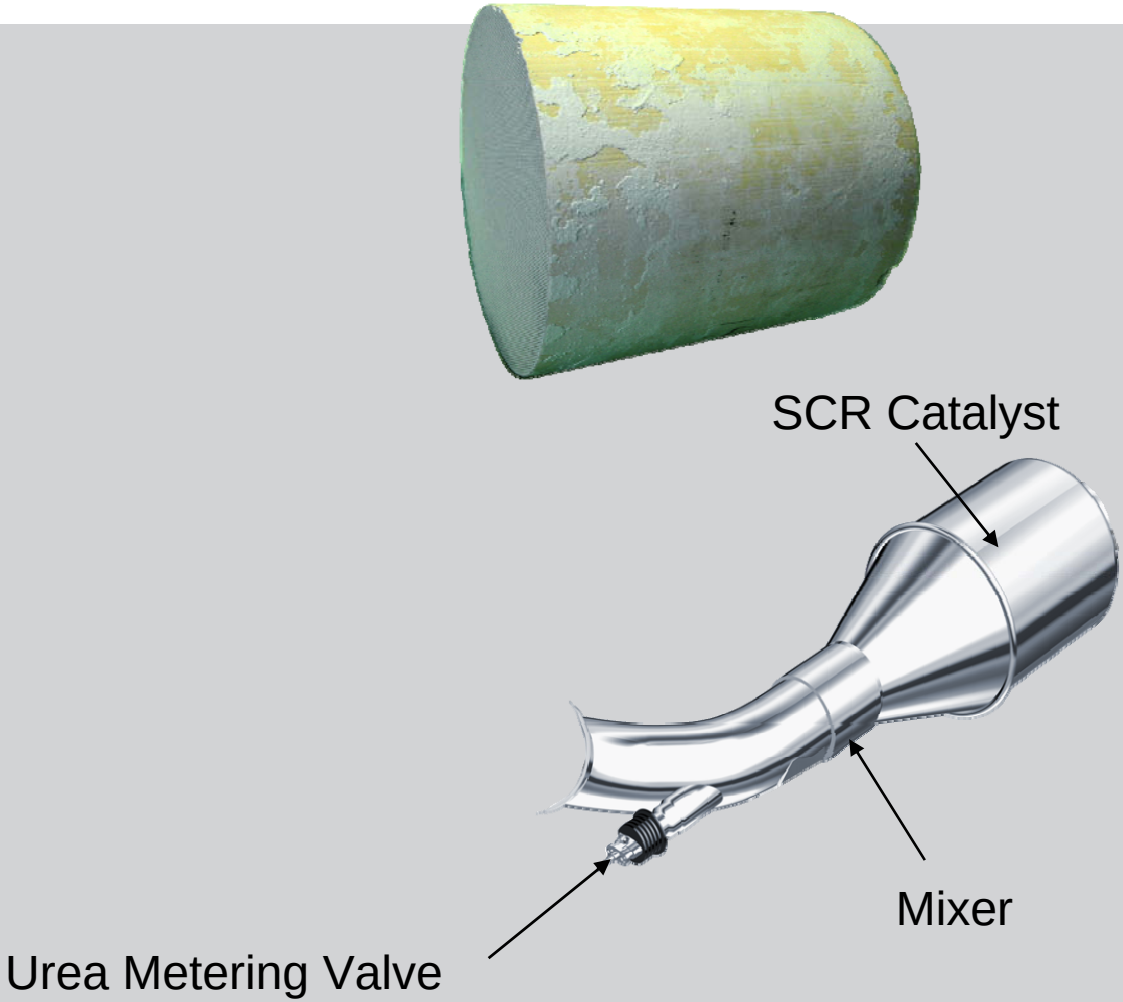
Correlation between Bench and Vehicle Ageing



SCR-System Structure



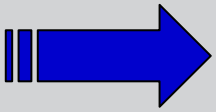
Components of SCR-System



SCR Catalyst

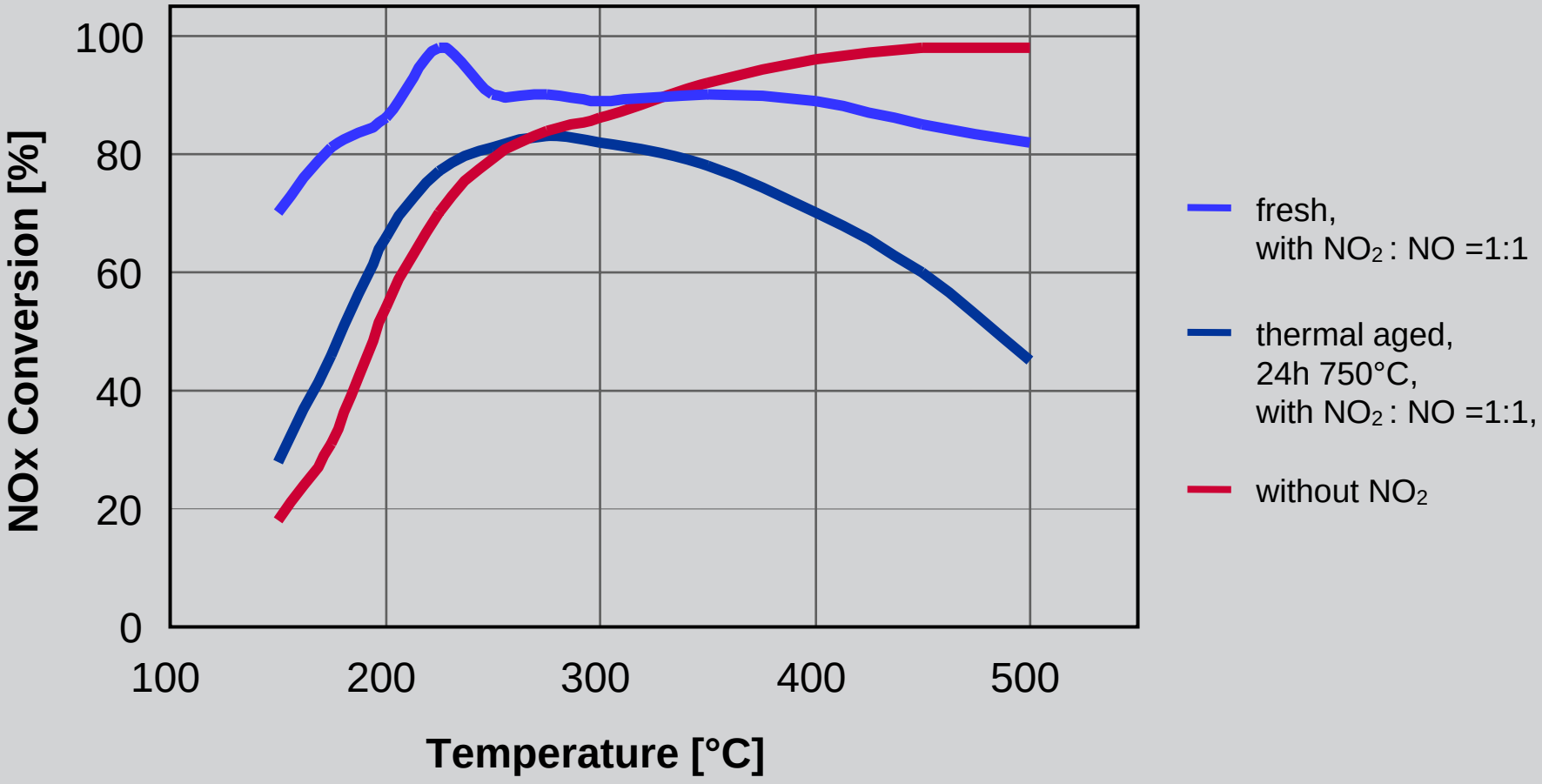
Conversion at a Function of:

- Temperature
- Mass flow
- NO/NO_2 Balance
- NH_3 Distribution and NO_x/NH_3 Ratio
- Ageing of the catalyst

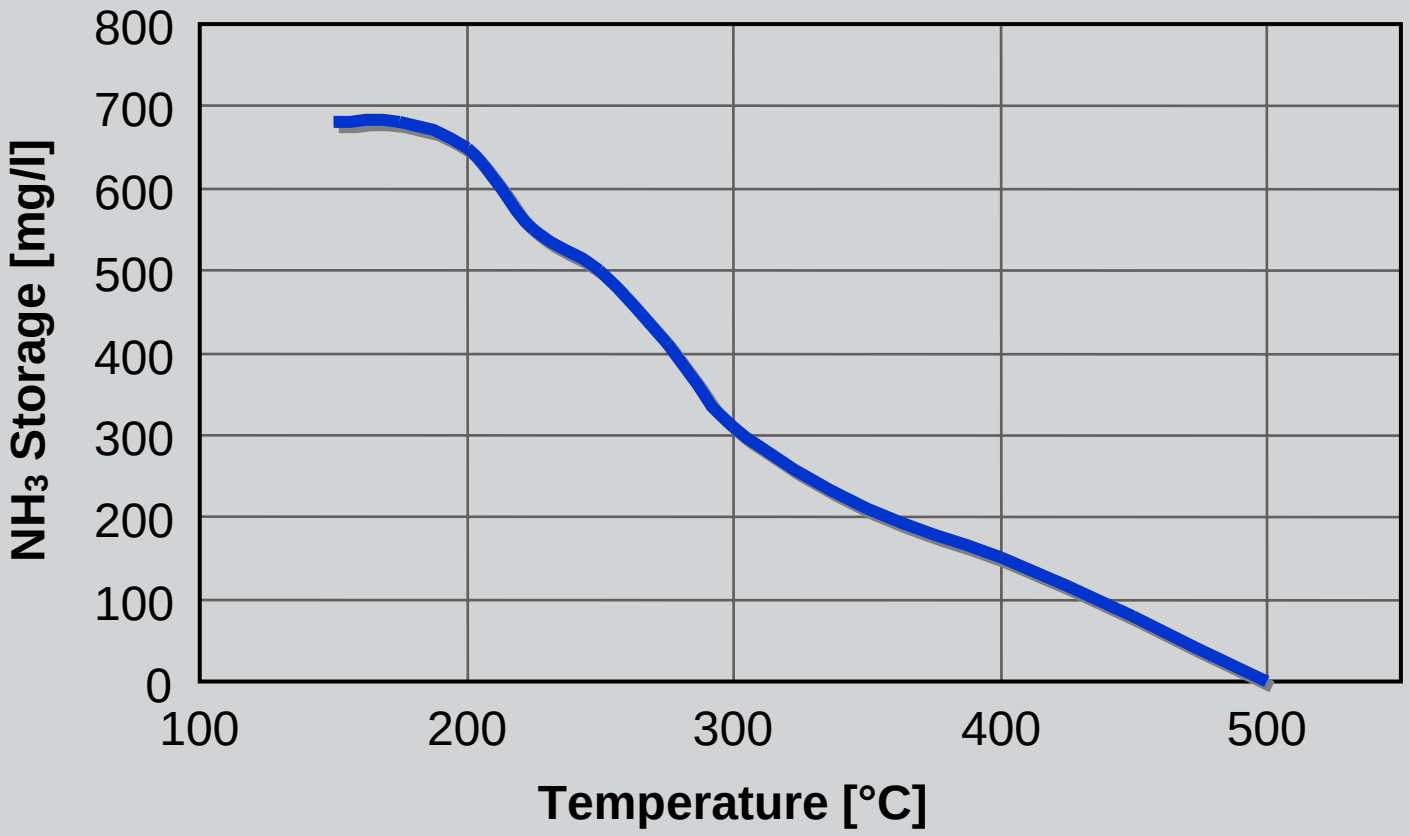


Control NH_3 Breakthrough by NH_3 Barrier Catalyst

Dependence on NO_2/NO Relation, Ageing



NH_3 Storage Capacity of SCR Catalyst

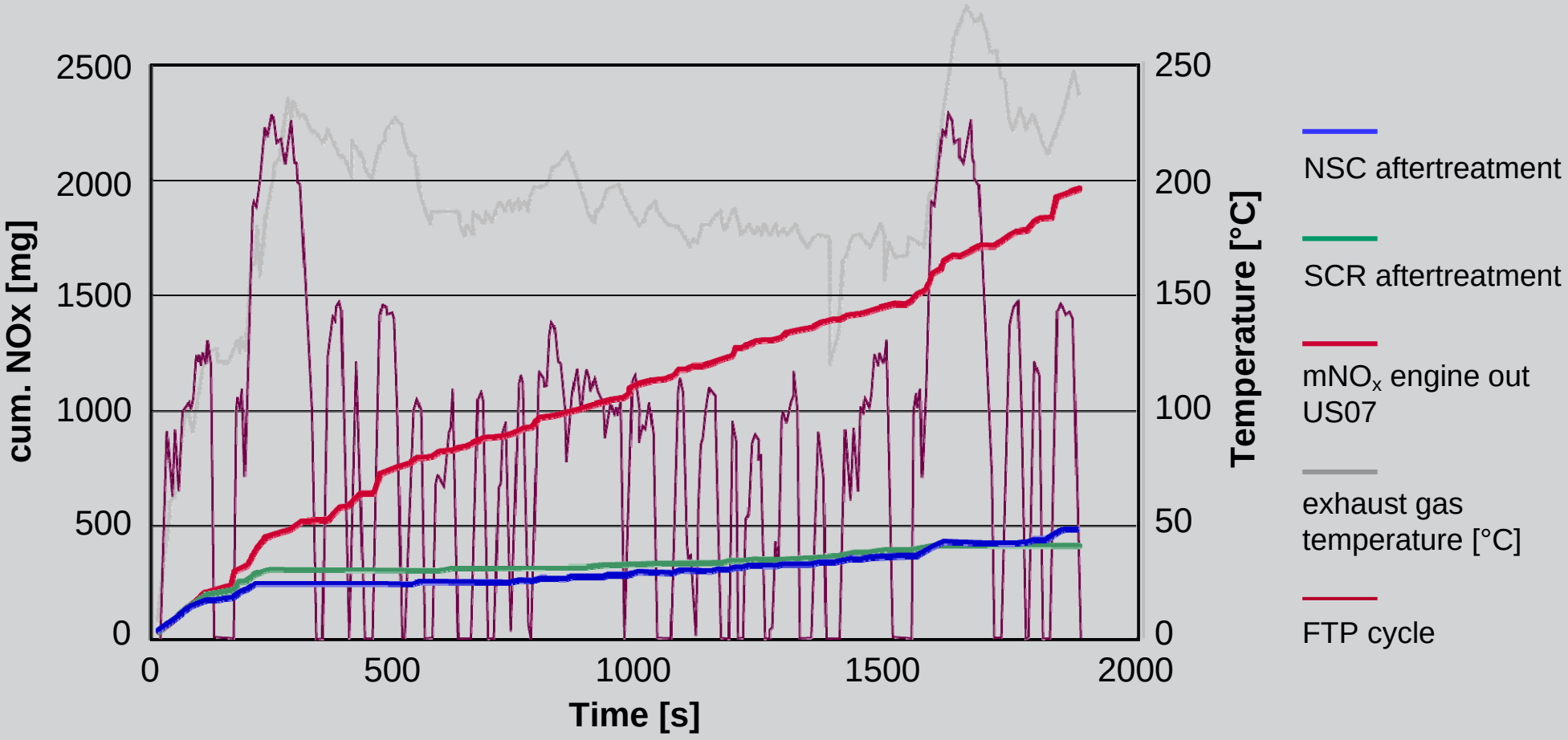


System Benchmark Test

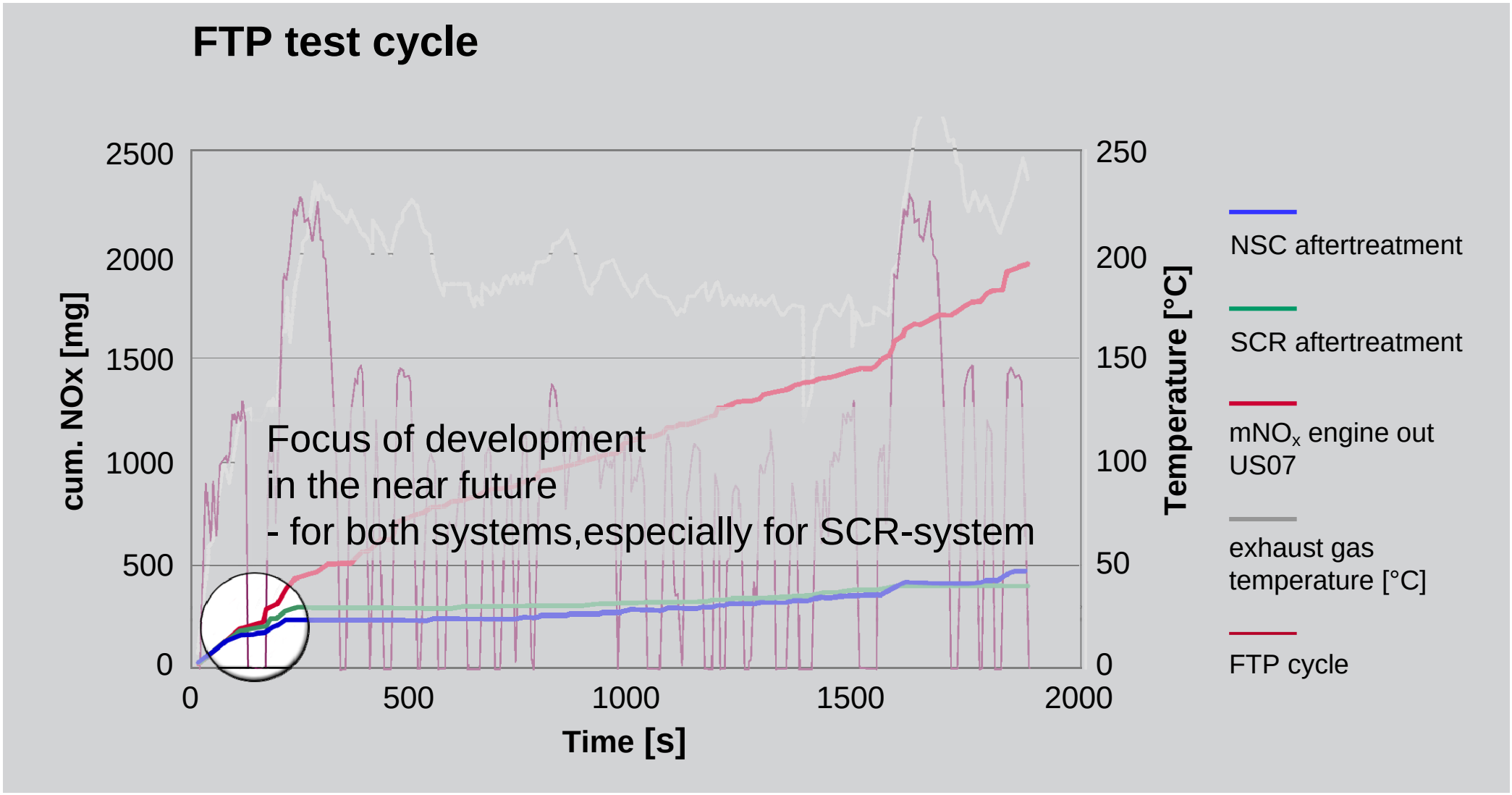
	NO_x Storage Cat	SCR System
NO_x Red. Potential (Golf) FTP US06 NEDC	 + + +	 + ++ +
NO_2 Emissions	+	+
HC	-	0
Fuel Consumption	-	0
Required Infrastructure	0	--
Servicing	0	-
Packaging Space	-	--
Error Rate / Complexity	0	-
Costs	-	--

NO_x Emission Results of SCR and NSC

in FTP Testcycle



NO_x Emission Results of SCR and NSC



System Applicability

Conclusion

- **Volkswagen uses leading edge technologies for the development of diesel engines**

- **Main focus of the diesel engine development is an optimised internal combustion system to achieve the emission standards**

- **For the LEV 2/BIN5 limits we need:**
  - a new combustion process
  - an optimised aftertreatment system
  - a high standard of fuel quality

- **LNT vs. SCR technique: There will be applications for both systems.**

Full speed ahead into a clean Diesel future.