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TNO report

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Euro 5 technologies and costs for Light-Duty vehicles
The expert panels summary of stakeholders responses

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Summary

This report is the result of the work carried out under on the Europeans Commission’s call for tender about “Technical support for the Commission DG Environment on the development of Euro 5 standards for light-duty vehicles and Euro VI standards for heavy-duty vehicles” (Reference: ENV.C.1/SER/2004/0039).
A consortium of TNO Automotive in Delft (project leader) in collaboration with LAT from Greece and Ricardo from the UK was selected to carry out the work. The work undertaken evaluates the technologies and associated costs involved to meet possible forms of Euro 5 passenger car emission legislation. The evaluation was initially based on the responses from the MVEG group to a questionnaire sent out by the Commission, asking for detailed technology and costs information related to a number of possible Euro 5 limit values. These responses were bundled by the TREMOVE team and presented to the consortium (Euro 5 panel).

The data supplied to the panel not only contained very little detailed information but also in most cases did not cover all of the costs associated with implementation on vehicles. Running costs and development costs were not supplied at all and are therefore not assessed in this report.

The initial information received therefore proved insufficient to provide detailed technology and costs data for all different Euro 5 scenarios requested by the Commission.

In order to meet the Commissions needs, the panel arranged specific meetings with key respondents to obtain more data to enable a cost model to be built. This model enabled ”scaling” of technologies and costs for several typical vehicle applications (swept volume dependant), based on some specific engine and vehicle data but extended to a range of vehicle classes and engine sizes.

Although the spread in data supplied by different stakeholders was considerable, by taking into account their baseline technology assumptions (Euro 4) and applying the model developed by the panel, it was possible to develop a technology and cost model that was reasonably consistent with the data supplied to the Commission.

The model was used to predict the costs for minimum and maximum technology solutions to meet the EC specified emission limit values scenarios. These solutions have been based on typical combinations of aftertreatment and internal engine measures. The combinations selected were based on the applicable limit values (for the scenarios) and technologies that were seen to be adequate to achieve these limits, based on the information supplied by the stakeholders to the panel.

The panel is reasonably satisfied with the consistency of the model and associated technologies required for each emissions scenario, and confident that the results are realistic within the assumptions and limitations as explained throughout the report. Key issues and assumptions were:

- the use of costs assumptions for the year 2010 and beyond, based on 2004 costs and production volume data (with the exception of PGM price development and thrifting). This ignores likely changes in costs due to technical progress and mass production;

- the assumption of a 30% price drop for PGM and a 30% reduction in PGM use (thrifting);
- the decision to allocate ¼ of the costs of engine-side measures to Euro 5;
- the fact that the costs and availability of urea (and distribution) for SCR technology on diesel vehicles have not been taken into account;
- very sparse information on N1 vehicles;
- very spare information on durability of NOx after treatment
- not being able to take into account development costs.

Apart from these limitations, the output produced by the panel also needs some further processing before it can be used in the modelling set-up of the CAFE programme. In particular, assumptions will have to be made on:

- the share of lambda 1 and lean burn engines in the 2010+ gasoline sales (the TREMOVE model cannot distinguish between these);
- the trade off between Euro 5 technologies and CO_2 emissions;
- the share of heavy (large) M1/N1 vehicles (the model cannot distinguish these from normal vehicles in the >2l category).

The panel cannot further elaborate on these questions. It will be up to the Commission to decide how to use the information presented here in the impact assessment of a proposal for a Euro-5 standard.

Next the result of the Euro 5 panels work is presented in 3 tables. The tables contain the technology scenario’s for respectively CI, SI Lambda 1 and SI lean technology and the costs associated with complying with the limit value scenario’s.

Table A: CI

CI			Min Technology				Max Technology			
	Limits (mg/km)	Engine Volume (l)	PM Reduction	both	NOx Reduction	costs	PM Reduction	both	NOx Reduction	costs
Scenario 1	PM: 2.5	<1.4	DPF closed	SEIM	Lean Denox cont (SCR)	758	DPF closed	SEIM	Lean Denox cont (SCR)	758
	NOx: 75	1.4-2.0	DPF closed	SEIM	Lean Denox cont (SCR)	920	DPF closed	SEIM	Lean Denox cont (SCR)	920
		>2.0 medium	DPF closed	SEIM	Lean Denox cont (SCR)	1210	DPF closed	SEIM	Lean Denox cont (SCR)	1210
		>2.0 large	DPF closed	SEIM	Lean Denox cont (SCR)	1936	DPF closed	SEIM	Lean Denox cont (SCR)	1936
Scenario 2	PM: 2.5	<1.4	DPF closed	SEIM	-	402	DPF closed	MEIM	Lean Denox store (LNT)	743
	NOx: 150	1.4-2.0	DPF closed	SEIM	-	517	DPF closed	MEIM	Lean Denox store (LNT)	974
		>2.0 medium	DPF closed	MEIM	Lean Denox cont (SCR)	1091	DPF closed	MEIM	Lean Denox store (LNT)	1271
		>2.0 large	DPF closed	MEIM	Lean Denox cont (SCR)	1796	DPF closed	MEIM	Lean Denox store (LNT)	2110
Scenario 3	PM: 8.5	<1.4	DPF open	MEIM	Lean Denox cont (SCR)	630	DPF closed	SEIM	Lean Denox cont (SCR)	758
	NOx: 75	1.4-2.0	DPF closed	MEIM	Lean Denox cont (SCR)	878	DPF closed	SEIM	Lean Denox cont (SCR)	920
		>2.0 medium	DPF closed	MEIM	Lean Denox cont (SCR)	1091	DPF closed	SEIM	Lean Denox cont (SCR)	1210
		>2.0 large	DPF closed	MEIM	Lean Denox cont (SCR)	1796	DPF closed	SEIM	Lean Denox cont (SCR)	1936
Scenario 4	PM: 8.5	<1.4	DPF open	MEIM	-	274	DPF closed	MEIM	Lean Denox store (LNT)	743
	NOx: 150	1.4-2.0	DPF closed	MEIM	-	475	DPF closed	MEIM	Lean Denox store (LNT)	974
		>2.0 medium	DPF closed	MEIM	-	629	DPF closed	MEIM	Lean Denox store (LNT)	1271
		>2.0 large	DPF closed	MEIM	Lean Denox cont (SCR)	1796	DPF closed	MEIM	Lean Denox store (LNT)	2110
Scenario 5	PM: 12.5	<1.4	DPF open	MEIM	Lean Denox cont (SCR)	630	DPF open	SEIM	Lean Denox cont (SCR)	672
	NOx: 75	1.4-2.0	DPF open	MEIM	Lean Denox cont (SCR)	760	DPF open	SEIM	Lean Denox cont (SCR)	802
		>2.0 medium	DPF open	MEIM	Lean Denox cont (SCR)	933	DPF open	SEIM	Lean Denox cont (SCR)	1052
		>2.0 large	DPF open	MEIM	Lean Denox cont (SCR)	1483	DPF open	SEIM	Lean Denox cont (SCR)	1623
Scenario 6	PM: 12.5	<1.4	-	MEIM	-	98	DPF open	-	Lean Denox store (LNT)	559
	NOx: 150	1.4-2.0	DPF open	MEIM	-	357	DPF open	MEIM	Lean Denox store (LNT)	856
		>2.0 medium	DPF open	MEIM	-	471	DPF open	MEIM	Lean Denox store (LNT)	1114
		>2.0 large	DPF open	MEIM	Lean Denox cont (SCR)	1483	DPF open	MEIM	Lean Denox store (LNT)	1798

MEIN = Mild Engine Internal Measures
SEIN = Strong Engine Internal Measures

Table B: SI-Lambda-1

SI lambda 1			Min technology			Max technology		
	Limits (mg/km)	Engine Volume (l)	Aftertreatment	EIM	min costs	Aftertreatment	EIM	max costs
Scenario 1	HC: 50	<1.4	optimized cat		33	optimized cat	optimized engine	156
	NOx: 24	1.4-2.0	optimized cat		55	optimized cat	optimized engine	212
	PM: 2.5	>2.0 medium	optimized cat		82	optimized cat	optimized engine	295
		>2.0 large	optimized cat		132	optimized cat	optimized engine	389
Scenario 2	HC: 75	<1.4	optimized cat		14	optimized cat	optimized engine	137
	NOx: 48	1.4-2.0	optimized cat		24	optimized cat	optimized engine	180
	PM: 2.5	>2.0 medium	optimized cat		35	optimized cat	optimized engine	248
		>2.0 large	optimized cat		56	optimized cat	optimized engine	314
Scenario 3	HC: 100	<1.4	no action	no action	0	no action	no action	0
	NOx: 80	1.4-2.0	no action	no action	0	no action	no action	0
	PM: 2.5	>2.0 medium	no action	no action	0	no action	no action	0
		>2.0 large	no action	no action	0	no action	no action	0
Scenario 4	HC: 100	<1.4	optimized cat		33	optimized cat	optimized engine	156
	NOx: 24	1.4-2.0	optimized cat		55	optimized cat	optimized engine	212
		>2.0 medium	optimized cat		82	optimized cat	optimized engine	295
		>2.0 large	optimized cat		132	optimized cat	optimized engine	389
Scenario 5	HC: 100	<1.4	optimized cat		14	optimized cat	optimized engine	137
	NOx: 48	1.4-2.0	optimized cat		24	optimized cat	optimized engine	180
		>2.0 medium	optimized cat		35	optimized cat	optimized engine	248
		>2.0 large	optimized cat		56	optimized cat	optimized engine	314
Scenario 6	HC: 100	<1.4	optimized cat		14	optimized cat	optimized engine	137
	NOx: 40	1.4-2.0	optimized cat		24	optimized cat	optimized engine	180
		>2.0 medium	optimized cat		35	optimized cat	optimized engine	248
		>2.0 large	optimized cat		56	optimized cat	optimized engine	314

Table C: SI-lean

SI lean			Min technology			Max technology		
	Limits (mg/km)	Engine Volume (l)	Aftertreatment	EIM	min costs	Aftertreatment	EIM	max costs
Scenario 1	HC: 50	<1.4	optimized cat	optimized fueling	70	optimized cat	optimized engine	149
	NOx: 24	1.4-2.0	optimized cat	optimized fueling	98	optimized cat	optimized engine	199
	PM: 2.5	>2.0 medium	optimized cat	optimized fueling	142	optimized cat	optimized engine	276
		>2.0 large	optimized cat	optimized fueling	202	optimized cat	optimized engine	359
Scenario 2	HC: 75	<1.4	optimized cat	optimized fueling	48	optimized cat	optimized engine	126
	NOx: 48	1.4-2.0	optimized cat	optimized fueling	61	optimized cat	optimized engine	162
	PM: 2.5	>2.0 medium	optimized cat	optimized fueling	86	optimized cat	optimized engine	221
		>2.0 large	optimized cat	optimized fueling	114	optimized cat	optimized engine	270
Scenario 3	HC: 100	<1.4		optimized fueling	45		optimized fueling	45
	NOx: 80	1.4-2.0		optimized fueling	56		optimized fueling	56
	PM: 2.5	>2.0 medium		optimized fueling	78		optimized fueling	78
		>2.0 large		optimized fueling	101		optimized fueling	101
Scenario 4	HC: 100	<1.4	optimized cat		25	optimized cat	optimized engine	149
	NOx: 24	1.4-2.0	optimized cat		42	optimized cat	optimized engine	199
		>2.0 medium	optimized cat		64	optimized cat	optimized engine	276
		>2.0 large	optimized cat		102	optimized cat	optimized engine	359
Scenario 5	HC: 100	<1.4	optimized cat		3	optimized cat	optimized engine	126
	NOx: 48	1.4-2.0	optimized cat		5	optimized cat	optimized engine	162
		>2.0 medium	optimized cat		8	optimized cat	optimized engine	221
		>2.0 large	optimized cat		13	optimized cat	optimized engine	270
Scenario 6	HC: 100	<1.4	optimized cat		3	optimized cat	optimized engine	126
	NOx: 40	1.4-2.0	optimized cat		5	optimized cat	optimized engine	162
		>2.0 medium	optimized cat		8	optimized cat	optimized engine	221
		>2.0 large	optimized cat		13	optimized cat	optimized engine	270

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1 Introduction

This report is the result of the work executed under Task 1 of a service contract for the Europeans Commission concerning “Technical support for the Commission DG Environment on the development ofEuro 5 standards for light-duty vehicles and Euro 6 standards for heavy-duty vehicles” (Contract no 070501/2004/381669/MAR/C1).
The work has been carried out by a consortium of TNO Automotive in Delft (project leader) in collaboration with LAT from Greece and Ricardo from the UK. The work deals with the evaluation of the technologies and associated costs involved to meet possible forms of Euro 5 passenger car emission legislation.

1.1 Background

Within the framework of the Clean Air For Europe (CAFE) programme the European Commission is preparing a Thematic Strategy to preserve air quality in Europe in line with the 6th Environmental Action Programme. The process followed should enable the determination of the optimal pollution reduction effort and the role of the main sources of pollution. A number of quantitative models are used to support the CAFE work, including the RAINS model for an analysis spanning all relevant sectors, and more specialised models for some individual sectors. For the transport sector, the latest version of the TREMOVE model (amongst others) will be used.
The results of the model calculations will inform the process of setting new emission standards for vehicles sold in Europe.
The next set of new standards for Light-Duty vehicles (LDV’s) are commonly known as Euro 5.
For setting these new standards in an appropriate manner (emission- and cost effective), detailed information on the availability of emission control technology and associated costs is required.
In order to obtain this information the Commission has send out two questionnaires to specific members of the Motor Vehicles Emission Group (MVEG). The questionnaire asks for information on the necessary technologies and associated costs in order to meet a number of prescribed technology scenarios.

The authors of this report formed an expert panel to analyse the responses to the LDV questionnaire. According to the contract, their task was (subtask 1b):

- forming an opinion on the factual correctness, plausibility and accuracy of the information provided in the responses to the MVEG questionnaire;
- analysing the degree of coherence between different responses received and highlighting any major differences;
- comparing the information received with outside information known to the members of the panel or made available to them by the Commission;
- identifying any significant gaps in the information provided through the responses to the questionnaire, and providing information to fill these gaps in the best possible way;
- communicating the findings of the panel in a report to the Commission.

The present report corresponds to these tasks.

The information received by the Commission in response to the questionnaires has come from several mostly independent sources, making it impossible to use this basic feedback directly as input for the model calculations. Therefore all the inputs have been summarised and checked for reason, degree of coherence and the completeness of the total information received. In order to meet the requirements of several stakeholders when supplying highly confidential information to the EC, confidential treatment of the information to be assessed is a major issue to be taken into account.

Based on the information received and on other available information with the EC, an objective and coherent projection of possibilities and costs to meet the requirements of the submitted scenarios has been established by the panel.
This assessment will in the end lead to a custom fit input for running the TREMOVE model calculations.

1.2 Methodology and activities

Methodology

The key task of the work was to objectively assess a large amount of technical and highly confidential information, and report on the findings in a comprehensive way to the European Commission. This panel consisted of 3 specialists on the topics: engine- and exhaust gas after treatment technology, emission policy and legislation, emissions modelling and testing. The actual team consisted of Raymond Gense from TNO-Automotive (project leader), Neville Jackson from RICARDO and Zissis Samaras from LAT.

This expert panel has reviewed information supplied to them by the EC directly (through the questionnaires output), completed with information directly from the stakeholders. In addition international open literature (papers etc.) was used for confirmation. The result of the assessment of all information is summarised in the folowing report. In order to preserve confidentiality concerning the information made available to the panel, this report at no point presents information from individual stakeholders. The experts have also not used confidential information from other projects executed within their companies.

The methodology used for assessing the information made available has been one of disaggregating the information received, into technical sub packages with typical emission reduction rates and costs linked to each of the sub packages. For this purpose the panel has used a cost detailed calculation spreadsheet, which has been filled with the information received (see appendix C for spreadsheet structure). The end result is a minimum and maximum cost specification for each of the possible legislative scenarios, with certain technology combinations linked to the scenarios.

Actual activities

The activities of the expert panel started after the EC had received back information from the stakeholders in answer to the passenger car questionnaire that was send out before the summer of 2004. The “stakeholders” are “the parties which participate in the MVEG group (Motor Vehicles Emission Group)” of the EC (http://europa.eu.int/comm/enterprise/automotive/mveg). The questionnaire contained specific questions about technologies, costs, durability and additional requirements for meeting 13 emission limit scenarios (7 Spark Ignition and 6 Compression Ignition) using the current type approval procedure as described in 70/220/EC.

Official responses to the EC's request for information were received from ACEA, AECC, AEGPL, Concawe, Honda, Mazda, Nissan, Swedish EPA, Toyota and UBA. ACEA, AECC, Honda, Mazda, Nissan, Toyota and UBA actually replied using the Excel spreadsheet format. AEGPL, Concawe and the Swedish EPA used written documentation to inform the EC about their ideas about Euro 5 limits and costs. In addition to the Excel input and the written statements, additional information was supplied by several stakeholders in the form of relevant papers and notices.
All information received by the EC was handed over to the panel, accompanied by a quantitative (Excel sheet) summary of the information received in the form of spreadsheets returned (draw up by the TML TREMOVE Team). This set of information was the starting point for the expert panels' work.

The next step for the panel was to assess the input on its coherence.
A first assessment of the information made available to the panel showed:

- questionnaires were filled out only partly
- additional (less stringent) scenarios were added
- limited explanations towards the technological background of the input were supplied (probably due the way the questionnaire was structured), but in return additional information exchange was offered by several stakeholders, on condition of strictest confidentiality.
- different angles of looking at the topic from manufacturers and equipment suppliers, leading to gaps in the chain of technologies and assumptions used.

This resulted in a large bandwidth of technologies and related costs in order to fulfil the limit value scenarios under investigation.

At this point the expert panel decided to make use of the additional information exchange offered, and additional meetings between some stakeholders and the expert panel were organised:

- 2 meetings with ACEA (general background of questionnaire response and engine internal measures)
- 2 meetings with AECC (general background of questionnaire response and precious metal prices)
- a meeting with Toyota (general background of questionnaire response)
- a general stakeholders meeting on the 30th of September 2004 (presenting the first findings of the panel to the stakeholders).

All information, ideas and explanations gathered were joined in a detailed technology- and costs spreadsheet, constructed for the purpose of the assessment by the panel. This spreadsheet identified sub-technologies and costs related to vehicle classes (fuel type and swept volume) that could be linked to each other in order to meet certain emission limitation scenario's (see appendix C).
Based on the material provided from the questionnaire, and on more detailed data obtained during stakeholder meetings, the panel were able to prepare specific sets of technology combinations required to meet certain scenario settings. From this analysis the costs related to the technology combinations are calculated. This output is the essential output of the underlying investigation and will be the input for the model calculations for the CAFE process.

In the next paragraphs the details (as far as can be displayed with the confidentiality agreements) of the panels work will be described.

- First the available technologies to further reduce passenger cars regulated emissions form Euro 4 onwards will be described.
- Secondly the current and reference Euro 4 baseline will be described, also taking into account special topics like, CO_2 emission reduction and real world emissions.

Based on this current baseline and available technologies, the selected minimum and maximum technology applications will be described.

2 Technology options for Euro 5 LDV Review of Technologies to Reduce Vehicle Emissions

2.1 Introduction

Significant investments continue to be made by the Automotive Industry and independent research establishments to further reduce vehicle emissions. Emissions reduction is generally a complex area with many interactions between technologies, impact on fuel economy, driving performance and costs and a complete review is beyond the scope of this report. However, this section provides an overview of the key technologies in research and development focusing on current critical issues.

In general, emissions reduction measures can be divided into 2 main areas:

- Combustion system developments to reduce engine out emissions
- Emission control technologies using “aftertreatment” post combustion

For Light-duty diesel engines, the key emissions challenges have generally been NO_x and particulate matter (PM), however, techniques to reduce NO_x and PM often lead to an increase in unburned hydrocarbon (HC) and carbon monoxide emissions (CO) which present additional challenges and can be a limiting factor in how far particularly NO_x emissions can be reduced.

For gasoline engines, emission control technology at present is dominated by three-way catalysis (TWC) which has proved to be very effective. However, this requires the combustion system to operate at stoichiometric (chemically correct) air to fuel ratio, which limits combustion efficiency and can introduce pumping losses at part load. Recent developments to improve combustion efficiency, reduce pumping losses and improve fuel economy through lean or stratified charge operation have required more complex lean emission control technologies to control NO_x and this has been a key area of research in recent years.

2.2 Combustion System Developments

Next the possibilities to reduce emissions by using combustion system developments are discussed. The measures discussed give a general overview of technical possibilities. The actual application of these measures in order to achieve Euro 5 level emissions depends largely on the development strategy of the individual manufacturer. The measures from this portfolio possibly used under the Euro 5 regime are further referred to as Engine Internal Measures (EIM).

2.2.1 Gasoline engine Technologies to Reduce NOx

The main technologies to reduce engine out NO_x from gasoline engines are Exhaust Gas Recirculation (EGR), Variable Valve Timing (VVT) which enables internal EGR and in the future, Controlled Auto Ignition (CAI).

2.2.2 *External Exhaust Gas Recirculation (EGR)*

Exhaust gas can be recirculated in controlled amounts back into the intake of the engine using an external circuit. Dilution of the oxygen/fuel charge with exhaust gas increases the heat capacity of the unburned mixture, reducing combustion or burned gas temperature. The NO_x formation process is highly dependent on the time spent at high temperature during combustion. EGR is effectively, an inert gas and does not react with fuel. As such, it acts as a thermal mass or heat sink and reduces overall temperatures during combustion. EGR is very effective at reducing engine out NO_x emissions but is also associated with an increase in engine out hydrocarbon (HC) emissions. EGR is the most effective and practical method of reducing engine out NO_x emissions in internal combustion engines.

2.2.3 *Internal Exhaust Gas Recirculation and Variable Valve Timing (EGR + VVT)*

If both the inlet and exhaust valves are opened simultaneously at the end of exhaust stroke, the pressure difference between the inlet and exhaust manifolds will generally cause exhaust gas to re-enter the cylinder. This is known as internal EGR. The reduction in engine out NO_x emissions will be less compared to external EGR because the internally recirculated exhaust gas is hotter. Although EGR generally increases HC emissions, this is less with internal than external EGR. The valve train required to achieve internal EGR must be capable of variable valve timing (VVT). If a variable valve train is fitted to the engine for other reasons, such as for an improved torque curve, it is more cost effective to enable internal EGR than fit an additional external EGR system which requires external pipework and control valve. It is less common to fit an EGR cooler to a gasoline engine than a diesel due to the negative impact on gasoline HC emissions

For a naturally aspirated engine, the operating range limit on NO_x reduction with EGR, both external and internal, is that as EGR is introduced, air is displaced and so the maximum load at which EGR can be used is limited. NO_x reduction potential with EGR on a naturally aspirated engine therefore reduces from around 50% at low load to zero at full load without downrating power or torque. NO_x reductions are possible in urban and rural driving with less potential for NO_x reduction in motorway driving, depending on the load factor on the engine, which is a function of the maximum output of the engine relative to the size and weight of the vehicle.

With a boosted engine it is possible to use EGR at higher loads than with a naturally aspirated. EGR is generally not used above about 50% load as this area is generally not encountered during normal driving and would penalise fuel economy through increased pumping losses. Such systems are also expensive to implement with little real world gain in emissions reduction.

2.2.4 *Controlled Auto Ignition (CAI)*

Controlled Auto-Ignition (CAI) is distinct from conventional spark ignition (SI) and compression ignition (CI) engine operating modes. Variants of this combustion type are numerous amongst which HCCI is one.

Combustion initiates simultaneously at multiple sites within the combustion chamber, and there is little or no flame propagation. CAI offers very low NO_x emissions as a result of much reduced combustion temperatures compared with the reaction zone of a SI engine. Stable combustion can be achieved with well optimised residual control with potential for very good fuel economy if part load pumping losses can be minimised. Auto-ignition in CAI combustion is achieved by retention of high percentage of combustion products. It uses conventional air fuel ratio (AFR) range and compression ratio, but requires advanced valve trains.

CAI engines use different valve timings from conventional engines, in order to achieve the required proportion of residuals in the cylinder. The valve train must be capable of short valve opening periods and control of the exhaust valve closure and inlet valve opening. There are three valve train options; lobe-switching and dual cam phasers, fully flexible mechanical valve train and camless valve train. Research has generally reported that neither zero load nor full load are possible with CAI. High load operation is limited by gas exchange and very low load operation is limited by exhaust temperature.

CAI has the potential to reduce the engine out NO_x emissions by a significant amount over a limited operating range. Due to the limited operating range, dual mode operation will be required with convention SI combustion. One of the key challenges for this type of combustion system remains consistent control of residuals to enable stable combustion and the transition from CAI to conventional SI combustion without misfire or changes in noise characteristics. Due to these significant challenges, it is unlikely that a gasoline engine operating in a predominantly CAI regime will appear in the market in the short to medium term.

2.2.5 *Diesel Engine Requirements to Meet Future NOx Emissions Limits*

The most significant challenge in diesel engine development is to cost effectively reduce NO_x emissions without increasing fuel consumption or CO_2 . Reducing engine out NO_x involves achieving more “Highly Pre-mixed and Lower Temperature” (HPLT) combustion. Lean pre-mixed combustion also results in reduced soot emissions (soot is produced when fuel is burned at an excess fuel to air ratio) and this must be combined with high rates of diluent, either excess air, EGR or a combination of both to lower NO_x emissions). The reduction of NO_x by suppressing combustion temperatures causes some significant challenges. In particular, products of incomplete combustion (HC and CO) are increased. This increases the challenge faced by the aftertreatment system. The issue is further compounded by the reduced exhaust temperatures resulting from low NO_x combustion. The strategy therefore results in a compromise between reduced NO_x emissions through lower combustion temperatures and limiting HC, CO emissions. Good control of mixing to provide a favourable local air/fuel ratio is required to minimise soot. Providing the combustion diluent (excess air and EGR must also be provided efficiently to avoid an increase in CO_2 emissions.

To promote highly pre-mixed and lower temperature combustion, developments will be required by all of the engine systems. However, rather than a step change in technology, a number of incremental developments will lead to progressive benefits. In particular the air and exhaust gas recirculation (EGR) systems will require significant improvements in thermal management and control. Operation at increased rates of EGR also leads to challenges in transient driveability, combustion stability and engine durability issues.

Although research work has shown that reduced emissions are possible, practical and robust demonstration, subject to production variation is a much more difficult challenge. To meet lower NO_x levels, a new generation of control systems will be necessary. New sensor technology and advanced model based control must be realised to enable improved combustion control and robustness.

The main technologies to reduce engine out NO_x from Diesel engines are

- Reduced Compression Ratio
- Increased EGR Cooling + Bypass Control
- Advanced fuel injection systems with higher pressures and flexible control
- Increased Flow Range Turbocharging
- Model Based Combustion Control Using New Sensor Technology

2.2.6 Reduced Compression Ratio

Reduction of engine compression ratio from the current production levels of 17-18.5 results in reduced compression pressures and temperatures and increased ignition delay. This trend is a critical enabler for low NO_x combustion. The reduction of compression ratio leads to several challenges. One of which is achieving acceptable cold start operation and high altitude cold driveability, which becomes more demanding. To meet this need, new technology such as ceramic glow plug and intake heating is becoming available. Secondly, HC/CO control becomes more challenging and this will force developments in the exhaust system design. Reducing the compression ratio itself does not effect fuel penalty or CO_2 emissions, but the requirement for example of ceramic glow plugs as a cold start and cold operation enabler does have a CO_2 impact due to an increased electrical power demand under cold conditions for a longer period than conventional strategies. Although this effect will be relatively small (a few percent) in an NEDC cycle, the real world impact could be much larger for frequent short journeys from cold start conditions.

2.2.7 Increased EGR Cooling + Bypass Control

Cooler EGR enables more highly pre-mixed combustion and increased EGR rates as the EGR is more dense, allowing higher in cylinder mass for a given boost pressure. However, low combustion temperatures at light load conditions leads to increased HC/CO emissions. EGR cooler bypass technology enables EGR temperature to be controlled and this is important to manage combustion temperatures.

As described in section 2.2.3, current applications generally do not apply EGR above 10 bar BMEP, typically 50%-60% of maximum torque. However, advanced EGR can be expanded to operate at higher load conditions. This may place added durability requirements on the EGR system. EGR has the potential to reduce engine out NO_x over a wide range of conditions.

2.2.8 *Advanced fuel injection systems with higher pressures and flexible control*

Improvements in EGR tolerance (reduced NO_x without a corresponding increase in PM emissions) can be obtained through improved atomisation by increasing injection pressure and reducing nozzle hole size. However, in combustion system design there is a trade-off between full load and part load operation. Nozzle hole size must be selected so that fuelling at rated power can be maintained within an acceptable crank angle period. Increased injection pressures allow nozzle flow rate reductions to improve part load emissions without sacrificing full load performance as the increased pressure allows use of smaller nozzle holes whilst achieving the maximum injection period allowed at full load. Furthermore, more responsive injectors using Piezo actuated control valves offer the potential to more accurately control injection characteristics and quantity. Improved opening and closing characteristics and up to 5 multiple injections will be beneficial to emissions, fuel consumption and combustion noise through improved mixing and better overall control of injection characteristics. It is likely that most common rail fuel injection systems will offer multiple injection capability and up to 1800 bar maximum rail pressure in production within the next 3 to 5 years.

Innovations in nozzle technology may also provide an opportunity to reduce the compromise between part load and full load operation. In particular variable nozzle area or spray angle offers benefits. Application of narrower cone angle offers the potential to reduce fuel impingement on the cylinder wall during early and late injection strategies. These concepts are at an early development stage and there have been problems in maintaining spray quality with variable area nozzles. As such, it is difficult to predict if and when such concepts could be introduced to the market

2.2.9 *Increased Flow Range Turbocharging*

Advanced turbocharging offers the potential to enhance performance, emissions and fuel consumption. Increased air supply will enable improved full load performance. Part load NO_x emissions can also be reduced through the application of increased EGR. Whilst turbochargers are continuously developed to provide increased flow range to provide high boost levels over a wide flow rate, the most practical approach to significantly enhance air supply in passenger car diesel engines is via Series Sequential (or two stage sequential) turbocharging. This consists of a high-flow turbocharger and a low-flow turbocharger, both of which are waste gated. At low engine speeds the smaller, low-flow turbo responds rapidly and provides most of the engine boost requirement. At moderate engine speeds the larger, high flow turbo begins to respond and the available boost pressure reaches a maximum. At high engine speeds the low flow turbo is bypassed to avoid being choked. With this system, significant control challenges must be overcome in order to achieve acceptable driveability. This technology is complex and expensive to implement. The first application of this technology to the passenger car market has been by BMW in a premium product, the 535D. Use of such systems in the mass market will need significant work in cost reduction.

2.2.10 *Model Based Combustion Control Using New Sensor Technology*

At Euro 4 emissions levels, achieving consistently robust and repeatable results in all production vehicles is a major challenge. If emissions legislation tightens further, robustness control is likely to become the most critical issue. To meet this need, control system developments will be essential. This is likely to be achieved through the combination of new sensor technology and improved processing capability. New sensors will provide direct feedback indicating combustion characteristics to the control system and when coupled with model based control of the air and EGR systems will enable adaptive control of the engine variables. Such systems also provide improved on-board diagnostic (OBD) capability. This technology is at an early stage and significant development is required. Advances in model based control will be an essential enabler for low NO_x strategies which operate much closer to engine combustion limits.

2.3 Emission Control Technologies

This section describes the key functions of current and future NO_x and Particulate emissions control technology. As is the case for the Engine Internal Measures (EIM), the emission control (or after treatment) technologies presented give a general overview of possibilities. The actual application of certain technologies (or combinations of technologies) under the Euro 5 regulations is largely dependant of the individual manufacturers development strategies.

There are two main strategies for NO_x reduction using catalysis; continuous reduction and storage with periodic reduction. Continuous reduction requires a constant feed of reductant whether during diesel or stoichiometric gasoline operation. Periodic NO_x reduction is required for NO_x trap type catalysts either for diesel or lean gasoline applications.

2.3.1 Continuous NO_x Reduction

Continuous lean NO_x conversion can be achieved by using ammonia and a Selective Catalytic Reduction (SCR) catalyst or hydrocarbons and a Lean NO_x Catalyst (LNC) as explained next.

2.3.2 Lean NO_x Catalysis

Hydrocarbon as a reductant is delivered either from the engine or by exhaust fuel injection. To achieve optimum NO_x conversion using hydrocarbons, a HC: NO_x ratio of ~6:1 is required. Therefore, a specific engine calibration or injection of fuel into the exhaust is required to give the desired ratio. Hydrocarbon reduction of NO_x is generally called Lean NO_x Catalysis (LNC). LNC offers a relatively low NO_x conversion efficiency (~10%). To improve the efficiency, non-thermal plasmas can be used to produce a more reactive hydrocarbon based species. The plasma is housed pre LNC and partially oxidises the hydrocarbons, which then react with NO_x over the catalyst. The plasma enables higher NOx conversion efficiencies (~50 – 70% over limited cycles) but has an associated fuel penalty. LNC fuel consumption penalty is generally 2-5% but there is currently no information on the associated plasma fuel consumption penalty. Over an LNC hydrocarbons react with NO_x in the following manner.

$$HC + NO_x + O_2 \rightarrow N_2 + H_2O + CO_2$$

LNC have durability issues and can be reversibly poisoned by fuel and oil sulphur. Degradation will be dependant on fuel and oil sulphur level, as well as thermal influences. Sulphur related poisoning will obviously diminish with low sulphur levels, but is still of concern due to general poor durability of this technology overall.

2.3.3 *Ammonia Based Selective Catalytic Reduction*

Selective catalytic reduction using ammonia as a reductant utilises the injection of urea into the exhaust. The urea hydrolyses to form ammonia and carbon dioxide. Ammonia can also be delivered to the exhaust through ammonium carbamate. Ammonium carbamate ($NH_2CO_2NH_4$) is a solid which sublimes > 60^oC to give ammonia and carbon dioxide.

Over an SCR catalyst, ammonia reacts with NO_x according to the following reactions:

$4NH_3 + 4NO + O_2 \rightarrow 4N_2 + 6H_2O$ (1)

$2NH_3 + NO + NO_2 \rightarrow 2N_2 + 3H_2O$ (2)

$4NH_3 + 2NO_2 + O_2 \rightarrow 3N_2 + 6H_2O$ (3)

Reaction 2 is more facile and occurs at lower reaction temperatures than either reaction 1 or 3. Thus, if the NO_x is present in a 1:1 ratio of $NO:NO_2$, the SCR system will perform with the highest efficiency at low temperatures.

SCR can provide high NO_x conversion efficiencies over a wide operating range (~ 60 - 80%). However, it has a lower temperature limit of ~180 – 200^oC. This may be an issue for light duty applications, where the majority of the ECE part of the NEDC is spent <200°C on most passenger car applications. Packaging may also be an issue for SCR on some smaller vehicles where space is at a premium. Most urban stop start cycles of short duration will not achieve sufficient temperature for SCR light off – similar challenges are faced by LNT and DOC technologies.

Urea may be more acceptable in passenger car applications for customers if urea tank can be sized such that it is only filled at service interval (~20,000km). This removes the problem of the need for a passenger car urea infrastructure and also the need for the customer to refill the tank themselves.

Solid SCR has the major advantage of requiring 28% of the volume of liquid urea to deliver the same mass of ammonia. Therefore, on board reductant storage will be less of an issue with solid SCR. The main disadvantage is that ammonium carbamate sublimes to give ammonia at temperatures >60^oC. This requires the application of a heated container to ensure delivery of ammonia over all climatic driving conditions.

2.4 NO_x Storage with Periodic Reduction

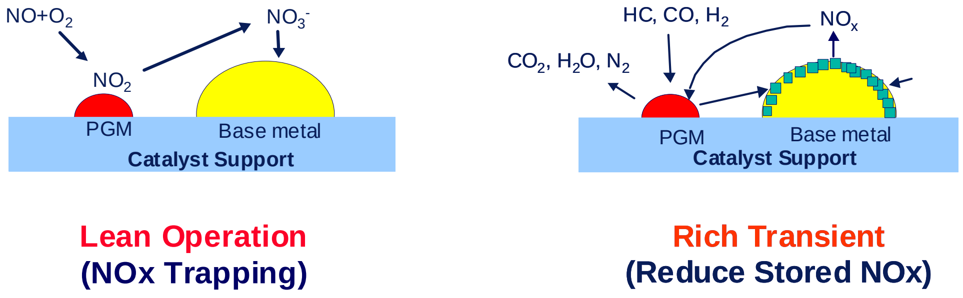
There are two main NO_x storage catalysts currently under development, Lean NO_x Trap (LNT) and Four Way Catalyst (4WC). The LNT can be used for gasoline and diesel applications. The 4WC is being developed primarily for diesel use. The future need for DPF/ 4WC on gasoline cars will be dictated by the ability of future systems to minimise PM formation in terms of mass and possibly number. A 4WC is an LNT formulation coated on a Diesel Particulate Filter (DPF), to provide a one brick solution for NO_x and Particulate Matter (PM) abatement.

LNT and 4WC work on the principle of storing NO_x under lean operation and periodically removing and reducing the stored NO_x. The NO_x is removed by provision of a rich gas mixture, which subsequently reduces the NO_x. The rich gas mixture can be produced in three main ways, from in-cylinder means, exhaust fuel injection and by the application of a fuel reformer. Figures 1 and 2 show the operation of LNT and 4WC.

In-cylinder reductant formation uses a calibration, which changes the injection timing and quantity to produce a rich gas mixture from the combustion chamber. This can have an impact on engine durability, but produces a high quantity of CO, which is a better NO_x reductant than hydrocarbons.

Exhaust injection of fuel into the exhaust system is used to produce a rich gas mixture, which does not interact with the base engine calibration. In this case, neat fuel or partially combusted fuel is used as the reductant. Exhaust fuel injection has a low impact on engine durability but does not provide the optimum gas mixture for NO_x reduction.

The use of a fuel reformer with exhaust injection provides a solution, which provides an optimised reductant but has limited impact on base engine durability. The reformer utilises neat fuel and reforms it into CO and Hydrogen (H_2). CO and H_2 are excellent reductants for NO_x. Fuel reformer technology is in its infancy and development work is required to provide a production ready solution.



Lean Operation
(NOx Trapping)

Rich Transient
(Reduce Stored NOx)

Figure 1 – LNT NO_x Storage and Reduction

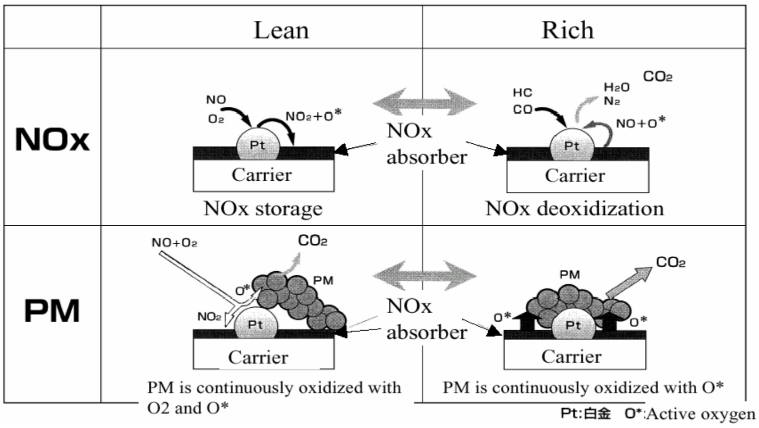


Figure 2 – LNT NO_x Storage and Reduction

The above schematic is published by Toyota and describes the operation of the Diesel Particulate – NO_x Reduction (DPNR) system, which is a type of 4WC.

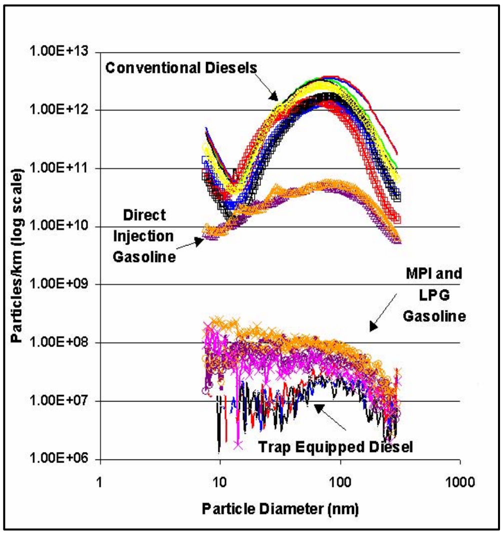
NO_x storage and reduction based catalysts give high NO_x conversion efficiencies depending on temperature (65-80%). Low temperature NO_x storage is limited by NO_2 formation which occurs at ~200^{o}C. The upper temperature limit is a function of the formulation but is in the range 400 – 500^{o}C. NO_x storage and reduction catalysts are reversibly poisoned by fuel and oil sulphur. Any sulphur seen by the LNT will be stored and thus there will still be a need for DeSOx even with low Sulphur fuels and oils. Low Sulphur fuels and oils enable the performance of the LNT to be maintained for longer and hence the period before DeSOx is required is longer – thus minimising fuel consumption associated with DeSOx. Removal of sulphur requires high temperatures of ~650^{o}C and rich conditions. However, high temperatures can thermally deactivate NO_x storage and reduction catalysts. LNT and 4WC have the major advantage that they require no external reductant supply, unlike SCR.
Durability data is scant but there is evidence that more recent LNT formulations are more durable than previously . However there are still serious concerns about the ability of LNT to maintain performance over 100,000km and beyond even with low sulphur fuels.

2.5 Particulate Filter Technologies

There are many potential filter technologies available for production use. They can be divided into the following types, ceramic wall flow, ceramic fibre, ceramic foam, electrostatic, metal non-blocking and sintered metal filters.

2.5.1 Ceramic Wall Flow Filters

The main technology currently used is ceramic wall flow. The ceramic materials commonly used are cordierite, silicon carbide and silicon nitride. The main advantage of ceramic wall flow filters is their high trapping efficiency. Under optimal conditions trapping efficiencies are high (see graph below which is steady state 50kph. However, under other conditions (typically high speed, high load and associated high exhaust temperature, release of large numbers of particles can be seen. These thermally released particles are materials that have previously penetrated and then accumulated downstream of the DPF. These emissions complicate the definition of trapping efficiency which still remains very high for carbonaceous particles.



Ref: DETR/SMMT/CONCAWE PARTICULATE RESEARCH PROGRAMME 1998-2001 SUMMARY REPORT/Jon Andersson; Barbara Wedekind (Ricardo DP 01/515 Unrestricted.)

For the ceramic wall flow filters, controlling regeneration can be assisted by the use of fuel borne catalysts, catalytic coating on the filter or an upstream diesel oxidation catalyst (DOC).

All three-soot regeneration modes are currently in the market. The latter is being used mainly in the retrofit market for passive regeneration using NO_2. Disadvantages of ceramic wall flow filters include exhaust back pressure increase, large volume requirements, packaging constraints and regeneration control.

Fuel borne catalysts (FBC) are added to the fuel. Through the combustion process, the FBC is intimately mixed with the particulate matter (PM) trapped in the filter. The FBC reduces the combustion temperature of the soot. FBC adds ash to the filter, which eventually reduces the filter capacity for PM storage. Current FBC applications require servicing to remove ash from the filter. However, future FBC applications will be service free. This is due to low FBC treat rates and novel filter designs.

Catalysed DPF (CDPF) consists of a ceramic filter coated with a catalytic wash coat. The catalyst wash coat generally contains platinum (Pt) as the precious metal. The catalytic coating reduces the combustion temperature of the soot. The soot combustion temperature is not reduced to a level as low as with FBC. Due to the precious metal requirement for CDPF there is an associated cost increase. Unlike FBC, CDPF is maintenance free as the ash stored in the filter only comes from the lube oil and is at much lower quantities than the ash stored from a FBC.

A DOC followed by uncoated DPF (as in Johnson Matthey CRT applications) uses nitrogen dioxide (NO_2) for soot oxidation. The DOC oxidises nitrogen oxide (NO), as the engine produces mainly NO, to NO_2. NO_2 oxidises soot and is itself reduced to NO. Oxidation of soot with NO_2 requires a high NO_2 to soot ratio. Generally light duty or passenger car applications do not rely on passive NO_2 soot regeneration. DOC-based DPF can lead to an increase in measured road-side NO_2 (not overall NO_x) concentrations and thus increase the chance of limit values being exceeded.

2.5.2 Metal Filters

Open metal filters have recently become production solutions for reducing PM. The open metal filters have low trapping efficiencies compared to wall flow filters and use NO_2 for soot oxidation. PM number counts from open filters may be many times higher than those from wall-flow filters. The advantage over the open filter is that is has limited effect on increasing the back pressure of the exhaust system.

Sintered metal filters have high trapping efficiencies for both mass and number like ceramic wall flow filters. Sintered metal filters can be used with either fuel borne catalysts or as a catalyst-coated filter. Both FBC and coated filters reduce the soot combustion temperature. Disadvantages are similar to wall flow ceramic filters, back pressure increase, large volume requirements, packaging constraints and regeneration control.

2.5.3 Ceramic Fibre, Ceramic Foam and Electrostatic Filter

Other filter systems have been developed using fibres, foam and electrostatic devices, however, they are not expected to become mainstream PM removal technologies. They may be used on niche applications. Their filtration efficiencies are generally low lower than wall flow filters for both mass and number.

2.6 Particulate Filter Re-generation

Soot accumulated on a particulate filter must be periodically removed as the restriction in flow rate and increase in back pressure will lead to significant performance degradation. Overload of soot in the filter can also lead to thermal degradation where uncontrolled soot combustion leads to excessive temperatures, damaging the substrate. Generally, combustion of the accumulated soot is achieved by raising the temperature of the gas stream to 400-550°C, depending on the use of catalytic coating or fuel additive. For passenger car applications where exhaust temperatures are relatively low in urban driving, active regeneration strategies are required since relying on passive regeneration where exhaust temperatures are in the right operating range will not be sufficient to cover all vehicle operating modes. Active regeneration must be optimised to maintain the integrity of the DPF, whilst minimising the fuel consumption penalty associated with the regeneration event. Active regeneration will require the use of pressure and temperature sensors to aid the understanding of soot loading, when to trigger regeneration and to monitor the regeneration event. The calibration challenge is a major issue to ensure DPF regeneration can be achieved over the majority of the operating map, especially for vehicles used in low speed stop/start driving patterns. Exhaust temperature increases are normally obtained through modified fuel injection strategies to encourage combustion at the end of the expansion cycle. Strategies also include an increase in unburned hydrocarbons, which can be oxidised in a pre-DPF catalyst creating an exotherm, further raising the exhaust temperature inlet to the DPF.

DPF re-generation strategies and robust calibrations remain a major part of any DPF implementation programme. Calibrations are often application specific and need to be re-worked in detail for any change in vehicle weight or power rating. Concerns still exist regarding the effect of late injection strategies on lubricant dilution due to fuel spray impingement on the cylinder walls and the durability of oxidation catalysts for HC/CO control when subjected to repeated exotherms during DPF re-generation.

Similar durability issues may also be experienced by other NOx reduction technologies such as SCR systems if they are repeatedly exposed to HC based exotherms although these issues are not currently well defined and understood.

3 The 2004 technology baseline

The starting point of the assessment made in this report is the technology baseline at the beginning of the Euro 4 timeframe at the end of 2004. This baseline is therefore comprises vehicle technology sold under the Euro 4 legislation, since this is the technology that is and will be applied in all new sold vehicles by the end of 2005.
Based on the information received by the panel and knowledge available within the panel this technology baseline can be described as follows:

CI (Diesel):

- Direct high pressure injection
- Cooled EGR
- Oxidation catalyst

The reference injector technology for high pressure injection is seen as being electromagnetic actuation with limited flexibility. Although the first Piezo actuated systems are already on the market, these systems are not yet at the level of sophistication that will be needed in order to fit into a Euro 5 system set-up. Increased and variable injection pressure, multiple pre-and post injection, and variable needle displacement are not yet state of the art by the end of 2004.

A particulate trap is *not* seen as a part of the Euro 4 baseline, although several vehicles already in 2004 are (or can be) equipped with such a filter. At the time the work of the panel started, the decision between mounting a particulate trap or further optimising the 3 stated baseline features listed above was not yet clear. It was shown however that the combination of flexible high pressure injection, an optimised combustion camber, optimised cooled EGR and an oxidation catalyst was able to fulfil the Euro 4 requirements even in heavier cars and therefore a (expensive and fuel consuming) PM trap is no technical necessity to meet Euro 4 standards. The fact that during the work of the panel the international political debate has given a large stimulation to PM traps mounted under Euro 4 vehicles is not seen as being of influence on the baseline.

NO_x after treatment for CI engines is also not seen as baseline technology, even though one manufacturer sells a DeNOx (and PM trap) equipped vehicle in some markets. However, it is evident that optimised combustion technologies applied to this engine are able to fulfil Euro 4 requirements without DeNOx (and PM trap) in the same type of vehicle.

SI (Gasoline):

For Gasoline engines a distinction has to be made between lambda 1 technology and lean/stratified technology. In case of the first technology, high efficiency, durable and sulphur insensitive, 3-way catalyst technology is applied successfully in high numbers for many years now. The lean/stratified technology in contrary is just penetrating the market in small numbers using (new) NOx storage technology. It is seen however is a technology with great potential for the future because of its fuel saving prospective.

Lambda 1:

- Multi point intake manifold fuel injection
- Closed loop, close coupled 3-way catalyst

- Minimal variable valve timing (mainly to increase engine efficiency)

Lean/stratified:

- Multi point direct fuel injection
- Closed loop, 3 way catalyst for lambda 1 mode and NO_x storage catalyst for lean operation
- State of the art sensor technology (linear lambda sondes and/or NOx sensor)
- Minimal variable valve timing to create internal EGR

In order to better understand the emission reduction potential of the technologies mentioned and included in the baseline, the panel has looked in detail into the available type approval data of current market vehicles.

The EU has adopted emission limiting measures already since the early nineties. These series of measures, also known as EURO standards, have followed a path towards the reduction of the exhaust emissions from passenger and light duty vehicles for the last 10 years. Throughout this decade 4 different sets of emission standards were adopted by EU with EURO 4 currently in effect.

Table 1 EU Emission Standards for Passenger Cars, g/km

Tier	Year	CO	HC	HC+NOx	NOx	PM
Diesel						
Euro 1	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)
Euro 2, IDI	1996.01	1	-	0.7	-	0.08
Euro 2, DI	1996.01[a]	1	-	0.9	-	0.1
Euro 3	2000.01	0.64	-	0.56	0.5	0.05
Euro 4	2005.01	0.5	-	0.3	0.25	0.025
Gasoline						
Euro 1	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-
Euro 2	1996.01	2.2	-	0.5	-	-
Euro 3	2000.01	2.3	0.2	-	0.15	-
Euro 4	2005.01	1	0.1	-	0.08	-
Values in brackets are conformity of production (COP) limits. a - until 1999.09.30 (after that date DI engines must meet the IDI limits)						

The control of the exhaust emissions takes place through the type approval procedure established in 70/220/EEC, 80/1268/EEC and their later amendments. In order to enhance the monitoring of emission pollutants the EU has enacted the publication of the exhaust emissions data of each vehicle that enters the market. These data represent the type approval emission values of each vehicle model and are available in databases such as the ones of the German Kraftfahrt-Bundesamt (KBA)[1] and the British Vehicle Certification Agency (VCA)[2].

Figure 3 and 4 present the type approval values of the most important regulated pollutants for gasoline and diesel vehicles sold in Germany and the United Kingdom, together with the corresponding emission standards.

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[1] http://www.kba.de/

[2] http://www.vca.gov.uk/carfueldata/index.shtm

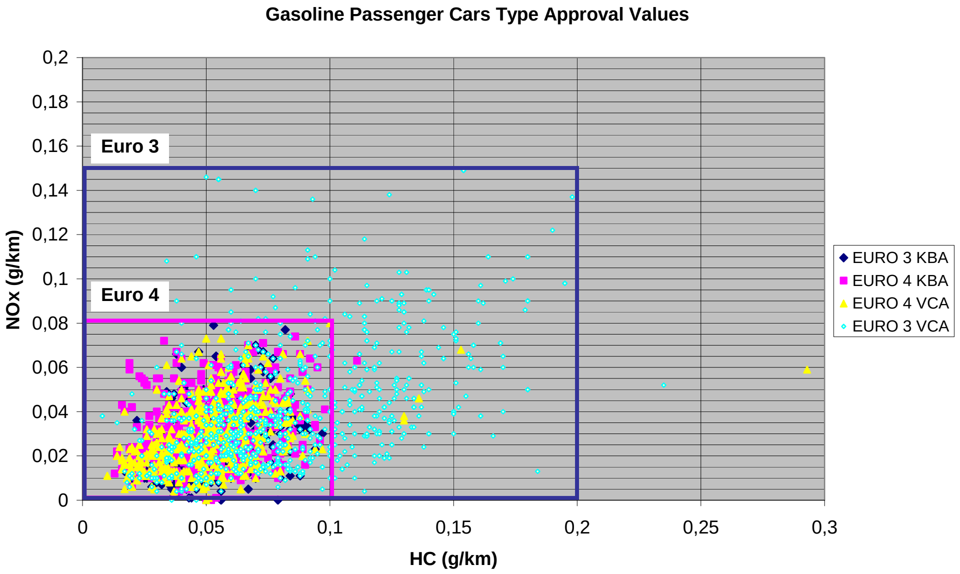

Figure 3 *NO$_x$ and HC emission type approval data for gasoline passenger cars*

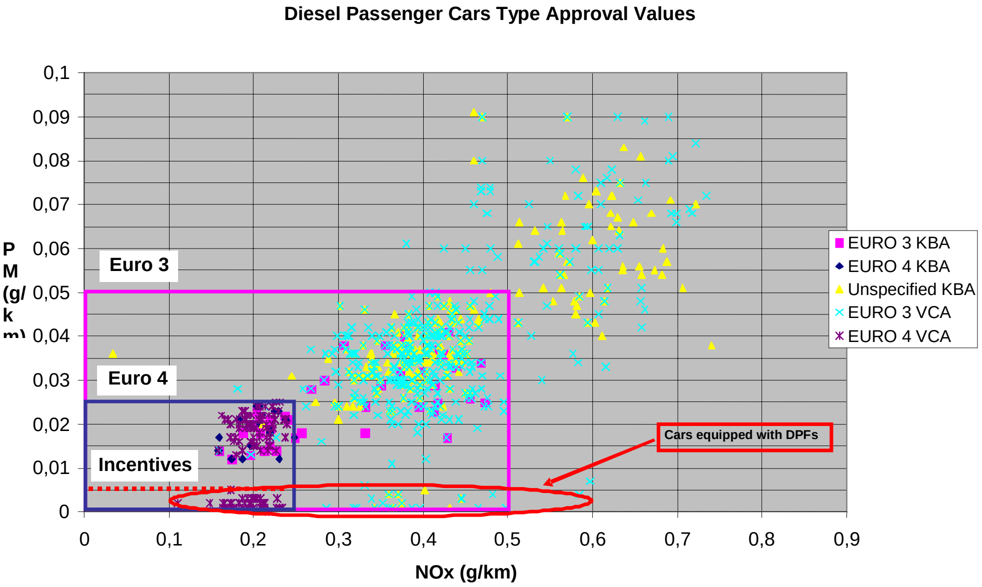

Figure 4 *NO$_x$ and particulate emission type approval data. Note that "Incentives" correspond to the incentive scheme (5 mg/km PM) recently enabled by the EC*

It is argued that type approval values provide only a snapshot in time based on pre series prototype vehicles and they do not account for in-use compliance and conformity of production and hence the official values contain results that lie above the development target[3]. However, they may also give a broader view of the potential of the

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[3] ACEA (2004). Derivation of the lowest workable particulate limit.

current technology for compliance with future emission standards. In this context, from Figure 3 it is made clear that the majority of gasoline passenger cars sold in the EU over the last 3 to 4 years comply with the EURO 4 emission standards although some of them are registered as EURO 3 vehicles. Additionally, it is seen that a large part of the type approved vehicles already now comply even with the most stringent limits discussed for Euro 5 emission standards (50 mg/km HC and 24 mg/km NO_x). This indicates a possible effort of the manufacturers to gain competitive advantages in the market and increase their readiness for future emission limits (or sell on the US market).

The picture for diesel cars is completely different from that for gasoline, in particular regarding EURO 4 cars. From Figure 4 it is seen that most of the EURO 4 compliant cars are gathered towards the upper right hand corner of the emission standards, while very few models appear to comply with the Incentive schemes of some EU Member States which are linked to a PM emission of below 5 mg/km. Additionally in Figure 4 a group of vehicles can be distinguished for their very low particle emissions due to them being fitted with PM traps. These models are shown in the next table. (Status 1-2005)

Table 2 Diesel vehicles with particle emissions below 10 mg/km

Unspecified	LANCIA PHEDRA	PHEDRA JTD
	VEL SATIS DCI	951
EURO III	CITROEN	C5
	CITROEN	C8
	FIAT	New Ulysse
	PEUGEOT	307
	PEUGEOT	406
	PEUGEOT	407
	PEUGEOT	607
	PEUGEOT	607
	PEUGEOT	807
	OPEL	Omega, Model Year 2003
Euro IV	AUDI	A6
	BMW	5 Series E60/E61
	FORD	New Focus
	FORD	Focus C-Max
	MERCEDES-BENZ	C Class
	MERCEDES-BENZ	E Class
	MERCEDES-BENZ	S-Class
	MERCEDES-BENZ	A-Class
	PEUGEOT	206
	PEUGEOT	307
	PEUGEOT	407
	SAAB	9-3
	TOYOTA	Avensis
	OPEL	Signum, MY2004
	OPEL	Vectra, MY2004
	VOLVO	New S40 Model Year 05
	VOLVO	V50 Model Year 05

In addition, in July 2004 the VDA, the association of German automotive manufacturers, announced that – following the currently established market trend – they will introduce particle filters to all diesel models sold in Germany until 2008/2009. Assuming the support of tax incentives based on the upcoming Euro 5 emission standards, VDA estimated that at least 25% of Diesel new registrations until the end of 2006 and 75% by the end of 2007 will be equipped with DPFs. Currently, there is are large number of Diesel car models sold in the German market that are equipped with Diesel particle filters. Table B.1 gives a summary of those models, together with the prices of the cars in the German market and the listed extra consumer price of fitting a DPF. All the models shown in Table 2 are included in Table B.1 as well. (Status 1-2005)

It is worth noting that the data of Table B.1 indicate clear trends between the price increase due to the DPF (as percent over the current price of the cars) and engine capacity and car price, as shown in Figure 5 and Figure 6 respectively. The price increase may reach 3,5% of the current prices of smaller capacity (and less expensive) cars, while for larger and more expensive cars this price increase does not exceed 1%.

This comparison can not be made for all DPF equipped cars, since some of them are not sold without a DPF.

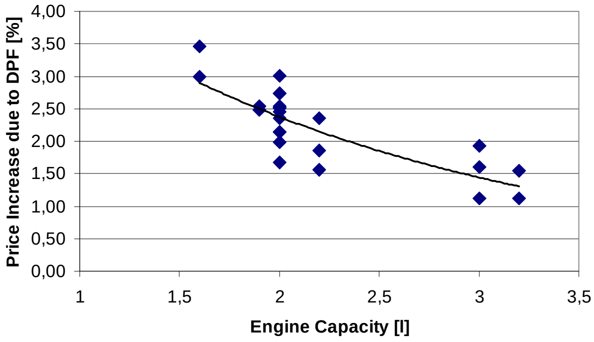


Figure 5: Price increase due to DPF in relation to engine capacity (data from Table B.1)

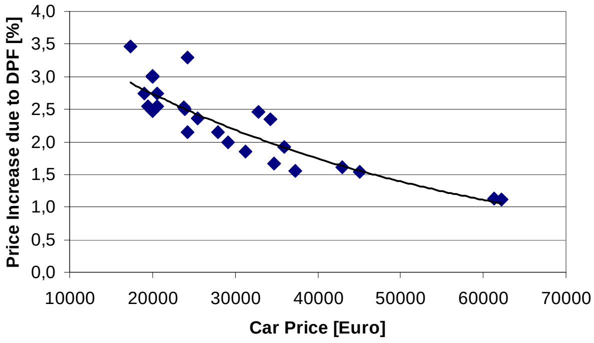
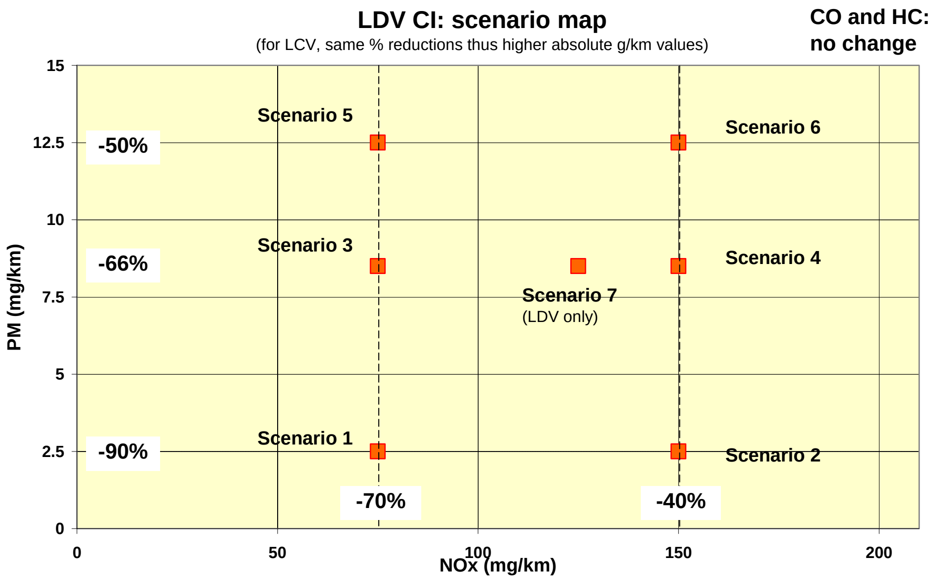


Figure 6: Price increase due to DPF in relation to basic car price (data from Table B.1)

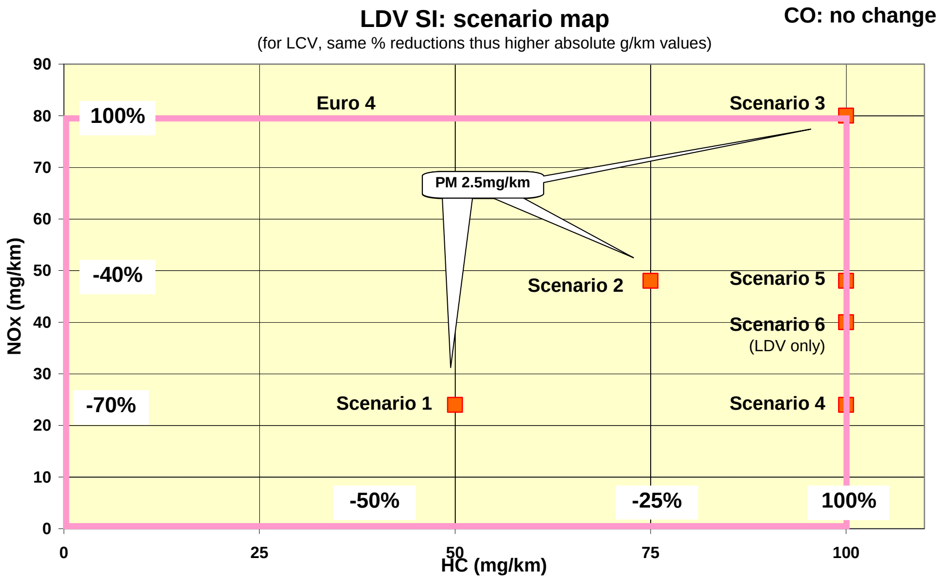
4 Technology maps

The process of assessing technology options and related costs for Euro 5 passenger cars is based on the 13 emission limit scenario's provider by the EC. The scenarios are graphically presented below:

Compression Ignition (CI) Engine Emission Scenarios



Spark Ignition (SI) Engine Emission Scenarios



In order to comply with the different scenarios, some of the earlier mentioned technologies have to interact with each other. How this interaction will be brought into practice is very much dependant of the individual manufactures technology baseline and development strategies. Based on the information received from the stakeholders the panel has developed minimum and maximum interaction applications. The “minimum” can be applied in case of a sophisticated, low engine out emissions base engine. The “maximum” will have to be applied in case of a base engine that has limited potential to be upgraded further then Euro 4. Min and Max applications have been developed for each vehicle type and Euro 5 scenario. The assumptions behind the technology application choices are presented next.

4.1 General approach

In order to be able to correctly assess the technologies that could be applied to live up to the Euro 5 scenarios under investigation, the panel made a set of assumptions, which are:

- Technology combinations used are made dependant of the respective emission limit value setting and the swept volume of the typical vehicles engine. This swept volume by itself in fact is basically a secondary emission related parameter, since for instance the vehicles mass, drag coefficient, frontal area and rolling resistance primary dictate the power demand and thereby the technical constellation of technologies needed to meet the emission limits. However the distinction made in the EC’s questionnaire: <1.4 l, 1.4-2.0 l and >2.0 l is seen to be a suitable set-up within the context of the assessment, since the swept volume is still strongly related to the primary parameters. For future assessments however other parameters should be considered since for instance applying extreme engine downsizing would disturb the current classification.
- In addition to the questionnaires basic swept volume categorisation, one vehicle class was split up into 2 classes by the panel: The > 2.0 l class was split up into 2.0 l (standard) and >2.0 l large. The panel made this split in order to be able to :
  - address the issue of very large vehicles that either need double exhaust systems for packaging reasons (with double sensors and control and canning), and
  - the N1 vehicles (under scenario 7) need to make a bigger step form Euro 4 to Euro 5 than M1, because of the less stringent (related to M1) emission limit setting for N1 categories under Euro 4. This also relates to the heavy M1 vehicles (>2.5 t.) that are currently allowed to perform according to N1 standards. Especially the class 2 and 3 N1 vehicles will be affected under scenario 7 since they will actually need a servere technology improvement towards Euro 5, were-as N1 class 1 is mostly already under Euro 4 sold with M1 Euro 4 technology.

  The split made in the >2.0 category however is not available in the TREMOVE model. In order to deal with this aggregation of the TREMOVE input set-up, the TREMOVE team will have to combine both >2.0 l categories based on sales figures.
- For every selected category a minimum and a maximum technology package has been established. “Minimum” and “maximum” reflect the level of sophistication of technologies used and the costs related to this level. This distinction has been made to reflect the effect of the differences in base engine (euro IV), development status and philosophies to reduce emission between the different manufacturers. It is assumed that both technology packages will in the end be equivalent in performance in emission reduction.
- The minimum and maximum technology packages are build up based on 2 basic items:

- **Engine internal measures** (further optimisation of mostly existing technology like EGR, turbo charging, valve timing, injection timing-and pressure)
- **After treatment measures** (adding additional components like a NOx-or PM trap, or optimised catalysts)

In addition to these main assumptions, additional assumptions have been made typically for CI (Diesel) or SI (Gasoline) technology.

4.2 Compression Ignition (CI) engine assumptions

For taking CI (compression ignition) engines from Euro 4 toward Euro 5, emissions of NOx and PM have to be reduced. Taking into account all information received by the panel, the following basic assumptions towards technology applications were made:

- Engine internal measures (EIM) will play an important role in achieving Euro 5 emission levels, but will in almost no case be sufficient to reach the Euro 5 limit proposal in the different scenarios. Therefore in most cases additional after treatment measures will have to be taken. The combination of both engine internal measures and after treatment will be used by the industry. The efficiencies needed from each of both measure types in this combination, is highly dependant of the base engine used and the companies typical development strategy. In order to deal with this topic, the minimum and maximum application's chosen by the panel reflect probable combinations of engine internal measures and after treatment. For this purpose the levels of engine internal measures are used: Mild Engine Internal Measures (MEIM) and Strong Engine Internal Measures (SEIM). The actual technologies behind MEIM and SEIM are not specified in detail (because of the large amount of different technical possibilities). The distinction is only made in costs.
- PM traps will most probably be standard equipment for all Euro 5 CI vehicles. (Although for some lighter vehicles PM emissions of 12,5 mg/km could be achieved with engine internal measures only). This assumption is based on the current state of political discussions in Europe about the need for early (before Euro 5) introduction of PM traps via national tax incentives and the reaction of the industry to this discussion. However to show the effect of application of a DPF compared to not using DPF, the <1.4 l minimum option for scenario 6 has been set up not using a DPF.
- Next to traditional wall flow filters, metal PM filters are available already in 2004. It is the assumption of the panel that, because of their easier integration into the total emission control concept and possible lower CO_2 penalty, the metal PM filters will have a significant market share under Euro 5. Especially for the least stringent scenarios and lightest vehicles, the lower efficiency of these filters could be sufficient in combination with engine internal measures.
- Based on available Euro 4 type approval data it can be concluded that emissions between 150 and 200 mg/km NOx (close to scenarios 2, 4 and 6) are possible already in the baseline (Euro IV) situation without NOx after treatment
- The well-known trade off between NOx and PM emissions will also be applicable when using exhaust gas after treatment. This for instance results in DeNOx not having to be applied for 150 mg/km in case a DPF is applied in the case of smaller vehicles (because of the possibility of higher engine out PM and therefore lower engine out NOx).
- Driven by the limit values of some Euro 5 scenarios (e.g. 75 mg/km), NOx after treatment will be applied on several all Euro 5 vehicles. In principle NOx after treatment for passenger cars will become available as LNT (Lean NOx Trap) and

SCR (Selective Catalytic Reduction using Urea). *If* such a system will be applied and under which conditions *which* system will be used is uncertain at this moment. LNT is not seen as a durable high efficiency solution at this moment and would need a major improvement before being comparable with SCR in this respect. Successful SCR implementation on the other hand is largely dependant of the availability of some kind of Urea (liquid or solid) supply infrastructure. The panel's choice on behalf of the assessment has been based on foreseeable durable efficiency of both systems. (See next bullet). For the application of SCR it's taken as a fact (and as a risk) that some kind of urea supply infrastructure should be available by at the latest 2009. The costs of urea supply and on-board handling could not be assessed and has therefore been left out.

- Further optimisation of engine internal measures during the next years is foreseen to further close the gap between the 150 g/km scenarios and vehicles without NOx after treatment at type approval. Thus NOx after treatment for the 150 g/km scenarios (if necessary) will have to be only moderate in order to ensure durable operation below 150 g/km over the vehicles lifetime. Only for the largest 2 vehicle classes above 2 litres (and N1 class 2 and 3) with high engine out NOx, highly efficient (and durable) NOx after treatment will have to be applied. This constellation leads to LNT (with not yet proven long term high efficiency) typically being applied for 150 g/km NOx scenarios and larger vehicles and SCR (with proven long term durable high efficiency) being inevitable for the 75 g/km NOx scenarios. Both options being adopted in combination with mild (MEIM) or strong (SEIM) engine internal measures, depending on the size of the vehicle and used in combination with a DPF.
- The fact that by using PM traps and DeNOx catalyst, the function of the baseline oxidation catalyst can be integrated into the PM trap or DeNOx catalyst.

Based on these assumptions the following technology applications have been linked to the EC's limit value scenarios.

Table 3 Compression ignition (CI)

			Min Technology			Max Technology		
	limits (mg/km)	**Engine Volume (l)**	**PM Reduction**	**both**	**NOx Reduction**	**PM Reduction**	**both**	**NOx Reduction**
Scenario 1	**PM: 2.5 NOx: 75**	<1.4	DPF closed	SEIM	Lean Denox cont (SCR)	DPF closed	SEIM	Lean Denox cont (SCR)
		1.4-2.0	DPF closed	SEIM	Lean Denox cont (SCR)	DPF closed	SEIM	Lean Denox cont (SCR)
		>2.0 medium	DPF closed	SEIM	Lean Denox cont (SCR)	DPF closed	SEIM	Lean Denox cont (SCR)
		>2.0 large	DPF closed	SEIM	Lean Denox cont (SCR)	DPF closed	SEIM	Lean Denox cont (SCR)
Scenario 2	**PM: 2.5 NOx: 150**	<1.4	DPF closed	SEIM	-	DPF closed	MEIM	Lean Denox store (LNT)
		1.4-2.0	DPF closed	SEIM	-	DPF closed	MEIM	Lean Denox store (LNT)
		>2.0 medium	DPF closed	MEIM	Lean Denox cont (SCR)	DPF closed	MEIM	Lean Denox store (LNT)
		>2.0 large	DPF closed	MEIM	Lean Denox cont (SCR)	DPF closed	MEIM	Lean Denox store (LNT)
Scenario 3	**PM: 8.5 NOx: 75**	<1.4	DPF open	MEIM	Lean Denox cont (SCR)	DPF closed	SEIM	Lean Denox cont (SCR)
		1.4-2.0	DPF closed	MEIM	Lean Denox cont (SCR)	DPF closed	SEIM	Lean Denox cont (SCR)
		>2.0 medium	DPF closed	MEIM	Lean Denox cont (SCR)	DPF closed	SEIM	Lean Denox cont (SCR)
		>2.0 large	DPF closed	MEIM	Lean Denox cont (SCR)	DPF closed	SEIM	Lean Denox cont (SCR)
Scenario 4	**PM: 8.5 NOx: 150**	<1.4	DPF open	MEIM	-	DPF closed	MEIM	Lean Denox store (LNT)
		1.4-2.0	DPF closed	MEIM	-	DPF closed	MEIM	Lean Denox store (LNT)
		>2.0 medium	DPF closed	MEIM	-	DPF closed	MEIM	Lean Denox store (LNT)
		>2.0 large	DPF closed	MEIM	Lean Denox cont (SCR)	DPF closed	MEIM	Lean Denox store (LNT)
Scenario 5	**PM: 12.5 NOx: 75**	<1.4	DPF open	MEIM	Lean Denox cont (SCR)	DPF open	SEIM	Lean Denox cont (SCR)
		1.4-2.0	DPF open	MEIM	Lean Denox cont (SCR)	DPF open	SEIM	Lean Denox cont (SCR)
		>2.0 medium	DPF open	MEIM	Lean Denox cont (SCR)	DPF open	SEIM	Lean Denox cont (SCR)
		>2.0 large	DPF open	MEIM	Lean Denox cont (SCR)	DPF open	SEIM	Lean Denox cont (SCR)
Scenario 6	**PM: 12.5 NOx: 150**	<1.4	-	MEIM	-	DPF open	-	Lean Denox store (LNT)
		1.4-2.0	DPF open	MEIM	-	DPF open	MEIM	Lean Denox store (LNT)
		>2.0 medium	DPF open	MEIM	-	DPF open	MEIM	Lean Denox store (LNT)
		>2.0 large	DPF open	MEIM	Lean Denox cont (SCR)	DPF open	MEIM	Lean Denox store (LNT)

4.3 Spark Ignition (SI) engine assumptions

For taking SI (spark ignition) engines from Euro 4 toward Euro 5, emissions of NOx HC and PM have to be reduced. Taking into account the limited information received by the panel, the following basic assumptions towards technology applications were made:

General

- Spark ignition technology application's for Euro 5 have to be divided into lambda 1 and lean burn concepts and addressed separately, because of possible large differences in exhaust gas after treatment technology. The split made in the SI category however is not available in the TREMOVE model. In order to deal with this aggregation of the TREMOVE input setup, the TREMOVE team will have to combine both SI categories based on sales figures.

4.3.1 *SI Lambda 1 concepts*

The following assumptions toward technology applications for Euro 5 SI lambda 1 concepts were made:

- The reduction of particulate matter for Lambda 1 concepts is not necessary, since data from current Euro III and IV vehicles show levels below 2.5 mg/km. This leads to no actions on this point under scenario 3.
- Scenarios 2, 5 and 6 are seen as being equivalent, because of PM being no issue for SI lambda 1 and consequences of the difference between 48 and 40 mg/km NOx can not be addressed based on the level of detail of the information supplied to the panel. This also applies to the different levels of HC emissions in the scenarios.
- Minimum and maximum technology applications have been established in which "minimum" being purely optimisation of the catalyst efficiency, without any change

in the engine and its calibration. This would be an option in case the base engine under Euro 4 is already rather sophisticated and therefore has low engine out emissions. The “maximum application” would be a combination of optimised catalyst efficiency and further sophistication of the Euro 4 engine in case this engine has higher engine out emissions.

- Technologies to achieve emissions on the level of the EC scenarios are already available and in production for the US market (SULEV). Since development costs are not part of the assessment (chapter 6: only components, packaging and validation), there is no need for correction of EU Euro 5 costs for the early US developments.
- Lowering NO_x and HC emissions by using the catalyst only is achieved by increasing the activity of the catalyst by increasing the relative precious metal loading (with total stable catalyst volume, via an increase in cell density if required) in relation to the base case (euro IV).
- Lowering NO_x and HC emissions via sophistication/optimisation of the engine is achieved by means of improved injection quality (atomisation and timing), variable valve timing and improved lambda/fuelling control (with linear lambda sondes).
- Very limited information was received on alternative fuels (LPG/CNG), but the general observation is that for LPG and CNG similar technologies will be applied as for petrol. For CNG the CNG catalyst efficiency has to be further improved (compared to Euro 4) in case the HC limit is tightened.

Based on these assumptions the following technology applications have been linked to the EC’s limit value scenarios for Lambda 1 SI engines.

Table 4 SI Lambda 1 concepts

	limits (mg/km)	**Engine Volume (l)**	**min**		**max**	
Scenario 1	**HC: 50**	<1.4	optimized cat		optimized cat	optimized engine
	NOx: 24	1.4-2.0	optimized cat		optimized cat	optimized engine
	PM: 2.5	>2.0 medium	optimized cat		optimized cat	optimized engine
		>2.0 large	optimized cat		optimized cat	optimized engine
Scenario 2	**HC: 75**	<1.4	optimized cat		optimized cat	optimized engine
	NOx: 48	1.4-2.0	optimized cat		optimized cat	optimized engine
	PM: 2.5	>2.0 medium	optimized cat		optimized cat	optimized engine
		>2.0 large	optimized cat		optimized cat	optimized engine
Scenario 3	**HC: 100**	<1.4	no action	no action	no action	no action
	NOx: 80	1.4-2.0	no action	no action	no action	no action
	PM: 2.5	>2.0 medium	no action	no action	no action	no action
		>2.0 large	no action	no action	no action	no action
Scenario 4	**HC: 100**	<1.4	optimized cat		optimized cat	optimized engine
	NOx: 24	1.4-2.0	optimized cat		optimized cat	optimized engine
		>2.0 medium	optimized cat		optimized cat	optimized engine
		>2.0 large	optimized cat		optimized cat	optimized engine
Scenario 5	**HC: 100**	<1.4	optimized cat		optimized cat	optimized engine
	NOx: 48	1.4-2.0	optimized cat		optimized cat	optimized engine
		>2.0 medium	optimized cat		optimized cat	optimized engine
		>2.0 large	optimized cat		optimized cat	optimized engine
Scenario 6	**HC: 100**	<1.4	optimized cat		optimized cat	optimized engine
	NOx: 40	1.4-2.0	optimized cat		optimized cat	optimized engine
		>2.0 medium	optimized cat		optimized cat	optimized engine
		>2.0 large	optimized cat		optimized cat	optimized engine

4.3.2 SI lean concepts

The following assumptions toward technology applications for Euro 5 SI lean concepts were made:

- A reduction of particulate matter emissions for lean concepts is necessary, since measured PM data from current lean Euro III and IV vehicles show levels above 2.5 mg/km. Discussions with the automotive industry pointed out that it will be possible to meet a 2.5 mg/km PM limit value for lean SI concepts by applying optimised fuelling only (injection pressure and timing and calibration). This optimisation however could lead to some decrease of the CO_2 benefit from lean SI concepts. For scenario's 1, 2 and 3 (2.5 mg/km PM) the described optimised fuelling is adopted in the technology applications of the panel.
- Lean NOx Trapping (LNT) will be the only NOx after treatment technology for SI lean burn engines. In relation to CI the necessary efficiencies are limited and the durability is not seen as a problematic issue (due to the different temperature windows required). Therefore SCR (with it's uncertainty about the urea infrastructure availability) is not seen to be necessary.
- Scenarios 5 and 6 are seen as being equivalent, because the difference between 48 and 40 mg/km NOx can not be addressed based on the level of detail of the information supplied to the panel.
- Minimum and maximum technology applications have been established in which "minimum" is optimisation of the storage catalyst (LNT) efficiency, without any change in the engine and its calibration. This would be an option in case the base engine under Euro 4 is already rather sophisticated and therefore has low engine out emissions. The "maximum" applications would be a combination of optimised catalyst efficiency and further sophistication of the Euro 4 engine in case this engine has higher engine out emissions. This optimisation of the engine is achieved by means of improved injection quality (automanisation and timing), variable valve timing and improved calibration. This engine optimisation would include optimised fuelling as used for reducing PM emissions.
- Lowering NOx and HC emissions by optimising the catalyst is achieved by increasing the activity of the catalyst by increasing the volume of the catalyst (with stable relative precious metal loading) in relation to the base case (euro IV).

Based on these assumptions the following technology applications have been linked to the EC's limit value scenarios for lean SI engines.

Table 5 SI lean concepts

	limits (mg/km)	Engine Volume (l)	min		max	
Scenario 1	HC: 50	<1.4	optimized cat	optimized fueling	optimized cat	optimized engine
	NOx: 24	1.4-2.0	optimized cat	optimized fueling	optimized cat	optimized engine
	PM: 2.5	>2.0 medium	optimized cat	optimized fueling	optimized cat	optimized engine
		>2.0 large	optimized cat	optimized fueling	optimized cat	optimized engine
Scenario 2	HC: 75	<1.4	optimized cat	optimized fueling	optimized cat	optimized engine
	NOx: 48	1.4-2.0	optimized cat	optimized fueling	optimized cat	optimized engine
	PM: 2.5	>2.0 medium	optimized cat	optimized fueling	optimized cat	optimized engine
		>2.0 large	optimized cat	optimized fueling	optimized cat	optimized engine
Scenario 3	HC: 100	<1.4		optimized fueling		optimized fueling
	NOx: 80	1.4-2.0		optimized fueling		optimized fueling
	PM: 2.5	>2.0 medium		optimized fueling		optimized fueling
		>2.0 large		optimized fueling		optimized fueling
Scenario 4	HC: 100	<1.4	optimized cat		optimized cat	optimized engine
	NOx: 24	1.4-2.0	optimized cat		optimized cat	optimized engine
		>2.0 medium	optimized cat		optimized cat	optimized engine
		>2.0 large	optimized cat		optimized cat	optimized engine
Scenario 5	HC: 100	<1.4	optimized cat		optimized cat	optimized engine
	NOx: 48	1.4-2.0	optimized cat		optimized cat	optimized engine
		>2.0 medium	optimized cat		optimized cat	optimized engine
		>2.0 large	optimized cat		optimized cat	optimized engine
Scenario 6	HC: 100	<1.4	optimized cat		optimized cat	optimized engine
	NOx: 40	1.4-2.0	optimized cat		optimized cat	optimized engine
		>2.0 medium	optimized cat		optimized cat	optimized engine
		>2.0 large	optimized cat		optimized cat	optimized engine

5 Additional topics

This chapter is not strictly speaking necessary for the completion of Task 1, the validation of the stakeholder responses to the LDV questionnaire. However, the panel feels that the topics addressed below need to be kept in mind when interpreting the results obtained and when using them for the preparation of new emission limit values.

5.1 Effects on CO_2 emissions of the discussed Euro 5 emission standards

The response to the questionnaire included statements on fuel consumption (CO_2 emission) effects related to the application of certain emission control settings. The information received showed a relatively large range of possible effects on CO_2 emissions. As illustrated in Figure 7, the values ranged from -3% (i.e. a reduction of CO_2 emissions) to +14%, depending on the underlying assumptions with respect to emission control technology assumed. Averaging of the responses to the questionnaire results in a value of about +2%.

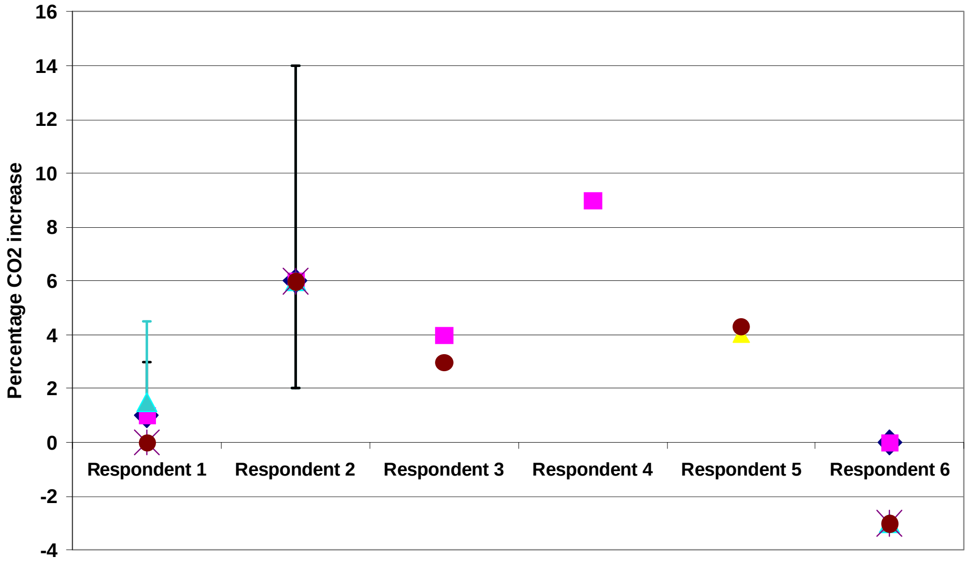


Figure 7 *Summary of the effects of the discussed Euro 5 emission standards on CO_2 emissions as received in responses to the questionnaire. The different markers designate different scenarios and vehicle classes.*

It is known that several different trends are possible depending on the different after-treatment systems and calibration schemes. In broad terms

- The closed DPF generally induces an increase in fuel consumption and hence in CO_2 emissions, basically due to the increased back pressure, but also to the post injection strategy required for filter regeneration.
- The SCR on the other hand is generally associated with an improvement of fuel consumption, since it is related with a more fuel efficient engine calibration.
- Engine measures that are currently under development and likely to be used - in particular optimised high-pressure injection (based on piezo-technology) – will also have beneficial effects on fuel consumption.

- For SI lean burn engines complying with tighter NOx and HC standards could lead to regulated emission optimised engine calibrations, overall possibly leading to increased usage of the lambda 1 operating conditions and therefore increased CO_2 emissions and fuel consumption.

From the responses to questionnaire it was not possible to isolate the effects of the different above mentioned technologies on fuel economy. The only actual data available at this moment are data on DPF and some very limited data from one combined DPF/LNT vehicle. SCR data are only available from some prototype Heavy-Duty engines, and are therefore seen as unsuitable to be used in a Light-Duty context. Therefore the panel concentrated basically on the DPF effect on fuel consumption, since most (if not all) of its increase is due to the increased back pressure. The results of a series of indicative calculations performed with Advisor2000, calibrated against chassis dyno data, are shown in Figure 8. These results indicate that a 4 to 5 fold increase of the back pressure during the NEDC (due to filter loading) just prior to filter regeneration may lead to an increase of fuel consumption of up to 5%. This means an average increase in CO_2 emissions of +2,5%, since the relationship between back pressure and fuel consumption is linear.

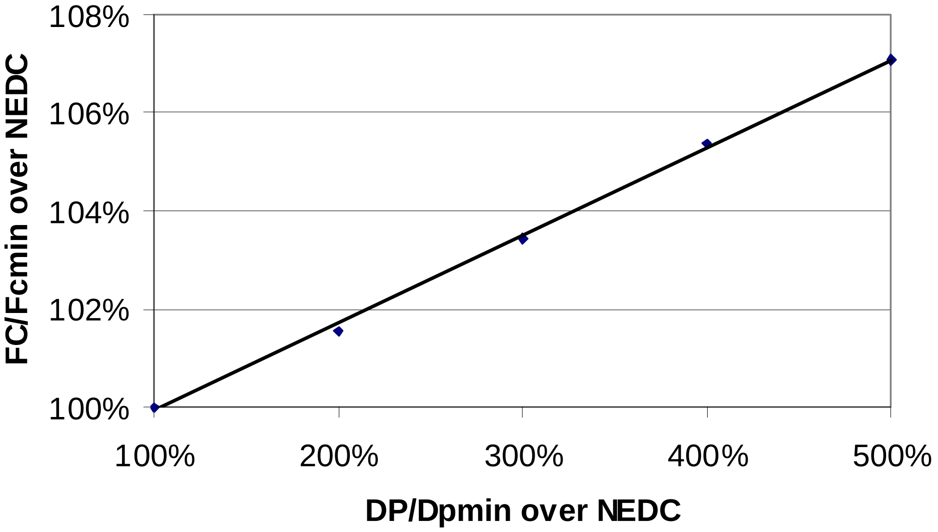


Figure 8 *Calculated effect of back pressure on fuel consumption over the NEDC with Advisor2000. The data refer to a Euro III mid-sized diesel car (<2.0 l) equipped with a 2.5l SiC DPF.*

Since the DPF sizes used are generally larger than the one assumed in the above calculations and optimised regeneration strategies may be developed, it is reasonable to assume that the fuel penalty can be reduced to values in the range of 1 to 2%, a value that is largely consistent with most of the data reported in the open literature.

In summary, the panel's conclusion is that the possible effect of closed DPF on CO_2 emissions is of the order of +1 to +2%. It should be recalled that this number refers to the direct effect of a DPF on a basic Euro 3 engined car, and does not account for the possible effects of engine optimisation towards a fuel consumption penalty resulting from a lower NOx calibration or improved fuel economy resulting from other after-treatment systems such as SCR. What kind of optimisations will actually occur in the future is difficult to predict and are largely dependent in the way CO_2 and NOx emissions reduction will be handled in European legislation.

5.2 Influence of the test procedure

Emission standards in Europe are set based on the European Driving Cycle (UDC). This driving cycle is now more then 30 years old and does only poorly reflect driving like utilised in real life. Although a Type Approval test cycle does not have to be linked completely to real world driving to be adequate for its purpose, some linkage is important. Lack of linkage could lead to sub-optimal technological solutions for day to day driving. This could be the case since the emission performance of vehicles is to a certain extent being developed towards meeting the test cycle requirements.

5.3 Auxiliaries

Another aspect of modern vehicle testing is the effect of auxiliaries on the power used (power assisted steering, air-conditioning), which may load the engine to such an extent that there is a significant influence on emissions and fuel consumption. The basic possibilities to take account of such effects are:

- Make sure that they absorb power during testing so that their influence is included in the standard test
- Measure their influence in a dedicated test

The first possibility would be recommended when the auxiliary concerned would (almost) always be used when the vehicle is in operation and the influence on power absorption is fixed (e.g. daytime running lights in a fuel consumption test). The second option would be recommended when the auxiliary would be used in a more random way (such as an air-conditioning might only be used under certain circumstances) and the power requirement may be dependant on the exact circumstances (such as ambient temperature and sun radiation for an airconditioner). The final results may then either be a combination of figures with and without the auxiliary, or a weighted average figure of the measurements with and without the auxiliary.

5.4 Fuels

Although the issue of fuel quality in relation to Euro 5 will be handled under the review of Directive 98/70/EC which is currently ongoing in a separate process some points should be made in this report.

Petrol and Diesel will be the major fuels for Euro within the scope of Euro 5. LPG and CNG will play increasing, but still minor role, and can be generally handled as now under SI Euro 4 regulations. Pure Hydrogen, and biomass-to-liquid fuels are beyond the scope of Euro 5.

The main issue as already mentioned in chapter 2 is the sulphur content of the fuels used. The engine and exhaust gas after treatment technologies that could be used in order to comply with Euro 5 scenarios are in principle are more sensitive to fuel quality than earlier technologies like 3-way and oxidation catalyst. Technologies like DPF (especially wall flow) and DeNOx (especially LNT) are yet extremely sensitive to sulphur and so produce increased CO_2 emissions (because of increased regenerations) and decreased durability to sulphur contents in the fuel of above 10 mg/kg. At this level of sulphur content in the fuel, the sulphur content of lubricant oil is starting to play an important role as well.

The effects of other fuel properties like fuel volatility, olefins content and aromatics content play a much less important role.

The oil industry have reacted to the legal requirement of introduction low sulphur fuels as laid down in Directive 98/70/EC, amended by Directive 2003/17/EC, including the introduction of almost sulphur free grades (< 10 mg/kg max. S) on a balanced geographical basis from 2005, heading for full area coverage in 2009.

5.5 Durability

On of the issues that was addressed in the questionnaire was the durability of technology to be applied to facilitate the step from Euro 4 tot Euro 5. Information was requested on the current durability interval (100.000 km) and an extended interval (200.000 km)
On this issue only very little and undetailed input was received. The input reached from "no information available" (especially on extended durability) up to "no difference to Euro 4".

Looking at this issue from a technical side one should take into account the following:
-Petrol PI technology will be similar for Euro 4 and Euro 5, using proven technologies with efficiencies and control strategies only modestly refined.
-Petrol DI-Lean burn technology under Euro 4 and 5 and will be equipped with NOx storage technology which is rather new on the market.
-First indications are that current durability of NOx storage systems (diesel and petrol) is highly influenced by the sulphur content of the fuel (10 ppm is max. for a reasonable life time).
-Diesel technology will under most Euro 5 scenario's face the introduction of new and advanced technologies (PM traps, storage catalysts and SCR DeNOx), which in the case of storage catalysts have not proven 100.000 km production vehicle in-use durability yet. 200.000 km durability information is not yet available for any light duty advanced technology.
-The durability requirement for the US market is already now at 120.000 miles (192.000 km) with equivalent emission limit values lower that Euro 4.

From the above no solid conclusions can be draw in relation towards the effects of an extended durability interval.
For petrol vehicles with homogeneous combustion however it is reasonable to assume that the extension of the durability period to 200.000 km will be technically achievable, however no costs data for this extension have been made available.
For diesel vehicles and lean burn petrol vehicles the technical feasibility of the extension to 200.000 km is unsure. The probable application of LNT and DPF and it's limited proven long term in use durability is the mean cause of this. From the US (EPA) [ref 31] information is available showing first promising result on light duty storage catalyst and DPF durability, but not from serial production vehicles, only from prototypes.

Development of LNT continues and some progress is being made but a breakthrough in durability will be required before this technology could be considered as a long term durable high efficiency application on diesel engines.

6 Costs

6.1 General

The main issue of the Euro 5 panels' assessment work was to establish the costs related to technology options that meet the EC's scenarios.
These costs however are highly confidential information only available at single manufactures level. This confidentiality issue was clearly revealed in the responses to the EC questionnaire, in which cost data provided were very limited and highly aggregated.

For the assessment to be made by the panel, detailed cost data should be available in order to be able to clearly distinguish between the detailed scenarios. Taking into account public information on this point was not seen as being a solution, because the public information available (market prices of vehicles with certain technologies under Euro 4) a) give little additional information on typical technologies, b) are market prices instead of costs and c) almost only relate to concepts with PM traps (and not yet DeNOx technology).

In order to be able to satisfy the desire for detailed additional cost information for several technology application's for Euro 5, the panel decided to build a detailed cost/technology model that could be linked directly to the technology application's specified in chapter 4. The model structure was based on the experts panels know how on technical measures that can be applied to minimise emissions. The model input was initially retrieved from the stakeholders input. But in order to retrieve more detailed cost data to fill the detailed model, confidential meetings were arranged with stakeholders (see paragraph 1.2). Because of the high level of confidential input in the model, the model itself will not be made available.
The set up of the model and the assumptions made to populate the model are presented next:

6.2 Technical

- The model is consistent with the set up described in chapter 4 "general". This means that costs for technologies are linked to a) emission limit values per component, b) swept volume of the engine and c) engine configuration (i.e. dual exhaust system)..
- In order to be able to calculate the additional costs for Euro 5, the base case (Euro IV) technology applications (as described in chapter 3) for each engine type (CI, SI lambda 1 and SI lean) and swept volume class is part of the model as well.
- Costs for each of the emission reduction technologies are basically linked to the effective size (litre) of the technology on the vehicle. This size is directly linked to the swept volume of the engine. Next to the effective reduction devices, necessary sensors and control equipment are added as well.
- The costs for engine internal measures are also made swept volume proportional.
- The engine internal measures (EIM) are seen to serve more purposes than reducing regulated emissions only. In addition to reducing regulated emissions improvements in CO_2 emissions, increased drive ability and reduction of noise emissions are additional benefits of engine internal measures. Even the marketability of certain vehicles equipped with certain high tech solutions could be increased. There are no

typical measures which affect only 1 of the 4 to 5 parameters. Flexible high-pressure injection for instance affects at least 4 of them, as does flexible valve timing. It is therefore the panel’s opinion that only part of the total costs for additional engine internal measures can be allocated to the Euro 5 legislation. Lacking quantitative information in order to substantiate a typical allocation, the panel decided to allocate 25% of the total costs for engine internal measures to Euro 5 regulated emissions reduction. It may be argued that because of the statement above, typical engine internal measures are not linked to Euro 5 legislation coming into force and that therefore the cost for EIM should be exempted completely for the Euro 5 assessment. On the other hand one could argue that because of Euro 5 legislation coming into force, additional demands are put on the EIM compared to what would be applied because of noise, fuel consumption and drive-ability, making the EIM more expensive then without Euro 5 coming into force. The panel feels that the last argument is reflected in the 25% rule.

- The costs for EIM are based on general input on the predicted maximum costs for EIM from Euro 4 towards Euro 5 one component manufacturer. This undifferentiated costs statement is made applicable within the context of the cost calculation by making this general costs proportional to the engine size. The basis is SEIM for a > 2.0 l large type of vehicle. The costs for MEIM are set on 50% of the cost predicted by the component supplier.
- For after treatment devices the swept volume is linked to the volume of the substrate/filter material and PGM loading (see chapter 5).
- The actual PGM loading of catalyst to achieve certain reduction efficiencies is subject to change over time. Optimised processes for producing catalyst lead to the possibility of “thrifting”, which means: less PGM mass on the catalyst with similar over all efficiency. This thrifting is an ongoing process for many years and leads to catalyst technology becoming less expensive over time if emission limit values would not have been changed. This effect on costs to a certain extent compensates the increased PGM loading needed due to more stringent emission limit values. Having in mind this effect, the PGM loading of Euro 5 catalyst technology has been corrected for thrifting that would have occurred without tightening the emission standards. This correction of -30% has been applied based on data over the last years (supplied by AECC members).
- For the class >2.0 l large the effective swept volume of these vehicles after treatment systems is increased by 50% compared to >2 l medium and the number of exhaust system sensor is doubled.
- No additional technical-or cost application has been added for N1 class 2 and 3, because of lack of detailed data received on this class. It is however assumed that the additional costs calculated for the M1 > 2 l large class are comparable to those of N1 class 2 and 3 under the M1 Euro 5 scenarios. N1 class 1 is treated as M1.

6.3 Economic parameters

- All costs used in the model are based on 2004 costs and prices (because of the questionnaires input being mainly 2004 related) and are corrected for price inflation with 2% per year.
- The model takes into account: catalyst *price*, *price* of some additional components (sensors), costs for engine internal measures and costs for packaging, redesign and validation. The reason for eventually using *price* instead of *costs* is due to the fact that the market for those components is so competitive that no cost information became available (even under highest confidentiality).

- The costs for basic development of technologies are *not* taken into account, since it was proven that (for the manufacturers) these costs are impossible to be allocated to certain typical developments.
- An important factor in the costs for exhaust gas after treatment is the price of PGM. It is therefore important for the assessment to predict the price of PGM in 2010. This prediction however proves to be extremely difficult. The PGM price is market (supply and demand) based and has been unstable during the time automotive catalysts have been used. Next to the automotive use, precious metal is also used for industrial catalysis, constructions and for jewellery. With an increasing demand for PGM from the automotive industry over the last decade (especially Pt) and mining capacity staying behind, a shortage of Pt has occurred. Because of this, the price of Pt has reached an all time high in the spring of 2004, which was more or less the moment at which the stakeholders made up their minds about the costs to be linked to the EC questionnaire.

  After detailed discussions with relevant experts on the topic of PGM demand and supply, it became reasonable to assume that the 2004 PGM price was really an all time high. Recent developments like large increasing mining capacity between 2004 and 2010 and a shift towards more and much cheaper Pd (instead of Pt) in future catalyst will probably lead to gradual stabilisation of the market. Due to this development the PGM price for the typical automotive PGM combination in 2010 could be situated around the average PGM price over the period between 1999 and 2004. Prominent PGM trading companies predict a significant drop in PGM price over the next years as well. Combination of the views of the PGM experts has lead to a price correction of the questionnaires PGM price of -30% for 2010.
- As far as the panel is informed the cost data supplied are based on uncertain production volumes of certain typical components in 2010. This leads to the panel's conclusion that cost figures for especially DeNOx and DPF (but also high pressure injection units) in 2010 and later, could be lower than expressed by the stakeholders now, if large volumes of the total new sold vehicles would be equipped with these components. Because of this aspect costs data should be seen as worst case.

The combination of the “min” and ”max” technology applications for each of the EC's scenarios with the cost data made available to the panel, lead to the additional costs as displayed in the next tables.

Table 6 Additional costs (€) for Passenger car CI from Euro 4 to Euro 5 in 2010

	limits (mg/km)	Engine Volume (l)	min	max
Scenario 1	PM: 2.5 NOx: 75	<1.4	758	758
		1.4-2.0	920	920
		>2.0 medium	1210	1210
		>2.0 large	1936	1936
Scenario 2	PM: 2.5 NOx: 150	<1.4	402	743
		1.4-2.0	517	974
		>2.0 medium	1091	1271
		>2.0 large	1796	2110
Scenario 3	PM: 8.5 NOx: 75	<1.4	630	758
		1.4-2.0	878	920
		>2.0 medium	1091	1210
		>2.0 large	1796	1936
Scenario 4	PM: 8.5 NOx: 150	<1.4	274	743
		1.4-2.0	475	974
		>2.0 medium	629	1271
		>2.0 large	1796	2110
Scenario 5	PM: 12.5 NOx: 75	<1.4	630	672
		1.4-2.0	760	802
		>2.0 medium	933	1052
		>2.0 large	1483	1623
Scenario 6	PM: 12.5 NOx: 150	<1.4	98	559
		1.4-2.0	357	856
		>2.0 medium	471	1114
		>2.0 large	1483	1798

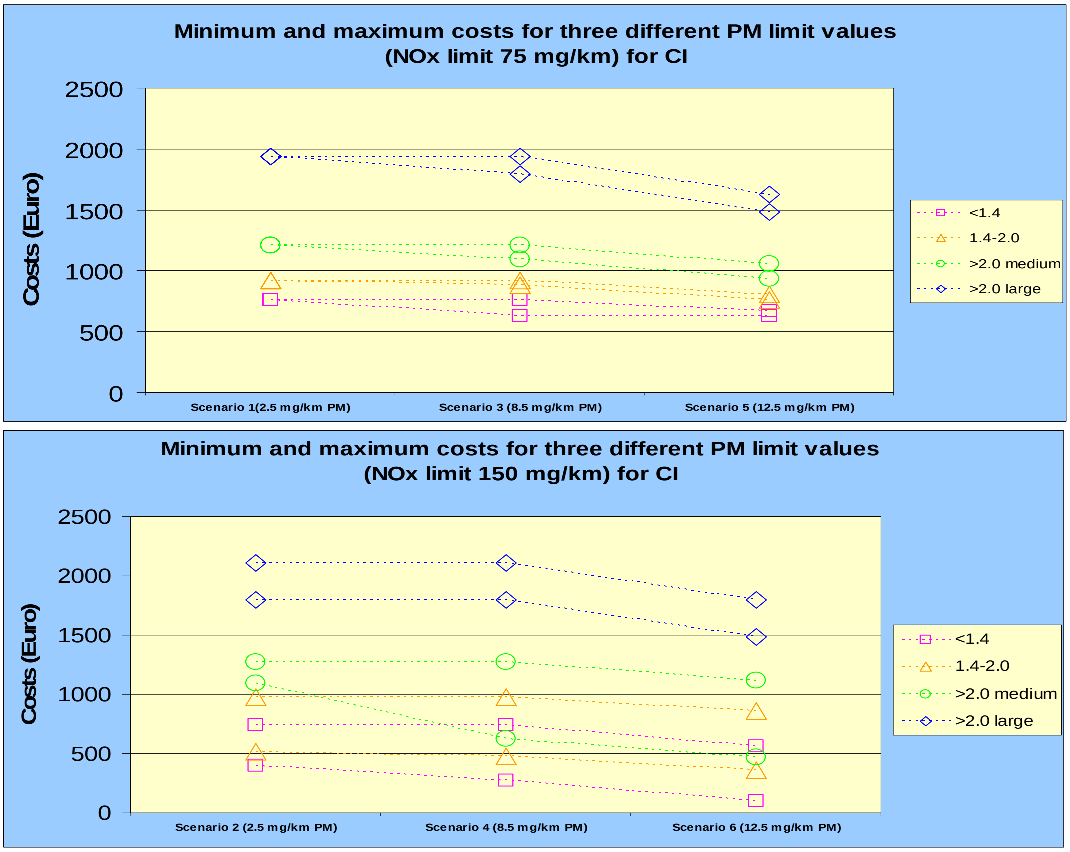


Figure 9 C1 Minimum and maximum costs

Table 7 Additional costs(€) for Passenger cars SI lambda 1 from Euro 4 to Euro 5 in 2010

	limits (mg/km)	**Engine Volume (l)**	**Min**	**max**
Scenario 1	**HC: 50** **NOx: 24** **PM: 2.5**	<1.4	33	156
		1.4-2.0	55	212
		>2.0 medium	82	295
		>2.0 large	132	389
Scenario 2	**HC: 75** **NOx: 48** **PM: 2.5**	<1.4	14	137
		1.4-2.0	24	180
		>2.0 medium	35	248
		>2.0 large	56	314
Scenario 3	**HC: 100** **NOx: 80** **PM: 2.5**	<1.4	0	0
		1.4-2.0	0	0
		>2.0 medium	0	0
		>2.0 large	0	0
Scenario 4	**HC: 100** **NOx: 24**	<1.4	33	156
		1.4-2.0	55	212
		>2.0 medium	82	295
		>2.0 large	132	389
Scenario 5	**HC: 100** **NOx: 48**	<1.4	14	137
		1.4-2.0	24	180
		>2.0 medium	35	248
		>2.0 large	56	314
Scenario 6	**HC: 100** **NOx: 40**	<1.4	14	137
		1.4-2.0	24	180
		>2.0 medium	35	248
		>2.0 large	56	314

Figure 10 S1 Minimum and maximum costs

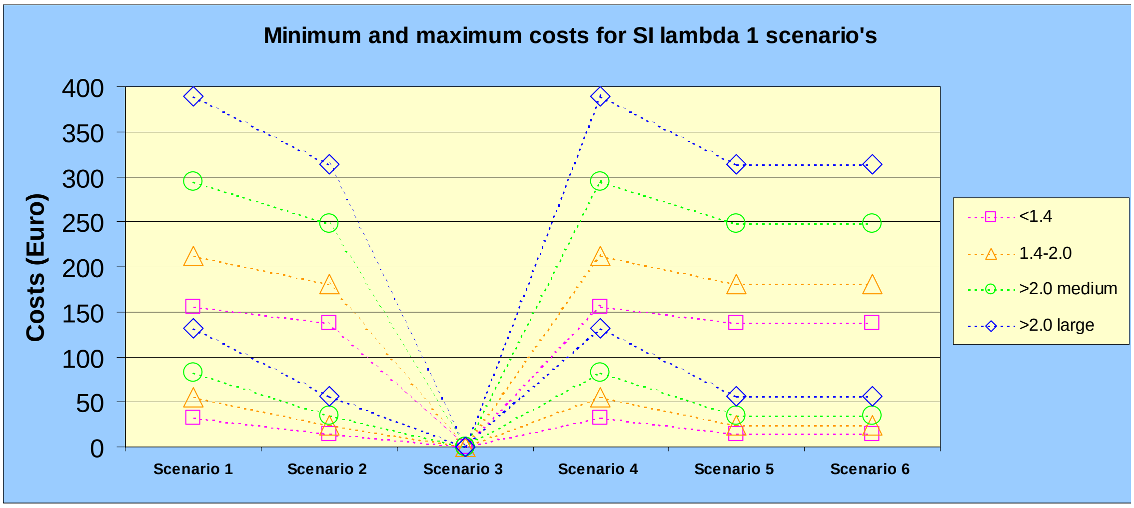
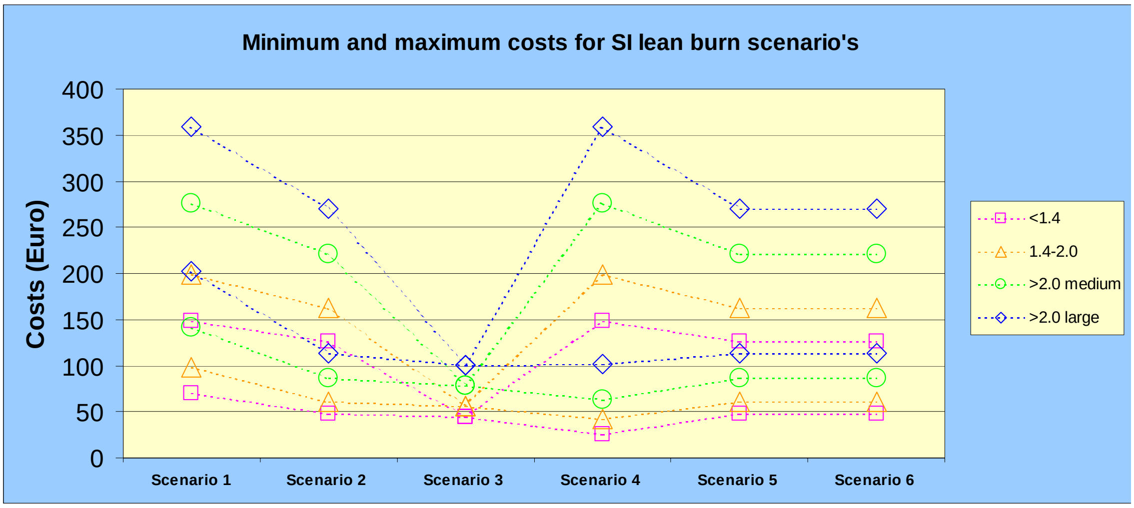


Table 8 Additional costs (€) for Passenger cars SI lean from Euro 4 to Euro 5 in 2010

	limits (mg/km)	Engine Volume (l)	min	max
Scenario 1	**HC: 50**	<1.4	70	149
	NOx: 24	1.4-2.0	98	199
	PM: 2.5	>2.0 medium	142	276
		>2.0 large	202	359
Scenario 2	**HC: 75**	<1.4	48	126
	NOx: 48	1.4-2.0	61	162
	PM: 2.5	>2.0 medium	86	221
		>2.0 large	114	270
Scenario 3	**HC: 100**	<1.4	45	45
	NOx: 80	1.4-2.0	56	56
	PM: 2.5	>2.0 medium	78	78
		>2.0 large	101	101
Scenario 4	**HC: 100**	<1.4	25	149
	NOx: 24	1.4-2.0	42	199
		>2.0 medium	64	276
		>2.0 large	102	359
Scenario 5	**HC: 100**	<1.4	3	126
	NOx: 48	1.4-2.0	5	162
		>2.0 medium	8	221
		>2.0 large	13	270
Scenario 6	**HC: 100**	<1.4	3	126
	NOx: 40	1.4-2.0	5	162
		>2.0 medium	8	221
		>2.0 large	13	270

Figure 11 S1 Minimum and maximum costs



7 Conclusions

The Euro 5 evaluation panel has assessed the information supplied to the Commission by stakeholders on technologies and costs to meet typical Euro 5 emission limit value settings with regard to coherence and completeness.

Despite a certain paucity of data returned in response to the LDV questionnaire, the panel was able to arrive at a picture of the technologies and costs implied by the scenarios, based on additional stakeholder input and their own knowledge. The panel is reasonably satisfied with the consistency of the costs and associated technologies required for each emissions scenario, and confident that the results presented above are realistic within the assumptions and limitations as explained throughout the report. Key issues and assumptions were:

- the use of costs assumptions for the year 2010 and beyond, based on 2004 costs and production volume data (with the exception of PGM price development and thrifting). This ignores the likely changes in costs due to technical progress and mass production;
- the assumption of a 30% price drop for PGM and a 30% reduction in PGM use (thrifting);
- the decision to allocate ¼ of the costs of engine-side measures to Euro-5;
- the fact that the costs and availability of urea (and distribution) for SCR technology on diesel vehicles have not been taken into account;
- very sparse information on N1 vehicles;
- not being able to take into account development costs.

Apart from these limitations, the output produced will also need some further processing before it can be used in the modelling set-up of the CAFE programme. In particular, assumptions will have to be made on:

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- the share of lambda 1 and lean burn engines in the 2010+ gasoline sales (the TREMOVE model cannot distinguish between these);
- the trade off between Euro 5 technologies and CO_2 emissions;
- the share of heavy (large) M1/N1 vehicles (the model cannot distinguish these from normal vehicles in the >2l category).

The panel cannot further elaborate on these questions. It will be up to the Commission to decide how to use the information presented here in the impact assessment of a proposal for a Euro-5 standard.

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A Detailed scenarios

DIESEL (Compression-ignition engine SCENARIOS (CI))

Scenario 1 CI		Passenger cars	Class I	Class II	Class III
Compression-ignition engines	**CO**	no change (0.5 g/km)	no change (0.5 g/km)	no change (0.63 g/km)	no change (0.74 g/km)
	HC	~ no change (0.06 g/km)	~ no change (0.06 g/km)	~ no change (0.08 g/km)	~ no change (0.1 g/km)
	NOx	-70% (75 mg/km)	-70% (75 mg/km)	-70% (100 mg/km)	-70% (117 mg/km)
	PM	-90% (2.5 mg/km)	-90% (2.5 mg/km)	-90% (4 mg/km)	-90% (6 mg/km)
	PM new metric	review at later date	review at later date	review at later date	review at later date

Scenario 1 CI (compression-ignition)

S1 CI: -70% NOx, -90% PM. No change CO & HC from Euro 4.

Limits for classes II & III in same proportion as Euro 4 between passenger cars & LCV classes II & III.

Scenario 2 CI		Passenger cars	Class I	Class II	Class III
Compression-ignition engines	**CO**	no change (0.5 g/km)	no change (0.5 g/km)	no change (0.63 g/km)	no change (0.74 g/km)
	HC	~ no change (0.06 g/km)	~ no change (0.06 g/km)	~ no change (0.08 g/km)	~ no change (0.1 g/km)
	NOx	-40% (150 mg/km)	-40% (150 mg/km)	-40% (200 mg/km)	-40% (230 mg/km)
	PM	-90% (2.5 mg/km)	-90% (2.5 mg/km)	-90% (4 mg/km)	-90% (6 mg/km)
	PM new metric	review at later date	review at later date	review at later date	review at later date

Scenario 2 CI (compression-ignition)

S2 CI: -40% NOx, -90% PM. No change CO & HC from Euro 4.

Limits for classes II & III in same proportion as Euro 4 between passenger cars & LCV classes II & III.

Scenario 3 CI		Passenger cars	Class I	Class II	Class III
Compression-ignition engines	**CO**	no change (0.5 g/km)	no change (0.5 g/km)	no change (0.63 g/km)	no change (0.74 g/km)
	HC	~ no change (0.06 g/km)	~ no change (0.06 g/km)	~ no change (0.08 g/km)	~ no change (0.1 g/km)
	NOx	-70% (75 mg/km)	-70% (75 mg/km)	-70% (100 mg/km)	-70% (117 mg/km)
	PM	-66% (8.5 mg/km)	-66% (8.5 mg/km)	-66% (13.6 mg/km)	-66% (20.4 mg/km)
	PM new metric	review at later date	review at later date	review at later date	review at later date

Scenario 3 CI (compression-ignition)

S3 CI: -70% NOx, -66% PM. No change CO & HC from Euro 4.

Limits for classes II & III in same proportion as Euro 4 between passenger cars & LCV classes II & III.

Scenario 4 CI		Passenger cars	Class I	Class II	Class III
Compression-ignition engines	**CO**	no change (0.5 g/km)	no change (0.5 g/km)	no change (0.63 g/km)	no change (0.74 g/km)
	HC	~ no change (0.06 g/km)	~ no change (0.06 g/km)	~ no change (0.08 g/km)	~ no change (0.1 g/km)
	NOx	-40% (150 mg/km)	-40% (150 mg/km)	-40% (200 mg/km)	-40% (230 mg/km)
	PM	-66% (8.5 mg/km)	-66% (8.5 mg/km)	-66% (13.6 mg/km)	-66% (20.4 mg/km)
	PM new metric	review at later date	review at later date	review at later date	review at later date

Scenario 4 CI (compression-ignition)

S4 CI: -40% NOx, -66% PM. No change CO & HC from Euro 4.

Limits for classes II & III in same proportion as Euro 4 between passenger cars & LCV classes II & III.

Scenario 5 CI		Passenger cars	Class I	Class II	Class III
Compression-ignition engines	**CO**	no change (0.5 g/km)	no change (0.5 g/km)	no change (0.63 g/km)	no change (0.74 g/km)
	HC	~ no change (0.06 g/km)	~ no change (0.06 g/km)	~ no change (0.08 g/km)	~ no change (0.1 g/km)
	NOx	-70% (75 mg/km)	-70% (75 mg/km)	-70% (100 mg/km)	-70% (117 mg/km)
	PM	-50% (12.5 mg/km)	-50% (12.5 mg/km)	-50% (20 mg/km)	-50% (30 mg/km)
	PM new metric	review at later date	review at later date	review at later date	review at later date

Scenario 5 CI (compression-ignition)

S5 CI: -70% NOx, -50% PM. No change CO & HC from Euro 4.

Limits for classes II & III in same proportion as Euro 4 between passenger cars & LCV classes II & III.

Scenario 6 CI		Passenger cars	Class I	Class II	Class III
Compression-ignition engines	**CO**	no change (0.5 g/km)	no change (0.5 g/km)	no change (0.63 g/km)	no change (0.74 g/km)
	HC	~ no change (0.06 g/km)	~ no change (0.06 g/km)	~ no change (0.08 g/km)	~ no change (0.1 g/km)
	NOx	-40% (150 mg/km)	-40% (150 mg/km)	-40% (200 mg/km)	-40% (230 mg/km)
	PM	-50% (12.5 mg/km)	-50% (12.5 mg/km)	-50% (20 mg/km)	-50% (30 mg/km)
	PM new metric	review at later date	review at later date	review at later date	review at later date

Scenario 6 CI (compression-ignition)

S6 CI: -40% NOx, -50% PM. No change CO & HC from Euro 4.

Limits for classes II & III in same proportion as Euro 4 between passenger cars & LCV classes II & III.

Scenario 7 CI		Class I	Class II (1,305 kg -->)
Compression-ignition engines	**CO**	no change (0.5 g/km)	no change (0.637 g/km)
	HC	~ no change (0.06 g/km)	~ no change (0.08 g/km)
	NOx	-50% (125 mg/km)	-50% (165 mg/km)
	PM	-66% (8.5 mg/km)	-66% (13.6 mg/km)
	PM new metric	review at later date	review at later date

Scenario 7 CI (compression-ignition) LCV only

S7 CI: -50% NOx, -66% PM. No change CO & HC from Euro 4.

Classes II & III merged into one weight class (category N1, 1,305 kg and above).

PETROL (Spark-ignition engine SCENARIOS (SI)

Scenario 1 SI		Passenger cars	Class I	Class II	Class III
Spark-ignition engines	CO	no change (1.0 g/km)	no change (1.0 g/km)	no change (1.81 g/km)	no change (2.27 g/km)
	HC	-50% (50 mg/km)	-50% (50 mg/km)	-50% (65 mg/km)	-50% (80 mg/km)
	NOx	-70% (24 mg/km)	-70% (24 mg/km)	-70% (30 mg/km)	-70% (33 mg/km)
	PM	2.5 mg/km	2.5 mg/km	4 mg/km	6 mg/km
	PM new metric	review at later date	review at later date	review at later date	review at later date

Scenario 1 SI (spark-ignition)

S1 SI: -70% NOx & -50% HC. No change CO. New limit for total PM mass (direct injection if part of a technology solution).

Limits for classes II & III in same proportion as Euro 4 between passenger cars & LCV classes II & III.

Scenario 2 SI		Passenger cars	Class I	Class II	Class III
Spark-ignition engines	CO	no change (1.0 g/km)	no change (1.0 g/km)	-44% (1.0 g/km)	-55% (1.0 g/km)
	HC	-25% (75 mg/km)	-25% (75 mg/km)	-25% (100 mg/km)	-25% (120 mg/km)
	NOx	-40% (48 mg/km)	-40% (48 mg/km)	-40% (60 mg/km)	-40% (66 mg/km)
	PM	2.5 mg/km	2.5 mg/km	4 mg/km	6 mg/km
	PM new metric	review at later date	review at later date	review at later date	review at later date

Scenario 2 SI (spark-ignition)

S2 SI: -40% NOx & -25% HC. No change CO. New limit for total PM mass (direct injection if part of a technology solution).

Limits for classes II & III in same proportion as Euro 4 between passenger cars & LCV classes II & III.

Scenario 3 SI		Passenger cars	Class I	Class II	Class III
Spark-ignition engines	CO	no change (1.0 g/km)	no change (1.0 g/km)	no change (1.81 g/km)	no change (2.27 g/km)
	HC	no change (100 mg/km)	no change (100 mg/km)	no change (130 mg/km)	no change (160 mg/km)
	NOx	no change (80 mg/km)	no change (80 mg/km)	no change (100 mg/km)	no change (110 mg/km)
	PM	2.5 mg/km	2.5 mg/km	4 mg/km	6 mg/km
	PM new metric	review at later date	review at later date	review at later date	review at later date

Scenario 3 SI (spark-ignition)

S3 SI: No change to Euro 4. New limit for total PM mass (direct injection if part of a technology solution).

Limits for classes II & III in same proportion as Euro 4 between passenger cars & LCV classes II & III.

Scenario 4 SI		Passenger cars	Class I	Class II	Class III
Spark-ignition engines	CO	no change (1.0 g/km)	no change (1.0 g/km)	no change (1.81 g/km)	no change (2.27 g/km)
	HC	no change (100 mg/km)	no change (100 mg/km)	no change (130 mg/km)	no change (160 mg/km)
	NOx	-70% (24 mg/km)	-70% (24 mg/km)	-70% (30 mg/km)	-70% (33 mg/km)
	PM				
	PM new metric	review at later date	review at later date	review at later date	review at later date

Scenario 4 SI (spark-ignition)

S4 SI: -70% NOx. No change CO & HC from Euro 4.

Limits for classes II & III in same proportion as Euro 4 between passenger cars & LCV classes II & III.

Scenario 5 SI		Passenger cars	Class I	Class II	Class III
Spark-ignition engines	CO	no change (1.0 g/km)	no change (1.0 g/km)	no change (1.81 g/km)	no change (2.27 g/km)
	HC	no change (100 mg/km)	no change (100 mg/km)	no change (130 mg/km)	no change (160 mg/km)
	NOx	-40% (48 mg/km)	-40% (48 mg/km)	-40% (60 mg/km)	-40% (66 mg/km)
	PM				
	PM new metric	review at later date	review at later date	review at later date	review at later date

Scenario 5 SI (spark-ignition)

S5 SI: -40% NOx. No change CO & HC from Euro 4.

Limits for classes II & III in same proportion as Euro 4 between passenger cars & LCV classes II & III.

Scenario 6 SI		Class I	Class II (1,305 kg -->)
Spark-ignition engines	CO	no change (1.0 g/km)	1.81 g/km
	HC	no change (100 mg/km)	130 mg/km
	NOx	-50% (40 mg/km)	-50% (50 mg/km)
	PM		
	PM new metric	review at later date	review at later date

Scenario 6 SI (spark-ignition)

S6 SI: -50% NOx. No change CO & HC from Euro 4.

Classes II & III merged into one weight class (category N1, 1,305 kg and above).

Euro 4 Emission limit values per vehicle class

Euro 4		Passenger cars	Class I	Class II	Class III
Spark-ignition engines	CO	1	1	1,81	2,27
	HC	0,1	0,1	0,13	0,16
	NOx	0,08	0,08	0,1	0,11
	PM	-	-	-	-
Compression-ignition engines	CO	0,5	0,5	0,63	0,74
	NOx	0,25	0,25	0,33	0,39
	PM	0,025	0,025	0,04	0,06

B DPF equipped vehicles in 2004

Table B.1 Vehicle models equipped with Diesel particle filters offered in the German market
Status 15 October 2004 Source Verkehrsclub Deutschland (VCD) www.vcd.org

Manufacturer	Model	Power (KW)	Emission Standard	Price Euro	Availability	Series/ Surcharge (euro)
AUDI	A4 2,0 TDI	103	Euro4		1st Quarter 2005	Surcharge approx. 600
	A4 3,0 TDI	150	Euro4	35.900	immediately	Surcharge 690
	A6 3,0 TDI	165	Euro4	42.900	November 2004	Surcharge 690
	A8 3,0 TDI	171	Euro4	61.300	immediately	Surcharge 690
BMW	525d	130	Euro4	38.550	immediately	in series
	525d Touring	130	Euro4	40.950	immediately	in series
	530d/Touring	160	Euro4	41.650	immediately	in series
	535d/Touring	200	Euro4	49.300	immediately	in series
CITROEN	Xsara Picasso HDi 1 10 FAP	80	Euro4	23.160	immediately	in series
	C5 HDi 110 Style FAP	80	Euro4	22.490	October 2004	in series
	C5 HDi 135 FAP Tendance	100	Euro4	25.690	October 2004	in series
	C5 HDi 1 10 FAP Style combination	80	Euro 4	23.490	October 2004	in series
	C8 2.0 HDi FAP	79	Euro3	27.360	immediately	in series
	C8 2.2 Hdi 130SX FAP	94	Euro3	28.880	immediately	in series

Manufacturer	Model	Power (KW)	Emission Standard	Price Euro	Availability	Series/ Surcharge (euro)
FIAT	Ulysse 2,2 JTD	94	Euro3, Euro4 in 2004	27.500	immediately	in series
	Lancia Phedra 2,2 16 V JTD	94	Euro3, Euro4 in 2004	32.400	immediately	in series
FORD	Ford focus TDCi 1 6	80,100	Euro4	17.350	4th Quarter 2004	Surcharge 600
	Ford focus TDCi 2.0		Euro4	19.975	4th Quarter 2004	surcharge 600
	Focus C-max TDCi 1 6	80	Euro4	20.050	immediately	Surcharge 600
	Focus C-max TDCi 2.0	100	Euro4	23.750	immediately	Surcharge 600
Mercedes Benz	A160CDI	60	Euro4	19.024	1st Quarter 2005	Surcharge 522
	A180CDI	80	Euro4	20.532	1st Quarter 2005	Surcharge 522
	A 200 CDI	103	Euro4	24.302	1st Quarter 2005	Surcharge 522
	C 200 CDI / T	90	Euro4	29.116	immediately	Surcharge 580
	C 220 CDI / T	110	Euro4	31 262	immediately	Surcharge 580
	E 200 CDI	90	Euro4	34.684	immediately	Surcharge 580
	E 220 CDI / T	110	Euro4	37.294	immediately	Surcharge 580
	E 280 CDI / T	130	Euro4	42.340	immediately	in series
	E 320 CDI / T	150	Euro4	45.066	immediately	Surcharge 696
	S 320 CDI	150	Euro4	62.234	immediately	Surcharge 696
	Viano 2,0 CDI	80	Euro4 *	32.819	January 2005	Surcharge 806
	Viano 2,2 CDI	110	Euro4 *	34.298	January 2005	Surcharge 806

Manufacturer	Model	Power (KW)	Emission Standard	Price Euro	Availability	Series/ Surcharge (euro)
OPEL	Astra 1 9 CDTI	88	Euro4	19.495	November 2004	Surcharge 495
	Astra 1 9 CDTI	110	Euro4	19.995	November 2004	Surcharge 495
	Vectra 1 9 CDTI Ecotec	88	Euro4	24.045	immediately	in series
	Vectra 1 9 CDTI Ecotec caravan	88	Euro4	25.295	immediately	in series
	Vectra 1 9 CDTI Ecotec	110	Euro4	24.845	immediately	in series
	Vectra 1 9 CDTI Ecotec caravan	110	Euro4	26.095	immediately	in series
	Signum 1 9 CDTI Ecotec	88	Euro4	25.595	immediately	in series
	Signum 1 9 CDTI Ecotec	110	Euro4	26.395	immediately	in series
PEUGEOT	206 Tendance HDi FAP 110	80	Euro4	16.400	immediately	in series
	206 SW Tendance HDi FAP 110	80	Euro4	17.800	immediately	in series
	307 Grand Filou/Tendance HDi FAP 110	80	Euro4	17.450	immediately	in series
	307 Tendance HDi FAP 135	100	Euro4	20.550	immediately	in series
	307 BREAK Grand Filou HDi FAP 110	80	Euro4	20.900	immediately	in series
	307 SW Premium HDi FAP 135	100	Euro4	23.800	immediately	in series
	407 Esplanade HDi FAP 110	80	Euro4	22.100	immediately	in series
	407 SW HDi FAP 110	80	Euro4	23.400	immediately	in series
	407 Esplanade HDi FAP 135	100	Euro4	23.600	immediately	in series
	407 SW HDi FAP 135	100	Euro4	24.900	immediately	in series
	607 Reference HDi FAP 135	98	Euro3	31.100	immediately	in series

Manufacturer	Model	Power (KW)	Emission Standard	Price Euro	Availability	Series/ Surcharge (euro)
PEUGEOT	807 HDi Esplanade FAP 110	79	Euro3	27.350	immediately	in series
	807 Platinum Pullmann Hdi FAP 13	94	Euro3	35.500	immediately	in series
RENAULT	Laguna Lim. 2.2 dCi	102	Euro4	27.050	immediately	in series
	Laguna Grandtour 2.2. dCi	102	Euro4	26.200	immediately	in series
	Vel Satis 2,2 dCi	102	Euro4	33.100	immediately	in series
SAAB	93 1 9 TiD	88	Euro4	25.500	immediately	in series
	93 1 9 TiD	110	Euro4	26.800	immediately	in series
TOYOTA	Avensis D-Cat	85	Euro4	24.300	immediately	Surcharge 800
VOLVO	S40 2,0 D	100	Euro4	23.950	immediately	Surcharge 600
	V50 2,0 D	100	Euro4	25.450	immediately	Surcharge 600
VW	GolfV1.9TDI	77	Euro4		End of 2004	Surcharge 565
	GolfV2.0TDI	103	Euro4	20.620	Autumn 2004	Surcharge 565
	Trade wind 2,0 TDI	100	Euro4	26.200	immediately	in series
	Trade wind 2,0 TDI Variant	100	Euro4	27.300	immediately	in series
	Phaeton V6 TDI 3.0	165	Euro4	60.480	November 2004	in series
	Touareg V6 TDI 3.0	165	Euro4 *	46.050	End of 2004	in series
	Touareg V10TDI	230	Euro4 *	72.450	Beginning of 2005	in series

* Euro 4 for N1 vehicles

C Cost model overview

🟩	Panel estimate based on stakeholder input
🟥	Direct stakeholder input (not all cells filled and large bandwith)
🟨	Calculation
🟪	Calculated panel output matched with direct stakeholder input

Swept volume specific cost build up for after treatment device

ECT	PGM / litre 2005	PGM price index 2010	Thrifting index 2010	Canning / litre	Monolith / litre	Washcooat / litre	Total Cost per litre 2010
DPF closed DPF open Lean Denox store 150 Lean Denox store 75 Lean Denox cont 150 Lean Denox cont 75	🟩	🟥	🟥	🟩	🟩	🟩	🟨
cell number	1	2	3	4	5	6	7
cell content	cost	factor	factor	cost	cost	cost	1*2*3+4+5+6

Cost build up per technology

CI Engine Volume

<1.4	technology	spec. catalyst Volume	cost catalyst/filter	ref. cost catalyst/filter stakeholders input	lambda sensor	Temperature sensor	Pressure Sensor	NOx Sensor+pump	design/validation	engine modifications	ss component	packaging	total costs 2005 Panel	total costs 2005 stakeholders	inflation	total costs 2010 assessment
	SEIM MEIM									🟩			🟪	🟥	🟩	🟨
	DPF closed DPF open Lean Denox store 150 Lean Denox cont 150 Lean Denox store 75 Lean Denox cont 75	🟩	🟪	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟪	🟥	🟩	🟨
1.4<l<2.0																
	SEIM MEIM									🟩			🟪	🟥	🟩	🟨
	DPF closed DPF open Lean Denox store 150 Lean Denox cont 150 Lean Denox store 75 Lean Denox cont 75	🟩	🟪	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟪	🟥	🟩	🟨
>2.0																
	SEIM MEIM									🟩			🟪	🟥	🟩	🟨
	DPF closed DPF open Lean Denox store 150 Lean Denox cont 150 Lean Denox store 75 Lean Denox cont 75	🟩	🟪	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟪	🟥	🟩	🟨
>>2.0																
	SEIM MEIM									🟩			🟪	🟥	🟩	🟨
	DPF closed DPF open Lean Denox store 150 Lean Denox cont 150 Lean Denox store 75 Lean Denox cont 75	🟩	🟪	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟪	🟥	🟩	🟨
cell number		8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
cell content		swept vulome*factor	7*8	cost	cost	cost	cost	cost	cost	cost	cost	cost	+11+12+13+14+15+16+17+1	cost	factor	19*21