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Selective Catalytic Reduction

(Final Report)

The most promising technology to comply with the imminent Euro IV and Euro V emission standards for HD engines

23 June 2003

Summary

Compliance with the emission standards, which will come into force in 2005 (Euro IV standards) and in 2008 (Euro V standards) respectively, will bring about the introduction of exhaust gas after-treatment systems on HD commercial vehicles.

The European HD vehicle manufacturers have chosen the Selective Catalytic Reduction technology and have decided to introduce SCR systems in combination with the use of an urea aqueous solution (32.5% urea in water) meeting the DIN 70070 standard, as reagent.

This technology is the only one that offers a solution to the dilemma of the trade-off between exhaust emission levels and fuel consumption. Field tests and extended durability runs have confirmed its effectiveness and reliability.

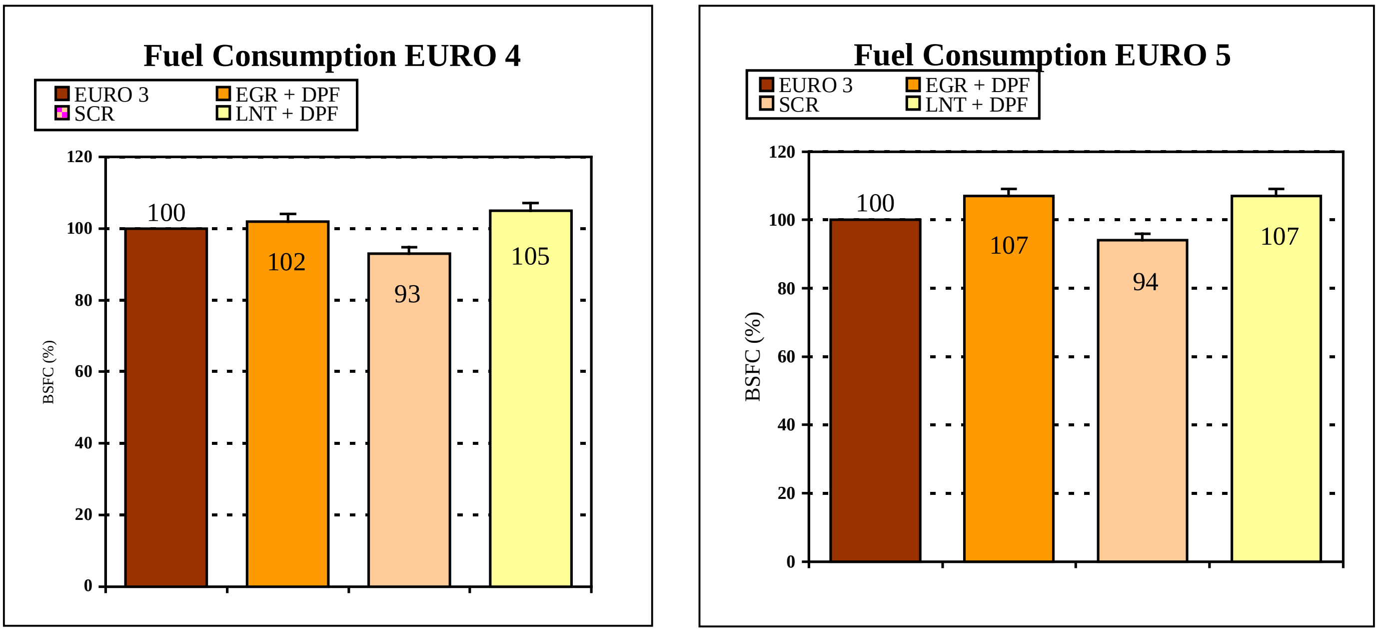

Fig. 1 - Fuel consumption impact of different exhaust gas after-treatment systems

The SCR technology is also the only exhaust gas after-treatment technology that is applicable to all engines and all missions.

Its introduction will require the installation of urea solution dispensers at the vehicle refuelling facilities to ensure the availability of this reagent needed to convert the oxides of nitrogen (NOx) into N_2. With the support of their trade associations, HD vehicle manufacturers are seeking the co-operation of the industries active in the production and distribution of urea and of the oil companies to make this a reality.

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1. Introduction

Heavy-duty commercial vehicles are today equipped exclusively with diesel engines as a result of their high level of reliability and low fuel consumption, two key characteristics sought after by fleet operators.

The progressive tightening of the emission standards for HD engines (see fig. 2) has, however, resulted in a dilemma: for a given technology level, NOx emissions and fuel consumption are inversely proportional. As diesel technology progressed, engineers had to sacrifice potential improvements in fuel consumption in order to comply with the ever more stringent NOx emission limit values.

Emission limit values from 1990 to 2008

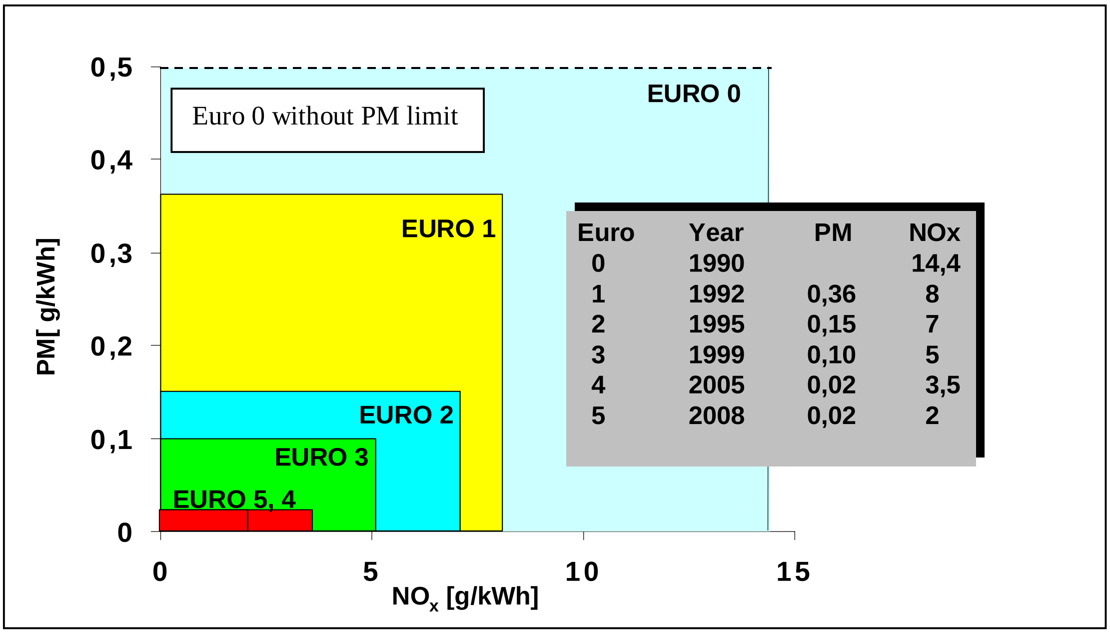


Fig. 2 - evolution of the NOx and PM emission standards for HD engines in Europe

Furthermore the imminent extremely low emission levels (Euro IV and Euro V standards) are approaching values, which cannot be met with basic engine technologies alone.

Thus, in recent years, much effort was concentrated in the development of exhaust gas after-treatment systems for diesel engines in order to achieve substantial reductions in exhaust emissions without having to compromise fuel consumption performance levels.

2. Technological options

A range of systems is being investigated to reduce HD diesel engine emissions, such as:

- Selective Catalytic Reduction systems using the hydrocarbons present in the exhaust stream or by injecting hydrocarbons or using various reduction agents,
- Diesel particle filters,
- NOx absorbers.

An exhaust gas after-treatment system for HD diesel engines must meet the following criteria:

⇒ High effectiveness at reasonable costs,

⇒ Optimum reliability,

⇒ Stable performance in extended durability,
⇒ Negligible impact on fuel consumption,
⇒ Optimum compatibility with engine technologies and other after-treatment systems.

Among these systems, the only one that has proven to meet all of the above criteria is the Selective Reduction Catalyst using a urea solution as a reagent.

2.1 SCR technology

Figure 3 shows the layout of a complex SCR system (some components, such as the oxidation catalysts, are optional parts of a SCR system), using a 32.5 % urea solution in water as reagent whilst figure 4 lists the various chemical reactions, which occur along the system.

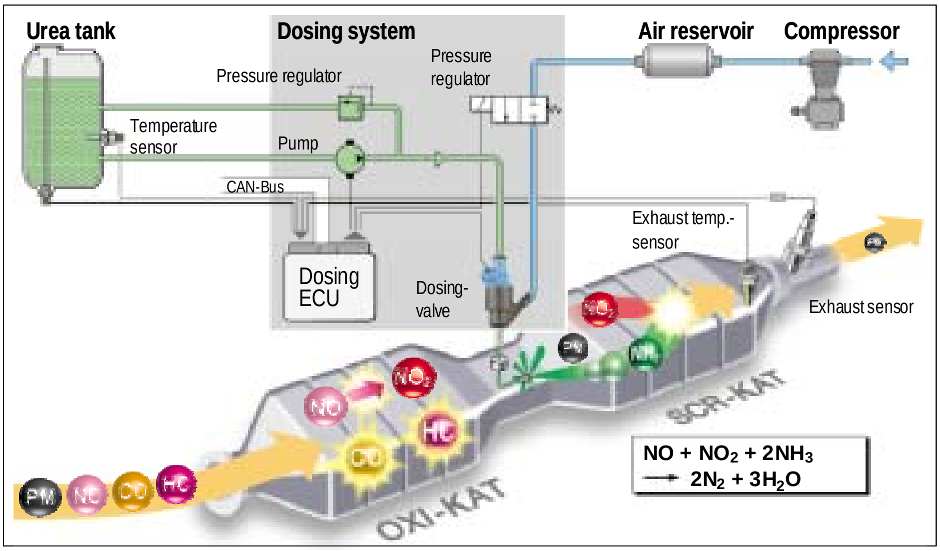


Fig. 3 - SCR catalyst and dosing system (Source: Bosch)

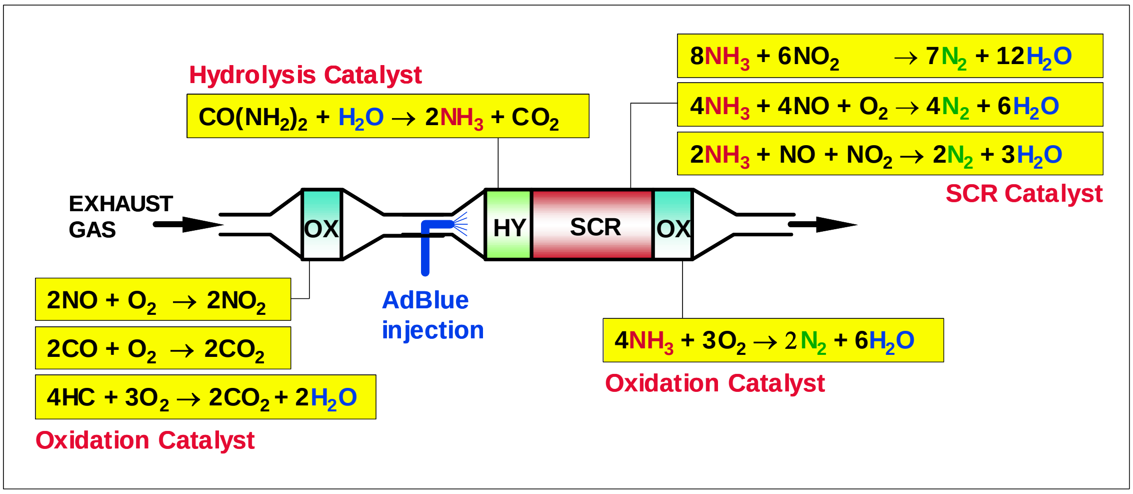


Fig 4 - Chemical reactions in a SCR system

The SCR technology for reducing nitrogen oxides (NOx) finds applications worldwide as an after-treatment system for power plants and waste furnaces. Ammonia (NH_3) could also be used directly as a reagent, but the solution of urea in water is by far the best reagent since it is a non-toxic product and there are no restrictions for its transport on rail, road or ships.

Furthermore, urea is a product largely used in agriculture and in industry and urea of various quality grades is readily available.

An oxidation catalyst may be used to improve the efficiency of the SCR by converting NO into NO_2 and by oxidising CO and hydrocarbons.

Accurate dosing of the urea solution and appropriate strategies during transient modes prevent an NH_3 slip.

The SCR technology, by converting directly NOx to N_2 outside the engine, allows the retaining of the engine calibrations, which correspond to the best compromise between fuel consumption and the formation of pollutants during the combustion process. Thus it is possible to:

⇒ comply with the Euro IV emission standards and, at the same time, achieve fuel consumption levels which are 7% lower than those of equivalent Euro III engines, while the consumption of the urea solution will amount to 3% to 4% of the fuel consumption;

⇒ comply with the Euro V emission standards and, at the same time, achieve fuel consumption levels which are 6% lower than those of equivalent Euro III engines, while the consumption of the urea solution will amount to 5% to 7% of the fuel consumption;

Numerous field tests have demonstrated that the effectiveness of a SCR system remains stable even when installed on HD vehicles, which are accumulating several hundred thousand kilometres.

2.2 Diesel Particle Filters

Figure 5 shows the working principle of an example of a Diesel Particle Filter (DPF). The particles are trapped on the interior walls of the filter. In combination with an EGR system, DPF technology offers the potential to meet future emissions standards.

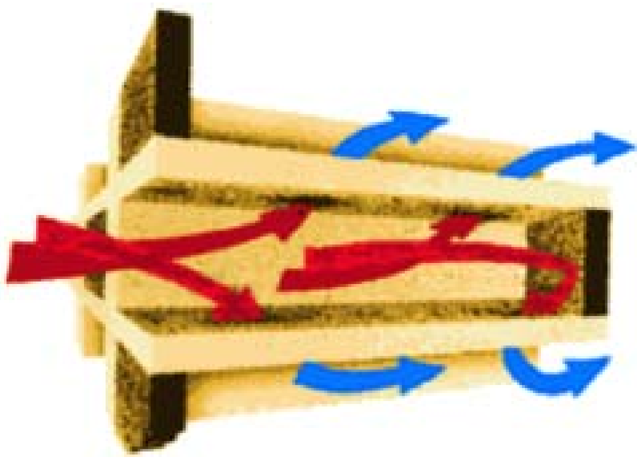


Fig. 5 - Diesel Particle Filter

In order to remove the particles from the filter walls, the filter must be periodically regenerated by active or passive regeneration concepts. The passive regeneration concept exploits driving patterns (occurring naturally or artificially created by retarded injection timing, or post injection, or richer air to fuel mixture, or by adding additives to the fuel) during which the exhaust gas temperatures reach values high enough for the filter regeneration to occur.

Notwithstanding the programmed regeneration of the filter, excessive accumulation of particles on the filter wall can still occur. This will then bring about uncontrolled regeneration resulting in local peak temperatures and cracks of the filter internal walls. Today’s failure frequency for "selected vehicles" with a mileage of 300.000 km is 5 % to 10 %.

DP filters are extremely sensitive to both the sulphur content of diesel fuels and the ash content of the lube oil. Sulphur and ashes give origin to particles, which are trapped by the filter walls but cannot be burned during regenerations and must be mechanically removed by using pneumatic filter cleaners. Even with the future 10 ppm sulphur fuels, the DPF cleaning intervals are too short (50 000 - 80 000 km) to be acceptable for HD vehicles.

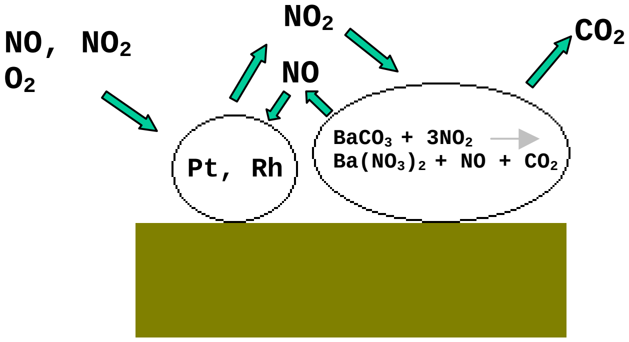
Another promising DPF technology uses NO_2 to lower the temperature at which the regeneration of the filter occurs. An oxidation catalyst positioned upstream of the DPF, converts most of the NO in the exhaust gas stream to NO_2, which then react with the carbon of the particle to give CO_2 and N_2. As not all NO_2 reacts with the particles trapped on the filter walls, NO_2 tail pipe emissions are 10 times higher than those of a conventional diesel engine with equivalent NOx emission level. Thus engines equipped with this DPF technology cannot be run in close ambient due to the legislation on health and safety of workplaces.

The above comments clearly show that the DPF technology is not easily applicable to all engines or all missions and is not yet mature for Heavy Duty applications.

Furthermore, the need for high EGR rates to control NOx emissions and for periodically creating the conditions required for regenerating the filter have a negative impact on fuel consumption, estimated between 2% (Euro IV engines) and 7% (Euro V engines).

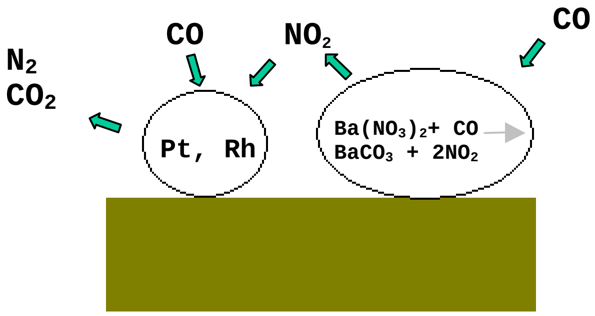
2.3 Lean NOx Traps

Figures 6 a & b show the working principle of a Lean NOx Trap (LNT).



Storage of NOx
under lean conditions

Fig. 6a - Lean NOx Trap



Regeneration
under rich conditions

Fig. 6b - Lean NOx Trap

Many issues still have to be answered before the LNT technology can be confirmed as an option for HD commercial vehicles.

LNT catalysts are very sensitive to the sulphur content of the fuel. Any small amount of sulphur in the fuel has an impact on its effectiveness, its durability and on fuel consumption.

The deterioration rate of its conversion efficiency is still to be proven, on account of the extended operating life of these vehicles/engines.

The size of a LNT for application on HD engines will be very large. As a consequence, it will require frequent desorption/conversion cycles with a corresponding substantial increase in fuel consumption (estimated values for a HD commercial vehicle: +5% for a Euro IV version, +7% for a Euro V version).

To meet even the Euro IV emission standards, an additional DPF may still be required.

Finally LNT is an expensive technology due to its high load of precious metals.

3. Prerequisites for the market introduction of SCR technology

Some exhaust gas after-treatment systems for diesel engines herein described require the availability of "sulphur free" diesel fuel since such a fuel is an enabling factor for their functionality.

In Europe, the maximum allowed sulphur content of diesel fuel will be lowered to 50 ppm in 2005.

On 30 January 2003, the EP and the Council agreed on a further reduction of the sulphur content of diesel fuels ($S \leq 10$ ppm) by 2008. At the same time, the EP and the Council adopted provisions for a phase-in of $S < 10$ ppm diesel fuel on an appropriately balanced geographical basis starting in 2005.

In addition to the above, vehicles equipped with the SCR technology must be able to find dispensers of the urea solution meeting the DIN 70070 standard at the refuelling stations.

HD vehicle manufacturers are seeking the full co-operation of the urea production/distribution companies and of the oil companies to meet this prerequisite.

Other issues to be addressed are:

⇒ the technology to be used for dispensing urea at the filling stations;
⇒ the definition of a standard for the filler nozzle for dispensing urea and for the corresponding filler neck of the urea tank in the vehicle;
⇒ the definition of an approach to be adopted for monitoring the actual use of urea during vehicle operations and confirm it via roadside inspections;
⇒ the infrastructure for dispensing the urea solution in Europe.

ACEA, in close co-operation with VDA, recently promoted the establishment of joint teams of experts to deal with the above.

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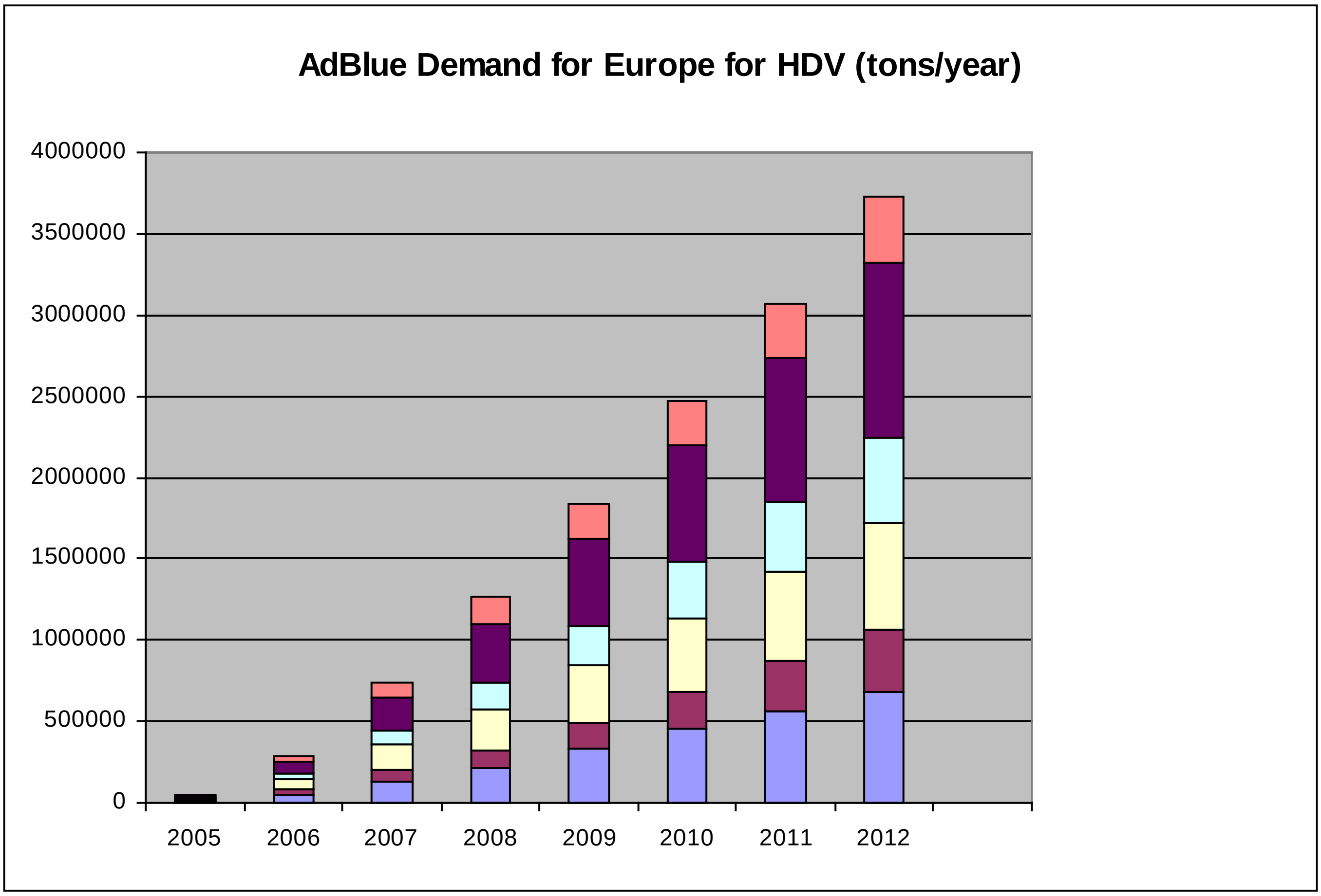
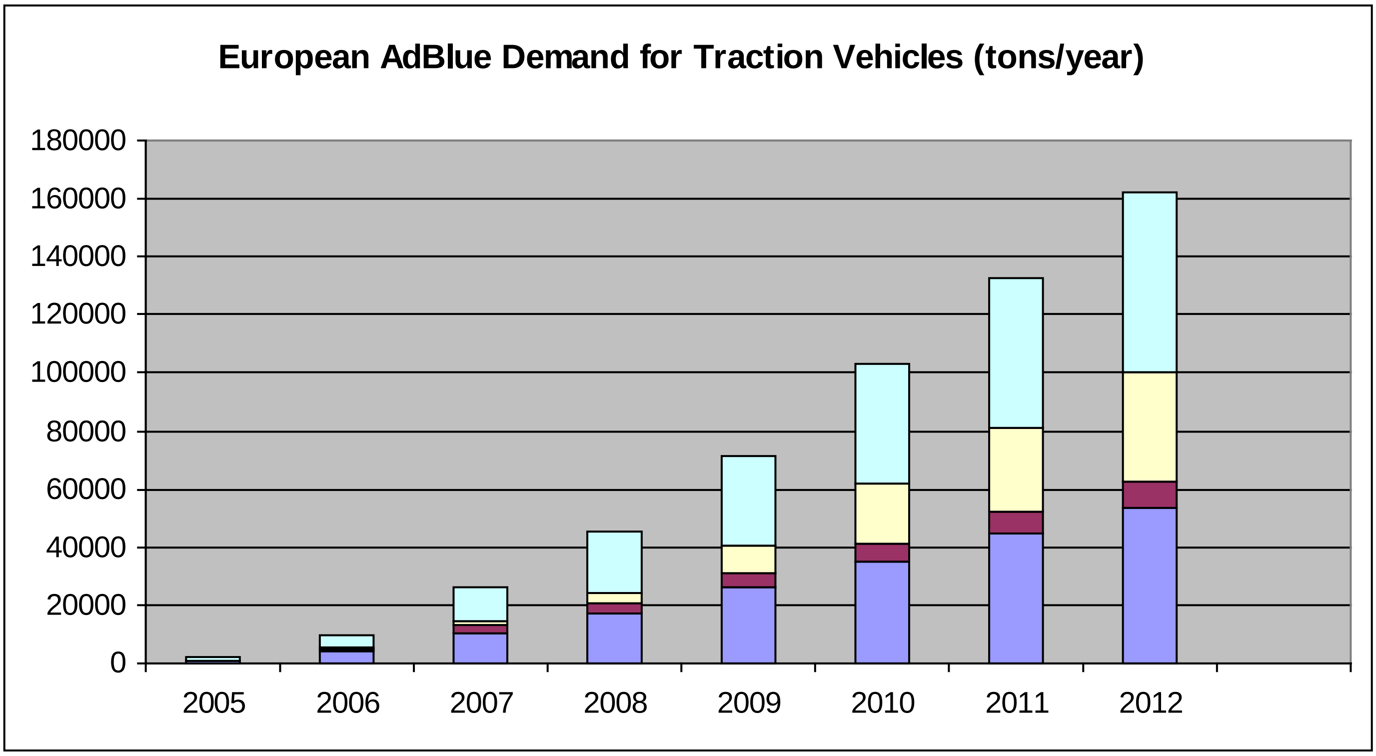
Annexe

Market demand for AdBlue

(AdBlue – commercial designation of the 32.5% urea solution used as reagent in vehicles equipped with SCR systems)


AdBlue Demand for Europe for HDV (tons/year)
4000000
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
2005
2006
2007
2008
2009
2010
2011
2012


European AdBlue Demand for Traction Vehicles (tons/year)
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
2005
2006
2007
2008
2009
2010
2011
2012

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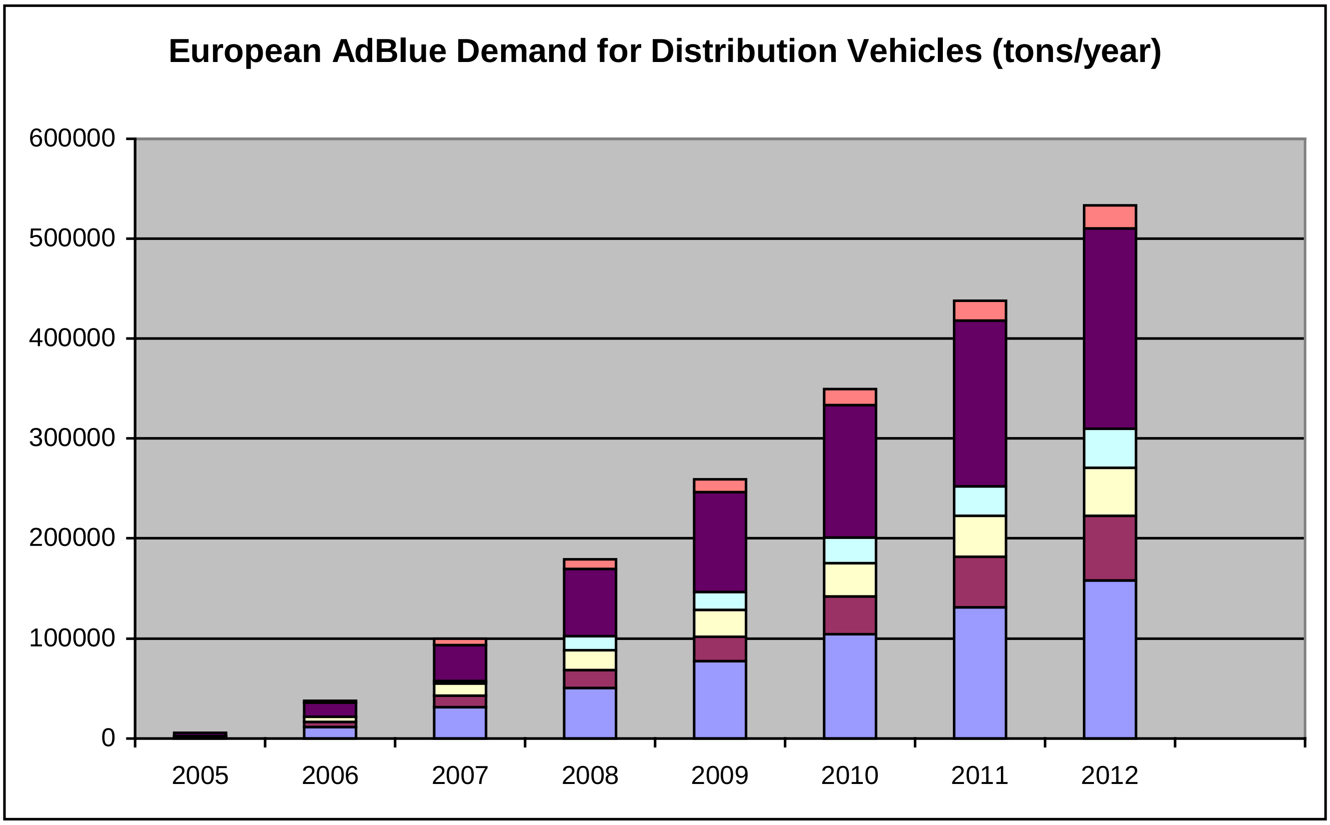
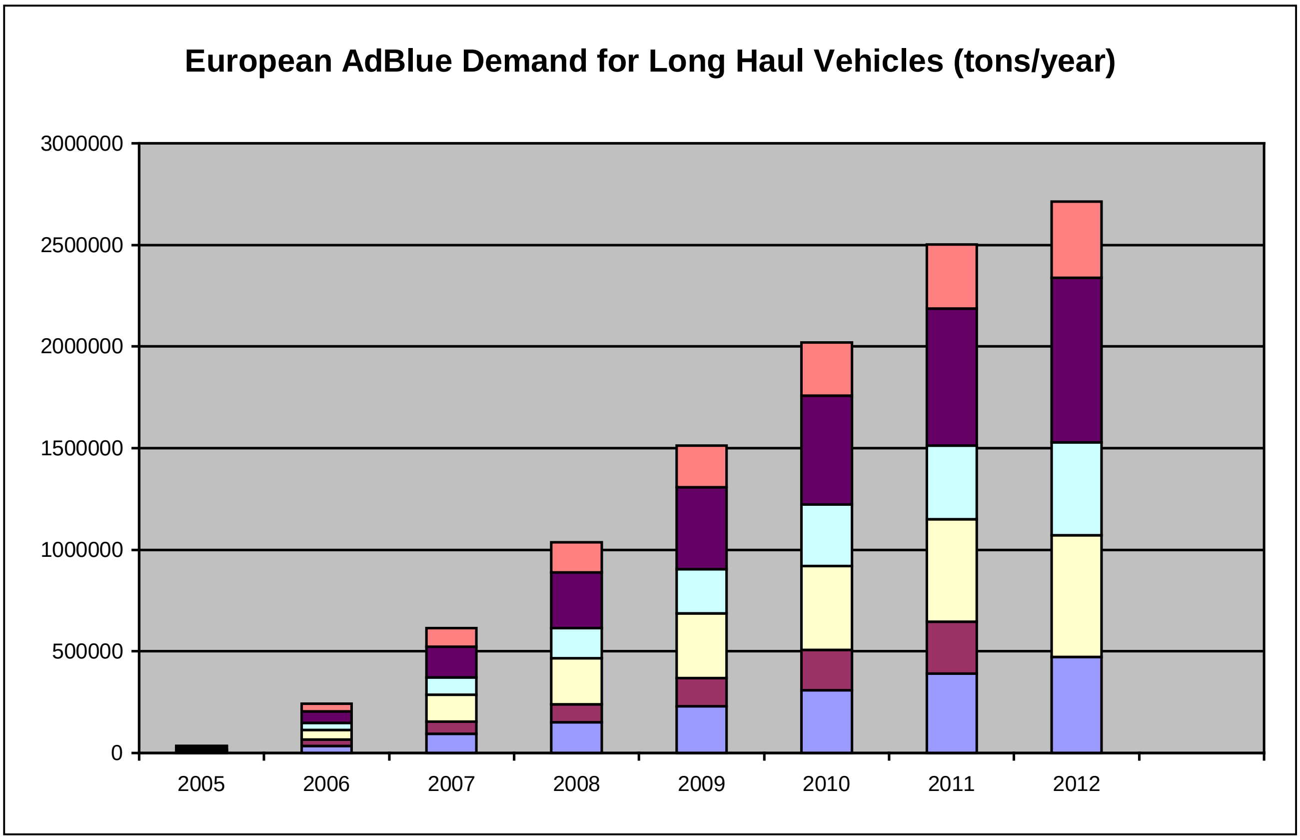
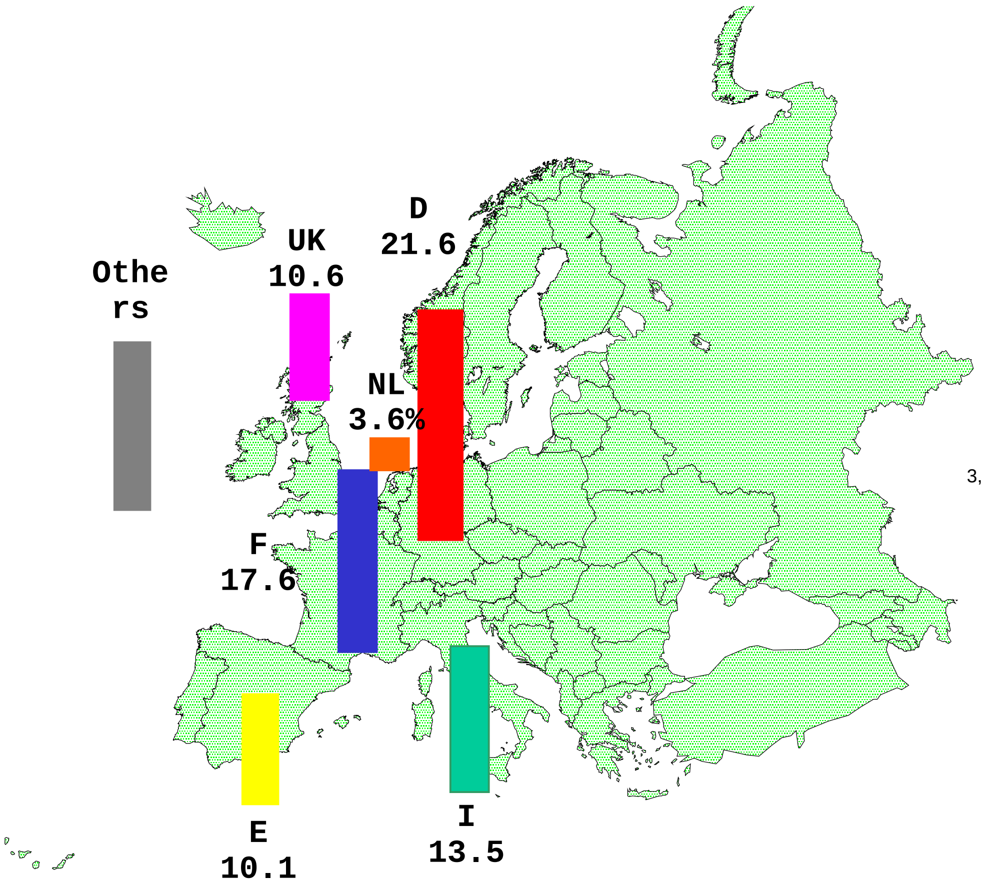
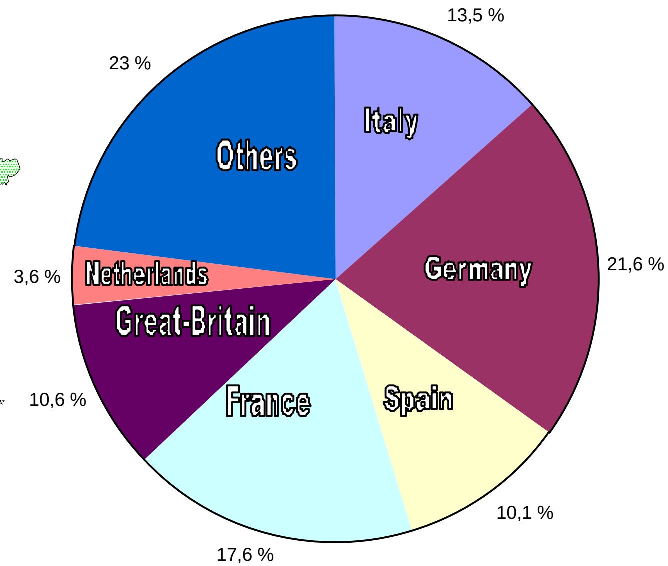

European AdBlue Demand for Distribution Vehicles (tons/year)
600000
500000
400000
300000
200000
100000
0
2005
2006
2007
2008
2009
2010
2011
2012


European AdBlue Demand for Long Haul Vehicles (tons/year)
3000000
2500000
2000000
1500000
1000000
500000
0
2005
2006
2007
2008
2009
2010
2011
2012


Othe
rs
UK
10.6
D
21.6
NL
3.6%
F
17.6
E
10.1
I
13.5


13,5 %
23 %
Italy
Others
Germany
21,6 %
3,6 %
Netherlands
Great-Britain
10,6 %
France
Spain
10,1 %
17,6 %

Selective Catalytic Reduction System Economics

Reference

40 ton Euro III truck Fuel consumption = 32 l/100 km

Diesel fuel price at the pump = 0.79 €/litre VAT = 20%

Cost/100 km = 32 x 0.63 = **20.12 €/100 km**

Future

40 ton truck meeting Euro IV via S C R technology

Urea price = 0.40 €/litre

Fuel consumption = 0.93 x 32 = 29.8 l/100 km Urea consumption = 0.05 x 29.8 = 1.5 l/100 km

Cost/100 km = 29.8 x 0.63 + 1.6 x 0.4 = **19.4 €/100km**

40 ton truck meeting Euro IV via a DPF + EGR

Fuel consumption = 1.02 x 32 = 32.6 l/100km

Cost/km = 32.6 x 0.63 = 20.5 €/100km

Savings

SCR versus Euro III technology	**~ 0,72 € /100km or ~ 3%**
SCR versus DPF + EGR	**~ 1,10 € /100km or ~ 5%**