

**MARKET OVERVIEW ON EXHAUST GAS TREATMENT SOLUTIONS  
FOR DIESEL ENGINES IN COMMERCIAL VEHICLES FOR  
MEETING CURRENT AND UPCOMING EMISSION LEGISLATION IN  
THE EUROPEAN UNION**

Steffens, Dirk  
VDI, Germany

Commercial vehicles, emission, SCR, EGR, European market overview

**ABSTRACT**

Emission legislation has been tightened over the last years in European Union (EU) countries. Euro 4 emission standard is mandatory since 1<sup>st</sup> of October 2006. Euro 5 will be mandatory in October 2009. Meanwhile especially Japan and the US set similar maximum permissible values for nitrogen oxides (NO<sub>x</sub>) and particulate matter (PM) for reducing exhaust emissions that cause health damages and pollution.

In the EU countries two different technologies, exhaust gas recirculation (EGR) and selective catalytic reduction (SCR) have been marketed by commercial vehicle manufacturers to achieve compliance with emission standards. EGR recirculates parts of exhaust gases to reduce NO<sub>x</sub> emissions. Particulate matter is mainly filtered in PM Filters. SCR exhaust gas treatment injects an urea solution as a reductant (so-called AdBlue) into the exhaust gas stream prior to a catalytic converter. A chemical reaction inside the catalytic converter neutralizes the NO<sub>x</sub> emissions. PM is scarcely produced due to the higher combustion temperature. Cost advantages of better fuel economy of SCR engines are partially absorbed by the need for AdBlue.

Most commercial vehicle manufacturers in the EU rely on SCR technology to meet conformity with Euro 4 emission standards. Sales figures show that many customers even skip compliance with Euro 4 legislation to early conform with the stricter Euro 5 standard already today. This reasons especially in incentives that have been introduced in various countries such as road toll reductions or tax exemptions. Additionally better fuel consumption and favourable residual value compared to Euro 4 systems (with EGR) lead to early compliance with the Euro 5 standard.

## 1. INTRODUCTION

Similar to developments in the USA or Japan, exhaust legislation for commercial vehicles in European Union (EU) countries has been continuously aggravated over the past decade, starting with Euro 1 in 1993, Euro2 in 1996, Euro 3 in 2001, Euro 4 in 2006, Euro5 in 2009 and Euro 6 approximately in 2012. The major drivers for the tightening of emission legislations reasons in realization that exhaust gases cause health problems and harm the environment. In particular legislation aims at reducing nitrogen oxides (NO<sub>x</sub>) and particulate matter (PM). NO<sub>x</sub> is believed to cause irritations in the respiratory system of humans and animals. Furthermore, NO<sub>x</sub> gases react with oxygen in the air to produce ozone (smog) and eventually acid rain due to the reaction of nitric acid and sulphuric acid dissolved in atmospheric moisture. Particulate matter is mainly a cause for asthma, lung cancer and cardiovascular diseases [10, 11, 13, 17].

## 2. EMISSION LEGISLATION IN EU COUNTRIES

Emission standards for Diesel fuelled commercial vehicles in many countries are based upon United Nations Economic Commission for Europe (UN ECE) standards commonly referred as 'Euro' standard [4]. Current emission standards in EU countries are referred to as Euro 1 up to Euro 5, whereas Euro5 comprises the strictest emission standard.

Figure 1 illustrates past, current and future emission legislation broken down to the four relevant emission categories Particulate Matter (PM), Nitrogen Oxides (NO<sub>x</sub>), Carbon Monoxides (CO) and Hydrocarbon (HC).

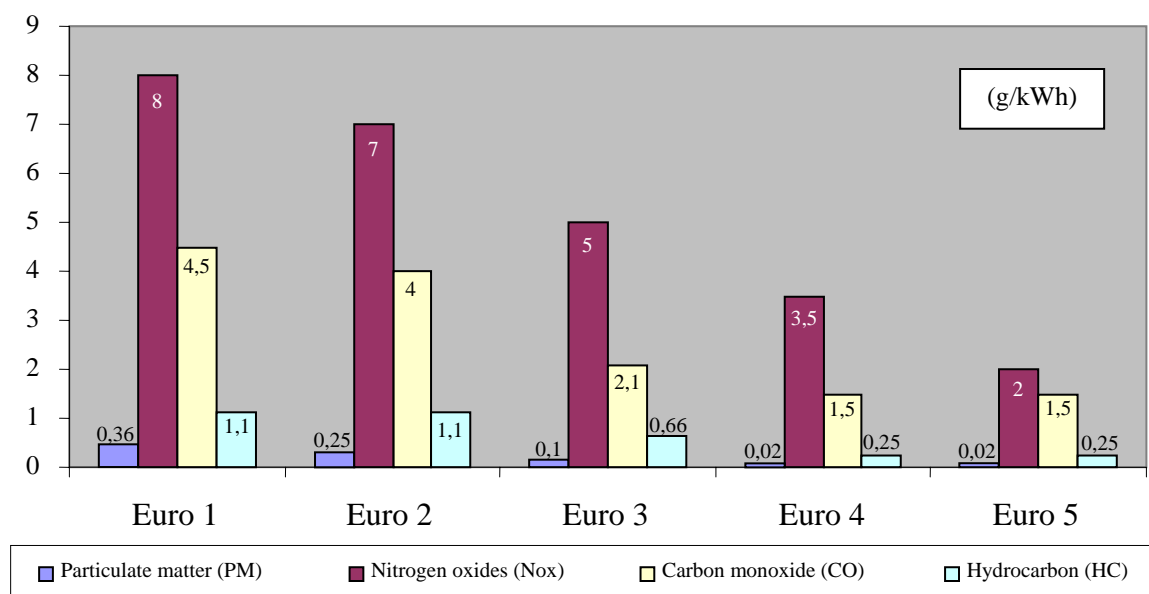


Figure 1: Past, current and future emission legislation in EU countries [1] [7]

Critical by law allowed values for NO<sub>x</sub> and PM according to EU emission legislation (Euro 4 up to Euro 6) are analogical to US legislation (EPA 07 and EPA 2010) and Japanese legislation (NST and NLT). Although, due to differences in European, Japanese and American test cycles, a direct comparison between the emission limits is difficult [3].

The Limits for Particulate Matter and Nitrogen Oxides are shown in figure 2 according to emission legislation in the EU, Japan and the USA.

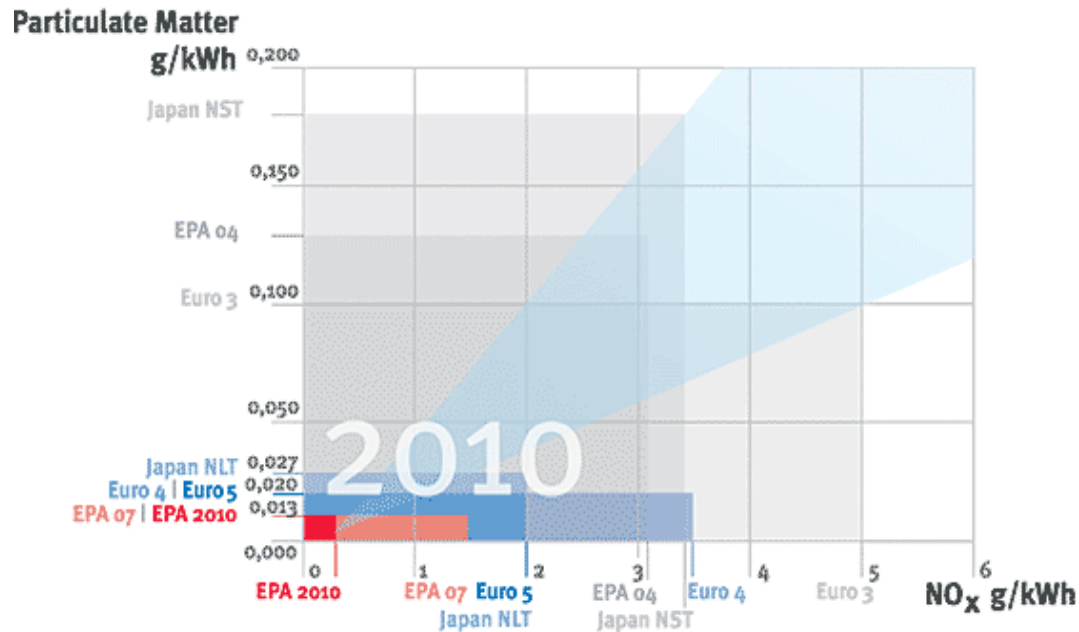


Figure 2: NO<sub>x</sub> and PM maximum allowed values according to emission legislation in Japan, USA, and EU-countries [15]

Besides EU-countries, Japan and the US many nations are also gradually aggravating their emission standards. Most nations harmonize with the Euro emission standard. For example it is expected that India will adopt Euro 3 in 2010, China will adopt Euro 3 in 2007 and Euro 4 in 2010. Brazil will probably introduce Euro 4 in 2009. Korea and Australia will introduce Euro 4 in 2008 [8, 15].

Meeting the upcoming emission standards becomes more and more a technological challenge, especially the expected Euro 6 standard which is expected to be similar to the American EPA 2010. To illustrate, some commercial vehicle manufacturers issued jestingly statements that “when operating trucks in highly polluted areas the air the truck intakes for combustion is more polluted than the exhaust gases it blows out...” [7].

### 3. TECHNOLOGIES TO MEET EMISSION REQUIREMENTS

In the European Union markets two technological solutions have been marketed to meet current emission legislation Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR).

#### 3.1 EGR technology

EGR is a technique for reducing NO<sub>x</sub> gases especially in Diesel engines. Portions of oxygen meagre exhaust gases are cooled and recirculated into the engine and mixed with oxygen rich intake air (see figure 3). Due to the fewer amount of oxygen molecules in the combustion air the peak combustion temperature and the amount of excess oxygen are reduced which result in less NO<sub>x</sub> formation.

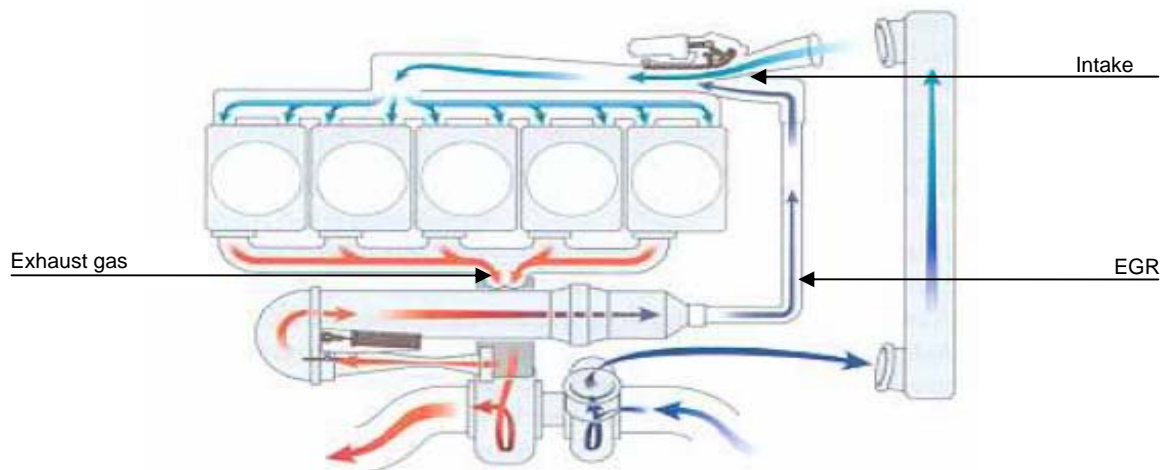


Figure 3: EGR functional principle [7]

However, there is a dilemma when applying EGR. The combustion at lower temperatures is a less efficient combustion process. Whilst NO<sub>x</sub> gases are reduced the amount of Particulate Matter remaining in the exhaust gas stream increases. Additionally, fuel consumption intensifies.

To reduce Particulate Matter in the exhaust gas stream below the by law required limits two measures are currently applied by commercial vehicles manufacturers. One method is to use EGR in combination with a catalytic converter – so called “PM filter”. The PM filter oxidizes hydrocarbons and carbon monoxide to water and carbon dioxide. Additionally, sooty particles are transformed into carbon dioxide through a sintered metal fleece. [7].

Another measure for reducing Particulate Matter is to reduce engine power in combination with high pressure fuel injection. High pressure fuel injection (up to 2200 bar) results in finer fuel atomization facilitating a more efficient combustion process with less PM emission [6].

EGR is currently used solely in Euro 4 engines. Euro 5 engines based on EGR have not been marketed yet.

### 3.2 SCR technology

The selective catalytic reduction method enables engines to operate under optimized combustion conditions (high temperatures, high peak pressure, and excess oxygen) that result in hardly any Particulate Matter emissions and improved fuel efficiency. The excessively produced NO<sub>x</sub> gases are converted into water and nitrogen via a catalytic converter as illustrated in figure 4. In order for the conversion step to function liquid/gaseous ammonium substances are injected into the exhaust gas stream which react with NO<sub>x</sub> gases inside the ceramic catalytic converter. Nitrogen oxides (NO<sub>2</sub> and NO) react with Ammonia (NH<sub>3</sub>) to form water (H<sub>2</sub>O) and nitrogen (N<sub>2</sub>) [1, 7].

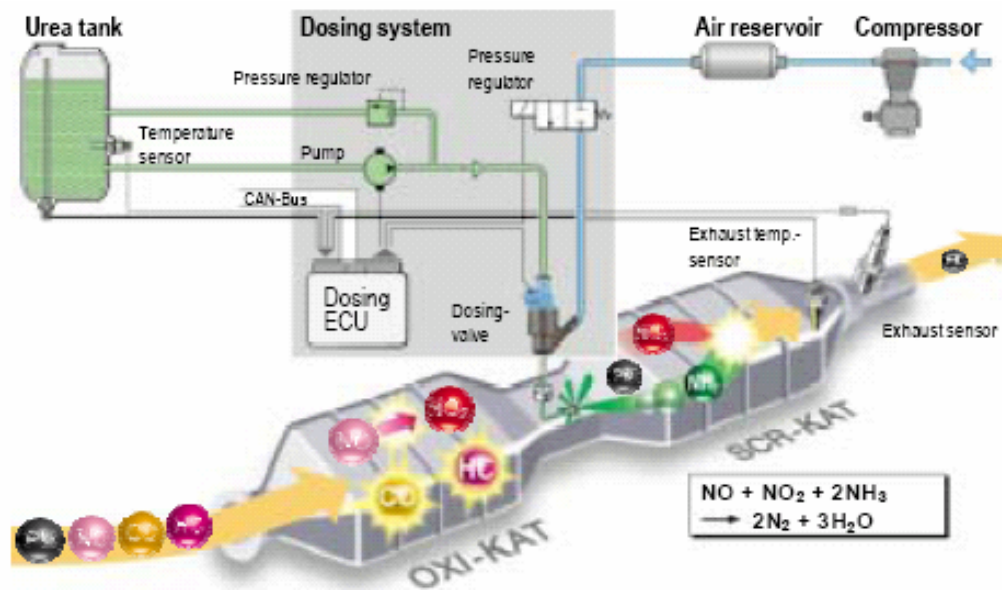


Figure 4: SCR catalytic converter (source: Robert Bosch Corporation)

The usage of ammonia is critical since it is a very aggressive and poisonous substance. The handling of ammonia is also critical. As a result urea is used for SCR engines. It is slightly less effective but far less hazardous. A variety of urea substances are currently on sale, the most popular of which is AdBlue.

Although commercial vehicles equipped with SCR technology have more payload due to the load from the catalytic converter, they consume up to 5% less fuel than comparable vehicles with Euro 3 engines [1, 4, 7, 16].

#### 3.2.1 AdBlue consumption, availability and costs

Tests show that today's trucks with SCR technology in Euro 5 consume between 1.5-2 litres of AdBlue per 100 KM. This is an equivalent to 5.5% AdBlue of total fuel consumption [1, 7, 16].

Availability of public AdBlue infrastructure at gas stations is currently rapidly developing. Additionally, 10 litre canisters are procurable at many gasoline stations. For fleet operators it is not uncommon to rely on standardized containers (i.e. 1,000 litre bulk containers IBC)

deposited on the fleet's premises. Truck drivers refuel AdBlue when returning to their home-base.

AdBlue prices vary between 0,29 €/litre and 0,43 €/litre for 1,000 litre containers [12] up to 0,6 €/litre at public gas stations [2].

Due to numerous AdBlue producers further price deterioration is expected.

### 3.3 Advantages/Disadvantages EGR versus SCR

Figure 5 illustrates advantages and disadvantages of EGR and SCR systems. Investment prices are based on sales figures of the German market [7]

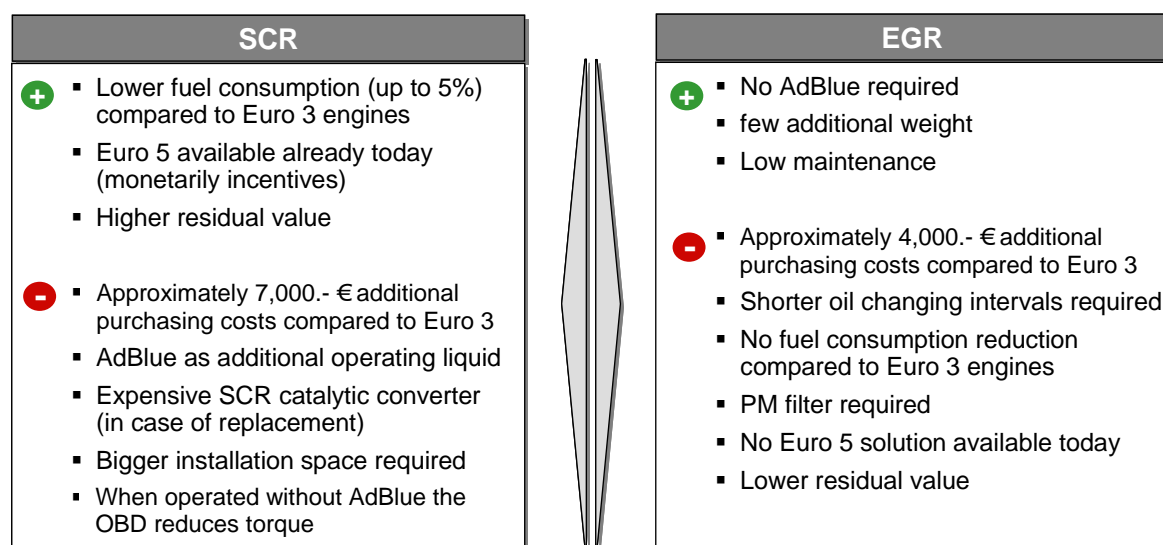


Figure 5: Comparison EGR versus SCR

In October 2007 the second stage of On-Board Diagnostic (OBD) will be mandatory for Euro 4 and Euro 5 exhaust gas treatment systems in all newly registered trucks. Such sensors measure NOx concentration in the exhaust gas stream. When the NOx level in the exhaust gas stream exceeds by law required levels, the motor performance/torque is reduced up to 40%. By these penalties the legislator hopes to eliminate potential misuse of SCR systems by driving without AdBlue.

## 4. MARKET PENETRATION OF EXHAUST GAS TREATMENT TECHNOLOGIES

### 4.1 Competitor overview in EU

Table 1 illustrates the usage of SCR and EGR technology by the main competitors in the European commercial vehicles market. Scania and MAN recently introduced Euro5 vehicles with SCR technology. According to press releases both are still working on EGR for Euro 5 as well.

	Euro 4	Euro 5	Euro 6
DAF	SCR	SCR	?
Iveco	SCR	SCR	?
MAN	EGR	EGR/SCR	?
Mercedes Benz	SCR	SCR	?
Renault	SCR	SCR	?
Scania	EGR	EGR/SCR	?
Volvo	SCR	SCR	?

Table1: SCR and EGR technology usage by competitors

For achieving Euro 6 emission standards a combination of SCR and EGR is expected [3].

### 4.2 Incentives for early compliance with Euro 5 legislation

As shown in table 1 the majority of truck manufacturers and thus customers in the EU rely on vehicles with SCR technology instead on EGR. This should seem unlikely since it is the more complex system and an additional operating liquid is required. But instead of meeting emission standards that are just absolutely necessary, customers even early comply with Euro 5 legislation. Up to now more than 10,000 Euro 5 trucks have been sold by Mercedes-Benz alone who leads this trend [7].

This is founded in various incentives for early compliance with Euro 5. Governmental incentives such as road toll reduction (in Germany 0.02 €/KM for Euro 5 vehicles compared to Euro 4 vehicles), tax benefits (in Denmark), advantageous depreciation models (in The Netherlands), or abolishment of night bans on highways (in Austria) are just some examples of many different models under current investigation in EU countries. Additionally, higher buy-back guarantees for lease trucks, higher residual value and better fuel economy pay off [9].

Customers also explain that besides monetarily reasons as shown in the following paragraph, early complying with Euro 5 pays off. The “green” image emphasizes their image as a reliable business partner. It also gives truck operators a differentiation aspect towards competitors which can be used in tenders.

### 4.3 Cost Effective Analysis

When calculating (see table 2) the costs and benefits for Euro 4 with EGR versus Euro 5 with SCR in comparison to Euro 3 the purchasing behaviour for early compliance with Euro 5 emission standard becomes clear [7].

	<b>Euro 3</b>	<b>Euro 4/EGR</b>	<b>Euro 5/SCR</b>
Purchase price	82,000 €	86,000 €	88,500 €
Road toll until 30.09.06	7,200 €	6,000 €	6,000 €
Road toll Oct.2006 -Oct.2009	43,200 €	43,200 €	36,000 €
Road toll after Oct. 2009	8,400 €	7,200 €	7,200 €
Fuel costs (AdBlue included)	182,784 €	182,784 €	179,128 €
Maintenance	38,500 €	41,800 €	39,500 €
Residual value	40,600 €	42,500 €	44,000 €
<b>Total costs</b>	<b>321,484 €</b>	<b>324,484 €</b>	<b>312,328 €</b>

Table 2: cost effective analysis

Assumptions: Artic truck, 430hp, long distance transport, initial registration: 01<sup>st</sup> of April 2006, 4 years of operation, Diesel costs: 1.02 €/litre, AdBlue costs: 0.68 €/litre, mileage on German highways: 120,000 km/year, total mileage in Europe: 140,000 km/year, maintenance interval: 100,000 km (Euro 3 and 5/SCR), maintenance interval: 60,000 km (Euro 4/EGR), Road toll cost according to today's costs;

Peter Stöffges confirms above calculation as well in his studies [14]

## 5. CONCLUSION

Due to increased environmental awareness and consciousness that pollution from cars and commercial vehicles cause many of today's health problems, the cleansing of exhaust gas becomes more and more important all over the world. As a result of the tightened emission regulation more and more technological complex and expensive exhaust treatment components are introduced in commercial vehicles.

In the EU SCR and EGR technology have been marketed to achieve conformity of Euro 4 and even Euro 5 emission standards. Whilst it appears that SCR is favoured by most commercial vehicles manufacturers and thus customers although it is the more complex technological system. More than 40,000 sold units prove that it is a viable option. And since emission targets converge in the EU, Japan and the USA the introduction of EGR and especially SCR systems can be expected in Japanese or American commercial vehicles in the near future.

Governmental incentives policy such as road toll reductions or tax exemptions in various European countries achieved that many commercial vehicle operators even early comply with Euro 5 standard although it becomes mandatory as early as 2009. It pays off to have cleaner trucks which could be a good example for passenger cars as well.

The first cars to be equipped with SCR technology have been presented at the Detroit Motor Show 2006 by Mercedes-Benz. The new technology will be marketed under the brand name "BlueTec" in late 2006 to promote Diesel vehicles in the US market.



## 6. REFERENCES

- [1] ACEA, "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
- [2] "AdBlue" available at: <http://de.wikipedia.org/wiki/AdBlue> (viewed on 29.07.2006)
- [3] "An der Abgasreinigung scheiden sich die Geister", VDI Nachrichten, Nr. 44, 29.10.2004
- [4] Coffey Geosciences "Investigation of implications for distribution and use of urea to improve Diesel vehicle emissions", available at: <http://www.ntc.gov.au/FileView.aspx?page=A02306400400180020&M=0&T=2> (viewed on 20.06.2006)
- [5] DGMK, „AdBlue as a reducing agent for the decrease of NO<sub>x</sub> emissions from diesel engines in commercial vehicles“, Research report 616-1, September 2003
- [6] "EGR" available at: <http://en.wikipedia.org/wiki/Egr> (viewed on 29.07.2006)
- [7] "Euro 4 Spezial, Die neue Abgasnorm“, Verkehrs Rundschau, Sonderbeilage Verlag Heinrich, Vogel GmbH, 04/2006
- [8] "Global Overview Colorado Conference" available at: <http://www.walshcarlines.com/pdf/Global%20Overview%20Colorado%20Conference.pdf> (viewed on 20.07.2006)
- [9] Jack Semple, „Euro 5 cleans up on mpg“
- [10] Levelton Engineering "The role of petroleum based alternative fuels in reducing emissions in the APEC region", APEC Expert Group on Fossil Energy, Singapore, Richmond, BC, Canada, 2000
- [11] "Nitrogen oxide" available at: [[http://en.wikipedia.org/wiki/Nitrogen\\_oxide](http://en.wikipedia.org/wiki/Nitrogen_oxide)] (viewed on 20.07.2006)
- [12] "AdBlue Preise" available at: <http://www.oelbestellung.de/shop/preis/AdBlue-1.000l-Container/208/>] (viewed on 20.07.2006)
- [13] "Particulate" available at: <http://en.wikipedia.org/wiki/Particulate> (viewed on 29.07.2006)
- [14] Peter Stöffges „Euro 5 schlägt Euro 3 im Wirtschaftlichkeitsvergleich“, 19.07.2005
- [15] PUREM, "Emissionsgesetzgebung weltweit" available at: <http://www.purem.de/emissionen.php> (viewed on 26.07.2006)
- [16] "Supertest Mercedes Actros 1848 Euro 5 - Eine saubere Lösung", Trucker, 07/2005
- [17] WHO „Air quality guidelines for Europe“, 2<sup>nd</sup> edition, Report Number European Series Number 91, WHO Regional Publications, Copenhagen Denmark 2000