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Future Diesel

Exhaust gas legislation for passenger cars, light-duty commercial vehicles, and heavy duty vehicles

- Updating of limit values for diesel vehicles -

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0. Executive summary

European legislation on exhaust emissions has made major progress with the adoption of limit value standards up to and including Euro 4 for passenger cars and light-duty commercial vehicles and Euro V for heavy-duty engines. Exhaust gas limit values need to be updated primarily for vehicles with diesel engines.

Article 3 of Directive 98/69/EC (passenger cars and light-duty vehicles), the joint position of the Council on Directive 99/96/EC (heavy-duty engines), and the conclusions of the Environment Council on 18 and 19 December 2000 on evaluation of the Auto Oil II programme contained corresponding instructions to the Commission. In a note on the topic of the "concept of the enhanced environmentally friendly vehicle (EEV) for light vehicles" dated 11 February 2003, the Commission stated that it would now attend to updating the exhaust gas limit values for passenger cars and light-duty vehicles.

The proportion of diesel passenger cars among new registrations in Germany has more than doubled in recent years and has now reached almost 40%. The trend for particulate emissions indicates that by 2020 the rapidly rising share of diesel passenger cars will lead to an increase in particulate emissions from passenger cars by a factor of 2.3 and therefore to an increase in particulate emissions from road transport by a factor of 1.6 compared with earlier assumptions. Roadside monitoring stations have shown no reduction in particulates which would correlate with the previous lowering of limit values for exhaust gases. Action is required in this area.

The problem of fine particulate emissions is currently being discussed with regard to air quality. The World Health Organisation, the EU Commission, the National Research Council, and the environmental agency in the United States are highlighting fine particulates as one of the current priorities for environmental hygiene in Europe and the United States. There are also indications of carcinogenic effects. To protect health, the technically feasible particulate reduction of well over 90% must be required for diesel engines.

A total of approximately 800,000 people die in Germany each year (all causes of death). According to an expert's report by Prof. Wichmann of GSF Neuherberg, approximately 1 to 2% of those deaths can be classified as premature deaths due to exhaust from diesel vehicles. According to the report, reducing particulate emissions as a risk-prevention measure, for example by using particulate traps, would prevent most of those premature deaths. The use of particulate traps would lead to a mean increase in the life expectancy of everyone in Germany by 1 to 3 months compared with the current situation.

With regard to NOx emissions, modern diesel passenger cars have a considerable disadvantage compared with cars that run on petrol. They emit eight to ten times more nitrogen oxides, thereby contributing among other things to the formation of summer smog, which is harmful to health. The NOx limit value for diesel passenger cars in Euro 4 is about three times higher than the limit for petrol cars.

Electronic injection systems in heavy-duty vehicles – first introduced with the Euro II limit value – allow different injection strategies to be used in the various ranges of the engine's characteristic curves. More recent studies have shown that Euro II engines are often deliberately optimised outside of the range of characteristic curves run in the type approval testing cycle to improve the specific consumption. This leads to a considerable increase in nitrogen oxide emissions. The consequence: in 2003, the mean NOx emission factor for heavy-duty vehicles is about 40% higher than previously assumed, which corresponds to an additional gap in coverage of around 115,000 t NOx in 2010.

Directive 1999/96/EC relating to measures to be taken against emissions from heavy-duty engines specifies a Euro V standard with an NOx limit value of 2.0 g/kWh, which will apply to the granting of operating licenses for new engine types starting in 2008. Within the framework of calculations for the planned measures to be taken by the German federal government to comply with NEC Directive 2001/81/EC, it has been shown that that limit value should be cut in half again to 1.0 g/kWh. This is the necessary measure that has the absolute maximum potential for reducing NOx. It must be taken into account when the EU Commission examines the Euro V limit values, particularly since similar circumstances exist in other European countries. That adaptation must be followed by a further reduction in the NOx limit value for heavy-duty engines to 0.5 g/kWh from 2010 onwards.

Particulate emissions by diesel engines in passenger cars and commercial vehicles have already been considerably reduced in the past few years by making changes to engines, i.e. improving combustion. Additional changes to engines that could reduce particulates by some 30 to 50%, depending on the current initial state, have the potential to just comply with the Euro 4/Euro IV limit values that will apply to type approval testing of diesel passenger cars and heavy-duty engines from 2005. However, as things now stand, a greater reduction in particulates is possible only with aftertreatment of exhaust gases, i.e. by using a particulate trap. The proven reduction rates are well over 90% for particulate mass and reach 99.999% for the number of particulates. This has been demonstrated for a series of different particulate trap systems.

The entry into force of the Euro 4 limit values starting in 2005 will result in the use of particulate trap technology only in certain diesel passenger cars. According to publications by German car manufacturers, small- and medium-sized diesel passenger cars with manual transmissions will be able to get by without particulate traps, while diesel passenger cars with automatic transmissions that are medium-sized or larger and all heavy diesel passenger cars will probably need particulate traps.

Toyota has been testing the combination of an NOx storage catalyst and a particulate trap, known as DPNR, since March 2002 in several European countries and plans to begin series production during the second half of 2003. It had not yet been determined in June 2003 which emission values could be achieved using the final design of the DPNR system for the European market. The German Federal Environmental Agency assumes that the DPNR system has the technical potential to comply with the limit values proposed in this report.

The PSA Peugeot Citroën group sold approximately 135,000 vehicles with series-produced particulate traps (known as FAP technology) internationally in 2001 and around 270,000 in 2002. PSA anticipates that approximately 1 million vehicles using FAP technology will be registered in 2004-2005.

A total of 14 passenger car types using particulate traps were offered for sale by French and Italian manufacturers in May 2003. The introduction of the particulate traps for another 20 passenger car types, including those made by German manufacturers, has been announced for autumn 2003 or early 2004.

FAP technology therefore defines the state of the art and the ability to set limit values on that basis. Almost all manufacturers of diesel passenger cars have particulate trap systems that are ready or almost ready for series production. The trap systems differ less with regard to the high rate of elimination, which can be achieved without difficulty, than with regard to their regeneration processes.

Particulate trap technology is also available for commercial vehicles. In the early 1990s, seven different systems with rates of elimination of over 90% were successfully tested on 1,100 city buses as part of the large-scale soot trap test by the German Ministry of the Environment. Numerous particulate trap systems have been approved in Switzerland after comprehensive testing of their suitability by public agencies (BUWAL [Swiss Agency for the Environment, Forests and Landscape] and SUVA, a major provider of compulsory accident insurance) for equipping construction machinery and their use is now mandatory at construction sites. According to the Association of German Transport Providers (VdV), approximately 5,000 city buses use particulate trap systems in Germany. More than 50,000 commercial vehicles throughout the world use trap systems, and USD 100 million in funding has been approved to equip 900,000 diesel vehicles as part of a programme in California.

It is currently doubtful whether the intention of the European Environment Ministers to implement particulate trap technology with the limit values for heavy-duty engines in Euro IV (and Euro V), which they declared when approving Directive 99/96/EC, will be fulfilled.

Updating the particulate limit values beyond Euro 4 for passenger cars and Euro IV/V for heavy-duty engines is technically feasible and necessary to prevent risks to health.

A further reduction of the mass-based particulate limit values by a factor of 10 is sufficient in principle to achieve the objective of protecting health, if effective particulate traps or equivalent technologies with a high reduction rate over the entire size range of the particulate matter, including nanoparticulates, are used. To avoid misplaced efforts in the form of technical developments aimed primarily at reducing mass, the particulate count must be controlled to support measures to limit particulate mass.

A Particle Measurement Programme (PMP) experts' group was created in 2001 at ECE-GRPE level to verify the suitability of mass-based particulate control for the future and to propose a method for controlling particulates which is more oriented to their effect. At the time of this report (June 2003), Phase II of the project was mostly complete, and the results and concrete suggestions to be made by the group were taking shape. In addition to an improved gravimetric method (U.S. 2007), the CPC (condensation particle counter) offers a system with which the particle count (more precisely: the particle concentration in l/cm^3) can be measured in the size range relevant to the effect of particulates, in line with the requirements of a type approval test.

The following proposals for updating the exhaust gas limit values for passenger cars as Euro 5 from 2008 and for adaptation of Euro V for heavy-duty engines can be derived from the above remarks:

The Euro 5 particulate limit value for passenger cars of 0.0025 g/km (for the time being only mass-based) should correspond to an emission reduction of 90% compared with the Euro 4 limit value. At 0.08 g/km, the NOx limit value for diesel passenger cars should correspond to the value for petrol cars in Euro 4.

As an adaptation of Euro V to come into effect from 2008, a further reduction of particulate emissions from heavy-duty engines down to the particulate trap level is also necessary for the same reasons as for diesel passenger cars. Because the Euro IV/V particulate limit values of 0.02 g/kWh in the ESC and 0.03 g/kWh in the ETC can be fulfilled even without a particulate trap, the reduction rate of 90% which can reliably be achieved using a particulate trap should be applied to those values. That results in 0.002 g/kWh in the ESC and 0.003 g/kWh in the ETC. With regard to NOx emissions, the NOx limit value in the Euro V standard should be cut in half from 2.0 to 1.0 g/kWh, and a further reduction to 0.5 g/kWh should occur from 2010.

In addition, the total number of particulates emitted by both passenger cars and heavy-duty engines limits should be limited in the size range that is relevant for health. The PMP group will propose annexes to Directives for precise definition of the improved gravimetric procedure and the CPC procedure by the end of 2003. In addition to reducing mass, that would primarily guarantee a reduction in the ultra-fine particulates that are relevant to health. Defined measurement procedures for gravimetric determination of particulate emissions at a low level are available in principle in the United States for use from 2007. Studies by the automotive industry confirm the availability and the high accuracy of this improved measurement procedure.

The additional costs for Euro 5 designs in diesel passenger cars and the appropriate combinations of measures to fulfil the aforementioned limit values are estimated to be €200 to €400 per vehicle compared with Euro 4 technology. In the case of heavy-duty engines, the additional costs for emission control going beyond the approved Euro V standard and the necessary exhaust gas aftertreatment systems, which substantially represent a further optimisation of the systems necessary for Euro V, will be negligible. The total additional costs compared with a Euro III engine will be between €1,500 and €3,000, depending on the size of the engine.

Upshot:

Updating of the emission limit values for passenger cars, light-duty commercial vehicles, and heavy-duty engines is being called for nationally and internationally. Implementation plans are currently being developed in the United States and Japan.

The health and ecological effects of particulates and NOx emissions necessitate a considerable reduction in limit values.

Technical control measures for an advanced emission level are already available. The costs per vehicle/engine of reducing emissions are slight and reasonable in relation to the effect achieved. Measurement procedures for clear-cut verification of limit values are available.

1. Introduction

European legislation on exhaust emissions has made major progress with the approval of limit value standards up to and including Euro 4 for passenger cars and light-duty commercial vehicles and Euro V for heavy-duty engines. A limit value standard going beyond Euro 4 is probably not necessary for passenger cars with petrol engines (air-fuel mixture formed externally). Exhaust gas limit values need to be updated primarily for vehicles with diesel engines.

Article 3 of Directive 98/69/EC (passenger cars and light-duty vehicles) instructs the Commission to do the following:

"The Commission shall submit proposals after December 31, 1999 on regulations to be effective from 2005, i.a. taking account of:

- *Recent research in health effects of particulates*
- *•Particulate emissions of GDI engines*
- *•Availability of aftertreatment systems, i.e. traps*
- *•Improvement of measurement procedures for fine particulates"*

Article 7 of Directive 99/96/EC (heavy-duty engines) specifies that:

"The Commission shall submit proposals no later than 12 months after entry into force, i.a. taking account of:

- *•Development of emission control technology and aftertreatment technology*
- *•Improvements of measurement procedures for very low PM levels*

Finally, the conclusions of the Environment Council on 18 and 19 December 2000 on evaluation of the Auto-Oil II programme contains the following text:

"In line with the conclusions of the Commission's report, and in order to give clear and early guidance to all stakeholders, the Council invites the Commission to:

- *Make continued efforts to significantly reduce nano-particulate emissions, and in particular devise a new measuring procedure for private cars, light duty vehicles and heavy duty vehicles taking into account the results of recent studies into the health effects of nano-particulate emissions.*
- *The Council invites the Commission to give consideration to the need to bring the provisions on limit values for diesel engines – for example, on emissions of nitrogen oxides – closer to the provisions for petrol engines."*

In a call for evidence in June 2002, the European Commission (DG Enterprise) asked for contributions on the issue of the feasibility of an NOx limit value of 2.0 g/kWh for heavy-duty engines in the Euro V standard and referred at that time to a possible further reduction of that limit value at the same time or later [1].

In a note on the "concept of the enhanced environmentally friendly vehicle (EEV) for light vehicles" dated 11 February 2003, the Commission stated that it would now attend to updating the exhaust gas limit values for passenger cars and light-duty commercial vehicles. The emphasis of the necessary further development is therefore clearly on NOx and particulates. CO_2 and HC emissions are therefore considered only marginally below.

In its memorandum on sulphur-free fuels, the German federal government stated in June 1999 that particulate emissions from passenger cars must be further reduced beyond Euro 4. At the Council of Environment Ministers on 4 March 2003, Germany presented a joint initiative for stricter emission limits for passenger cars and commercial vehicles with diesel engines, which had been approved at the German/French Environment Council on 27 February 2003. Concrete proposals are to be prepared in bilateral working party meetings. The automobile and oil industries will participate. In March 2003, the EU Commission began a survey of Member States to determine the various positions concerning the introduction of EEV (enhanced environmentally friendly vehicle) values for passenger cars. EEV values are indicative limit values that could provide a basis for tax subsidies. They are not generally-applicable limit values for type approval testing or the registration of vehicles.

In its opinion, the German federal government declared:

"*Germany is of the view that standards for further reducing NOx and particulate emissions from diesel passenger cars should soon be determined and be made mandatory as of 2010 and that before that time they could form the basis for tax relief according to previous practice. Germany also considers that stricter limit values are needed for heavy-duty engines (Directive 88/77/EEC).*

This document will not explore the issue of fuel quality, because it is assumed that sulphur-free fuel (≤ 10 ppm sulphur) will be available during the time period at issue here.

Overall, this document is oriented to the situation in Germany, although conditions will be similar in other European countries.

2. Legislation on exhaust gases – a comparison of the U.S., Japan, and Europe

A comparison of exhaust gas legislation requires more than just a consideration of the various limit values throughout the world. All background conditions that are relevant for the level of requirements must be included, such as different test cycles, the combination of various limit value rates with different requirements for long-term durability, the phase-in of limit values, control of off-cycle emissions, and requirements for the harmonisation of production, long-term durability, periodic monitoring, field monitoring, on-board diagnosis, etc.

For example, in the United States there are phase-in periods for the federal tier 2 standard between 2004 and 2007 for passenger cars and light duty vehicles and in 2008 and 2009 for the heavier end of the spectrum of light-duty vehicles. The vehicles can be certified in eight different emission classes (bins). There is a phase-in in the United States between 2007 and 2010 for the federal standards for heavy-duty engines planned for 2007, with different degrees of fulfilment for the engines that are sold, depending on the type of engine (petrol or diesel) and the type of pollutant [2].

These different requirements cannot simply be weighed against each other, which is why the comparison below is limited to the qualitative trend that can be derived from the specific limit values for NOx and particulates.

2.1 Diesel passenger cars

The NOx limit values for diesel passenger cars prescribed under Euro 3 are approximately 35% lower than the concurrent U.S. standards, while those stipulated under Euro 4 are 6 times higher.

This applies to tier 2/bin 5 standards throughout the United States. The Japanese limit value for 2002 is about 40% less than the Euro 4 limit value; from 2005, the Japanese limit value is about 40% lower than the Euro 4 limit value (**Figure 1**).

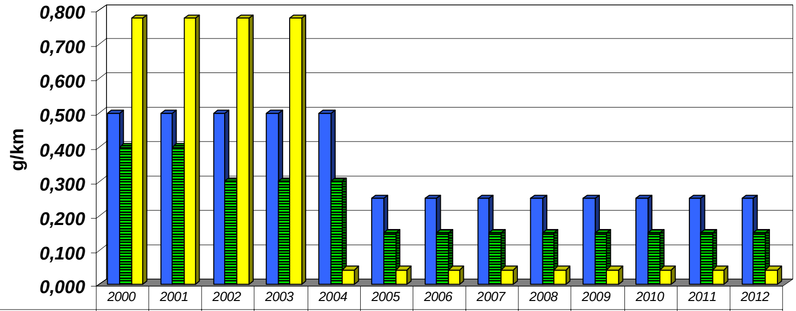
The limit value for particulate according to Euro 3 is about 20% lower and the Euro 4 limit value is around four times higher than the American tier 2/bin 5 particulate standards, while the Japanese limit value for 2002 corresponds approximately to the Euro 3 limit value (**Figure 2**). From 2005, the Japanese limit value will be approximately 45% lower than the Euro 4 limit value.

Comparative measurements of diesel passenger cars in various test cycles are available from research projects on field monitoring [28]. **Figure 3** compares NOx emissions from Euro 3 diesel passenger cars in the currently valid New European Driving Cycle with the emissions in FTP, and **Figure 4** compares particulate emissions. These are necessarily only passenger cars with a European design; that group does not yet include very low-emission types. The correlation shows that the results of both cycles are almost equal for NOx and particulates as a first approximation. Including all other different background conditions whose effect on the level of requirements cannot be exactly quantified, it is possible to make a direct comparison of the U.S. standards and the European limit values in the same dimension.

Aside from their environmentally-based political requirements, the strict American standards must also be viewed in light of the fact that diesel passenger cars in the United States currently have only a small market share of around 1 to 2%; in other words, special attention to this technology has not yet been necessary from a political standpoint, and it has not been required of manufacturers because – with the exception of VW – they hardly offer any diesel models in the United States. However, a potential change in the trend is beginning to emerge, because passenger cars and light-duty commercial vehicles with diesel engines have recently begun to appear attractive in the U.S. due to their fuel economy. A large market share corresponding to European conditions or a 40% share of cars on the road is being used as a potential objective in energy scenarios.

However, the potential energy savings have not yet been weighed against increasing particulate emissions, whose reduction also has high political priority. Based on the political approach, the American limit values represent “technology forcing” more than the European limit values do.

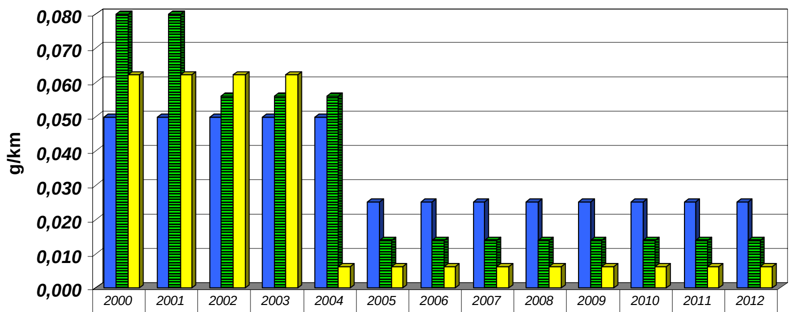
NOx limit values for diesel cars in g/km



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
EU	0,500	0,500	0,500	0,500	0,500	0,250	0,250	0,250	0,250	0,250	0,250	0,250	0,250
Japan	0,400	0,400	0,300	0,300	0,300	0,150	0,150	0,150	0,150	0,150	0,150	0,150	0,150
USA (Tier 2: Bin 5)	0,776	0,776	0,776	0,776	0,043	0,043	0,043	0,043	0,043	0,043	0,043	0,043	0,043

Fig. 1

PM limit values for diesel cars in g/km



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
EU	0,0500	0,0500	0,0500	0,0500	0,0500	0,0250	0,0250	0,0250	0,0250	0,0250	0,0250	0,0250	0,0250
Japan	0,0800	0,0800	0,0560	0,0560	0,0560	0,0140	0,0140	0,0140	0,0140	0,0140	0,0140	0,0140	0,0140
USA (Tier 2: Bin 5)	0,0621	0,0621	0,0621	0,0621	0,0061	0,0061	0,0061	0,0061	0,0061	0,0061	0,0061	0,0061	0,0061

Fig. 2

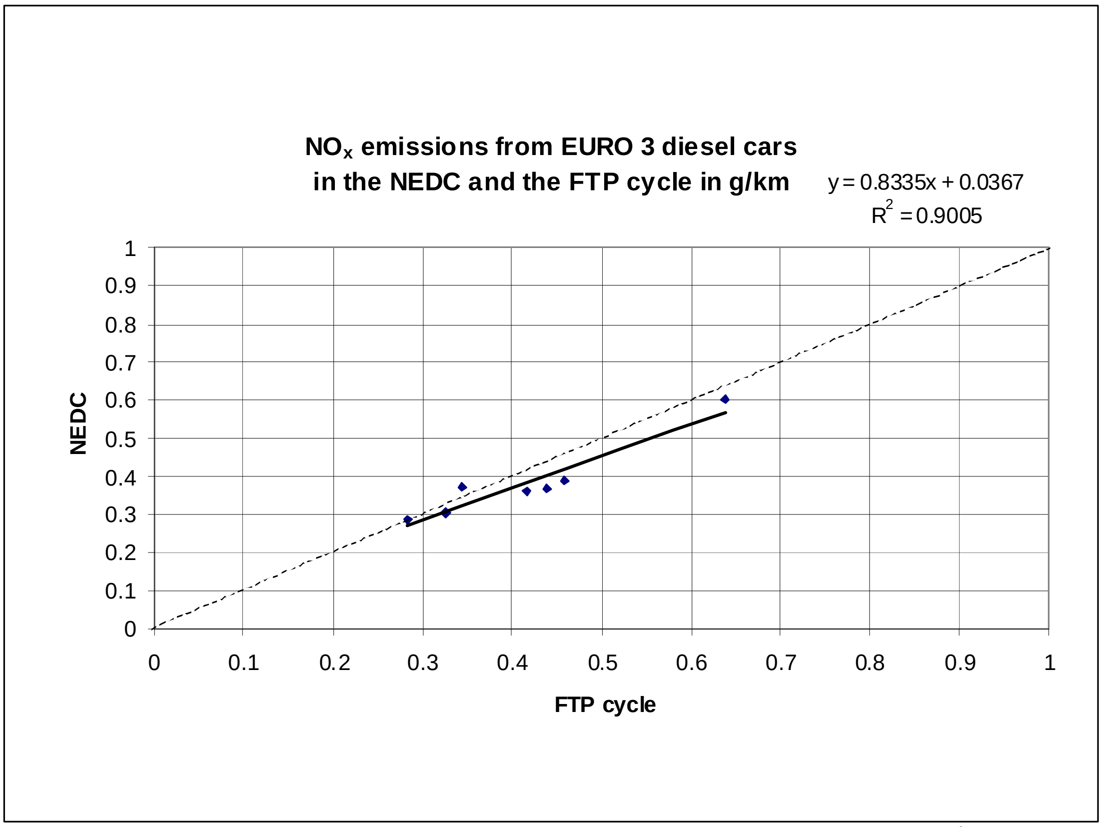

NO$_x$ emissions from EURO 3 diesel cars
in the NEDC and the FTP cycle in g/km
y = 0.8335x + 0.0367
R^2 = 0.9005
NEDC
FTP cycle
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Fig. 3

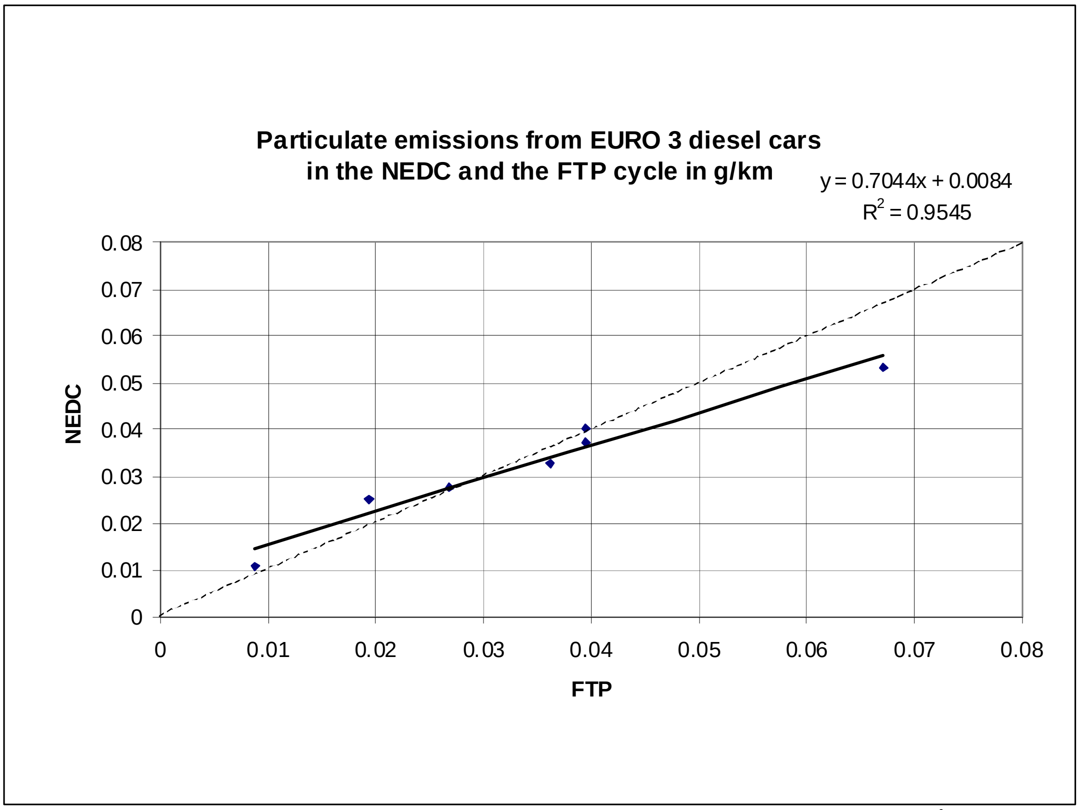

Particulate emissions from EURO 3 diesel cars
in the NEDC and the FTP cycle in g/km
y = 0.7044x + 0.0084
R^2 = 0.9545
NEDC
FTP
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08

Fig. 4

2.2 *Heavy-duty engines*

The picture is somewhat different for exhaust gas limit values for heavy-duty engines.

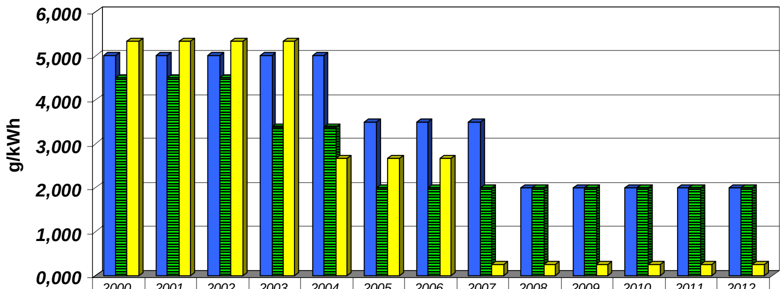
While the NOx limit value according to Euro IV is somewhat higher than the concurrent U.S. standard, the Euro V limit value is eight times higher than the drastically-reduced U.S. standard (**Figure 5**).

In contrast, the current Euro III limit value for particulates is about 20 % higher than the concurrent U.S. standard. When the Euro IV/V limit value enters into force, it will be 75 % lower than the U.S. standard for two years, while the positions will be reversed by the planned U.S. standard from 2007. At that time, the Euro IV/V limit value will be two times higher than the U.S. standard (**Figure 6**).

The Japanese limit values approved in early 2003 for the period from 2005 will be 7.5 times higher than the U.S. standard for NOx and 2 times higher than the U.S. standard for particulates from 2007 and therefore approximately on the level of Euro V (**Figures 5 and 6**).

Comparative measurements of heavy-duty engines in different test cycles are available from validation studies done within the framework of developing a world-wide heavy-duty certification procedure (WHDC, working party of ECE-GRPE) [29]. These are results for eight engines measured in the United States, Japan, and Europe, some of which were equipped with particulate traps. With regard to NOx emissions, **Figure 7** primarily shows that the NOx level of all engines was approximately equal in the range around 5.0 g/kWh, so the relationship between the results in the US-FTP and the European ETC cannot be considered to represent a correlation over a large range. A considerably larger range was covered by particulate emissions from the tested engines (**Figure 8**). The linear correlation shows that the particulate emissions in the FTP were about 20% higher than in the ETC. However, that statement must be viewed with reservations given the relatively small number of engines and the European design of most of the engines. The group contained only one engine designed for the U.S. market. Based on the little data that is available and including all other different background conditions whose effects on the level of requirements cannot be exactly quantified, it can also be said for heavy-duty engines that the U.S. standards and the European limit values can be directly compared in the same dimension.

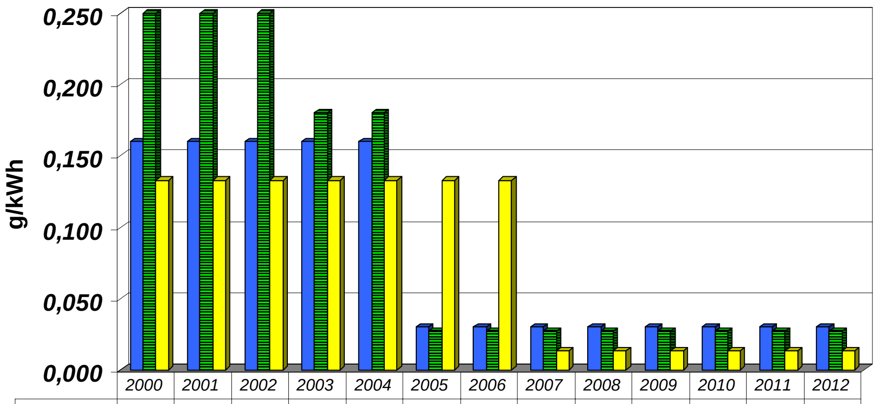
NOx limit values for heavy-duty engines in g/kWh



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
EU (ETC)	5,00	5,00	5,00	5,00	5,00	3,50	3,50	3,50	2,00	2,00	2,00	2,00	2,00
Japan	4,50	4,50	4,50	3,38	3,38	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00
USA	5,32	5,32	5,32	5,32	2,66	2,66	2,66	0,27	0,27	0,27	0,27	0,27	0,27

Fig. 5

PM limit values for heavy-duty engines in g/kWh



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
EU (ETC)	0,160	0,160	0,160	0,160	0,160	0,030	0,030	0,030	0,030	0,030	0,030	0,030	0,030
Japan	0,250	0,250	0,250	0,180	0,180	0,027	0,027	0,027	0,027	0,027	0,027	0,027	0,027
USA	0,133	0,133	0,133	0,133	0,133	0,133	0,133	0,013	0,013	0,013	0,013	0,013	0,013

Fig. 6

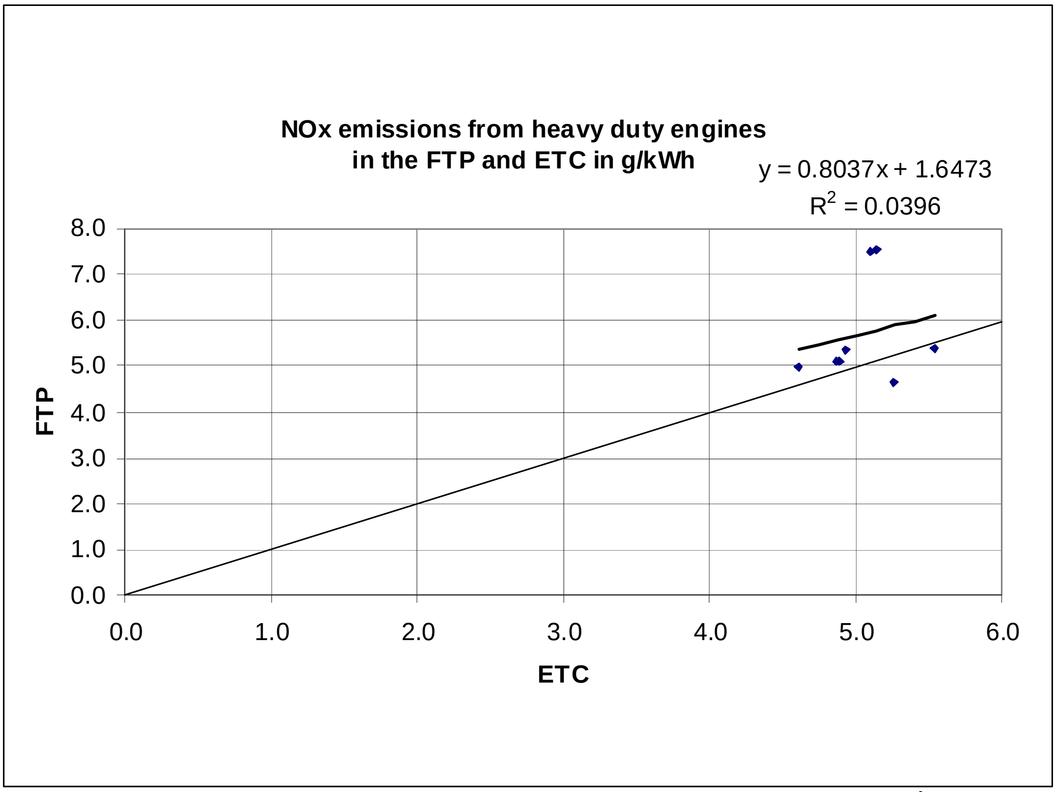

NOx emissions from heavy duty engines
in the FTP and ETC in g/kWh
y = 0.8037x + 1.6473
R2 = 0.0396
FTP
ETC
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0

Fig. 7

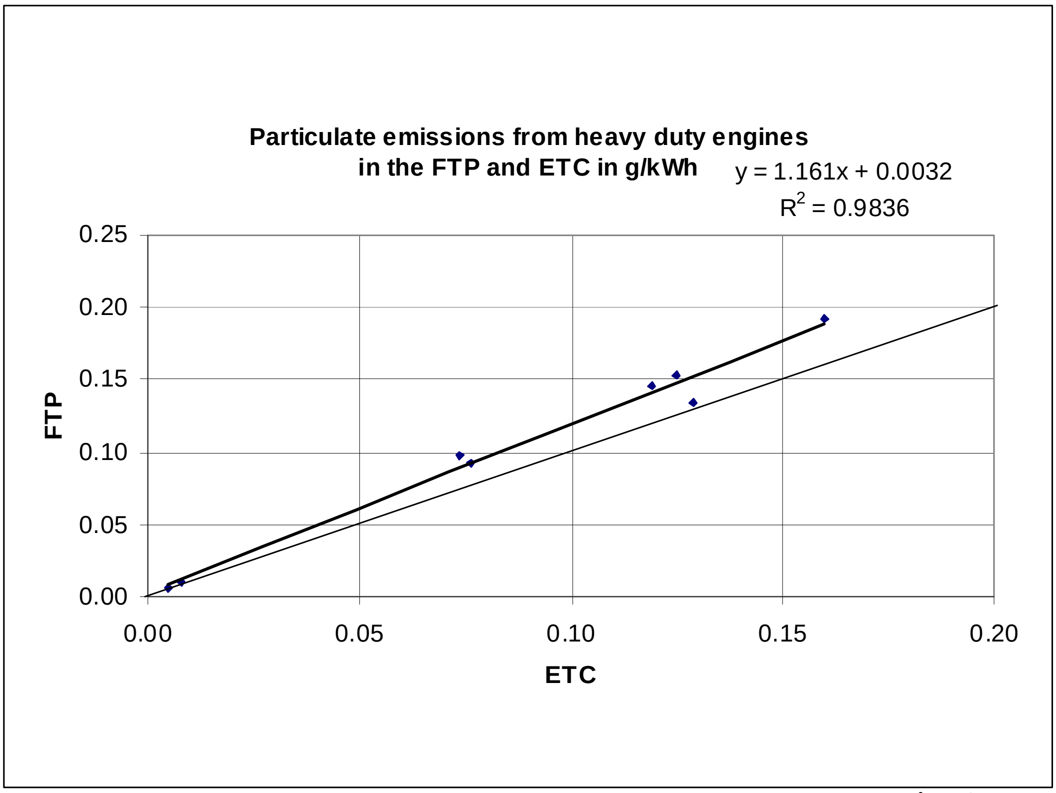

Particulate emissions from heavy duty engines
in the FTP and ETC in g/kWh
y = 1.161x + 0.0032
R2 = 0.9836
FTP
ETC
0.25
0.20
0.15
0.10
0.05
0.00
0.00
0.05
0.10
0.15
0.20

Fig. 8

2.3 Consent Decree in the United States

Seven manufacturers (Caterpillar Inc., Mack Trucks Inc., Renault Vehicules Industries, Volvo Truck Corporation, Cummins Engine Company, Detroit Diesel Corporation, and Navistar International Transportation Corp.), which together supply 95% of the American commercial vehicle market, delivered diesel engines from 1993 to 1998 which included "cycle-beating" in their electronic engine control. This meant that the nitrogen oxide emissions in normal (highway) operation were up to three times higher than the corresponding legal limits.

Those actions led to the Consent Decree of October 1998, an agreement between the U.S. EPA and the manufacturers concerned. In addition to direct fines totalling USD 83.4 million, the industry agreed to spend more than USD 1 billion to develop and replace the control software of the engines that used cycle-beating (1.3 million units) and to retrofit other older engines to reduce emissions (total cost > USD 850 million); they also promised to finance research projects that would lead to further reductions of emissions beyond those required by the law (USD 109.5 million).

Comprehensive documentation by the EPA concerning the Consent Decree and all of the related activities can be found on the Internet at the following address: http://www.epa.gov/oeca/ore/aed/diesel.

2.4 Conclusions

The future American standards for diesel passenger cars are much stricter than the Japanese and European limit values. This will also be the case from 2007 for heavy-duty engines.

International harmonisation of requirements and limit values is still in its early stages. The above comparison is intended merely as information; further development at the EU level must primarily be oriented to the situation in Europe.

Upshot:
Calls for updating the EU Directives for passenger cars and heavy goods vehicles are based on a broad international consensus. They are based on national demands and those ascertained within the framework of the EU. For both diesel passenger cars and heavy-duty engines, the future limit values for NOx and particulates world-wide reflect the political intention of drastically reducing emission levels. That results in the indirect requirement to achieve effective exhaust gas aftertreatment for both NOx and particulates.

3. Health-related and ecological justification for stricter exhaust gas limit values

The quantitative reduction objectives and the further qualitative requirements from an environmental viewpoint are compared below with the trend for pollutant emissions from road transport.

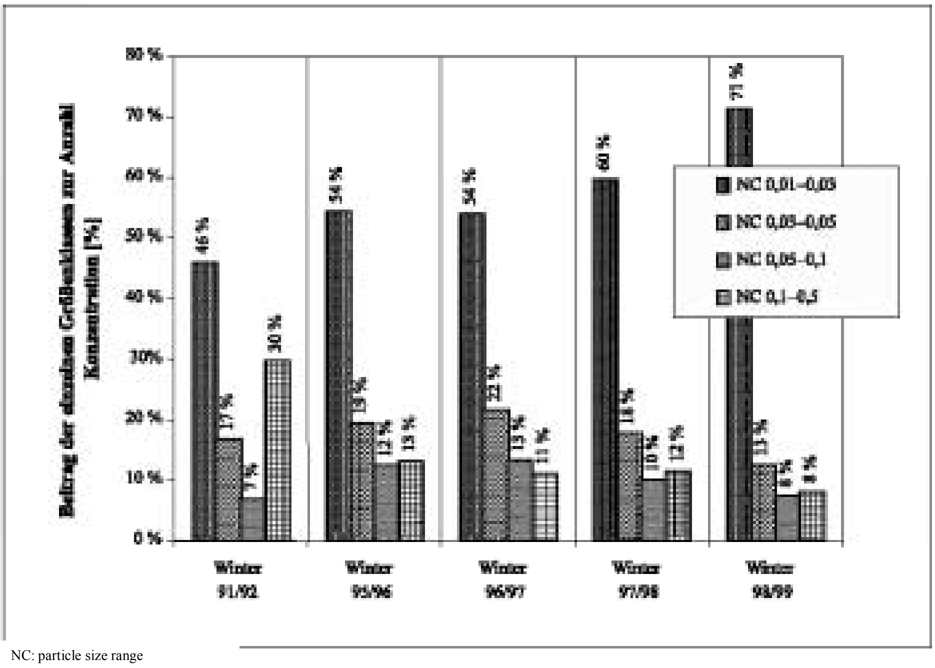
3.1 Exposure levels and EU emission reduction objectives

The problem of fine particulate emissions is currently being discussed in western countries in relation to air quality. The World Health Organisation, the EU Commission, the National Research Council, and the environmental agency in the United States are highlighting fine particulates as one of the current priorities for environmental hygiene in Europe and the United States.

The German *Länder* Committee for Pollution Control (LAI) assumes that road transport is responsible for 45 % to 65 % of the PM_{10} peak pollution close to roads. In cities, one-third of the mass of PM_{10} is due to secondary aerosols originating from long-distance transport. Any further attribution of the suspended particulate matter fraction of the PM_{10} to various sources should be viewed with caution. The mass portion of the $PM_{2.5}$ fraction in central Frankfurt in the late 1990s was estimated to be two-thirds of the PM_{10} fraction and according to conservative estimates is thought to have declined from an annual mean of 77 µg/m^3 in 1978 to 22 µg/m^{3}in 1998 [3].

In Germany, the size distribution of particulates has been measured in Erfurt since 1991. The 0.01 µm to 2.5 µm size range is covered. **Figure 9** shows the trend over time for the particulate count and mass concentration. The total particulate count (0.01 µm to 2.5 µm) has remained approximately stable since 1995-96 after a considerable increase. The same applies to ultrafine particulates (0.01 µm to 0.1 µm), whose concentration since that time has ranged between 14,000 and 20,000 particles per cm^3, with a 24-hour maximum of 50,000 particles per cm^3, while the fraction of the smallest particles (0.01 µm to 0.03 µm) has continued to increase. In contrast, the proportion of $PM_{2.5}$ declined considerably during the observation period [3].

7-year trend for relative particulate count for different size classes in Erfurt, winter 1991/92 to 1998/99 (stated as a percentage)



NC: particle size range

Source: Wichman et al. 2000

Fig. 9

It is anticipated that the limit values for PM_{10} contained in the 22nd German Federal Pollution Control Regulation (BImschV), which will be valid from 2005, will be exceeded, particularly for roadside monitoring stations. For example, the 24-hour limit value of 50 µm/m^3 at the three PM_{10} roadside monitoring stations for Berlin (which may be exceeded 35 times) was exceeded between 50 and 60 times in 2001. The annual mean values of the three stations were each

35 µm/m^3, so they just managed to comply with the annual mean value of 40 µm/m^3 that will apply from 2005. In contrast, the stricter limit value of 20 µm/m^3 from 2010 was clearly exceeded [30].

Analyses of the origin of particulates [31] showed that somewhat more than half of the PM_{10} concentration measured on roads is caused by traffic travelling directly past the station. That contribution from transport can be divided into diesel exhaust emissions (about 40%), abrasion from tyres (7-25%), and dispersion/road abrasion of 40-53% [32; 33].

In contrast, there is hardly any information about the percentage of PM_{10} background pollution caused by transport.

The annual mean concentration of elemental carbon (EC) at the Berlin background stations not directly influenced by traffic is between 2 and 3 µm/m^3 [30, 31]. EC is measured in suspended particulate matter as a proxy for diesel soot, but it also comes from other combustion processes, of which the most important source is domestic fuel. As a simplification, if one assumes that the influence of that source is negligible in summer, then about 75% of the urban EC background concentration, i.e. 1.5-2.3 µm/m^3, is caused by transport[1]. Because diesel soot particles contain approximately 50% EC, the result is a background contribution by transport to PM_{10} levels on roads of 3-4 µm/m^3 or approximately 10% of the annual mean value measured at roadside monitoring stations in Berlin. That means that diesel soot emissions cause about 30% of PM_{10} pollution.

However, in addition to the soot particles from diesel exhaust, nitrates formed from NO also contribute to PM_{10} levels. LAI assumes that the nitrates caused by transport contribute approximately 10-15% to PM_{10} levels [34]. Therefore, they should not be omitted from the discussion of particulate pollution from diesel exhaust.

Previous experience indicates that values for particulate counts can vary by more than four decimal powers. The concentration maximum at a traffic measurement point in Dresden [35] in the range of particle diameter 20-50 nm had an annual mean value of 5,800 cm^{-3} and a relative share of the particulate count (measurement range: 3-800 nm) of 35.5%. The mean count concentration in the entire measurement range was 16,330 cm^{-3} from April 2001 to March 2002. Wichmann found comparable values near roads in Erfurt for the size range 10 to 500 nm over three year years with a mean concentration of 17,900 cm^{-3}. Most of his distribution was in the interval of 10-30 nm.

In an initial estimate, the LAI report [35] concludes that motor vehicle emissions contribute about 50% for the diameter interval of 5 to 50 nm. The count concentration is therefore more strongly influenced by diesel emissions than the particulate mass concentration is. For reasons of health protection, both the mass of the diesel particulates in exhaust gas and their count should be further reduced.

According to current computer scenarios, the nitrogen oxide emissions caused by transport in Germany will be 72% lower in 2015 than in 1987, although a further significant reduction cannot be expected in subsequent years. According to those calculations, it is likely that the values recommended by WHO (annual mean value: 40 mg/m^3) will not be exceeded on roads with heavy traffic, but this is not certain. Problems may result for current forecasts if in future a disproportionate share (i.e. considerably more than 40%) of the distance travelled by petrol

[1] Derived from statistics for EC pollution levels at the Nansenstrasse urban background station of 4.6 and 3.5 µg/m³ for the six-month winter and summer periods respectively [2, p. 99].

passenger cars is replaced by diesel cars with much higher nitrogen oxide emissions that will not be further reduced by Euro IV.

An important cause for more far-reaching NOx reduction in the transport sector is the Directive on National Emission Ceilings (NEC Directive 2001/81/EC of 23 October 2001), which limits annual emission loads of SO_2, NOx, NH_3, and NMVOC in the Member States by the year 2010. According to Article 6 of the Directive, a national programme for compliance with the NECs was to be submitted to the Commission by the end of 2002. All approved EC Directives, including decisions to impose stricter standards and to improve fuel quality by 2010, have been taken into account in motor vehicle emissions. According to the most recent calculations, to comply with national emission limits for NOx in Germany by 2010 (1,051 kt), NOx must be reduced by 190 kt. In addition, a reduction of 35 kt NH_3 and 197 kt NMVOC from all sources must be achieved; the national emission limit for SO_2 is already met in the reference scenario. Without taking further measures, available calculations indicate that all sources in Germany in 2010 will contribute a total mass of 1,241 kt NOx, of which around 534 kt alone will come from road transport and 736 kt will come from transport (road transport plus other transport) [5].

3.2 National objectives for reduction

Among the pollutants emitted by motor vehicles which represent a carcinogenic risk, soot particles (in this case the EC content of the particles), benzene and benzo(a)pyrene are the most important. Objectives for reducing human toxicity from particulate emissions or exposure to particulates from all sources and keeping the additional risk of cancer as a result of inhalation below the rate of 1:2,500 (short term) or 1:5,000 (long term) in densely-populated areas are particularly important. As an intermediate step toward minimisation in comparison with the level from 1988, this requires a reduction of over 90% by 2005 or a reduction of over 99% by 2020 (**Figure 10**) and therefore remaining below an EC concentration of 0.8 $\mu g/m^3$ from all sources. This national objective therefore goes much further than the PM_{10} limit value of 40 $\mu g/m^3$ from 2005 and 20 $\mu g/m^3$ from 2010 which is specified within the framework of European Air Quality Directive 1999/30/EC.

Reduction targets

Problem area	General aim	Short-/medium-term measure or target	Long-term aim or target reduction rates
Human toxicity	Reduce the additional risk of cancer through inhalation in densely-populated areas to that of rural areas	In densely-populated areas by 2005 (a, c): **Risk 1 : 2,500** i.e. 90 % reduction compared with 1988	In densely-populated areas by 2020 (a, c): **Risk 1 : 5,000** i.e. 99 % reduction compared with 1988
	Significant lowering of the mortality and morbidity risk from fine particulates	PM_{10} (JMW) (d): **from 2005: 40 µg/m^3** **from 2010: 20 µg/m^3**	PM_{10} (AM): ? µg/m^3
	Reduction in toxicological pollution levels		NO_2 (AM) [WHO]: 40 µg/m^3
Sources: a: SRU 1994, b: SRU 1996, c: UBA 1997, d: EU 1999, e: UN-ECE 1999, f: BMU 1998; g: EU-Kyoto 1998; h: Enquete 1990 IFEU 8/2000			

Fig. 10

3.3 Effect of NOx emissions

Nitrogen oxides are air pollutants with both a direct and an indirect effect. Nitrogen dioxide (NO_2) is an irritant gas with oxidising characteristics. It can lead to an increase in respiratory diseases. Because NO_2 is involved – along with hydrocarbons – in the formation of ozone, the emission of nitrogen oxides must be reduced not only due to their direct effect, but also due to their contribution to ozone formation. Nitrogen oxides also contribute to the destruction of forests. In acidified soils, nutrients are broken down more quickly and therefore washed away. Toxic cations (aluminium), which attack roots, are then released. As a consequence, organisms are deprived of nutrients; the water balance is destroyed. At the same time, the soil is deprived of important structural elements, and the soil structure is degraded. The metabolic activity of the soil organisms is reduced, which interfere with the formation of humus. Acidification contributes to the dieback of forests through these effect mechanisms. The acidification of surface waters lowers the pH level. This primarily affects water bodies with a low chemical buffer capacity. The consequences are declining fish stocks and reduced diversity of other water organisms, because only acid-tolerant forms of life can adapt to those conditions. An evaluation system has been developed which reflects the sensitivity of species to pH reductions and the spin-off effects.

Nitrogen oxides also contribute to eutrophication (excess nutrition) of the North Sea and the Baltic Sea. This results in increased plant growth in bodies of water, causing greater consumption of oxygen. In addition, more biomass is killed off, sinks through the water, and leads to low-oxygen and oxygen-free zones, in which sapropel is formed. Consequently, the existing ecosystem with its self-cleansing mechanisms collapses.

3.4 *Effect of diesel exhaust; result of using particulate traps*

Particles whose main source is vehicles with diesel engines are considered to be the current most important problem for air pollution according to the 2002 environmental report by the Council of Experts on Environmental Issues [3]. It is estimated that diesel engine emissions account for 84% of carbon particulates averaged across Germany; in cities that figure is over 90%. The diameter of most diesel soot particles ranges from 0.02 µm to 0.5 µm.

It can be considered certain that inhalable suspended particulate matter that has access to the lungs, measured as particulate mass PM_{10} and $PM_{2.5}$, can have adverse effects on morbidity and mortality as a result of respiratory and cardiovascular diseases after both long-term and short-term exposure. Moreover, total mortality and therefore life expectancy are worsened. Indications that these effects are also caused by ultrafine particles ($PM_{0.1}$) must be taken seriously. The available studies on the relevance of fine particulates for human health indicate the need to reduce emissions of fine particulate matter and to limit exposure to pollution [3]. The carcinogenicity – with regard to the risk of lung cancer – of diesel soot has been demonstrated in animal studies. Indications of carcinogenicity in humans have increased in the past few years.

A relative increase in daily mortality and hospital admissions for respiratory diseases; data on the use of bronchodilators, coughing, and symptoms of the lower respiratory tract; and changes in lung function (peak expiratory flow, PEF) can be associated with a measured increase of PM_{10} or $PM_{2.5}$. As an illustration, **Figure 11** shows an estimate of how a three-day episode with daily concentrations of 50 or 100 µm/m³ PM_{10} can affect a population of 1 million people.

The current level of knowledge about the effects of particulate matter was published in April 2002 by the Health Effects Institute (HEI) (**Figure 12**). The fundamental connection between increased particulate concentrations in the ambient air and specific clinical pictures all the way to increased mortality is confirmed. Further research is needed on the particulate characteristics that are relevant to their effects, the biological mechanisms involved in the effect of particulates, and the sensitivity of specific risk groups.

Estimated number of people (in a population of 1 million) whose health is affected during a period of 3 days with increased concentrations of particulates

Indicator for effects on health	**Number of people following a 3-day episode of PM_{10}**	
	50 µg/m³	**100 µg/m³**
Number of deaths	4	8
Number of people admitted to hospital with respiratory problems	3	6
Person days of bronchodilator use	5,00	10,200
Person days with deterioration of symptoms (coughing and symptoms of the lower respiratory tract in general)	6,000	12,000

Source: WHO, 1996 and 2000

Fig. 11

UNDERSTANDING THE HEALTH EFFECTS OF COMPONENTS OF THE PARTICULATE MATTER MIX: PROGRESS AND NEXT STEPS (HEI, April 2002)

...... Epidemiologic studies over the last decade have reported associations between short-term increases in exposure to PM and increases in morbidity and mortality, particularly among those people with respiratory or cardiovascular disease. ..... Recent studies funded by HEI and other agencies have corroborated and extended the associations found in the earlier studies. The recent epidemiologic studies and studies of controlled exposure to PM in humans and other species have begun to provide information about critical issues in PM research:

[A] the size and chemical composition of particles that may cause harmful human health effects,

[B] the potential biologic mechanisms of PM effects that underlie the epidemiologic associations previously reported

[C] the groups of people that may be particularly sensitive to the effects of PM.

Nevertheless, to inform future regulatory discussions on control strategies, a systematic research effort is required to develop a better understanding of the health effects of different components of the PM mixture and the mechanisms of PM effects. ....

Fig. 12

The U.S. Environmental Protection Agency reached the following conclusion on the effect of diesel exhaust in 2002 [6, 7]: *"Emissions from heavy-duty vehicles contribute significantly to a number of serious air pollution problems. Ground-level ozone, particulate matter (PM), nitrogen oxides (NOx), sulphur oxides (SOx),and volatile organic compounds (VOCs) adversely affect public health, contributing to premature mortality, aggravation of respiratory and cardiovascular disease, decreases in lung function and increased respiratory symptoms changes to lung tissues and structures, altered respiratory defence mechanisms, and chronic bronchitis. In addition diesel exhaust PM, especially from older engines, has been found recently by U.S. EPA as likely to be a cause of increased risk of lung cancer and respiratory disease."*

The effect on health of using particulate traps in Germany has been investigated in an expert's report [23]. The report by Prof. Wichmann of GSF Neuherberg from June 2003 reaches the following conclusion:

"According to the statement of a WHO working party, the level of knowledge has clearly increased in recent years and confirms the relationship between exposure to fine particulate matter ($PM_{2.5}$) and effects on health. The working party recommends using $PM_{2.5}$ as an indicator for effects on health caused by particulate matter in Europe in addition to PM_{10}, which contains both fine and large particulates (WHO 2003).

Knowledge about exposure of the population in Germany to $PM_{2.5}$ is rudimentary due to a lack of measurements. However, data is available for PM_{10} which allows $PM_{2.5}$ levels to be estimated. According to that data, the average PM_{10} concentration in Germany is approximately

25 µg/m^3, and assuming a conversion factor of 0.6 would result in a mean $PM_{2.5}$ concentration of 15 µg/m^3.

Lambrecht et al. (1999) have estimated the contribution of motor vehicle exhaust to PM_{10} levels in Germany. The proportion is 5.5 mg/m^3 for background pollution in the city and 2.3 µg/m^3 PM_{10} in the country, from which a mean value of approximately 4 µg/m^3 PM_{10} can be calculated. Because the particulates in motor vehicle exhaust have a diameter of less than 2.5, they also cause pollution levels of approximately 4 µg/m^3 $PM_{2.5}$. Moreover, diesel passenger cars and heavy goods vehicles contribute more than 90% of the mass of diesel soot exhaust. Therefore, the assumption seems justified that the particulate mass of $PM_{2.5}$ motor vehicle exhaust comes almost entirely from diesel vehicles. However, a reduction potential of only 3 µg/m^3 $PM_{2.5}$ is used for the standard model in the report in order to obtain a conservative estimate.

To estimate risk, epidemiological data is needed that provides information about the connection between long-term exposure to particulates and the health of the population. Several studies are available that provide significant exposure-effect relationships.

The new study by Pope et al. (2002) for the American Cancer Society (ACS), which has shown a linear correlation between exposure to $PM_{2.5}$ and mortality for all causes of death, mortality from respiratory and cardiovascular disease, and lung cancer, is the most suitable for obtaining quantitative estimates. No significant correlation was found for particulates having a diameter greater than 2.5 µm.

That study was also used by WHO in the 2002 World Health Report. It assumes that the linear exposure-effect relationship that was found in the range between 7.5 and 50 µg/m^3 $PM_{2.5}$ is valid.

The information on mortality in Germany that is needed to calculate risk is taken from the currently available statistics on causes of death (German Statistical Office 2003).

In the report, the approach of the 2002 World Health Report is linked to the mortality data and estimated pollution levels from Germany as a standard model. Several alternative scenarios are also explored in a sensitivity analysis.

Conclusions

1. *The current mean exposure of the German population to particulates is approximately 25 µg/m^3 PM_{10} and approximately 15 µg/m^3$PM_{2.5}$. It is assumed that the reduction potential to be obtained by using particulate traps in diesel vehicles will be approximately 3 µg/m^3 $PM_{2.5}$.*
2. *Using the models of the World Health Organisation for 2002 as a basis, there is a linear exposure-effect relationship above 7.5µg/m^3 $PM_{2.5}$ for the increase in mortality as particulate pollution increases.*
3. *A total of about 800,000 people die in Germany each year (all causes of death).*
4. *Approximately 1 to 2% of those deaths can be attributed to diesel vehicles. That corresponds to 10,000 to 19,000 deaths per year. Approximately 8,000 to 17,000 of those deaths involve people with respiratory or cardiovascular diseases, and approximately 1,100 to 2,200 of those deaths involve people with lung cancer.*
5. *The use of particulate traps would largely prevent that number of premature deaths.*

6. *Because respiratory and cardiovascular diseases and lung cancer lead to death at a relatively advanced age, the reduction in the life expectancy of each individual as a result of those diseases is much less than the reduction resulting from causes of death that occur earlier in life. Therefore, it is more meaningful to consider life expectancy than mortality.*
7. *If one simply calculates the effect on life expectancy, then the broad use of particulate traps would lead to a mean increase in life expectancy of 1 to 3 months compared with the current situation.*
8. *The three-country study that was recently presented for Switzerland, Austria, and France stated that approximately 6% of deaths in those countries can be attributed to particulate pollution, of which half are due to particulates from motor vehicle transport (Künzli et al. 2000). The difference from the estimate presented here for Germany is that an important new epidemiological study has been published in the meantime (Pope et al. 2002) and modified, more conservative model assumptions were used (based on the WHO 2002 World Health Report).*
9. *The estimate presented in this expert's report is based on significant epidemiologically-confirmed increases in risk as well as recognised calculation procedures, and is therefore scientifically sound. However, it is unsatisfactory that no detailed health impact assessment has been done so far for Germany – in contrast to other countries – concerning the health risk resulting from particulates. That would provide much more accurate and detailed information than is currently possible based on simplified model assumptions.*

Discussion

The numerical data that has been obtained contains numerous simplified assumptions and uncertainties. However, these are conservative statements, i.e. tending more toward underestimation than overestimation of the actual effects of particulate pollution on human health.

The following must be kept in mind:

- *It is assumed that the toxic potential of all fine particulates is equally great. Actually, there are indications that particulates from motor vehicle exhaust cause a higher risk than other particulates.*
- *Only city and rural background pollution – not pollution close to roads – are considered, because sufficient information on the number of people who are exposed is not available.*
- *It is assumed that most of the mass of fine particulates from motor vehicle exhaust comes from diesel vehicles.*
- *It is assumed that it is possible to use particulate traps to prevent emission of most of the mass of the fine particulates from the exhaust of diesel vehicles.*
- *It will also be possible to use other technical processes to reduce particulate emissions from vehicle transport and therefore to reduce the health risk. It is not the subject of this report to evaluate the success of those measures.*

- *The estimates that have been presented consider only particulate mass. The particulate count could not be taken into consideration because no long-term studies are available in which the particulate count was measured in regions with different pollution levels.*
- *The estimate done here of the potential for reducing mortality or for prolonging life expectancy by using particulate traps does not take into consideration the fact that when one risk is eliminated, the relative importance of other risks increases somewhat. That means it must be expected that the calculated health advantage would not be fully achieved. This slight reduction in what is achieved should be negligible, however. Moreover, it must be kept in mind that the advantage of lower particulate exposure would most likely not be fully realised immediately, but rather after a delay of several years (Künzli et al. 2000).*
- *In connection with studies on short-term effects, some corrections of the originally published effect estimators are necessary. This does not relate to the long-term studies used here."*

As stated above, it is more plausible to consider the effect of diesel exhaust on life expectancy than the mortality caused by diesel exhaust. Accordingly, a mean increase in life expectancy of 1 to 3 months can be expected as a result of using particulate traps compared with the current situation. In contrast, statements about how many deaths are to be attributed to exhaust gases from diesel vehicles must be interpreted cautiously. The reduction in life expectancy attributed to vehicle exhaust could for the most part be prevented by effective particulate traps. However, when exploring the question of whether the mentioned number of deaths caused by diesel exhaust can be prevented, it must be considered that in the strict sense what is being prevented is not deaths but rather their premature occurrence due to a shorter life expectancy. It is theoretically possible to use specific conventions to calculate how many premature deaths could be prevented by the use of particulate traps, but not without the risk of an incorrect interpretation. Therefore, the presentation of the life span that can be gained is easier to communicate.

The Fraunhofer-Gesellschaft of Hanover and ifeu institute did a study back in 1998 that used unit-risk factors to compare petrol and diesel engines. It shows that based on current models the carcinogenic potency of diesel engine exhaust is higher by at least a factor of 10 than that of petrol engine exhaust (**Figure 13**). Those statements were recently confirmed by studies in Sweden [8] (**Figure 14**).

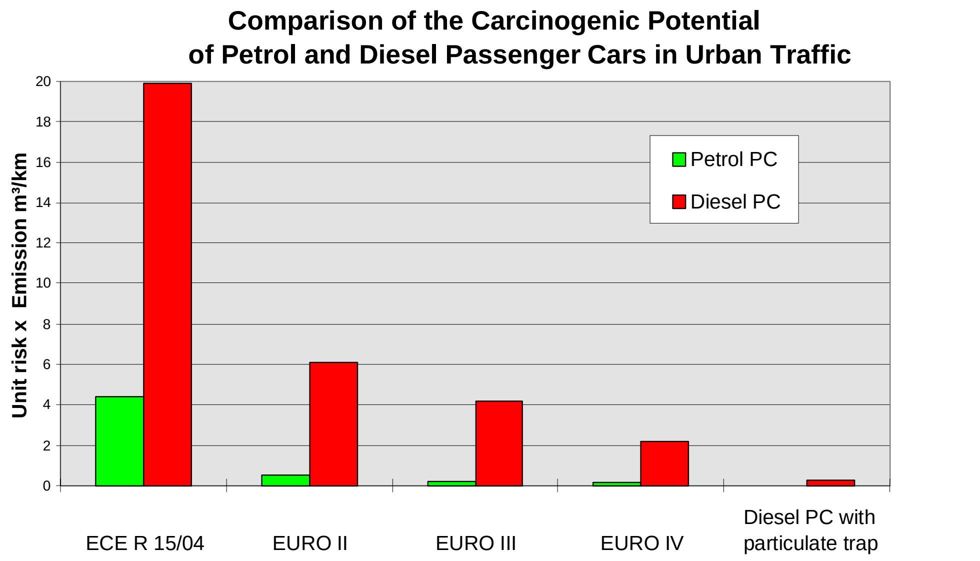
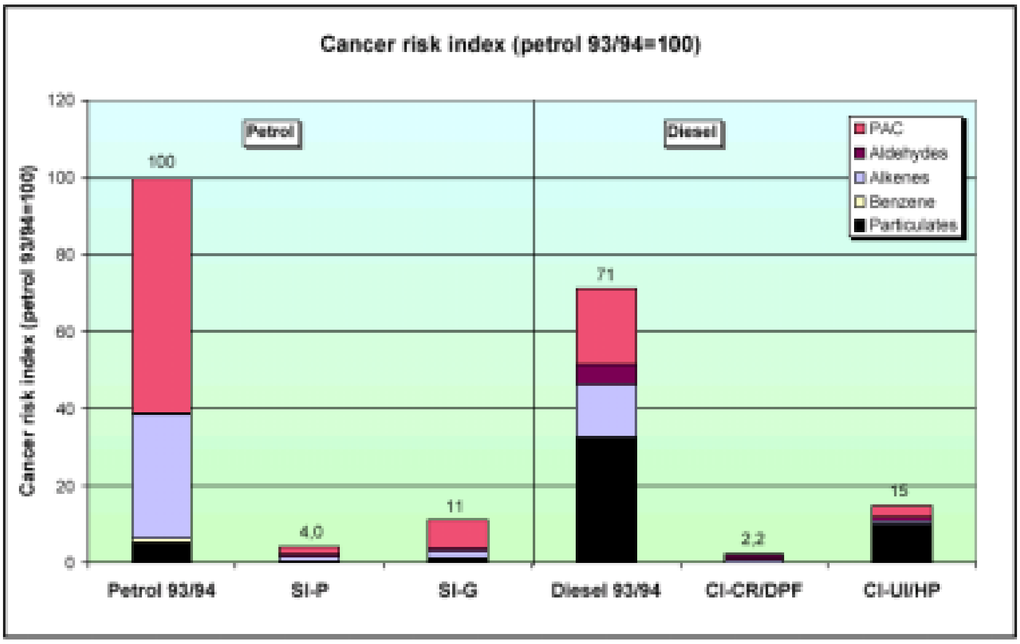


Fig. 13



Source: ECOTRAFFIC, May 2002

Fig. 14

This problem can be solved by particulate traps. By using efficient traps, the gap between the health effects of exhaust gases from diesel and petrol engines is narrowed to such an extent that there is no significant difference. Overall, the trap can be used to reach the level of particulate concentrations in the ambient air.

3.5 The effect of diesel particulates on climate

An article by the climate researcher Mark Z. Jacobson of Stanford University [26] deals with the impact of diesel and petrol vehicles on climate. The effect of diesel particulates on climate is so strong, he says, that it would more than offset the lower fuel consumption and resulting lower CO_2 emissions of diesel vehicles compared with petrol vehicles.

The article presents a very comprehensive model of the impacts on climate which for the first time quantifies new direct and indirect effects as a result of soot particles. One interesting effect is, for example, that when a soot particle absorbs light and therefore warms the surrounding air, the relative air humidity there drops. That causes any aerosol particles made of salt solutions that are present to shrink and therefore impairs their ability to reduce climate forcing by albedo. The article describes a total of 12 mechanisms for the impact of soot on climate, all of which are included in the climate model. The research result indicates that diesel cars – contrary to public opinion – will heat the earth's atmosphere much more than petrol vehicles do.

One important point is that a much shorter dwell time for soot particles (black carbon, BC) in the atmosphere is used than for CO_2 and CH_4, for example, which means that measures to reduce soot would lead to a much faster reduction in the impact on climate. Therefore, the effectiveness of those reduction measures, when considered over five years, is very high for soot particles, even if they do not account for the majority of anthropogenic warming.

According to the assumptions used by M. Jacobson in his climate model, soot warms the atmosphere 360,000-840,000 times more effectively than the same mass of CO_2. Accordingly, diesel vehicles that fulfil the Euro 3 standard will heat the atmosphere more over the next 100 years than petrol vehicles will. Conversely, this means that since diesel vehicles without particulate traps typically contribute an 80% share of soot to particulate emissions, a diesel passenger car must remain below a particulate emission level of 0.0015 g/km to have an advantage over petrol vehicles with regard to the impact on climate. That is far below the Euro 4 limit value (0.025 g/km) and can certainly be achieved using the particulate trap.

Feichter et al. [24] support the statements by M. Jacobson that aerosols have a great influence on climate and that soot particles have a positive, i.e. warming, effect on radiation. However, among other things they criticise the fact that Jacobson's model was integrated over only five years, whereas integration over many years is necessary for a more meaningful climate simulation.

According to Sato et al. [25] it is rather unlikely that reducing BC emissions is the best way to prevent global warming. They justify that statement among other things by saying that as soot emissions are reduced, OC (organic compounds) and sulphate aerosols are also reduced, which in turn has a cooling effect so that the net effect should be estimated as very slight.

Scientific knowledge about the impact of all aerosols on climate is very complex, and many effects are involved. In the third report by the Intragovernmental Panel on Climate Change (IPCC), the radiation forcing that is used as a measure of the disruption of the radiation balance is said to be +0.2 W/m^2 for BC and is therefore higher than that for N_2O, for example. It must be kept in mind that the value was still +0.1 W/m^2 in the second IPCC report, and has now been corrected upward. Other scientists, such as Jacobson [26], Hansen, and Sato [27] assume that the radiation forcing is most likely around +0.5 W/m^2 and higher.

Most climate researchers agree that diesel soot exhibits radiation forcing with a warming effect, although the quantification must still be discussed in detail. Therefore, the warming of the atmosphere as a result of diesel soot is probably an additional argument for updating particulate limit values.

3.6 Trend for numbers of vehicles and vehicle kilometres

The most important instrument for evaluating the future trend for pollutant emissions by traffic and the measures to be derived from them to fulfil environmental quality objectives is the TREMOD computer model. Important assumptions from earlier calculations were updated in version 2.1 of October 2001 (previous edition August 2000, version 2.0); these primarily involve the trend for numbers of vehicles and the increasing share of diesel cars in the vehicle kilometres travelled in Germany.

The “new” and “old” TREMOD calculations are compared below. The new calculations are also conservative assumptions overall, i.e. statistical data from official sources is used and only measures that have already been approved are included (**Figure 15**). The future share of diesel cars with particulate traps is assumed to be 10%, according to Directives that have already been passed.

The sharply rising share of diesel cars among new registrations and therefore their share in the total number of passenger cars and the distances they travel plays the most important role in that regard. In Germany, the proportion of diesel cars among new registrations has more than doubled in the past few years, reaching almost 40% (see **Figure 16**).

In terms of engine technology, efficient direct-injection engines with turbochargers are particularly popular and now account for well over 90% of the diesel cars that are registered. According to the trend that has already occurred, an increase in the share of the distance travelled by diesel cars in the total distance travelled by passenger cars is said to be 29% by 2010 and 36% by 2020, instead of the earlier assumption of 14% (**Figures 17 and 18**). That results in a shift in the share of the distance travelled from petrol cars to diesel cars, while the increase in the total distance travelled by cars is smaller than previously assumed. The distance travelled by commercial vehicles (other motor vehicles) remains almost unchanged from earlier assumptions, and the distance travelled by road transport overall is now somewhat lower.

The updating of exhaust gas limit values for diesel cars beyond Euro 4 and the adaptation for heavy-duty engines of Euro V standard which are being discussed here are accordingly not included in the new calculations.

Preliminary notes on calculations using the TREMOD model:

The new calculations relate to version 2.1 of TREMOD of 31.10.2001. Based on version 2.0 of August 2000 and the report written about it (UFOPLAN Nr. 298 45 105), the following work was carried out:

- Updating of **data on volume of traffic and kilometres travelled** for passenger car and heavy-duty traffic for the years 1998 to 2000 based on DIW's calculations of vehicle kilometres /ViZ 2000/ and traffic analyses carried out by the ifo Institute of autumn 2000.
- Updating of **fuel consumption data** for 1999 and 2000 using the current statistics of MWV.
- Updating of **data on existing vehicles** and new registrations of passenger cars for 1999 and 2000,
- Adaptation of calculations for 1998 - 2000 to the **energy balance**.
- Updating of the baseline scenario up to 2020 to take account of the **2015 traffic prognosis** for federal highways planning.
- Modification of assumptions to update the **fleet composition** up to 2000, in particular the share of diesel passenger cars in overall kilometres travelled. **[Conservative assumptions on the use of particulate traps]**
- Re-calculation of **CO2 scenarios** for road traffic. Here the latest data from the KBA, the ACEA and other sources were taken into account.
- Taking into account of the planned introduction and thus the influence of sulphur-free fuel (10 ppm) on emissions (in particular NOx) in the scenarios (still to be carried out!).
- Updating of scenarios for **rail and air traffic and shipping** on the basis of the "Transport report for 2015."

Source: ifeu 10/2001, (UFOPLAN No. 298 45 105)

Fig. 15

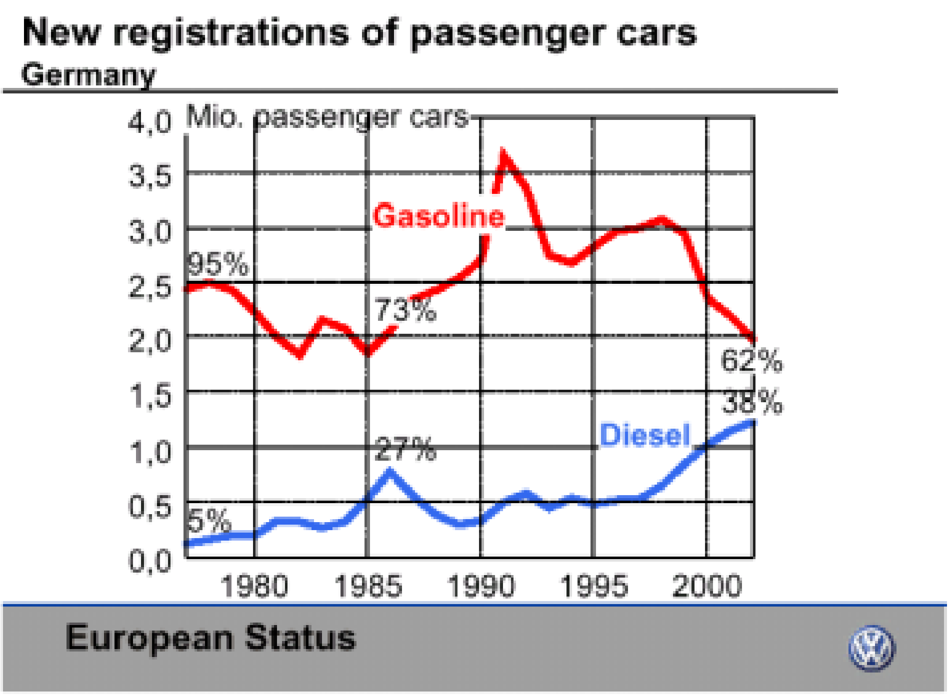


Fig. 16

Total distance travelled in Germany (vehicle-km/a) – TREMOD 2.0 (08/2000)

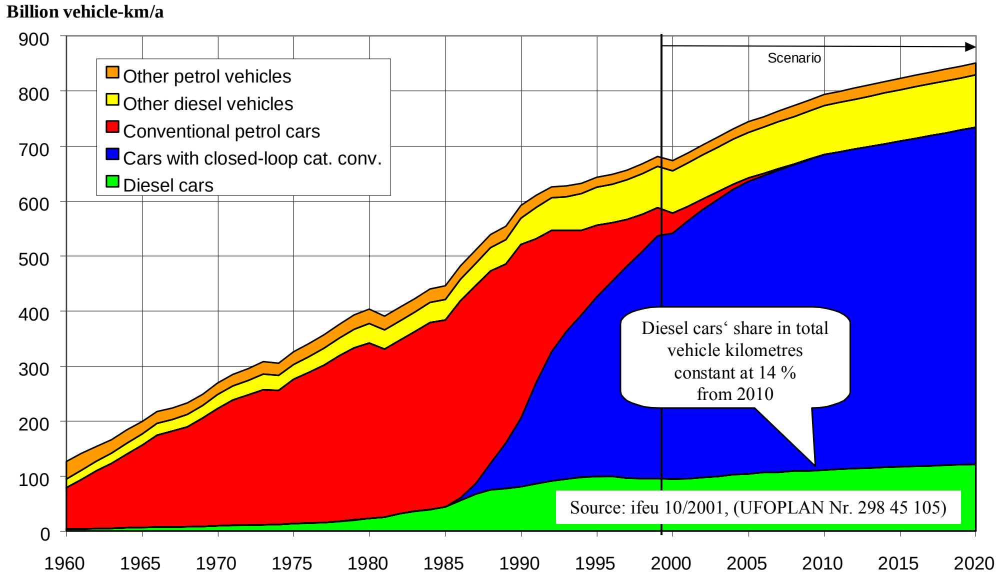


Fig. 17

Total distance travelled in Germany (vehicle-km/a) – TREMOD 2.1 (10/2001)

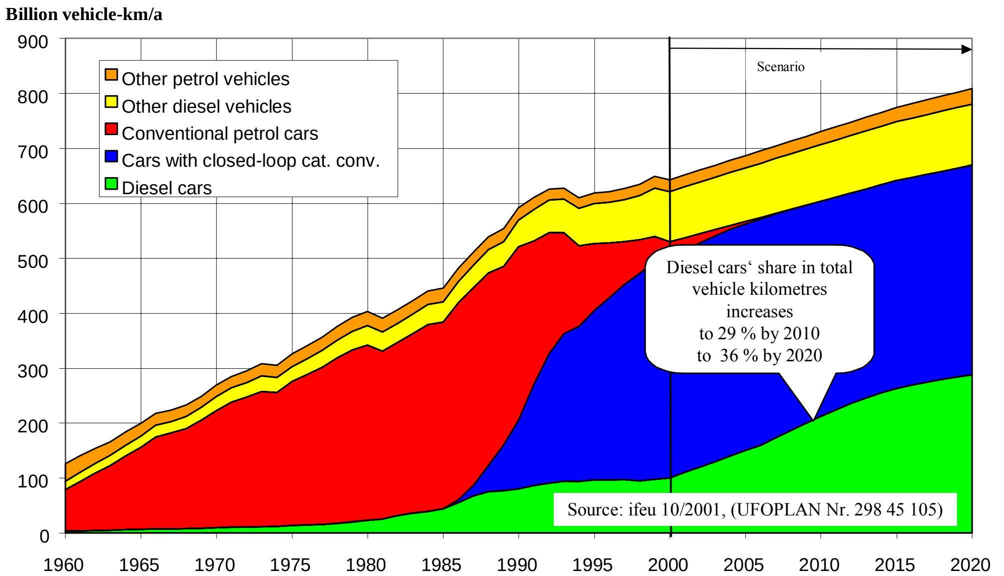


Fig. 18

3.7 Trend for pollutant emissions by road transport

The “new” and “old” TREMOD calculations are compared below.

3.7.1 New findings on the emission factors of commercial vehicles

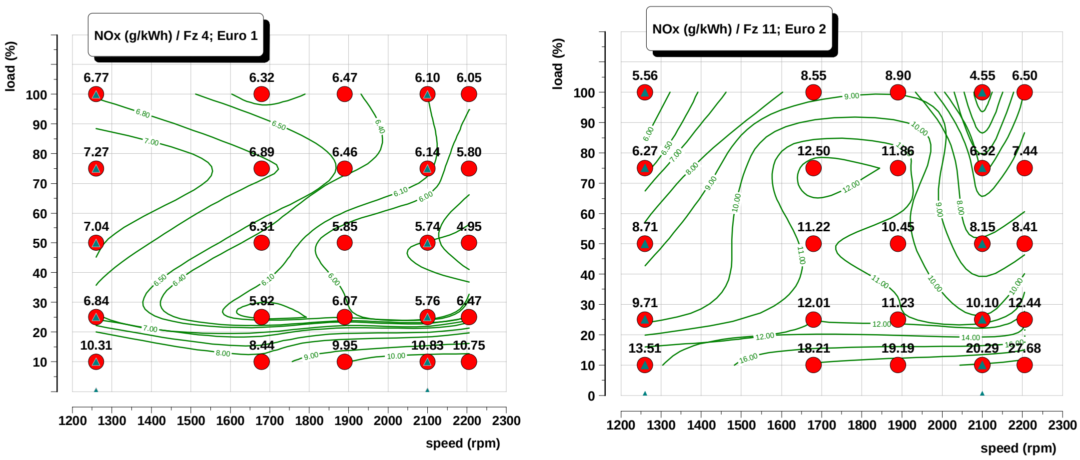
The emission factors were previously updated based on the measurement results for Euro 0 and Euro I engines according to the percentage limit value reductions of the subsequent limit value stages Euro II to Euro V. More recent studies indicate that the actual reduction rates of the new engine designs in actual operation most likely remain far behind earlier assumptions. Electronic injection systems in heavy-duty commercial vehicles – introduced as of the Euro II limit value – allow different injection strategies to be used in the various ranges of the engine’s characteristic curve. Recent studies have shown that Euro II engines are deliberately optimised outside of the range of characteristic curves driven in the type approval testing cycle to improve the specific consumption. In return, this leads to a considerable increase in nitrogen oxide emissions. The NOx emission factors for heavy-duty vehicles must therefore be corrected upward to a considerable degree.

Euro II standard heavy-duty engines are tested for pollutant emissions in the so-called 13-stage test as part of type approval testing. Pollutant emissions are measured at 13 specified measurement points in the engine’s characteristic curve and converted to an overall result that is combined into one value using specific weighting factors, which must then be below the limit value for the respective limit value level. The emission behaviour of numerous heavy-duty engines has been tested on engine test stands in Germany, Austria, Switzerland, and the Netherlands over the past four years. To evaluate emissions under real driving conditions, measurements were also taken outside of the type testing points. An example of two comparable engines (Euro I: 230kW/2,100 rpm and Euro II: 230k/W 2,100 rpm) by the same manufacturer is shown in **Figure 19** in an NOx characteristic curve with corresponding interpolated isolines. Rotation speeds at 10 of the 13 measurement points in the 13-stage test were n=1,260 rpm and n=2,100 rpm. The other three measurement points are measurements at idle speed. A relatively even emission behaviour can initially be observed for the Euro I engine, while it will be seen for the Euro II engine that much higher NOx emissions occur between the relevant test rotation speeds.

This demonstrates the potential of electronic control in modern diesel engines. In Euro II engines, fuel consumption can be improved by a few percent in the mean rotation speed range between type testing points, although much higher nitrogen oxide emissions, which clearly exceed the level of the adjacent testing points and the limit value, must be accepted in return.

The majority of emission factors for road transport have been recalculated as part of the work on the new Handbook on Emission Factors (HBEFA 2.0). S. Hauberger of the Technical University in Graz has recalculated the emission factors of heavy-duty commercial vehicles on the basis of the new measurement data [4]. The ifeu institute of Heidelberg, which prepared the TREMOD model (Data and Calculation Model: Pollutant Emissions by Motorised Transport in Germany) for the German Federal Environmental Agency, has included those new emission factors for heavy commercial vehicles in the TREMOD 3.0 model and recalculated the emissions from commercial vehicle transport in a preliminary version.

Heavy duty engines: comparison between a EURO 1 and EURO 2 NOx characteristic curve



Source:
RWTÜV 2002

Fig. 19

Although Euro II commercial vehicles will account for only 13% of the distance travelled in the year 2010, NOx emissions will increase by almost 50%. The reason is that the new mean emission factors for both Euro II and Euro III commercial vehicles are much higher than the emission factors previously developed on the basis of information from the commercial vehicle industry.

Three points should be taken into account when evaluating the interim results:

1. Due to the new definition of vehicle categories in HBEFA 2.0, ifeu had to change the weighting of the number of vehicles and distances travelled in TREMOD. A more detailed survey of the number of vehicles at the German Federal Motor Vehicle Authority (KBA) is currently being done as part of the TREMOD work for the German Statistical Office. However, that data is not available for the moment. Therefore, statistics from the KBA were used which show new registrations of heavy goods vehicles and tractors for semi-trailers in great detail according to size classes in a time series from 1970 to 2001. Complete updating will be required before the overall calculation on the basis of the detailed KBA data on numbers of vehicles is done according to the new structure. However, no significant changes are anticipated.

2. The calculations still do not contain a correction for the energy balance. Due to the differences in energy consumption between “new” and “old,” a consistent overall calculation of road transport using TREMOD 3.0 is not possible because a meaningful comparison of energy balances is not yet possible. It will not be possible until a calculation that includes all new factors (passenger cars, light-duty vehicles, motorised two-wheelers, etc.) is done by HBEFA 2.0. Because, according to the new emission factors, the fuel consumption of heavy-duty commercial

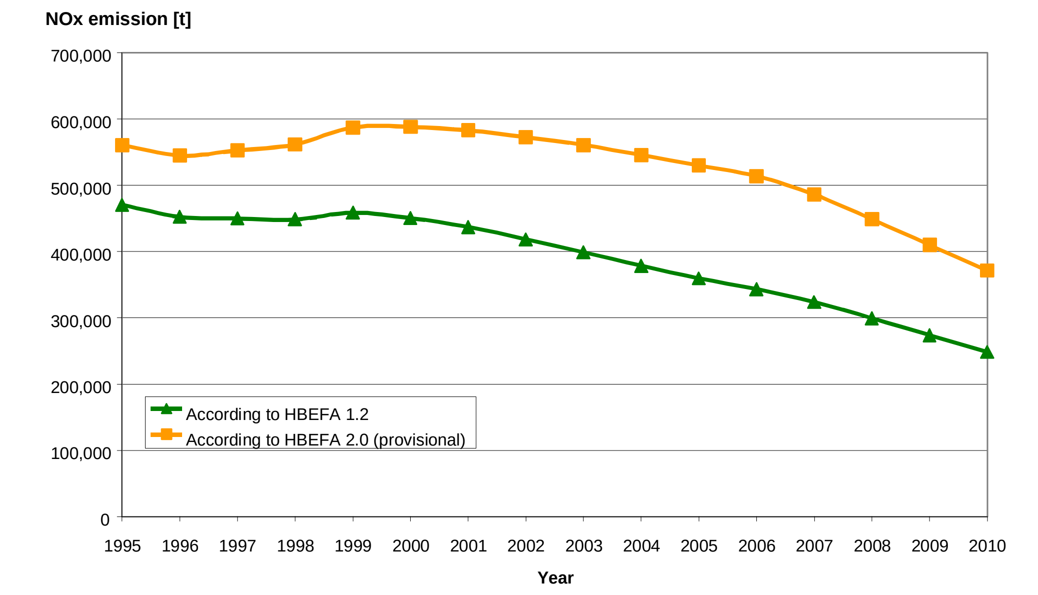
vehicles is a few percent lower than previously assumed, the correction for the energy balance could result in a less increase in the total quantity of pollutant emissions by heavy-duty commercial vehicles.

3. Due to the great effort and high costs involved in corresponding measurement programmes, the emission factors of heavy-duty commercial vehicles for the Euro III emission class have previously been based on measurements of only four different engine types. Emission factors for Euro IV and Euro V vehicles were determined – as in the past - based on the limit value reduction. Because 80% of heavy-duty commercial vehicles in 2010 will be Euro III, IV, and V vehicles whose actual emission behaviour cannot be determined by measurements until several years have passed, the forecast involves some uncertainties. The extent of that uncertainty cannot currently be quantified. A final estimate cannot be made until measurement data for the engine characteristic curves is available in representative quantities. Results for additional Euro III engines from current projects are not expected until autumn 2003 at the earliest.

3.7.2 NOx emissions

The trend for NOx emissions and the comparison between new and old calculations is shown in the following illustrations (**Figures 21 and 22**). **Figure 22** shows that in the future NOx emissions from commercial vehicles ("other vehicles, diesel") will account for the largest share of transport-related NOx emissions.

NOx emissions from heavy-duty commercial vehicles will be considerably higher due to the new emission factors. **Figure 20** shows the trend for NOx emissions from heavy-duty vehicles in Germany from 1995 to 2010 according to current knowledge. Until 1996, NOx emissions from heavy-duty vehicles using the interim data records of HBEFA 2.0 were about 20% higher than previously assumed within the framework of HBEFA 1.2. The deviation increases further starting around 1996, when Euro II limit values were introduced for heavy-duty commercial vehicles. Although Euro II commercial vehicles represent only 13% of the distance travelled in 2010, emissions are up by almost 50%. That is because the mean emission factors are higher for both Euro II and Euro III commercial vehicles than previously assumed.



NO_x emissions from heavy-duty commercial vehicles in Germany according to HBEFA 1.2 and HBEFA 2.0 (provisional)

Fig. 20

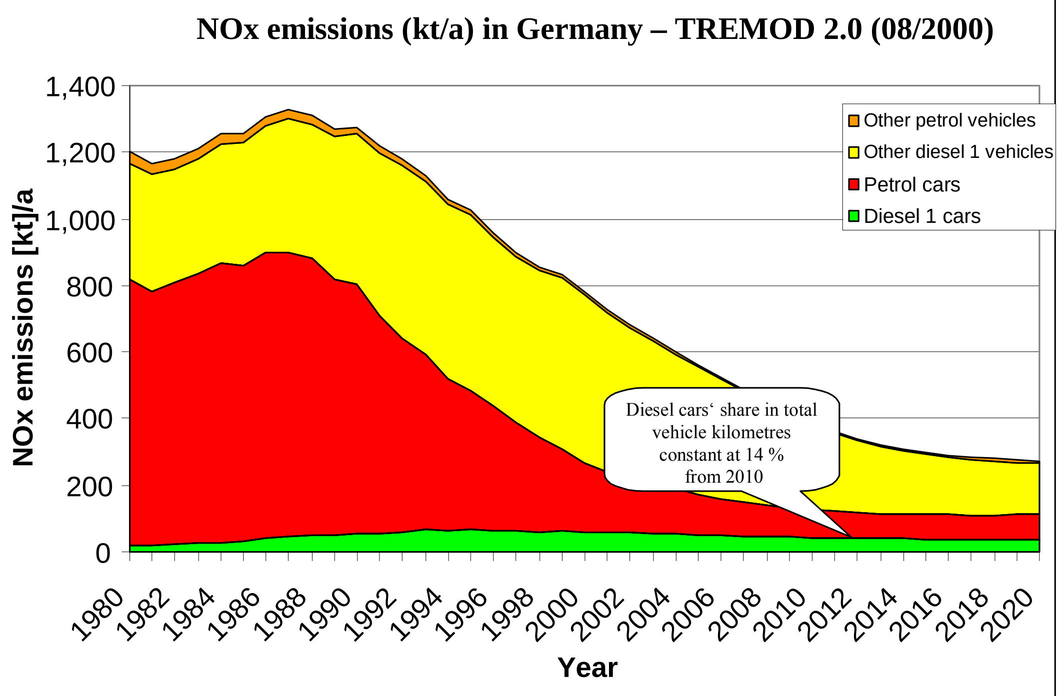


Fig. 21

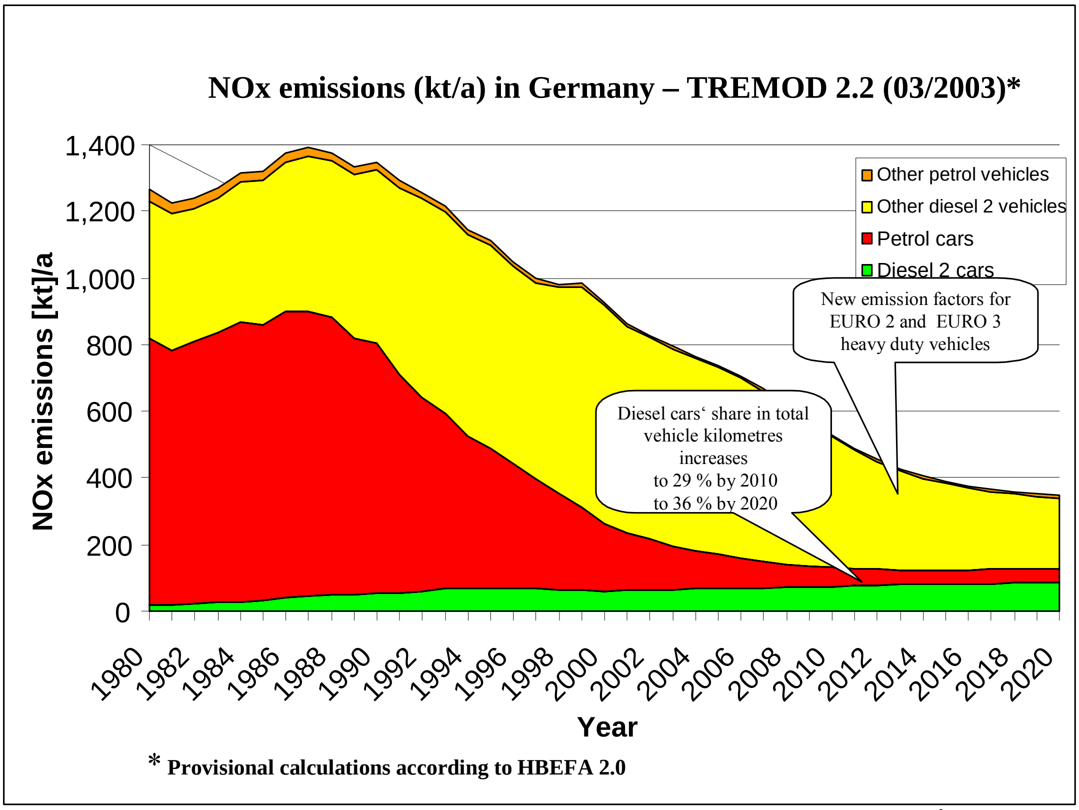


Fig. 22

Based on the interim TREMOD calculations using the new emission factors for heavy-duty vehicles, it can be assumed in spite of some uncertainty that the absolute emission of nitrogen oxide by heavy duty vehicles are 370,000 t by 2010 so that there remains an additional coverage gap with regard to the NEC directive of around 115,000 t NOx. The resulting increase in emissions must now be offset by additional measures so that the obligations of the NEC Directives can be fulfilled.

Assuming that a limit value of 1.0 g/kWh for heavy-duty engines is technically feasible and will be introduced in the course of the adaptation of the Euro V standard from 2008-2009 instead of the NOx limit value of 2.0 g/kWh intended for review in Directive 1999/96/EC and that, as a result of tax incentives and the toll charged on heavy goods vehicles in Germany, corresponding heavy-duty engines will come onto the market so early that their share of new registrations will already have reached 100% by the year 2008, then the result is a calculated NOx reduction of 36 kt for 2010. That measure would therefore make the absolute highest contribution to a reduction compared with all other measures considered for all stationary and mobile sources within the framework of the planned measures for fulfilment of NEC Directive 2001/81/EC.

3.7.3 Particulate emissions

The trend for particulate emissions and the comparison between new and old calculations indicates that the rapidly rising share of diesel cars by 2020 will lead to an increase in particulate emissions from cars by a factor of 2.3 and therefore to an increase in particulate emissions from road transport by a factor of 1.6 compared with earlier assumptions (**Figures 23 and 24**). The previous calculated rate for the reduction of particulate emissions from road transport by 2020 compared with the mid-1990s therefore drops from 86% to 77%. There is obviously a need for action in this area, which will be considerably increased by the greater share of diesel passenger cars.

In the emission forecast, particulate emissions and NOx emissions from diesel passenger cars would stagnate if limit values remained unchanged from 2002 to 2020. Total emissions of particulates (particulate mass) have decreased 40% in the last ten years and will decline further due to measures taken for heavy goods vehicles. However, it is doubtful whether the number of ultrafine particulates will decrease.

Ultrafine particulates cannot be reliably reduced by limiting mass, because, for example, 1,000,000 particles that are 10 nanometres in size are just as heavy as a single particle that is 1 µm in size.

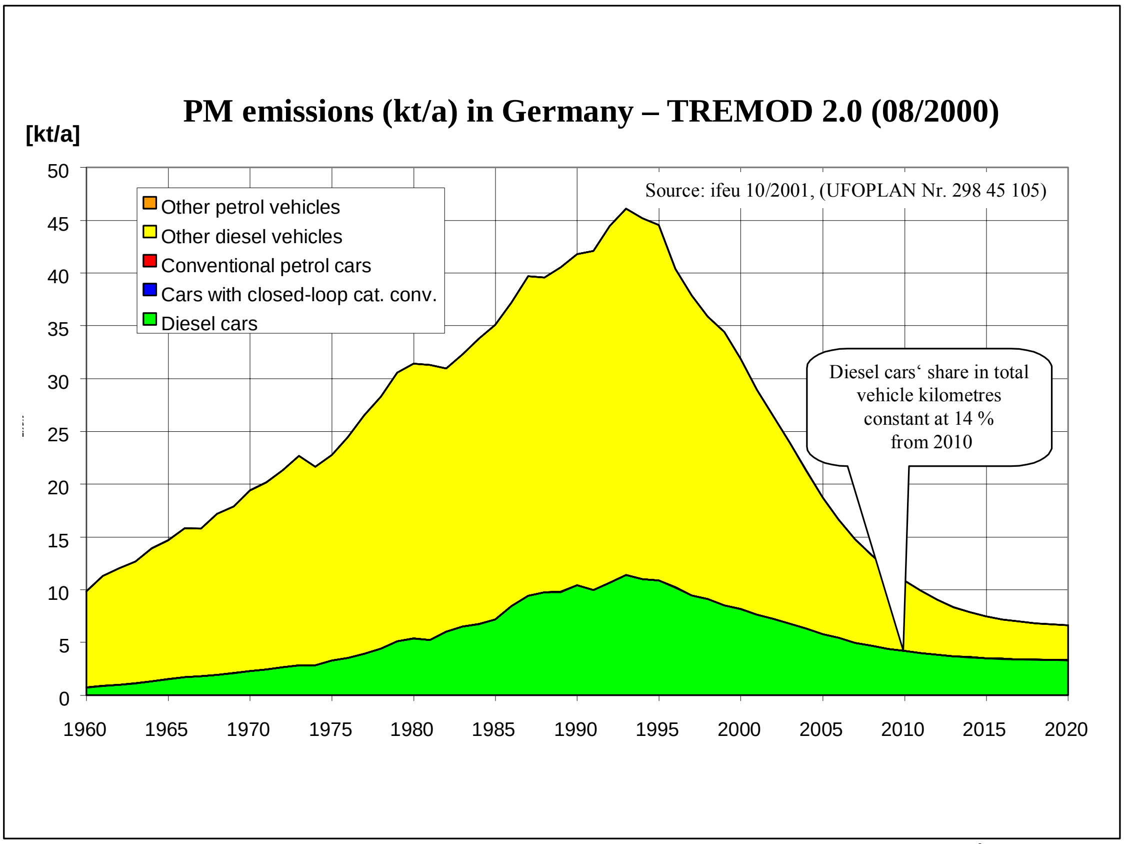


Fig. 23

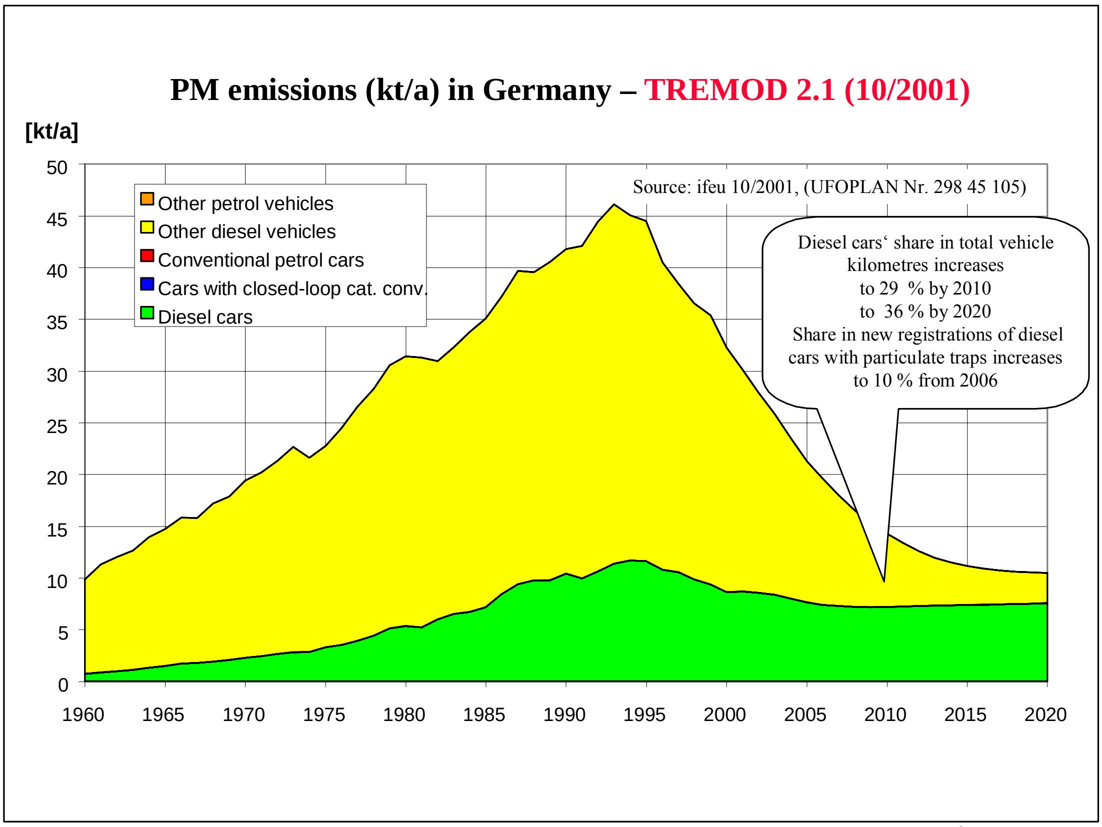


Fig. 24

3.8 Conclusions

The instructions by the Council to the Commission to update the exhaust gas Directives for passenger cars, light-duty commercial vehicles, and heavy-duty engines have already been mentioned.

There are health and ecological justifications for updating the exhaust gas Directives:

The World Health Organisation (WHO), the National Research Council, and the EPA of the United States have established the particular health effects of diesel exhaust (respiratory diseases). In addition, there is a suspicion of carcinogenicity.

A total of approximately 800,000 people die in Germany every year (all causes of death). Approximately 1 to 2% of those deaths can be classified as early deaths due to exhaust emissions from diesel vehicles. Using particulate traps would prevent most of these premature deaths. It is more plausible to consider the effects of diesel exhaust on life expectancy than the mortality caused by diesel exhaust. The use of particulate traps would lead to an expected mean increase in life expectancy of 1 to 3 months compared with the current situation. In the strict sense, what is being prevented is not deaths but rather their premature occurrence due to a shorter life expectancy.

The carcinogenic potency of the diesel engine exhaust from current car models without particulate traps is ten times higher than that of petrol engine exhaust, due to their particulate emissions. If a diesel passenger car has an efficient trap, the gap between the health effects of exhaust gases from diesel and petrol engines narrows to such an extent that there is no significant difference. Overall, the trap can reduce the level of particulate concentrations in exhaust to the level of the particulate concentration in the ambient air.

M. Jacobson's hypotheses concerning the effect on climate of diesel soot as an aerosol can be an additional argument for updating particulate limit values for diesel vehicles.

Diesel cars today emit eight to ten times more nitrogen oxide than cars that run on petrol, thereby contributing to summer smog, which is harmful to health.

No major changes in the number of commercial vehicles or the distance they travel can be discerned for the future compared with the trend that has previously been assumed. That means that adapting Euro V exhaust gas limit values for heavy-duty engines and therefore further reducing particulate emissions to the particulate trap level is necessary for the same reasons as for diesel passenger cars.

Directive 1999/96/EC on measures to be taken against emissions from heavy-duty engines specifies a Euro V standard with (among other things) an NOx limit value of 2.0 g/kWh, which will apply beginning in 2008, for the granting of operating licenses for new engine types. Within the framework of calculations for the planned measures to be taken by the German federal government to comply with NEC Directive 2001/81/EC, it has been shown that it will be necessary to cut that limit value in half again to 1.0 g/kWh as the measure that has the absolute maximum potential for reducing NOx. A further reduction in the limit value to 0.5 g/kWh must follow as of 2010.

These reasons are consistent with the instructions by the Council to the Commission and those presented in the introduction concerning the updating of the exhaust gas Directives for passenger cars, light-duty commercial vehicles, and heavy-duty engines.

Upshot:
Health effects due to particulate emissions and exposure to pollution indicate a need for action with regard to both particulates and NOx. This would provide a mean increase in human life expectancy of 1 to 3 months as a result of an effective reduction in particulates and fulfilment by 2010 of the obligations resulting from the NEC Directive, particularly since NOx emissions from heavy-duty commercial vehicles of emission classes Euro II and Euro III are 50% higher than previously assumed, which corresponds to an additional gap in coverage of around 115,000 t NOx.

4. Potential for reducing emissions from diesel engines

The particulate emissions from diesel engines in passenger cars and commercial vehicles have already been considerably reduced by changes in engine design over the past few years, i.e. by improving combustion. The oxidation catalysts that are now standard in diesel passenger cars make a small contribution to this, although they can reduce only the volatile components (added hydrocarbons) contained in the total particulate mass, not the elemental carbon particles to which the main health-impairing effects of the particulates are attributed.

Depending on the current initial state of the engines of diesel passenger cars and of heavy-duty engines, additional measures that in some cases can reduce particulate mass by 30 to 50% are necessary to improve engine combustion and make it just possible to comply with the Euro 4 limit values applicable to type testing as of 2005. However, as things now stand, a drastic reduction in particulate size is possible only by aftertreatment of exhaust gas, i.e. by a particulate trap. The proven reduction rates based on particulate mass are considerably higher than 90%, so it is possible to remain well below the particulate limit values of Euro 4 for passenger cars or Euro V for heavy-duty engines.

Engine design measures and the aftertreatment of exhaust gas to reduce particulates do not directly influence nitrogen oxide emissions. However, it is possible to take advantage of the reverse correlation of particulate emissions and nitrogen oxide emissions to optimise overall emission behaviour when aftertreatment of exhaust gas is used. For example, particulate traps allow engine combustion to be adjusted to relatively high gross particulate emissions, which are then eliminated by the particulate trap, thereby ensuring relatively low nitrogen oxide emissions. However, taking advantage of this trade-off to reduce particulates or NOx when using aftertreatment of exhaust will seldom be sufficient on its own to comply with future limit value stages.

Figure 25 shows the various strategies to reduce NOx and particulates using the example of a heavy-duty engine.

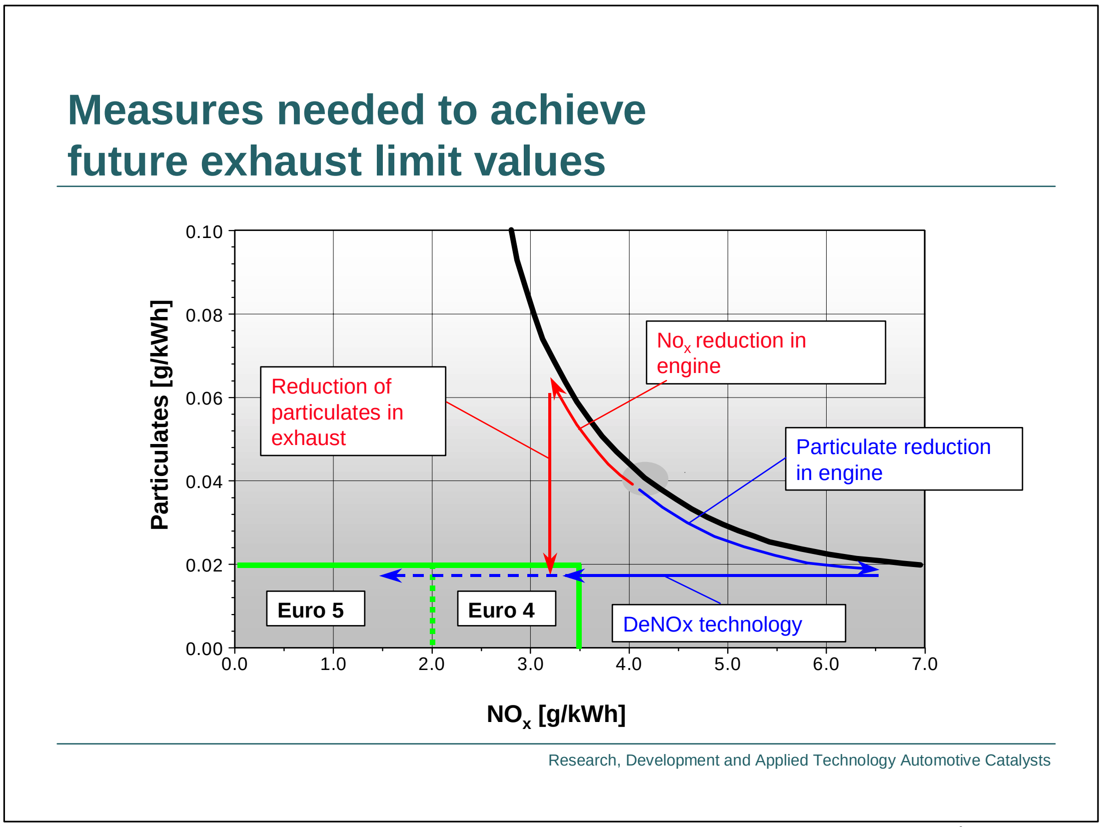


Fig. 25

4.1 Reducing NOx (cars and commercial vehicles)

Aside from typical particulate emissions by diesel vehicles, the relatively high nitrogen oxide emissions of diesel engines as a result of the combustion process they use represent the greatest problem, while hydrocarbon emissions are low based on the principle used and can effectively be reduced even further using oxidation catalysts.

A diesel passenger car with a particulate trap does have one disadvantage compared with a car that runs on petrol: it discharges eight to ten times more nitrogen oxide than current new petrol vehicles, thereby contributing to the formation of the summer smog, which is harmful to health (**Figure 26**). The NOx limit value for diesel passenger cars contained in Euro 4 is about three times higher than the limit for petrol passenger cars. In contrast to petrol cars, very few diesel cars comply with Euro 4 limit values.

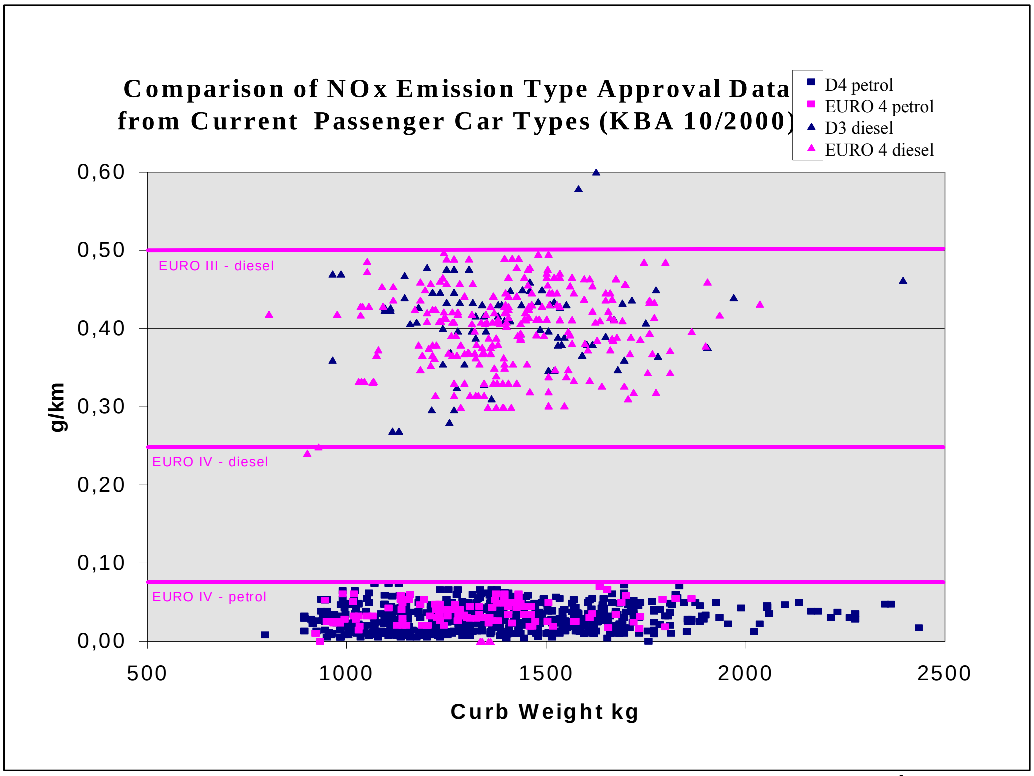


Fig. 26

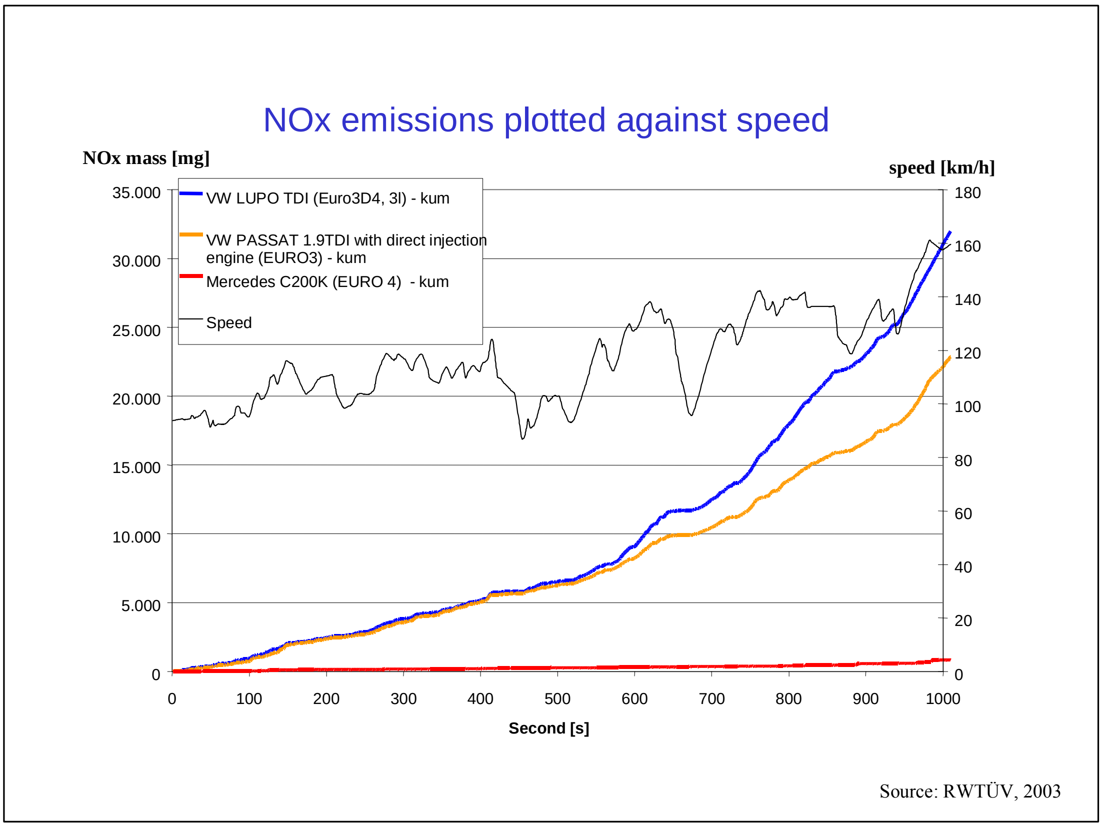


Fig. 27

Figure 27 shows the cumulative NOx emissions from two modern diesel passenger cars (VW Lupo TDI and VW Passat 1.9 TDI) compared with emissions from a petrol passenger car (Mercedes C 200) in a motorway cycle extending up to 160 km/h. This also shows that NOx emissions by the diesel car are more than one order of magnitude greater than those of the petrol car.

The following measures for reducing NOx are available in principle for diesel passenger cars and heavy-duty engines and have the following reduction rates compared with current levels:

Changes in engine combustion processes:	20-30 % (already partially implemented)
Exhaust gas recirc. electronically controlled	20-50 % (already partially implemented)
NOx storage catalysts	70-90 % (used in GDI engines)
Selective catalytic reduction (SCR)	70-95%

These technologies are for the most part fully developed and could already be used in series production today if the engine makers had decided to do so in sufficient time in the past.

Changing engine combustion involves the following measures: high-pressure injection and controlled injection process, where applicable pilot injection, special design of swirl and tumble, four-valve technology, and turbocharger with variable geometry, etc.

Exhaust gas recirculation is a technology that has been used for a long time in different variations and can be further optimised in the future using electronic control and, where applicable, can take the form of cooled exhaust gas recirculation.

NOx storage catalysts have not yet been used in series production of diesel engines. However, they are available in series-produced models with direct-injection petrol engines (VW FSI), whose lean combustion process is similar to that of the diesel engine. One disadvantage of this technology is that regeneration of the storage catalyst is necessary on a regular basis, which requires enrichment of the otherwise lean mixture up to the range of $\lambda = 1$. This increases consumption by several percent during overall operation, which is more acceptable for operators of diesel passenger cars than for the operators of commercial vehicles. The advanced development of NOx storage catalysts and the high reduction rates of over 90% which have been achieved have been demonstrated by the EPA for heavy-duty diesel engines [10]; see **Figure 28**.

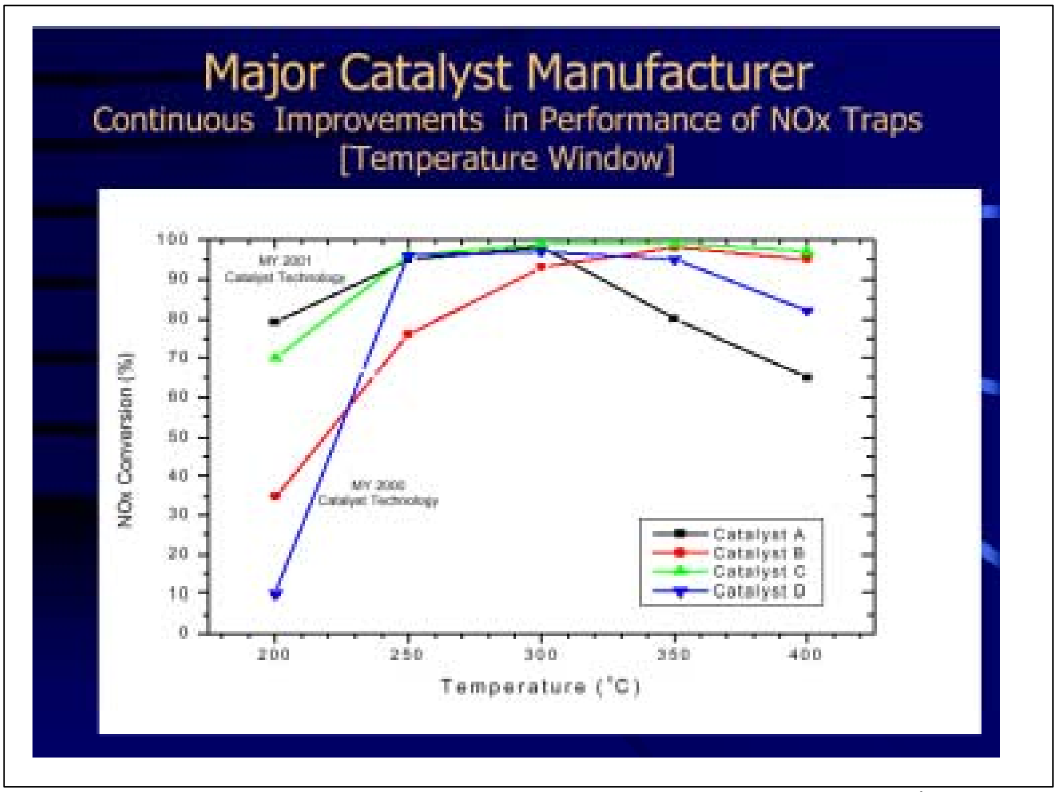


Fig. 28

Toyota has been testing the combination of an NOx storage catalyst and a particulate trap, known as DPNR, in field use in several European countries since March 2002 and is planning to introduce it into series production in the second half of 2003. The final results for the long-term durability of the DPNR system from the field testing were not yet available in May 2003. According to Toyota, when the DPNR system is new, it reduces both NOx and particulate emissions by more than 80%. In the New European Driving Cycle with a passenger car of reference mass class 1400 kg, levels of 0.13 g/km NOx and 0.005 g/km particulates were achieved using an DPNR system that had undergone accelerated ageing [9]. **Figure 29** shows measurement results obtained by the U.S. EPA, which show a trend in the FTP toward a lower emission level for NOx as well as a lower emission level for particulates [10]. It had not yet been determined in June 2003 which emission values could be achieved with the final design of the DPNR system for the European market. Type testing values of publication standard were not yet available from Toyota. The German Federal Environmental Agency assumes that the DPNR system has the technical potential to comply with the limit values proposed below.

Toyota Diesel Particulate NOx Reduction (DPNR) Diesel Tested at NVFEL
[System Integration]

Test Cycle	NOx (g/mile) Test Results	NOx (g/mile) Tier 2 Bin 5	PM (g/mile) Test Results	PM (g/mile) Tier 2 Bin 5 Std	NMHC (g/mile) Test Results	NMHC (g/mile) Tier 2 Bin 5 Std	Fuel† Economy (mpg)
FTP75*	**0.05**	0.05	**0.006**	0.01	**0.07**	0.075	37
US06**	**0.14**		**0.005**	0.07	**0.19**		35
HWFET***	**0.001**	0.075	**0.002**	-	**0.12**	-	53
NYCC****	**0.003**	-	**0.007**	-	**0.04**	-	22

* Final Tier 2 FTP Bin 5 Intermediate Life (50k) standards, NMHC reported for NMOG
** Final Tier 2 SFTP 4k standards, US06 std is NOx + NMHC = 0.14, PM is a weighted Std
*** Highway Fuel Economy Test NOx limit is 1.5 times the FTP standard
**** New York City Cycle
† Fuel economy numbers are not adjusted and so are not directly comparable to manufacturer reported City/Hwy fuel economy numbers for other vehicles

Fig. 29

Peugeot has also announced that a similar technology will be used in series production for 2003. The diesel passenger car models of both manufacturers equipped in this way will most likely fall well below the Euro 4 limit values.

The most interesting technology in the view of the German Federal Environmental Agency is selective catalytic reduction (SCR) because its regulated version provides the highest reduction rates – over 95% – and simultaneously allows the engine to reduce fuel consumption by 10% compared with the previous design without SCR and therefore to reduce CO_2 emissions accordingly. That means that when SCR is used in commercial vehicles it can pay for itself after about two years of operation, after which it leads to ongoing savings. Due to the space it requires and the need for a supply of reduction agent (for example urea in an aqueous solution) it is more likely that this technology, which has been successfully been tested in field studies for several years now, will be used in commercial vehicles instead of passenger cars. Its high effectiveness – including in dynamic operation – has been repeatedly demonstrated (**Figure 30**).

The European Association for Emission Control by Catalyst (AECC) and RICARDO Consulting Engineers have tested the durability of an unregulated SCR system in combination with a particulate trap system on a Euro III heavy-duty engine in forced durability studies lasting more than 1,000 hours. The results show that an NOx value of 1.0 g/kWh and a particulate value of less than 0.01 g/kWh in the ESC and the ETC can easily be obtained without major degradation, i.e. mass-based reduction rates of over 85% were achieved over the long term for both NOx and particulates [11].

These results mean it is possible for a Euro III engine with an NOx emission that barely complies with the limit value of 5 g/kWh and an unregulated SCR device with a reduction rate of 85% can achieve an emission level of 0.75 g/kWh over the long term, offering a sufficient safety margin for a limit value of 1.0 g/kWh; see **Figure 31**.

The conversion rate can be increased to over 95% by using an NOx sensor and regulating the SCR system (**Figure 32**).

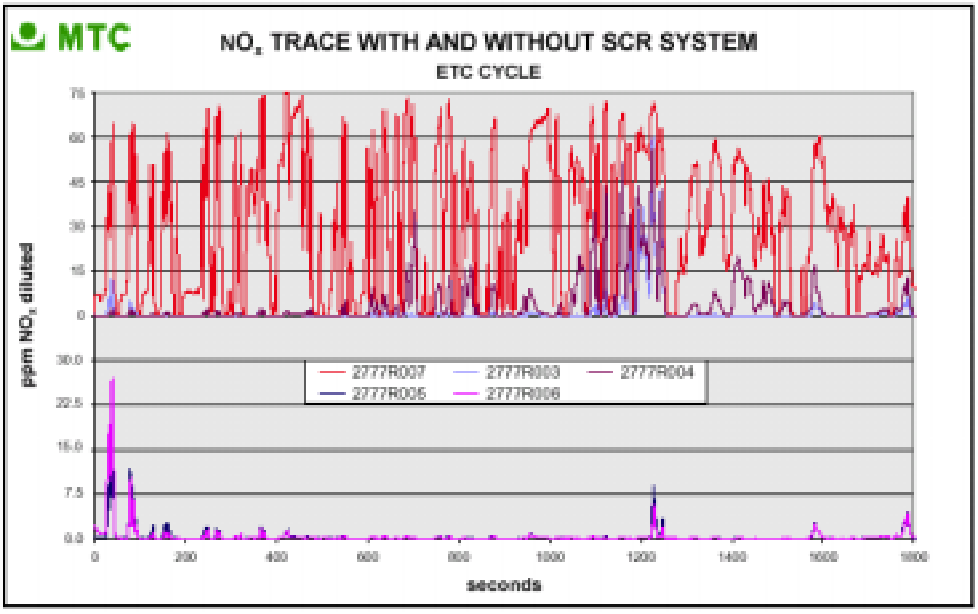


Fig. 30

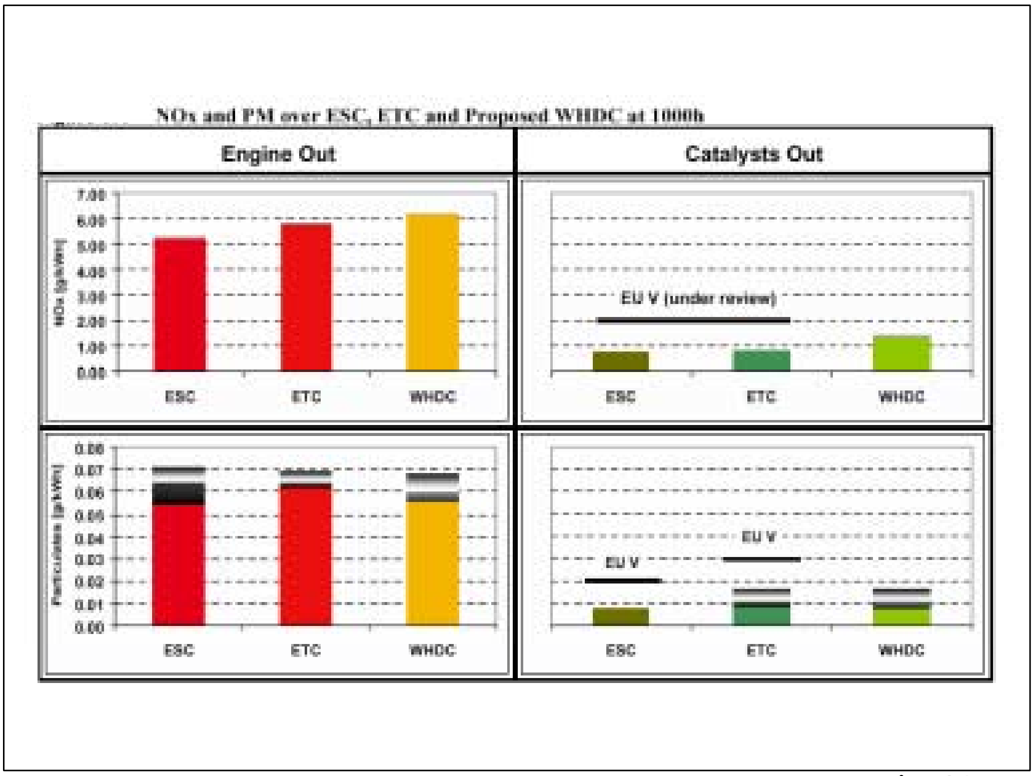

NOx and PM over ESC, ETC and Proposed WHDC at 1000h
Engine Out
Catalysts Out
NOx [g/kWh]
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
ESC
ETC
WHDC
EU V (under review)
Particulates [g/kWh]
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
EU V
EU V

Fig. 31

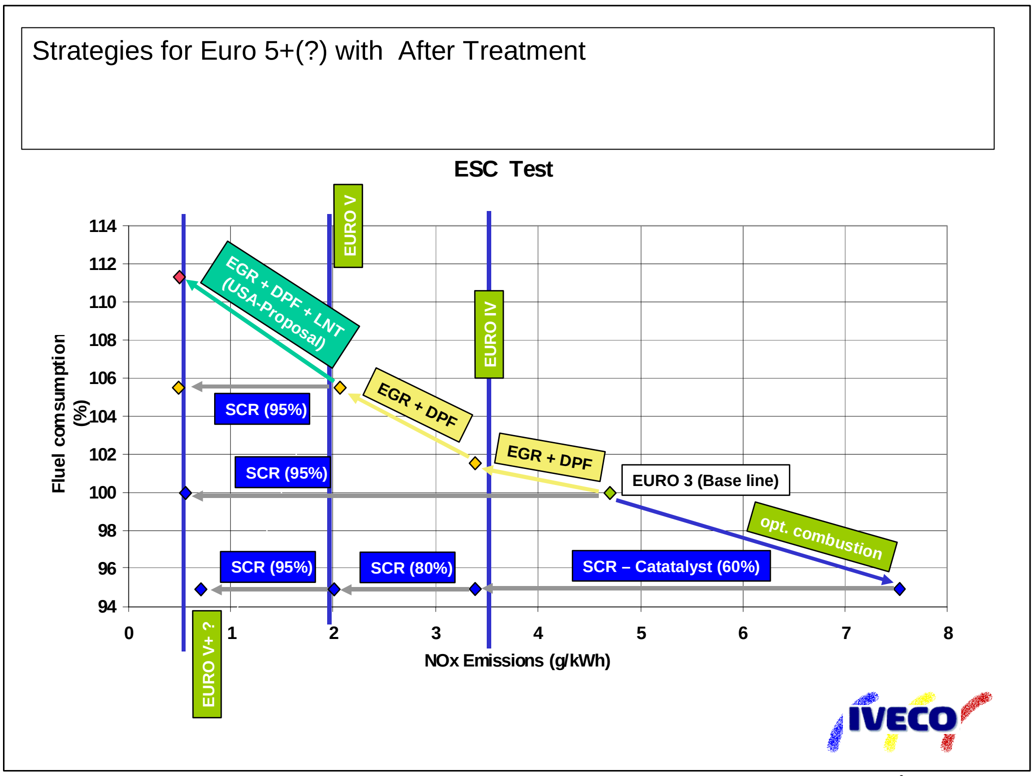

Strategies for Euro 5+(?) with After Treatment
ESC Test
Fuel comsumption (%)
NOx Emissions (g/kWh)
EURO V
EURO IV
EURO V+ ?
EGR + DPF + LNT (USA-Proposal)
EGR + DPF
EGR + DPF
SCR (95%)
SCR (95%)
SCR (95%)
SCR (80%)
SCR – Catatalyst (60%)
EURO 3 (Base line)
opt. combustion
IVECO

Fig. 32

4.2 Controlling particulate emissions

The developments towards reducing particulate emissions from passenger cars and commercial vehicles must be considered separately. The information relates to the usual type testing procedure and test cycles at ambient temperature. An aspect that has barely been considered comes into play at a considerably reduced emission level: particulate emissions at low temperatures. Like the trend for petrol engines, the potential for further improving diesel engines will also have to be sought in this area. This may also apply to particulate emissions by petrol engines.

4.2.1 Diesel passenger cars

The entry into force of the Euro 4 limit value from 2005 will lead to use of particulate trap technology only in certain diesel passenger cars. According to publications by the German auto makers, small- and medium-sized diesel passenger cars with manual transmissions will be able to get by without particulate traps, while diesel cars with automatic transmissions that are medium-sized or larger will probably require particulate traps.

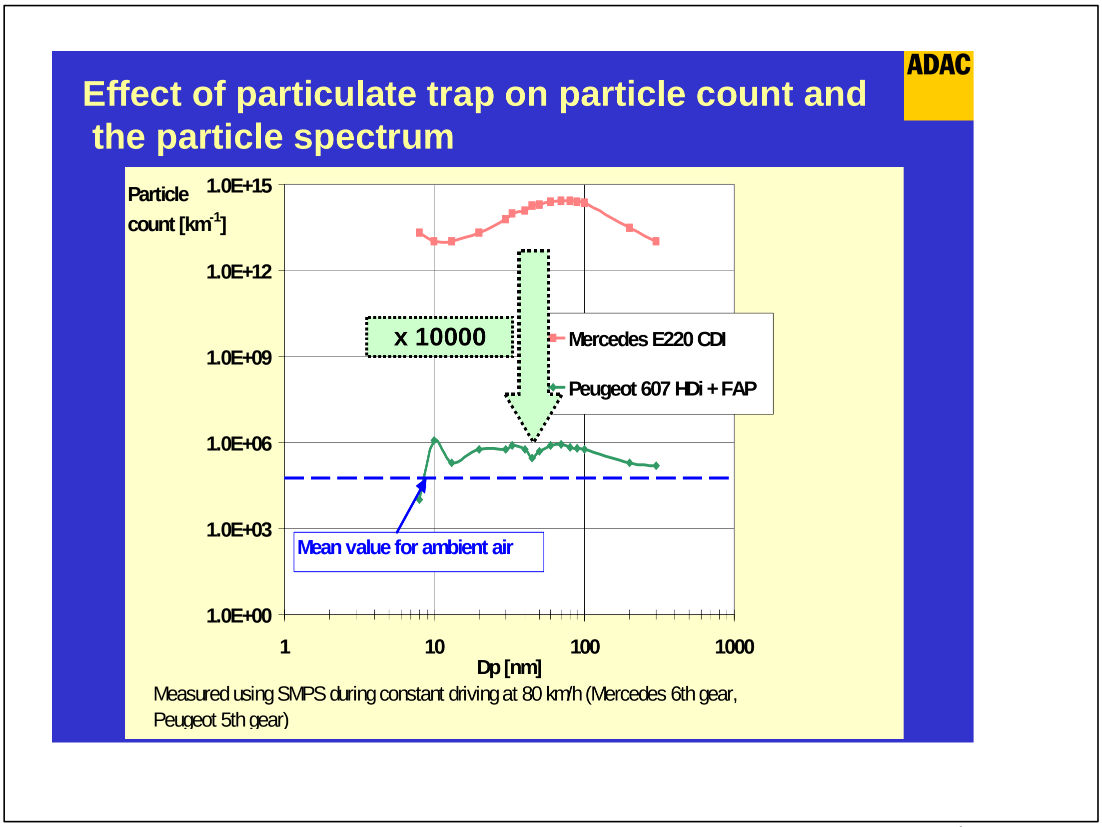


Fig. 33

ADAC, Germany's leading automobile association, has demonstrated that the first diesel passenger car with a series-produced particulate trap has a 99.999% rate of elimination over 80,000 km, i.e. the particulate count is reduced by a factor of 10,000 and the minimum residual particulate concentration in the exhaust gas is at the level of the ambient air (**Figure 33**).

According to measurements by ADAC, the Peugeot 607 with FAP has a particulate emission of 0.0010 g/km in the New European Driving Cycle [12]. There is not yet a relevant product for retrofitting diesel passenger cars, aside from individual products offered by small supplier companies.

The first series-produced particulate trap system for passenger cars by the PSA group (FAP) has been delivered in the following quantities:

Registration figures for Peugeot cars and Citroen cars with the FAP particulate trap system in Germany (up to and including 9 July 2002):

Germany	2001	2002 (first half of the year)	Total
Peugeot 307 (since August 2001)	5,179	5,412	10,591
Peugeot 406 (since July 2001)	2,758	1,881	4,639
Peugeot 607 (since January 2001)	2,152	963	3,135
Citroen C5 (since 2001)	4,596	3,815	8,211
Total	16,686	13,893	26,576

Registration figures for Peugeot cars and Citroen cars with the FAP particulate trap system in Europe (up to and including 9 July 2002):

Europe	2001	2002 (first half of the year)	Total
Peugeot 307 (since August 2001)	31,551	58,682	90,243
Peugeot 406 (since July 2001)	22,527	9,481	32,018
Peugeot 607 (since January 2001)	24,254	9,973	34,227
Citroen C5 (since 2001)	36,389	16,640	53,029
Total	116,722	96,798	209,517

The PSA Peugeot Citroën group sold about 135,000 vehicles with FAP technology internationally in 2001 and around 270,000 in 2002; by spring 2003 they had sold 400,000 such vehicles. PSA is expecting around 1 million registrations of vehicles using FAP technology in 2004-2005.

FAP technology therefore defines the state of the art and the possibility of setting limit values on that basis. Particulate trap systems are ready or almost ready for series production by nearly all manufacturers of diesel passenger cars. The trap systems differ less with regard to their high rate of elimination, which can be achieved without difficulty, than with regard to the regeneration processes they use. The time of series introduction, which could occur well before the Euro 4 limit values enter into force, will be determined less by technical aspects than by the decisions of manufacturers or manufacturer associations based on market strategies and political motivations.

According to statements by individual manufacturers, a tax incentive could provide a major impetus.

According to German Federal Environmental Assistance (DUH) and various press releases, the following types of passenger cars were available with particulate traps in May 2003:

Peugeot	807	HDI 2.2 l 94 KW (128 HP)
		HDI 2.0 l 79 KW (107 HP)
	607	HDI 2.2 l 89 KW (133 HP)
	406	HDI 2.2 l 89 KW (133 HP)
		HDI 2.0 l 79 KW (107 HP)
	307	HDI 2.0 l 79 KW (107 HP)
Citroën	C5	2.0 HDi FAP 79 KW (107 HP)
		2.2 HDi FAP 94 KW (130 HP)
	C8	2.0 HDi FAP 79 kW (107 HP)
		2.2 HDi FAP 94 kW (128 HP)
Fiat	Ulysse	2.0 JTD FAP 80 KW (109 HP)
		2.2 JTD FAP 94 KW (128 HP)
Lancia	Phedra	2.0 JTD FAP 80 KW (109 HP)
		2.2 JTD FAP 94 KW (128 HP)

According to various press releases, the following diesel cars with a particulate filter, most of which comply with Euro 4, are to be launched on the market in summer or autumn 2003 for the International Automobile Fair (IAA) in September:

Peugeot	Two other models with the following engines have been announced:	
		1.6 l 80 KW(109 HP) FAP and EURO 4
		2.0 l 100 KW (136 HP), FAP and EURO 4
Renault	Mégane	1.9 dCi (versions with 120 HP and 140 HP)
	Scénic	1.9 dCi (120 HP)
	Laguna	2.2 dCi (150 HP)
	Espace	2.2 dCi (150 HP)
	Vel Satis	2.2 dCi (150 HP)
Toyota	Avensis D-Cat	
Audi	A4	2.0 TDI, 140 HP
BMW	530d	

Ford	Focus C-Max	1.6 TDCi, 110 HP
		2.0 TDCi, 136 HP
Mercedes	C 200 CDI	125 HP
	C 220 CDI	145 HP
	E 200 CDI	
	E 220 CDI	
Opel	Vectra	1.9 DTI, 150 HP
Volkswagen	Passat	2.0 TDI, 140 HP
	Tuareg	
	Phaeton	

Several manufacturers have said provisional that particulate traps will add between €300 and €800 to their vehicle prices. It must be emphasised that these are market prices and that the real added costs are much lower based on larger quantities and series production. Depending on the technical effort required by the various systems, the real additional costs range from €150 to €300, according to the German Federal Environmental Agency. If the vehicles have particulate traps as standard equipment, as is the case at Peugeot, a higher price will not be charged.

4.2.2 Direct-injection petrol engines (GDI, FSI)

Direct-injection petrol engines have an internal mixture formation that is similar to a diesel engine; they also have a lean combustion in broad characteristic curve ranges similar to that of diesel engines. Therefore, particulate emissions similar to those from a diesel engine can occur, as has already been demonstrated by measurements reported in several publications. Because there will be a sharp increase in the number of passenger car models with direct-injection petrol engines in the future, they must be taken into account when updating particulate limit values. As mentioned in the introduction, the Council has asked the Commission to examine this.

A Swedish study shows, for example, that particulate emissions from passenger car models with direct-injection petrol engines can, under certain operating conditions, be at the level of diesel cars without particulate traps [13] (**Figure 34**).

Back in July 1997, the Mitsubishi Carisma 1.8 GDI, which had just been introduced, was tested for pollutant emissions at the technical authority RWTÜV in Essen, Germany. The particulate emissions in the New European Driving Cycle prescribed under 91/441/EEC were between 0.0045g/km and 0.0076 g/km; the mean value was 0.0056 g/km. That value is about twice the Euro 5 proposal, which is discussed in greater detail below.

To a great extent, the design of the engine determines whether a relevant particulate emission is produced and in what characteristic curve ranges it occurs. Whether a relevant particulate emission occurs during type testing in the New European Driving Cycle under a relatively low load also depends on engine design, among other things. Particulate emissions similar to those of diesels must be expected, at least under operating conditions with a high load and outside of the type testing cycle.

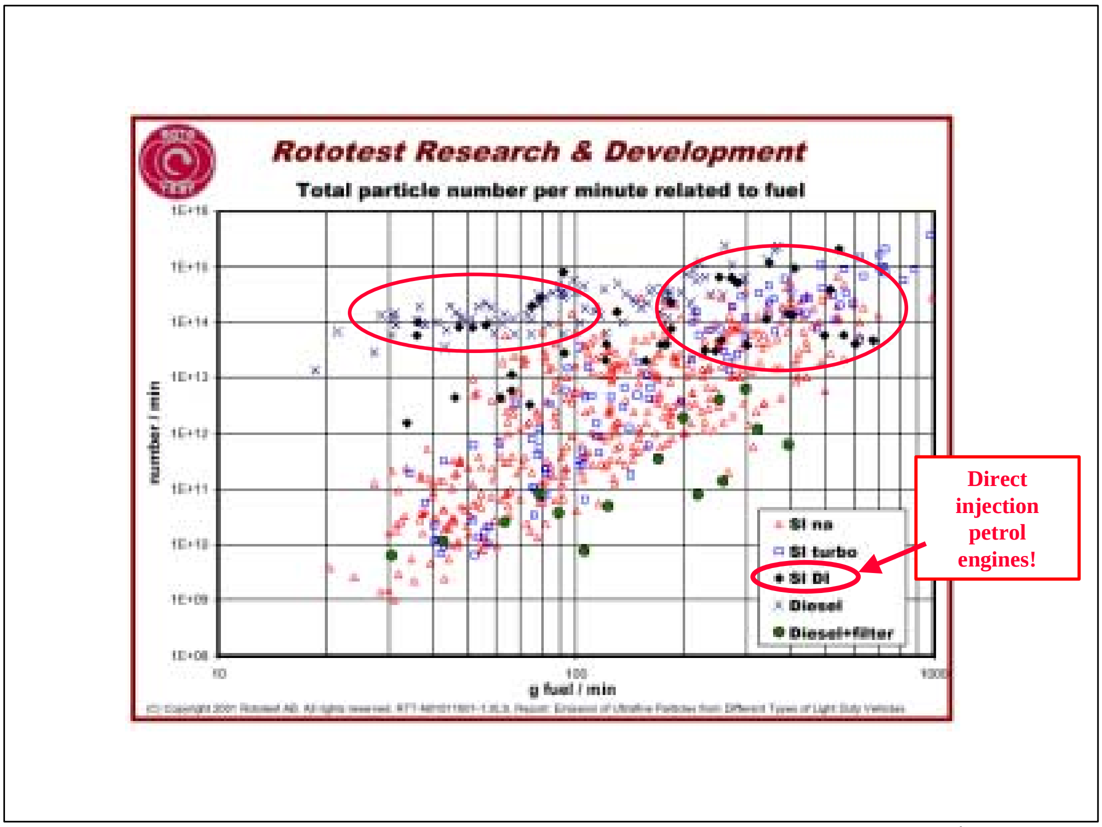


Fig. 34

Fundamentally, control of particulate emissions by direct-injection petrol engines should be required using the same processes and based on the same limit values as for diesel engines. There is no reason for a direct-injection petrol engine to be allowed a higher limit value than a diesel engine.

4.2.3 Heavy-duty engines

Further developments for the future Euro IV limit value can be assessed as follows:

Technical solutions involving particulate traps, which fall far below the limit value for particulates, and technical solutions that use catalysts to reduce nitrogen oxide, taking advantage of the reverse correlation of particulate and nitrogen oxide emissions so they can remain just below the particulate limit values, are to be expected for heavy-duty engines. It is not yet apparent what market share each technical solutions can be expected to have, and this will not become clear until one or two years after the Euro IV – or Euro V – limit values enter into force, if early use is not pushed by subsidies or other measures. With the expected use of NOx-SCR catalyst systems, engines will also comply with the Euro 5 particulate limit values by using the reverse correlation of particulate and nitrogen oxide emissions.

It is currently doubtful whether the intention of the European Environment Ministers of implementing particulate trap technology with the limit values for heavy-duty engines in Euro IV and Euro V, which they declared when approving Directive 99/96/EC, will be fulfilled. We assume for the moment that from 2005 about 30% of new registrations will be for commercial vehicles with effective particulate traps. However, it can also be seen that exhaust gas recirculation in conjunction with an oxidation catalyst can be sufficient for compliance with Euro V, depending on the initial state of the engine. Manufacturers that are planning such a system will necessarily neglect the implementation of particulate traps if signals are not sent or decisions made in sufficient time indicating that Euro V will include lower limit values.

Particulate trap technology is available. Back in the early 1990s, it was successfully tested on 1,100 city buses as part of large-scale soot trap trial by the German Federal Ministry of the Environment. After comprehensive testing of their suitability by public agencies in Switzerland (BUWAL [Swiss Agency for the Environment, Forests and Landscape] and SUVA, a major provider of compulsory accident insurance), many particulate trap systems have been authorised for retrofitting on construction equipment and their use is now mandatory at construction sites [14].

According to the Association of German Transport Providers (VdV), approximately 5,000 city buses have been retrofitted with particulate trap systems. Most of these use the CRT (continuously regenerating trap) system, which is particularly appropriate for retrofitting thanks to its simple design. The BVG, Berlin's public transport authority, has retrofitted around 800 buses, to quote just one example. More than 50,000 commercial vehicles throughout the world are using retrofitted particulate trap systems, and USD 100 million in funding has been approved to retrofit 900,000 diesel vehicles as part of a programme in California.

Particulate trap technology has been available for years now in different constellations (various filter media combined with different regeneration strategies). By 2000, the list of particulate trap systems that had been tested and authorised (placed on the "filter list") by agencies in Switzerland (BUWAL and SUVA) for use in construction equipment – which often has diesel engines similar to those used in commercial road vehicles – already included a total of 36 soot trap systems by 16 manufacturers. Further development relates to optimising the systems for series production with a view to absolute reliability of regeneration, improved durability, longer intervals between maintenance, and minimum exhaust backpressure.

Some exhaust aftertreatment technologies that are aimed at just complying with the Euro IV/Euro V particulate limit value are currently being developed. One of these is the "PM-Cat," an open-pore system ("filterless soot reduction") that uses flow phenomena to eliminate particulates on a metallic honeycomb structure. Its effectiveness ranges from only 20% up to a maximum of 80% depending on operating conditions. The PM-Cat is far from achieving the high rates of elimination of genuine particulate traps [15].

4.3 Limit values for heavy-duty engines in the United States from 2007

In December 2000, the EPA announced phase 2 of the emission standards for heavy-duty engines, which are to enter into force starting in model year 2007 with a phase-in until 2010 [16]. The law was passed in January 2001.

The particulate limit is 0.01 g/bhp-h in combination with an NO_x limit of 0.2 g/bhp-h. There will be a phase-in for the limits starting with 50% of all engines sold in 2007 and ending with 100% of engines sold in 2010. The following can be stated even without more detailed consideration of the correlations between the American dynamic test cycle and the European dynamic test cycle: the NOx limit is less than the Euro V limit value (2.0 g/kWh) by one order of magnitude, and the particulate limit is about one-third of the EURO IV/V limit value (0.03 g/kWh in the ETC).

An integral part of the legislation is that every two years the EPA will publish a progress report on technical developments towards compliance with these limit values. The first report in the series was published in June 2002 [17]. The EPA has also created an Independent Review Panel with 50 members from industry, the sciences, government agencies, and environmental organisations to prepare a report on the topic. The Panel began its work in May 2002 and submitted an initial draft report in September 2002 [18]. The draft reaches the following conclusions concerning technologies to reduce NO_x and particulate trap technology:

"*The Panel found that significant progress is being made to develop NOx adsorbers and catalyzed particulate trap systems for use in diesel engines in 2007. NOx adsorbers and catalyzed particulate trap systems are the primary technologies being developed by engine manufacturers, vehicle manufacturers and aftertreatment manufacturers in North America, Europe and Japan for US applications in 2007. The worldwide focus on a particular technology significantly enhances its potential for success. In each case, the Panel found examples of significant progress that has occurred since the 2007 Rule was finalized in 2001.*

Companies are rapidly moving beyond purely technical issues to address product development issues like fuel economy impacts and "first cost." "First cost " numbers are being discussed as a factor in selecting technology alternatives. Other product development issues, such as reliability, long-term durability, maintenance and fuel economy are also being addressed."

The EPA has held consultations with more than 20 companies and confirms that in its view both particulate traps and NO_x catalysts will be available by 2007 for use in series production. That is also expressed in numerous technical publications by the manufacturers of engines and exhaust aftertreatment systems and by research institutes (such as the Diesel Engine Emission Reduction Conference, San Diego, August 2002), which indicate that the fundamental testing on engine test stands was successful and that development is now entering the series implementation phase.

4.4 The costs of reducing emissions

Estimates of the costs of future emission control technologies and exhaust aftertreatment systems naturally involve many uncertainties, because the unit numbers and – as a function of them – the production technologies that are used are very important. When familiar components or components that have been further optimised are used, cost estimates are relatively simple. Overall, there are very few publications on this subject, and past experience has shown that in reality even optimistic cost estimates were usually considerably undercut later. Generally speaking, information provided by the industry should be understood as market prices. Manufacturing costs are discussed below.

4.4.1 Diesel passenger cars

Many possible combinations of different technical measures can be used to reach a Euro 5 stage for diesel passenger cars which goes beyond Euro 4.

Figure 35 contains a detailed, thoroughly-researched compilation of costs with possible ranges according to a publication by Kolke [36]. A limit value of 0.08 g/km for NOx and 0.0025 g/km for particulates were assumed as Euro 5 standard. According to Kolke, the additional costs for the Euro 5 designs and appropriate combinations of measures to meet the aforementioned limit values range from €200 to €400 per vehicle compared with Euro 4 technology. These costs are considered realistic.

Costs involved in reducing emissions from diesel cars

System components	EURO 2	EURO 4	EURO 5 concepts: PM trap, $DeNO_x$ min.	PM trap, $DeNO_x$ max.	Zeolite, $DeNO_x$ min.	Zeolite, $DeNO_x$ max.	Zeolite, SCR min.	Zeolite, SCR max.	Combination of DeNOx/ PM trap min.	Combination of DeNOx/ PM trap max.
Exhaust gas treatment	65€	65€	65€	65€	65€	65€	65€	65€	65€	65€
Oxidation cat. converter	61€	61€	17€	17€	-€	-€	-€	-€	-€	-€
Higher loading on oxidation cat. converter	-€	18€	18€	18€	-€	-€	-€	-€	-€	-€
SCR cat. converter including dosing unit	-€	-€	-€	-€	-€	-€	139€	153€	-€	-€
Particle trap system	-€	-€	153€	307€	-€	-€	-€	-€	-€	-€
Zeolite cat. converter with reduction agent	-€	-€	-€	-€	128€	153€	128€	153€	-€	-€
DeNOx cat. converter	-€	-€	77€	102€	77€	102€	-€	-€	-€	-€
DeNOx/particle reduction cat. converter	-€	-€	-€	-€	-€	-€	-€	-€	128€	153€
Improvement of combustion chamber geometry	-€	-€	-€	-€	-€	-€	-€	-€	-€	-€
Increase the injection pressure (not always quantifiable)	-€	-€	-€	-€	-€	-€	-€	-€	-€	-€
Improved exhaust gas return	-€	-€	36€	46€	36€	46€	46€	46€	46€	46€
Complete exhaust gas system	**126€**	**145€**	**366€**	**555€**	**305€**	**367€**	**378€**	**418€**	**239€**	**264€**
Complete exhaust gas system (with trap replaced at 80,000km)					382€	459€	455€	510€	316€	356€
Additional costs compared with EURO 2		18€	240€	429€	179€	240€	252€	292€	113€	138€
Additional costs compared with EURO 4		-	221€	411€	161€	222€	234€	273€	94€	120€

Source: Kolke, 2003

Fig. 35

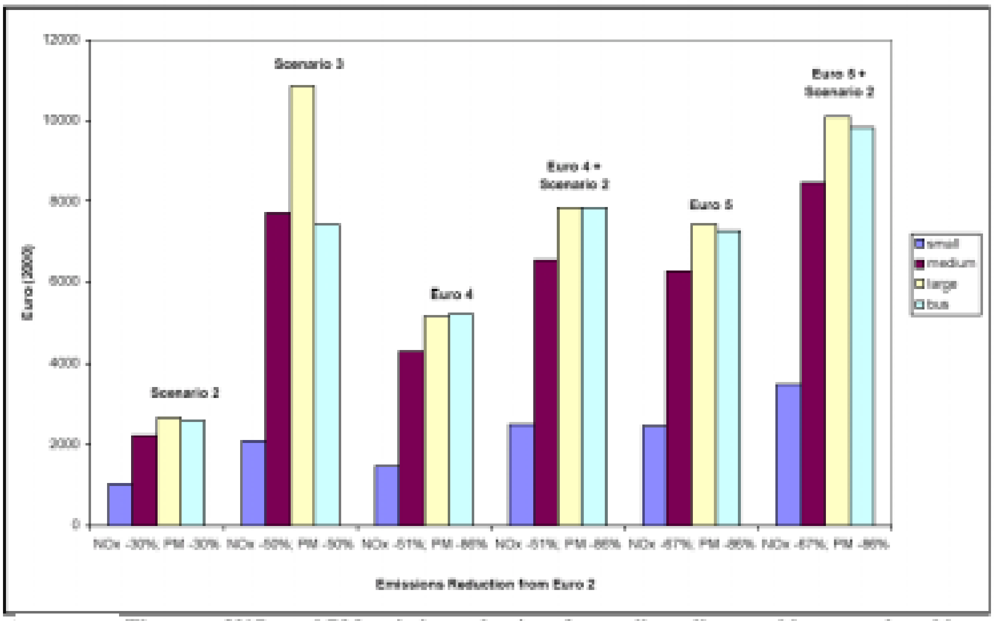
4.4.2 Heavy-duty engines

Several research institutes were appointed by the EU Commission to prepare a joint study of the costs of various emission control technologies and exhaust aftertreatment systems for heavy-duty engines [19]. The study, which was published in 2002, is based on a survey of commercial vehicle and engine manufacturers and the supplier industry. The questions concerned the technologies necessary for compliance with future limit value stages up to and including Euro V. The results of the study are discussed here because the same technologies are also appropriate and necessary to achieve more ambitious objectives for emission control and limit values without substantial added costs compared with the Euro V design. The study reaches the following conclusions:

"…These technologies (…to meet EURO 4 standards….) are likely to add between €1,000 and €7,000 to the cost of new truck engines compared with the current product, and fuel consumption is estimated to increase by about 3%, except where SCR is used on its own. Under this scenario fuel consumption is predicted to decrease by about the same amount. Based on data supplied by component suppliers the lower range of this cost estimate could be more realistic for volume production.

The technologies required for Euro 5 are likely to add a further €1,000 to €3,500 to the cost of an engine compared with the Euro 4 product. The widespread use of SCR will result in a reduction in fuel consumption of 3 to 5% compared to current production engines…..”

The costs derived for various scenarios and engine sizes are shown in **Figure 36**. According to our estimate and given the interests of the manufacturers, this data from the commercial vehicle and engine manufacturers, which indicates costs between €4,000 and €10,000 per vehicle for the most extreme scenario, should be considered market prices.



The cost of NO_X and PM emission reductions for small, medium, and large truck and bus engines

Fig. 36

The report [19] contains a separate table that also shows costs based on information from suppliers to the automotive industry, which in our view is realistic based on series production of large quantities.

Cost of individual components*

Technology	*Cost range €*
Diesel oxidation catalyst	290-820
Continuously regenerating filter (without oxidation catalyst)	240-650
Catalysed soot filter	880-2250
Selective catalyst reduction	340-2500
'Cleanup' oxidation catalyst	100-290

* Some of these costs are for the substrates and coatings only and do not include the cost of fitting such as stainless canning, injectors, backpressure monitors etc. Therefore it is expected that these will be significantly lower than the OEMs costs

We therefore assume that the added costs for emission control going beyond Euro V and the necessary exhaust aftertreatment systems, which substantially represent a further improvement to the systems necessary for Euro V, would be between €1,500 and €3,000 compared with a Euro III engine, depending on engine size and subject to series production in large quantities.

4.5 Conclusions

Within the framework of calculations for the planned measures to be taken by the German federal government to comply with NEC Directive 2001/81/EC, it has been shown that cutting the Euro V limit value for heavy-duty engines in half again to 1.0 g/kWh is the measure with the absolute maximum potential for reducing NOx. A further reduction to 0.5 g/kWh should follow at the time of entry into force in 2010. The development of the corresponding emission control technology has made a great deal of progress and will be available in sufficient time before 2008 and 2010.

Updating the particulate limit values in a Euro 5 standard for passenger cars and adapting Euro V, as well as a subsequent standard for heavy-duty engines from 2010, is necessary for health-related and ecological reasons and is technically feasible with regard to the individual measures.

One important technology for reducing particulate counts by several orders of magnitude, the particulate trap, has been introduced for series production of passenger cars and will soon be available for series production of commercial vehicles. However, it is not yet certain whether introduction of this effective technology can be ensured merely by further reducing the mass-based limit values.

With regard to heavy-duty engines, it is conceivable that exhaust gas recirculation in conjunction with an oxidation catalyst may be sufficient for compliance with Euro V, depending on the initial state of the engine. Manufacturers who adopt such a system will necessarily neglect the implementation of particulate traps if signals are not sent or decisions made in sufficient time indicating that limit values under the Euro V and subsequent standards will be lowered.

The additional costs for Euro 5 designs in diesel passenger cars and the appropriate combinations of measures to comply with the aforementioned limit values are estimated to range between €200 and €400 per vehicle compared with Euro 4 technology. The additional costs for emission control for heavy-duty engines going beyond the approved Euro 5 stage and the necessary exhaust aftertreatment systems, which substantially represent a further optimisation of the systems needed for Euro V, would be between €1,500 and €3,000 compared with the Euro III engine, depending on engine size and subject to series production in large quantities.

According to assessment of independent experts and the conclusions of the EPA, developments in the United States towards compliance with the limit values that are to take effect from 2007 show that the necessary technologies will most likely be available in sufficient time for use in series production. Even if the combinations of future NOx and particulate limit values differ in the U.S. and Europe, it must be assumed that the same technologies – albeit in different constellations – will be able to fulfil requirements in both the U.S. and Europe.

A study conducted for the EU Commission by several well-known European research institutes reached the following conclusion concerning heavy-duty engines [19]:

"The technology to meet both the Euro 4 and 5 emission standards exists although no common approach emerged from the literature review or the manufacturers' survey. The most likely solutions are EGR with DPF and DOC; SCR on its own; and SCR with DPF (with DOC), possibly with advanced turbocharging. Each has its own advantages and disadvantages. It is extremely unlikely that any EU manufacturer will use NOx adsorbers, the regulators preferred solution in the US. ……………………

Current expectations are that SCR will be universally used to meet the Euro 5 requirements. Most manufacturers expect to use it in combination with DPF and DOC, possibly with advanced turbocharging. One manufacturer expects to use SCR on its own with no other after-treatment device. A few manufacturers expect to combine SCR with EGR, but in general EGR on heavy duty engines is likely to be only a short lived interim technology. ……………….

This study did not explicitly address the potential for further reductions in emissions beyond those mandated in the Euro 5 requirements. However, results from a recent AECC study suggest that it may be feasible with currently available technology to meet emission limits approximately half the Euro 5 limits, although there may be a fuel consumption penalty."

As mentioned above, reducing CO and HC emissions will not be discussed in greater detail here. If catalytic exhaust gas aftertreatment systems are used in commercial vehicles the way they are used in diesel passenger cars, a further reduction of CO and HC emissions by at least one order of magnitude will occur almost automatically.

Upshot:
It is necessary for reasons of health and technically feasible to reduce particulate limit values in a Euro 5 stage for cars and light-duty commercial vehicles by a factor of 10 from Euro 4 levels and adapt the Euro V stage for heavy-duty engines accordingly, as well as to reduce the NOx emissions from diesel passenger cars to the level of petrol cars in a Euro 5 stage. The required emission control technology is realisable until 2005. Therefore starting in 2005 the market introduction can be supported by incentives in the circulation tax. Germany is of the opinion that according to political agreements with France standards for the further reduction of NOx and particulate emissions for diesel passenger cars should be implemented in due time. These standards should be made obligatory starting 2010. Beyond it is ecologically necessary and technical feasible to adapt the NOx limit value of the Euro V stage for heavy-duty engines to 1.0 g/kWh, and further reduce it to 0.5 g/kWh from 2010. The additional costs of a Euro 5 design for diesel passenger cars ranges from €200 to €400 per vehicle compared with Euro 4 technology; the additional costs for heavy-duty engines going beyond Euro V will be between €1,500 and €3,000 compared with the Euro III engine.

5. Methodological approach to limiting particulate emissions

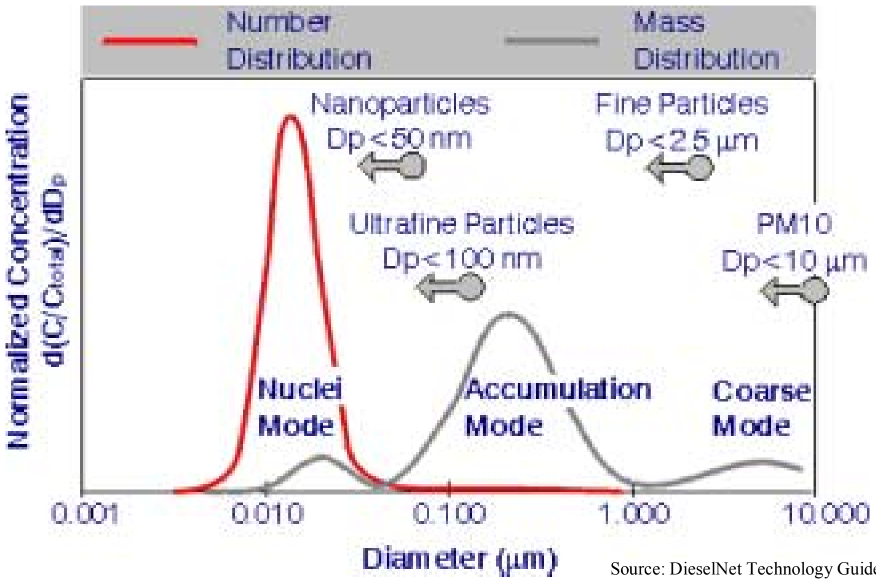
The total mass of particulate emissions in exhaust gases primarily contains the following fractions according to the applicable legal definition in the type approval testing (**Figure 37**):

- Nanoparticulates (nucleation mode) having a diameter of less than 100 nm occur most frequently in terms of number, but due to their low mass make up only a small portion of the total particulate mass.
- Agglomerated particulates (accumulation mode) having a diameter greater than 100 nm account for only a small portion of the particulate count, but they constitute most of the mass.

Assuming that a specific effect is to be attributed to every respirable particle with a diameter of less than 0.5 μm, then for reasons of health protection it is important to reduce the particulate count, which does not have a fixed relationship to the particulate mass. Conversely, it will not be sufficient in future to reduce the particulate mass in order to reduce the particulate count effectively and to the same extent. For example, the particulate mass can currently vary by a factor of 6 while particulate counts remain the same, and based on the same particulate mass the particulate count can vary by a factor of 2, as shown by comparative measurements on passenger cars done for the ACEA [20] (**Figure 38**). It is possible to considerably reduce the mass of particles by reducing the agglomerated particles, while at the same time the large number of nanoparticulates are barely reduced.

A further reduction in mass-based particulate limit values, for example by a factor of 10, is sufficient in principle to achieve the objective of protecting human health if effective particulate traps or comparable technologies with a high rate of reduction over the entire size range of the particles, including nanoparticulates, are also used. To avoid misplaced efforts in the form of technical developments aimed primarily at reducing mass, the particulate count must be controlled in support of measures to limit particulate mass.

With that objective in mind, it would make sense to require the size distribution curve of particulate emissions to remain below a boundary that is set at a very low level, as schematically illustrated in **Figure 39**. That boundary curve would not necessarily have to be a straight line. It could be adapted to the typical path of a particulate size distribution that would be necessary to achieve an effective reduction in the number of nanoparticulates. However, such a limitation would require a measurement method that is appropriate for type approval testing and can be used to determine the size distribution of a particulate count in several size classes. Such measurement methods have previously been available only as laboratory methods in the scientific sector and are unable to fulfil the requirements of a method appropriate for type approval testing, as has now been demonstrated by the Particulate Measurement Programme (PMP) of ECE-GRPE, which is described below.



Source: DieselNet Technology Guide 1999

Fig. 37

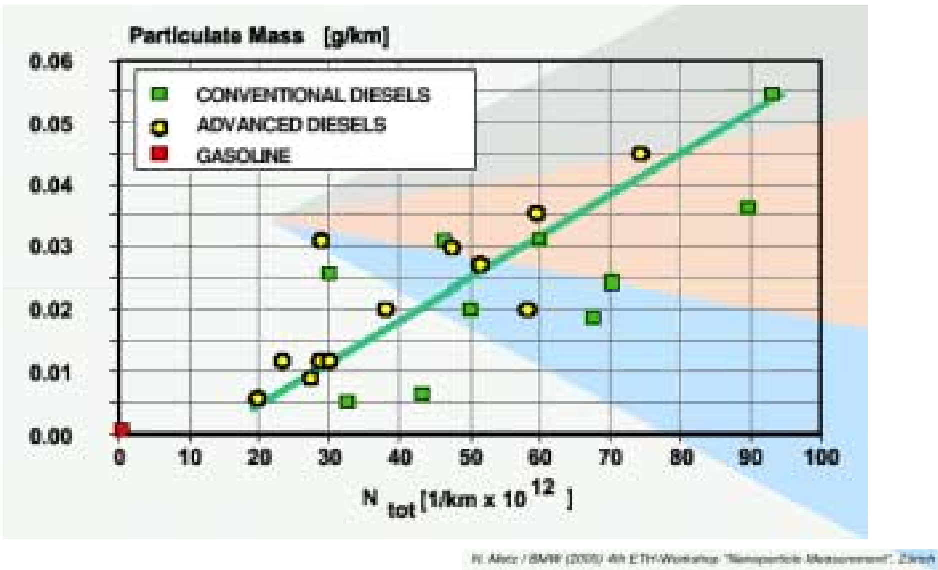


Fig. 38

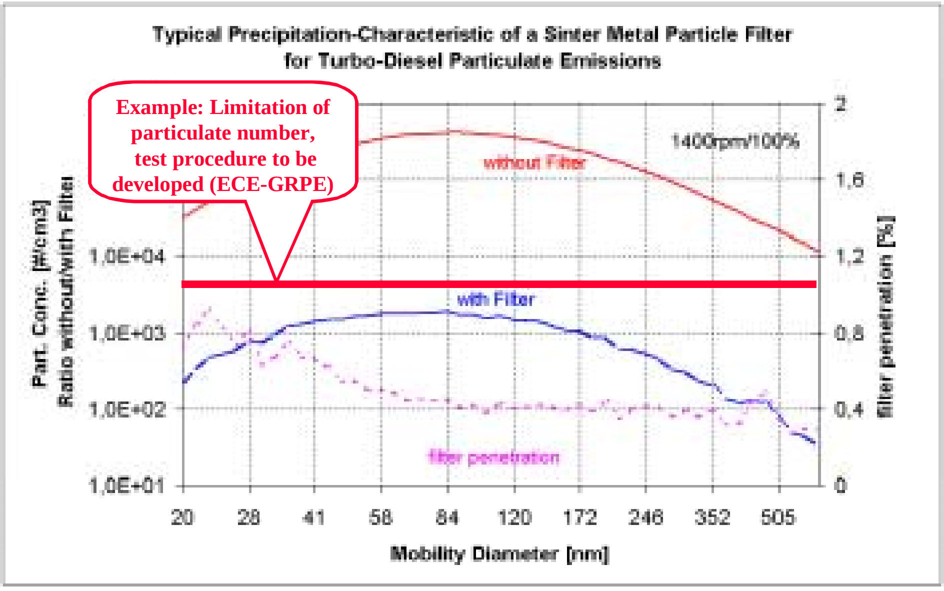


Fig. 39

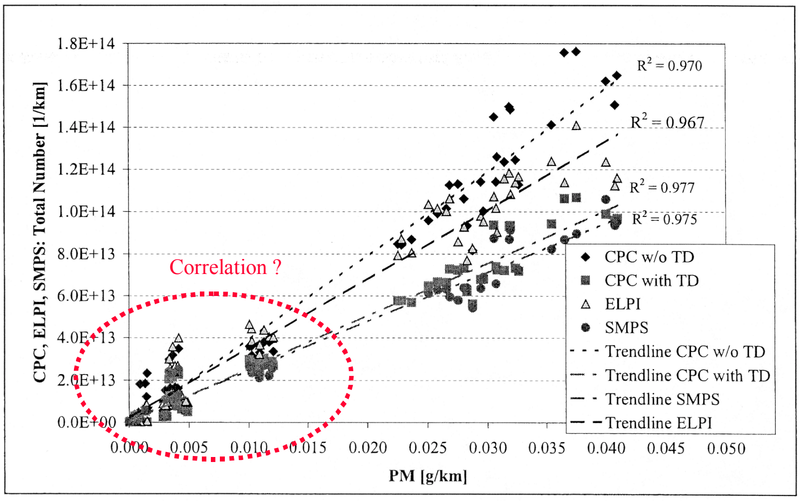


Figure 1: *Correlation between CPC w/o & with TD, SMPS, ELPI and PM of all 7 gasoline and diesel vehicles for* ***NEDC2000 & steady state tests*** *in the ACEA programme II.*

Source: ACEA, 2002

Fig. 40

Particularly in the range of the lower particulate emissions that are envisaged in the future, which are all-important here, there is no inevitable or physically-caused relationship between particulate mass and the particulate count, and exhaust gas aftertreatment systems can have an additional influence on that relationship. **Figure 38**, which is from a measurement programme carried out on behalf of ACEA, also shows the effect that the measurement system used can have on the quantity and quality of the measured particulate emission [21].

To verify the suitability of mass-based particulate control for the future and to propose a method for particulate control that is more oriented to effects, a Particle Measurement Programme (PMP) experts' group was created at ECE-GRPE level and in co-ordination with the EU Commission. It was chaired by the UK and included participants from many Member States and associations.

5.1 Particle Measurement Programme (PMP)

The following text describes the remit, procedures, and original schedule of the PMP Group in May 2001:

"ECE-GRPE PARTICLE MEASUREMENT PROGRAMME (PMP),
GRPE 42nd , 29 May – 1 June 2001

The GRPE Particulate Measurement Programme (PMP) is a collaborative programme operating under the auspices of the UNECE WP29/GRPE Group. Its focus is on the development of a new approach to the measurement of particles in vehicle exhaust emissions, which may be used to replace or to complement the existing regulated mass based system.

In this context "system" comprises a description of the test procedures, sampling equipment and measurement instrumentation.

To assist in the setting of future limit values for light-duty vehicles and heavy-duty engines, the programme will provide data on the emissions of particles from engines employing a range of advanced technologies, and in particular from different diesel particle filters (DPF), measured using the new PMP recommended test system.

PMP is open to contributions from governments, industry and NGOs who are members of the GRPE.
Literature reviews reporting studies on the health effects and assessing instrumentation, analytical methodologies and the future of particle measurements will be undertaken under several national programmes. The relative importance of particle mass, size, number, surface area, and chemical composition on human health is yet to be decided.

Based on an initial literature study the programme will be divided into the following elements:

Phase I - development of candidate systems

Phase II - testing programme and validation of systems

Phase III - characterisation of advanced technology

TIMESCALE

The programme began in March 2001 and will end in March 2003. It is the intended to:

transmit a formal proposal for a test system(s) to the UNECE in October 2002 for discussion at the January 2003 meeting of GRPE *deliver preliminary data on emission levels from advanced technology to the UNECE in December 2002 for discussion at GRPE*

deliver final data on emission levels from advanced technology to the UNECE in March 2003 for discussion at GRPE."

Most of Phase II of the project had been completed at the time this report was prepared (June 2003), and the conclusions to be reached by the group and the concrete proposals it would make were taking shape. The progress of the work was described as follows in an interim report to the GRPE in May 2003:

"The measurement system evaluation phases of Phases I and II of the government sponsored measurement programmes are now drawing to a conclusion, with potential systems worthy of further evaluation in a round robin test identified. The work on thermodesorbers outlined in the report to the last GRPE session in January 2003 is now in its final stages. ………….

All of the individual reports from the national programmes are nearing completion and work is currently underway on the compilation of a summary report that draws together overall conclusions and recommendations. This will be finalised in the next few weeks once all its constituent reports are completed. The sponsoring Governments will agree its conclusions and recommendations jointly. ……………..

The large number of measurement systems assessed within the government sponsored programmes makes it difficult to summarise all the results succinctly. Therefore this progress report focuses on the results from those candidate systems that offer some potential, based on the available results. The final results will be presented in the report of the national programmes in the coming weeks. The main national programmes came to similar conclusions regarding the best performing measurement systems. ……………

Improvements to the filter method, adopting some of the requirements in the US 2007 procedure for heavy duty engines, has improved repeatability for the low emissions levels tested in this programme, chosen to be approximately representative of future emissions. Whilst there remain some questions to be resolved on some details of the procedure, improving the existing system appears to be the best approach. ……………

One of the measurement systems, CVS + thermodenuder/thermodiluter + CPC, offers the advantage of counting the number of particles and so increasing the overall sensitivity of the measurement procedure. Whilst the medical evidence remains unclear over which metric is responsible for the health impacts observed, it appears prudent to further evaluate the potential of a number based system. ………….

It is recommended that a selection of the measurement systems identified by these work programmes as potential candidate type approval measurement systems be further evaluated in a round robin test.

Based on the results currently available these are:

- *Modified 2007 PM (a gravimetric filter based mass measurement system).*
- *CVS + thermodiluter + CPC (a number based measurement system). "*

The CPC (condensation particle counter) is a system for time-resolved measurement of particle counts (more exactly: particle concentrations in l/cm^3) in the size range relevant in terms of effect. It meets the requirements of type approval testing.

The schedule now anticipates completion of the annexes to the Directives for both procedures by late 2003 and submission to the GRPE in January 2004, after which a round robin test will be conducted on that basis.

5.2 Measurement accuracy that can be achieved using gravimetry

An integral part of the following proposals is a reduction in the particulate limit value for diesel passenger cars to 0.0025 g/km and for heavy-duty engines to 0.002 g/kWh in the ESC and to 0.003 g/kWh in the ETC, each of which would be introduced starting in 2008.

Therefore, it must be asked whether such limit values can be introduced on the basis of a gravimetric measurement method that has been improved from the current level of the Directives, as proposed by the ACEA or OICA among others, with a measurement accuracy that is sufficient to meet the requirements of a type testing procedure.

In the chapter on the possible accuracy of particulate measurement for passenger cars and light-duty vehicles, which is contained in a report dated January 2003 [22], submitted to the PMP working party of GRPE, OICA reaches the following conclusion:

"In order to determine the limit of detection of the entire process (weighing, filter handling, loading, weighing) NEDC-blank tests (tests without vehicle) were performed by DaimlerChrysler). As a result, the LOD is estimated to be 0.025 mg. This is equivalent to approximately 1 mg/km in an NEDC which is 4 % of the Euro-IV emission limit. By further optimisation steps of the gravimetric method (e.g. optimised flow, micro balance with increased accuracy) it will be possible to decrease the LOD to approximately 0.01 mg filter loading.

The mean value of all 10 tests is 0.0002 g/km with a standard deviation of 0.00015 g/km. One contribution to this relatively high standard deviation is from the decreasing "particle-source." Compared with the Euro-IV limit of 0.025 g/km this standard deviation of 0.00015 g/km is less than 1% of that limit value. Tests with very low emission vehicles had smaller standard deviations of about 0.0001 g/km."

Therefore, the vehicle manufacturers confirm that compliance with a limit value of 0.0025 g/km can be verified by measurements with a standard deviation of 0.00010 to 0.00015.

As the leading technical authority, RWTÜV of Essen, Germany, reaches the following conclusion in a letter to the German Federal Environmental Agency dated 12 February 2003:

"Even when the limit values for particulates are reduced to 0.0025 g/km or 0.002 g/kWh / 0.003 g/kWh, particulates can still be measured by gravimetric determination methods. However, it must be kept in mind that both the resolution and the repeatability (from one test to another) and reproducibility (from one laboratory to another) will no longer correspond to the values that were previously common. The variations from individual measurement series may have greatly increased values. Moreover, it is possible that more soluble than insoluble components will be found using gravimetry, particularly when particulate-reducing or carbon-reducing exhaust gas treatments are used. Because soluble portions are frequently not produced until aftertreatment and do not have a linear correlation to the temperatures in the system to be tested or in the measurement technology that is used, greater fluctuations between individual measurements must be anticipated …

To summarise, the following can be stated:

- *Even in the case of extremely low limit values, gravimetry can be used to obtain information about components emitted by the engine which can be collected on the filter medium.*
- *Repeatability, reproducibility, etc. will no longer reach the levels that were previously common.*
- *Changes in procedures or appropriate pre-treatment of samples can still bring about considerable improvements but will require further testing.*
- *With aftertreatment systems that reduce particulates or carbon to very low levels, it will still be possible to evaluate how far below limit value the emissions come on the basis of the current particulate definition. However, the components evaluated using gravimetry will then clearly have a different composition than was previously the case, because it will no longer be possible to detect the emitted carbon sufficiently."*

5.3 Conclusions

Introducing a limitation to the particulate count in addition to limiting mass offers the following advantage: because the mass and the number of particulates do not exhibit a high degree of correlation, the mass criterion would ensure that "large" particulates are controlled, while the number-based criterion would simultaneously reduce the "small" particulates that are relevant due to their effect on health. The mass criterion could perhaps be fulfilled without a particulate trap, but the number-based criterion could not.

Upshot:
A further reduction in the mass-based particulate limit values by a factor of 10 is sufficient in principle to achieve the objective of protecting health, if effective particulate traps or equivalent technologies with a high reduction rate over the entire size range of particulate matter, including nanoparticulates, are also used. To avoid misplaced efforts in the form of technical developments aimed primarily at reducing mass, the particulate count must be controlled in support of measures to limit particulate mass.
The measurement procedure to limit particulate mass to a low level is available (U.S. 2007). Studies by the automotive industry confirm the availability and high degree of accuracy of this improved measurement procedure. The condensation particle counter (CPC), which is needed to support a reduction in the number of particles, will be defined in conformity with the Directive by the end of 2003. That means that introduction for passenger cars within the framework of a Euro 5 stage and an expansion of the Euro V Directive for heavy-duty engines are feasible.

6. Proposals for future legislation on exhaust gas

Sections 6.1 and 6.2 contain the main aspects of the necessary updating of legislation regulating exhaust gases from passenger cars and heavy-duty engines. They are based on limit values for exhaust gases. The previous principle of international legislation on exhaust, which is that limit values are prescribed in the form of results to be achieved, not methods to be used, is retained. Additional elements of legislation on exhaust gases which may need to be introduced or updated depending on the vehicle or engine category include:

- Controlling cold-start emissions and emissions at low temperatures (-7° C)
- Evaporation emissions
- On-board diagnosis (OBD) and on-board measurement (OBM)
- Long-term durability testing
- Requirements for long-term durability
- Emission control outside of the test cycle (off-cycle emissions)
- Field monitoring
- Inclusion of alternative fuels

These additional requirements will not be discussed in detail here.

6.1 Passenger cars and light-duty commercial vehicles

The following principles for updating of Euro 5 exhaust gas limit values can be derived from the above remarks:

- The limit values should be fuel neutral.
- The particulate limit value (mass-based) must be defined at the level of the particulate trap. For example, the Peugeot 607 with FAP, which represents the state of the art, has a particulate emission of 0.0010 g/km according to measurements by ADAC during the New European Driving Cycle. A limit value of 0.0025 g/km would offer a considerable safety margin in that regard and would correspond to a 90% reduction from the Euro 4 limit value.
- A reduction of the mass-based particulate limit values by a factor of 10 is sufficient in principle to achieve the objective of protecting health, if effective particulate traps or equivalent technologies with a high reduction rate over the entire size range of particulate matter, including nanoparticulates, are used. Defined measurement procedures for gravimetric determination of particulate emissions at a low level are available in the United States for use from 2007. To avoid misplaced efforts in the form of technical developments aimed primarily at reducing mass, the particulate count must be controlled to support measures to limit particulate mass and must be announced in sufficient time.
- The NOx limit value for diesel passenger cars should be set at the level for Euro 4 petrol cars, i.e. 0.08 g/km. The summation limit value HC + NO_x for diesel passenger cars is omitted.
- The HC limit value must be considered separately. Assuming that the Euro 4 limit value for diesel passenger cars is 0.25 g/km for NOx and 0.30 g/km for HC + NOx, the HC emission of a diesel passenger car with a high proportion of NOx in the summation HC + NO_x (80 to 90%), due to the principle used, is about 0.03 to 0.05 g/km. Applying the Euro 4 limit value of 0.10 g/km for petrol engines to diesel engines in the Euro 5 standard would allow an effective doubling or trebling of HC emissions from them, which must be viewed critically from an environmental viewpoint given the sharply rising share of diesel passenger cars in the distance travelled. To prevent this, an HC limit value of 0.05 g/km is specified in Euro 5 for both petrol and diesel passenger cars.

- The implementation of these limit values is technically realisable by 2005. According to current EU-directives tax incentives for future exhaust emission limit values can be implemented. Germany is of the opinion that according to political agreements with France standards for the further reduction of NOx and particulate emissions for diesel passenger cars should be implemented in due time. These standards could be used as basis for tax incentives before becoming obligatory starting 2010.

The following additional aspects must be taken into account for light-duty commercial vehicles, although overall the approach will be analogous:

- Up to and including Euro 4, the limit values for passenger cars apply to class I light-duty commercial vehicles. Because the class II light-duty vehicles also include numerous types that are similar to passenger cars and because this class includes both petrol and diesel engines, passenger car limit values should in future also apply to class II light-duty vehicles. A limit value for all pollutant components that is 25% higher than the limit value for Euro II is proposed only for class III light-duty vehicles, which almost exclusively have diesel engines and are designed more like real commercial vehicles than passenger cars.

Figure 41 shows the Euro 5 proposal for passenger cars and light-duty commercial vehicles. To allow a comparison, Euro 3 and Euro 4 limit values are shown in **Figure 42**.

Proposed EURO 5 for passenger cars and light-duty commercial vehicles

Valid from*	**Vehicle class/ group**		**Reference weight RW (kg)**	**CO (g/km)**	**HC (g/km)**	**NOx (g/km)**	**Particulate mass (g/km)**
	Class	Group		**Petrol Diesel**	**Petrol Diesel**	**Petrol Diesel**	
01.01.2010	Passenger cars	-	All	1.0	0.050	0.08	0.0025
01.01.2010	Light-duty commercial vehicles	I	RW ≤ 1305	1.0	0.08	0.08	0.0025
		II	1305 < RW ≤ 1760	1.0		0.08	0.0025
		III	1760 < RW	1.25		0.10	0.0032

* The implementation of these limit values is technically realisable by 2005. Germany is of the opinion that according to political agreements with France standards for the further reduction of NOx and particulate emissions for diesel passenger cars should be implemented in due time and should be made obligatory starting 2010.

Fig. 41

Exhaust limit values for passenger cars and light commercial vehicles up to 3.5 t gross weight (limit values for series production)

Euro 3 (EC-Directive 98/69/EC) *)

Valid from	Vehicle class/ /-group		Reference mass RW (kg)	CO (g/km)		HC (g/km)		NO_x (g/km)		HC + NO_x (g/km)		Particle mass (g/km)
	Class	Group		Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Diesel
01.01.2000	Pass. cars	—	All	2,3	0,64	0,20	—	0.15	0.50	—	0.56	0.05
01.01.2000	Light	I	RW ≤ 1305	2.3	0.64	0.20	—	0.15	0.50	—	0.56	0.05
01.01.2001	commercial	II	1305 < RW ≤ 1760	4.17	0.80	0.25	—	0.18	0.65	—	0.72	0.07
	vehicles	III	1760 < RW	5.22	0.95	0.29	—	0.21	0.78	—	0.86	0.10

Euro 4 (EC-Directive 98/69/EC) *)

Valid from	Vehicle class/ group		Reference mass RW (kg)	CO (g/km)		HC (g/km)		NO_x (g/km)		HC + NO_x (g/km)		Particle-mass (g/km)
	Class	Group		Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Diesel
01.01.2005	Pass. cars	—	All	1.0	0.50	0.10	—	0.08	0.25	—	0.30	0.025
01.01.2005	Light	I	RW ≤ 1305	1.0	0.50	0.10	—	0.08	0.25	—	0.30	0.025
01.01.2006	commercial	II	1305 < RW ≤ 1760	1.81	0.63	0.13	—	0.10	0.33	—	0.39	0.04
	vehicles	III	1760 < RW	2.27	0.74	0.16	—	0.11	0.39	—	0.46	0.06

Fig. 42

6.2 Heavy-duty engines

To adapt the Euro V exhaust gas limit values for heavy-duty engines, it is particularly necessary to make a further reduction in particulate emissions all the way to the level of the particulate trap for the same reasons as for diesel passenger cars. In addition, the NOx limit value for the Euro V standard should be cut in half to 1.0 g/kWh in order to comply with NEC Directive 2001/81/EC, and the NOx limit value should be further reduced to 0.5 g/kWh from 2010.

Directive 1999/96 EC relating to measures to be taken against emissions from heavy-duty engines specifies a Euro V limit value stage that includes among other things an NOx limit value of 2.0 g/kWh for both the stationary and dynamic European test cycle, which will apply as from 2008 for the granting of operating licenses for new engine types and from 2009 to all new heavy-duty engines brought onto the market. Article 7 of the Directive instructs the Commission to examine the available technology for compliance with the NOx limit value for 2008 by 31 December 2002 and where applicable to submit any new proposals in a report to the European Parliament and the Council. That report is also to discuss a further reduction in the Euro V NOx limit value beginning in 2008-2009 or at a later time.

A further reduction in the limit values for CO and hydrocarbons is not urgent according to the current level of knowledge.

The following aspects are to some extent analogous to those for passenger cars:

- The limit values should be fuel neutral.
- It is necessary to cut the NOx limit value for Euro V in half to 1.0 g/kWh in order to comply with NEC Directive 2001/81/EC and to further reduce the NOx limit value to 0.5 g/kWh as Euro VI from 2010.
- A stricter limit value for particulates should be introduced as from 2008 in order to adapt the Euro V standard. The limit value for particulates (based on mass and on the European stationary cycle [ESC] and the European transient cycle [ETC]) must be defined at the "particulate trap level." Because the particulate limit value of 0.02 g/kWh in the ESC and 0.03 g/kWh in the ETC can be fulfilled even without a particulate trap by using an effective exhaust gas aftertreatment to reduce NOx and taking advantage of the mutual dependency of NOx and particulate emissions, the reduction rates of 90% which can reliably be achieved using particulate traps should be applied to those values for the update. That results in 0.002 g/kWh in the ESC and 0.003 g/kWh in the ETC.
- A reduction in the mass-based particulate limit values by a factor of 10 is sufficient in principle to achieve the objective of protecting health, if effective particulate traps or equivalent technologies with a high reduction rate over the entire size range of particulate matter, including nanoparticulates, are also used. Defined measurement procedures for gravimetric determination of particulate emissions at a low level are available in the United States for use from 2007. To avoid misplaced efforts in the form of technical developments aimed primarily at reducing mass, limitation of the particulate count in support of measures to limit particulate mass is necessary and must be announced in sufficient time.
- A transient test cycle for heavy-duty diesel engines is being developed as part of the world-wide heavy-duty certification procedure (WHDC),which in future will be introduced at the EU level along with other new requirements (such as limitation of off-cycle emissions). It is not yet certain when this will occur. There is still no data to provide a basis for discussion of limit values in reference to the WHDC. The limit values proposed below may be adapted for the WHDC later.
- The European Load Response Test (ELR) will not be necessary in the future because it was originally proposed only as a "dynamic supplement" to the stationary ESC and was introduced jointly with the ESC and the dynamic ETC as part of a compromise. It provides no information at very low emission levels.

The proposed limit values are shown in **Figure 43**. **Figure 44** contains the limit values for heavy-duty diesel engines which have previously been approved.

Proposed limit values for emissions from heavy-duty engines

(limit values for series production)

	EURO V 1999/96/EG from 2008/09		EURO VI from 2010	
	ESC	ETC 1), 2)	ESC	ETC 1), 2)
	g/kWh	**g/kWh**	**g/kWh**	**g/kWh**
CO	**1.5**	**4.0**	**1.5**	**4.0**
HC	**0.46**		**0.46**	
NMHC		**0.55**		**0.55**
Methane		**1.1 3)**		**1.1 3)**
NOx	**1.0**	**1.0**	**0.5**	**0.5**
Particulates	**0.002**	**0.003**	**0.002**	**0.003**

1) Additional transient test for diesel engines with exhaust aftertreatment systems
For gas engines transient test only3) For natural gas engines only

Fig. 432)

~~Limit values for exhaust emissions from heavy-duty engines~~

(limit values for series production)

	EURO 0	**EURO I**	**EURO II**	**EURO III**		**EURO IV/V**	
	88/77/EWG	91/542/EWG		1999/96/EWG			
	Since 1988/90	Since 1992/93	Since 1995/96	Since 2000		Since 2005/06 resp. 2008/09 *)	
		1.stage	2.stage	ESC- and ELR-test 1)	ETC-test 2), 3)	ESC- and ELR-test 1)	ETC-test 2), 3)
	g/kWh	**g/kWh**	**g/kWh**	**g/kWh**	**g/kWh**	**g/kWh**	**g/kWh**
CO	**12.3**	**4.9**	**4.0**	**2.1**	**5.45**	**1.5**	**4.0**
HC	**2.6**	**1.23**	**1.1**	**0.66**		**0.46**	**-**
NMHC	**-**	**0**	**0**	**-**	**0.78**		**0.55**
Methane	**-**	**0**	**0**	**-**	**1.6 4)**		**1.1 4)**
NOx	**15.8**	**9.0**	**7.0**	**5.0**	**5.0**	**3.5/ 2.0 *)**	**3.5/2.0 *)**
Particulates	**-**	**0.4**	**0.15**	**0.1**	**0.16 5)**	**0.02**	**0.03 5)**
Soot	**-**	**-**	**-**	**0.8 m^{-1}**	**-**	**0.5 m^{-1}**	

1) Modified/more stringent test procedure for all diesel engines
2) Additional transient test for diesel engines with exhaust aftertreatment systems
3) For gas engines transient test only
4) For natural gas engines only
5) For diesel engines only
*) In Euro 5 (from 2008/09) only the NOx limit value will be lowered from 3.5 to 2.0 g/kWh

Fig. 44

7. Literature

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