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Lead markets for environmental technologies: The case of the particulate filter for Diesel passenger cars

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Abstract:
Technologies which reduce the level of pollutants in the exhaust fumes of diesel vehicles are a key factor in enabling future emissions ceilings to be satisfied. In principle, a reduction of pollution by automobiles is achieved by way of politically prescribed ceilings and adherence thereto based on advanced vehicle engineering. The diffusion of such technology, however, is not simply a matter of the interplay of political regulation and response by carmakers. It is a complex process contingent on and shaped by a variety of factors. This case study uses the example of introduction of the particulate filter for diesel vehicles on the German market to examine how emissions ceilings come about as well as the technological development strategies employed by carmakers to meet those ceilings. Our study will show that Peugeot, an automobile manufacturer, through its early introduction of technology designed to meet prospective emissions ceilings (i.e. standards already resolved but not yet put into effect), created favourable preliminary conditions on the basis of which to develop a lead market. Political steering instruments, however, proved to have a predominantly impeding effect in terms of market constitution, with players from commercial enterprise taking on a more dominant role in the process. This case study illustrates that engineering competency in the field of pollutant reduction can be a competitive advantage for vehicle manufacturers and that such competency is an imperative prerequisite for companies wishing to access new markets, given the long-term international tendency to lower emissions ceilings.

Zusammenfassung: Technologien zur Reduktion von Schadstoffen in den Abgasen von Diesel-Pkw sind für die Einhaltung zukünftiger Schadstoffemissionsgrenzwerte von zentraler Bedeutung. Prinzipiell kommen Schadstoffreduktionen von Automobilen durch politische Verordnung von Grenzwerten und deren Einhaltung durch technologische Weiterentwicklungen der Fahrzeuge zu Stande. Die Diffusion der Technologien ist allerdings kein simples Wechselspiel von politischer Vorlage und Reaktion der Automobilhersteller, sondern ein komplexer Prozess, der durch eine Vielzahl von Faktoren bedingt und gestaltet wird. Die Fallstudie untersucht am Beispiel der Einführung des Partikelfilters für Diesel-Pkw auf dem deutschen Markt, wie Emissionsgrenzwerte zu Stande kommen und welche technologischen Entwicklungsstrategien die Automobilhersteller zu ihrer Einhaltung verfolgen. Es zeigt sich, dass der Automobilhersteller Peugeot durch die verfrühte Einführung einer Technologie zur Einhaltung schon beschlossener, aber noch nicht gültiger Grenzwerte günstige Vorbedingungen für die Entstehung eines Lead-Marktes geschaffen hat. Politische Steuerungsmuster erwiesen sich allerdings für die Konstitution des Marktes als eher hemmend, eine größere Bedeutung kommt zivilgesellschaftlichen Akteuren zu. Die Fallstudie illustriert, dass technologische Kompetenz im Bereich Schadstoffreduktion ein Wettbewerbsvorteil für Automobilhersteller sein kann und angesichts des langfristigen, internationalen Trends zur Verschärfung von Schadstoffgrenzwerten zur Erschließung neuer Märkte unabdingbar ist.
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1. Introduction

The automobile sector is a central industry in all industrialised countries, contributing between four and eight percent of GDP in OECD countries and providing between two and four percent of all jobs. The UN estimates that, for every skilled job in the automobile industry, seven to ten jobs are created in related sectors. (UN 2002:12).

By the same token, however, both the production process and the operation of automobiles are associated with serious environmental risk and environmental damage. Road traffic is one of the biggest sources of atmospheric pollution and has a particularly strong impact on air quality in towns and cities. Vehicle exhausts contain the pollutants carbon monoxide, nitrogen oxides, hydrocarbons and particle mass. In spite of the reduction in exhaust contaminants achieved in industrialised countries for individual vehicles (using technology such as the three-way catalytic converter), chances are that the continued increase in the number of kilometres driven as well as in the absolute number of automobiles on our roads will produce further increases in the overall burden through such contaminants (Ifeu 2001), in addition to which vehicle emissions of carbon dioxides are a major contributor to the greenhouse effect.

The regulation of vehicle emissions is a political field which is strongly influenced by vested economic interests as well as ecological objectives. The highly technical regulating process for exhaust ceilings by the EU is a strongly politicised one, since it is pegged to the economic and political interests of member states. The automobile industry, however, is also actively involved in the regulating process. Indeed, it is important to analyse the industry's contribution to this process in order to understand its results (Arp 1993). When the EU first began regulating exhaust ceilings, the desire to establish a uniform market through the standardisation of technical criteria in automobiles played a more substantial role in the development of ceilings than did environment-policy considerations. The fact that emissions standards within the EU have been consistently raised is not, however, owing to any greater value placed on ecological goals, but is attributable case by case to the respective special interests and strategies of the players involved as well as the political control concept inherent in the regulating process as economic integration is pursued (Arp 2002). But economic and environmental goals are not necessarily contradictory. In principle, a reduction of pollution by automobiles is achieved by way of politically prescribed ceilings and the adherence thereto based on advanced vehicle engineering. The spread of such technology, however, is not simply a matter of the interplay of political regulation and response by carmakers. It is a complex process contingent on and shaped by a variety of factors.

Even beyond the borders of the European Union, economic integration through international automobile trading between Europe, the USA and Japan would appear to be instrumental in promoting the introduction of more stringent emissions standards. Indeed, even where individual national policy makers are implementing isolated environment strategies, growing trade intercourse among the different nations is helping to raise ecological standards in the countries involved in such trade. This application of more rigorous environment regulations as a result of greater economic integration is called the California Effect. For more than 30 years now, California – because of its high population level one of the key automobile markets in the US – has been setting the benchmark in the USA in terms of its strict emissions ceilings, with federal policy makers and individual states eventually following its lead whenever it moves the goalposts. This effect is easily explained. Carmakers who wish to remain in business on the Californian market are obliged to respond to the standards prescribed in that state by continually improving the emissions performance of their vehicles. Once automobile manufacturers have developed their products to comply with the stricter standards which this market versus others imposes on them, they will have a vested interest in seeing the standards raised in other markets, thus enabling them to leverage their new-found competitive advantage and to manufacture their new products at a lower cost. This, in turn, leads to national governments promoting stricter standards in support of their domestic industries. At the end of the day, the automobile industry itself, normally opposed to more restrictive standards, actually works towards their introduction (Vogel 1995, 1999). As a consequence, the afore-described markets which spearhead this development become lead markets, since they are responsible for the spread of political standards and green technologies.

The exhausts produced by diesel vehicles are also accountable for a substantial share of air pollution. Diesel technology remains under discussion for the following two reason: First, because the health hazard posed by particulate emissions (they damage the respiratory tracts and the cardiovascular system and are also carcinogenic) and the impact on the environment of nitrogen oxides (acidification and ozone formation) are still controversial issues. The biggest health hazard is probably posed by nanoparticles, the absolute number of which need not be reduced if, for example, the overall particle mass can be reduced by means of the better combustion of larger particles. The size of particles is contingent, among other factors, on the type of engine used, and there are concerns that, while modern engines featuring fuel-injection technology may produce less particle mass, they could nonetheless be producing larger amounts of ultra-fine particles and nanoparticles (Abdul-Khalek et al. 1998, Kittelson 2001, Diabaté 2003). A recent study by the German Federal Environmental Agency (UBA) estimates that particulate emissions from Diesel engines cause 10.000 to 18.000 premature deaths in Germany through respiratory and cardiovascular diseases as well as lung cancer each year (Wichmann 2003). Second, because recent studies have indicated that particulate emissions contribute far more potently to the greenhouse effect than previously assumed (Jacobson 2002). This finding is of particular significance given that German carmakers have entered self-imposed commitments which include a stronger marketing of diesel vehicles as a way of reducing emissions of carbon dioxide (VDA 2000: 134).

The aim of this case study is to examine a) how emissions standards are devised and how they evolve, b) the markets which develop by regulating standards and c) the technological strategies carmakers use to conform with such standards. The subject of our study was the technology used to reduce particle mass (nitrogen oxides) in the exhaust emissions of diesel vehicle. We will be discussing the extent to which and under which conditions lead markets develop for the applicable green technologies and which role policy makers play in steering such development.

2. Emissions regulation in the automobile industry

The first exhaust standards to be introduced for passenger cars and heavy vehicles by the EU were contained in its Directive 70/220/EEC. The ceilings it prescribed were far less stringent than those in Japan and the USA, with compliance requiring little to no technical modification. The primary objective of this directive was to create technically uniform standards to facilitate trade amongst EU member states. It was only in the early 80s that the discourse on stricter emissions standards took on a sharper tone in Europe. Germany's federal government, followed by the Netherlands, Denmark and Greece, began to question its course of prioritising economic harmonisation on the reduction of hazardous emissions given clear evidence of environmental damage as well as mounting public pressure.

The regulating process set into motion at that time was strongly marked by the conflicts of interest among individual member states whose diverging positions were based on the technological competence of their national automobile industries and on their differing perceptions of the ecological problems involved. Germany, supported by Greece, Denmark and the Netherlands, insisted on emissions standards which would require the introduction of three-way catalytic converters for petrol-engine cars – a technology with which sections of the German industry had already gained some experience. France, the UK, Spain and Italy opposed more stringent standards, since their national automobile industries favoured the lean burn engine (a less efficient solution for reducing vehicle emissions) and thus boasted engineering competence in this field. A broad-based and lengthy process of negotiation resulted in the passing of Directive 88/76, a compromise solution which graduated standards according to cubic capacity and which prescribed the three-way catalytic converter for larger classes of vehicle. It was only four years later that Directive 89/458 laid down emissions ceilings which now prescribed the catalytic converter even for vehicles with less cubic capacity.

The 1991 Directive 91/441/EC and the 1994 Directive 94/12/EC stipulated the ceilings for the Euro 1 and Euro 2 standards, respectively, the latter making catalytic converters mandatory for all vehicle classes.[1] The standards for particles and nitrogen oxides in diesel exhaust outlined in Euro 2 remained far less stringent than those dictated by US and Japanese policy makers. The German government, in particular, had advocated stricter ceilings, failing, however, before the European Parliament in the face of a vigorous lobby campaign by the automobile industry. The industry had successfully pressed a case around its claim that the technology needed would generate disproportionately high costs given the level of reduction it would enable (Wurzel 2002: 156).

The currently valid and future emissions ceilings for diesel cars (the Euro 3 standard and the Euro 4 standard as of 2005, respectively) were laid down in Directive 98/69 of 1998. This directive followed a four-year process of research, negotiation and discussion, which can roughly be grouped into two periods. The first consisted of formulation of an initial proposal on future emissions ceilings by the EU Commission based on the Auto Oil I Programme from 1994 to 1996. The second period lasted from 1996 to 1998 and involved public debate over the proposal and its ultimate resolution in the form of the said directive .

[1] See Tiessen 2002 for a detailed description of the negotiation process

2.1 Auto Oil I

The Auto Oil I research programme involved participation by officials from the Commission, the Association of the European Oil Refining and Marketing Industry (Europia) and the Association of European Carmakers (ACEA). The aim of the programme was to provide policy makers with objective information about the most cost-efficient measures with which to reduce traffic pollution to a level which would satisfy the stipulations of the European Union's air purity standards (Com (96) 248 Final).

The Commission hoped the Auto Oil I Programme would enable it to push through tougher exhaust standards, to keep the costs for the industry moderate and to weaken the influence of individual member states – an influence which, in the 80s, was such that it could practically block proposals by the Commission over quite a length of time. Prior to Auto Oil I, prospective emissions ceilings would be discussed and negotiated by the Motor Vehicle Emissions Group (MVEG) before the issue entered the EU's legislative process. MVEG members included representatives from EU governments, industry representatives and EU administrators. To avoid drawn-out discussions which would result in numerous compromises being made (as had been the case for the predecessor body, the Emissions Ceilings Group), the Commission collaborated with the industry only where Auto Oil I was concerned [2]. The Commission also hoped this would enable them to better incorporate and control both industries (Taminiau 2001: 274).

A three-step procedure was adopted for the programme. First, the Commission stipulated future air quality goals for the EU, which were inspired by the WHO air-pollution ceilings. In a second step, a model was drawn up to ascertain how air quality would develop to the year 2010 if exhaust emissions were not reduced. The third part of the process involved outlining the contribution which each industry would have to make to improve air quality. The contributions of industry were to be made contingent on the costs and effectiveness of the measures decided on. Costs were to remain at a minimum, but effectiveness maximised. Three packages of measures to reduce exhaust emissions were given primary consideration: engine-modification measures, fuel optimisation and improvements in vehicle inspection (Godwin 1999).

The possible effects of reduction and the cost of individual measures were examined within the framework of the EPEFE technical research programme, i.e. the European Programme on Emissions, Fuels, and Engine Technologies. EPEFE was jointly run by the Association of European Carmakers (ACEA) and the Europia, the oil industry association, as part of the Auto Oil I Programme. The aim of EPEFE was to gain a better understanding of how engine technology and fuels interacted and what influence they had on pollutants in exhaust fumes. The programme ascertained the reduction potential inherent in individual technical measures and the costs involved. This information was then used to optimise standards.

[2] MVEG, the EU Parliament and environmental organisations were merely given information about the ongoing status of the programme.

2.2 Strategies by the automobile industry as part of Auto Oil I

From the perspective of the industry involved, the Auto Oil I Programme presented a welcome method for determining future emissions ceilings. “The programme,” explained one industry representative, “helped to determine and illustrate the actual costs of any further development.” (ACEA 2003).

Critics of the programme emphasised that both industry associations used their position in the programme to formulate unnecessarily high cost estimates and thus ensure that ceilings were only marginally reduced, so as to keep development costs from being incurred. They also, it was claimed, attempted to offload future costs to the respectively other industry (Taschner 2003, Rodt 2003, Taminau 2001). Since improvements in vehicle emissions levels can be achieved by either means of advances in vehicle engineering or by changes in the composition of fuels, each industry has a vested interest in seeing the regulations which govern the respectively other industry tightened, resulting in the achievement of environmental goals, while the bill for related costs is footed by others (Taminiau 2001: 278). The strategy of industry associations to often put a high price tag on environmental-protection technology, has been adequately substantiated in the past. Industry brandishes the threat of high costs, referring to the impediment such costs represent in terms of competitive strength and ultimately to the loss of jobs this would entail (SIE 1998). Critics attribute the success of industry to the fact that, given the pressure the industry asserted, the Commission’s proposal for Euro 3 and Euro 4 was twice as high as originally planned (Resch 2003, Taminau 2001). The degree of influence wielded by the industry is said to be a consequence of its intimate incorporation into the Auto Oil I Programme and its leadership in terms of technological know-how coupled with the fact that the Commission was understaffed (Taminau 2001, Taschner 2003, Wurzel 2002).

2.3 Outcome of Auto Oil I

And yet the Commission’s first proposal on future emissions standards was nonetheless to the disliking of the automobile industry, since the Commission’s estimate burdened it with 765 million ECU p.a. against the only 3.1 million or so ECU p.a. it charged to the oil industry

(Friedrich et al. 2000). The governments of the different EU member states took differing views on this proposal. Austria, Denmark, Finland, Germany and the Netherlands criticised it as being too slack. Greece, Portugal and Spain expressed their concern about the costs for the oil industry. Italy demanded more stringent restrictions on benzole. France and England alone welcomed the proposal (Wurzel 2002: 166). The European Parliament deemed all the standards applied to be inadequate, putting forward their suggestion for lower ceilings at both readings of the directive concerned. Bernhard Lange, the responsible reporting officer, had previously raised doubt about the cost estimates formulated for individual measures, criticising that they were too high. In light of the technology available and the development potential of such technology, it was possible, he said, to achieve the ceilings for petrol and diesel engines outlined in the proposal for the year 2000 at an earlier date than scheduled. Lange went on to explain that the costs associated with a reduction in nitrogen oxides had been overestimated. While he felt that the targets for 2005 were acceptable, he was convinced that they should be prescribed as mandatory rather than being guideline values. (Lange 1997). Environmental organisations such as the European Environmental Bureau (EEB) likewise criticised the Commission's proposal, explaining that the ceilings it contained were too lax since the stipulated costs in no way reflected the actual costs incurred by technological development. (Taschner 2003).

A compromise between the EU Parliament, the Commission and the Council on these ceilings was ultimately only tailored by the mediation committee[3]. In the case of the upper limit for particle mass and nitrogen oxides, the Parliament only managed to some degree to assert its stance, though it was successful in calling for the standards scheduled for 2005 to be made mandatory and not, as originally planned, to be seen as indicative values. The standards for the year 2000 were not toughened (see Table 1). All further debate on the tightening of emissions ceilings is being discussed with a view to the Euro 4 standard due to become effective in 2005.

Table 1: Emissions ceilings

Pollutant (ceilings in g/km)	Commission proposal	First reading, European Parliament	Joint position of the Council	Second reading, European Parliament	Mediation committee
2000	Euro 3 (2000) mandatory values				
Nitrogen oxides (NO_x)	0.50	0.40	0.50	0.40	0.50
Particles (PM)	0.05	0.04	0.05	0.04	0.05
2005	Euro 4 (2005)				
Nitrogen oxides (NO_x)	0.25 indicative value	0.19 mandatory value	0.25 indicative value	0.19 mandatory value	0.25 mandatory value
Particles (PM)	0.025 indicative value	0.02 mandatory value	0.025 indicative value	0.02 mandatory value	0.025 mandatory value

Sources: Friedrich et al. 2000, Taminiau 2003, EU 2003

2.4 Outlook on future EU emissions standards for diesel vehicles

We can expect to see more stringent emissions ceilings being put into place beyond the year 2005 (Euro 5). The Commission is planning to use the findings of the Clean Air for Europe (CAFE) programme as a basis for Euro 5. Commenced in 2001, the objective of the CAFE programme is to develop integrated, long-term political strategies for air-quality conservation. Initial results are expected in mid-2005. Some of the items of focus in this programme include an examination of existing national and EU air-conservation schemes, the preparation of a catalogue of measures to improve air quality, and the formulation of

[3] See Friedrich et al. 2000 and Wurzel 2002 for details on the negotiation process.

proposals for new EU directives. There are plans to put further restrictions on particle and nitrogen oxide emissions, with a change in the regulation meaning that particle emissions will no longer be gauged according to mass alone, but also according to size. The plans provide for an open, participative process versus a revised version of the Auto Oil I Programme. Initial activities within the EU Commission have been scheduled for this summer (Greening 2003). It is too early at this stage to comment on the level of future values and on when they might be introduced. What is foreseeable is that future negotiations will see existing lines of conflict reaffirmed. Industry representatives, for instance, are already making their position clear that the transportation sector has contributed its share to air-quality conservation and that the onus must now be on other industries to do their part. What’s more, California’s super-ultra low vehicle emissions standard – the toughest of its kind in the world right now – is being rejected as too expensive for the industry (Greening 2003).

There are also discussions ongoing at EU level about the Enhanced Environmentally Friendly Vehicle (EEV) scheme aimed, for one thing, at achieving an extensive degree of equality for all engine concepts and at further reducing emissions. According to the parties involved, this standard will only impact on passenger-vehicle emissions in the long term (Mönch 2003).

2.5 Tax incentives

In Germany, the D4 standard offers tax exemption for vehicles which meet the Euro 4 norm before it becomes effective in 2005. This policy is unparalleled in the EU. Tax incentives for specific technologies such as the particulate filer are not on the books at this point in time. In principle, however, individualised incentives are possible and something which environment associations have repeatedly called for (Rodt 2003).

2.6 Assessing the process from the perspective of technological potential: Technology forcing?

The Auto Oil I Programme sets out a profound revision of the EU regulation on emissions. For the first time ever, standards have been devised on the basis of cost/benefit considerations, where previous ceilings were lowered in response to the best-available technology (Friedrich et al 2000). It is worth noting that, with its Auto Oil I Programme, the EU Commission is not pursuing policy goals aimed at promoting innovation, even though it could well assume that technological innovation would inevitably be forced upon the industry once a particular level of emissions ceilings was prescribed. As early as 1992, representatives of the EU Parliament taking part in a symposium on the future of emissions regulation warned that orienting future standards on the cost/benefit ratio and by-stepping the BAT principle could cost the automobile industry some of its competitive standing in the field of environment-relevant engineering (Wurzel 2002: 157).

To assess current corporate strategies, it is essential to establish to what extent the standards decided in 1998 were technologically feasible at the time. Had the necessary technology been developed, or had it at least been foreseeable, these standards would have constituted nothing more than a response to the technological status quo. If the contrary is true and the technology needed had either not been developed or only in rudimentary form, these standards would have represented a case of technology forcing. As a rule, the prerequisite for introduction of certain standards in Europe is their technical practicability within the stipulated timeframe (Mönch 2003, Rodt 2003), whereby the definition of “technically practicable”, what sort of time scope such practicability entails and what sort of costs will be involved are issues of debate.

In the view of the automobile industry the ceilings proposed by the European Parliament for Euro 3 and Euro 4 would have required a policy of technology forcing. Given the wave of criticism by environmental associations faced during the policy-making process as well as the briefing submitted by the reporting officer, the automobile industry ran a targeted lobby campaign spanning from the time the Commission put forward its proposal to the ultimate resolution of the directive, the aim of the campaign having been to prevent the Parliament from making any changes to the proposal that would entail further restrictions. At hearings, information forums and discussion sessions, the industry presented its cost estimates for any emissions-reduction measures and its view on necessary future exhaust standards, moreover attributing only minimal development potential to technologies which would enable reduced emissions (Taschner 2003, Rodt 2003, Lange 2003).

In the opinion of experts and those involved in the regulating process, the standards adopted for particulate and nitrogen oxide emissions for the Euro 3 norm, due to take effect in 2000, required no special development efforts on the part of carmakers. In this particular case, the industry had successfully flexed its muscles and would now need to make relatively minimal efforts to gear existing technologies to the new standards. It was only the values contained in Euro 4 (valid as of 2005) that would put more pressure on manufacturers in terms of technology development, requiring special development efforts and new engineering solutions altogether. This pressure was brought to bear on the industry by the Parliament, who turned the non-compulsory guideline values for 2005 as proposed by the Commission into binding ones. (Taschner 2003, Lange 2003, Mönch 2003).

It is important to stress at this point that “development pressure” must always be seen as relative to the timeframe component. The Federal Environment Office, for example, came to the conclusion back in 1995 that particulate filters and NO_x traps designed to reduce nitrogen oxide and particulate emissions, i.e. vehicle features such as were necessary to conform with the standards as of 2005, could have been developed to market maturity by around 1998 if an adequate degree of effort had been exercised. (UBA 1995). In summary, we can say of Euro 4 that it was a time-delayed “soft” case of technology forcing. While the necessary technology was not yet available at the time, it was deemed feasible in principle. The only issue of contention was the timeframe required. The UBA and EEB both contended that the standards could have been introduced at a much earlier point in time if carmakers had been prepared to make the effort. Euro 3 was not a case of technology forcing, since compliance was possible subsequent to only minimal development efforts by the industry.

The relative nature of the term “technology forcing” becomes evident given the differing references made to the US regulating process. Environmental regulators there set stringent ceilings in conjunction with short timeframes, since air-conservation policy is strongly focussed on reducing vehicle emissions. The industry, for its part, often cannot meet the stipulated values on time, thereby forcing deadlines to be postponed until such time as the necessary technological status has been achieved. One example of this was illustrated by the efforts to introduce the 3-way catalytic converter, which was postponed several times in the 70s, even though the low emissions values this technology enabled made its introduction imperative. The industry had successfully asserted that it could not build it (Tiessen et al. 2002). In its argumentation, the ACEA now points out that the proposals put forward by European environmentalists would lead to the same game of ceiling-setting and non-compliance (ACEA 2003). The environmentalists likewise refer to the regulatory style used in the US, though their line of argumentation is different. They say they do not want similarly strict standards as those in the USA, that in Europe the principle of technical feasibility applies, so that the standards introduced could be binding ones. In other words, although the proposals made by environmentalists may go beyond that which the automobile industry desires, they do take actual development potential into account. Environmentalists, too, wish to avoid the kind of situation which is apparent in the USA.

3. The spread of diesel vehicles and their markets

The markets for technology which reduces harmful emissions in diesel cars are situated in economic regions with strict emissions regulations. Hence, diesel cars are subjected to the sharpest regulation in the USA, Japan and the EU, in all of which regions prevails the political will to introduce even tougher standards. The USA currently boasts the most stringent exhaust norms of all – norms which, at least on a political level, the EU considers to denote the way to the future and which are likely to influence how prospective EU standards are formulated (Walsh 2000, Lange 2003).

Within the United States itself, California has assumed the pioneer role, leading the way into the future on a platform of maximised emissions standards for automobiles. The regulations governing exhaust values, however, are far more complicated than in the EU. For one thing, California has issued a number of different standards, to which carmakers are required to conform using a dedicated table outlining the specifications for each section of their fleet. And varying values and predefined engine operating cycles apply for each emissions class. Stricter values are allocated for the first either 50,000 miles or five years of operation, for example, than for operations after 100,000 miles or 10 years. The currently strictest standard for diesel cars in California is the ULEV (Ultra Low Emission Vehicle) standard. As of 2004, the SULEV (Super Ultra Low Emission Vehicle) standard will apply. Both these standards apply for diesel and petrol vehicles alike.

Table 2: Emissions ceilings in California

Californian emissions standards for diesel and petrol cars, g/m (g/km)					
Norm	Year	Particles	Nitrogen oxides	Particles	Nitrogen oxides
		50,000 miles / 5 years		100,000 miles / 10 years	
ULEV		-	0.2 (0.124)	0.04 (0.025)	0.3 (0.186)
		50,000 miles / 5 years		120,000 miles / 11 years	
SULEV	2004	-	-	0.01 (0.006)	0.02 (0.012)

Source: Dieselnet.com

The ceilings valid in Japan since 2002 slightly exceed those of the Euro 3 standard, with substantial restrictions governing diesel vehicles and their emissions in metropolitan centres. By the same token, however, diesel vehicles do not play much of a role in Japan. It is the EU market which provides the stimulus to develop technology that will reduce diesel emissions.

Table 3: Emissions ceilings in Japan

Japanese emissions standards for diesel cars, g/km			
Vehicle category	Year	Particles	Nitrogen oxides
Small sized cars ~1.25t	1997	0.08	0.4
	2002	0.052	0.28
Medium sized cars ~1.25t	1998	0.08	0.4
	2002	0.056	0.3
Light duty trucks ~1.7t	1997	0.08	0.4
	2002	0.052	0.28

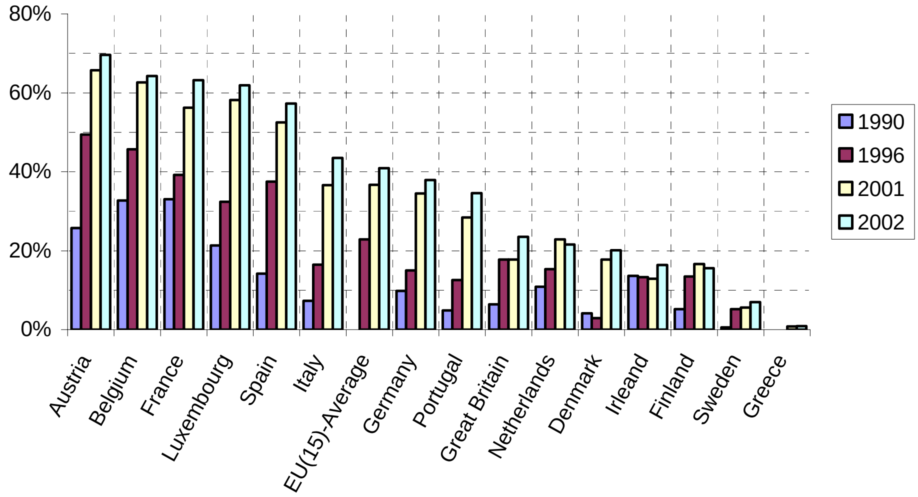
Source: ECMT 2000

Where use of the particulate filter is concerned, the picture we get when we look at the regulations which apply in the USA and Japan is this: In Japan, the ceilings for particulate matter could currently be met even without the use of filters, since the regulations there are less restrictive than the Euro 3 standard. Future measures are in the works to further reduce hazardous emissions, though a timetable is not yet foreseeable. Whether or not a particulate filter is required to meet the ULEV standard which currently applies in California or whether the ceiling which lies somewhere between Euro 3 and Euro 4 can be satisfied through engine modification alone is not ascertainable from where we stand. The SULEV standard, to become applicable as of 2004 and which will restrict particulate emissions to less than half of the value defined by the Euro 4 norm to be put into effect in 2005, will make the use of a particulate filter necessary.

Market development for diesel passenger cars

In Europe, sales figures for diesel vehicles have risen considerably over recent years, the main purchasing incentives being the low price of diesel fuel (except in the UK) and the good mileage such vehicles normally offer. Rough calculations show that the higher purchasing price on diesel vehicles is balanced out within one to three years by the low fuel costs, good mileage and low maintenance costs (Brückner 2002).[4] In Austria, Belgium, France and Spain, more than 50 percent of all newly registered vehicles in 2002 were diesels. In Germany, the share of diesel vehicles was up from around five percent in 1975 to 38 percent in 2002. The biggest markets in Europe are presently Germany and France. In the first half of 2002, 20.5 and 23.5 percent of overall European turnover in the sector for diesel vehicles was generated by these two countries, respectively. Because the self-imposed commitments by the automobile industry to reduce CO_2 emissions include a pledge to vigorously support the introduction of diesels, we can expect to see increasing marketing efforts in this area and a continued increase in the number of new registrations for diesel vehicles. A current forecast by Volkswagen puts the figure for the year 2005 at fifty percent of overall turnover from sales within the EU (Schindler 2002).

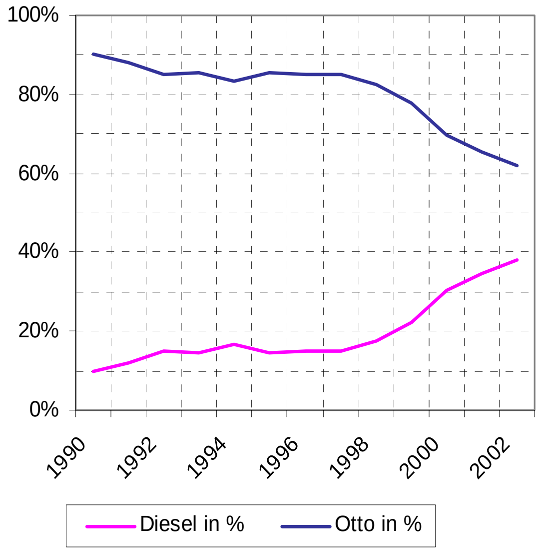
Table 4: Percentage of diesel vehicles based on the total number of new registrations of passenger cars in the years 1990, 1996, 2001 and 2002 in the European Union

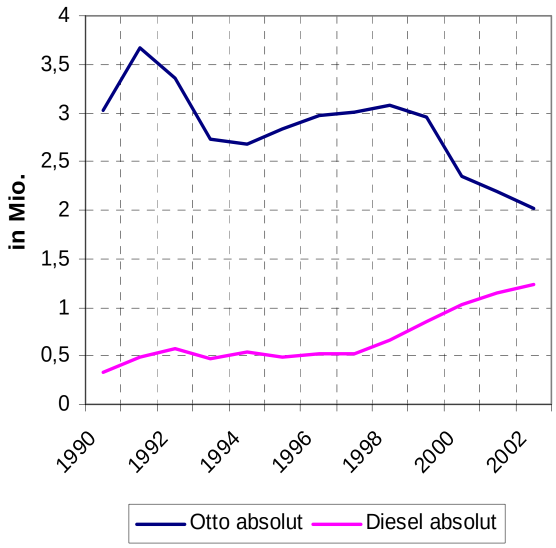


Source: AAA (Association Auxiliaire de l`Automobile)

[4] It is important to note, however, that in Scandinavian countries, for instance, diesel passenger cars are subjected to a higher tax.

Table 5: Percentage of diesel passenger cars based on the total number of new registrations in Germany





Source: AAA (Association Auxiliaire de l`Automobile)

With a market share of around one percent, the USA is not a factor in the equation as far as sales markets for diesel passenger cars go. German manufacturers in the USA do, however, see a potential market there[5]. Even vehicles which conform to the Euro 4 norm, do not meet US emissions standards. To sell European diesels there will require further technological development. Given the growing market for diesel vehicles and the likelihood that exhaust standards will become even more restrictive, the market for technology which satisfies such standards is also experiencing growth. With respect to carmakers' competitive advantage and lead-market effects, two assumptions can be made. First, that long-term, global marketing strategies for diesel vehicles only make sense if such vehicles comply with the standards prescribed in all economic regions (i.e. in Europe, the USA and Japan). Second, that lead markets governed by strict emissions standards, such as California or Germany, are likely to boast an ecologically aware buyer market open to the acceptance of vehicle offerings which enable premature compliance with emissions ceilings – with or possibly even without tax advantages playing a role.

Since compliance with emissions ceilings requires the use of technologies which car manufacturers purchase from their components suppliers, we can also expect strict standards to produce lead-market effects in corresponding supplier industries – a theory exemplified by the fact that the first suppliers of three-way catalytic converters still maintain the biggest market shares to this day (Tiessen 2002).

[5] A high-ranking symposium was held in California in 2002 with the backing of the environmental agencies in that state. There have also been repeated statements of intent by German carmakers to step up marketing efforts there in support of diesel passenger cars (Handelsblatt 12.2.2003).

4. Technologies designed to reduce hazardous emissions

A whole range of suitable technologies is at different stages of development, each being pursued by the automobile industry with different levels of enthusiasm. We can categorise the technology applicable to diesel engines into two groups: exhaust treatment and engine modifications. Based on the present-day status of development, certain methods of exhaust treatment require fuel to contain less than 10 ppm of sulphur.[6] Current ceilings for nitrogen oxides and particulate emissions can be met using existing technologies. Compliance with the Euro 4 or SULEV standards, however, requires making considerable engine modifications and then combining them with exhaust treatment technology.

4.1. Engine modification

The two pollutants which exhaust treatment using standardised oxidising converters has not been able to sufficiently reduce are nitrogen oxides (NO_x) and particles. To understand how engine modifications can effectively reduce them, it is important to understand how these substances are created during the combustion process.

The problem with diesel-based technology, in particular, is that direct injection is likely to cause a local surplus of fuel in the cylinder's combustion chamber. A lack of oxygen leads to insufficient combustion, as a result of which particles are produced (Wachter 2002). NO_x is generally created when the combustion temperature is high, when the combustion temperature remains at its maximum for a long period and when a particular fuel-air mix is produced. While the simplest solution would be to reduce the combustion temperature, this would automatically increase particle emissions. The share of NO_x produced is always contingent on the share of particles produced and vice versa (Carstens et al. 2001). The aim of any engine modification must therefore be to achieve an effective trade-off between the different emission-reduction measures.

4.1.1 Exhaust gas recirculation

One effective method of reducing NO_x is exhaust gas recirculation (EGR). EGR redistributes some of the exhaust into the charge air. Adding exhaust gas to the fresh air diminishes the concentration of oxygen in the fuel-air mixture contained in the combustion chamber, which in turn causes combustion to be "slowed down", enabling the maximum combustion temperature to be reduced and thus less NO_x to be produced. In diesel engines, the EGR system can presently only operate in partial load. Developers are now working on adapting EGR for full load operation, so as to achieve further reductions of NO_x – the prerequisite, however, is the development of new materials and compound materials as well as cooling for the recirculated exhaust (Flaig et al. 2000). EGR can effect substantial reductions in NO_x emissions, but it also increases fuel consumption and particulate emissions. An optimal trade-off can, however, be found (Wachter 2002).

[6] See Enclosure 1 for an overview.

4.1.2 Direct injection systems

Increasingly, modern diesel engines are being designed to feature electronically controlled high-pressure injection systems only. The benefits of such systems are improved running smoothness and better mileage. The high pressure these systems use distributes fuel evenly and finely in the combustion chamber. Hence, combustion is improved and less particles are produced (Pucher 2002).

Leading carmakers currently subscribe to two main variations on the injection system, one of which is the unit-injector technology by Bosch, used mainly by the VW Group, and the other being the common-rail concept used by all other major manufacturers. The rule is: the higher the injection pressure, the better the distribution of fuel in the combustion chamber, resulting in less particulate emissions in exhaust. While a high degree of injection pressure may not prevent NO_x emissions, again, an optimal trade-off between NO_x and particles can be found. Future developments will see the concept of direct injection being further enhanced through pilot- or pre-injection, improvements to the injection process and multiple injection (Dorenkamp et al. 2001).

4.1.3 Homogeneous combustion

Given that it relies on heterogeneous combustion which causes fuel surpluses in individual parts of the combustion chamber and thus prevents full combustion, diesel-engine technology is clearly inferior to petrol-engine systems in terms of particulate emissions. Carmakers intend to switch to homogeneous combustion in order to neutralise this drawback. The virtue of a diesel engine (i.e. its better mileage) could, however, remain unaffected. Compression firing of a homogeneous mix illustrates that consistent temperature distribution within a homogeneous combustion process can drastically reduce NO_x generation without producing any significant amount of particulate emissions (Kahrstedt et al. 2001). To date, however, it has only been possible to use homogeneous combustion in conjunction with low rotational speeds and in partial load. High demands are also made on the electronic control of the combustion process. Things are currently still at a very early stage of development.

4.2 Exhaust treatment

4.2.1 Particulate filters

Particulate filters help to radically reduce particulate emissions. The filter is integrated into the exhaust area, where it captures the particles contained in the exhaust. These particles eventually clog up the filter, causing exhaust counter-pressure to be increased and larger amounts of fuel to be consumed. It is therefore necessary to regenerate the filter at regular intervals by burning off the particles. Their combustion along with the oxygen contained in the exhaust requires a temperature of over 600°C, i.e. a temperature which diesel exhaust in passenger cars can hardly achieve, even at full throttle (Michelin et al. 2002). Regeneration measures therefore need to be undertaken, so as to ensure that the filter is either properly regenerated as of a certain particulate load (discontinuous regeneration) or that filter loading is restricted (continuous regeneration). Regeneration measures can be subdivided into active and passive systems, whereby active systems require heat, while passive ones generally utilise catalytic effects (Herrmann et al. 2001). Table 4 lists different regeneration measures which are normally combined.

Table 6: The categorisation of regeneration measures

	Active	Passive
Continuous	Generation of reactive components: – Plasma technology (ozone, OH radicals, NO2)	Generation of reactive components: – CRT system (NO2 effect)
Discontinuous	– Burner – Engine modifications (e.g. multiple injection)	– Fuel additive – Catalytically coated filter

Source: Herrmann et al. 2001

4.2.2. Catalytic converters for the reduction of nitrogen oxides

Two concepts are currently considered to be particularly promising:

The SCR converter:

The SCR (Selective Catalytic Reduction) converter uses ammonia to oxidise nitrogen oxides into nitrogen and water. Since safety considerations prevent the use of ammonia, however, urea is generally used, disintegrating into ammonia in the hot exhaust gas. The SCR converter is regarded as a future technology in commercial vehicle engineering, even though this field of development still harbours problems which need solving (e.g. the absence of an infrastructure for urea). While the SCR converter has so far been deemed too big for use in passenger cars, the technology could, in principle, be used for such vehicles (Elsener et al. 2001).

Adsorber converter:

The NO_x adsorber converter (also referred to as the NO_x storage converter or NO_x trap) is amongst the technologies currently enjoying the most attention in terms of development efforts. Indeed, a model for passenger cars with direct-injection petrol engines has already been developed to series maturity and has for some time now been available on the market in Europe. (Krebs et al. 2001). In contrast to conventional converters, which normally convert NO_x to N_2, adsorber converters store (or adsorb) nitrogen oxides (much like a sponge would) until their capacity is exhausted. Once this eventuates, the engine electronics temporarily switch from their standard lean operation to low-oxygen operation, allowing the converter to regenerate itself (Pischinger et al. 2003).

5. Carmakers' technological development strategy

To meet the Euro 3 norm, it was necessary to advance the technological status quo, so as to achieve improvements in injection technology, in combustion chamber design and in the design of exhaust treatment systems (VDA 1998). Euro 3 required no more than the enhancement of conventional technology.

The technology needed to satisfy the demands of Euro 4, on the other hand, was not yet clear when the standard was drawn up in 1998. All the parties involved agreed that the standard would be technically feasible only after a time of development, with different estimates made as to how long this would take. Technical surveys, however, concluded that it was possible to meet the stipulated ceilings either through engine modification or exhaust treatment measures (Neunzig et al. 1998, Faiz et al. 1996, UBA 1995). In its yearbook 2000, however, the Association of the German Automobile Industry (VDA) set out the guidelines for future developments: The goal of engineers, it stated, was, where possible, to prevent emissions being produced at all, rather than filtering them out later (VDA 2000). In the meantime, engine modifications are seen to be a sufficient means of achieving compliance with Euro 4 for small and medium-size engines, with particulate filter systems for the reduction of nitrogen oxides and, if necessary, catalytic converters being used in particularly heavy, high-performance vehicles only (Schindler 2002). According to the VDA guideline, automobile manufacturers are concentrated on coming up with engine modifications – as indicated by Audi's and VW's finished development of a number of Euro-4-compatible models. As a consequence, a call by the federal environment minister[7] in 1999 to introduce a particulate filter system onto the market by way of self-initiative was rejected on the grounds that it constituted a construction regulation which was unacceptable in principle, given that such regulation served to distort competition. The association also denied the existence of production-series-type particulate filters (VDA 2000: 151). It is moreover assumed that agreement has been reached within the automobile industry not to launch exhaust-treatment technology such as particulate filters or NO_x traps onto the market prematurely (Rodt 2003).

5.1 Peugeot introduces the particulate filter

In late 1999, the French automobile Group PSA Peugeot Citroen was the first manufacturer to introduce a particulate filter system for diesel passenger cars in France. In May 2000, the system was launched on the German market too. First introduced as a standard series feature in a premium-class car, the FAP system (Filtre à particules) has since been used in other models, all the way down to lower middle-class vehicles[8]. This system now allowed particulate emissions to be reduced to 0.001g/km, i.e. well below the ceiling of 0.025g/km as stipulated for the EU as of 2005.

[7] The environment ministry addressed the issue with manufacturers after a survey by the Fraunhofer Institute for Toxicology and Aerosol Research had recommended introducing filters in light of the health hazard posed by particles.

[8] The particulate filter was first introduced as a standard series feature in the model 807 (premium class) in May 2000. It was then successively included in the Peugeot 406 and 307, likewise as a standard series feature (though only for the 307 version with a 2-litre-cubic-capacity engine). The filter is not available for vehicle models below the Golf class (206 and 106) – not even as an extra.

Peugeot introduced the FAP system, it says, to make use of the competitive advantage which such environment-friendly technology offers, the Group's concrete objective being to use particulate filters to increase market share for its vehicles. This strategy differs from that of other manufacturers such as VW or Audi, whose aim is to secure competitive advantage through early compliance with the Euro 4 standard, the specifications of which are mirrored in Germany's own D4 norm (tax-incentive standards). This technology allowed Peugeot to reduce its emissions of particle mass to almost zero, though it does not contribute to reducing nitrogen oxides[9].

The German market has dual significance in Peugeot's strategy. First, it is the biggest market for environmental technology, so Peugeot counted on a good deal of demand for vehicles with particulate filters. Second, Germany is a key reference and test market; advancements in the automobile sector which are successful in Germany would generate demand stimulus in other markets.

Peugeot presumed that the filter would be a success in Germany and anticipated that the purchasing behaviour there would be emulated in other countries. Given its vision (as well as the lower costs resulting of uniformity in production), it offered this filter as a standard in all other markets as well. (Schalberger 2003). For Peugeot, the German market was a calculated lead market which would create demand stimulus in other countries if the particulate filter proved successful there. The response Peugeot's introduction of its filter solicited from other carmakers was predominantly subdued. Even though Peugeot proved that, using the filter, it was possible to achieve an emissions standard, at least for particulate emissions, which fell far below the Euro 4 norm and did so five years in advance of the date specified by regulators, manufacturers maintained their official course aimed at complying with emissions ceilings through engine modifications. Even the emerging public discourse of the day about the health hazard posed by particles and the need for the filter did not effect any change in this position.

German manufacturers had substantial reservations about the technical feasibility of the particulate filter, arguing that there could be no certainty as to their durability and that the filter would cause a higher degree of fuel consumption. One of the reasons the FAP system was publicly dismissed was Mercedes' unfavourable experience with the technology. After the company had fitted a number of its models for the US market with the particulate filter 20 years previously, it was forced to take it from the market again because regeneration of the filter did not work[10]. As a consequence of this fiasco, Mercedes did not continue development on the particulate filter (Wüst 2003). According to the people at DaimlerChrysler and Volkswagen, exhaust treatment measures aimed at enabling compliance with the Euro 4 limit had not been in the pipeline at the time – except for heavy VW automobiles (Wüst 2000).

[9] Peugeot is currently further developing its FAP system in the hope of making it eligible for tax incentives on the basis that it will reduce nitrogen oxide emissions. See Item 5.3

[10] The material of which the filter is made could not take the strain of the high temperatures to which it was exposed during regeneration and it broke. There was also an absence of reliability about whether or not the temperature necessary for regeneration would always be reached; in the event that it was not, the filters clogged up and the vehicles simply broke down.

And yet Peugeot's lead was remarkable in one way: Normally, automobile manufacturers agree on a common course when it comes to certain themes. They do so via their national trade associations. It is unusual for a player to break away from this practice (Roth 2003). Peugeot's introduction of the particulate filter was something akin to the introduction of the three-way catalytic converter, only this time its was a French group that launched the technology on the market and the German manufacturers who were intent on preventing this technology from asserting itself.

5. 2 Long-term testing by ADAC and the Federal Environment Office

In August 2001, Germany's premier automobile club, ADAC, and the Federal Environment Office (UBA) published the results of long-term testing which examined the durability of the FAP system. The test found not only that the filter drastically reduced particulate emissions (especially ultra-fine particles), but it also disproved the validity of the scepticism other manufacturers had vis-à-vis the particulate filter. Functionality remained intact even after a driving distance of 80,000 km, nor did the testers establish any significant increase in fuel consumption (UBA 2001). ADAC and UBA therefore advised other manufacturers to switch their focus away from the graduated Euro 4 plan and instead follow PSA's lead to reduce particulate emissions to practically zero by using the filter (Fröhlich-Merz 2001). Even before the particulate filter was introduced, its manufacturers had contacted UBA, requesting confirmation of the environmental tolerability of the additive it contained. The idea to test the filter was a joint decision by UBA and ADAC, whose aim it was to prove the functionality of the filter and to generate awareness for the technology among the greater public. This unlikely coalition between ADAC and UBA was established because of ADAC's vested interest in clean technology, given that it understands its role in connection with health matters to be one of a protector of consumer interests. As far as ADAC is concerned, the health of motorists needs to be protected if motoring is to remain an attractive proposition in the long term (Rodt 2003, Demmel 2003).

This proof of the particulate filter's functionality hugely increased public pressure on carmakers, with environmental organisations and the media demanding of the other manufacturers that they close ranks with Peugeot. From Germany's government, in turn, they demanded that use of the particulate filter in new vehicles be given special tax consideration.

German carmakers found themselves in the uncomfortable position of having to defend their own strategy centred on engine modification. There was no longer any room for doubt about the functionality of the filter. Peugeot offered other manufacturers licensing agreements on production of its FAP system. The stance of the other carmakers saw no significant change, however. They continued to reject the filter, though they did make changes to their official communication strategy. Public doubt about the functionality of the technology was expressed in press releases and statements in the year 2001, which referred to the fact that the Euro 4 standard made no specifications regarding the technology to be used, that the particulate filter did not solve the problem of nitrogen oxides and that it was important to take a holistic approach to the reduction of hazardous emissions. In this regard, it was proclaimed, Peugeot's particulate filter is nothing more than a marketing stunt (VDI 2001, Giesen 2003, Skibbe 2003, Metz 2003). Filters, the opponents said, should only be used where no other technological solutions were conceivable as a means of conforming with Euro 4.

5.3 Automobile manufacturers' current technological strategies

While it is difficult to define a timeframe within which a change of strategy took place, 2002 did see an increase in the number of individual companies testifying that they would at least consider early introduction of diesel filters (Zeit 2002, FTD 2003). This development may have something to do with an initiative launched in November 2002 entitled “No diesels without a filter”, the aim of which was to push through tax breaks for particulate filters (with a deadline set for 1 July 2003) using pressure instruments such as the media, PR measures, lobbying, public campaigns and advertising measures.[11] This was a demand to which Germany's federal environment minister, Jürgen Trittin, gave his verbal backing, though he did not initiate any concrete measures.

Still under pressure from the public domain, German carmakers defended their strategies. VW's CEO Pischetsrieder, for one, publicly announced that a filter would cost between 200 and 600 euros, depending on engine size, a cost which VW wished to spare its customers. Pischetsrieder went on to say that his company's development efforts had been oriented on the formal political criteria which demanded that emissions of both particles and nitrogen oxides be reduced to the level prescribed by Euro 4. It was left to the automobile industry, he explained, to decide which technology it would use. At the same time, Pischetsrieder left all options open by claiming that a particulate filter had never been ruled out. (FTD 19.2.2003, Zeit 27.3.2003, Welt 6.4.2003). Similar arguments were forthcoming from spokespeople at Mercedes and from the president of the carmakers' association (VDA), Bernd Gottschalk, who described the targeted endorsement of particulate filters as discontinuous government policy which manufacturers could not focus on (Spiegel 11/ 2003, Rheinische Post 2.4.2003).

In addition to the rhetoric confusion created by official rejection and acceptance, the indications in the spring of 2003 were that other automobile manufacturers were now working on particulate filters. Press reports, unconfirmed by the carmakers themselves, claimed that the international motor show in Frankfurt in the autumn of 2003 (the IAA) would see Audi, BMW, DaimlerChrysler, Toyota and even Volkswagen showcasing a particulate filter (FAZ 12.04.2003). In February 2003, Ford was the first to break with the consensus among automobile manufacturers that particulate filters would only be used where no other

[11] A joint initiative entered into by the Federal Environment Office, the German arm of the World Health Organization, Greenpeace, BUND (an environmental conservation organisation), Germany's Child Protection Association and ADAC (the automobile club) and coordinated by the Environment Support Society of Germany (DUH), this project calls for (and the call is echoed in the media) special tax considerations for particulate filters, for Euro-3-conform diesels with particulate filters to be eligible to the same tax incentives as Euro-4-conform diesels which do not feature such filters, and special tax considerations for the retrofitting of older vehicles. Diesel filters, the group argues, are available in principle to all carmakers. There is no proof, it says, that they cause increased fuel consumption. And a German initiative is necessary, since EU-wide regulation would be too lengthy a process. The reason for the group's public commitment is the health risk posed by particulate emissions. (Resch 2002).

alternative was possible (Reinking 2003). The current strategies can be summarised as follows:[12]

Ford was the first manufacturer in Germany to announce (in early 2002) that its development cooperation with the PSA Group would produce not only a new generation of engine, but that the partners would be looking to find ways of enhancing particulate filters. A filter which produces less particle ash, it explained, would be on the market well before 2005 (von der Weiden 2002). Ford fixed its sights on a second-generation additive system with longer regeneration and maintenance intervals. The development of more advanced diesel engines in a joint effort with the PSA Group is aimed at achieving compliance with the Euro 4 norm (Hennen 2003). The FAP system is now also featured in a number of Fiat and Lancia models.

At the same time, Toyota announced its system for exhaust treatment – a system which would drastically reduce both particulate matter and nitrogen oxides in exhaust and thus by far outperform the standards stipulated in Euro 4. Its so-called DPNR system (Diesel Particulate NO_x Reduction) is to be put to market by the end of 2003 (Menzel 2002). Renault plans to be the first carmaker (in the second quarter of 2003) to introduce a series-standard particulate filter which features a catalytically coated filter element rather than requiring an additive, while undertaking engine modifications to reduce nitrogen oxides (Renault 2003). Both these manufacturers intend to meet the Euro 4 standard at an earlier-than-prescribed date, enabling buyers to take advantage of the vehicle-tax benefits associated with the D4 norm.

We are meanwhile seeing a change in strategy at PSA. Whereas, at the time that it introduced the particulate filter, the company was focused on gaining competitive advantage by offering clean technology at no extra cost, its development of an integrated system (in conjunction with Ford) to reduce nitrogen oxide emissions by way of engine modifications is now aimed at benefiting from the tax advantages of compliance with the D4 norm.

Volkswagen, on the other hand, continues to favour another strategy. This carmaker only intends to introduce a filter system as series standard in vehicles which would otherwise not be able to meet the Euro 4 norm, while particulate filters will only be available for its smaller models at an extra charge – since Volkswagen has doubts about the demand for particulate filters among buyers (Reinking 2003). Audi, a VW subsidiary, nonetheless plans to introduce a particulate filter as of autumn 2003, though likewise only as an extra (FAZ 2003).

We can currently identify four different exhaust treatment systems developed by different companies. Three of them (FAP, CRT, Renault) are strictly particulate filter systems, each based on a different regeneration strategy. The FAP system is the only one to date used as a

[12] We determined current engineering strategies based on the written and telephone interviews we conducted. Given the political sensitivity of this topic and the commitment to confidentiality on the part of the engineers interviewed, these strategies ought to be viewed as trends or proclaimed intentions rather than fixed developments. If, on the other hand, we look at the course of development based on past announcements by the companies involved, we can establish that, if nothing else, introduction of the particulate filter at least effected a change in the companies' PR campaigns. We were not able to determine how long the individual companies had been working on their respective technologies or when exactly they were due to be launched on the market.

series feature. Toyota's DPNR system is the only one which claims to reduce both particle and nitrogen oxide emissions.

Peugeot's FAP system:

Regeneration of the filter element is initiated in the event that the exhaust backpressure measured by a pressure sensor exceeds a certain limit. This is the case every 400 to 600 km (depending on the style of driving), for which the following two measures are responsible:

- Multiple injections, regulated by common-rail injection, cause the exhaust temperature to be raised to over 450°C.

- An additive which envelopes the particles is mixed into the fuel, causing the particles to be combusted at a temperature of only around 400°C.

The additive is stored in a separate tank, from which it is successively dispensed into the fuel. To ensure the system runs smoothly, the filter requires cleaning every 80,000 km (as part of the inspection job) to cleanse it from all the residue produced by the additive. The tank is then refilled with fresh additive. This filter removes more than 99.9% of all particulate matter (Michelin et al. 2002).

The CRT system:

Another system for the reduction of particles is the CRT system (Continiously Regenerating Trap), which features an oxidising catalyst positioned before the particulate filter to oxidise the NO and NO_2 contained in the exhaust gas. The particulate matter stored in the filter is systematically combusted, using NO_2, at temperatures starting at 250°C, i.e. at temperatures which are substantially lower than that required for oxidisation using oxygen. This system, which requires fuel with a sulphuric content of less than 10 ppm, is already being successfully tested in commercial vehicles such as city buses and selected fleets. It has not, however, been developed to series maturity for passenger cars. The CRT system is being worked on by Johnson Matthey, a chemicals company with a vast amount of experience in catalytic technology (Herrmann et al. 2001).

The "Renault system":

Renault has co-operated with Ibiden, Engelhard and Eberspächer to develop a particulate filter system which requires no additives. Like the filter element used in the FAP system, this element is made of silicon carbide and features one-end-open/one-end-closed functionality. Again, like the FAP system, regeneration is initiated periodically – every 300 to 500 km, depending on the style of driving. Here too multiple injections temporarily raise the exhaust temperature to reach as much as 570°C. A catalytic coating on the filter ensures that particulate matter is combusted even at this temperature. Renault additionally intends to fit its models with an improved oxidising catalyst and a system of exhaust gas recirculation (Renault 2003).

Toyota's DPNR system:

Japan's Toyota has developed a new exhaust gas treatment system (DPNR or Diesel Particulate and NO_x Reduction System) for the reduction of both particles and nitrogen oxides. The DPNR catalyst has a porous ceramic structure with a special coating which can store and dissolve NO_x. The system also features high exhaust gas recirculation rates as well as a low combustion temperature, enabling nitrogen oxide emissions to be further reduced. The discharging of NO_x in the catalyst causes the monovalent generation of reactive oxygen, which oxidises the particulate matter. Excess oxygen ensures that the particles combust very rapidly. The combustion process and decomposition of the NO contained in the NO_x storage catalyst is initiated by the system control, which temporarily switches to a richer-combustion mode. This releases NO and reactive oxygen, which respond to carbon monoxide and hydrocarbon to produce N_2, water and CO_2. The particulate matter is combusted together with the reactive oxygen (Paquet 2001).

6. Strategies by components suppliers

Individual manufacturers do not build particulate filter systems as complete systems (just as they do not build whole catalytic converters for exhaust gas). Different manufacturers produce individual modules. The first thing needed to filtrate particles is the filter material itself. Additional components are then needed, depending on the regeneration strategy used. Additive-based regeneration requires a measuring-out system for the additive, while regeneration using a catalytically coated filter requires an effective coating. In a final step, a components manufacturer then "cans" the particulate filter system in a metal casing and integrates it into the exhaust system (Stöpler 2003).

Product development by suppliers is strongly contingent on the engineering strategies of the carmakers. Despite the fact that individual production steps are separated, the companies involved, from those who produce filter systems to the carmakers, co-operate closely. Collaboration with carmakers is the normal procedure. In their work, manufacturers of filter material are least of all dependent on the specifications made by carmakers. Their products are quasi independent of the type of regeneration the filter uses and of the type of automobile in question (Rippe 2003, Teubner 2003). And yet filter manufacturers do join forces with car manufacturers and satisfy their wishes, even though their most important partners are other components suppliers (Vogt 2003). Manufacturers of catalytic coating and additives enter a medium level of co-operation with carmakers, since these products need to be specifically adapted to the demands of individual carmakers (Teubner 2003). The closest co-operation with the automobile industry is maintained by "canners" – the manufacturers of exhaust systems. Their job is to develop complete particulate filter systems – in conjunction with automobile companies – and to gear such systems to engine management apparatus (Stöpler 2003, Stüttem 2003, Teubner 2003).

6.1 The companies

The only filter material so far used as series standard is produced by the Japanese firm Ibiden (Michelin et al. 2002). A ceramic structure made of silicon carbide, it is currently being used by Peugeot, with Renault and Toyota also planning to do so. This material is present-day standard, even though other companies produce filters for diesel cars. Corning, a leading manufacturer of catalyst substrates, offers a filter made of Cordierite. The people at NGK, likewise a manufacturer of substrate material for catalytic converters, have developed a filter made of silicon carbide. Emitec, originally a producer of metal catalysts, is also in the process of developing a particulate filter. HJS Fahrzeugtechnik, a small vehicle-technology firm, which to date has been building particulate filters made of sintered metal, recently sold the rights to the manufacturing, further development and sale of its filter to Bosch (Westfalenpost 2003), with Bosch anticipating rapid growth in the demand for particulate filters for diesel cars (Handelsblatt 2003).

Where the production of additives is concerned, two firms, Rhodia and Octel, lead the market. Rhodia manufactures Eolys, an additive already used as a series feature in Peugeot's FAP system. The leading manufacturers of catalytic coatings, Engelhard, Johnson Matthey and OMG, also command the market for coatings for three-way catalytic converters. Engelhard will be the first to take catalytic coating for Renault's particulate filter system to market (Scherm 2003).

The manufacturers of exhaust systems act as system integrators. Their job is to develop systems which meet the demands of carmakers and which can be integrated into their respective makes of automobile. Faurecia, one of the world's major components suppliers, once belonged to the PSA Group, and even today Peugeot still holds the majority of shares in the company (Teubner 2003). The FAP system was developed in co-operation with Faurecia and Tenneco Automotive Gillet (Stöpler 2003, Michelin et al. 2002). Other suppliers include Eberspächer, which manufactures particulate filters for Renault, Zeuna Stärker and Friedrich Boysen. The customer structure of these companies is generally broad-based, though there are exceptions. Friedrich Boysen, for instance, manufactures exhaust systems for BMW (Teubner 2003). Almost all these companies confirm that they develop their particulate filter systems upon commission by major German carmakers.

6.2 Research & development

Particulate filter technology is by no means a new issue for components suppliers, with initial development activity for commercial and off-road vehicles dating back to the late 80s (Treiber 2003, Glück 2003, Rippe 2003, Vogt 2003, Scherm 2003, Teubner 2003). The expertise for such development was generally provided by experience gained in the development of catalytic converters (Treiber 2003, Rippe 2003, Vogt 2003, Scherm 2003). Given the increasing spread of diesel cars, the discourse surrounding the hazard of particulate emissions and the advances made in diesel technology, manufacturers all stepped up their research efforts on particulate filters in the 1990s. Added impetus was provided by market introduction of the FAP system, which prompted more demand for particulate filters by other carmakers (Glück 2003, Rippe 2003, Vogt 2003, Scherm 2003). Even at this stage, other automobile manufacturers already feared losing competitive edge and therefore called for development efforts to be undertaken in the area of particulate filters (Glück 2003). The "No diesel without a filter" initiative is currently putting tremendous pressure on carmakers (and they on suppliers) to introduce particulate filters (Treiber 2003, Rippe 2003). NO_x storage catalysts and enhanced oxidising catalysts are also being developed for passenger cars.

6.3 Assessment from a supplier perspective

The technological strategies subscribed to by carmakers (with the exception of Ford) are aimed at developing diesel filter systems independently of any co-operation with the PSA Group. Suppliers emphasise their close co-operation with manufacturers. By the same token, however, they are keeping a lid on any information concerning the current status of developments. Engelhard, for instance, offers a catalytic coating which is compatible with all filter types available. While this technology has been on the market since 2001 (Scherm 2003), it still needs to be adapted to satisfy the demands of vehicle manufacturers in terms of their regeneration strategies and engine management systems. Before the system can be used, therefore, a certain amount of time is first required for preparation. We were not able to find out just how much time is needed and what sort of difficulties might arise. Renault intends to use this system as series standard in its vehicles. Developments are also ongoing in collaboration with a German carmaker. Upon inquiry, we were given to understand that all the manufacturer products involved (filter material, additives, coatings) had been developed to maturity. The problems that present themselves are system integration into vehicles and the regeneration strategy (Stüttem 2003, Stöpler 2003, Teubner 2003).

The best practicable means in the area of particulate filter technology are presently considered to be additive-based systems and systems with catalytically coated filters. In the long term, the use of additives is to be avoided. For one thing because they are not completely combusted, leaving ash residue in the filter. For another the additive-based solution is considered to be too expensive (Treiber 2003). According to the experts, most carmakers currently favour a solution which does not involve the use of additives (Stüttem 2003, Treiber 2003, Teubner 2003). To achieve the Euro 4 norm, however, additive-based systems will probably still be widely used. The CRT system is regarded as being too large, and hence too complicated, to integrate into the exhaust system. Another dilemma is sulphur sensitivity (Rippe 2003, Teubner 2003).

Based on this information, we can conclude that other vehicle manufacturers too would be in a position to introduce particulate filters in a relatively short span of time. The only explanation for the fact that they have not previously been used is that carmakers have adhered strictly to the political stipulations governing emissions ceilings, despite the technological advances made.

7. Outlook and discussion

It is clear that introduction of the filter by Peugeot and the support of ADAC and UBA have accelerated development activities by other manufacturers. The VDA policy to only make use of filters where necessary and by no means any earlier than such time, would appear to have been rendered no longer applicable. According to Peugeot, it has sold 450,000 cars fitted with diesel filters around the world since 1999, 35,000 of them in Germany. Peugeot also supplies its FAP system to Ford, Lancia and Fiat. The changed technological strategies will affect the components supplying industry, even though such implications are not yet foreseeable. If the filter technology should become more widespread and buyer demand continue to increase, Germany could be said to play the role of a lead market. Right now, this technology is gaining acceptance among manufacturers – a fact which substantiates the possibility of a lead market being established.

The evolvement of a lead market has been boosted by UBA and ADAC support, by its endorsement on the part of a number of other private players as well as by the media impact such support has generated. Had it not been for the public discourse initiated by these players concerning the health hazard posed by particulate mass, other manufacturers would have been able to continue to pursue their individual technological courses of development and would have introduced or even begun to develop particulate filters either at a much later date or not at all. The effectiveness of public pressure on automobile manufacturers is a fact verified by components suppliers for particulate filters.

In the case of the diesel filter, one manufacturer has made use of a pilot market with particular environmental preferences and no political regulation in an effort to create competitive advantage for itself vis-à-vis its market rivals. The course opted for by the EU Commission to determine ceilings in accordance with the cost principle versus their effectiveness, resulting in too unrestrictive and, more importantly, too future-oriented emissions ceilings, has retarded the spread of particulate filters. By introducing this technology, Peugeot proved that it was possible to comply with the Euro 4 standard on particles five years earlier than the industry had claimed in the Auto Oil I Programme. Although it is not yet foreseeable whether or not and, if so, when, diesel-filter technology will be more widely used, it does appear to be obvious that diesel-engine technology in cars will only continue to have market viability around the world in combination with diesel filters. The export of diesel cars to California, for example, is only possible if diesel filters or similar technology is used. If we look at the long-term tendency with respect to emissions regulation and the discussion surrounding zero-emission vehicles, it becomes clear that diesel cars can only maintain a competitive standing vis-à-vis engine concepts such as fuel cells in a capacity as “almost-zero-emission vehicles”. The same applies to less-developed technologies for reducing nitrogen oxides. It will only be possible to export diesel cars to the USA and Japan (should the ceilings which apply in that country become more restrictive) if considerable advances are made in emissions-reduction technology.

A focus on components suppliers for particulate filters reveals that a dynamic industry exists, broad sections of which are dependent on the development plans of car manufacturers and which are experiencing growth. Bosch, one such supplier, intends to embark on the production of diesel filters with a view to the USA as one of its target markets (Handelsblatt 7.5.2003). Stricter emissions ceilings for particulate mass would be likely to have a positive effect on the industry. There are also first indications that suppliers for Peugeot have gained competitive advantage in the area of particulate filter systems. As the German Newspaper Handelsblatt reports, the PSA suppliers Tenneco, Faurecia and Ibiden are currently facing strong demand for their products since a growing number of car manufacturers intend to introduce particulate filters earlier then 2005. Other firms like Bosch will not be able to put their filter systems on the market until 2005 (Handelsblatt 06.08.2003)

Co-operation by PSA with Ford, Fiat and Lancia and the experience gained ahead of other firms does, make an extra competitive edge no surprise. Other suppliers are developing different types of filter systems in co-operation with other carmakers, but a lead-market for PSA and their supplier's products is gaining shape.

Representatives of the supplier industry have confirmed that, subsequent to introduction of the filter by Peugeot, other carmakers stepped up development efforts. We can therefore presume that the wakeup call issued through Peugeot's activities has led automobile manufacturers to run the dual strategy of publicly discrediting the filter, but striving, internally, to occupy part of the market on which Peugeot has set its sights.

Rather than negotiating emissions ceilings as in the past, with some sections of the automobile industry in favour of tighter standards (given the technological competence at their disposal) and other sections opposed to such restrictions, the Auto Oil I Programme saw the industry united in its backing for introduction of the highest possible ceilings. This may have something to do with the fact that the automobile industry had hoped to achieve reductions in hazardous emissions by minimising the level of pollutants in fuel and thus offloading the costs involved on the oil industry. It may, however, also have to do with the fact that the industry did not recognise the possible competitive advantage and the export opportunities for low-emission vehicles. The lead-market effects we observed in connection with our case study can be summarised as follows:

- There is an ecologically sensitised market for technologies to reduce harmful emissions in diesel exhaust beyond the stipulated ceilings.

- In view of the tougher ceilings which we can expect to see in future, the automobile industry itself will deem it wise in the long term to forge ahead with the development of environment-friendly technology.

- Introduction of the filter by Peugeot has illustrated that a buyer market existed even before its "forced" introduction as prescribed by emissions regulations.

- Introduction by Peugeot of the particulate filter also demonstrated that technological development times can be substantially shorter than the industry predicted.

- It is possible to converge political strategies in the area of environment policy. One thing that would make sense, for instance, would be to combine the reduction of CO_2 emissions through the greater spread of diesel vehicles with a reduction in particulate emissions.

- The public commitment of private players towards promoting more environmentally friendly technologies reveals a need on the part of policy makers to initiate further improvements.

- For the automobile industry, stricter emissions ceilings do not necessarily produce competition-distorting costs, but are likely to create competitive advantage.

7.1 Epilogue: German car manufactures, the particulate filter and the 60th international motor show in Frankfurt/Germany

From the 11th to the 21st of September, the 60th international motor show (IAA) will be held in Frankfurt/Main, Germany. It is one of biggest and most important motor shows in the world and certainly the most important one for German car manufactures. Most of the German car producers have announced the presentation of particulate filter systems for a number of their passenger car models during the IAA. The laudable those announcements are, one must not forget that they come four years too late. It was in 1999, when Peugeot first introduced their particulate filter system and German car manufactures had nothing better to do then impertinently discredit Peugeot's new technology in public. Their dismissive attitude has not only decreased their chances in gaining competitive advantage in a growing technology field but also shown the manufacturers' ignorance towards environmental and consumer protection. For more then 20 years, scientists, environmental organisations as well as federal agencies have been warning about the hazards related to particulate emissions in Diesel exhausts but German car manufactures reacted ignorant and inflexible and protracted the development of new environmental technologies. Their behaviour demonstrated not only lack of responsibility beyond bureaucratic regulation but also the neglect of stakeholder inclusion into corporate management.

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Interviews

Interviews were conducted with the following individuals and ACEA in connection with this case study:

ACEA	Association des Constructeurs Européens
Ambrosi, Nikolaus	Renault
Demmel, Anton	ADAC
Glück, Karl-Heinz	OMG
Feth, Gerd Gregor	Frankfurter Allgemeine Zeitung
Giesen, Norbert	DaimlerChrysler
Greening, Paul	DG Industry, European Commission
Hennen, Isfried	Ford
Hohenthal, Moritz von	Motortechnische Zeitschrift
Lange, Bernhard	Member of the EU Parliament
Metz, Norbert	BMW Group
Mönch, Lars	German Federal Environment Office
Naschke, Wolfgang	Rhodia
Resch, Jürgen	Deutsche Umwelthilfe
Mr Rippe	Corning
Rodt, Stefan	German Federal Environment Office
Schalberger, Thomas	Peugeot
Skibbe, Alexander	Volkswagen
Dr Scherm	Engelhard
Dr Stöpler	Faurecia
Mr Stüttem	Zeuna Stärker
Taschner, Carola	European Environmental Bureau
Teubner, Klaus	Eberspächer
Tölkes, Elvira	Opel
Treiber, Peter	Emitec
Vogt, Claus Dieter	NGK

Inquiries were also made with the press offices at the following automobile companies and with representatives from these companies (who requested to remain unnamed):

Audi, BMW, DaimlerChrysler, Ford, Opel, Toyota